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Water requirement and use by *Jatropha curcas* in a semi-arid tropical location

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ABSTRACT

Increasing emphasis on biofuel to meet the growing energy demand while reducing emissions of greenhouse gases, *Jatropha curcas* has attracted the attention of researchers, policy makers and industries as a good candidate for biodiesel. It is a non-edible oil crop, drought tolerant and could be grown on degraded lands in the tropics without competing for lands currently used for food production. *J. curcas* being a wild plant, much about its water requirement and production potential of promising clones in different agroclimatic conditions is not known. Water use assessment of *J. curcas* plantations in the semi-arid tropical location at ICRISAT, Patancheru indicated that crop evapotranspiration of *J. curcas* under no moisture stress varied from 1410 to 1538 mm per year during 2006–2009. Under field conditions the crop evapotranspiration varied from 614 to 930 mm depending on the atmospheric demand, rainfall and crop phenological stage. Patterns of soil-water depletion indicated that with growing plant age from two to five years, depth of soil-water extraction increased from 100 to 150 cm by fifth year. Monthly water use of *Jatropha* varied from 10–20 (leaf shedding period) to 140 mm depending on water availability and environmental demand. This study indicated that *J. curcas* has a good drought tolerance mechanism, however under favorable soil moisture conditions *Jatropha* could use large amounts of water for luxurious growth and high yield. These findings highlight the need to carefully identify suitable niche areas for *Jatropha* cultivation and assess the implications of large *J. curcas* plantations on water availability and use under different agroecosystems, particularly so in water scarce regions such as semi-arid and arid regions in the tropics.

1. Introduction

The Semi-Arid Tropics (SAT) is home for 38% of the poor in developing countries, 75% of which are in the rural areas. High rainfall variability, severe land degradation, poor soils, frequent droughts, high population density and low investments all leading to poverty and fragile livelihoods characterize the rainfed areas in the SAT [16]. Land degradation and desertification are becoming major issues in India and Ajai et al. [2] have reported that about 105.48 m ha of land (32.07% of the country's total geographical area) is undergoing land degradation. Common property resources (CPR) in the villages of India are degraded and are in urgent need of rehabilitation.

1.1. *Global warming and biodiesel as an alternate fuel*

Several countries have started encouraging biofuels and are providing incentives for green energy to meet ever-growing

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demand for energy, while reducing the greenhouse gas emissions through use of fossil fuels.

The European Union is one of the biggest markets for biodiesel and plans to use more biofuels in the coming years, setting a target to replace 10% of transport fuel with biofuel by 2020. India is projected to become third largest consumer of transportation fuel by 2020 after USA and China. Hence oil import will continue to be an enormous burden on India's budget. Moreover, all countries have a commitment toward minimizing their CO_2 emissions. An indicative target of 20% blending of biofuels, both for biodiesel and bio-ethanol, by 2017 is proposed in the National Policy on Biofuels declared by the Government of India [6].

1.2. *Biodiesel from* Jatropha curcas

Biodiesel is derived from cotton, rapeseed oil, soybean oil, seeds of *Pongamia pinnata*, *J. curcas* and others. Biodiesel from the *J. curcas* has an advantage over other crops, as it is a non-edible oil crop and can be refined under normal atmospheric temperature and pressure conditions. Also, *J. curcas* is not browsed by animals and is drought tolerant. *Jatropha* cultivation has a good potential to rehabilitate degraded wastelands by greening them while providing employment to the rural poor and meeting rural energy demands [14,15]. These make *J. curcas* an excellent candidate for biodiesel production. Interest in *J. curcas* as a source of oil for producing biodiesel has arisen as a consequence of its perceived ability to grow in semi-arid regions with low nutrient requirements and little care [12]. Various aspects of *Jatropha* for biodiesel production are studied by several researchers [1,13,14,15]. Many of these dealt with the cultivation management practices including fertilizers, cropping systems and spacing. Thus, there is a need for detailed studies on water requirement and use of *J. curcas* in semi-arid regions.

