

An overview on water management in coconut (*Cocos nucifera*)

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ABSTRACT

Coconut (*Cocos nucifera* L.) is a small holder's plantation crop cultivated predominantly in the humid tropics and tropical belts of India. Water is one of the critical inputs required in coconut production that plays important roles in growth, development and productivity. Though the coconut-growing regions in the coastal belt are endowed with high rainfall, the rainy period is confined to a few months (4 to 5) during the monsoon season and palm experiences moisture stress during remaining months. Water requirement of young and adult palms varies as per the soil type and agro-climatic regions. Lysimetric studies have indicated actual water use by the palms and crop-coefficient values for coconut. Among the irrigation methods, drip irrigation is the best system which ensures water saving to the extent of 33% of Eo and increase in the nut yield to the tune of 90–100% compared to no irrigation. Further, the application of fertilizers through drip system (fertigation) increases water and fertilizer-use efficiency and results in 25 to 50% savings in fertilizer dose for the crop and increase in the productivity of palms to the tune of 50–75% in various regions of the country.

Key words: Coconut, Drip, Fertigation, Irrigation, Yield

Irrigation has played a major role in the development of ancient civilization which can be understood from the historical and archaeological findings. The oldest civilization with irrigation was developed along the Nile River about 6000 BC. The system of irrigation in those days was surface or gravity irrigation. Trickle irrigation, which applies water in drops, is considerably a new approach compared to these methods and developed from sub irrigation, where irrigation is applied by raising the water table.

Coconut is the major plantation crop cultivated predominantly in the humid tropics and tropical belts of the India extending throughout the peninsular region comprising Kerala, Karnataka, Tamil Nadu, Andhra Pradesh, Goa, parts of Maharashtra and the north eastern region. Coconut is cultivated in wide range of soils, viz. sandy, sandy loam, laterite and alluvium etc. The major socio-economic features in which the coconut is cultivated include predominance of small and marginal holdings, medium to resource poor farm environment and less marketed surplus etc.

One of the critical resources in coconut production is the availability of water. Though the coconut-growing re-

gions in the coastal belt are endowed with high rainfall, the rainy period is confined to a few months during the monsoon season. Therefore, the palm experiences moisture stress conditions for varying periods extending up to 6–7 months in a year. Unfavourable soil and climatic conditions create moisture stress from December to May, which necessitates coconut palms to be irrigated. In the coconut-growing region other than the coastal belt, coconut has to be grown throughout the year by supplemental irrigation. The adverse effect of moisture stress on the productivity of coconut has been well established at ICAR–Central Plantation Crops Research Institute (CPCRI), Kasaragod and well documented (Kasturi Bai *et al.*, 2009). Utilization of the available water in the most effective manner by optimizing irrigation schedules and adopting soil moisture-conservation practices and water-harvesting techniques assume particular significance in coconut cultivation. An earlier review of the research work carried out on water management aspects of coconut in India was made by Yusuf and Varadan (1993). The present review focuses on the results of research carried out in the last 2 decades in different coconut-growing regions of India under different themes.

METHODS OF IRRIGATION

Irrigation methods commonly adopted in coconut gardens are flooding, basin, sprinkler or perfo-spray and drip

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irrigation. Out of this, drip irrigation is the most popular for coconut when grown as monocrop and sprinkler irrigation (perfo irrigation) for coconut-based cropping system (Dhanapal *et al.*, 1999).

Flood irrigation and basin irrigation

Flood irrigation, an ancient method of irrigating crops, is very simple, wherein water is delivered to the field by ditch, pipe, or some other means and simply flows over the ground. In basin irrigation, water is applied in the basins of 1.8 to 2.0 m radius around the palm and there is wetting of root zones. Irrigation channels are provided in the centre of the 2 rows of coconut and each basin is connected with this channel. In this method also there will be water loss due to deep percolation and surface evaporation. Therefore, application of water in the basin through hose pipe is being advocated to reduce water loss in transit. This is being done in the Kallada Tree Irrigation Project in Kerala (GoK, 1982). Though higher yield of coconut could be realized under flood irrigation than basin irrigation, there is considerable wastage of irrigation water under flood irrigation (Bhaskaran and Leela, 1978), as is being practiced in certain areas of Tamil Nadu and East and West Godavari districts of Andhra Pradesh.

