Abstract: Jatropha curcas has attracted the attention of researchers, policy makers and industries as a good candidate for biodiesel to meet the growing energy demand. 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. Jatropha curcas is a wild plant that is not much researched and little is known about its water requirement and production potential of promising clones in different agroclimatic conditions. Water use assessment of Jatropha curcas plantations in the semi-arid tropical location at ICRISAT, Patancheru indicated that crop evapotranspiration of Jatropha curcas under no moisture stress varied from 1410-1538 mm per year during 2006-2009. Under field conditions the crop evapotranspiration varied from 614-930 mm depending on atmospheric demand, rainfall and phonological 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 cm to 150 cm by fifth year. Monthly water use varied from 10-20 mm to 140 mm depending on water availability and environmental demand. This study indicated that Jatropha curcas has a good drought tolerance mechanism, however under favourable soil moisture conditions, Jatropha could use large amounts of water for luxurious growth and high yield. These findings highlight the need to carefully assess the implications of large Jatropha 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.
Expert in dryland agriculture, biodiesel and Jatropha

Opposed Reviewers:
Dear Sir,

I am enclosing a research paper entitled “Water requirement and use by *Jatropha curcas* in a semi-arid tropical location” for consideration of publication in the journal entitled *Biomass & Bioenergy*. Authors of the research paper are

AVR Kesava Rao (Corresponding author)
Suhas P Wani
Piara Singh
K Srinivas and
Ch Srinivasa Rao

All authors are affiliated to International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) located at Patancheru, Andhra Pradesh, India.

Global demand for biofuels is increasing largely due to the policy decisions made in the USA and Europe to enhance use of biofuels to meet the targets for reducing the carbon emissions. *Jatropha curcas* is considered as a potential candidate for biodiesel production worldwide. There are very few studies on the water requirement of this important biodiesel crop in the semi-dry regions. Hence, a detailed study has been undertaken at ICRISAT to assess the water requirement of *J. curcas* in the natural rainfed conditions and the results are worth publishing. These results might help building confidence in promoting large-scale rainfed cultivation of *Jatropha curcas* on degraded lands.

Hence it is requested that the research paper may be considered for publication in the journal at the earliest.

With warm regards

AVR Kesava Rao
(k.rao@cgiar.org)
Water requirement and use by *Jatropha curcas* in a semi-arid tropical location

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Piara Singh (p.singh@cgiar.org); K Srinivas (k.srinivas@cgiar.org)
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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. *Jatropha curcas* is a wild plant that is not much researched and little is known about its water requirement and production potential of promising clones in different agroclimatic conditions. Water use assessment of *Jatropha curcas* plantations in the semi-arid tropical location at ICRISAT, Patancheru indicated that crop evapotranspiration of *Jatropha curcas* under no moisture stress varied from 1410–1538 mm per year during 2006-2009. Under field conditions the crop evapotranspiration varied from 614-
930 mm depending on the atmospheric demand, rainfall and crop phonological 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 cm to 150 cm by fifth year. Monthly water use of *Jatropha* varied from 10-20 mm (leaf shedding period) to 140 mm depending on water availability and environmental demand. This study indicated that *Jatropha curcas* has a good drought tolerance mechanism, however under favourable soil moisture conditions, *Jatropha* could use large amounts of water for luxurious growth and high yield. These findings highlight the need to carefully assess the implications of large *Jatropha 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.

Keywords: *Jatropha curcas*, Water requirements, Semi-Arid Tropics, Soil moisture, Biodiesel

1. **Introduction**

The Semi-Arid Tropics (SAT) is home for 38 per cent of the poor in developing countries, 75 per cent 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. Land degradation and desertification are becoming major issues in India and Ajai et al (2009) [2] have reported that about 105.48 m ha of land (32.07% of the country’s total geographical area) is undergoing processes of 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 began providing incentives for green energy to meet ever-growing 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 oil with biofuel by 2020. India is projected to become third largest consumer of transportation fuel in 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 towards minimizing their C emissions. An indicative target of 20% blending of biofuels, both for bio-diesel 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 rapeseed oil, soybean oil, seeds of *Pongamia pinnata* and *Jatropha curcas*. Biodiesel from the *Jatropha 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, *Jatropha curcas* is not browsed by animals and is drought tolerant. *Jatropha* cultivation has a good potential to rehabilitated degraded wastelands by greening them while providing employment to the rural poor and meeting rural energy demands [12,13]. These make *Jatropha curcas* an excellent candidate for biodiesel production. Interest in *Jatropha 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 [10]. Various aspects of *Jatropha* for biodiesel production are studied by several researchers [1,11,12,13].

