

COMPARATIVE STUDY ON PHYSIOLOGICAL POTENTIAL OF *PINUS SYLVESTRIS* L. AND *PINUS BUNGEANA* ZUCC. EX ENDL. TO GROW IN BULGARIAN URBAN PARKS

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Abstract

Pinus bungeana Zucc. ex Endl. is a picturesque multi-trunked pine tree native to north-eastern and central China with symmetrical crown and grey-green, mottled, exfoliating bark. This species is already introduced into European urban parks, although there is still limited information about its appearance when full grown. The first *P. bungeana* tree in Bulgaria was planted in the arboretum of the University of Forestry in Sofia. The aim of this study is to compare needle gas exchange in this tree and *Pinus sylvestris* L. Both experimental trees are at similar age and grow out of their natural range of distribution. The net photosynthesis (A_N) in response to various air temperatures and light conditions was analyzed in both *P. bungeana* and *P. sylvestris* needles. Temperature and light responses of photosynthesis obtained in this study show insignificant differences between *P. bungeana* and *P. sylvestris*. The established features are signs for higher tolerance of *P. bungeana* to shade and cold, than *P. sylvestris*. Therefore, it can be assumed that *P. bungeana* has physiological potential to grow in Bulgarian urban parks, similar to *P. sylvestris*.

Key words: light curve, photosynthesis, temperature response.

Introduction

As an integral component of urban green infrastructure, park trees selection is crucial to successfully shaping a better urban environment (Li et al. 2011). An important requirement for high aesthetics of urban parks is enrichment of tree species diversity. But the general picture is that a few species make up a large proportion of the urban park tree population. An issue concerns preferences for or against native trees versus non-indigenous species. Most planting sites in communities

are quite different from natural forests to which trees are genetically adapted. But certain species can tolerate compacted soils and pollutants better than others, and some of these are native to distant, analogous climatic regions. Therefore, some non-indigenous species can withstand urban stresses better than some “native species”, and these should not be excluded just because they are classified as exotic (Gerhold and Porter 2006).

Arboreta, by displaying and distributing trees, have been very influential in the choice of species used in designing urban

forests (Gerhold 2006). Botanic gardens were planted to showcase rare or interesting species. Many of exotic species causing problems in our vegetated areas escaped from these gardens (Koch 2000). Designers of urban landscapes, who specified which trees were to be planted and where, depended first on gardeners, and later on horticulturists, arborists, and foresters for the cultivation and care of the trees. Miller et al. (2015) proposed a model with three groups of factors for selecting species for urban uses: the site factors, economic factors and social factors. Clark and Kjelgren (1989) recommended rigorous site analysis when making species selections, especially relative to radiation load, temperature, the availability of water and soil properties. Trees in the urban environment are subjected to a number of stresses which are very different from those suffered by trees in typical rural conditions. On the other hand, through proper planning, design, and management, urban trees can mitigate many of the environmental impacts of urban development by moderating climate, reducing building energy-use and atmospheric carbon dioxide, improving air quality, lowering rainfall runoff and flooding, and reducing noise levels (Nowak and Dwyer 2006). Design qualities, longevity, ease of cultivation, and mass propagation were identified as the main criteria for the selection of tree species by Pauleit (2003). However, the physiological potential for adaptation of species to specific conditions in an urban territory still missed in set of criteria for selection of park species.

The aim of this study is to evaluate the physiological potential of *Pinus bungeana* Zucc. ex Endl. to grow in Bulgarian urban parks. For this purpose, specific responses of *P. bungeana* and *P. sylvestris* photosynthesis to various light and temperature

conditions were compared.

P. bungeana is a picturesque multi-trunked pine tree native to northeastern and central China with symmetrical crown and grey-green, mottled, exfoliating bark. This species occurs in mountains, often on limestone rocks and on south-facing slopes, scattered and mixed with angiosperms. Its altitudinal range is probably between 500 m and 2150 m a.s.l. It is a light demanding species and therefore is usually restricted to sites less suitable for other trees, especially angiosperms. *P. bungeana* was introduced to England in 1843 but is still not very common in gardens and parks of Europe (Luscombe 2013). *P. sylvestris* was chosen for comparison due to its well-studied biological characteristics for the Bulgarian mountains and similar to *P. bungeana*'s light and temperature requirements within their natural ranges of distribution.

