# LEAF PHOTOSYNTHESIS OF KENAF (CV. EVERGLADES 41) AS AFFECTED BY DIFFERENT LIGHT INTENSITY AND TEMPERATURE REGIMES

S.V. Archontoulis[1, 2] *, P.C. Struik[1] and N.G. Danalatos[2]

[1] Wageningen University, Dept. of Plant Sciences, Crop and Weed Ecology Group, Haarweg 333, 6709 RZ Wageningen, The Netherlands. E-mail: sotirios.archontoulis@wur.nl
[2] University of Thessaly, Dept. of Crop Production and Agricultural Environment, Fytoco, 38446 Volos, Greece.

ABSTRACT: Plant production is driven by photosynthesis. Kenaf (*Hibiscus cannabinus* L., Malvaceae) is a highly productive, warm-season annual crop, with a $C_3$ – photosynthetic pathway. In the present work, the effect of different light intensity and temperature regimes on leaf photosynthesis ($CO_2$ assimilation) and transpiration rate were investigated. The gas exchange measurements took place in an open field kenaf crop in central Greece, on three days (July 11$^{th}$, August 11$^{th}$ and September 8$^{th}$) during the summer of 2004, using an LC-pro portable leaf chamber. The results demonstrated that maximum net assimilation rates of about 50 kg $CO_2$ ha$^{-1}$ h$^{-1}$ could be reached (at 1675 μmol PAR m$^{-2}$ s$^{-1}$), particularly at early stages of development. These data may explain the high biomass production of kenaf under Greek (and more generally Mediterranean) conditions, observed in recent studies. Moreover, the optimum temperature for maximum assimilation increased with an increase in light intensity. Transpiration rates increased exponentially with an increase in leaf temperature at all light levels. At temperatures above 35 $^{o}$C, a single leaf may transpire the equivalent of 30 mm per day at full canopy.

Keywords: kenaf, $CO_2$ balance, photosynthesis, transpiration

## 1 INTRODUCTION

Kenaf (*Hibiscus cannabinus* L., Malvaceae) is a warm-season annual crop, with a $C_3$ – photosynthetic pathway, achieving high biomass yields in Greece [1, 2]. Although kenaf is a $C_3$ crop and uses $CO_2$, solar radiation, water and nitrogen less efficiently than $C_4$ crops, recent studies from Greece and Italy showed assimilation rates in excess of 50-58 kg $CO_2$ ha$^{-1}$ h$^{-1}$ (32-37 μmol $CO_2$ m$^{-2}$ s$^{-1}$) [2, 3].

The global environment is changing rapidly; especially $CO_2$ concentration and air temperature are increasing. The earth's atmospheric $CO_2$ concentration has increased from 280 ppm since the start of the industrial revolution, to a current level of around 370 ppm, and continues to rise at approximately 1.8 ppm per year [4]. Due to the increase of the $CO_2$ level, it is expected that the maximum, minimum and mean global temperatures will also increase by 3–4 $^{o}$C [4]. These key factors affect plant growth, development and function, starting with photosynthesis, the most important process in the plant kingdom, sustaining all life forms on earth.

Temperature affects the photosynthetic rate due to its pervasive role in the regulation of the plant's biochemical reaction rates, the plant's morphogenesis, and the exchange of $CO_2$ and energy between the plant and the atmosphere. Plants show an optimum range of temperature for photosynthesis, and beyond this range carbon assimilation decreases [5]. It has been shown for kenaf (cv. Tainnung 2) that this happens when leaf temperature increases from 26 to 40 $^{o}$C [3].

The level of irradiance is an important ecological factor which determines the assimilation rate. Under high (photoinhibition) or low light intensities, the diffusion rate of $CO_2$ from the air to the stomata is the major factor limiting $CO_2$ assimilation. Under saturated light conditions (2000-2300 μmol m$^{-2}$ s$^{-1}$) and abundant water supply, maximum kenaf (cv. Tainnung 2) assimilation rate ranged from 47 to 59 kg $CO_2$ ha$^{-1}$ h$^{-1}$ (29.9 to 37.7 μmol $CO_2$ m$^{-2}$ s$^{-1}$) [3].

