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FAO CROPWAT Model-Based Irrigation Requirements for Coconut to Improve Crop and Water Productivity in Kerala, India

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Abstract: The irrigation requirements for coconut in Kerala are general in nature. This study determined the irrigation requirements for coconut, using CROPWAT based on agro-ecological zones (AEZs) for proposing the recommendations. The irrigation recommendations are generated based on the climatic, soil, and crop characteristics. The results showed that the irrigation requirements varied with the locations. Overall, for the state of Kerala, the irrigation requirements varied from 350 to 900 L of water per coconut palm, with the irrigation intervals ranging from three to nine days based on the AEZs. Moreover, this study also confirmed the variation of the water requirements observed within the districts. The quantity of water required per palm varied between 115 to 200 liters per day (LPD) per palm, which is lower than the existing recommendations of 175 to 300 LPD per palm. The proposed irrigation requirements appraised with the presently followed recommendations of the Kerala state, and its advantages discussed for improving the crop and water productivity. In nutshell, if the current recommendation is adopted, 30% of the water used for irrigation can be saved, as well as leading to an improvement in crop production.

Keywords: water requirement; irrigation scheduling; water saving; agro-ecological zone

1. Introduction

Coconut (*Cocos nucifera* L.) is an important crop that falls under the plantation group and is mainly cultivated in the following countries: India, Malaysia, Philippines, Sri Lanka, and the South Pacific islands. It plays a major role in the livelihood of many of the people in these areas, by providing nuts and giving employment opportunities through the different industries associated with coconut production. Even though coconut is found mainly in coastal areas, it can grow in various soils with different moisture conditions and regimes. In Kerala, it is mostly grown in laterite/lateritic soils of the ultisol order (gravelly soils), which are prone to drought and are frequently exposed to intermittent moisture shortfall throughout the summer season [1]. This moisture deficit during its growth stage has a serious impact on its productivity [2]. Many researchers have reported an impediment in the growth of recently planted trees, and a yield decline in mature trees because of a moisture deficit, which makes the cells of the coconut root absorption zone sedentary as a result of processes such as desiccation and suberization, thereby harmfully disturbing the water and nutrient absorption process [1,3]. Several studies suggest the prominence of irrigating coconut fields, thereby maintaining the soil moisture and growth of coconut, and obtaining an unrelenting yield without any production loss [4–10]. Coconut physiology in relation to water availability and the antagonistic effects of a scarcity of water (stress) on productivity are well established [11–14].

Water is an indispensable input for any sustainable agricultural production [15]. Kerala, which is in the south-west region of India, receives an average annual rainfall of 3000 mm. but experiences an extended dry period of about six months because of the uneven temporal distribution of rainfall. In addition to this, spatial variation aggravates the deficit of the soil moisture for a period of 100 to 110 days in Southern Kerala, and approximately 125 to 150 days in Northern Kerala [16]. Earlier studies on the analysis of long term data on rainfall showed that these long moisture deficits are usual and have been found over many years [17].

Coconut palm produces fronds, inflorescences, and nuts throughout the year, and hence, it demands a continuous supply of water and nutrients from the soil. The productivity of coconut in Kerala is very low and is only 7486 nuts per ha per year. However, it is higher in the neighboring states of Tamil Nadu, Andhra Pradesh, and Maharashtra, with 14,872, 14,997, and 9745 nuts per ha per year, respectively [18,19]. A lack of irrigation, low fertile nature of soils, and incidence of diseases are the most important causes attributed to this shortfall in productivity in Kerala. Inadequate water availability has been a major regulating factor in the summer months (December–May), particularly in the hilly terrain (mid- and high-land), because of the high evaporative demand experienced by coconut [20], and the lowering groundwater table.

Earlier studies by several R&D institutes in the state (viz. Kerala Agricultural University (KAU), ICAR-CPCRI (Central Plantation Crops Research Institute), and CWRDM (Centre for Water Resources Development and Management)) have revealed that sufficient soil moisture by way of irrigation/rainfall can augment crop production. Irrigation improved the yield by 15% to 40% compared with the unirrigated (rainfed) crops for most of the crops in Kerala, based on the secondary data.

With respect to coconut, a tangible yield improvement by irrigation was observed in many field experiments in Kerala, (India), Sri Lanka, and Brazil. In Kerala, Nair reported that the irrigation significantly increased the yield (range 15 to 39 nuts per palm) over the control rain-fed treatment (average annual yield of 90 nuts per palm) after three years of irrigation, with water of 500 L per palm at different intervals (cv. West Coast Tall (WCT)) during the dry period from December to May [21]. In another study, the irrigation showed an increment in the annual average yield of coconut cv. West Coast Tall (WCT) by 30–40 nuts per palm (i.e., from 50 to 60 nuts in the unirrigated crops, to 90 nuts per palm for the irrigated crops) over a six year period [10].