According to Shelford's "Law of tolerance" (Shelford 1931) plant responses to temperature can be expressed in terms of three cardinal temperatures: the minimum and maximum temperatures at which the process ceases entirely, and the optimum range of temperature over which the highest rate can be maintained, assuming that temperature is limiting factor (Fitter and Hay 2012). An alternative approach has been to apply the Arrhenius equation (from chemical kinetics) to plant processes. The recent variants of this law for photosynthesis (Medlyn et al. 2002) and for respiration (Tjoelker et al. 2001, Smith and Dukes 2013) include energy for activation and energy for deactivation of these processes. Various peak functions are suggested as an alternative by some eco-physiologists (Kattge and Knorr 2007, Friend 2010). One of the most suitable equations for the photosynthesis response to temperature is proposed by June et al.

(2004) and his model was used in this article. Theoretical causes for photosynthetic light-response curve were raised by Blackman (1905) and were improved by many authors subsequently (Rabinowitch 1951, Thornley 1976, Prioul and Chartier 1977, Leverenz and Jarvis 1979, Marshall and Biscoe 1980). At low light intensities, AN increases linearly with irradiance, with the light-driven electron transport limiting photosynthesis. The initial slope of the light-response curve based on absorbed light (quantum yield) describes the efficiency with which light is converted into fixed carbon. This mathematical description is useful because it contains variables with a clear physiological meaning that can be derived from light-response curves and used to model photosynthesis. The recent variant of this non-rectangular hyperbola, proposed by Norman et al. (1992), was used in this article.

The optimal temperature for net photosynthesis can vary with species, ecotype, site, and time of the year (Larcher 2003). Respiration is especially sensitive to temperature, with a temperature coefficient Q_{10} of approximately 2 (respiration doubles when the temperature rises by 10 degrees), whereas the Q_{10} values of the electron transport and enzyme reactions of photosynthesis are 1 and 2–3, respectively (Fitter and Hay 2012). As a result, the light-saturated rate of net photosynthesis for most conifer species during the growing season is greatest at approximately 20 °C and is depressed below 10–15 °C and above 30 °C (Stenberg et al. 1995). Freezing temperatures increase the sensitivity of conifer photosynthesis to photoinhibition, even in hardened tissues and under low irradiance levels (Öquist and Huner 1991). Photoinhibition is detected by a reduction in quantum yield and, in many cases, the light-saturated

rate of net photosynthesis (Powles 1984). Leverenz and Öquist (1987) established that in *P. sylvestris* the quantum yield during the winter season is consistently lower than during the growing season. At high irradiance, photosynthesis becomes light saturated and is limited by carboxylation rate, which is governed by some combination of CO₂ diffusion into the leaf and carboxylation capacity (Lambers et al. 2008). Photosynthetic efficiency in the intermediate light range (curvature parameter) provides information for adaptation (acclimatization) of the plant to light regime (Ögren 1993).

Materials and Methods

Site description

The experiment was conducted in the arboretum of the University of Forestry in Sofia, Bulgaria (42° 39' 09" N, 23° 21' 30" E, 590 m a.s.l.). This urban site is unnatural both for *P. sylvestris* (in relation to altitude) and *P. bungeana* (in relation to longitude and altitude). Sofia is located in the North Temperate Zone and characterized with moderate hydro-thermal regime. During the last two decades (1996–2015) the average annual temperature for Sofia region has increased with 0.98 °C (+10 %) in comparison to referent period (1961–1990) on a background of 0.58 °C (+5 %) for the overall country. For the same period precipitation sum in Sofia increased with 96.4 mm·yr⁻¹ (+17 %), but the likelihood for pouring rain (> 100 mm/day) increased with 30 % (Alexandrov et al. 2004, NOAA 2016). These tendencies showed that climate change in Sofia is exacerbating and therefore enhances abiotic risks for plants.

Plant material and gas exchange measurements

For the physiological measurements, two conifer species: *Pinus sylvestris* L. and *Pinus bungeana* Zucc. ex Endl. were chosen. Two experimental trees are approximately the same age and grow near each other in the arboretum of the University of Forestry in Sofia.

Gas exchange measurements were acquired using a LI-6400 portable infrared gas analyzer (LI-COR Ltd., Lincoln, Nebraska, 68504 USA) seven times within the period December 2015 – May 2016 in clear sky days with varied air temperatures. Data were taken after a minimum 30-minute calibration period (LiCor 2012). To determine the temperature dependence on net photosynthesis (A_N), incident air temperatures (T_A) were recorded during the measurements. Four branches with different geographical exposition were selected in the middle parts of the crowns both of the sample trees. Randomly chosen six mature needles of these branches were used for measurements. Five values for each parameters at each branches were recorded when gas exchange was stable as indicated by: (a) visually stable intercellular CO_2 concentration and net CO_2 assimilation rates values, (b) a total coefficient of variation (CV) – calculated as the sum of CO_2 and H_2O CV % – of less than 0.5 %. (Broadbent 2012).

