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Article

Reclaimed Water Use in Biofuel Production

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Abstract: *Jatropha curcas* L., a toxic species that does not interfere with the food chain, produces biodiesel of better environmental quality than mineral oils. However, in order to cultivate it sustainably, it is necessary to optimize the limited resources used, mainly water and soil. Therefore, in arid areas, it is necessary to cultivate under intensive conditions, irrigate with reclaimed water and cut production costs. To optimize water consumption, partial root-zone drying (PRD), which keeps a part of the root system dry, was used. This water management strategy, employed successfully in other oil crops, yielded less fruit per bunch, but more fruit bunches per plant. This fact will probably allow to establish higher planting density and, consequently, higher productivity per surface unit. This is one of the few available options for improving profitability as production per tree is stable (1.25 kg seed plant^{-1} year^{-1} for the most productive trees, with excellent climate and soil, and no limitations water use). A high percentage of fruit lying on the ground (24%) and non-uniform timing in fruit production (except some specimens) greatly hinder its mechanization. Although this crop's environmental and socio-economic benefits are not taken into account, it is very difficult, with only the calculated water consumption (15.5 m^3

water per L of oil or 5.6 m^3 water per L of oil according to our best estimations), to consider it a profitable option.

Keywords: *Jatropha curcas*; water consumption coefficient; partial root-zone drying (PRD); biodiesel; subsurface drip irrigation (SDI)

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1. Introduction

Cultivating *Jatropha curcas* L., a toxic species that does not interfere with the food chain, can provide renewable fuel for the transport sector, a sector that accounts for one third of energy consumption in Spain [1]. However, in order to offer a sustainable solution, unconventional water resources must be used, which avoids competition for "green water" (effective rainfall), and "blue water" (surface and groundwater). Soil, a limited, non-renewable resource, is another productive factor to be optimized if we wish to find an enviro-friendly solution. Therefore, the intensive cultivation of this species by using reclaimed water and irrigation techniques to achieve optimized production is the only option that has appeared in developed countries. Very little information is available about how to address *Jatropha curcas* cultivation under these particular conditions because its high genetic variability [2] makes carrying out such studies difficult. Nonetheless, some recent publications have provided information on its response to drip irrigation with reclaimed water [3,4] under dry conditions.

Cost-benefit studies have estimated *J. curcas* production costs to be between 3 and 10 times the revenue generated by selling diesel in cultural practices in developing countries [3], so reducing these costs is essential. Yet the literature offers no studies into intensive production costs. Moreover, a global analysis should introduce the associated environmental (particulates are 80% cheaper than those produced by mineral fuels [5], carbon emissions are lower, risk of erosion decreases when soil is cultivated, *etc.*) and economic (financial resources and economic activity are used and generated in the country, which lowers the trade deficit) benefits.

Partial root-zone drying (PRD), a technique that has been developed based on knowledge of the physiological mechanisms that control plant transpiration and root-shoot signaling under water shortage conditions, consists in irrigating only one side of the root zone so that the plant can be simultaneously exposed to both wet and dry soil [6]. This technology, which was developed in the 1990s in Australia, offers three benefits: increased water use efficiency with no loss of yield; reduced vegetative growth (improved reproductive/vegetative balance); and improved fruit quality [7,8]. Although there are no studies that have analyzed the response to PRD in *Jatropha curcas*, the results obtained for another oil fruit, olive, and explained by the best stomata closure when PRD [9] is used, led us to conclude that it would be possible to increase its oil yield [6].

This paper analyzes the feasibility of using an irrigation management technique (PRD) to improve water productivity by providing data to advance the study of the economic viability of *Jatropha curcas* production.