Coconut plantations that are irrigated or at least given life-saving water application throughout the dry period (summer) showed higher nut yields in parts of Karnataka. This was the obvious outcome from the irrigation, nutrient, and physiological experiments conducted between 1978 and 2005 in different geographic locations of India. The reasons attributed to these higher yields are as follows: (a) irrigation; (b) life-saving water application during a drought or dry period; and (c) better rainfall distribution, even though it is a low-rainfall zone [22]. All of these factors triggered higher yields in the Arisikeri area (Karanataka) under partial rain-fed conditions. However, two other locations on the west coast, Kasaragod (in Kerala) and Ratnagiri (in Maharastra), resulted in very low yields, as these plantations are purely rain-fed. As mentioned earlier, these two regions face a soil moisture deficit during dry/summer seasons, resulting in a low yield. Similarly, an Infocrop model simulated yield in different places showed that the enhanced modern irrigation management with micro irrigation (drip) will result in higher yields [23].

Long-term irrigation experiments in various perennial crops under different agro-climatic conditions are limited, mainly because of the difficulty in conducting multi-location irrigation experiments in perennial crops, by satisfying all of the required experimental conditions. The results from the isolated experiments may not actually have a wider applicability. It was in this context that CWRDM initiated this project, and by considering all of these factors, the present study was carried out with the objective to develop a site-specific crop water requirement for all of the agro-ecological zones (AEZs) of Kerala.

2. Materials and Methods

2.1. Study Area

The area selected for the current study is the state of Kerala, which falls in the south-west region of India (8°18′ to 12°48′ N and 74°52′ to 77°22′ E), and has an area of 38,863 square kilometers. The Eastern side of the state is bound by Western Ghats, the western side by Lakshadweep Sea, the northern side by Karnataka, and the southern and eastern side by the Tamil Nadu state. The population of the Kerala state (as per the 2011 census) is 33.3 million, and it accounts for 3.01% of India's population. The population density of the state is 859 persons per km^2, one of the highest in the country, and exerts a lot of pressure on the per capita availability of water resources. This state has a humid tropical climate, categorized by the presence of high-intensity (heavy) rainfall, a high relative humidity, ample sunshine, and a high ambient air surface temperature. Besides these, the state is gifted with discrete elevation variations, from the upsurge of the land mass from 5 m below the mean sea level (msl), and rising to heights of 2695 m within a diagonal distance of 120 km. The aerial distribution of the slope classes showed that 89% of the area is considered to be slopes (Figure 1). From the presented Figure 1, it is clear that the state has a rolling topography with a Shuttle Radar Topography Mission (SRTM) digital elevation model at a 90 m resolution, and this topography plays a major role in water runoff and soil erosion. The significant erosion of the fine-textured topsoil and organic matter from the majority of the areas, as a result of the heavy rainfall and rolling topography, has given rise to soil consisting of large particles, and gravel with a low water holding capacity, thereby making irrigation more important.

