Elsevier Editorial System(tm) for Biomass and Bioenergy
Manuscript Draft

Manuscript Number:

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

Article Type: Research Paper

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

Corresponding Author: Dr Kesava Rao AVR, Ph.D

Corresponding Author's Institution: ICRISAT

First Author: Kesava Rao AVR, Ph.D

Order of Authors: Kesava Rao AVR, Ph.D; Suhas P Wani, Ph.D; Piara Singh, Ph.D; Srinivas K, M.Sc; Srinivasa Rao Ch, M.Sc

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.

Suggested Reviewers: Johan Rockstorm Ph.D
Executive Director, Stockholm Environment Institute
rockstorm@eng.uz.ac.zw
Expert in biofuels research and policy

Albert Nikiema Ph.D
Scientist, ICRISAT, Niamey, Africa
a.nikiema@icrisatne.ne;a.nikiema@gmail.com
Expert in Biodiesel and Jatropha curcas

Venkateswarlu B Ph.D
Director, Central Research Institute for Dryland Agriculture, India
director@crida.ernet.in

Expert in dryland agriculture, biodiesel and Jatropha

Opposed Reviewers:

ICRISAT Science with a human face
International Crops Research Institute for the Semi-Arid Tropics

Dated 27 August 2010

From
Dr. AVR Kesava Rao
Scientist (Agroclimatology)
Global Theme on Agroecosystems

To
The Chief Editor
Biomass & Bioenergy

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)

Headquarters: Patancheru 502 324, Andhra Pradesh, India
Tel +91 40 30713071 **Fax** +91 40 30713074 +91 40 30713075 **Email** icrisat@cgiar.org

Liaison Office: CG Centers Block, NASC Complex, Dev Prakash Shastri Marg, New Delhi 110 012, India
Tel +91 11 32472306/32472307/32472308 **Fax** +91 11 25841294

ICRISAT-Bamako
BP 320
Bamako
Mali
Tel +223 20223375
Fax +223 20228683
Email icrisat-w-mali@cgiar.org

ICRISAT-Bulawayo
Matopos Research Station
PO Box 776,
Bulawayo, Zimbabwe
Tel +263 83 8311 to15
Fax +263 83 8253/8307
Email icrisatzw@cgiar.org

ICRISAT-Lilongwe
Chitedze Agricultural Research Station
PO Box 1096
Lilongwe, Malawi
Tel +265 1 707297/071/067/057
Fax +265 1 707298
Email icrisat-malawi@cgiar.org

ICRISAT-Maputo
c/o IIAM, Av. das FPLM No 2698
Caixa Postal 1906
Maputo, Mozambique
Tel +258 21 461657
Fax +258 21 461581
Email icrisatmoz@panintra.com

ICRISAT-Nairobi
(*Regional hub ESA*)
PO Box 39063, Nairobi,
Kenya
Tel +254 20 7224550
Fax +254 20 7224001
Email icrisat-nairobi@cgiar.org

ICRISAT-Niamey
(*Regional hub WCA*)
BP 12404
Niamey, Niger (Via Paris)
Tel +227 20 722626, 20 722529
Fax +227 20 734329
Email icrisatsc@cgiar.org

www.icrisat.org

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

International Crops Research Institute for the Semi-Arid Topics (ICRISAT), Patancheru, Andhra Pradesh 502 324, India

Email : AVR Kesava Rao (k.rao@cgiar.org); Suhas P Wani (s.wani@cgiar.org)
Piara Singh (p.singh@cgiar.org); K Srinivas (k.srinivas@cgiar.org)
Ch Srinivasa Rao (s.rao@cgiar.org)

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-

* *Corresponding author*. Tel.: + 91 40 30713506; Fax : +91 40 30713075.
Email : k.rao@cgiar.org (AVR Kesava Rao)
Address : Scientist (Agroclimatology)
GT-Agroecosystems, ICRISAT, Patancheru 502324
Andhra Pradesh, India

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 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 *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 *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:

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

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 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}]

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 in to 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,

$$ET_c = K_c \, ET_o$$

where ET_c crop evapotranspiration [mm d^{-1}],

K_c crop coefficient [dimensionless],

ET_o reference crop evapotranspiration [mm d^{-1}].