2. Methodology

2.1. Experimental Design and Irrigation System Description

For this experiment, a *Jatropha curcas* plantation was used, which was set up 5 years ago on the grounds of the Agricultural Experimental Farm of Cabildo de Gran Canaria (Canary Islands), with a planting frame of 3 m between aisles and 2.5 m between trees. In early February 2014, trees were pruned with a chainsaw, which left tree height at 1.30 m and a crown diameter of approximately 0.75 m. Then new specimens were planted between trees in the old aisles (at a distance of 1.5 m) to leave new aisles of 2.5 m. However, this study only presents the data of the mature trees. At the end of February 2014, a subsurface irrigation system was buried 0.2 m deep to replace the previous surface drip irrigation. A severe cochineal attack meant two pesticide treatments had to be applied using summer mineral oil. No more pests or diseases were observed above the treatment threshold. The soil of this land is classified as Anthrosol [10] (ISSS/ISRIC/FAO, 1998) or Torriarent [11]. The orchard has an automatic weather station, used to calculate reference crop Penman-Monteith's evapotranspiration (ET_0) with data available since 2000. A problem occurred in this weather station in 2014, which meant that we were only able to obtain precipitation data for 5 months (April–August), during which time accumulated rainfall was low, and the average value for 2000–2014 was not distinguished (26.6 L/m^2) from the 22.7 L/m^2 collected during this period, while annual precipitation was 196 L/m^2. The 248 m^2 plot was divided into three blocks (each line of trees constituted one block), in which the two treatments were applied: a control (Tc), which consisted in applying a daily dose of 2.6 L/m^2; a second treatment (Ta), which received the same dose, but was irrigated alternately (weekly) on either side of the trees. A line of five trees with 12 emitters/tree was irrigated in each block; thus, each treatment irrigated three lines of five trees each, and each treatment consisted in 15 trees distributed into three lines: A, B and C (Tc) and D, E and F (Ta). A subsurface irrigation system (SDI) with integral drippers, pressure-compensating at range 1.5–4.0 bar, anti-siphon and high anti-drain mechanism, spaced at 0.5 m with delivery rates of 2.5 l hour^{-1}, was used to apply reclaimed water. Irrigation lines were spaced at 1.2 m, which left trees in the center. Irrigation time was adjusted to apply a constant daily dose of water (with irrigation twice daily) to match the reference crop evapotranspiration (ET_0) average measured in the last 14 years. Then two irrigations/day were organized, and each irrigation lasted 20 min for Tc (the two lines simultaneously irrigated the same tree) and 40 min for Ta, but only one of the lines irrigated each tree (partial root drying "PRD"). Each subunit had one flowmeter and readings were taken weekly.

2.2. Soil, Plant Analysis and Yield-Related Parameters

Composite soil samples between 0 and 0.2 m deep were taken, which coincided with the beginning of the experiment: 0.2 m apart from tree trunks (in the wet bulb, loc 1), between two trees for each line (loc 2) and in the aisles (loc 3). A dry combustion technique was used with a LECO CNS 2000 analyzer to determine organic carbon (CO, as a %) and total nitrogen (N_{tot}). Soluble salts were estimated by electrical conductivity (EC) at the 1:5 soil/water ratio, expressed in (dS/m) 1:5. Available nitrate (mg/kg) was determined by extraction with 0.01 M calcium chloride and was then analyzed by ion chromatography. Available phosphorus (P, mg/g) was determined by the method of Olsen and

Sommers [12]. Exchangeable cations were extracted with an ammonium acetate solution buffered to pH 7. Extracted cations (expressed in meq/100 g), potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na) were analyzed by optical emission spectrophotometry (ICP_OES). Composite samples of young leaves were taken from each tree line. N (%) was determined by the dry combustion LECO CNS 2000 technique. For the other analyzed elements P, K, Ca, Mg, Na (expressed in %), B, Cu, Fe, Mn and Zn (in mg/kg), the digestion technique was adopted using nitric acid in a microwave for the ICP_OES and subsequent analyses.

