Light-Response Curves for Jatropha Curcas Provenances under Field Conditions in Costa Rica

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Abstract:

Widespread consideration on the potential for Jatropha curcas to produce biodiesel has recently brought attention on the species. However little solid information on key physiological and management aspects exist on the species for Central America. A gene bank, established at the Experimental Station Fabio Baudrit, located in La Garita de Alajuela, Costa Rica, comprised of a number of 52 accessions from around the country and abroad, identified 10 potential provenances of importance. Through annual monitoring, the provenances Turrubares, Cruce Jaco, Barro Turrubares, Orotina, Marichal, Tempate 1, San Vito, Mexico, India, Tempate, were identified as the most productive. Data gathering was made during the same hours of the morning from 8 am to 11 am, through the beginning of the rainy season (June-August). A characterization of the quantum yield of individuals from these provenances was performed. The light saturation point ranged from 154 µmol (photon) m^{-2} s^{-1} *(eq.1, Provenance Orotina) to 988 µmol(photon)* m^{-2} s^{-1}*(eq. 1 Provenance San Vito). The maximum assimilation rate was exhibit by San Vito provenance (16.6 µmol (*$CO_2 m^{-2}$ s^{-1}*), which is consistent with other variables such as respiration and its light compensation point. Respiration ranged from 1 µmol (*CO_2*)* m^{-2} s^{-1}*(Tempate) to 5 µmol(CO2)* m^{-2} s^{-1}*(Turrubares). The data from Turrubares exhibited inconsistencies and the curve did not adjust well; fluctuations in cloud cover and stomatal closure affected data from this site, signaling the sensitivity of the species but also its quick adaptation to changing conditions.*

Keywords: Jatropha curcas, CO2 assimilation, light curves, modeling.

1. Introduction

The use of biofuels can potentially contribute to climate change mitigation, rural development and energy security. Widespread attention on the potential for *Jatropha curcas* to produce biodiesel planting the species on marginal land with low inputs has recently brought attention on the species. This has led to large plantations in Asia, Africa and America. Work with *J. curcas* has shown low water use, good growth on marginal and degraded lands, high oil yields, and low labor costs (Everson et al. 2013).This species is characterized by its resistance to drought, its fast growing nature, its easy reproduction and its short life cycle (Jongschaap et al 2007; Kumar and Singh 2014; Lowe et al 2012; MAG, 1991). Its productivity depends on the plant-specific factors such as the distribution of dry matter, the proportion of female / male flowers, the size and weight of the seed, seed oil content, toxicity, the floral induction and floral sync. (Chikara et al. 2013).

As a general expectation, aided by models and empirical data, increase in CO_2 levels can have either positive or negative effects on plant acclimation which affects net primary production (Griffits and Jarvis 2005, Griggs 2002). Drought has substantial negative influences on many physiological processes of plants such as photosynthesis, stomatal behavior, chlorophyll fluorescence and metabolite accumulation. According to Maes et al (2009), there are two great concerns regarding cultivation of the species: i) little information on the basic agricultural aspects of plantation and ii) it is considered a wild species, with an almost null improvement or domestication degree. In fact, a small amount of information exists on species' physiology; although drought resistance is widely studied (AbouKheira and Atta 2009; Kesava et al. 2012). The objective of this paper is to obtain a photosynthetic rate profile of the selected provenances under normal field conditions.

2. Material and Methods

2.1. Site and species of study

The research was carried out at the "Agricultural Experiment Station Fabio Baudrit Moreno (EEAFB)" research station of the University of Costa Rica located in the province of, Alajuelaat 840m.a.s.l. Average annual rainfall is 1940 mm distributed from May to November with an annual average ambient temperature of 22° C. The plantation was established in 2009 with a 3x2 m arrangement and received constant pruning and weed maintenance. Three individuals with three repetitions each from the ten most productive provenances were measured using a gas exchange measuring equipment. The selected provenances were: Turrubares, Cruce Jaco, Barro Turrubares, Orotina, Marichal, Tempate 1, San Vito, Mexico, India, Tempate,

Figure 1: Germoplasm bank of Jatropha curcas, at Fabio Baudrit Experimental station, La Garita. Costa Rica.

