Sowing time and plant density effects on growth and biomass productivity of two kenaf varieties in central Greece

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Abstract

Growth and biomass productivity of two promising, late-maturing kenaf varieties (Tainnung 2 and Everglades 41) were investigated under two different sowing times (1/6 and 1/7/04) and two plants densities (20 and 40 pl m^{-2}). A field experiment using a 2x2x2 factorial completely randomized block design was carried out on a deep, fertile soil in central Greece in 2004. The growth characteristics (plant height, stem diameter, leaf area index) and the biomass productivity (leaves, stems, and storage organs) of the crop were measured in subsequent harvests throughout the growing period. Leaf photosynthesis was measured for different radiation and temperature conditions. A significant effect of sowing time on all growth indices was found with the earlier crop attaining much higher values by end of the growing period. Plant height, stem diameter and leaf area index reached maximum values in excess of 300 cm, 2.57 cm, 4.32 in case of early crop and 305 cm, 2.27 cm, 3.44 for the late crop, respectively. The total dry biomass reached 16.52 t ha^{-1} (dry stems 14.81 t ha^{-1}) for the early crop, and 13.34 t ha^{-1} (dry stems 10.81 t ha^{-1}) for the late crop. Considering that maximum growth rates exceeding 240 kg $ha^{-1}d^{-1}$ were measured, the large difference in biomass production was attributed to the longer period available for the early crop for maximum growth. A slight, but non-statistically significant superiority on biomass productivity of variety Tainnung 2 vs. Everglades 41 was found.

Keywords: kenaf, biomass production, fiber crops, Greece.

1. Introduction

Kenaf (*Hibiscus Cannabinus* L., Malvaceae) is an annual, fibber, fast growing tropical crop, which due to its high productivity and the modest inputs required, is gaining particular attention by the E.U. during the last decade especially for its multiple industry uses for pulp production and energy applications. During the last 5 years, considerable efforts have been made in order to study the adaptability of kenaf varieties in European environments, with respect to crop performance under various soil and climatic conditions, proper planting time and population in Mediterranean and central European environments. It was found that sowing time strongly depends on the specific climatic conditions, whereas in Mediterranean environments very early planting (before April) may result in poor- and unhomogeneous emergence, in contrast to later planting (mid-June) which results in reduced biomass yields, apparently due to shorten available time for growth and reduced availability of solar radiation (Cosentino *et al*., 2004; Fernado *et al*., 2004; Alexopoulou *et al*., 2004b; Di Virgilio *et al*., 2004; Danalatos and Archontoulis, 2004a;). So, the first experimental results suggest that proper planting time might be in May, when soil temperature exceeds 15^0C. In particular under central Greek conditions early planting in mid-May shows a great superiority (30-40%) on biomass yield, versus a delayed planting by one month (Danalatos and Archontoulis, 2004). Concerning the proper plant density, most recent experimental data show that under Mediterranean conditions, populations of 20-25 pl m^{-2}, seem to be ideal for suitable growth, radiation efficiency and hence maximum final biomass production (Danalatos and Archontoulis, 2004a; Cosentino *et al*., 2004; Fernado *et al*., 2004; Alexopoulou *et al*., 2004b; Di Virgilio *et al*., 2004). Among the various kenaf varieties, the late-maturity ones such as Tainnung 2 and Everglades 41 were found quite promising (Alexopoulou *et al*., 2000; Angelini *et al*., 1998), with maximum total dry matter production of 20-24 t ha^{-1} (Alexopoulou *et al*., 2000). Final production of kenaf seems to be determined by the duration of its growing period (Danalatos and Archontoulis, 2004a; Cosentino *et al*., 2004; Fernado *et al*., 2004; Alexopoulou *et al*., 2004b; Di Virgilio *et al*., 2004). Maximum growth rates for both two varieties grown in Greece may fluctuate in the range 240-300 kg ha^{-1} d^{-1}, (maximum rates for C_3-crops) resulting in final dry matter production and dry stem yield in excess of 22.5 and 17 t ha^{-1}, respectively (Danalatos and Archontoulis 2004a).