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_c *Jatropha curcas*) was computed based on ET_o and crop coefficients. Evapotranspiration of *Jatropha curcas* under actual field conditions (ET_{actual} *Jatropha curcas)* 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 3rd year onwards and the yield obtained was 600 kg ha^{-1} during 2007, 1560 kg ha^{-1} during 2008 and 1000 kg ha^{-1} 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_c *Jatropha curcas* under no moisture stress conditions varied from 1410–1538 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 *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_c *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 cm. 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* needs less water, under favourable soil moisture conditions, *Jatropha* could use large amounts of water for luxurious growth and high yield.

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

[1] Achten WMJ, Verchot L, Franken YJ, Mathijs E, Singh VP, Aerts R, Muys B (2008). *Jatropha* bio-diesel production and use. Biomass and Bioenergy 32(12), 1063-1084.

[2] Ajai, Arya AS, Dhinwa PS, Pathan SK and Ganesh Raj K. (2009). Desertification / land degradation status mapping of India. Current Science, Vol. 97, No. 10:1478-83.

[3] Allen RG, Pereria LS, Dirk Raes and Martin Smith. (1998). Crop Evapotranspiration – Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56.

[4] Blesgraaf RAR. (2009). Water use of Jatropha. MSc-thesis submitted to the Delft University of Technology, Council for Scientific and Industrial Research, South Africa.

[5] Carolyn K. Yoder and Robert S. Nowak. (1999). Soil moisture extraction by evergreen and drought-deciduous shrubs in the Mojave Desert during wet and dry years. Journal of Arid Environments. 42: 81–96.

[6] Government of India. 2008. National Policy on Biofuels. Ministry of New and Renewable Energy. New Delhi 110 003. pp. 18

[7] Holl, MA, Gush MB, Hallowes J and Versfeld DB. (2007). *Jatropha curcas* in South Africa: An Assessment of its Water Use and Bio-Physical Potential. In: Report to the Water Research Commission on the project “Investigation into the Impacts of Large-Scale

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

[8] IPCC, 2007: Summary for Policymakers. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 7-22.

[9] Jongschaap REE, Corre´ WJ, Bindraban PS, BrandenburgWA. (2007). Claims and Facts on *Jatropha curcas* L.: Global *Jatropha curcas* Evaluation, Breeding and propagation programme. Report 158. (Plant Research International BV, Wageningen, The Netherlands and Stichting Het Groene Woudt, Laren, The Netherlands).

[10] Richard Brittaine and NeBambi Lutaladio. 2010. Jatropha: A Smallholder Bioenergy Crop. The Potential for Pro-Poor Development. Integrated Crop Management Vol. 8–2010. FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, Rome, 2010.

[11] Sreedevi TK, Suhas P Wani, Srinivasa Rao CH, Raghu Chaliganti and Ramalinga Reddy. (2009). *Jatropha* and *Pongamia* rainfed plantations on wastelands in India for improved livelihoods and protecting environment. In Proceedings of 6th International Biofuels Conference, March 4-5, 2009: Winrock International, New Delhi. Pp. 102-122.

[12] Wani SP, Osman M, Emmanuel D'Silva, Sreedevi TK. (2006). Improved Livelihoods and Environmental Protection through Biodiesel Plantations in Asia. Asian Biotechnology and Development Review 8, 11-29.

[13] Wani SP, Sreedevi TK, Marimuthu S, Kesava Rao AVR and Vineela C. (2009). Harnessing Potential of *Jatropha* and *Pongamia* plantations for improving Livelihoods and Rehabilitating Degraded lands. In Proceedings of 6th International Biofuels Conference, March 4-5, 2009: Winrock International, New Delhi. Pp. 256-272.