ICRISAT's watershed consortia have initiated work to rehabilitate the degraded CPRs and low-quality private lands through establishing biodiesel plantations through public–private partnerships (PPP). Potential of biodiesel plantations in improving rural livelihoods and protecting environment was studied by Wani et al. [14,15] and Sreedevi et al. [13]. Kaushal et al. [11] reported that non-productive soil evaporation was reduced as a larger share of the rainfall was channeled to productive plant transpiration and groundwater recharge, and at the same time a more stable (less erosive) runoff resulted in reduced soil erosion and improved downstream water conditions. On the other hand, the results indicated that at the sub-basin scale, reductions in runoff generation as a result of large-scale conversion of wastelands to *Jatropha* cropping may pose problems to downstream water users and ecosystems.

There appears to be a great enthusiasm by policy makers and industries in several countries on *J. curcas* cultivation for biodiesel production knowing well that *J. curcas* is still a wild plant and little is known about the production potential of promising clones in different agroclimatic conditions. The positive claims and hype on *J. curcas* production in many countries is not based on research data and experimentation [10,14]. Although *J. curcas* grows in semi-arid and arid tropical areas and can therefore be considered as drought tolerant, there is little known on water use and water use efficiency of *J. curcas* as a crop [10]. A few research results are available about the influence of *J. curcas* cultivation on the local water balance and there are very few studies on the water requirement of this crop in the dry regions. Hence, a detailed study has been undertaken at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) with an objective of assessing the water requirement of *J. curcas* under rainfed conditions.

2. Materials and methods

2.1. *Site description*

ICRISAT, Patancheru is situated at 17.53°N latitude and 78.27°E longitude at an altitude of about 545 m and enjoys typical hot semi-arid climate. Annual average rainfall is 900 mm received in about 51 rainy days. About 76% of the annual rainfall is received in the southwest monsoon period (June–September). August is the rainiest month. Monthly rainfall characteristics are presented in Table 1. Because of the altitude and away from the sea makes the location continental having high summer temperatures and very cool winters. Maximum air temperature in May can go up to 43 °C and during December–January the minimum air temperature can dip down to 5 °C. Strong winds are common during monsoon period, particularly in the beginning and average winds up to 30–32 km h^{-1} were observed on certain days of June. Bright sunshine varies from 4 to 10 h per day during the year, lowest during July and August due to dense clouding in the monsoon season. January–May experience above 9 h of bright sunshine. Both Alfisols and Vertisols dominate the SAT region of India and same is true in ICRISAT Patancheru campus.

Table 1 – Rainfall characteristics of ICRISAT, Patancheru (Database: 1975–2009).

Element	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average (mm)	9	8	20	28	30	111	189	233	155	92	23	4	902
Highest (mm)	56	58	163	128	141	241	460	665	422	361	240	31	1473
Lowest (mm)	0	0	0	0	0	19	59	40	40	0	0	0	558
SD (mm)	15	16	34	30	33	54	88	136	92	78	43	8	223
CV (%)	172	208	169	107	110	49	46	58	60	85	192	214	25
Rainy days	1	1	1	2	2	7	10	11	9	5	1	0	51

SD: Standard Deviation CV: Coefficient of Variation.

Table 2 – Soil properties of experimental field BL-3 at ICRISAT, Patancheru.

Physical properties				Chemical properties				
Sand, %	Silt, %	Clay, %	Depth, cm	pH	EC, dS m^{-1}	OC, %	Phosphorus, ppm	Exchangeable K, ppm
47.4	16.6	36.0	0-15	8.9	0.29	0.67	2.68	158.3
42.7	15.3	42.1	15-30	9.3	0.94	0.48	1.40	134.5

The experimental site has Vertisol soil having depth up to 3 m. Average bulk density of the soil is about 1.35 g cc^{-1} with maximum water holding capacity of about 40% v.v. Drainage characters indicate that the soil is moderately to imperfectly drained with slow and very slow permeability. Table 2 shows the physical and chemical properties of the soil. Mean value of soil pH was 8.9 in 0–15 cm depth and 9.3 in 15–30 cm depth. Electrical Conductivity (EC) was 0.29 dS m^{-1} in 0–15 cm soil depth and 0.94 dS m^{-1} in 15–30 cm depth. Values of soil pH and EC clearly indicate the presence of salts and soil salinity.