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 (2006, 2009)[12,13] and Sreedevi et al (2009)[11].

There appears to be a great rush by policy makers and industries in several countries on *Jatropha curcas* cultivation for biodiesel production knowing well that *Jatropha 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 *Jatropha curcas* in many countries is not based on research data and experimentation [12,9]. Very little research results are available on the influence of *Jatropha 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 *Jatropha curcas* under rainfed conditions.

2. Materials and methods

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 (Jun-Sep). 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 hours per day during the year, lowest during July and August due to dense clouding in the monsoon season. January to May experience above 9 hours of bright sunshine. Both Alfisols and Vertisols dominate the SAT region of India and same is true in ICRISAT Patancheru campus.

*Jatropha curcas* (ICJC-06114) seedlings were planted in November 2004 at a spacing of 3 x 2 m in the BL-3 field of ICRISAT, Patancheru. 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 dSm\(^{-1}\) in 0-15 cm soil depth and 0.94 dSm\(^{-1}\) in 15-30 cm depth. Values of soil pH and EC clearly indicate the presence of salts and soil salinity. 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.

Soil moisture in the \textit{Jatropha} plantation was monitored from November 2005 using the neutron probe (Troxler model 4302) and 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 \textit{Jatropha} plants. Neutron probe measurements were taken at 12 representative locations in the plot (Figure 1) from 45 cm up to 225 cm at 15 cm interval. Neutron probe was earlier calibrated under similar soil conditions.

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:

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

where

\[
\begin{align*}
ET_o & \text{ reference evapotranspiration [mm day}\^{-1}] \\
R_n & \text{ net radiation at the crop surface [MJ m}\^{-2}\text{ day}\^{-1}] \\
\end{align*}
\]
Jatropha 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 Oct-Nov 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 into a winter dormant phase with low metabolic rates till March as evident from low crop evapotranspiration during this period.

New 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. 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,

$$ET_c = K_c \cdot ET_o$$

where $ET_c$ is crop evapotranspiration [mm d$^{-1}$], $K_c$ is crop coefficient [dimensionless].
ET<sub>o</sub> reference crop evapotranspiration [mm d<sup>-1</sup>].

Following the FAO56 [3] document, crop coefficients for different phonological stages of *Jatropha curcas* are assumed which ranged between 0.3 and 1.1. Evapotranspiration of *Jatropha curcas* under non-water limiting conditions (ET<sub>Jatropha curcas</sub>) was computed based on ET<sub>o</sub> and crop coefficients. Evapotranspiration of *Jatropha curcas* under actual field conditions (ET<sub>actual Jatropha curcas</sub>) was estimated from the neutron probe soil moisture measurements and using simplified water balance approach.

### 3. Results and discussion

#### 3.1 Seed yield

At ICRISAT Patancheru, India, *Jatropha curcas* started giving seed yield from 3<sup>rd</sup> year onwards and the yield obtained was 600 kg ha<sup>-1</sup> during 2007, 1560 kg ha<sup>-1</sup> during 2008 and 1000 kg ha<sup>-1</sup> during 2009 [11,13]. *Jatropha 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 *Jatropha 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 (Figure. 2) that during April to June, evapotranspiration requirements are high due to atmospheric demands as well as the vegetative stage of plantation. However, this is the period in which the actual availability with respect to demand is low. During July to October, soil moisture status is sufficient to satisfy much of the crop evapotranspiration requirements; this period coincides with flowering and fruit setting stage.
*Jatropha curcas* has used about 70 to 90% of the rainfall received during 2006-09. 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: *Jatropha curcas* under no moisture stress conditions varied from 1410–1538 mm per year during 2006-2009. Annual ET$_{\text{actual}}$ 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, annual transpiration of *Jatropha curcas* was monitored using Heat Pulse Velocity technique through the measurement of sap flow[7,4]. 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 *Jatropha curcas* and found to be between 300-500 mm under conditions of below average rainfall.

