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Assessment of Crop Water Footprint for Different Varieties of Groundnut (*Arachis hypogaea*)

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ABSTRACT

Background: Water Footprint is a recently used indicator which helps to reduce water depletion and alleviate water stress in areas of drought and proper crop cultivation. Hence a study was taken up to assess the crop water footprint of different groundnut varieties namely TMV 7, VRI 2, VRI 3, VRI Gn 5, VRI Gn 6, CO 3, CO Gn 4, ALR 3 and TMV Gn 13 cultivated during *Kharif* and *Rabi* seasons at Tiruchirapalli district of Tamil Nadu.

Methods: The total water requirement, blue and green crop evapotranspiration, blue and green crop water use and total water footprint for different varieties of groundnut were estimated using CROPWAT 8.0 Windows. A comparison was made between the water footprint of groundnut varieties and the strategies to reduce water footprint is presented.

Result: The total water footprint for groundnut varieties ranged from 2603 to 4889 m^3 ton^{-1} (CV of 26%) during *kharif* season, while it was ranged from 1465 to 2470 m^3 ton^{-1} (CV of 18%) during *rabi* season. It was found that in all groundnut varieties the blue water footprint is higher than the green water footprint, while VRI Gn 5 variety had minimum total water footprint. It was concluded that, the groundnut production is affected by different levels of blue water stress which requires effective irrigation practices and water management strategies to enhance the crop production.

Key words: Blue and green water footprint, Crop evapotranspiration, Groundnut.

INTRODUCTION

Groundnut, also commonly known as Peanut (*Arachis hypogaea*), is a tropical legume mainly grown to produce oil and for human and animal consumption (Rami *et al.,* 2013). Groundnut is the major oilseed and single largest source of edible oils in India. India is the second largest producer of groundnuts after China (Shruthi *et al.,* 2017). Gujarat is the largest producer contributing 25 per cent of the total production of groundnut followed by Andhra Pradesh, Tamil Nadu and Karnataka (Sameer *et al.,* 2014). Groundnut accounts for about 50 per cent of area and 45 per cent of oil production among the soil seed crop in India. In Tamil Nadu, Groundnut is grown in an area of 3.355 Lakh Hectare with normal production of 9.112 Lakh Metric Tonne and productivity of 2,716 kg/ha. It can be sold as shelled or unshelled to generate income, thereby improving the farmer's income (Murray and Kostadini, 2016). Groundnuts have large water footprints per unit of mass and protein (Mekonnen and Hoekstra, 2011) and contribute already today in different parts of the world to blue water stress (Fulton *et al.,* 2019; Vanham *et al.,* 2020). Groundnut is relatively drought tolerant crop but pod yield reduction is very high if proper soil moisture during critical growth stages like flowering and pod formation (Baskaran *et al.,* 2020). The amount of water used by the crop is determined by the potential evapotranspiration during the crop period and the degree of soil cover (Allen *et al.,* 1998). The water requirement varies with soil type and agro-climates. Currently information about a commodity's individual water consumption is essential, which is called as water footprint of that commodity. Water footprint is defined as the total volume of freshwater that is used to produce the product (Hoekstra and Hung, 2002). The freshwater used can be further differentiated as green, blue or grey. Green refers to rainwater, blue is the surface and groundwater used for irrigation, and grey is the freshwater used to disperse fertilizer and pesticides. Crop production requires both blue and green water resources (Mekonnen and Hoekstra, 2011). The productivity of food crops like paddy, groundnut and pulses can be increased to the target levels by proper water

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management practices. Measurement of water footprint is important because it establishes a basis for understanding how much of water, the individual commodities consume (Hoekstra and Hung, 2002). Increased demand for food crops has meant that countries are relying more on underground aquifers in the absence of rain. Since the world's freshwater supplies are depleting, it is critical to know the water footprint in order to study, measure, and implement more efficient practices in agricultural sector. Veettil and Mishra (2016) indicated that due to changing pattern in climate variable and sectorial water demands, studies related to variability of water footprint is desirable for formulating water management practices. Zhao *et al.* (2016) investigated the variations of blue and green water resources under different land use change, agricultural irrigation expansion and climate variability scenarios. Mali *et al.* (2015) assessed blue and green components of evapotranspiration of 15 major crops grown in agricultural production units of Gomati basin by using CROPWAT model. It was reported that the blue water use by *rabi* crops was considerably higher than that of *kharif* crops. Adarsh *et al.* (2019) mentioned that the specific role of pulses in cropping system includes low water footprint and provides economic profitability to farmers.