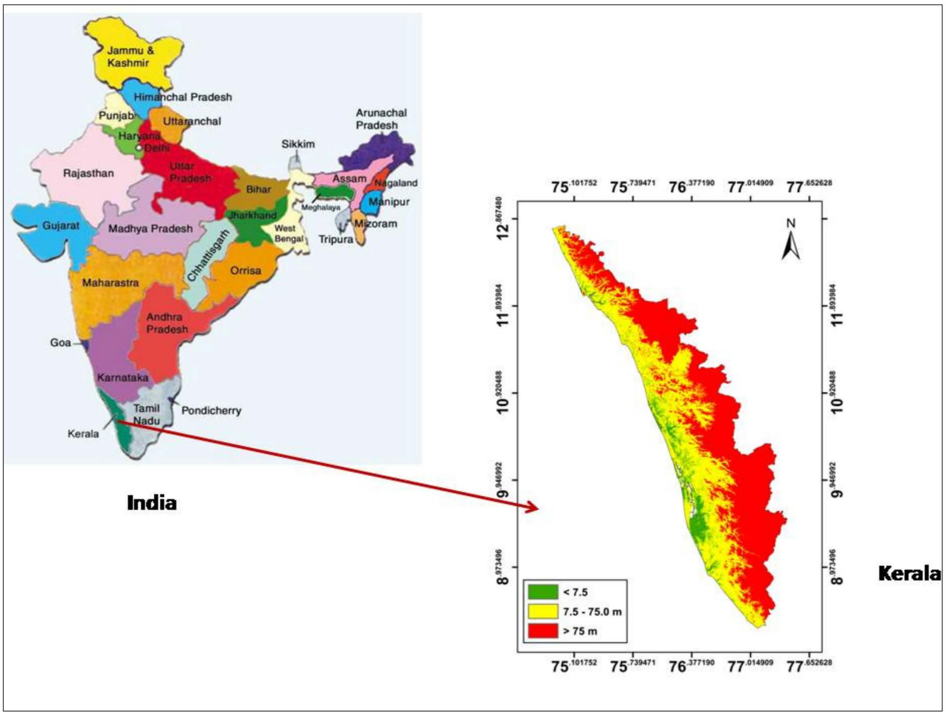


Figure 1. Geographic location of the selected study area along with the physiographical map using an SRTM 90 m Digital Elevation Model (DEM) image of Kerala state.

In Kerala, the irrigation efficiency is low, and the main reason for this is that the irrigation recommendations are not site (location) specific, and lack information on the scheduling of irrigation for different crops. Recommendations from the Package of Practices by the Kerala Agricultural

University reveal that the current scheduling of the water requirements and the recommendation of irrigation for coconut in the Kerala state is of a wide-ranging nature (as shown in Table 1), and does not account for the characteristic features of different agro-ecological zones. In this study, the entire state was divided into the following two regions: (i) the north-eastern portion of the Thrissur and Palakkad districts, and (ii) the rest of Kerala as the other region. However, site-specific scientific precise information is a crop water requirement, based on the soil type and agro-climatic or ecological information, in order to have effective water budgeting, the proper regional planning of water resources, and to achieve a higher crop productivity.

Table 1. Irrigation requirement of coconut as per the Kerala Agricultural University (KAU) Recommendation.

Parameters	Soil Texture			
	Sandy	Sandy Loam	Loam	Silty Clay
Available soil moisture (cm/m)	8	12	17	21
Quantity of water/irrigation/palm in liters in a basin with a 1.8-m radius	600	900	1300	1600
Frequency of Irrigation (days)				
All areas in Kerala, except for the north-eastern portion of the Thrissur and Palakkad districts	3–4	5	7–8	9
North-eastern portion of the Thrissur and Palakkad districts	2–3	3–4	5–6	6–7

(Source: KAU, 2011).

The agro-ecological zone (AEZ) was taken as the base unit for the current study, because each AEZ has a comparable amalgamation of yield potentials and limitations, and provides a common platform for generating any kind of recommendation [24]. Generally, in Food and Agriculture Organization (FAO) reports, AEZ is defined as the zones that are delineated based on the climatological, soil, land type, length of growing period, and suitability characteristics. All of these can be used to compute the potential production based on the aforementioned characteristics, and also for suggesting the effective/best management systems under which the crops are grown and achieve a higher productivity.

2.2. Methodology

FAO-model CROPWAT 8.0 was used as a decision support system (DSS) for computing the reference crop evapotranspiration (ET_o) of all of the agro-ecological units (AEUs) of Kerala [25]. CROPWAT uses the equation of Penman–Monteith for calculating the ET_0, and several studies across the globe have suggested that this model has comparable data to that of the original water requirements of crops [26,27]. CROPWAT integrates several parameters, such as the geo coordinates of the area, surface temperature (max. and min.), Relative Humidity (RH - max. and min.), wind speed, and solar radiation/sunshine hours, and calculates the ET_o and crop evapotranspiration (ET_c) by considering different climates, crops, and soil types. The model has the provision of calculating the unknown parameters of the RH and wind speed (if the data is not available) based on the available known parameters, such as the geo coordinates and surface temperature.

The irrigation requirement for coconut was calculated for the AEZs and AEUs in Kerala, which were demarcated by the National Bureau of Soil Surveying and Land Utilization Planning (NBSS & LUP), Bengaluru, by considering the soil type, length of growing period (LGP), precipitation, ambient temperature, slope, and so on. With respect to the soil, the available water content per meter depth of soil (mm/m) and the soil depth (cm) present in each of the AEUs were considered for the calculation of ET_o. The ET_c was worked out for coconut by using the crop coefficient, according to Equation (1). The crop details considered for the irrigation water requirement are presented in Table 2 [7,26–30].

$$ET_c = K_c \times ET_o \quad (1)$$

Table 2. Crop details considered for the water requirement.