Table

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 dSm^{-1}**	**OC** %	**Phos-phorus ppm**	**Exchan-geable 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

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
2007	187	11.2	24	190	197
2008	220	12.5	51	195	205
2009	247	13.6	120	223	220

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

Figure1

Click here to download high resolution image

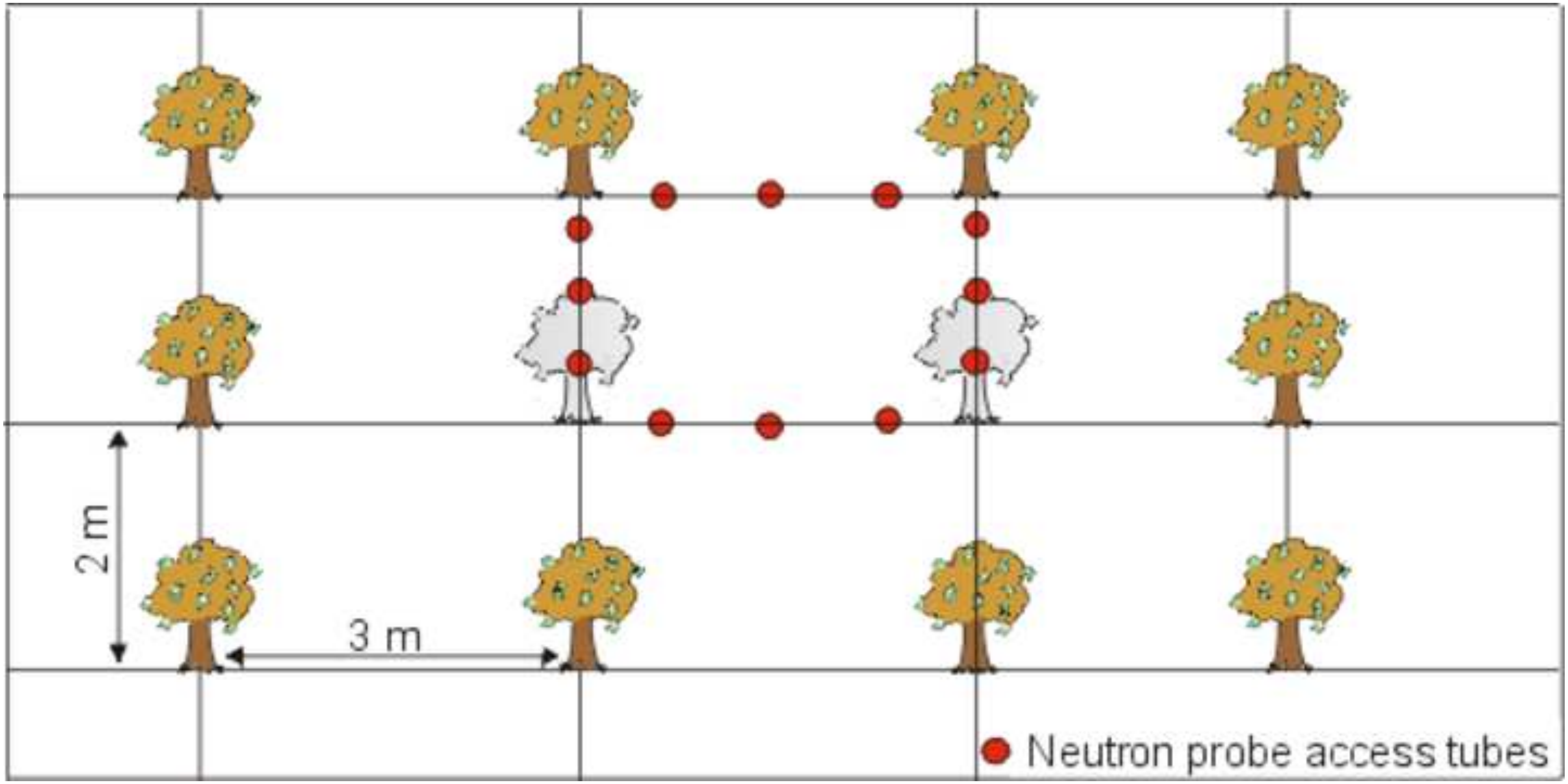
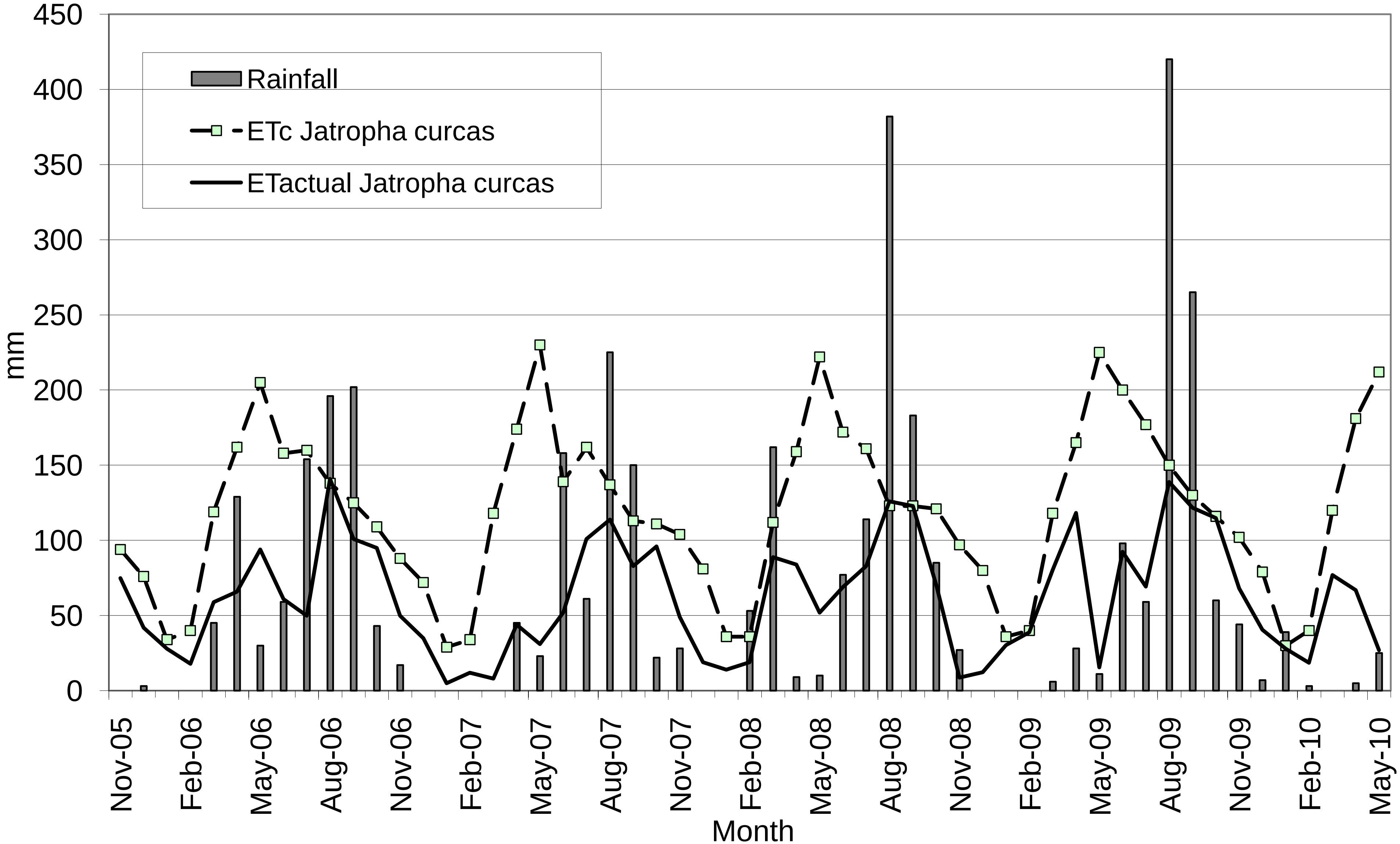
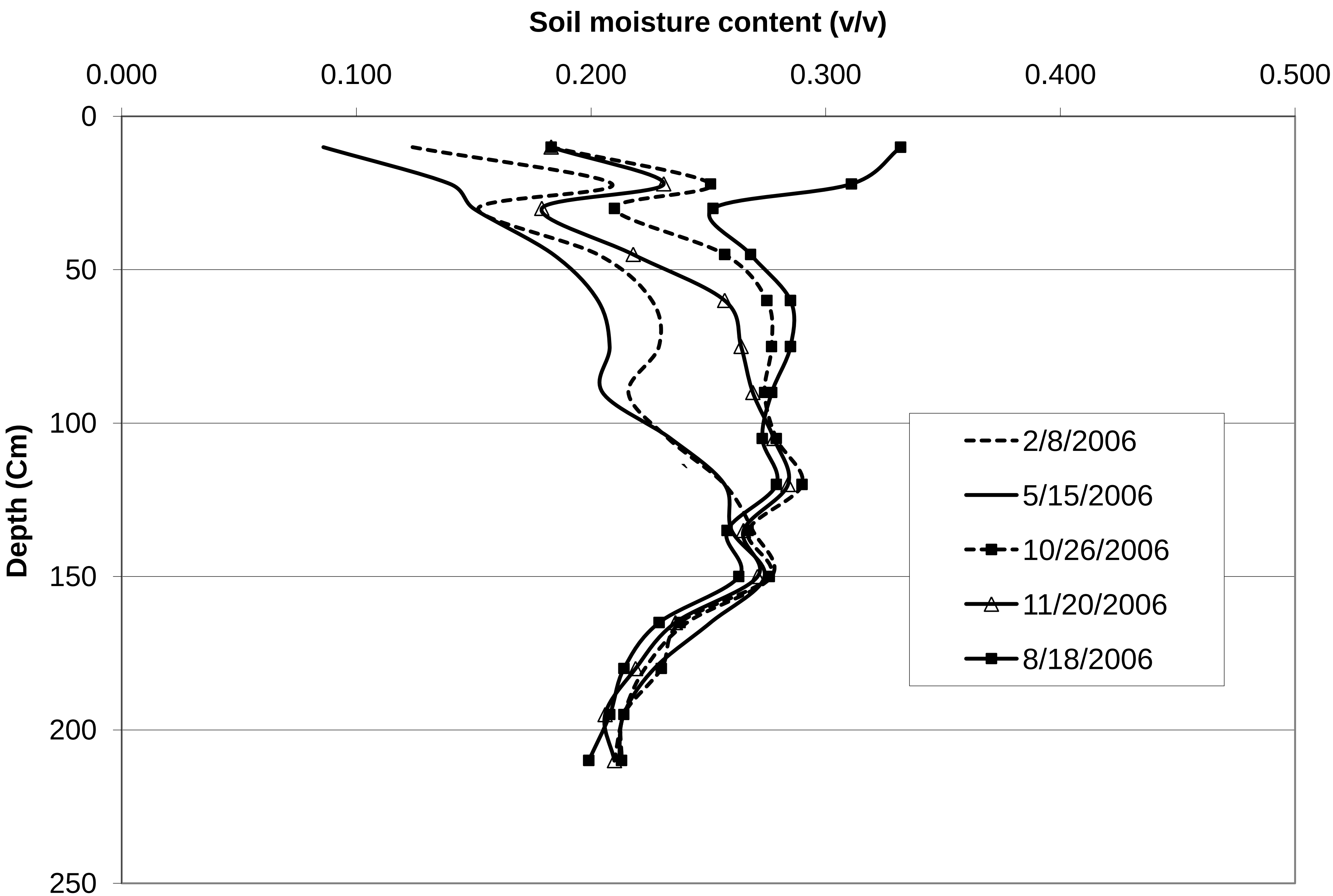