Hence identification of water footprint of crops and cropping pattern is the need of the hour to find out the best crop for a region, particularly to avoid water stress in that region and also helps in switching over to less water intensive crop. The aim of this study was to estimate the total water footprint using the FAO CROPWAT model 8.0 Windows for different groundnut varieties namely TMV 7, VRI 2, VRI 3, VRI Gn 5, VRI Gn 6, CO 3, CO Gn 4, ALR 3 and TMV Gn 13, as it is required for studying the irrigation water management strategies to get maximum production.

MATERIALS AND METHODS

Study area

The water footprint of groundnut varieties cultivated in Tiruchirapalli District of Tamil Nadu, India was estimated in this study. Tiruchirappalli District is a centrally located district in Tamil Nadu State, has an area of 4403.83 km^2. The topography of Tiruchirappalli District is almost plain except for the short range of Pachaimalai hills in the North. Tiruchirapalli district is located between 10° 00' N and 11° 30' N and 77° 45' E and 78° 50' E and 78 m above mean sea level. Tiruchirappalli district is agriculturally rich due to the availability of fertile lands and presence of perennial rivers. Agriculture is the main occupation of major population in the study area. Agriculture sector provides the major source of income to the population and the major crops are paddy, banana, sugarcane, cotton, groundnut, maize *etc*. Oilseeds are also one of the major crops cultivated in the study area. It includes groundnut (6232 ha), gingely (1567 ha), castor (255 ha) and sunflower (85 ha) crops. Fig 1 shows the district area coverage of oilseeds in which groundnut is the major oil seed crop cultivated in the study area. TMV and VRI are the promising varieties of groundnut cultivated. It is sown during the month of June-July (Anippattam) (*Kharif* season) and December-January (Margazhipattam) (*Rabi* season). TMV 7, VRI 2, VRI Gn 5, VRI Gn 6, TMV Gn 13 are the varieties sown during June-July. TMV 7, CO 3, CO Gn 4, VRI 2, VRI 3, ALR 3, VRI Gn 5, VRI Gn 6, TMV Gn 13 are the varieties sown during December-January. A detailed description of the varieties via duration (days), average yield of pods under rainfed and irrigated condition (kg/ha), shelling percentage and oil content percentage is given in Table 1 and 2.

Estimation of crop water requirement using CROPWAT 8.0

CROPWAT 8.0 was used to estimate the crop water requirement. Firstly, monthly reference evapotranspiration was estimated by Penman Monteith equation (Allen *et al.,* 1998) in CROPWAT 8.0 window from the meteorological data collected from the observatory. The equation for estimating the daily grass-reference evapotranspiration is given as follows:

$$ET_0 = \frac{0.408 * \Delta\,(R_n - G)\,\Delta + \gamma \dfrac{900}{[T + 273]} * u * (e_a - e_d)}{\Delta + \gamma\,(1 + 0.34 * u)} \qquad (1)$$

Where;

ET_0 = reference evapotranspiration [mm day^{-1}], R_n = net radiation at the crop surface [MJ m^{-2} day^{-1}], G = soil heat flux density [MJ m^{-2} day^{-1}], T = mean daily air temperature [°C], u = wind speed at 2 m height [m s^{-1}], e_s = saturation vapour pressure [kPa], e_a = actual vapour pressure [kPa], e_s-e_a = saturation vapour pressure deficit [kPa], Δ = slope of vapour pressure curve [kPa °C^{-1}], γ= psychrometric constant [kPa°C^{-1}].

The full dataset for 22 years (1995-2017) collected from the meteorological observatory located at Agricultural Engineering College and Research Institute, Kumulur, Lalgudi Taluk, Trichy were used in estimating reference evapotranspiration.