2.2. *Experimental details*

J. curcas (ICJC-06114) seedlings were planted in November 2004 at a spacing of 3 × 2 m in the BL-3 field of ICRISAT, Patancheru. One-year old plants were pruned at 50 cm height when plants dropped their leaves during winter and moisture stress. Chemical fertilizers were applied every year after first year; nitrogen was applied at the rate of 76 kg ha^{-1} and phosphorus was applied at the rate of 10 kg ha^{-1} during 2006 and 2007. As the crop was growing, fertilizers dose was increased and nitrogen was applied at the rate of 92 kg ha^{-1} and phosphorus was applied at the rate of 50 kg ha^{-1} during 2008 and 2009 through urea and single super phosphate.

2.3. *Protocol for water use assessment*

Soil moisture in the *Jatropha* plantation was monitored from November 2005 using the neutron probe (Troxler model 4302) calibrated under similar soils and also by gravimetric method. Soil moisture up to 30 cm was measured using gravimetric method. Access tubes for neutron probe were provided in the interspaces in such a way that the soil volume sampled by the instrument was most directly influenced by the *Jatropha* plants. Neutron probe measurements were taken at 12 representative locations in the plot (Fig. 1) from 30 up to 225 cm at 15 cm interval.

Weather was monitored at the Agromet Observatory, ICRISAT campus which is about 200 m away from the experimental site. Daily reference crop evapotranspiration (ET_o) was computed following the FAO Penman–Monteith method [3] as follows:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

where ET_o 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 at 2 m height [°C]; u_2 wind speed at 2 m height [m s^{-1}]; e_s saturation vapor pressure [kPa]; e_a actual vapor pressure [kPa]; $e_s - e_a$ saturation vapor pressure deficit [kPa]; Δ slope of vapor pressure curve [kPa $°C^{-1}$]; γ psychrometric constant [kPa $°C^{-1}$].

Crop evapotranspiration under standard conditions is denoted by ET_c which is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil-water conditions and achieving full production under the given climatic conditions. In the crop coefficient approach the ET_c is calculated by multiplying the reference crop evapotranspiration, ET_o, by a crop coefficient, K_c. Thus,

$$ET_c = K_c \cdot ET_o$$

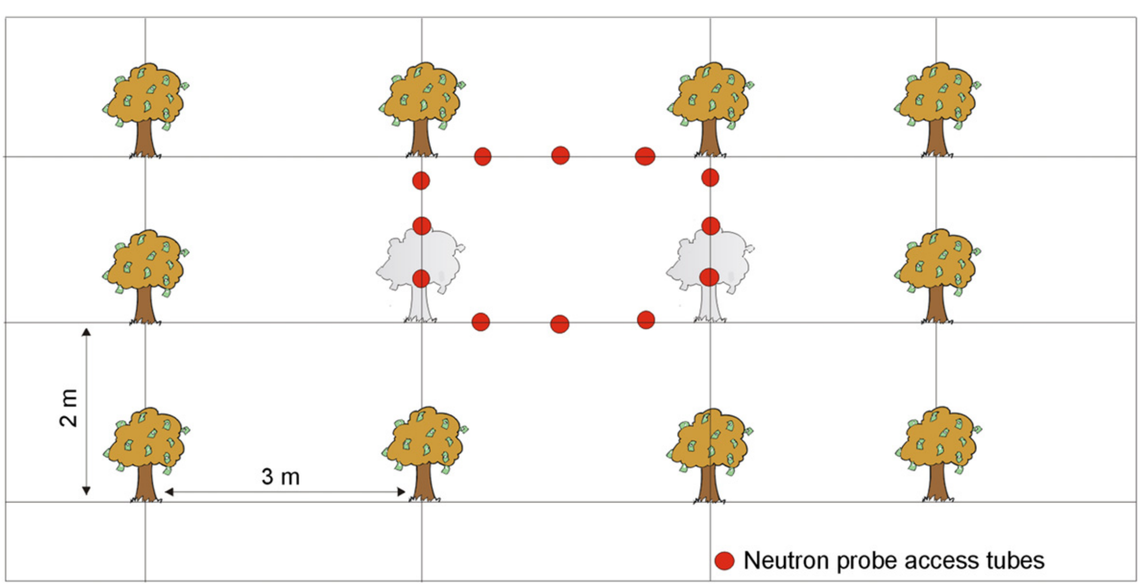

Fig. 1 – Layout of neutron probe access tubes for soil moisture measurement in *Jatropha curcas* at ICRISAT, Patancheru.