The ripe fruits of each tree used in the different treatments and the fruits found on the soil were collected weekly for 15 weeks. The following parameters were measured in the field: number of mature fruit per bunch and number of bunches with ripe fruit (fertile bunches), for each tree at each collection time. From the obtained data, the following parameters were calculated: number of harvested fruit per tree (by adding those collected from trees and those found on the soil). In the laboratory, the ripe fruits and seeds of each tree and each harvest were weighed. Also for each tree, two new variables were calculated: accumulated number of fruits per bunch and accumulated seed production over time.

2.3. Statistical Analysis

An analysis of variance (ANOVA) was carried out with the SPSS statistical package (version 22) using the generalized linearm. The dependent variables were treatment (PRD: Ta *vs.* Tc), collection date and tree, including the analysis of the following performance parameters: number of fruit per bunch, number of bunches with ripe fruit per tree (fertile bunch/tree), total number of mature fruit (including fallen fruit) and number of fruit collected from the tree top, weight of the yield obtained per fruit and seed (expressed in g DM/tree), and amount of water applied (Tc and Ta) and their interaction. Mean separation was tested by least significant difference (LSD) after setting the significance level at $\alpha = 0.05$. The results were aggregated to cumulative production.

3. Results and Discussion

Jatropha is a species that tolerates dryness, but adequate production is not possible if it does not receive enough water. It needs an annual minimum of 500–600 L/m^2 for appropriate flowering and setting [13]. As in all semiarid regions, 196 L/m^2 per year is insufficient, and irrigation must be used in these zones [14]. Annual rainfall must reach 1000–1500 L/m^2 to achieve acceptable production without irrigation [15]. The amount of water supplied during the experimental period was 2.6 (L/m^2·day^{-1}), and water consumption was measured from the flowmeter readings at 680 L/m^2. The monthly amount of water used, compared with monthly evapotranspiration (ET_0) from February to November 2014 (which was similar to the 14-year average ET_0), was 961 mm *versus* 1015 mm, which was higher in autumn, but lower in summer and autumn 2014 (Figure 1). The applied dose (assuming no precipitation) contributed between 65% and 110% of the measured daily ET_0 for 2014.

Regarding the response to climatic factors, the daily average minimum temperature for the available period was always above 10 °C. Therefore, temperatures coincided with optimal crop growth conditions (20–28 °C, [16]).

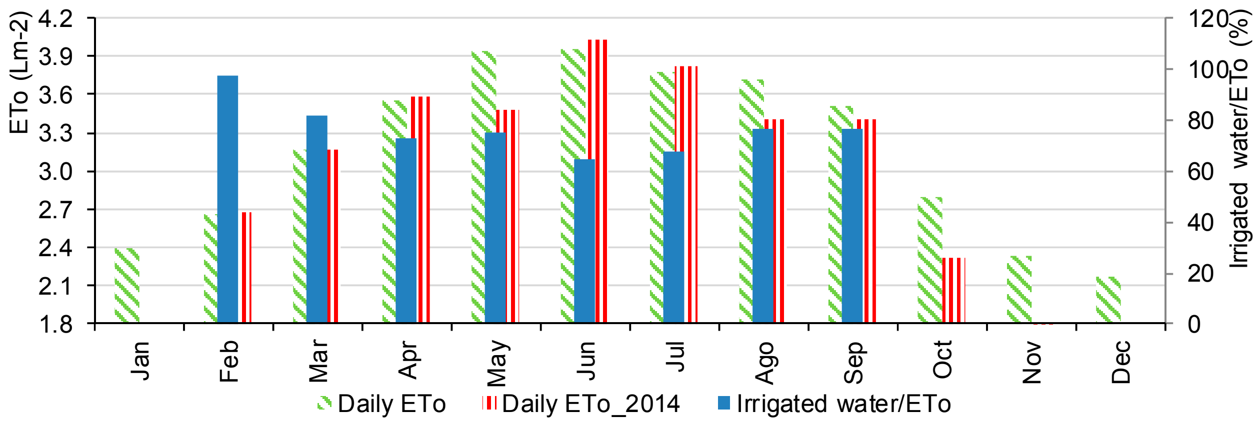


Figure 1. Average reference crop evapotranspiration (ET_0) for available 14 years (**green**), daily ET_0 from the experimental period 2014 (**red**) and irrigated water/ET_0 in % (**blue**).