The effective rainfall (P_{eff}) was calculated by using Soil Conservation Service method of the United States Department of Agriculture (USDA SCS) as it is one of the most widely used methods. The rainfall data for 22 years (1995-2017) was also collected from the meteorological observatory located at Agricultural Engineering College and Research Institute, Kumulur, Lalgudi Taluk, Trichy.

The crop evapotranspiration (ET_c) under optimal conditions was estimated which is equal to crop water requirement (CWR). Optimal means disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions and achieving full production under the given climatic conditions. ET_c was estimated at a ten day time step throughout the total growing season as mentioned by Michael (1978) as follows:

$$ET_C = ET_0\, K_C \qquad (2)$$

Where;

ET_o = represents the reference evapotranspiration and K_c = refers to the crop coefficient. The crop coefficient is calculated by two methods as explained below.

FAO56 Tabulated K_c

Crop coefficients are used to estimate the crop water requirement. Generally, the value of crop coefficient is taken from the FAO Crop Evapotranspiration guidelines (Allen *et al.,* 1998) for different crops at different stages and the crop water requirement is calculated. The value of K_c for groundnut was taken from the tabulated K_c values given in the FAO Crop Evapotranspiration guidelines (Allen *et al.,* 1998) for different crops at different stages.

Estimation of blue and green water evapotranspiration

Subsequently the green water evapotranspiration (ET_{green}) was calculated as the minimum of total crop evapotranspiration (ET_c) and effective rainfall (P_{eff}), with a ten day time step. The total green water evapotranspiration is obtained by summing up ET_{green} over the growing period (Hoekstra *et al.,* 2011).

$$ET_{green} = \min (ET_c , P_{eff}) \quad (3)$$

The blue water evapotranspiration (ET_{blue}) is estimated as the difference between the total crop evapotranspiration (ET_c) and the total effective rainfall (P_{eff}) on a daily basis (Hoekstra *et al.,* 2011).

$$ET_{blue} = \max (0, ET_c - P_{eff}) \quad (4)$$

When the effective rainfall is greater than the crop total crop evapotranspiration, ET_{blue} is equal to zero. The total blue water evapotranspiration is obtained by adding ET_{blue} over the whole growing period (Hoekstra *et al.,* 2011).

Estimation of crop water footprint

The water footprint of a product is defined as the total volume of fresh water that is used directly or indirectly to produce the product. The estimated crop evapotranspiration in mm is converted to $m^3\ ha^{-1}$ by applying a factor 10 which is called as crop water use (Hoekstra *et al.,* 2011).

$$CWU_{green} = 10^* ET_{green} \quad (5)$$

$$CWU_{blue} = 10^* ET_{blue} \quad (6)$$

The green component in the process water footprint of a crop ($WF_{proc,green,}$ $m^3\ ton^{-1}$) was calculated as the green component in crop water use (CWU_{green}, $m^3\ ha^{-1}$) divided by the crop yield Y ($ton\ ha^{-1}$). The blue component of water footprint ($WF_{proc,blue}$, $m^3\ ton^{-1}$) was also calculated from blue component in crop water use (CWU_{green}, $m^3\ ha^{-1}$) in the similar way. The equations used are listed below (Hoekstra *et al.,* 2011):

$$WF_{proc,green} = \frac{CWU_{green}}{Y} \quad (7)$$

The yield under rainfed and irrigated conditions for different varieties is shown in Table 1 and 2, respectively. Thus the crop water footprint for groundnut varieties is estimated by the above methodology.

$$WF_{proc,blue} = \frac{CWU_{blue}}{Y}$$

RESULTS AND DISCUSSION

Crop coefficient (K_c) for groundnut

The value of K_c for groundnut was 0.40 during the initial stage, 1.50 during the middle stage and 0.60 during the end stage. The crop coefficient curve for groundnut is given in the Fig 2. According to Allen *et al.* (1998), it varies with plant development stage, beginning with small values during establishment, reaching a maximum value in full-developed plants and, then decreasing at the end of vegetative cycle and early maturation. The results were in agreement with results obtained by Ramachandran *et al.* (2021) who suggested that, K_c values are useful in determining crop water requirement and efficient irrigation schedules.