Despite its great potential for multiple uses (paper, construction materials, energy), only few articles report experimental field data on the physiology of kenaf. Especially data on assimilation rate as affected by environmental and agronomic factors are scarce. Knowledge on kenaf's carbon balance, as a response of assimilation and respiration rate to environmental conditions, is fundamental for understanding and assessing crop growth and productivity.

The objective of the present work is to determine the effect of different light intensities (in the range of 0 to 2000 μmol PAR m$^{-2}$ s$^{-1}$) and temperatures (in the range of 10 to 40 $^{o}$C) on leaf photosynthesis and transpiration of the kenaf variety Everglades 41.

## 2 MATERIALS AND METHODS

### 2.1 Experimental area – experimental set-up

All gas exchange measurements took place at the University of Thessaly experimental site in Palamas, Karditsa, located in Western Thessaly, central Greece (coordinates: 39$^{o}$25'43.4'' N, 22$^{o}$05'09.7'' E, altitude 107 m) during the summer of 2004. The soil was a deep loamy fertile soil, classified as Aquic Xerofluvent [6]. The measurements were conducted in a kenaf field experiment (treatments: 2 sowing dates × 2 varieties × 2 plant densities in a completely randomized block design with 3 replicates), and particularly in the treatments "$S_1V_2D_1$" and "$S_2V_2D_1$"; where $S_1$ is sowing date 1/6/04, $S_2$ is sowing date 1/7/04, $V_2$ is cultivar Everglades 41, and $D_1$ is plant density 20 plants m$^{-2}$. All plots received a basal dressing of 50 kg P ha$^{-1}$ and 100 kg K ha$^{-1}$ before sowing, while a top dressing of 100 kg N ha$^{-1}$ (as ammonium sulphate) was applied when the plants reached a height of 0.4 m. Weather data (radiation, air temperature, rainfall, air humidity, wind speed and class-A pan evaporation rate (PET) was recorded hourly on an automatic meteorological station which had been installed a few meters from the experimental site.

2.2 Gas exchange measurements

Net photosynthetic rate (A), transpiration rate (E), stomatal conductance (Gs), intercellular $CO_2$ concentration (Ci), leaf temperature (Tl), chamber temperature (Tch), atmospheric $CO_2$ concentration (Cref) and incident irradiance at leaf surface (Qleaf) were instantaneously measured using the LC-pro, Leaf Chamber Analysis System (Li-Cor, Lincoln, England). All parameters were automatically recorded every 5 minutes over a 5-hour period. Temperature and incident irradiance in the leaf chamber were adjusted each time (records under artificial conditions set by analysis system). Measurements were done from 12:00 to 20:00 h for three different days (treatment "$S_1V_2D_1$" on July and August 11$^{th}$ and "$S_2V_2D_1$" on September 8$^{th}$). The crop received drip irrigation at frequent intervals, to fully match the PET. Irrigation was applied on the dates 9/7, 4/8, and 30/8 with approximately 50 mm per irrigation.

## 3 RESULTS AND DISCUSSIONS

### 3.1 Weather conditions

The study area is characterized by a typical Mediterranean climate with hot, dry summers and cool humid winters. Figure 1 illustrates the diel trend of weather parameters in the study area during the observation days. Wind speed was in the range of 0.6-1.0 m s$^{-1}$ during the observation period. Maximum air temperatures during gas exchange measurements were moderate on September 8$^{th}$ but very high on July 11$^{th}$. Irradiance levels were very high on the first two observation dates, but significantly lower on the observation date in September. The relative humidity fluctuated at low levels around 40-50% during the observation period. In combination with the high temperatures, especially on July 11$^{th}$, one might expect high transpiration needs. The daily evaporation on July 11$^{th}$, August 11$^{th}$, and on September 8$^{th}$ was 6.56, 6.39, and 6.32 mm, respectively (i.e. average water losses of about 64 t ha$^{-1}$). The irradiation measured in the Thessaly lowlands during the summer months reached values close to the maximum for earth surface level.