The soil samples results are presented in Table 1. Significant differences were found in almost all the parameters according to the sampling site. In loc 1, a significantly higher basicity was observed. Significantly higher Ca and Na contents, but lower salinity, OM, C/N, P, K and Mg, were also found. Despite not being significant, the nitrate values were lower in bulbs, which can be accounted for by greater nutrient absorption from the roots that grew preferentially in the area. Therefore, the soil explored by roots mostly had a basic character, no salinity problems, a high OM content and a very stable character.

Table 1. Means pH values in water (1:2.5), electrical conductivity 1:5 (EC in dS/m), lime, organic matter (OM, expressed as a %), total nitrogen (N_{tot}, expressed as %), available nitrate (expressed as mg N/kg), Olsen phosphorus (expressed as mg P/kg), extracted cations (expressed as me/100 g): potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na) for the three sampling locations: (1) wet bulb; (2) between lines; (3) between aisles.

Loc		pH	EC	Limestone	OM	N_{tot}	C/N	Nitrate	P	K	Ca	Mg	Na
1	med	8.52	0.31^{a}	5.05^{a}	$5.29^{a,b}$	0.33^{b}	9.38^{a}	109.18^{a}	53.42^{a}	4.47^{a}	24.80^{c}	7.54^{a}	3.35^{b}
	std	0.037	0.08	0.17	0.18	0.01	0.16	136.86	4.38	0.26	0.48	0.12	0.19
2	med	8.37^{b}	0.51^{a}	5.91^{b}	5.66^{b}	0.34^{b}	$9.78^{a,b}$	384.1^{a}	65.06^{b}	8.40^{b}	22.92^{b}	9.33^{b}	2.58^{a}
	std	0.041	0.09	0.19	0.20	0.01	0.18	151.61	4.85	0.29	0.54	0.13	0.22
3	med	8.11^{a}	1.08^{b}	5.87^{b}	4.87^{a}	0.29^{a}	9.97^{b}	1261.05^{b}	64.64^{b}	8.93^{b}	21.25^{a}	9.1^{b}	3.2^{b}
	std	0.046	0.10	0.21	0.22	0.01	0.20	167.62	5.37	0.32	0.59	0.14	0.24

Note: Different letters in superscript following values (a, b, c) indicate statistical significance.

Regarding leaf parameters, the Ta plants exhibited significantly higher content than the Tc ones, but only for Na^{+}. The macronutrient contents of the plants used herein fell within the same range as other authors have reported (Figure 2). Dorta-Santos [4] stated that no productivity constraints occurred with the nutrient contents in the young leaves that they obtained. However, the K content obtained in our experiment was below that reported in [4] and [17], but similar to that obtained by [18] and [19]), and may be associated with progressive soil K depletion in wet bulbs (Figure 2), in which no K fertilization was applied. Dorta-Santos [4] found that the soil parameters which mostly influenced seed production were P and K. Given the richness of our soil P, K fertilization is recommended.