2.2 Photosynthesis at light saturation and Light curves

The equipment used in the study was the gas exchange Ciras II (PP Systems ®) system. The CIRAS-II requires a pre-boot measurement of about 10 minutes warming. The device allows simultaneous display in color screen and in real time, up to 15 measurement variables and graphs in Microsoft Windows environment. The manufacturer claims the computer screen has been optimized for use in the field, but in practice it may be difficult to visualize, especially when working in bright sunlight. Prior to beginning any measurement, it is necessary to establish parameters program. Light curves were recorded for Jatropha curcas, details of treatment measurements listed as follows: CO_2 to 380 ppm (mol (CO_2) mol (air) $_{-1}$) averaged with ambient CO_2 control, "Photon flux density" (PFD) of 0-2000 mol (quanta) m^{-2} s^{-1}, in 100 mol (quanta)) m^{-2} s^{-1}, Relative Humidity (RH) ranging from 46 to 70%. To adjust the net photosynthetic data to PN/PAR curves, the Ye et al 2007 model was employed.

The model, based on the analysis by Lobo et al (2013), present a nonrectangular hyperbola–based model (Eqs. 1). His and further models are well described in the literature (Ye 2007, Abe et al 2009, Kaipiainen 2009, Prioul, et al 1977).

The model is presented below:

$PN = \phi(Io\_Icomp) \times [(1 - \beta \times I)/(1 + \gamma \times I)] \times (I - Icomp)$ (Eq. 1)
Where: PN= net photosynthesis rate [µmol (CO_2))m^{-2} s^{-1}] ϕ (Io_Icomp) = quantum yield from Io to Icomp [µmol (CO_2) μmol^{-1}(photons)] β = adjusting factor γ = adjusting factor
I = photosynthetic photon flux density [µmol (photons))m^{-2} s^{-1}]
Icomp= light compensation point [µmol (photons))m^{-2} s^{-1}]

3. Results and Discussion

Figure 1 shows the CO_2 assimilation curves as a function of PAR per provenance on selected plants of J. curcas.The behavior of the curves for all treatments presents several phases; at start, from absence of light until the light compensation point is reached we can see an increase with increasing photon flux density (PAR); where the CO_2 assimilated by photosynthesis (Pn) is in balance with respiration; after this point and up until 250 µmol (photon)m^{-2} s^{-1}, an exponential increase can be seen where already at this point we can see differences in assimilation levels among provenances. It can be inferred from the figure that there is already a difference in maximum quantum yield, which is the slope in that range. Between 200 and 800 µmol (photon)m^{-2} s^{-1}there is a region of slow decline on a logarithmic behavior. India and Orotina reached this point earlier, proven by the light saturation point (Table 1).

The main results from the analysis of the curves are to determine the maximum Pn obtained from each provenance. Yong et al (2010) determined this value to be approximately 800 µmol (photon)m^{-2} s^{-1}, which is in line with the findings of the current study. In order to accurately describe the net CO_2 assimilation by a plant leaf (PN) as a function of an increase in the photosynthetic photon flux density (PAR), the net data from the CIRAS-II was fitted to a photosynthetic light-response curve (Eq 1) ranging from 0 to approximately 2 000 µmol (photon)) m^{-2} s^{-1}. The best response curve for each site is presented in figure 2; assimilation parameters, including respiration ared escribed in table 1. The maximum quantum yield ϕmax, interpreted as the quatum yield (ϕ) between the light compensation point (Icomp) and the point and the ϕ(I), at a I= 200 µmol(photon) m^{-2} s^{-1}ranges from 0.0194 (Tempate) to 0.0471 (India) µmol (CO_2) μmol^{-1} (photons); exception is Turrubares, which did not adjust well to the curve. In this paper the R^2 values are as good as in Lobo et al (2013) (Table 1); which suggests that the data here presented adjusts well with the models presented; which is the best way to compare the models as the use of R^2 for model selection, has no obvious meaning for nonlinear regression).

The same author considers that there is no single definitive mathematical model to describe the assimilation curve ideal for all sets of data or situations, therefore suggesting that the best PN/PAR curve is the one among all available that fits best the original data; issue that it was verified on the present data as well.

Table 1. Maximum values from regression model employed to fit the net photosynthetic light response curves for 10 provenances of Jatropha curcas provenances. Icomp: light compensation point [µmol(photon)m^{-2} s^{-1}]; Imax: light saturation point [µmol(photon)) m^{-2} s^{-1}];PNmax: Light-saturated net CO2 uptake [µmol(photon)m^{-2} s^{-1}]; RD : dark respiration [µmol(CO_2)) m^{-2} s^{-1}]; ϕ(Icomp_I200): Quantum yield between Icomp and I200 [µmol (CO2)$mmol^{-1}$ (photons)]; PgMax: Maximum gross photosynthesis rate [µmol(CO_2)) m^{-2} s^{-1}].