Cropping Season	Duration (Days)	Crop Coefficient (Kc)	Spacing	Depth of Active Root Zone (cm)	Canopy Spread as a Percentage of Spacing	Management Allowable Deficit (MAD)
Coconut	Perennial	0.75	7.5 m × 7.5 m	90	70	0.50

2.3. Irrigation Interval

The irrigation interval is the gap of application of water to any crop at a particular stage of growth, and is expressed in days.

$$I = SMra \text{ or } I = AWC \times MAD \times D \quad (2)$$

where I is the irrigation interval in numbers of days; $SMra$ is the easily accessible soil moisture, which is $AWC \times D \times MAD$ in mm; AWC is the available water content in the soil, which is ($FC - PWP$) in mm/m; MAD is the management allowable deficit (in percentage); D is the depth of the effective root zone in m; and ET_c is the crop evapotranspiration in mm/day.

2.4. Comparison with the Existing Recommendations of the Kerala Agricultural University

The district-wise irrigated area of the Kerala state has been taken from the Department of Environment and Statistics [31], and the amount of irrigation water was calculated based on the irrigation recommendations for coconut in the State by the Kerala Agricultural University, and it was compared with our current calculation using CROPWAT, based on the agro-ecological zones, by calculating the reduction in the irrigation volume. The districts have been grouped into three categories, that is, (1) districts with a large area (more than 20,000 ha) of coconut under irrigation, (2) districts with a medium area (1000 to 20,000 ha) of coconut under irrigation, and (3) districts with a small area (less than 1000 ha) of coconut under irrigation.

3. Results and Discussion

The concept of an agro-ecological zone definition was framed by the FAO, with a resilient importance on a similar climate, soil, and topography to identify the prospective areas available for the specific crops or for a mixture of crops, so that the production potential can be maximized. The delineation of the agro-ecological units at a district level is aimed at the generation of information for enabling the transfer of appropriate agro-technology in order to meet the production requirements. NBSS & LUP classified the Kerala state into five agro-ecological zones (AEZ) and twenty-three agro-ecological units (AEU). The five AEZ demarcated in Kerala are as follows: AEZ I, coastal plains; AEZ II, midland laterites; AEZ III, foothills; AEZ IV, high hills; and AEZ V, Palakkad plains (Figure 2).

The results obtained from the water requirement calculations of coconut on an AEU basis using CROPWAT are discussed hereunder. The quantity of water required to irrigate a basin with a 1.8 m radius, and the irrigation frequency of the selected three districts (Palakkad, Thrissur, and Wayanad) are presented in Appendix A (Tables A1–A3). The results show that in the Palakkad district, the irrigation requirement varied from 600 to 800 L of water per palm per irrigation, with the irrigation interval ranging from three to eight days. In the case of the Thrissur district, the irrigation requirement ranged from 350 to 750 L of water per palm, with an irrigation interval of three to seven days.

It can be inferred from the reported appendices that, even within the district, there are differences, confirming our hypothesis of a specific/location-specific irrigation recommendation, and hence AEUs might be the possible scientific units/blocks for the computation of the crop water requirement and the generation of an irrigation recommendation, so that the maximum possible crop production could be realized with a precise quantum of water [32]. The difference is mainly due to the spatial and temporal variation of the climatic parameters, and also because of the different soil types existing in the region. Individual district-wise recommendations have been submitted to the State Planning Board, Government of Kerala, for making policy decisions on irrigation management.

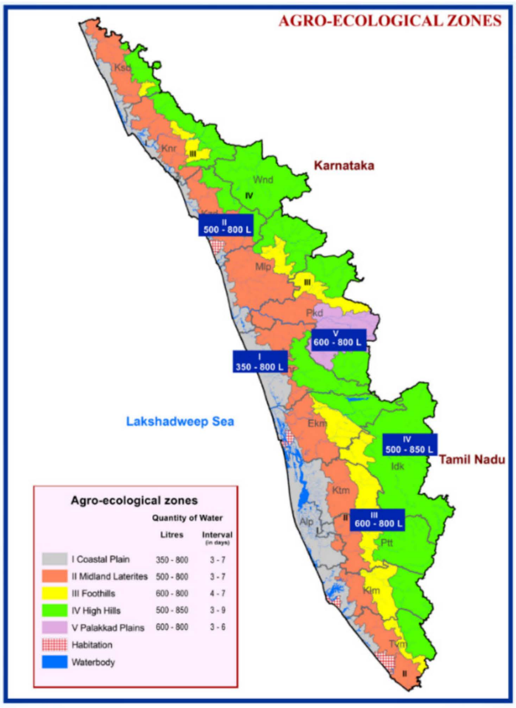


Figure 2. Irrigation requirements of coconut in the agro-ecological zones (AEZ) of Kerala.