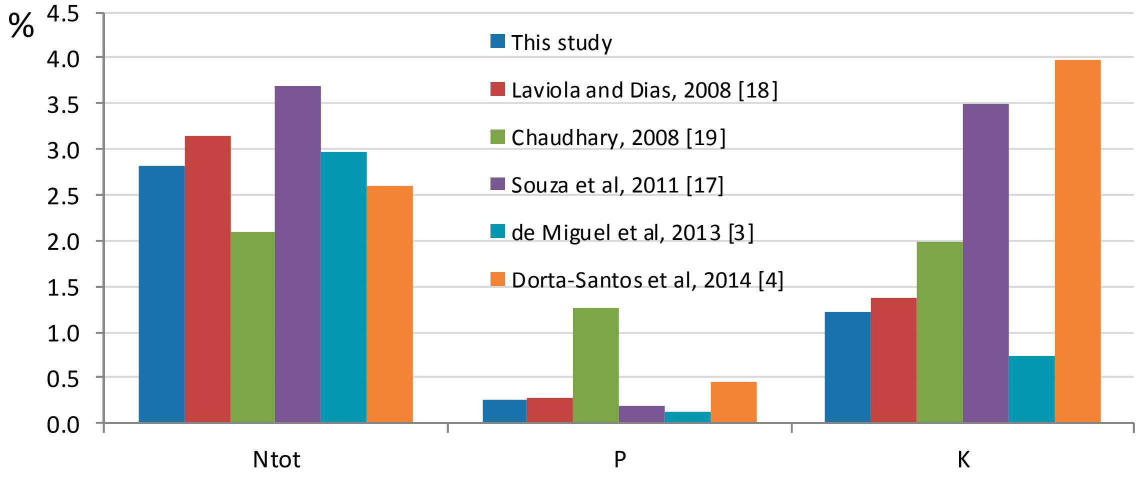


Figure 2. Macronutrient contents in the leaves (%) obtained herein and those reported by other authors.

When analyzing the results for tree variables, we found significant differences for number of fruit/bunch. This result agrees with those obtained by [20] and [2], who observed differences when analyzing diverse *Jatropha* populations, although the range of variation indicated by these authors (0.2–9 and 6.6–12.3, respectively) was much wider than that found in our trees. Significant differences were also noted in number of fertile bunch/tree (parameter for which [2] found no differences). A third parameter, number of fruit/tree, which must be added to the other two parameters, also presented significant differences, which again coincides with the findings of [20]. However, no differences were found by [2]. In contrast, average fruit weight did not significantly differ among trees, and this result also coincided with that obtained by [20], even when average fruit weight (1.52 g/fruit) was much lower than that obtained in this experiment (4.82 g/fruit). These results contrast with those obtained by Zegbe *et al*. [21], who studied the influence of PRD on yield, fruit quality at harvest, flesh firmness, total soluble solids concentration, and many other parameters in apple trees. These authors obtained the same values between the control treatment and PRD, yet water use efficiency improved by 120% in PRD trees.

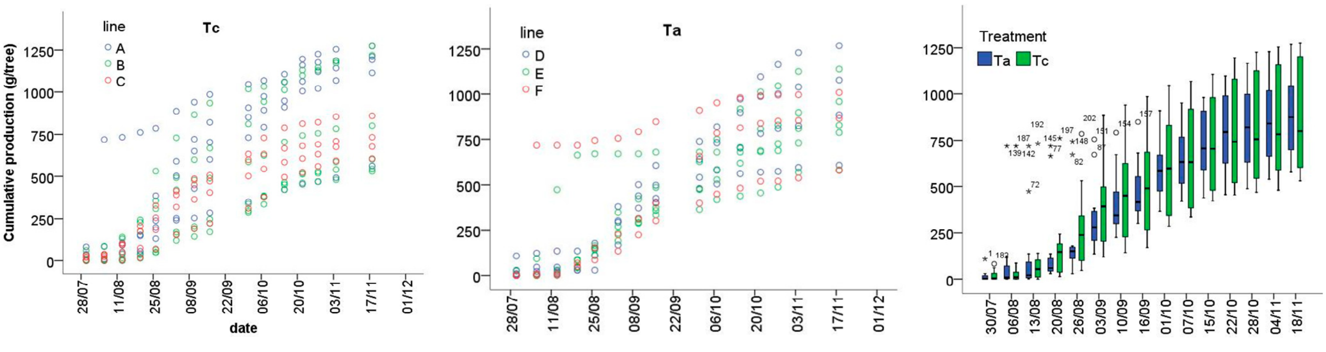
When the evolution of these parameters *versus* harvest week (after 15 weeks) was analyzed, differences were found in four parameters: number of fruit/bunch (and with the tree variable); average fruit weight (unlike that obtained for trees); and weight/tree nuts and seeds, with higher yields found between weeks 3 and 9. The wide variability among trees coincided with [2], who stated that lack of uniformity within populations is one of the main problems for planning commercial *Jatropha* production. Thus, as the differences between trees were so marked, it was difficult to observe the effects of the studied management practices. However, in this study we found differences between Ta and Tc for two parameters, number of fruit per bunch and number of fertile bunches per tree. Although Ta had significantly less fruit/bunch than Tc (2.5 *vs.* 3.05, respectively), no significant differences were obtained for weight of harvested fruit.