Crop water footprint for groundnut during *Kharif* season

Table 3 presents the crop water footprint during *Kharif* season. Based on the assessment, the total water requirement for groundnut varieties ranged from 538 to 602 mm with mean of 554 mm (CV of 5%). VRI Gn 6 had the maximum water requirement (602 mm) compared to the other varieties. The total water footprint for groundnut varieties ranged from 2603 to 4889 $m^3\ ton^{-1}$ with mean of 3395 $m^3\ ton^{-1}$ (CV of 26%). TMV 7 had maximum total water footprint (4889 $m^3\ ton^{-1}$) and VRI Gn 5 had minimum total water footprint (2603 $m^3\ ton^{-1}$). The average yield of pods (2133 kg/ha) and percentage of oil content (51%) was also high in VRI Gn 5. The green and blue water footprint for different groundnut varieties is shown in Fig 3. It was found that for all varieties the blue water footprint is higher than the green water footprint. The average green water footprint was 1404 $m^3\ ton^{-1}$ and blue water footprint was 1990 $m^3\ ton^{-1}$ during *kharif* season. Due to vagaries of monsoon, kharif groundnut shows great unstability in production and productivity. The timing and duration of moisture stress is responsible for reduction in yield. By following practices like incorporation of decomposed coconut coirpith in soil, soil mulches, broad bed and furrow system of planting and also beds covered with polyethylene film mulches can be effective water management in *kharif* Groundnut.

Crop water footprint for groundnut during *Rabi* season

Table 4 presents the crop water footprint during *rabi* season.

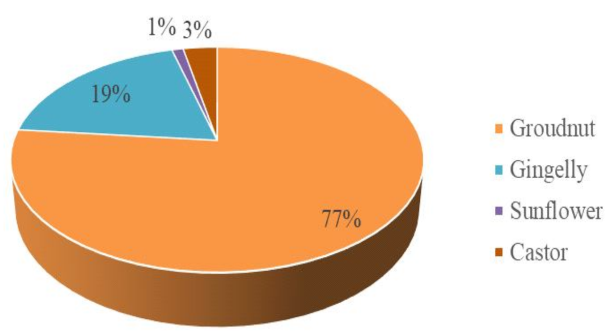

Fig 1: Oil seeds area coverage in the study area.
(Source: Tamil Nadu Rural Transformation Project Report, 2018-19).

Table 1: Description of groundnut varieties grown during *Kharif* season (June-July).

Particulars	TMV 7	TMV Gn 13	VRI 2	VRI Gn 5	VRI Gn 6
Duration (days)	100-105	100-105	100-105	105-110	120-125
Average yield of pods under rainfed (kg/ha)	1100	1613	1790	2133	1916
Shelling %	74.0	71.4	74.8	75.0	75.0
Oil content %	49.6	50.0	48.0	51.0	50.0

Source: https://agritech.tnau.ac.in/agriculture/oilseeds_groundnut.html.

Table 2: Description of groundnut varieties grown during *Rabi* season (December-January).

Particulars	TMV 7	TMV Gn 13	VRI 2	VRI 3	VRI Gn 5	VRI Gn 6	CO 3	CO Gn 4	ALR 3
Duration (days)	100-105	100-105	100-105	90	105-110	120-125	115-120	115-120	110-115
Average yield of pods under Irrigated (kg/ha)	1900	2580	2060	1830	2384	2403	2150	1950	2720
Shelling %	74.0	71.4	74.8	73.0	75.0	75.0	70.0	70.0	69.0
Oil content %	49.6	50.0	48.0	48.0	51.0	50.0	49.2	52.7	50.0

Source: https://agritech.tnau.ac.in/agriculture/oilseeds_groundnut.html.