Before budburst of the two experimental trees, measurements for constructing the photosynthetic light-response curves were made in April 2016. The measurements were conducted in two levels within the crowns (sun and shade) by standard protocol according to Evans and Santiago (2012) at 2000, 1000, 500, 250, 100, 50, 25 and 0 $\mu mol \cdot m^{-2} \cdot s^{-1}$ intensity of PAR.

The projected area of the needles was determined with an open source software

ImageJ (Abramoff 2004) to recalculate measured photosynthesis.

Data analysis

Temperature dependence of A_N was determined by the equation (1), suggested by June et al. (2004):

$$A_N(T_A) = A_{T_o} \cdot e^{-\left(\frac{T_A - T_o}{w}\right)^2} \quad (1),$$

where: A_N is the net photosynthesis; T_A is the ambient air temperature (independent variable); T_o is the optimal temperature for A_N ; A_{T_o} is the photosynthetic rate at T_o ; and w is the width of the temperature tolerance of the photosynthesis.

Light curve of photosynthesis was fitted by the function (2) of Norman et al. (1992).

$$A_N(I_A) = \frac{q \cdot I_A}{\left[1 + \left(\frac{q \cdot I_A}{A_{Max}}\right)^p\right]^{1/p}} - R_D \quad (2),$$

where: I_A gives the absorbed quanta per unit leaf area in the chamber, q is the photochemical efficiency at low light levels, A_{Max} is the assimilation rate at light saturation, R_D is the dark respiration rate, and p is a photosynthetic efficiency in the intermediate light range (curvature parameter).

The differences between regressions parameters both for temperature and light curves of *P. sylvestris* and *P. bungeana* for each studied physiological parameters were assessed with Z-test according Clogg et al. (1995) – equation (3).

$$Z = \frac{|C_1 - C_2|}{\sqrt{SE_{C_1}^2 + SE_{C_2}^2}} \quad (3),$$

where: C_1 and C_2 are the same regression parameters for *P. sylvestris* and *P. bungeana* responses and SE_{C_1} and SE_{C_2}

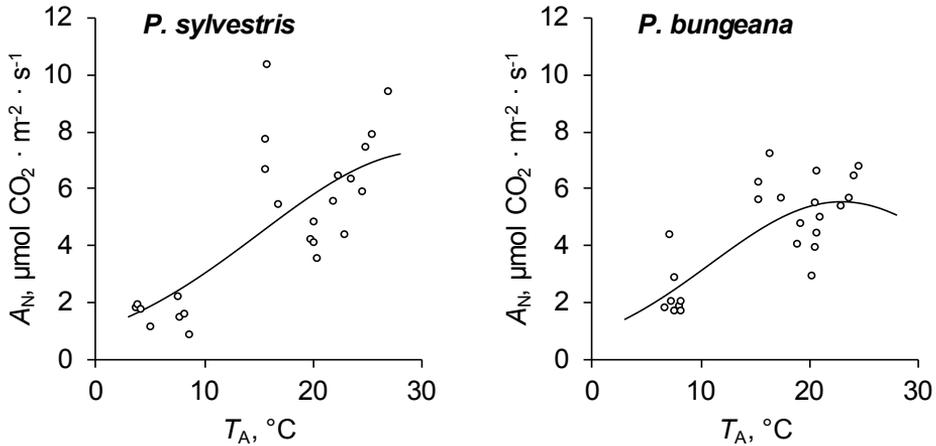


Fig. 1. Regression between ambient air temperatures (T_A) and net photosynthetic rate (A_N) in *P. sylvestris* and *P. bungeana* needles.

Note: Mean values ($n = 5$) for every case of measurements ($N = 24$) are shown with \circ ; Equation (1) regression lines are shown with —.

are standard errors of C_1 and C_2 , respectively.

All regression lines were fitted to the data applying the least-squares approach of the Microsoft Excel Solver routine using the Newton algorithm.

Results

A_N increased significantly with increase of air temperatures both in *P. sylvestris* and *P. bungeana* needles (Fig. 1).

The regression analysis identified moderate relations between the net photosynthetic rate and air temperature both in *P. sylvestris* and *P. bungeana* needles (Table 1).

A_N have greater variation in *P. sylvestris* needles by comparison with *P. bungeana* due to lower photosynthesis in winter and higher photosynthesis in spring. Furthermore, A_N in *P. bungeana* reaches saturation at temperature, within the measured range, whereas A_N in *P. sylvestris* increase constantly. The opti-

Table 1. Regression statistics: T_A -response of A_N .