Sprinkler or perfo irrigation

In this method, irrigation water is applied similar to natural rainfall and water is distributed through a system of pipes usually by pumping and is then sprayed into the air through sprinklers, so that it breaks up into small water drops which fall to the ground. In the pump supply system, sprinklers and operating conditions must be designed to enable a uniform application of water. Systematic studies based on the climatic approach on irrigation requirement of West Coast Tall (WCT) coconut palms were conducted at the ICAR-CPCRI, Kasaragod, during 1976–85, in red sandy-loam soil. The response to 3 depths of irrigation water (IW), viz. 20, 40 and 60 mm, at 3 frequencies based on irrigation water : cumulative pan evaporation (IW : CPE) ratios of 1.00, 0.75 and 0.50 were evaluated. Palms irrigated with 20 mm of water at IW : CPE ratio of 1.00 the highest mean yield of 91.8 nuts/palm followed by the same depth of irrigation at 0.75 IW:CPE ratio (87.2 nuts/palm) (CPCRI, 1988).

Drip irrigation

Drip irrigation, sometimes called trickle irrigation, involves dripping water onto the soil at very low rates (2–20 litres/h) from a system of small-diameter plastic pipes fitted with outlets called emitters or drippers. Water is applied close to palms, so that only part of the soil in which the roots grow is wetted. The concept of surface trickle (often

called drip irrigation) has spread from Israel to Australia, North America and South Africa by late 1960 and eventually throughout the world. It has the special features such as low application rate, application of water over a long period to meet the water requirement, avoiding wastage as water is applied at frequent intervals to suit the infiltration rate and water is applied near or into the plant's root zone (Carr, 2011).

Water spread and placement of emitter/micro tube

In trickle irrigation, the water distribution for different soil is an important factor to be understood before initiation of irrigation, as the volume of roots wetted has relationship with the quantities of water uptake. Soil water distribution is determined by the soil properties and the way the water is added and withdrawn from the profile. Factors which generally differentiate the soil water regime for trickle from other irrigations systems are: (i) The flow regime is 2 or 3 dimensional rather than vertical only, (ii) the water is added at high frequency, and (iii) soil water is maintained within a relatively narrow range.

Earlier studies indicated that at least 15% of the active root zone should get wetted for proper growth and productivity of palms (Dhanapal *et al.*, 1995; Maheswarappa *et al.*, 1997; Mathew *et al.*, 1999).

Studies on the coconut root absorption indicated that 0.75 m to 1.25 m away from the bole is the active absorption zone and hence, it was recommended to place the emitter or micro tubes in the centre of that area (1 m away from bole). Thus, considering the water spread from a single point source, it is recommended to place at least 4 emitters for laterite and red sandy soils, while 6 emitters are required for sandy soil (Mathew and Maheswarappa, 2001). Keller *et al.* (1992) have designed a drip system of irrigation suitable to water-shortage situation as compared to the standard drip systems designed for full irrigation to meet potential evapotranspiration, and its productive and economic advantages have been described in Kerala. However, as per Thampan *et al.* (2006), the limited size of the wetted soil volume under drip irrigation was identified as a cause for concern during an on-farm evaluation of drip irrigation in South India, although that view may have been influenced by the fact that only very small quantities of water (32 litres/palm/day) were being applied.

Water requirement of young coconut palms

Climate is the major determinant of the water needed for optimum growth and yield of coconut palms. Crop water requirements are normally expressed by the rate of evapotranspiration (ET) in mm per day or mm per period. The evaporation (Eo) together with the crop coefficient (Kc) gives the water requirement of crop. Since the growth and

reproductive stages occur simultaneously after the juvenile period, coconut palm requires readily available moisture throughout its life cycle (Murray, 1977).