### 3.2 Crop characteristics

Specific Leaf Area (SLA, green leaf area over leaf weight), Leaf Area Index (LAI, leaf area over surface area) are of great importance in understanding the processes of plant growth and photosynthesis.

**Table I:** Crop growth data of kenaf (cv. Everglades 41) on the dates at which gas exchange measurements took place (each value is an average of three replicates).

| Day | 11/7/04 | 11/8/04 | 8/9/04 |
|---|---|---|---|
| Treatment | $S_1V_2D_1$ | $S_1V_2D_1$ | $S_2V_2D_1$ |
| Plant height (cm) | 48 | 165 | 160 |
| Number of main nodes per plant | 11.5 | 33.3 | 37.8 |
| Dry weight (t ha$^{-1}$) | 0.74 | 5.01 | 4.02 |
| SLA (m$^2$ kg$^{-1}$) | 24.09 | 17.15 | 18.53 |
| LAI (m$^2$ m$^{-2}$) | 1.02 | 2.07 | 2.62 |

SLA and LAI influence the leaf area ratio and thus the relative growth rate of the crop. The higher SLA and LAI, the higher the growth rate (more light intercepted, higher net assimilation rate) and thus the higher the biomass production. Table I summarizes some crop growth data measured during the days on which gas exchange was measured. [2].

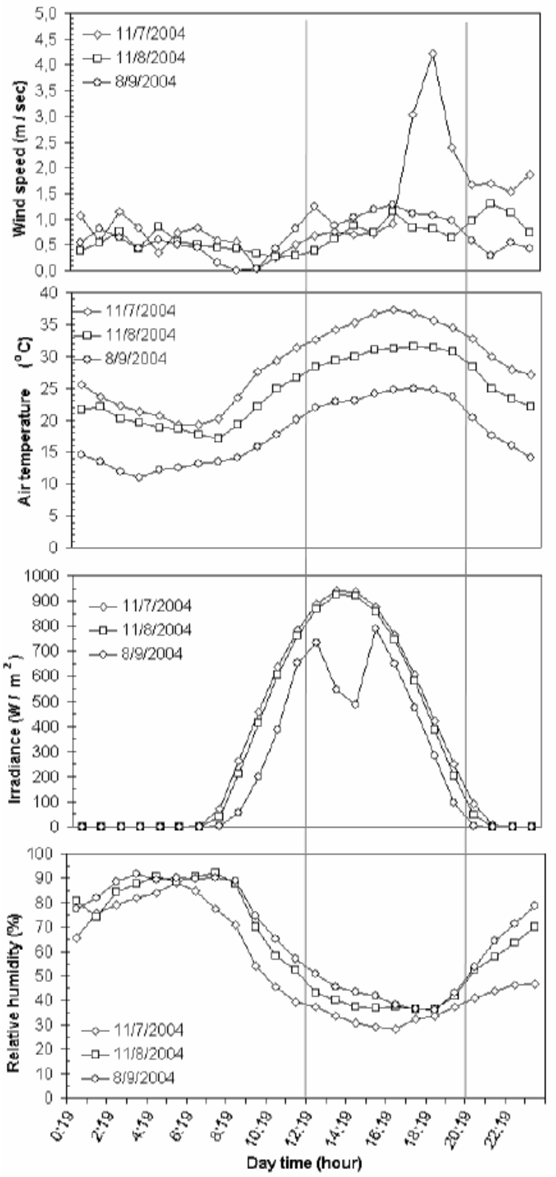


**Figure 1:** Diel trends in weather data (wind speed in m s$^{-1}$, air temperature in $^o$C, incident irradiance in W m$^{-2}$ and relative humidity in %) in the study area in 2004 for three days (July 11$^{th}$, August 11$^{th}$, and September 8$^{th}$). All gas exchange measurements were conducted between 12:00 and 20:00 h.

### 3.3 Temperature response curve

Figure 2 illustrates the net assimilation rate (in kg $CO_2$ ha$^{-1}$ h$^{-1}$) of kenaf as a function of leaf temperature at various levels of light intensity (in μmol m$^{-2}$ s$^{-1}$) for three different days. The equipment was programmed to provide a temperature range of 5-45$^o$C, but due to the extremely high temperatures prevailing during the first two observation days (Fig. 1) and the fact that temperature adjustment in this LC-pro is limited to ± 10 $^o$C, the actual range was smaller, especially during the first observation day.

