

EFFECTS OF LOW-LIGHT INTENSITY AND
TEMPERATURE ON PHOTOSYNTHESIS AND
TRANSPIRATION OF *Vigna sinensis* L.

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A B S T R A C T

Photosynthesis in cow pea (*Vigna sinensis* L.) seedlings was studied at different temperatures and light levels to show their impact on water use efficiency. Three-week-old plants were used at the two-primary-leaves stage. This stage was maintained by continuous apex tipping thus, avoiding any trifoliate leaf formation. Light intensity ranged from 30 to 350 $\mu\text{mol m}^{-2}\text{s}^{-1}$ by varying the lamp-leaf distance. The temperature ranged from 18 to 28°C. Net photosynthesis and transpiration were measured using a portable photosynthetic meter.

A strong interaction between assimilation, light and temperature was evidenced. At high light intensities the assimilation rate was significantly affected by temperature, but no positive effects were observed at lower light levels. A strong light and temperature interaction for transpiration and water use efficiency of *Vigna sinensis* L. was also detected. This short term experiment demonstrated that a low light intensity at high temperature reduced water use efficiency. These findings can be used to stimulate a wide-ranging discussion on how self-shading can affect the natural form of a tree or the efficiency of a training system in relation to the environmental conditions.

Key words: *Vigna sinensis* L. seedlings, photosynthesis and transpiration, light intensity

INTRODUCTION

Generally, the photosynthetic and transpiration response to

temperature and light is studied in single factor experiments (Nobel, 1991; Mathis, 1995; Schulze and Caldwell, 1995; Pessarakli, 1996).

The curve of photo-synthetic response to light is well known in its biologically meaningful parameters, i.e. maximum rate of net photosynthesis and photon flux compensation point, when the temperature is optimal for species but not in different sub-critical temperatures. On the other hand, there is a well described photosynthetic response to temperature at optimal light levels, with net photosynthesis becoming positive starting from a minimum temperature then reaching the maximum at about 28°C for “C3” plants and decreasing at higher temperatures, but not at different low-light levels. Transpiration follows different patterns as it is driven by air vapour pressure deficit. As stomata opening is the common path for gas exchanges in several conditions, transpiration is well correlated with photosynthetic activity.

Our goal is to describe photosynthesis and transpiration at low-light levels and at optimal and sub-optimal temperatures, as the efficiency of plant canopy, for light and water use, dramatically depends on this interaction along with the seasonal changes and the canopy formation. Crop productivity and quality are dependent on light interception and distribution in the canopy because infra- and inter-plant shading influences CO₂ net assimilation and transpiration due to different temperatures, humidity and light levels inside the canopy. Even adaptation and acclimation are influenced by this relation, being water use efficiency

(WUE) one of the main factors for ecological success in several climates. This work was carried out in a laboratory, testing light-temperature interaction on two-primary-leaves *Vigna sinensis* L. plants, as this physiological stage can be quite stable in controlled conditions.

MATERIAL AND METHODS

Cow pea (*Vigna sinensis* L.) seedlings were grown in a growth chamber under controlled environment (24±2°C, 16 h photoperiod), illuminated by a lamp with emission spectrum wavelengths ranging from 400 to 700 nm with two major peaks at 440 and 640 nm (OSRAM-FLORA L58/77 lamp, 58 W).

Three-week-old plants were studied at the two-primary-leaves stage (Fig. 1). This stage lasts for several weeks if the vegetative apex is continuously tipped avoiding any trifoliate leaf formation (mature leaves). The two primary leaves perform at

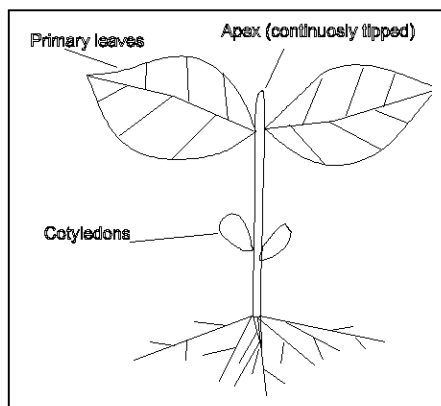


Figure 1. Drawing of the 2-leaves-plants *Vigna sinensis* L. utilized in the experiment

increasing photosynthetic activity, reaching a maximum when they are 2-week-old; later on photosynthesis is stable for at least two more weeks, then progressively decreases.

Light intensity (photosynthetically active radiation, PAR) on the tested leaves ranged from 30 to 350 $\mu\text{mol m}^{-2}\text{s}^{-1}$ by varying the lamp-sample distance from 1 m to 10 cm.