For the state as a whole, these irrigation recommendations were grouped on agro-ecological zones (AEZ), and the results are presented in Table 3 and Figure 2. The output showed that the irrigation requirement varied in the range of 350 to 900 L of water per palm per irrigation, with the irrigation interval ranging from three to nine days. These quantities need to be increased by 30% to 40%, depending on the conveyance and application efficiencies. For the field application, based on the type of irrigation, the gross irrigation requirement may be calculated. For instance, in the drip irrigation, the application efficiency can be considered as 90%, and hence 11% more water needs to be applied [33].

These calculated irrigation requirements have been compared with the presently followed recommendation of the Kerala Agricultural University, which is also based on empirical calculations and is presented in Table 4 [32]. It showed that the recommendations generated from the current study are useful to farmers, as they can select and practice based on their location (site specific recommendation). In addition, this study considered the efficiency parameters and ET calculation with the observed climatic parameters, and hence the results of the per day water requirement of coconut coincides with the earlier experimental studies [28–30]. Even if we take the higher part of the irrigation requirement, approximately 100 L of water per palm per day could be saved, and if the quantum is converted for the entire coconut irrigated area, it will be a saving of a huge quantity of water at a state level. Carr [1] summarized the water relations and irrigation requirements of coconut by daily water use from various studies carried out around the globe, and indicated a range of 75 to 220 L per palm per day, which is nearer to our current findings. The current recommendation of the Kerala Agricultural University is on the higher side, when compared with the output from the current study [32]. The current study becomes all the more relevant in the context of water scarcity, faced globally, including in India, because of the increasing demand and the lesser availability of water in various sectors [34].

Table 3. Irrigation requirement and frequency for coconut in the AEZ of Kerala.

Parameters	Agro-Ecological Zones *										
	I		II			III		IV		V	
	Coastal Plains		Midland Laterites			Foothills		High Hills		Palakkad Plains	
	Sandy	Loam to Clayey	Sandy	Loam	Clayey	Sandy to Loam	Clayey	Sandy to Loam	Clayey	Loam	Clayey
Quantity of water/irrigation/palm in liters in a basin of a 1.8-m radius **	350 to 500	600 to 800	500 to 550	600 to 650	800	600	750 to 800	550 to 600	750 to 850	600	800
Irrigation interval in days **	3 to 5	4 to 7	3 to 5	4 to 6	5 to 7	4 to 6	5 to 7	3 to 6	6 to 9	3 to 5	4 to 6

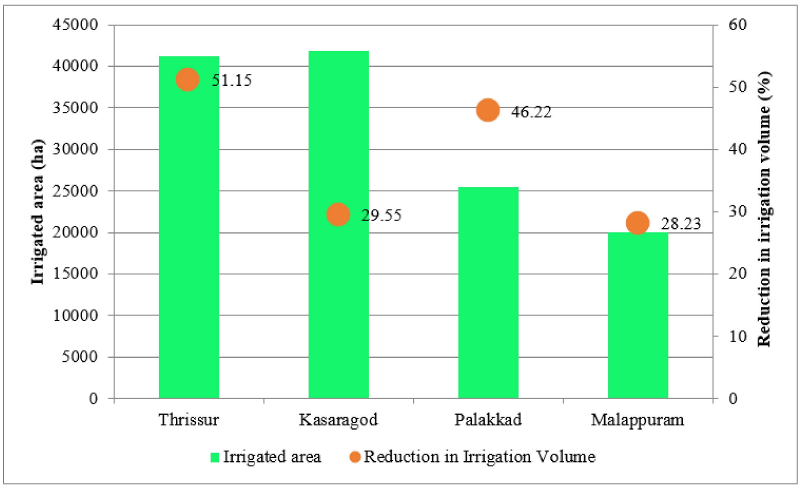
* National Bureau of Soil Surveying and Land Utilization Planning (NBSS & LUP) classification (Nair et al., 2012). Refer to the attached figure. ** Shorter irrigation interval is for the months from March to May. Add 30% to 40% to the above values depending upon the conveyance and application efficiencies.

Table 4. Comparison of presently followed and new recommendations derived from the study. CWRDM—Centre for Water Resources Development and Management.