The total water requirement of 1-year-old coconut seedlings was found to be 1,591 and 1,533 mm/year when irrigation was given at 80 to 100% and 60 to 100%, respectively, of available soil moisture. Coir-dust mulching of 15 cm thickness helped reduce the water demand by 40 to 55%. The water requirement of young palms in the initial years (up to 3 years) is very low, as the number and size of leaves are small (Shanthamalliah *et al.*, 1978).

Crop coefficients are empirical factors that are specific to the crop, climatic and agronomic conditions in which they are derived. In order to determine crop coefficients for coconuts in Kerala in the dry season, Jayakumar *et al.* (1988) attempted to quantify the ETo from climatic methods and relate it to ETcrop from observations. They used a pair of drainage lysimeters to measure the actual water use of 6-year-old WCT palms in laterite clay loam over a 6-month dry period (November to May). The modified versions of climatological methods (Doorenbos and Pruitt, 1977) are Penman formula, Blaney-Criddle method, radiation method and observant. The actual water use (ETc), averaged over five-day intervals, ranged from 2.7 to 4.1 mm/day (mean 3.3 mm/day). By comparison, reference crop evapotranspiration (ETo) averaged 6.2 mm/day (by Penman equation), 4.6 mm/day (by Blaney Criddle) and 5.3 mm/day (by USWB Class A pan) (Doorenbos and Pruitt, 1977). The corresponding crop coefficients (Kc) of 0.54, 0.73 and 0.65, respectively, were recommended for the irrigation requirement calculation in the dry season.

The evapotranspiration rates of 5-year-old palm (cv. 'WCT'; 3 m tall with 6 or 7 functional leaves) grown in an Oxisol of the west coast of India was quantified by Rao (1989) through soil moisture depletion studies and lysimetric measurements. The rate was found to increase from 2.9 mm/day during December to 5.5 mm/day during April, which coincided with summer period and later reduced to 2.3 mm/day during June, due to receipt of monsoon rains. The ETc varied from 3.3 mm/day in June to 7.8 mm/day in April, with an annual mean of 5.1 mm/day. By comparison, evaporation from a USWB Class A pan averaged 4.4 mm/day over the year.

Depending on the season, Kc varied from 0.78 to 0.85 in the winter (November–February), 0.60 to 0.68 in the monsoons (June–August) and 0.87 to 0.96 in the summer (March–May), with an annual mean value of 0.82. Nelliatt (1968) reported that irrigating @ 45 litres of water once in 4 days through basin method combined with application of 0.15 m³ of red earth in planting pits prior to planting in littoral sandy soil resulted in quick and vigorous growth of young palms.

Joshi *et al.* (1988) observed the maximum ET to be 6.6 mm/day in sandy-loam soil when irrigation was scheduled with 20 mm of water at an IW : CPE ratio of 1.0 during March under Kasaragod (Kerala) condition. The ET rates were reduced to 4.0 and 2.3 mm/day when the IW : CPE ratios were 0.75 and 0.50 respectively. They suggested scheduling irrigation with 20 mm water at an IW : CPE ratio of 1.0 was adequate to meet the water requirement of coconut for optimum growth.

By using tritiated water (tritiated water is a radioactive form of water where the usual hydrogen atoms are replaced with tritium), the transpiration of adult coconut palm was estimated to be 65 litres/day (Vasu and Wahid, 1990). Mohandas *et al.* (1989), while assessing the crop water requirement for coconut at Coimbatore (Tamil Nadu), measured the transpiration rate of coconut (cv 'VHC 1') leaves and it was found to be 7.5 µg/cm²/sec and the estimated water requirement ranged from 55 litres/day/palm in December to 115 litres/day/palm in June. Varadan *et al.* (1990) estimated the irrigation depth and interval for coconut based on soil, crop and climatic approach for various districts of Kerala. From the above review, it is clear that there is much variation with regard to consumptive use of coconut palm and the variations are mostly due to the soil, climate and method adopted for quantification.