A portable photosynthetic meter (LCA4 - ADC, UK) was used to measure the difference between incoming and outgoing CO_2 in a cuvette (leaf chamber), containing a part, sized 6.25 cm^2 , of the illuminated leaf. This value was assumed to depend on the photosynthetic process (CO_2 uptake) and respiration process (CO_2 release) and will be shortly called "assimilation" (net assimilation, ADC software).

The difference between the relative humidity (RU) of the outgoing (enriched by the leaf transpiration) and incoming (reference, generally fixed between 8 and 12% RU) air was used for the calculation (ADC software) of water loss by the leaf (shortly "transpiration").

The temperature inside the cuvette was approximately set at 18, 24 and 28°C, by controlling room temperature and automatically measured by the instrument.

The measurements were carried out starting from a lower light to a higher light intensity on one leaf and from a higher to a lower light intensity

on the other leaf on the same plant. This was done in order to describe any influence of leaf stress in experimental conditions or effects on stomata opening due to the measurement itself.

RESULTS AND DISCUSSION

Assimilation. Figure 2 reports typical scans of CO_2 assimilation as a function of incident light intensity. The scans were performed on three plants both at an increasing (up) and decreasing (down) light intensity. The temperature varied along the measurements on the same plant of around 2°C (from 26 to 28°C) without significant influence on the assimilation. The scans obtained at increasing and decreasing light intensity were very similar, indicating a strong repeatability of the measurement techniques. Figure 3 reports the assimilation obtained in five cycles (each cycle being formed by a scan up and a scan down) considering three different plants. The CO_2 assimilation increased as a function of light

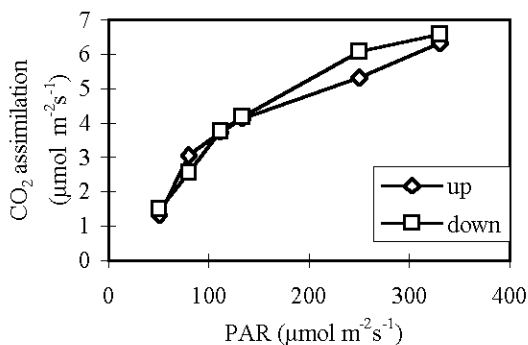


Figure 2. CO_2 assimilation at increasing (up) and decreasing (down) light intensity in the same plant (lines are guides for the eye)

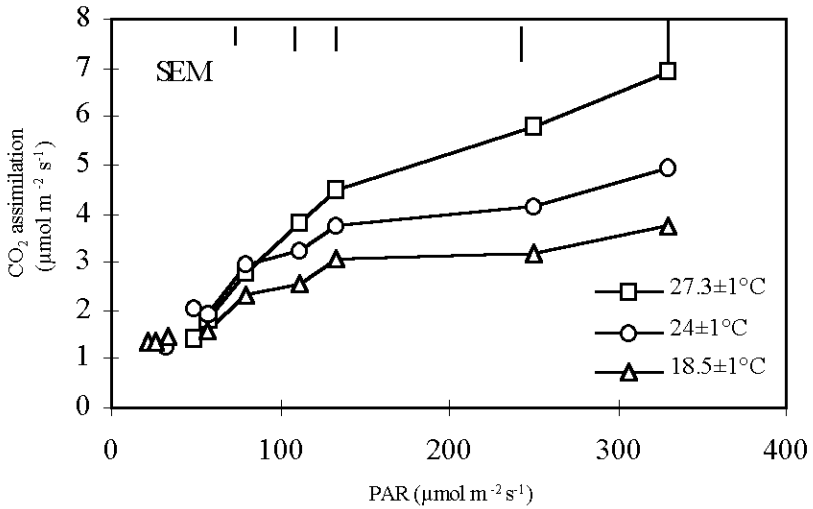


Figure 3. CO₂ assimilation at different temperatures as a function of light intensity. The data are mean of five cycles (each cycle being formed by a scan up and a scan down) considering three different plants. SEM=standard error of the means is reported in the upper part of the figure (lines are guides for the eye)

intensity and temperature, but at PAR lesser than about 50 µmol m⁻²s⁻¹ no difference of assimilation at different temperatures was detected.