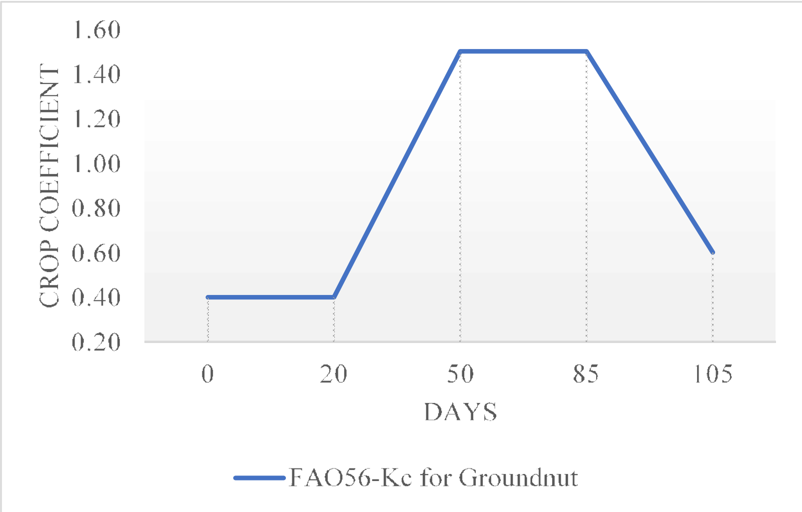

Fig 2: Variation of crop coefficient for groundnut at different stages.

Table 3: Crop water footprint for groundnut varieties grown during *Kharif* season.

Varieties	Total water requirement (mm)	ET_{Green} (mm)	ET_{Blue} (mm)	CWU_{Green} (m^3 ha^{-1})	CWU_{Blue} (m^3 ha^{-1})	WF_{Green} (m^3 ton^{-1})	WF_{Blue} (m^3 ton^{-1})	Total water footprint (m^3 ton^{-1})
TMV 7	538	215	323	2145	3233	1950	2939	4889
TMV Gn 13	538	215	323	2145	3233	1330	2004	3334
VRI 2	538	215	323	2145	3233	1198	1806	3004
VRI Gn 5	555	230	325	2303	3250	1080	1524	2603
VRI Gn 6	602	281	322	2806	3217	1465	1679	3144
Minimum	538	215	322	2145	3217	1080	1524	2603
Maximum	602	281	325	2806	3250	1950	2939	4889
Mean	554	231	323	2309	3233	1404	1990	3395
SD	28	29	1	286	12	337	559	877
CV (%)	5	12	0	12	0	24	28	26

SD: Standard Deviation; CV: Coefficient of Variation.

Based on the assessment, the total water requirement for groundnut varieties ranged from 331 to 482 mm with mean of 421 mm (CV of 12%). Due to the seasonal changes, the total water requirement of groundnut in *rabi* season is less than *kharif* season. VRI Gn 6, CO 3 and CO Gn 4 had the maximum water requirement (482 mm) compared to the other varieties. The total water footprint for groundnut varieties ranged from 1465 to 2470 m^3 ton^{-1} with mean of 1892 m^3 ton^{-1} (CV of 18%). Co Gn 4 had maximum total water footprint (2470 m^3 ton^{-1}) and VRI Gn 5 had minimum total water footprint (1465 m^3 ton^{-1}). It is noted that in both seasons VRI Gn 5 had minimum total water footprint. Moreover, water footprint of VRI Gn 5 is less during the *rabi* season (1465 m^3 ton^{-1}) than *kharif* season (2603 m^3 ton^{-1}). Though the highest average yield of pods was seen in ALR 3 (2720 kg/ha) variety, the water footprint was less in VRI Gn 5 variety with an average yield of pods (2384 kg/ha) and percentage of oil content (51%). The green and blue water footprint for different groundnut varieties during *rabi* season is shown in Fig 4. It was found that for all varieties the blue water footprint is higher than the green water footprint. The average green and blue water footprint were 206 m^3 ton^{-1} and 1686 m^3 ton^{-1} respectively during *kharif* season, while it was reduced in *rabi* season.

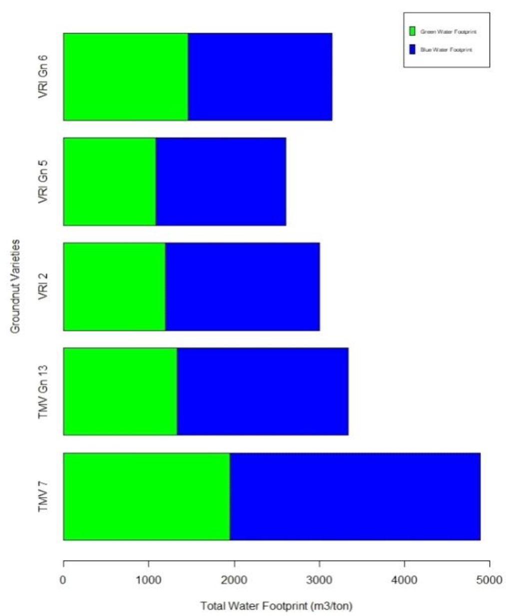

Fig 3: Total crop water footprint for groundnut varieties during *Kharif* season.