The data on the temperature response are plotted in Fig. 2. At each level of PAR, a polynomial curve can be fitted through the temperature response of the photosynthesis, at least for the later two observation dates. Two types of interaction between temperature and PAR can be observed: i. The optimum temperature for photosynthesis increases with an increase in the level of radiation; and ii. Beyond the optimum, the temperature response is stronger at a higher radiation level than at a lower PAR level. These experimental results are consistent with predictions of temperature responses from the crop growth simulation model GECROS [7].

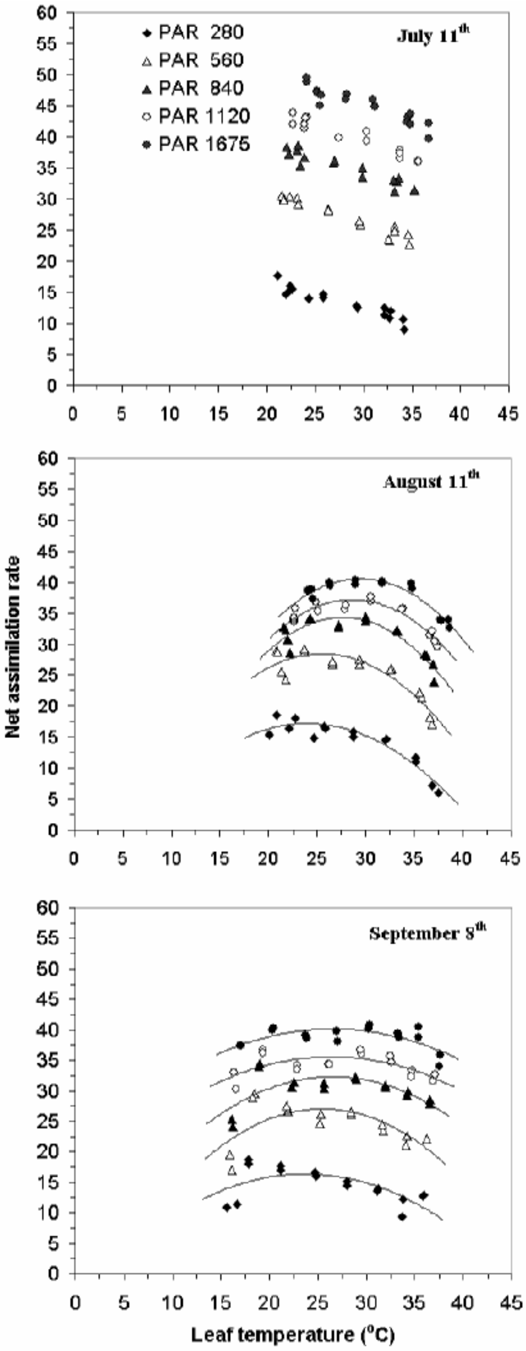


**Fig. 2:** Temperature response curves of kenaf (cv. Everglades 41) at five light intensities (PAR) and for three observation days in central Greece in 2004. (Net assimilation rate of flag leaf in kg $CO_2$ $ha^{-1}$ $h^{-1}$).

The maximum net photosynthetic rate (> 50 kg $CO_2$ $ha^{-1}$ $h^{-1}$) was recorded on July 11th at a light intensity of 1675 μmol $m^{-2}$ $s^{-1}$ and a leaf temperature of 25 °C. The total dry weight of the plant at that date was lower than on the later two days (Table I), resulting in lower (maintenance) respiration needs and more assimilates available for growth. The maximum assimilation rate decreased over time (for other two dates with similar development stages: 42 kg $CO_2$ $ha^{-1}$ $h^{-1}$; 1675 μmol $m^{-2}$ $s^{-1}$; Fig. 2) and was found for higher leaf temperatures (25-29 °C). The increase in optimum temperature for photosynthesis may be attributed to the adaptation of the leaves to high temperatures.