Between 50 and 130 µmol m⁻²s⁻¹ a steady increase of the assimilation for all the temperatures occurred, a flex appeared at PAR of about 130 µmol m⁻²s⁻¹

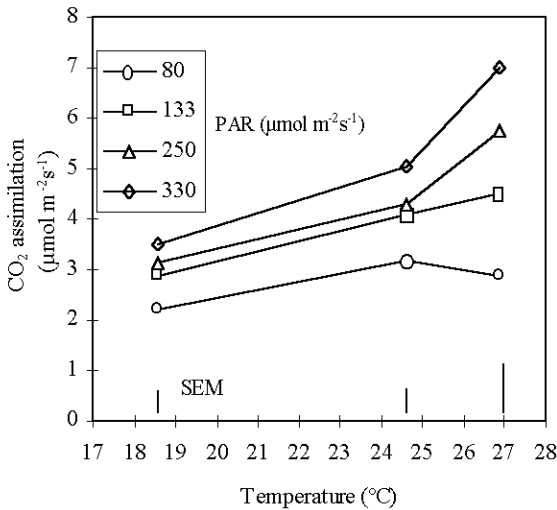


Figure 4. CO₂ assimilation as a function of temperature, at different light intensities. SEM=standard error of the means is reported in the lower part of the figure (lines are guides for the eye)

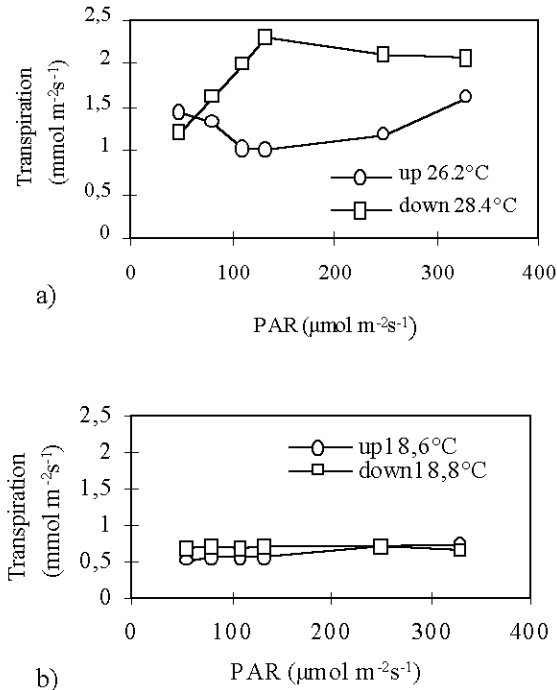


Figure 5. Transpiration as a function of incident light intensity in a scan at increasing (up) and decreasing (down) intensity in the same plant at different temperatures: $27.3 \pm 1.1^\circ\text{C}$ (a) and $18.7 \pm 0.1^\circ\text{C}$ (b) (lines are guides for the eye)

and then increases of assimilation were found mainly at higher temperature.

The general trend toward a CO_2 assimilation increase with rising temperature and light intensity can be better seen in Figure 4; at 24°C the maximum level was reached with very low light while the assimilation was still increasing at 27°C with the highest light levels.

Transpiration. Figure 5 reports typical changes of transpiration as a function of incident light intensity. The scans were performed both at increasing and decreasing light intensity at different temperature. Transpiration was more dependent on temperature rather than on light level (Fig. 5).

At a sub-optimal temperature for metabolic activity of *Vigna sinensis* L.

(18.8°C), transpiration was low and stable at any light level. Around the optimal temperature (27°C) differences occurred when scanning up and down. These differences seem to be linked to a small increase ($+2^\circ\text{C}$) of temperature during scanning down.

Finally, at 27°C water use efficiency in *Vigna sinensis* L. rose by increasing light intensity (Fig. 6) reaching a maximum at about $250 \mu\text{mol m}^{-2}\text{s}^{-1}$. At a lower temperature no increase in that parameter was detected at different light levels. Water use efficiency was maximized by minimal stomata opening when temperature and light were optimal, but it was low and stable when the temperature was sub-optimal or light below $100 \mu\text{mol m}^{-2}\text{s}^{-1}$ (Fig. 6).