Figure2



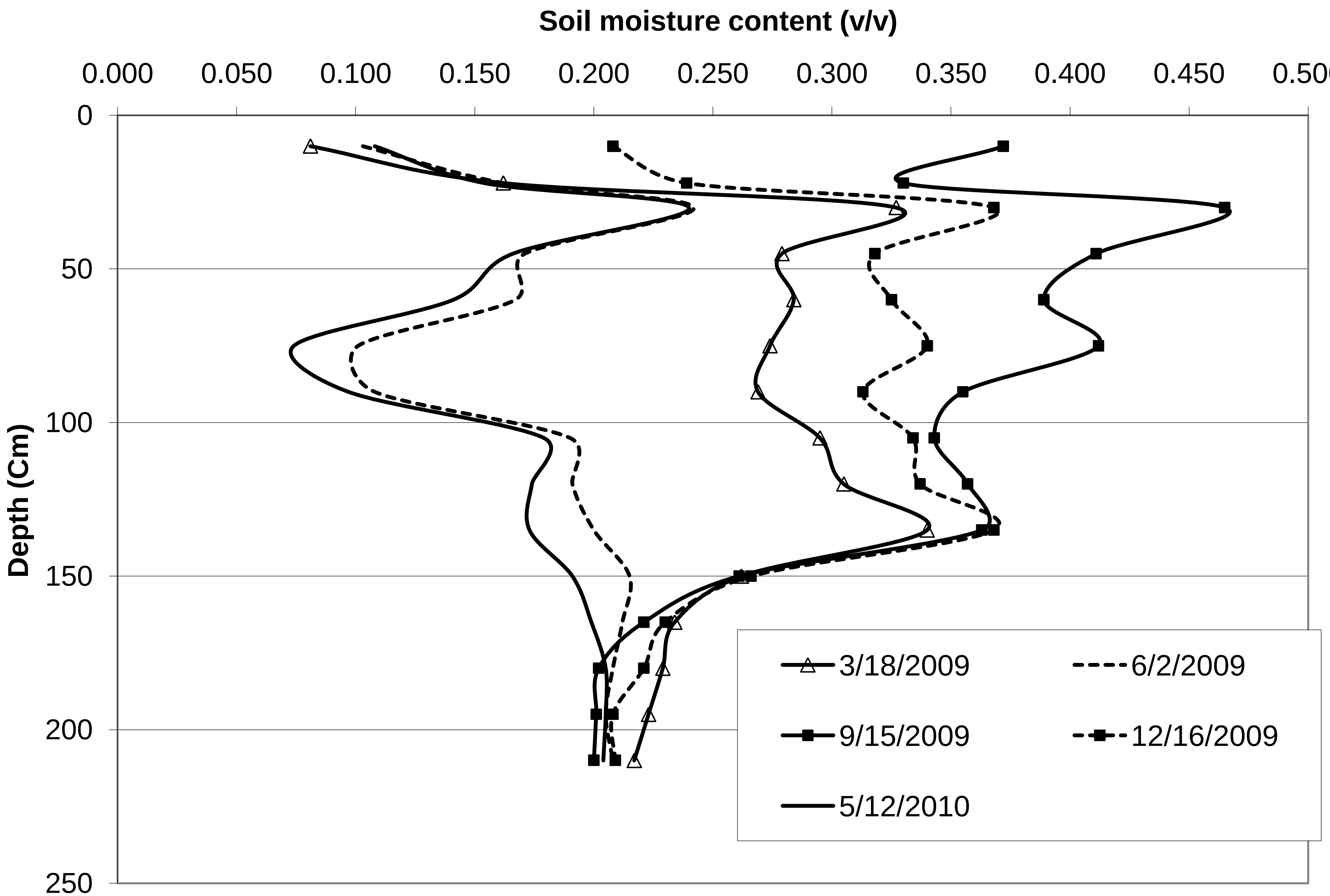
Rainfall
ETc Jatropha curcas
ETactual Jatropha curcas
mm
450
400
350
300
250
200
150
100
50
0
Nov-05
Feb-06
May-06
Aug-06
Nov-06
Feb-07
May-07
Aug-07
Nov-07
Feb-08
May-08
Aug-08
Nov-08
Feb-09
May-09
Aug-09
Nov-09
Feb-10
May-10
Month

Figure3



Soil moisture content (v/v)
0.000
0.100
0.200
0.300
0.400
0.500
0
50
100
150
200
250
Depth (Cm)
2/8/2006
5/15/2006
10/26/2006
11/20/2006
8/18/2006

Figure4


Soil moisture content (v/v)
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.350
0.400
0.450
0.500
0
50
100
150
200
250
Depth (Cm)
3/18/2009
6/2/2009
9/15/2009
12/16/2009
5/12/2010

figures-captions

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