Water requirement of adult palms

In coconut, the initiation and differentiation of vegetative and reproductive primordia and enlargement of cells are very sensitive to moisture stress. The palm is mostly grown under rainfed condition by the vast majority of coconut growers, particularly in the major coconut-growing state of Kerala. Excess moisture during the monsoon period which varies from 4 to 6 months and moisture stress during summer are common phenomena in the west coast of India. Based on climatological data available from various stations of Kerala, consumptive use of coconut was quantified using different methods (Saseendran and Jayakumar, 1988). Out of the 4 methods used, Penman's (modified) method was found to predict crop water requirements most agreeable with climatological demands of the place. They computed the mean yearly consumptive use of coconut to be 1,126 mm (37 litres/palm/day for a basin area of 12 m²) and the mean annual irrigation requirement to be 338 mm (4656 litres/palm for a basin area of 12 m²), spread over the non-monsoon months of January–May and November and December. The mean effective rainfall for the state as a whole unit under coconut-based land use was found to be of the order of 22% (SW monsoon–June to September), 41% (NE monsoon–October to December), 85% (January–February) and 48% (hot weather period–March to May). Only 27% of the annual rainfall was found

to be effective under coconut-based land use in the coconut system.

Drip irrigation and nut yield

Significant response in nut yield has been reported owing to drip irrigation in different soil types when compared to the yield in the rainfed control palms. The irrigation requirement of immature palms of WCT (from 5 to 7 years old) was reported by Nelliath and Padmaja (1978) in Kerala. Best treatment in terms of nut yield and water-use efficiency was the application of 40 mm of irrigation water (I) when the cumulative potential evaporation (CPE) total reached 53 mm (I-CPE ratio 0.75, which is equivalent to a Kc value of 0.75). In this way, an average of 680 mm of water was applied in the summer months, yielding a total of 157 nuts/palm over the 3 years after the palms started bearing. By comparison, when the IW : CPE ratio was 0.5, the total yield was significantly less, i.e. 126 nuts/palm.

Bhaskaran and Leela (1978) described a long experiment in Kerala (lasting for 12 years) with 'WCT' grown in red sandy-loam soil. Water was applied @ 800 litres/palm every 7 days (equivalent to 2 mm/day only) in 2 m radius basins during the summer months. It took 3 years before the full yield benefits (averaging + 30 nuts/palm/year compared with pre-irrigation yields of a variable 40) were realized. Before that, in the 'transition period', the yield increase was about half of this. The largest increase (+39 nuts/palm) was produced by palms initially classified as 'low' yielding (20 to 40 nuts/palm). The increase in yield was owing to an increase in female flower production and setting percentage.

In Kerala, Nair (1989) reported the results of an irrigation trial, in which water was applied at 500 litres/palm (at a plant density of 178 palms/ha, this is equivalent to 9 mm) at different intervals (cv. 'WCT') during the summer months (December to May) over a 5-year period. Water was applied in 1.8 m radius basins to a sandy clay loam soil. Compared to the control rainfed treatment (average yield of 90 nuts/palm), significant increases (range +15 to 39 nuts/palm) in yield were obtained in the third and subsequent years from irrigated palms when the 'cumulative potential evaporation' totalled to 50 or 25 mm.

Coconut yield under drip irrigation with 30 and 45 litres water/day/palm was at par with basin irrigation at 600 litres/palm/week (Varadan and Madhava Chandran, 1991). The main reasons for 34% water saving in the 66% of E_o through drip treatment were the reduction in the quantity of applied water and avoidance of loss due to deep percolation. Though more water was applied with 100 and 133% E_o under drip and basin irrigation, it did not contribute towards higher yield, probably because the excess water might have moved beyond the root zone and was not used

by the palms. Venkitaswamy *et al.* (1997) reported that nut yield under drip irrigation at 100% of E_o was at par with basin irrigation at IW : CPE ratio of 1.0 under Tanjavur condition of Tamil Nadu. Kapadiyal *et al.* (1998) reported 45–50% saving of water applied through trickle irrigation compared to surface irrigation in the south Saurashtra region of Gujarat. With the water thus saved, 1 extra hectare could be brought under irrigation thereby increasing the net income of the farmers.