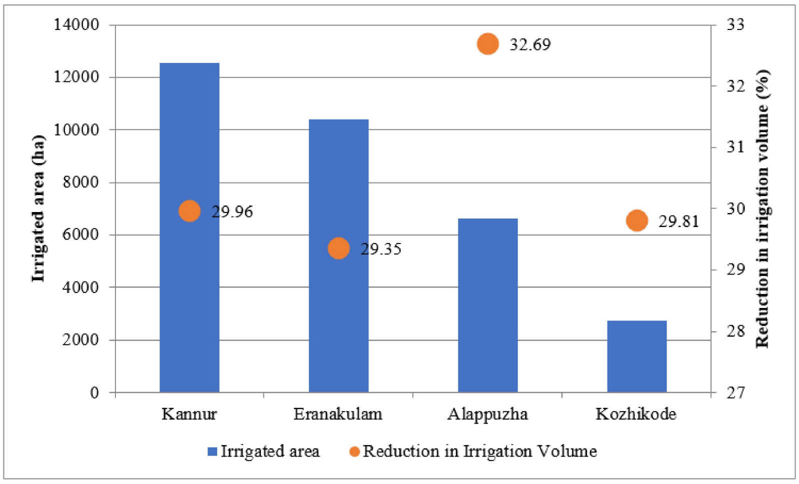
Present Recommendation (KAU)	New Recommendation (CWRDM)
• Only two zones for whole of Kerala	• Five zones based on the agro-ecological zones of NBSS & LUP
• Efficiency not considered	• Efficiency considered
• Based on pan evaporation data—two values (6 mm and 4 mm) for two zones	• Based on CROPWAT 8 using the data from all of the AEZs/AEUs (temperature, Relative humidity, sunshine hours, windspeed, Altitude, latitude)
• Water loss from the field based on crop spacing (100% area)	• Water loss from the field based on canopy cover (70% area)
• Water requirement (WR) values are on the higher side (175 to 300 liters per day (LPD) per palm)	• WR values are found to be closer to the lysimetric and other field studies (115 to 200 LPD per palm)

To have a clear understanding of the difference in the amount of water needed, we simulated the irrigation requirement for the farmers, if they adopt the recommendation. This was done by using the district-wide irrigated area of coconut. The irrigation water quantity was calculated using both the earlier recommendation of KAU and the present study, and is presented in Figure 3a–c. The results showed that for the state as a whole, approximately 29.39% of the water quantity used can be saved if we adopt the current recommendation based on the agro-ecological zoning. Moreover, it is interesting to note that the districts like Thrissur and Palakkad, which have a larger area under irrigation, have a saving of up to 51.15% and 46.22%, respectively. This confirms the fact that the scientific irrigation requirement calculation considering all of the factors will have a definite impact on water saving for irrigation. It is suggested that these recommendations need to be followed by the farmers in order to increase their productivity for coconut, as well as to save a huge quantity of water.

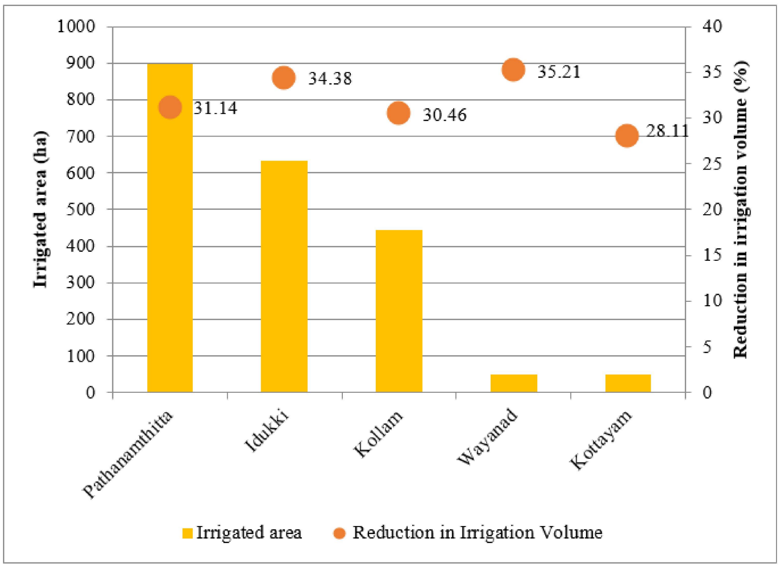
Coconut is sensitive to drought, and data showed that upon irrigation, there was an annual yield improvement of 20–40 nuts per palm (i.e., 30%–50% increase in nut production), resulting in 4 to 12 kg copra, which has been noticed in Kerala [23]. With irrigation at 2 mm per day (or 100 L per palm per day) with a frequency of one-week intervals, an improvement in the yield was reported after the third year. Irrigation increases the number of inflorescence spikelets and the production of female flowers, and decreases the rate of inflorescence abortion and early nut fall (premature nuts) [35]. The floral primordial initiation stage is critical to water stress and has a definite negative impact on the coconut yield. Coconut is more sensitive to water and temperature stress with respect to the number of female flowers/inflorescence and nut setting, and climate variability also has a negative impact on coconut productivity [36]; hence, it is advocated to adopt irrigation for improving nut productivity. The methods of irrigation that are suitable for coconut are basin irrigation; micro-irrigation, such as sprinklers; and drip irrigation. Hence, based on the aforementioned facts, it is suggested to follow these revised recommendations for achieving the maximum water and crop productivity, with a high water-use efficiency.