In the scope of the European project "Biomass Production Chain and Growth Simulation Model for Kenaf (Biokenaf)", the objective of the present work is to investigate and validated previous results on the potential growth and productivity of the two promising kenaf varieties Tainnung 2 and Everglades 41 under two different sowing dates and two plant populations in central Greece in the light of experimental field data (second year experimental procedures). Such potential growth and productivity data will serve as reference in future land use analyses of alternative at lower hierarchical levels of production with the availability of water and/or nutrients at sub-optimal levels.

2. Materials and Methods

A field experiment was carried out on a deep, fertile, loamy soil located in western Thessaly, central Greece (Karditsa plain, coordinates: 39°25'43.4'' N, 22°05'09.7'' E, altitude 107.5 m) in 2004. The soil is classified as Aquic Xerofluvent, having groundwater table fluctuating from some 150-200 cm below the surface in May to deeper layers later in the summer. A 2x2x2 factorial completely randomized block design was used in three blocks. The factors were: a) sowing date: S_1=June 1^{st} and S_2=July 1^{st}, variety: V_1= Tainnung 2 and V_2= Everglades 41, and plant density: D_1=20 and D_2=40 plants m^{-2}. Sowing was done at rows 0.5 m apart with plant distances within the row of 0.10 m and 0.05 m for D_1 and D_2, respectively. Germination rate for both varieties was measured two weeks before planting and showed high seed quality (>95%). All plots had received a basal dressing of 50 kg P ha^{-1} and 100 kg K ha^{-1} on 29-5-2004, while a top dressing of 100 kg N ha^{-1} (as ammonium sulphate) was applied when the plants reached a height of 0.5 m. The crop received drip irrigation (500 mm until 07/10/2004) at frequent intervals, and for full matching the potential evapotranspiration (100% of PET), the latter being determined using a class-A evaporation pan. The growth (plant height, stem diameter, and LAI) and the dry biomass productivity (leaves, stems, storage organs) of the crop were measured in subsequent harvests throughout the growing period and particularly on the dates: 4/7, 21/7, 4/8, 19/8, 8/9, 2/10, 30/10 and 19/11/2004. Weather data (radiation, air temperature, rainfall, air humidity, wind speed and class-A pan evaporation rate) were recorded hourly on an automatic meteorological station installed next to the experimental site. All data were subjected to analysis of variance for each character using MSTAT-C (version 2.1, Michigan State University, 1991) software. Standard soil physical and chemical analyses were carried out at the Institute of Soil Mapping and Classification, Larissa. The studied soil is imperfectly drained (artificial drainage), having groundwater table fluctuating from some 150-200 cm below the surface in May (180 cm during sowing in 2004) to deeper layers later in the summer and is classified as Aquic Xerofluvent. It is a calcareous (pH=8), fertile (organic matter content >1% at a depth of 50 cm) loam (sand 40-42%, silt 40-41%, clay 18-19%) developed in recent alluvial deposits and represents a large part of the west Thessaly lowland (central Greece). Its high fertility status and water availability may ensure high growth rates and productivity of summer crops under supplemental irrigation.

3. Results and Discussion

3.1 Climatic conditions

The study area is characterized by a typical Mediterranean climate with hot, dry summers and cool, humid winters. As illustrated in Fig. 1, the air temperature fluctuated 1-4 ^{o}C in relation to mean climatic value for the most of the growing period. From mid-June to mid-July the average air temperature was similar to the climate value (26 ^{o}C) to decreased thereafter until the end of September to levels 22.8 ^{o}C (2.8 ^{o}C under the climatic value). After this period and until crop maturation, air temperature increased in regular levels for the area. The total rainfall amount (effective rainfall) during the growing period was 190 mm, 83 mm less than in an average year (Fig. 1). 35% of the effective rainfall was recorded at the end of July. In general, the growing period of 2004 was somewhat cooler and drier than in an average year.