Provenance	Light compensation point (Icomp [µmol(photon) m–2 s–1])	Light saturation point (Imax [µmol(photon) m–2 s–1])	Lightsaturated net CO_2uptake (PN(Imax): [µmol(CO_2) m–2 s–1])	Dark respiration (RD : [µmol(CO_2) m–2 s–1])	Quantum yieldbetween Icomp and I200 (ϕ(Icomp_I200) = µmol (CO_2) $mmol^{-1}$ (photons))	Maximumgross photosynthesis rate (PgMax: [µmol(CO_2) m^{-2} s^{-1}])	R^2
Barro Turrubares	26.1	555	12.4	1.2	0.0379	16.5	0,994
Cruce Jaco	52.7	829	17.1	3.2	0.0458	26.3	0,998
India	80.8	502	12.4	4.2	0.0471	18.5	0,974
Marichal	91.2	648	13.2	3.8	0.0385	19.7	0,973
Mexico	29.3	705	15.2	2.5	0.0466	24	0,983
Orotina	19.7	154	6.8	2.1	0.033	9.2	0,940
Pozon	38.2	803	16.6	1.9	0.0417	23.9	0,998
San Vito	54.3	988	18	3.6	0.0437	30.6	0,969
Tempate	52.9	642	9.4	1	0.0194	12.1	0,991
Turrubares	46.5	49	0.3	5	0.0003	5.5	0,099

This can be easily observable in figure 2, which suggests that the model used can explain satisfactorily explain the behavior for *J.curcas* regardless of provenance. However the same authors suggests that the Ye (2007) (equation 1) approach to calculation of (I) produces a result that is much more realistic and useful, since Pn can be seen changing with changing "I", which for ecophysiological purposes are focus of analysis when Pn is above the light compensation point, which means that a net CO_2uptake is taking place. This species resource to tolerance strategies to cope with stress on its habitat. Major abiotic stress which is often accompanied with high temperature is light intensity. Light varies in intensity both temporally (as a result of the diurnal cycle) and spatially (as a result of shading by clouds and other organisms and objects) throughout the day. Excess light leads to photo inhibition, a sustained decline in photosynthetic efficiency, associated with damage to P680 (Mathur et al. 2014). The values of PAR and precipitation are described in figure 3. Measurements took place during the onset of the rainy season, which rules out stress by water deficit in the soil, and as observed by the range of maximum and minimum radiation present, the exposure remains steady throughout these months.

Jatropha curcas has been receiving attention lately as a potential oily seed producing species which can be converted to biodiesel; however growing conditions on its performance such as temperature range and sites have scarcely been studied. J. curcas is distributed over the arid and semi-arid areas of Mesoamerica and in all tropical regions. Photosynthesis is one of the most sensitive processes to drought stress. The inhibitory effects of drought on photosynthesis may be associated with low CO*2* availability due to low stomata conductance and/or impairments in carbon assimilation metabolism (Silva et al. 2012). As a conclusion, as with Lobo et al 2014 it is considered optimum to employ Excel routines to identify best fits for Pn/I curves to test the sensitivity of field data. Other aspects such as reproductive cycle synchrony, can aid to understand peaks on photosynthetic activity and response to stress.