Drip irrigation along with mulching will be a useful practice with regard to both soil-moisture conservation and soil temperature regulation in case of littoral sandy soil. The available soil moisture in littoral sandy soil at the ICAR-CPCRI, Kasaragod, Kerala, was found to be higher by 22.2 to 28.8% under such a situation in comparison to drip without mulch (Maheswarappa *et al.*, 1998). In basin irrigation also, the available soil moisture stored in the mulch treatment (using coconut leaves), on fourth day after irrigation, was 36.8 to 37.6 mm, while it was 18.2 to 19.9 mm in the absence of mulch, indicating the beneficial effect of mulching in conserving soil moisture. Similarly, there was reduction in the soil temperature under irrigated, mulched plots by 1.6 to 1.7°C compared to un-mulched rainfed plots at 15 cm depth. Though the nut yield of 'WCT' palms (>20 years old) under all irrigated treatments were at par with each other (66–72 nuts/palm/year), they were significantly superior to that of rainfed control (26.8 nuts/palm/year), thus resulting an increase in the yield to the tune of 145–150% (Dhanapal *et al.*, 2002).

The impact of drip irrigation levels {66, 100 and 133% of open pan evaporation (E_o)} along with basin irrigation (100% of E_o) and rainfed control with and without mulching on coconut ('WCT' variety, aged 21 years) in littoral sandy soil was studied by Dhanapal *et al.* (2002) at the ICAR-CPCRI, Kasaragod, Kerala. The drip irrigation @ 27 litres of water/palm/day during December–January and 32 litres of water per palm per day during February–May months (i.e. 66 % of E_o) resulted in water saving. Though the yield under various irrigation treatments (both drip and basin) was similar, it was significantly higher than rainfed control to the tune of 145–150%. The copra yield was 2,087 to 2,202 kg/ha under irrigated treatments, while it was only 499 kg/ha under rainfed condition, highlighting the beneficial effect of irrigation for coconut palms. The annual leaf production and leaf-nutrient status of coconut was also better in the irrigated treatments than to the rainfed control.

In Kasaragod (Kerala), Dhanapal *et al.* (2003) did not find any difference in nut yield for 'COD' × 'WCT' hybrid palms (> 20 years old) grown in laterite soil with gravelly clay when drip irrigation was done either at 66 and 100% of E_o or basin irrigation was practiced. The highest yield

(119.7 nuts/palm/year) was observed in the drip-irrigated treatment at 100% of Eo closely followed by basin irrigation and drip irrigation with 66% of Eo (116 and 113.6 nuts/palm/year respectively). The yield performance for drip irrigation at 33% of Eo and rainfed control was more or less the same, but significantly lower than others. From their subsequent studies, Dhanapal *et al.* (2004a, b) reported that drip irrigation increased the annual leaf production and leaf-nutrient status (N and K) of 'WCT' palms grown in laterite soil compared to the rainfed palms. As was the case with 'COD' × 'WCT' hybrid coconut, there was no difference in female flower production and nut yield when irrigation was done either at 66 and 100% of Eo or through basin method. The nut characters like nut weight, copra thickness and copra content were superior under irrigated treatments to the rainfed control. Drip irrigation equal to 66% of Eo proved to be economically efficient method of irrigation (net returns with ₹42,200/ha) coupled with water saving of 34% compared to 100% of Eo through basin and drip methods. Under the northern Kerala conditions, they suggested to irrigate palms through drip method @ 27 litres/palm/day during December–January months and 32 litres/palm/day during February–May for higher yield.

The study conducted by Jayakumar *et al.* (2017) at Coimbatore (Tamil Nadu) emphasized that, adoption of drip fertigation with polythene mulching in 'VHC 3', hybrid coconut garden, increases the productivity, besides ensuring the higher efficiency of water, nutrients and profitability.