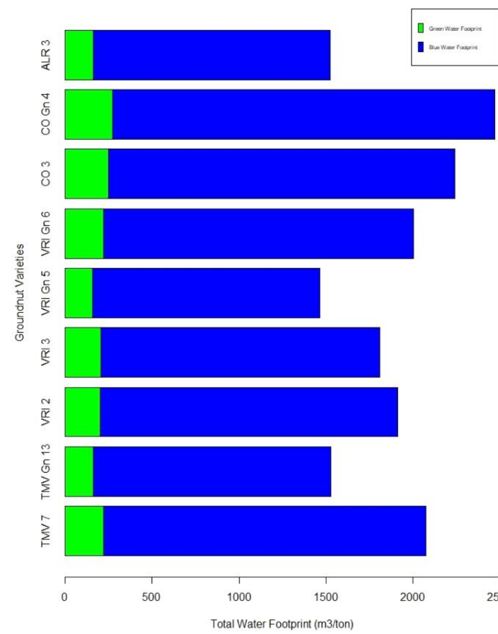

Fig 4: Total crop water footprint for groundnut varieties during *Rabi* season.

Table 4 Crop Water Footprint for Groundnut Varieties grown during *Rabi* season.

Varieties	Total water requirement (mm)	ET_{Green} (mm)	ET_{Blue} (mm)	CWU_{Green} (m^3 ha^{-1})	CWU_{Blue} (m^3 ha^{-1})	WF_{Green} (m^3 ton^{-1})	WF_{Blue} (m^3 ton^{-1})	Total water footprint (m^3 ton^{-1})
TMV 7	394	42	352	419	3522	221	1854	2074
TMV Gn 13	394	42	352	419	3522	162	1365	1528
VRI 2	394	42	352	419	3522	203	1710	1913
VRI 3	331	38	294	376	2938	205	1605	1811
VRI Gn 5	415	44	371	443	3708	156	1308	1465
VRI Gn 6	482	53	428	533	4284	222	1783	2005
CO 3	482	53	428	533	4284	248	1993	2240
CO Gn 4	482	53	428	533	4284	273	2197	2470
ALR 3	415	44	371	443	3708	163	1363	1526
Minimum	331	38	294	376	2938	156	1308	1465
Maximum	482	53	428	533	4284	273	2197	2470
Mean	421	46	375	458	3752	206	1686	1892
SD	52	6	46	60	457	40	306	346
CV (%)	12	13	12	13	12	20	18	18

SD: Standard Deviation; CV: Coefficient of Variation.

The average blue water use by different varieties of groundnut was 3233 m^3 ha^{-1} during kharif season and 3752 m^3 ha^{-1} during *rabi* season. Mali *et al.* (2015) indicated that, the blue water use by *rabi* crops is higher than that of *kharif* crops. The results agreed with the results obtained by Vanham *et al.* (2020) who indicated that, current global nut production is affected by different levels of blue water stress, in many regions of the world. Hence effective irrigation practices should be adopted to reduce the blue water stress and enhancing the crop production.

CONCLUSION

The total water footprint for groundnut varieties ranged from 2603 to 4889 m^3 ton^{-1} (CV of 26%) and 1465 to 2470 m^3 ton^{-1} (CV of 18%) during *kharif* and *rabi* seasons, respectively. It was noted that in both seasons VRI Gn 5 variety had minimum total water footprint compared to other varieties. Blue water footprint is higher than the green water footprint. Hence the groundnut production is affected by different levels of blue water stress. In recent decades, water demand always exceeds rainfall and at the same time, exploitation of groundwater has increased greatly particularly for agricultural purpose. The only solution is judicious use of water by adopting modern water management techniques and thus the yield of crops can be boosted and full yield potential to be exploited.

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