Table 3 – Growth characters of *Jatropha curcas* in BL-3 field at ICRISAT, Patancheru.

Year	Plant height (cm)	Stem diameter (cm)	Branches/plant	N–S spread (cm)	E–W spread (cm)
2006	149	8.8	12	151	147
Std. Dev.	16.5	2.1	1.6	26.4	33.5
2007	187	11.2	24	190	197
Std. Dev.	20.8	2.8	2.9	31.7	47.3
2008	220	12.5	51	195	205
Std. Dev.	23.4	2.7	11.3	35.6	42.8
2009	247	13.6	120	223	220
Std. Dev.	26.9	2.6	32.4	39.0	39.5

where ET_c crop evapotranspiration [mm day^{-1}], K_c crop coefficient [dimensionless], ET_o reference crop evapotranspiration [mm day^{-1}].

Following the FAO 56 [3] document, crop coefficients for different phenological stages of *J. curcas* are assumed to range between 0.3 and 1.1. Evapotranspiration of *J. curcas* under non-water limiting conditions (ET_c *J. curcas*) was computed based on ET_o and crop coefficients. Evapotranspiration of *J. curcas* under actual field conditions (ET_{actual} *J. curcas*) was estimated from the neutron probe soil moisture measurements.

2.4. *Protocol for growth and seed yield assessment*

J. curcas is a plant having deciduous nature and sheds its leaves during the dry season. After the withdrawal of southwest monsoon by the end of September and occasional rains in October–November through cyclonic activity in the Bay of Bengal, winter and dry season starts by November at the study location. Soil moisture starts depleting from December onwards and the plant sheds all leaves in January and enters in to a winter dormant phase with low metabolic rates till March as evident from low crop evapotranspiration during this period.

New leaf flushes start by the 1st week of April and flowering is initiated by May/June depending on the quantum of summer showers received. Vegetative growth is observed during May–September. Harvesting of pods is during September–December.

Plant height was measured, as the vertical distance between the base of the shrub and the topmost branch. Quite often, the topmost branch will not be directly over the base of the tree, so adjusted accordingly. To improve accuracy, 3–5 height measurements were made and average plant height was calculated. Total number of branches on each plant was recorded and average number of branches per plant was calculated. Stem diameter of plant was measured at 10 cm height from the stem base. This stem diameter was calculated from the measurements of stem girth, at the same height above the stem base. Crown width was measured at two perpendicular directions, for example East–West and North–South directions or the widest crown width and the one perpendicular to it. Crown width can be used to calculate the crown area and, in combination with the crown depth, to calculate the crown volume. Similar approach was adopted by Iida et al. [8] for recording similar observations. Harvesting and shelling: The maturity of pods in *Jatropha* occurs in a sequential order on the plant; therefore the repeated