In the Konkan region of Maharashtra, basin irrigation done for 35 years old 'WCT' coconut grown in sandy soil gave the highest yield (91 nuts/palm/year) closely followed by drip irrigation at 100% of Eo (85 nuts/palm/year), whereas the palms under no irrigation gave the lowest yield of 57 nuts/palm/year. Based on the yield, cost benefit ratio and saving of water, the drip irrigation with 30 litres of water/palm/day from October to January and 40 litres during February–May with four drippers placed at a distance of 1 m away from the bole could be recommended (Nagwekar *et al.*, 2006).

Drip irrigation increased the number of functional leaves, bunches and female flowers in 25 years old 'Tiptur Tall' variety of coconut grown in clay loam at Agricultural Research Station, Arsikere (Karnataka). The yield was the highest (97.8 nuts/palm/year) with drip irrigation at 100% of Eo (allowing the water to drip @ 4 litres/h up to the 30 cm depth by putting 6 drippers in 30 cm × 30 cm × 30 cm pits with the help of conduit pipe) followed by basin irrigation (306 litres water was applied in basins of 1.8 m radius) at IW : CPE equal to 1.0 at 3 cm depth (93.2 nuts/palm/year). The yield was the lowest for the rainfed palms

(51.6 nuts/palm/year). The net returns and benefit : cost (B : C) ratio were also the highest with drip irrigation at 100% of Eo followed by basin irrigation and drip irrigation at 66% of Eo. The water to be applied during summer months (February–May) was 65–75 litres/palm/day, while for winter months (November–January) it was 40–50 litres/palm/day (Basavaraju and Hanumanthappa, 2009).

Response of coconut roots to drip irrigation

Study conducted by Dhanapal *et al.* (2000) has revealed that the number of main roots from one-fourth of the basin area was higher under irrigated palms (1,149–1,212) compared to rainfed palms (429). In general, the fine root initiation responded more to irrigation than the main roots. Irrespective of the methods of irrigation, the dry weight of roots was more in the irrigated palms compared to the rainfed palms under littoral sandy soil.

Influence of irrigation on physiological parameters

Rajagopal *et al.* (1989) studied the influence of irrigation on leaf water relations and dry-matter production in 'WCT' coconut palms (>20 years old) grown in red sandy loam soil at the ICAR–CPCRI, Kasaragod, using I:E ratios such as 1.0, 0.75, 0.5 and the rainfed control. Irrigation was provided using sprinklers with perforated spray pipes placed horizontally between 2 rows of palms to wet the basin. They observed 4 to 5-fold increases in the soil water deficit at I:E ratios of 0.5 and 0.0 as compared to 1.0. Coconut palms experienced severe moisture stress at an irrigation level of 0.50, resulting in greater stomatal resistance (111%) and epicuticular wax content (32%) and reduced transpiration rate (10%), leaf water potential (68%) and reproductive dry-matter production (22%), compared with well-watered palms. Based on the relationship between the soil water deficit and the stomatal resistance, the critical soil water deficit for irrigation scheduling was suggested as 110 mm.

The drip irrigation is a system where not only the available water is used to the optimum with negligible losses, but also because of presence of dry zones in root-system possibly act as the stomata regulation system to provide optimal physiological efficiency for higher WUE and better yields. According to Naresh Kumar *et al.* (2002), response of plant to irrigation depends on various internal and external factors. The leaf-moisture status and its photosynthetic efficiencies are interrelated and largely influence the final economic yield. In order to assess the extent of this influence on yield, 'WCT' coconut palms (>20 years old) grown on sandy and laterite soils were given different levels of irrigation through drip {sandy-66, 100 and 133 % of open pan evaporation (Eo); laterite-33, 66 and 100 % of Eo} and basin (100% of Eo) along with palms without any

irrigation. Naresh Kumar *et al.* (2002) found the photosynthetic rate, Y leaflet and PS II efficiency to vary with the irrigation level and soil type. Irrigation increased female flower production and their retention to produce higher nut yields. The drip irrigation provided conditions for better physiological efficiency of source and sink for high WUE and yield.