This result agrees with that obtained by [9] via PRD techniques, who found fewer, but slightly larger, olive fruits. Ta had a significantly higher average (14.88 fertile bunches/tree) *vs.* Tc (11.77). This indicates that the smaller number of fruits per bunch was compensated for by greater fertility, which resulted in the equivalent total production. This finding is promising as it suggests that if planting density can increase, the trees irrigated by an alternate irrigation method will be able to produce the same yield as they produce more fertile bunches/tree, despite having less space. This improvement in the balance between vegetative growth and reproductive development has already been reported in the first studies conducted in cultured PRD vines [6,7], which is one of the reasons for improved water efficiency in these systems.

The mean values obtained for the other parameters were: percentage of fruit fallen on soil, 24%; average fruit weight, 4.82 g; weight of production obtained for both fruit and seed (148 and 63.66 g/tree and harvesting, respectively); and finally, 955 g seed/plant for 15 weeks, which coincides with [2] for improved variety.

Figure 3 presents the cumulative seed yield (expressed as g DM/tree) obtained during the production period. Wide variability among trees was observed, which was also the case between the less and more productive trees in the same line, and differences were between 44% and 48% for Tc and Ta, respectively.

Figure 3b represents the cumulative production of seeds for both treatments. The amplitude of the boxes corresponded to the marked difference among trees on the same treatment. Except for a few specific examples, we observed that very little was harvested in month 1, and the same occured for the last few weeks. Due to the wide variability obtained between individuals, we were unable to distinguish significant differences between Ta and Tc production (1177 and 1173 kg/ha, respectively), which was less than 1875 kg/ha cited by [22] and [20]. We also saw that fewer g of seeds were initially harvested in Ta, but the average harvested weight since October was slightly greater. Whether this trend continued for the following year must be monitored. Some authors have cited that oil yield from seeds was 28%, while Mo Fi [23] cited an oil yield of between 55% and 60% w/w, which coincided with the 55%–58% found in the Canaries, because they expressed this yield in white seed performance terms. When we took the 35% v/w value as a reference, and assumed a density of 0.96 kg/L, it was possible to estimate the irrigation water required to produce 437.5 L of oil per ha by considering 6800 m^3/ha of water used. Thus *Jatropha* needed 15.5 m^3 of water per L of oil obtained.



(**a**) (**b**)

Figure 3. (**a**) cumulative production of seeds throughout the collection period (g/tree) for the three lines of each treatment (15 trees per treatment); (**b**) box-plot diagram of the cumulative production of seeds for both treatments.

Hence, the obtained production hardly guarantees profitability for this crop. Indeed, by assuming a price of 0.2 € and 0.7 €/ L for water and oil, respectively, water expenditure would multiply the income earned from selling *Jatropha* by 4. Yet when we considered the production of the best trees

(1.25 kg/tree and year), and by assuming that young trees recently initiated production (2667 trees/ha), oil yield would be 1214 L/ha, which is the equivalent of 5.6 m^3 water/L of oil, where water use would represent 1.6 times the income made from selling the oil. Only for yields above 5000 kg of seed/ha, or if the price paid for the biodiesel was over 0.7 €/kg, would *Jatropha* production be interesting. Some authors [24] have cited a sales price of 5 $/kg of seed, which would ensure profitability. Therefore, in order to improve profitability, it is essential to reduce the planting framework and increase the number of productive trees per hectare. It remains to be verified whether oil content is higher for the alternate irrigation method, as in olives [6].