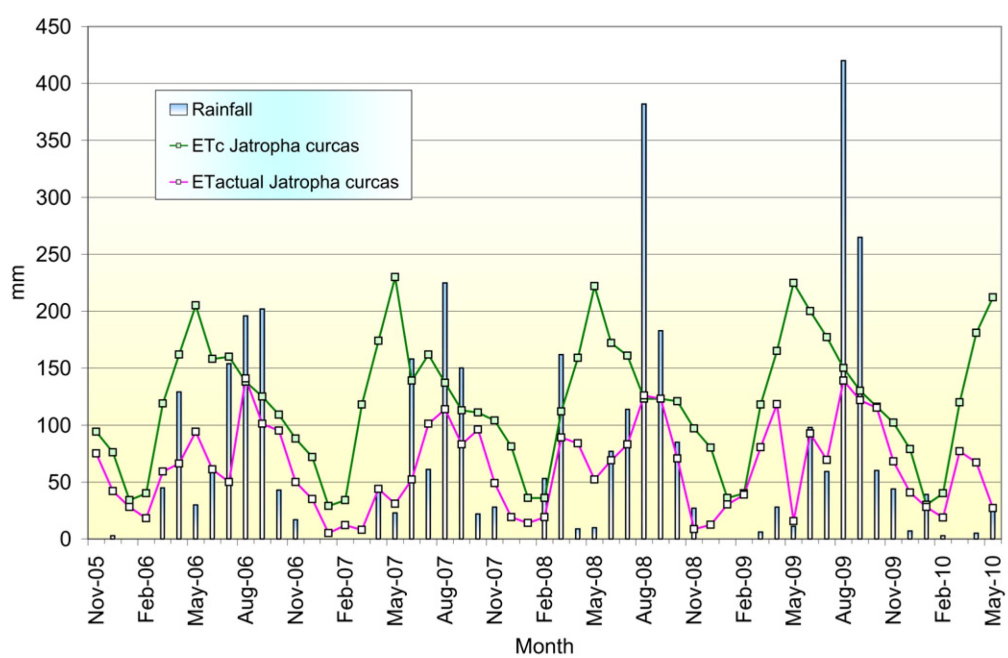

Fig. 2 – Monthly rainfall and evapotranspiration requirements of *Jatropha curcas* at ICRISAT, Patancheru.

Table 4 – Evapotranspiration demands of *Jatropha curcas* at ICRISAT, Patancheru.

Element	Year			
	2006	2007	2008	2009
Rainfall (mm)	875	712	1102	998
ET_o *Jatropha* (mm) Reference crop evapotranspiration	1624	1631	1659	1760
ET_c *Jatropha* (mm) under non-water limiting conditions	1410	1432	1442	1538
ET_{actual} *Jatropha* (mm) under actual field conditions	798	614	751	930

harvesting of the matured pods was done on sixty individual plants and recorded oven dry weights. Manual shelling of pods was done to extract seeds from dried pods and seed yield was extrapolated on hectare basis.

3. Results and discussion

3.1. *Seed yield*

At ICRISAT Patancheru, India, *J. curcas* started producing seed yield from third year onwards and the yield obtained was 600, 1560 and 1000 kg ha^{-1} with a standard deviation of 187, 479 and 287 during 2007–2009 respectively [13,15]. *J. curcas* is drought tolerant, however, it is seen that distribution of rainfall is more important than the amount of rainfall for obtaining high yields. Even though rainfall during 2009 was higher, lower seed yield during 2009 was due to delayed onset of southwest monsoon and drought conditions at a later stage aborted flowers which reflected in low seed yield as compared to 2008. Growth characters of *J. curcas* were measured and average values are given in Table 3. Plant height increased from 149 cm in 2006 to 247 cm in 2009 and number of branches increased from 12 to 120 during the same period.

3.2. *Evapotranspiration*

Monthly crop evapotranspiration values indicated (Fig. 2) that during April–June, evapotranspiration requirements are high due to atmospheric demand as well as the vegetative stage of plantation. However, this is the period in which the actual moisture availability with respect to demand is low. During July–October, soil moisture status is sufficient to satisfy much of the crop evapotranspiration requirements; this period coincides with flowering and fruit setting stage.

J. curcas has used about 70–90% of the rainfall received during 2006–2009. Rainfall during March–May was about 181 mm in 2008 and only 45 mm in the year 2009 and hence, soil moisture contribution during May 2009 was only 16 mm compared to 52 mm in 2008. July 2009 received the record lowest rainfall of just 59 mm against the average of 189 mm leading to drought conditions. Rainfall during August–September was 685 mm in 2009 compared to the 565 mm in 2008. Annual ET_c *J. curcas* under no moisture stress conditions varied from 1410 to 1538 mm per year during 2006–2009. Annual ET_{actual} was 930 mm in 2009 and in 2008 it was 751 mm (Table 4). However, seed yields were more in the year 2008 compared to 2009 due to better distribution of rainfall particularly during March–May and also during July–September.