In conclusion, the optimum temperature for kenaf (cv. Everglades 41) assimilation is between 25 and 29 °C and depends on the development stage. Below and beyond this optimum the photosynthetic rate is lower. In the sub-optimum part, the photosynthetic machinery is limited by the enzymatic reaction rates (kinetic properties of Rubisco are temperature-dependent). In the supra-optimum part, the oxygenation reaction of Rubisco increases more than the carboxylation, so that photorespiration becomes more important. [8].

3.4 Light response curve

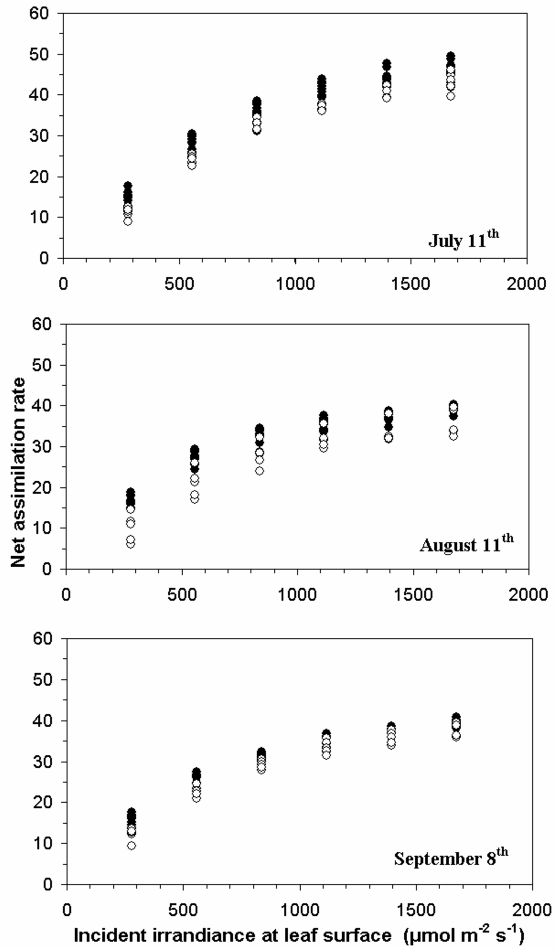


**Fig. 3:** Light response curves of kenaf cv. Everglades 41 at two temperature ranges and on three observation dates in central Greece in 2004. Data are net assimilation rates of flag leaf in kg $CO_2$ $ha^{-1}$ $h^{-1}$. (●: temperature range 20-30 °C; ○: temperature range 30-40 °C).

Radiation drives photosynthesis. Plotting the net assimilation rate versus the incident irradiance, light response curves were constructed (Fig. 3). For simplicity, only two ranges were distinguished (above and below 30 $^oC$). The plotted data show that at low irradiance (until 600 μmol $m^{-2}$ $s^{-1}$) the rate of $CO_2$ assimilation increases linearly and is light-limited. At high irradiance, photosynthesis becomes light-saturated and is limited by the carboxylation rate, which is governed by some combination of $CO_2$ diffusion into the leaf and carboxylation capacity [8].

On all observation dates, the temperature range 20-30 $^oC$ provides higher rates of net assimilation than the range 30-40$^oC$, due to low photorespiration in the former temperature range. Based on Fig. 3 it can be stated that on the dates August 11$^{th}$ and September 8$^{th}$, $CO_2$ fixation was stabilized at light intensities greater than 1500 μmol $m^{-2}$ $s^{-1}$, in contrast to the first observation day when the rate seems to increase even beyond that light level.

### 3.5 Transpiration rate

Most of the water taking part in the transpiration process is used for cooling purposes, i.e. to maintain a certain temperature equilibrium in the plant. Plotting transpiration rates measured on August 11$^{th}$ against the leaf temperature (Fig. 4), provides an exponential relationship, independent of radiation, which can be well described by the formula:

$Y=0.1246e^{0.1457*temp}$ ($R^2$=94%, Fig. 4).