4. Conclusions

This study obtained an average yield of 1200 kg seed/ha. Seed yield did not increment as a result of alternative irrigation (PRD). The aforementioned wide genetic variability of *Jatropha* plants was verified, which makes conducting studies into optimizing agronomic practices difficult. However, some parameters were affected by the tested water management as less fruit per bunch were produced, but the most fertile bunch per tree occurred when plants were irrigated alternately. Therefore by PRD, is it possible to increase planting density by maintaining productivity/tree since such management provides a larger number of fertile branches per tree, which increases total production. In fact in order to make *Jatropha curcas* production profitable, reduced spacing between trees is one of the few options as production per tree is very stable (1.25 kg seed/tree in the best young trees in this experiment with excellent climate and soil). Another factor that influences profitability is the large percentage of fruit that falls to the ground (24%), so it is necessary to collect it. Except for a few specimens, production increased throughout the production period, which made it very difficult to improve the harvesting process using machinery. With the calculated 15.5 m^3 of water consumption per L of oil obtained (5.6 m^3 water/L according to our best estimations once young trees started producing), it is very difficult to make this crop profitable if the environmental and socio-economic benefits are not considered.

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Conflicts of Interest

The authors declare no conflict of interest.

References

1. Ministerio de Industria, Energía y Turismo. *La Energía En España 2010*; Ministerio de Industria, Energía y Turismo: Madrid, Spain, 2010. (In Spanish)
2. Yi, C.; Reddy, C.; Varghese, K.; Bui, T.N.H.; Zhang, S.; Kallath, M.; Kunjachen, B.; Ramachandran, S.; Hong, Y. A New *Jatropha curcas* Variety (JO S2) with Improved Seed Productivity. *Sustainability* **2014**, *6*, 4355–4368.