Irrigating coconut palms through basin method @ 200 litres/palm, once in 4 days during January–March increased the mean photosynthesis rate (P_n), stomatal conductance (g_s), internal CO_2 concentration (C_i) and transpiration rate (E) of 'WCT' palms (25 years old) than palms grown under rainfed conditions. The oval-shaped canopy had more photosynthesis efficiency, WUE and productivity than X-shaped and semi-circle-shaped canopies, indicating that canopy shape plays a role in the overall performance of photosynthesis, WUE and productivity in coconut (Naresh Kumar and Kasturi Bai, 2009).

Fertigation

Fertigation is the most advanced and efficient method of fertilizer application, which ensures application of fertilizers through irrigation water directly to the root zone of the crop throughout the cropping period. Fertigation optimizes the use of water and fertilizers enabling to harness higher crop yields and also ensures a healthy soil and environment. It also increases the fertilizer-use efficiency, saves fertilizer costs, reduces labour requirement and supplies nutrients according to crop demand during varying physiological stages (Shigure *et al.*, 1999; Subramanian *et al.*, 2012). Soluble fertilizers, viz. urea and potassium chloride, can be combined and supplied through drip irrigation. In studies conducted by Subramanian *et al.* (2012) at the ICAR–CPCRI, Kasaragod, fertilizers like urea, diammonium phosphate (DAP) and muriate of potash (MoP) were tried as source of NPK nutrients through fertigation. To use DAP in fertigation, water should be added to it and kept overnight so that it gets dissolved in water. This solution, after filtering, can be directly used in fertigation tanks for supply of N and P nutrients. These fertilizers in the form of solution can be added in the fertilizer tank meant for that purpose or pumped in to the system through venturi unit. The required fertilizer can be supplied from December to May in 6 equal splits (70 g urea, 60 g DAP and 170 g MoP for 1 split), avoiding monsoon seasons for high rainfall zone. For other areas, fertilizer can be supplied in 6 equal splits (once in 2 months) throughout the year (Subramanian *et al.*, 2012).

Fertigation studies carried out in West Coast Tall ('WCT') variety of coconut in red sandy loam (Subramanian *et al.*, 2012) at Kasaragod (Kerala) indicated that fertilizer application (either through drip fertigation or

soil) improved palm growth (trunk height and girth at base) than no fertilizer application. The leaf production was similar in the case of drip fertigation @ 50, 75 and 100% of recommended dose of fertilizers (RDF) or 100% RDF through soil. It was higher than either with no fertilizer application or drip fertigation @ 25% of RDF. The nut yield was the highest (131 nuts/palm/year) with 100% RDF through fertigation, but was at a par with 75 and 50% NPK applied through drip irrigation (123 and 121 nuts/palm/year) respectively. The lowest yield of 81 nuts/palm/year was recorded when no fertilizers were applied. Physiological parameters such as photosynthesis (P_n), transpiration (E) and stomatal conductance (g_s) were also improved with drip fertigation than direct soil application of fertilizers or no fertilizer application. The study indicated that adoption of fertigation (50% of RDF) increases the productivity to the tune of 50% compared to no fertilizer application coupled with 50% saving of chemical fertilizers which ensures the higher efficiency of nutrients in the crop production.

In Arsikere (Karnataka), application of 75% of RDF (NPK @ 500, 320, 1,200 g/palm/year) through drip fertigation in 10 equal splits at monthly intervals (excluding May and October, the rainy months) for 42 years old 'Tiptur Tall' coconut palms grown in red sandy loam gave higher nut and copra yield (87.4 nuts and 13.2 kg/palm/year respectively) (Basavaraju *et al.*, 2014). This increase in yield was attributed to higher number of female flowers and nut setting percentage. A higher net return and benefit-cost ratio obtained in this treatment indicated the possibility of saving 25% of the RDF by adopting fertigation.