3.2 Plant height

Figure 2 illustrates the plant height evolution for the studied kenaf varieties, plant populations and sowing times. It can be clearly seen that both varieties performed similar growth rates throughout the growing period (Fig. 2b). On the other hand, plant height evolution was almost identical for the two studied plant populations (Fig. 2c). As expected, significant differences in plant height were found between the early and late plantings, throughout the growing period ($P=0.05$). Concerning average growth rates, it can be observed that after an initial growth with relatively low rates (1.9 cm d^{-1}), plant height increased with average rates of about 2.65 cm d^{-1} throughout the growing period (max 4.4 and 3.99 cm d^{-1} for early and late crop respectively). It is noticeable that the growth rates of the early and the late plantings run almost parallel to each other so that the difference in plant height remained almost the same, and the greater final height of the early crop was due to the its larger growing period (Fig. 2a). Kenaf plants reached their maximum height upon 50% of flowering, which were 330 and 305 cm, for the early and the late plantings, respectively ($P=0.05$). Previous data from Danalatos and Archontoulis (2004a), confirm this superiority of the early plantings.

3.3 Stem diameter

As illustrated in Figure 3, stem diameter was significantly affected *(P=0.05)* only by sowing time, with the late crop characterized by smaller diameter throughout the growing period. Maximum increase in stem diameter was observed one month after emergence for both sowing times in excess of 0.05 cm d^{-1}. The increase in stem diameter generally follows the increase in plant height. The final stem diameter was recorded upon 50% of flowering and was 2.56 and 2.28 cm for S_1 and S_2, respectively. A slight but non-significant superiority of D_1 plantation was found during most of cropping period (Fig. 3b).

3.4 Leaf area index (LAI)

As presented in Fig. 4a, the LAI of the early crop increased with low rates from emergence to the 1st decade of July, and with great rates until the 1st decade of September to reach a maximum value of 4.3 (almost closed canopy). Then LAI decreased slightly, but until the first days of October it remained above 3.8, to degrease drastically thereafter, apparently due to the ageing and falling off of the older leaves at advanced development stages. The LAI of the late crop increased with similar rates and reached by mid-September a peak value of 3.44 (*P=0.05*). Then it fluctuated around 3 until mid-October to decrease substantially thereafter as in the case of the early crop. It should be noticed that in the period from mid-August to mid-September, a superiority (*P=0.05*) of Tainnung 2 versus Everglades 41 was observed, as illustrated in Fig. 4b. Finally, the LAI was affected by plant population but only at late development stages (after the end of September; Fig. 4c). Previous data from Danalatos & Archontoulis (2004a) present higher LAI values (5.8 and 4.5 for S_1 and S_2 respectively) if sowing takes place 2 weeks earlier.

3.5 Assimilation rate

Assimilation rate of kenaf varieties Tainnung 2 and Everglades 41 was measured using an LCPRO- leaf chamber apparatus. Photosynthetic rate was measured in a temperature range (15-28 ^oC) and global radiation (0-1000 W m^{-2}). Kenaf plant has a C_3 photosynthetic pathway, and is characterized by high light-use efficiency and a high maximum assimilation rate comparing to other C_3 plants. Figure 5 represent the relation between net assimilation rate of kenaf variety Tainnung 2 and Everglades 41 at kg CO_2 ha^{-1} h^{-1} versus photosynthetically active radiation in temperature range 15-38^oC during the growing period of 2004. It can be clearly seen that the maximum assimilation rates were in excess of 50 kg CO_2 ha^{-1} h^{-1} at Par 460 (W m^{-2}) during mid-July for both studied kenaf varieties.

3.6 Total dry biomass and dry stem biomass

Figures 6 and 7 present the increase in the total dry matter and the stem dry matter, respectively, for the two studied sowing dates, the two varieties and the two plant populations. It can be observed that plant population had a minimal effect on growth and productivity of both varieties. Figures 6b and 7b show a non-significant superiority of variety Tainnung 2 concerning to Everglades 41, for both stem and total dry matter, throughout the growing period. As expected, a superiority of the early versus the late crop was found, performing significantly (*P=0.05*) higher stem and total dry matter production (Figs. 6a & 7a), which confirms that kenaf final yield may be drastically reduced (>20%) if sowing is delayed by one month. These data are in accordance with previous findings (Campbell and White, 1982; Manzanares, *et al*., 1997; Danalatos & Archontoulis, 2004).