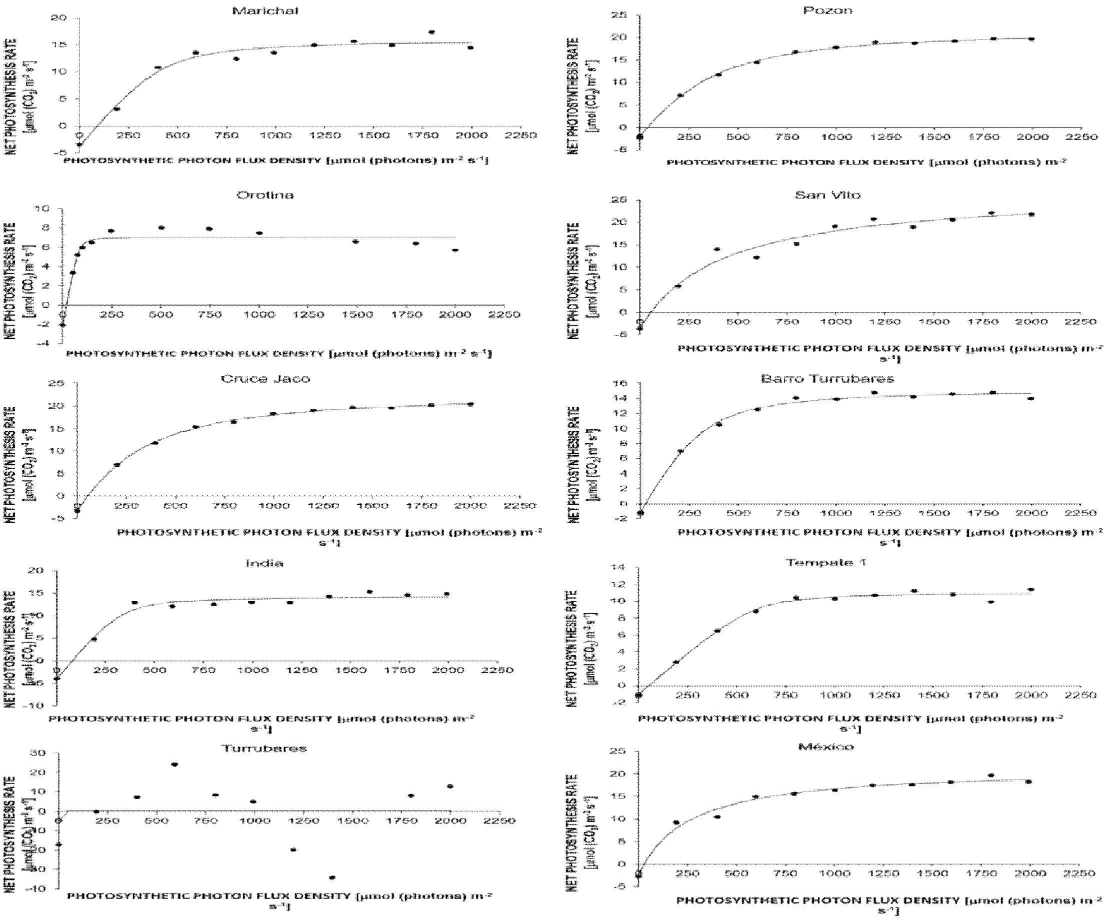

Figure 2: Highest best fitted Light-saturated net CO2 uptake response curves from 10 chosen provenances at a *J.curcas* germoplasm bank at the EEFBM, Costa Rica.

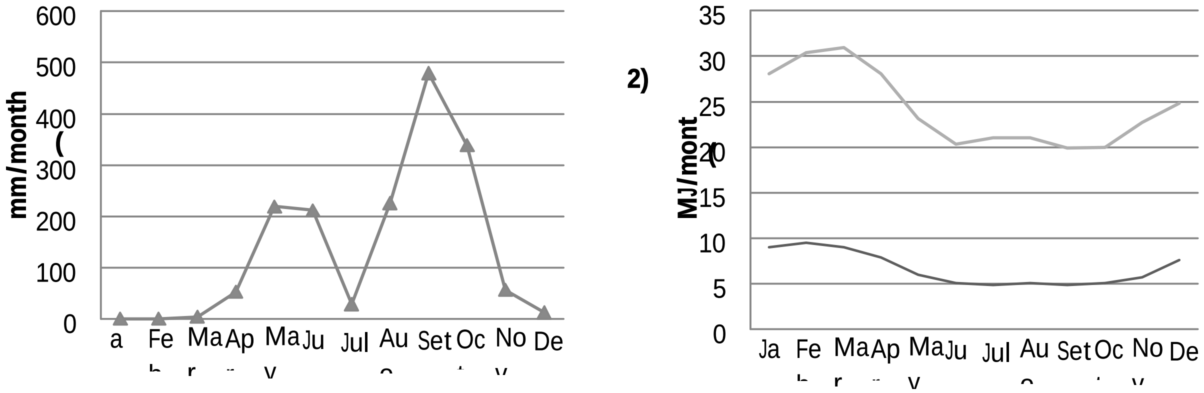

Figure 3. Aevrage monthly precipitation and average monnthly maximum and minimum radiation at Estación Experimental Fabio Baudrit, 2014

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