Nath *et al.* (2016) found that application of 75% of RDF (NPK @ 690, 400, 1,050 g/palm/year) through drip fertigation at 66 % Eo (fertilizers were given during October to April in 10 equal splits at 20 days interval) recorded significantly higher number of functional leaves (34.8), bunches/palm (11.9), number of female flowers (284.5) and nut setting percentage (32.4) in 41 years old 'Assam Green Tall' grown in Alluvial clay loam at Kahikuchi (Assam) compared to the control and other fertigation treatments, except 100% NPK through drip irrigation. The mean nut and copra yield/palm also followed a similar trend. Though the net return for applying 75% NPK fertilizers through drip irrigation was at a par with that of 100% NPK through drip irrigation, the former gave the highest benefit : cost ratio compared to all other treatments, thus indicating the possibility of saving 25% of the recommended fertilizers by adopting fertigation, which ensures higher productivity in coconut.

On the contrary, Khandekar *et al.* (2016) from Ratnagiri (Maharashtra) could not make any savings in the quantity of fertilizers through fertigation. The yield of coconut and

copra (113.8 nuts/palm and 18.6 kg/palm respectively) was higher under 100% RDF (NPK @ 1,000, 500, 1,000 g/palm/year) applied through drip system (in 8 splits during October to May) compared to other treatments. The net returns (₹1,08,090/ha) were also the highest in this treatment.

Based on the studies taken up on fertigation in coconut at different centres of AICRP on Palms from 2007–08 to 2012–13, the nut and copra yields under fertigation of 50% recommended dose of NPK were at a par with fertigation of 75% RDF and soil application of 100% RDF at Aliyarnagar and Veppankulam (Tamil Nadu), Mondouri (West Bengal) as well as Kasaragod (Kerala) Centres. However, at Ambajipeta (Andhra Pradesh), Arsikere (Karnataka) Centres, application of 75% recommended dose of NPK through fertigation recorded significantly higher nut and copra yield/palm/year compared to soil application of 100% recommended dose of NPK and at par with 100% recommended dose of NPK through fertigation (Maheswarappa and Rajkumar, 2014; Bandyopadhyay *et al.*, 2019).

Seawater irrigation for coastal sandy soil

Sea water irrigation is ideal for the soils of coastal belt, as it suits the condition required for such irrigation, i.e., the area should experience heavy rainfall and the soil of that area should be highly porous. The use of quality water for irrigation is of paramount importance for agricultural crop production. However, crops differ in their tolerance to poor-quality irrigation water. The perennial crops have advantages over the annuals and biennials in tolerance capacity, i.e. their life-cycle extends over a long period and thus, we cannot critically pin point, which stage is affected more and even if affected in 1 season, it can recover in the ensuing wet season. Thus, coconut, which is predominately grown along the coasts of Kerala, Andhra Pradesh, West Bengal, Odisha etc. can be irrigated with sea water for its sustainable productivity (Yusuf and Varadan, 1993).

The response of coconut to sea water irrigation in coastal sandy soils is tremendous, as the crop can tolerate a pH of 8.5. Since the coastal areas are fed with high rainfall, the accumulated salt due to sea water irrigation during summer months can be easily washed away from the root zone during the wet season. In this context, Yusuf and Varadan (1993) cited a study by Shanmugam (1973) which demonstrated that coconut palms cultivated in sandy or sandy-loam soils can withstand irrigation with sea water up to a salt content of 0.6 to 1.0% @ 90 litres/ palm twice a week.

CONCLUSION

Water is one of the critical resources in coconut production and plays an important role in growth, development

and productivity. Though the coconut-growing regions in the coastal belt are endowed with high rainfall, the rainy period is confined to a few months during the monsoon season and hence requires supplemental irrigation during non-rainy months. From the above review, it has clearly shown that the water requirement of young and adult palms varies as per the soil type and agro-climatic regions. Among the irrigation methods, drip irrigation is the best, which ensures water saving without affecting productivity. Further, application of fertilizer through drip system (fertigation) resulted in increased fertilizer-use efficiency and savings in fertilizer dose (25 to 50%) for the crop.

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