	A_{T_0}	$\pm SE$	T_0	$\pm SE$	w	$\pm SE$	R^2	F-value	df	P-value
<i>P. sylvestris</i>	7.32	1.04	30.58	6.01	21.90	4.87	0.560	13.35	23	<0.001
<i>P. bungeana</i>	5.54	0.19	22.94	2.01	17.06	2.32	0.578	14.36	23	<0.001
Z statistics	Z-test	P-value	Z-test	P-value	Z-test	P-value				
	0.899	0.184	1.680	0.046	1.205	0.114				

Note: Statistically significant different (Z-test, P-value < 0.05) regression parameters are shown in bold.

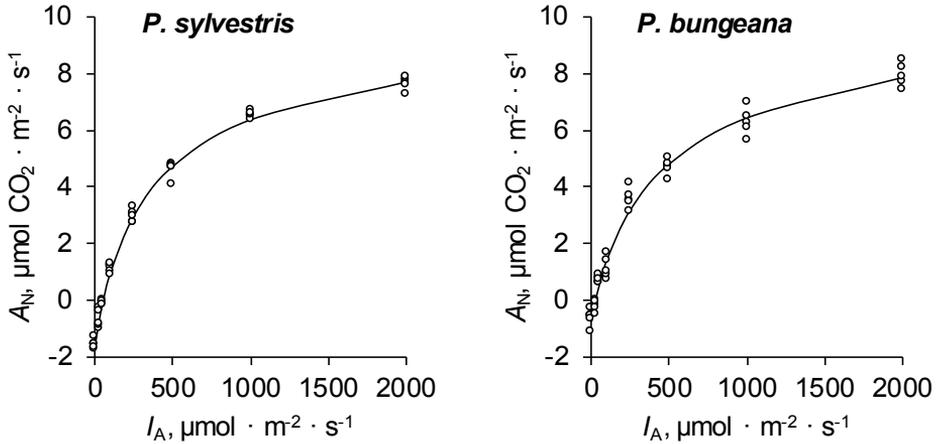


Fig. 2. Regressions between incident light intensity (I_A) and net photosynthetic rate (A_N) in *P. sylvestris* and *P. bungeana* sun needles.

Note: Mean value of A_N ($n = 5$) at each rate of I_A ($N = 8$) are shown with \circ ; Equation (2) regression lines are shown with —.

mal for photosynthesis temperatures (T_O) is the only significant different (P -value = 0.046) parameter of the temperature dependence of photosynthesis in both species. Strong relationships between A_N and incident light (I_A) are observed both in sun and shade parts of crowns of *P. sylvestris* and *P. bungeana* (Fig. 2 and Fig. 3).

A rising photosynthesis is observed both in *P. sylvestris* and *P. bungeana* sun needles in high light intensity, which is a sign for high demand of light both in two studied species.

Except R_D , all other regression parameters in light curves of sun needles of *P. sylvestris* and *P. bungeana* are statistically insignificantly different (Table 2).

P. bungeana photosynthesis has higher variation at each level of incident light than *P. sylvestris* photosynthesis, which reflect on coefficient of determination ($R^2 = 0.995$ and $R^2 = 0.983$ in *P. sylvestris* and *P. bungeana* regression line respectively).

P. bungeana shade needles have higher A_{Max} and reach light saturation at higher

Table 2. Regression statistics: I_A -response of A_N in sun needles of *P. sylvestris* and *P. bungeana*.

	A_{Max}	$\pm SE$	R_D	$\pm SE$	ρ	$\pm SE$	q	$\pm SE$	R^2	df	P-value
<i>P. sylvestris</i>	11.82	0.69	1.55	0.09	0.04	0.01	0.80	0.08	0.995	39	<0.001
<i>P. bungeana</i>	11.87	1.69	0.73	0.16	0.03	0.01	0.74	0.16	0.983	39	<0.001
Z statistics	Z-test	P-value	Z-test	P-value	Z-test	P-value	Z-test	P-value			
	0.03	0.49	4.47	<0.01	0.45	0.33	0.33	0.37			

Note: Statistically significant different (Z-test, P-value < 0.05) regression parameters are shown in bold.