Measured dry leaf litter and pruned lopping data indicated that about 1 t of dry leaf litter and about 1.7 t of pruned lopping were added to the soil in 2009 as compared to 0.67 t of dry leaf litter and 1.03 t pruned lopping in 2008. Even though more biomass was produced in 2009, results indicated that higher annual water usage may not necessarily reflect in higher seed yields. In South Africa, annul transpiration of *J. curcas* was monitored using Heat Pulse Velocity technique through the

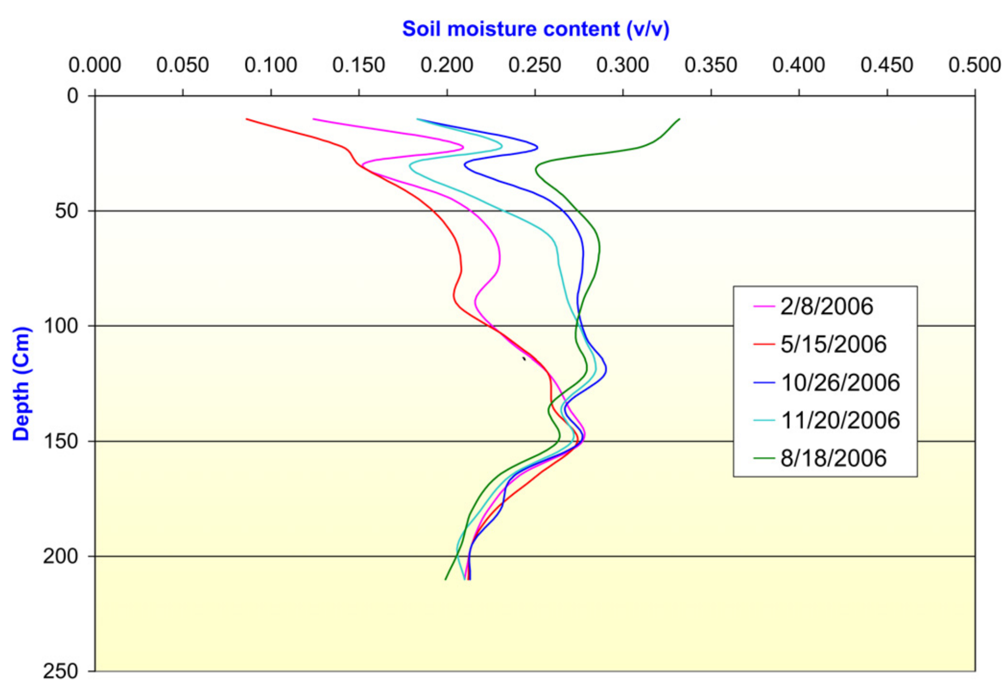

Fig. 3 – Distribution of volumetric soil moisture content for two-year young *Jatropha curcas* at ICRISAT, Patancheru.