At air temperatures above 35$^oC$, a single leaf transpired the equivalent of 30 mm per day of a full canopy.

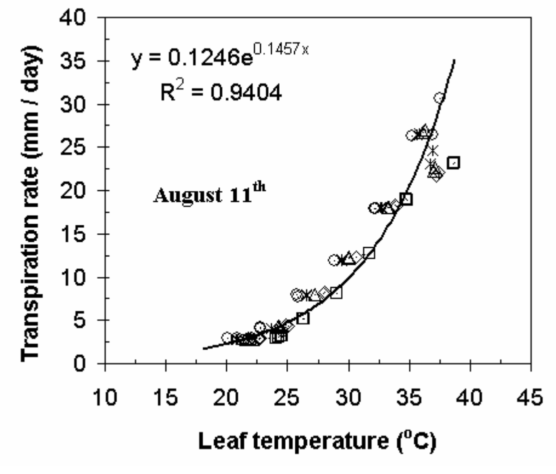


**Fig. 4:** Leaf transpiration rate of kenaf (cv. Everglades 41), as a function of leaf temperature at different light intensities on August 11$^{th}$, 2004 in central Greece. Different markers represent different levels of irradiance.

## 4 CONCLUSIONS

It can be concluded that kenaf (cv. Everglades 41) is characterized by a high photosynthetic capacity. Maximum rates of about 50 kg $CO_2$ $ha^{-1}$ $h^{-1}$ were achieved at early crop development stages, when the maintenance respiration was still at a low level. The optimum temperature for maximum assimilation increased with an increase in light intensity; the optimum temperature for kenaf was in the range of 25-29 $^oC$. Transpiration rates increased exponentially with increasing leaf temperature at all light levels. At temperatures above 35 $^oC$, transpiration may reach 30 mm/day. The above data may explain the particularly high biomass production of kenaf under Greek, and more generally under Mediterranean conditions, found in recent studies, and can be used in crop-growth simulation models to predict kenaf growth and biomass yield.


## 5 ACKNOWLEDGEMENTS

This work was partially financed by the E.U. Project QLK5-CT-2002-01729 "Biomass Production Chain and Growth Simulation Model for Kenaf".


## 6 REFERENCES


[1] Danalatos, N.G., and Archontoulis, S.V., 2004. Potential growth and biomass productivity of kenaf under central Greek conditions: II. The influence of variety, sowing time and plant density. Proceedings of the 2nd World Biomass Conference, 10-14 May, Roma, Italy, pp. 319-322.

[2] Danalatos, N.G., and Archontoulis, S.V., 2005. Sowing time and plant density effects on growth and biomass productivity of two kenaf varieties in central Greece. Proceedings of the International Conference on Industrial Crops and Rural Development, 17-21 September 2005, Murcia, Spain, pp. 889-901.

[3] Cosentino, S.L., Riggi, E., and D'Agosta, G., 2004. Leaf photosynthesis in kenaf (*Hibiscus cannabinus* L.) in response to water stress. Proceedings of the 2nd World Biomass Conference, 10-14 May, Roma, Italy, pp. 374-376.

[4] Heinemann, A.B., Maia, Aline de H.N., Neto, D.D., Ingram, K.T., and Hoogenboom, G., 2005. Soybean (*Glycine max* (L.) Merr.) growth and development response to $CO_2$ enrichment under different temperature regimes. European Journal of Agronomy (in press).

[5] Allen, D.J., and Ort, D.R., 2001. Impacts of chilling temperatures on photosynthesis in warm-climate plants. Trends in Plant Science 6, 36–42.

[6] USDA, 1975. Soil Taxonomy. A basic system of soil classification for making and interpreting soil surveys. Agric. Handbook 466. Washington DC, 754 pp.

[7] Yin, X., and van Laar, H.H., 2005. Crop Systems Dynamics. An ecophysiological simulation model for genotype-by-environment interactions. Wageningen Academic Publishers, Wageningen, The Netherlands, 153 pp.

[8] Atwell, B., Kriedemann, P., and Turnbull, C., 1999. Plants in action. Adaptation in nature performance. Macmillan publishers Australia PTY LTD.