Short communication

The response of CO₂ exchange rate to photosynthetic photon flux density for several *Populus* clones under laboratory conditions*

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**Abstract.** No significant differences were found between four mathematical equations describing the response of CO₂ exchange rate to photosynthetic photon flux density in seven poplar clones under laboratory conditions. Choice of an optimal equation for poplar may be based on the contemplated aims. High significant differences (at $p < 0.001$) were found among the clones.

From all environmental factors, effects of photon flux density on CO₂ exchange rates ($P_N$) and consequently on growth have been most frequently reported [2, 25]. Variations in response of CO₂ exchange rate to photon flux density among different genotypes have been well documented [11, 15] and have been used for comparing different genotypes and species [1, 12]. In all these studies authors used various mathematical equations for describing response of $P_N$ to photon flux density, while others employed extensive studies on theoretical and mathematical derivations of these equations.

A mechanistic model of leaf photosynthetic response to photosynthetic photon flux density has been developed [21] and has since been discussed by many authors [7, 8, 9]. Based on the common Michaelis–Menten form and taking into account some general assumptions, Rabinowitch [21] could describe the $P_N$–photon flux density relation by a non-rectangular hyperbola. Bliss and James [3], in their extensive biometrical study, described response of CO₂ exchange rate to photon flux density by a rectangular hyperbola form, while Thornley [23] summarized different kinds of photon flux density response curves from literature in his work on mathematical models in plant physiology. Waggoner [24] also stated that a physico-chemical analysis of net CO₂ exchange rate can produce a non-rectangular hyperbola.

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i.e. the familiar Michaelis–Menten equation, although the physiological process is summarized by a rectangular hyperbola which relates CO₂ exchange to photon flux density. Other chemical models [e.g. 17] include photorespiration and logically provide the physiological models represented by the simple curve of CO₂ exchange rate in a prediction of crop yields.

In this study four different basic equations mentioned in the literature and summarized in Table 1 were studied for different poplar (Populus) clones in order to compare their efficiency in describing the response of CO₂ exchange rates of poplar to photon flux density under laboratory conditions.

For the laboratory experiments 1-yr-old cuttings from poplar, clones Unal, Beaupré, Columbia River, Trichobel, Italica, Robusta and Nigra Ghoy were grown in a phytotron (Weiss, Germany) under constant environmental conditions. Sufficient water and nutrient solution were supplied. Response of CO₂ exchange rate (Pₐ) to photosynthetic photon flux density (I) was studied using a ventilated, controlled environment assimilation chamber (Siemens, Germany) described earlier [16]. Attached leaves of optimal leaf ages [5] were used for the determinations. The assimilation chamber temperature was set at 25°C, atmospheric humidity was 16.8 g m⁻³ and the wind velocity was about 1.6 m s⁻¹. Photosynthetic photon flux density was provided by three high pressure sodium lamps (Philips, SON/T, 400 W) giving a maximum of 1200 μE m⁻² s⁻¹ and was filtered by a 5 cm layer of water. Photon flux densities, being changed by various layers of cheese cloth, were measured with a Lambda (Licor, USA) quantum sensor. Air from outside the laboratory with a CO₂ concentration of 350 cm⁻³ m⁻³ was sucked in and buffered through a 1 m³ container. Carbon dioxide exchange was measured differentially using a Unor (Maihak, Germany) infrared gas analyser, calibrated against gases of known concentration. After each series of light experiments, dark respiration (Rₑ) was measured.

Curve fittings and calculations of different coefficients were performed in a regression analysis programme using a non-linear least squares fitting technique. At least five replications of the photon flux density response were made for each clone, while each response curve was based on eleven experimental points, Rₑ excluded. For each equation and for each clone mean determination coefficients were calculated. These determination coefficients (r²) were tested for significant differences in a two-way analysis of variance and by Duncan's new multiple range test.

Fittings of all equations tested and represented in Table 1 were significantly (at p = 0.01; t-test) good for the seven clones (Figure 1) with an average r² > 0.81. Determination coefficients ranged between 0.68 for clone Columbia River and 0.98 for clone Nigra Ghoy. Since equations 1, 2 and 3 (Table 1) can be derived from one single basic equation, only this general equation has been used in the analysis of variance.

The two-way analysis of variance, carried out on determination coef-