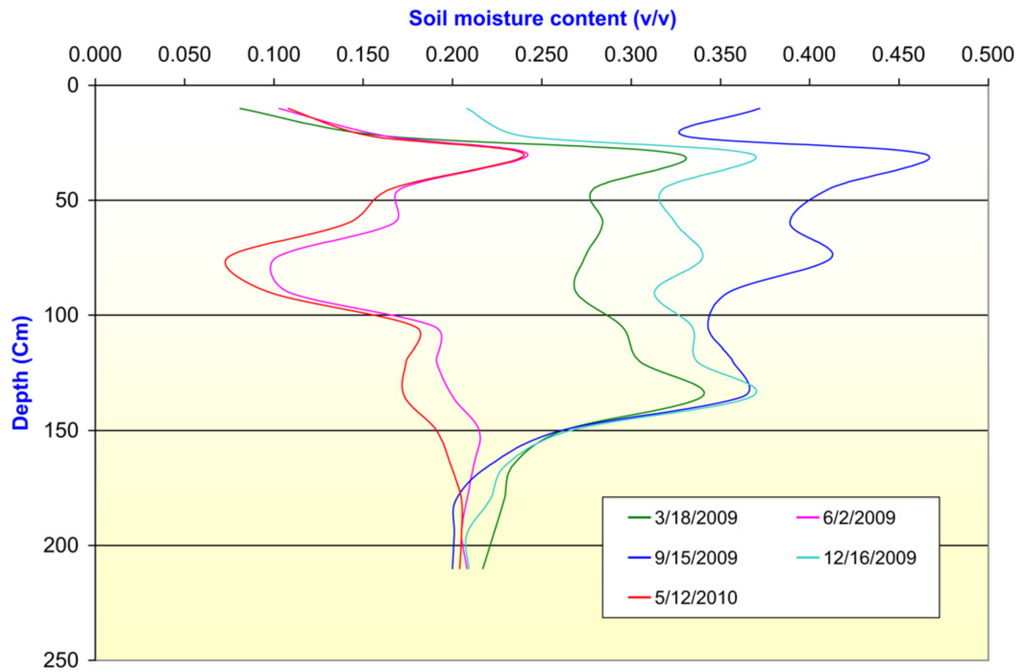

Fig. 4 – Distribution of volumetric soil moisture content for five-year young *Jatropha curcas* at ICRISAT, Patancheru.

measurement of sap flow [4,7]. It was observed that the average total annual transpiration varied from 144 to 361.8 mm. Annual transpiration totals were also obtained for the same location using Leaf Area Index of *J. curcas* and found to be between 300 and 500 mm under conditions of below average rainfall.

Monthly water use of *Jatropha* varied from 10–20 (leaf shedding period) to 140 mm depending on water availability and environmental demand. Study indicates that contrary to the belief that *J. curcas* needs less water, under favorable soil moisture conditions *J. curcas* could use large amounts of water for luxurious growth and high yield. In southern Nevada, annual and seasonal evapotranspiration (ET) were compared among Mojave Desert shrubs with different leaf phenologies over a three-year period by Carolyn and Robert [5]. The study concluded that ET in the Mojave Desert is dependent largely on winter precipitation and the amount of soil water available during the growing season rather than on species composition.

3.3. *Soil moisture extraction*

With a view to understand the moisture uptake from the different soil layers, distribution of the volumetric content of soil moisture throughout the soil profile of 225 cm was studied for all the 74 dates of sampling from 10 October 2005 to 28 May 2010. To have clarity in presentation, patterns for five representative dates each for the two-year and five-year young *J. curcas* are presented in the Figs. 3 and 4. Patterns of soil-water depletion indicated that two-year young *Jatropha* plantation was able to extract water up to a soil depth of about 100 cm and later at the age of five years, it was able to extract water up to 150 cm. It was evident that *J. curcas* causes significant changes in soil-water dynamics compared to bare soil or grassland. In South Africa also continuous measurements of matric potential and soil-water content in *J. curcas* plot and in an adjacent grassland control site at corresponding depths beneath the soil surface confirmed the uptake by the plants for transpiration [7].

4. Conclusions

Assessment of water requirements of *J. curcas* is an important step for promoting its wide-scale cultivation however the literature survey did not yield much information. Water use assessment of *J. curcas* plantations in the semi-arid tropical location at ICRISAT, Patancheru indicated that ET_c *J. curcas* under no moisture stress conditions varied from 1410 to 1538 mm per year during 2006–2009. Under the actual field conditions the evapotranspiration requirements of *J. curcas* varied from 614 to 930 mm depending on the atmospheric demand, rainfall and crop phenological stage. Patterns of soil-water depletion indicated that *Jatropha* plantation extracted soil water from 100 cm depth at two-year age and up to 150 cm soil depth by five years age. Monthly water use of *Jatropha* varied from 10–20 (leaf shedding period) to 140 mm depending on water availability and environmental demand. Study indicates that contrary to the belief that *Jatropha* needs less water, under favorable soil moisture conditions, *Jatropha* could use large amounts of water for luxurious growth and high yield. *Jatropha* plantation yield varied from 600 kg ha^{-1} at third year to 1560 kg ha^{-1} varying mainly with the distribution of rainfall during the season rather than with total rainfall amount during the year and plant age. Further studies with this plantation are in progress.

With increasing demand of water and land resources for food production and possible adverse impacts of the climate change on water availability and increased occurrence of droughts and floods [9] the issue of biofuel production needs careful and well thought strategy in India and other water scarce regions in the tropics. It has to be a win–win situation approach to produce biofuel particularly biodiesel without competing for land and water resources much needed for food production. Developing wastelands which are not suitable for crop production and enhancing rainwater use efficiency and creating livelihood opportunities for the rural poor could be a win–win situation. Further research, related to water use and yield assessment of *J. curcas* and ways to improve the oil content will give confidence in promoting wider-scale propagation of this crop.

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