a. Large area under irrigation



b. Medium-sized area under irrigation



c. Small-sized area under irrigation

Figure 3. (**a**), Districts with a larger area under irrigation of coconut in Kerala. (**b**), Districts with a medium area under irrigation of coconut in Kerala. (**c**), Districts with a smaller area under irrigation of coconut in Kerala.

4. Conclusions

The productivity of coconut in Kerala is very low compared with the neighboring coconut growing states. The current recommendations for the irrigation of coconut in Kerala are broad in nature and are divided into two zones for the entire state of Kerala. Hence, an effort has been made to calculate the water requirement of coconut based on AEU, and then grouping them AEZ-wise for targeting the recommendations, using the FAO-CROPWAT model. To conclude, the study showed that the irrigation requirement for the state of Kerala varied from 350 to 900 L of water per coconut palm, with the irrigation interval ranging from three to nine days based on the AEZ and indicated the variation in the water requirement within a district. The quantity of water required per palm varied between 115 to 200 LPD per palm, which is lower than the existing recommendations of 175 to 300 LPD per palm. The findings from this study have been given to the Kerala Agricultural University for revising the existing recommendations, and based on several discussions, the information has been approved and included in the current package of practices recommendations. It is recommended that these revised recommendations need to be adopted by farmers, and it is suggested that the Department of Agriculture can initiate field level demonstrations with progressive farmers about the new water requirements. These irrigation recommendations will pave the way for reducing the yield gap in the Kerala state when compared with other states, by improving crop and water productivity.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Irrigation requirements and frequency for coconut in the Palakkad District of Kerala.

AEU	Blocks Covered	Quantity of Water in Liters in a 1.8-m Basin	Irrigation Interval in Days
19	North-eastern parts of the Attappady block	750	4 to 7
18	A central stretch of land adjacent to Unit 4.6 in Attappady	750	5 to 8
15	Rest of the Attappady block (west to units 4.6 and 4.5)	800	5 to 7
23	**Chittur Block**—Eruthempathy, Kozhinjampara, Nalleppilly, Pattanchery, Perumatty, Vadakarapathy, and Muthalamada **Malampuzha Block**—Elappully, Polpully, Pudussery, and Chittur-Thathamangalam Municipality	800	3 to 6
22	**AlathurBlock**—Alathur, Erimayur, Kannambra, Kavasseri, Kizhakkencheri, Puducode, Tarur, Vadakkancheri, and Vandazhi **Kollamgode Block**—Koduvayur, Kollengode, Puthunagaram, and Vadavannur **Kuzhalmannam Block**—Kannadi, Kottayi, Kuthannur, Kuzhalmannam, Mathur, Peringottukurissi, and Thenkurissi **Malampuzha Block**—Akathethara, Malampuzha, Marutharode, Peruvemba, and Puthuppariyaram **Nenmara Block**—Ayiloor, Elavancherry, Melarcode, Nemmara, and Pallassana **Palakkad Block**—Keralassery, Kodumba, Kongad, Mankara, Mannur, Mundur, Parli, Pirayiri, and Palakkad Muncipality	600	4 to 6
10	**Ottappalam Block**—Ambalapara, Ananganadi, Chalavara, Lakkidi-Perur, and Vaniyamkulam **Pattambi Block**—Koppam, Kulukkallur, Muthuthala, Nellaya, Ongallur, Pattambi, Thiruvegapura, Vallapuzha, and Vilayur **Sreekrishnapuram Block**—Cherpulacherry, Kadampazhipuram, Karimpuzha, Pookkottukavu, Sreekrishnapuram, Thrikkadeeri, and Vellinezhi **Thrithala Block**—Anakkara, Chalissery, Kappur, Nagalassery, Pattithara, Thirumittacode, Thrithala, Ottappalam Muncipality, and Shornur Muncipality	650	4 to 5
14	**Nenmara Block**—Nelliyampathy and parts of the Nenmara Block	650	6 to 8
13	**Mannarkad Block**—Alanallur, Kanjirampuzha, Karakurissi, Karimba, Kottoppadam, Kumaramputhur, Mannarkad, Thachampara, Thachanattukara, and Thenkara	600	4 to 7