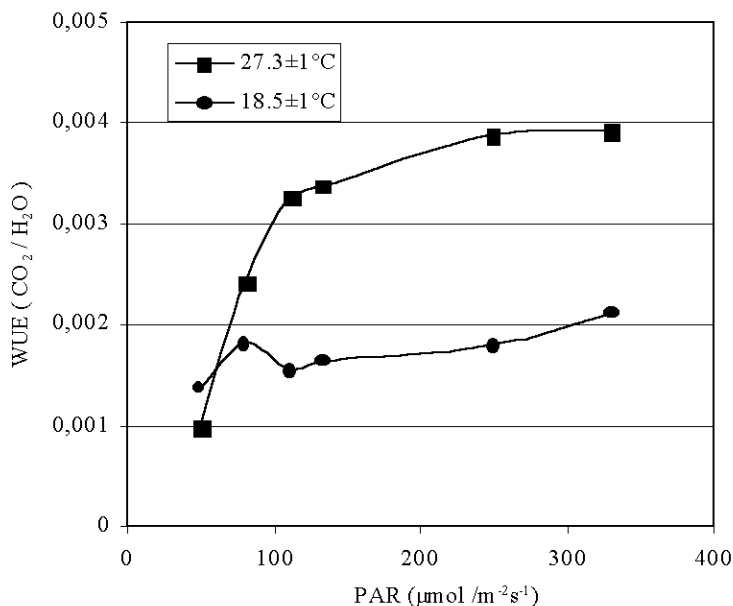


Figure 6. Water use efficiency (WUE) as a function of light intensity at two different temperatures (lines are guides for the eye)

CONCLUSION

The present investigation evidenced a strong interaction between light and temperature, as Gaastra (1959) already described. Actually, in the present research it has been demonstrated that this interaction determines very different water use efficiency both at low and high temperature as a function of light level. The results indicate that shaded leaves have a very poor efficiency in hot conditions and similar to that of well-lit leaves at sub-optimal temperatures.

At very low light levels (below $50 \mu\text{mol m}^{-2}\text{s}^{-1}$) net photosynthesis is not positively influenced by

temperature, as the whole plant metabolic activity increases but photon flux does not permit a similar increase of photosynthesis. When the light intensity is lesser than $130 \mu\text{mol m}^{-2}\text{s}^{-1}$, the optimal temperature for CO_2 assimilation seems to shift from 27 to 24°C . At a higher light level the CO_2 assimilation response curve presents its typical pattern increasing clearly over 27°C .

As transpiration depends not only on the temperature and light intensity but also on the initial status of the stomata (open/closed), the higher rates are obtained after illuminating ($>130 \mu\text{mol m}^{-2}\text{s}^{-1}$) at a high temperature (stomata remain

open also at lower tested light levels). Generally, high temperature make transpiration rates to increase for all light intensities but below $130 \mu\text{mol m}^{-2}\text{s}^{-1}$ this rise is very low. It seems that this light level is somehow a threshold for *Vigna sinensis* L. in the studied physiological age.

Finally the interest in studying light and temperature interaction has been confirmed by this laboratory experiment showing that water use efficiency is very low at both low temperature and light intensity. At a higher light level the efficiency is high only at high temperatures. From this last result it can be speculated that all internal shaded parts of the canopy in a hot climate should be much less efficient than the external, well-lit part, losing water in a comparable way (Marangoni et al., 1992; Neri and Scudellari, 1994) but not assimilating as much.

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WPLÝW NATĘŻENIA ŚWIATŁA I TEMPERATURY NA FOTOSYNTEZĘ I TRANSPIRACJĘ SIEWEK *Vigna sinensis* L.

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S T R E S Z C Z E N I E

Badania fotosyntezy siewek *Vigna sinensis* L. prowadzono przy różnym natężeniu światła w temperaturze od 18 do 28°C, aby wykazać wpływ tych czynników na efektywność wykorzystania wody przez roślinę. W doświadczeniu użyto trzytygodniowych roślin w stadium pierwszych dwóch liści. Dla podtrzymania tego stadium wierzchołki roślin stale usuwano, aby nie dopuścić do wytwarzania trójlistków. Zmiany natężenia światła w zakresie 30-350 $\mu\text{mol m}^{-2}\text{s}^{-1}$ uzyskiwano przez zmianę odległości pomiędzy lampą a liściem. Do określenia natężenia fotosyntezy i transpiracji zastosowano przenośne urządzenie pomiarowe.

Stwierdzono powiązane ze sobą oddziaływanie światła i temperatury na fotosyntezę i transpirację. Przy silnym nasświetleniu wyższa temperatura istotnie zwiększała tempo asymilacji, lecz takiej zależności nie obserwowano przy niższym natężeniu światła. Stwierdzono również silnie powiązane ze sobą oddziaływanie światła i temperatury na tempo transpiracji oraz efektywność wykorzystania wody przez rośliny. Ten ostatni wskaźnik zmniejszył się w warunkach słabego nasświetlenia przy wyższej temperaturze.

Słowa kluczowe: siewki *Vigna sinensis* L., fotosynteza i transpiracja, natężenie światła