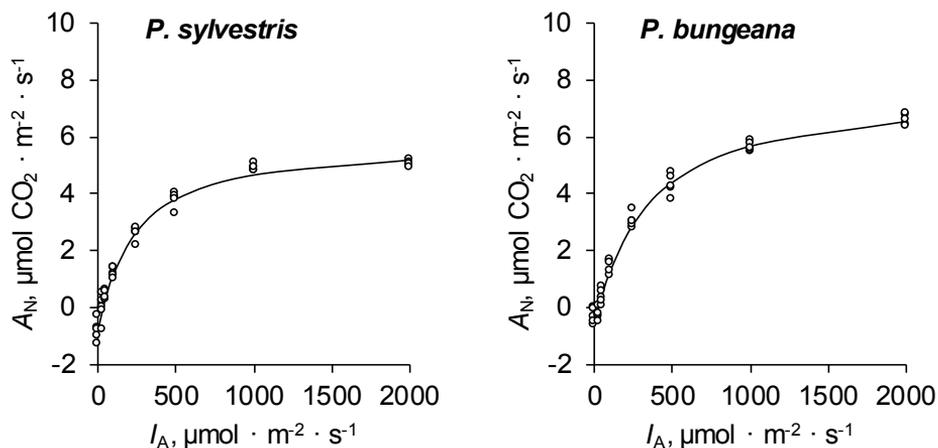


Fig. 3. Regressions between incident light intensity (I_A) and net photosynthetic rate (A_N) in *P. sylvestris* and *P. bungeana* shade needles.

Note: Mean value of A_N ($n = 5$) at each rate of I_A ($N = 8$) are shown with \circ ; Equation (2) regression lines are shown with —.

level of I_A than *P. sylvestris* (Fig. 3).

Except A_{Max} , the other three regression parameters in light curves of shade needles in experimental species are statistically insignificantly different (Table 3).

Discussion

Temperature and light responses of photosynthesis in *P. Bungeana*, obtained in this study, have small differences with same ones in *P. sylvestris*. The established low-

er optimal for photosynthesis temperature is probably because *P. bungeana* is more cold hardy (Peng and Bo 2007), but also might be an indication for better adaptation of *P. sylvestris* to the local climate.

The values of A_{Max} and R_D in needles of *P. sylvestris*, calculated by light curves regressions is close to values, which are observed for the same species by James et al. (1994) in Scotland tree line (around 600 m a.s.l.) and higher than established by Anev et al. (2016) for other three species from genus *Pinus*. Less intensive R_D

Table 3. Regression statistics: I_A -response of A_N in shade needles of *P. sylvestris* and *P. bungeana*.

	A_{Max}	$\pm SE$	R_D	$\pm SE$	p	$\pm SE$	q	$\pm SE$	R^2	df	P-value
<i>P. sylvestris</i>	6.47	0.39	0.73	0.11	0.03	<0.01	1.09	0.18	0.98	39	<0.001
<i>P. bungeana</i>	8.07	0.54	0.51	0.11	0.02	<0.01	1.08	0.18	0.99	39	<0.001
Z statistics	Z-test	P-value	Z-test	P-value	Z-test	P-value	Z-test	P-value			
	2.41	0.01	1.37	0.09	0.60	0.27	0.02	0.49			

Note: Statistically significant different (Z-test, P-value < 0.05) regression parameters are shown in bold.

in *P. bungeana* sun needles is probably because both lower rate of growth (and therefore lower requirements of energy) and better shade tolerance. The last claim is confirmed with higher A_{Max} in the shade needles of *P. bungeana* than the same in *P. sylvestris*.

Quantum use efficiency (p) varied slightly both in sun and shade part of the crowns in *P. sylvestris* and *P. bungeana* trees. As a light demanding species (Stefanov and Ganchev 1953, Luscombe 2013), p is low in two experimental trees probably due to thin crowns (Gilman and Watson 1994, Durrant et al. 2016, YiMing et al. 2006) and low chlorophyll concentration (Broadmeadow and Jackson 2000) in the needles of *Pinus* species. For *P. sylvestris* Leverenz and Öquist (1987) established similar values of p in April (0.017) and much higher value in July (0.057).

The close to 1.0 values of q both in sun and shade needles in two experimental species confirms the conclusions of Leverenz (1988) that even if within-leaf variation in light acclimation is big, the same whole-leaf variation is small.

Conclusions

P. bungeana has response to variation in air temperature and incident light intensity similar to *P. sylvestris*. The established small differences between examined physiological parameters are indications for higher tolerance of *P. bungeana* to shade and low temperature. Therefore, it can be assumed that *P. bungeana* has a comparable to *P. sylvestris* physiological potential to grow in Bulgarian urban parks and even has the potential to withstand more extreme low air temperature and incident light.

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