Table A2. Irrigation requirements and frequency for coconut in the Thrissur District of Kerala.

AEU	Blocks Covered	Quantity of Water in Liters in a 1.8-m Basin	Irrigation Interval in Days
14	**Chalakkudy Block**—Kodassery and Athirappally	650	4 to 6
6	**Chavakkad Block**—Thaikkad, Vadakkekad, Pookode, and Punnayur **Chowwannur Block**—Kattakampal and Porkulam **Kunnamkulam municipality** **Puzhakkal Block**—Arimpoor, Adat, Kaiparamba, and Tholur **Mullessery Block**—Mullessery, Elavally, Pavaratty, and Venkitangu **Anthicad Block**—Manalur, Chazhoor, Anthicad, and Thanniyam **Cherpu Block**—Vallachira, Cherpu, Avinissery, and Paralam **Kodakara Block**—Nenmenikara **Irinjalakkuda Block**—Parappukkara, Kattur, Karalam, Muriyad, Purathissery, and Irinjalakkuda municipality **Vellangallur Block**—Vellokkara, Padiyur, Poomangalam, Putthenchira, and Vellangallur **Mala Block**—Alur	650	4 to 6
10	**Chowwannur Block**—Choondal, Chowwannur, Kadavallur, and Kandanassery **Vadakkanchery Block**—Vadakkanchery, Deshamangalam, Erumapetty, Velur, Thekkumkara, Kadangode, Varavoor, Mullurkara, and Mundathikode **Pazhayannur Block**—Thiruvilamala, Chelakkara, Kondazhy, Panjal, and Vallathol Nagar **Ollukkara Block**—Kolazhy, Madakkathara, and Nadathara **Thrissur Corporation** **Puzhakkal Block**—Avannoor, Mullamkunnathukavu, and Eyyanthol **Kodakara Block**—Pudukkad, Alagappa Nagar, and Kodakara **Mala Block**—Annamanada and Kuzhur **Chalakkudy Block**—Melur, Koratty, Pariyaram, and Kadukkutty **Chalakkudy Municipality**	500	3 to 4
5	**Kodungallur Block**—Methala **Mala Block**—Mala and Poyya	600	3 to 5
15	**Pazhayannur Block**—Pazhayannur **Ollukkara Block**—Puthur and Pananchery **Kodakara Block**—Mattathur, Trikkur, and Varamdarappilly	750	4 to 7
2	**Chavakkad Block**—Kadappuram, Orumayur, and Punnayurkulam **Chavakkad municipality** **Guruvayoor municipality** **Thalikkulam Block**—Vadanappally, Nattika, Thalikkulam, Vallappad, and Engandiyur **Mathilakam Block**—Edathurathy, Kaipamangalam, Mathilakam, Perinjanam, and Sreenarayanapuram **Kodungallur Block**—Eriyad and Edavilangu **Kodungallur municipality**	350	3 to 4

Table A3. Irrigation requirements and frequency for coconut in the Wayanad District of Kerala.

AEU	Blocks Covered	Quantity of Water in Liters in a 1.8-m Basin	Irrigation Interval in Days
20	**Kalpetta Block**—Kottathara, Vengappally, Muttil, and Mooppainad **Mananthavady Block**—Mananthavady, Edavaka, and Panamaram **SulthanBathery Block**—Meenangadi, Nenmeni, and Ambalavayal **Kalpetta Municipality**	600	5 to 6
21	**Mananthavady Block**—Thirunelly and Poothadi **SulthanBathery Block**—Noolpuzha, Mullankolly, Pulpally, and SulthanBathery	850	6 to 9
15	**Kalpetta Block**—Vythiri, Pozhuthana, Thariyode, Padinjarethara, and Meppadi **Mananthavady Block**—Vellamunda, Thondernadu, Thavinjal, and Kniyambetta	500	3 to 7

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