3. De Miguel, A.; Martínez-Hernández, V.; Leal, M.; González-Naranjo, V.; de Bustamante, I.; Lillo, J.; Martín, I.; Salas, J.J.; Palacios-Díaz, M.P. Short-term effects of reclaimed water irrigation: *Jatropha curcas* L. cultivation. *Ecol. Eng.* **2013**, *50*, 44–51.
4. Dorta-Santos, M.; Tejedor, M.; Jiménez, C.; Hernández-Moreno, J.M.; Palacios-Díaz, M.P.; Díaz, F.J. Recycled Urban Wastewater for Irrigation of *Jatropha curcas* L. in Abandoned Agricultural Arid Land. *Sustainability* **2014**, *6*, 6902–6924.
5. Makkar, H.P.S.; Becker, K. *Jatropha curcas*, a promising crop for the generation of biodiesel and value-added coproducts. *Eur. J. Lipid Sci. Technol.* **2009**, *111*, 773–787.
6. Aganchich, B.; El Antari, A.; Wahbi, S.; Tahi, H.; Wakrim, R.; Serraj, R. Fruit and oil quality of mature olive trees under partial rootzone drying in field conditions. *Grasas y Aceites* **2008**, *59*, 225–233.
7. Dry, P.R.; Loveys, B.R.; Botting, D.; During, H. Effects of partial root-zone drying on grapevine vigour, yield, composition of fruit and use of water. In Proceedings of the 9th Australian Wine Industry Technical Conference, Adelaide, South Australia, 16–19 July 1995; pp.128–131.
8. Loveys, B.R.; Stoll, M.; Dry, P.R.; McCarthy, M.G. Using plant physiology to improve the water use efficiency of horticultural crops. *Acta Hortic.* **2000**, *537*, 187–197.
9. Wahbi, S.; Wakrim, R.; Aganchich, B.; Tahi, H.; Serraj, R. Effects of partial rootzone drying (PRD) on adult olive tree (*Olea europaea*) in field conditions under arid climate: I. physiological and agronomic responses. *Agric. Ecosyst. Environ.* **2005**, *106*, 289–301.
10. Food and Agriculture Organization of the United Nations (FAO). *World Reference Base for Soil Resources*; World Soil Resources Report 84; FAO: Rome, Italy, 1998.
11. Soil Survey Staff. *Keys to Soil Taxonomy*, 8th ed.; USDA-Natural Resources Conservation Service: Washington, DC, USA, 1998.
12. Olsen, S.R.; Sommers, L.E. Phosphorus. In *Methods of Soil Analysis*, *Part 2*, 2nd ed.; Page, A.L., Miller, R.H., Keeney, D.R., Eds.; American Society of Agronomy, Inc. and Soil Science Society of America, Inc.: Madison, WI, USA, 1982; pp. 403–430.
13. Behera, S.K.; Srivastava, P.; Tripathi, R.; Singh, J.P.; Singh N. Evaluation of plant performance of *Jatropa curcas* L. under different agro-practices for optimizing biomass—A case study. *Biomass Bioenergy* **2010**, *34*, 30–41.
14. Maes, W.H.; Trabucco, A.; Achten, W.M.J.; Muys, B. Climatic growing conditions of *Jatropha curcas* L. *Biomass Bioenergy* **2009**, *33*, 1481–1485.
15. Ouwens, K.D.; Francis, G.; Franken, Y.J.; Rijssenbeek, W.; Riedacker, A.; Foidl, N.; Jongschaap, R.; Bindraban, P. *Position Paper on Jatropha curcas: State of the Art, Small and Large Scale Project Development*; Fuels from Agriculture in Communal Technology: Wageningen, The Netherlands, 2007.
16. Brittaine, R.; Lutaladio, N. *Jatropha: A Smallholder Bioenergy Crop—The potential for Pro-Poor Development*; Integrated Crop Management Volume 8; FAO: Rome, Italy, 2010; pp. 1–114.
17. De Souza, P.T.; de Barros Silva, E.; Grazziotti, P.H.; Fernandes, L.A. NPK fertilization on initial growth of physic nut seedlings in Quartzarenic Neossol. *Rev. Bras. Cienc. Solo* **2011**, *35*, 559–566.
18. Laviola, B.G.; Dias, L.A.D. Nutrient concentration in *Jatropha curcas* L, leaves and fruit and estimated extraction at harvest. *Rev. Bras. Cienc. Solo* **2008**, *32*, 1969–1975.

19. Chaudhary, D.R.; Ghosh, A.; Chikara, J.; Patolia, J.S. Soil characteristics and mineral nutrient in wild *Jatropha* population of India. *Commun. Soil Sci. Plant Anal.* **2008**, *39*, 1476–1485.
20. Heller, J. Physic Nut Jatropha curcas L. Promoting the Conservation and Use of Underutilized and Neglected Crops. 1; International Plant Genetic Resources Institute: Rome, Italy, 1996.
21. Zegbe, J.A.; Behboudian, M.H. Plant water status, CO_2 assimilation, yield, and fruit quality of "Pacific Rose™", apple under partial rootzone drying. *Adv. Hortic. Sci.* **2008**, *22*, 27–32.
22. Dehue, B.; Hettinga, W. *GHG Performance Jatropha Biodiesel*; Ecofys: Utrecht, The Netherlands, 2 June 2008.
23. Mofijurn, M.; Masjuki, H.H.; Kalam, M.A.; Hazrat, M.A.; Liaquat, A.M.; Shahabuddin, M.; Varman, M. Prospects of biodiesel from *Jatropha* in Malaysia. *Renew. Sustain.Energy Rev.* **2012**, *16*, 5007–5020.
24. Rucoba, A.; Munguía, A. Rentabilidad de *Jatropha curcas* en asociación con cultivos y monocultivo en tierras de temporal de Yucatán. *Rev. Mex. Agron.* **2013**, *33*, 565–575.

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