Monthly water use of *Jatropha* varied from 10-20 mm (leaf shedding period) to 140 mm depending on water availability and environmental demand. Study indicates that contrary to the belief that *Jatropha curcas* needs less water, under favorable soil moisture conditions, *Jatropha 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 3-year period by Carolyn and Robert (1999)[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 *Jatropha curcas* are presented in the Figures 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 *Jatropha 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 *Jatropha 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]. The simple water balance model used in the present study could produce results that are satisfactory.

4. Conclusions

Assessment of water requirements of *Jatropha curcas* is an important step for promoting its wide-scale cultivation however the literature survey did not yield much information. Water use assessment of *Jatropha curcas* plantations in the semi-arid tropical location at ICRISAT, Patancheru indicated that ET of *Jatropha curcas* under no moisture stress conditions varied from 1410–1538 mm per year during 2006-2009. Under the actual field conditions the evapotranspiration requirements of *Jatropha curcas* varied from 614-930 mm depending on the atmospheric demand, rainfall and crop phonological stage. 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 up to 150
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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 [8] 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-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 *Jatropha curcas* and ways to improve the oil content will give confidence in promoting wider-scale propagation of this crop.

5. **Acknowledgements**

The financial support for this study provided by the Government of Andhra Pradesh, India and International Fund for Agricultural Development (IFAD), Rome, Italy is gratefully acknowledged.
References


Planting of *Jatropha curcas* on Water Resources, through Process-Based Research and Modelling”. WRC Report No 1497/1/07.


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

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

SD: Standard Deviation   CV: Coefficient of Variation
Table 2. Soil properties of experimental field BL-3 at ICRISAT, Patancheru

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>Chemical properties</th>
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<tbody>
<tr>
<td>Sand %</td>
<td>Silt %</td>
</tr>
<tr>
<td>47.4</td>
<td>16.6</td>
</tr>
<tr>
<td>42.7</td>
<td>15.3</td>
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</tbody>
</table>
Table 3. Growth characters of *Jatropha curcas* in BL-3 field at ICRISAT, Patancheru

<table>
<thead>
<tr>
<th>Year</th>
<th>Plant height (cm)</th>
<th>Stem diameter (cm)</th>
<th>Branches/plant</th>
<th>N-S spread (cm)</th>
<th>E-W spread (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>149</td>
<td>8.8</td>
<td>12</td>
<td>151</td>
<td>147</td>
</tr>
<tr>
<td>2007</td>
<td>187</td>
<td>11.2</td>
<td>24</td>
<td>190</td>
<td>197</td>
</tr>
<tr>
<td>2008</td>
<td>220</td>
<td>12.5</td>
<td>51</td>
<td>195</td>
<td>205</td>
</tr>
<tr>
<td>2009</td>
<td>247</td>
<td>13.6</td>
<td>120</td>
<td>223</td>
<td>220</td>
</tr>
</tbody>
</table>
Table 4. Evapotranspiration demands of *Jatropha curcas* at ICRISAT, Patancheru

<table>
<thead>
<tr>
<th>Element</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2006</td>
</tr>
<tr>
<td>Rainfall (mm)</td>
<td>875</td>
</tr>
<tr>
<td>$\text{ET}_0$ Jatropha (mm) Reference crop evapotranspiration</td>
<td>1624</td>
</tr>
<tr>
<td>$\text{ET}_0$ Jatropha (mm) under non-water limiting conditions</td>
<td>1410</td>
</tr>
<tr>
<td>$\text{ET}_{\text{actual}}$ Jatropha (mm) under actual field conditions</td>
<td>798</td>
</tr>
</tbody>
</table>
Figure 2
Figure 4

Soil moisture content (v/v)

Depth (Cm)

- ▲ 3/18/2009
- --- 6/2/2009
- ■ 9/15/2009
- ---- 12/16/2009
- 5/12/2010
Water requirement and use by *Jatropha curcas* in a semi-arid tropical location

AVR Kesava Rao, Suhas P Wani, Piara Singh, K Srinivas and Ch Srinivasa Rao

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

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

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

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