Figs. 6a & 7a show that both early and late crops exhibited similar growth rates so that the greater biomass production of the early planting can be attributed to the larger period available for growth. Actually, after a period of establishment and initial growth (about one month), the early crop performed average growth rates of about 195 kg $ha^{-1}d^{-1}$ in total dry biomass (max 240 kg $ha^{-1}d^{-1}$) and 136 kg $ha^{-1}d^{-1}$ in dry stem biomass (max 170 kg $ha^{-1}d^{-1}$) until the first decade of September. In a similar way, late crop performed average growth rate in access of 147 kg $ha^{-1}d^{-1}$ in total dry biomass (max 157 kg $ha^{-1}d^{-1}$) and 121 kg $ha^{-1}d^{-1}$ (max 190 kg $ha^{-1}d^{-1}$) in dry stem biomass until the end of October. Maximum dry biomass production was achieved by the end of October (5-15 days after 50% flowering) in excess of 16.52 and 13.34 t ha^{-1} for the early and late plantings, respectively, and maximum dry stem yields of 14.81 and 10.81 t ha^{-1}, for the early and late plantings, respectively. The subsequent drop in total dry matter during November (Fig. 6a & 7a) is due to the defoliation of the plants, whereas stem dry yield remained almost unaffected.

4. Conclusions

It can be concluded that Tainnung 2 and Everglades 41 are two very promising kenaf varieties, high light-use efficient, exhibiting great assimilation rates under constraint free conditions. They are characterized by similar growth indices (such as plant height, basal stem diameter, leaf area index and biomass production) throughout their growing periods and they reach under central Greek conditions great biomass yields, in excess of 16.5 t ha^{-1} for total dry biomass and 14.81t ha^{-1} in dry stem yield. Kenaf growth and productivity was not significantly affected by plant population, so that maximum productivity may be obtained with 200,000 plants ha^{-1}. Contrary to plant population, there is a great effect of sowing time (in all studied characteristics), so that a delayed sowing by 3 weeks or more may drastically reduce crop's productivity due to the shorter period available for growth.

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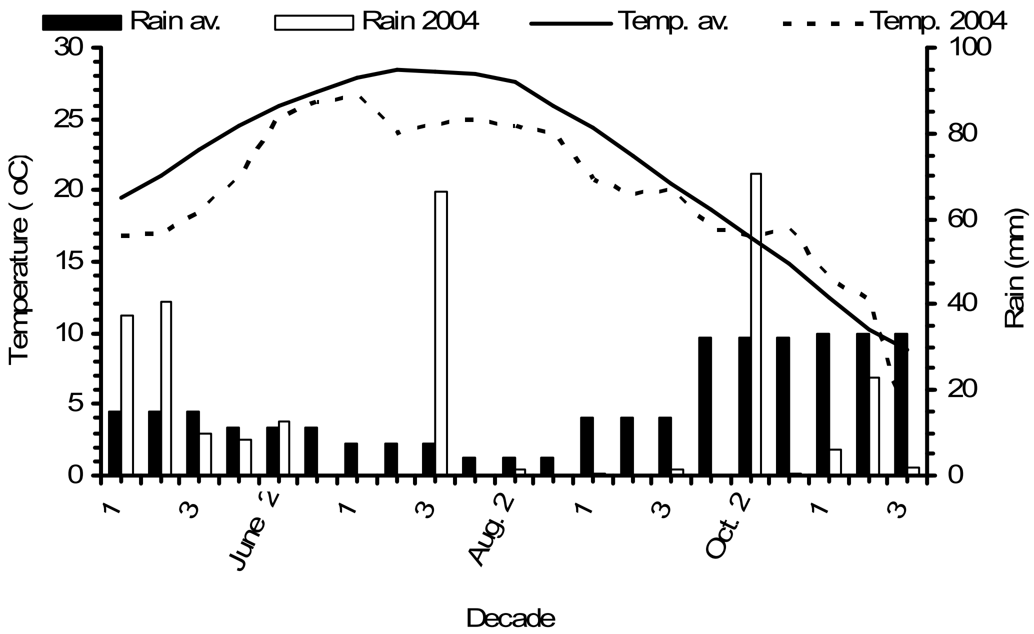

Figure 1: Air temperature and precipitation (10-day mean values) recorded in the study area in 2004 and in an average year (average of 30 years).

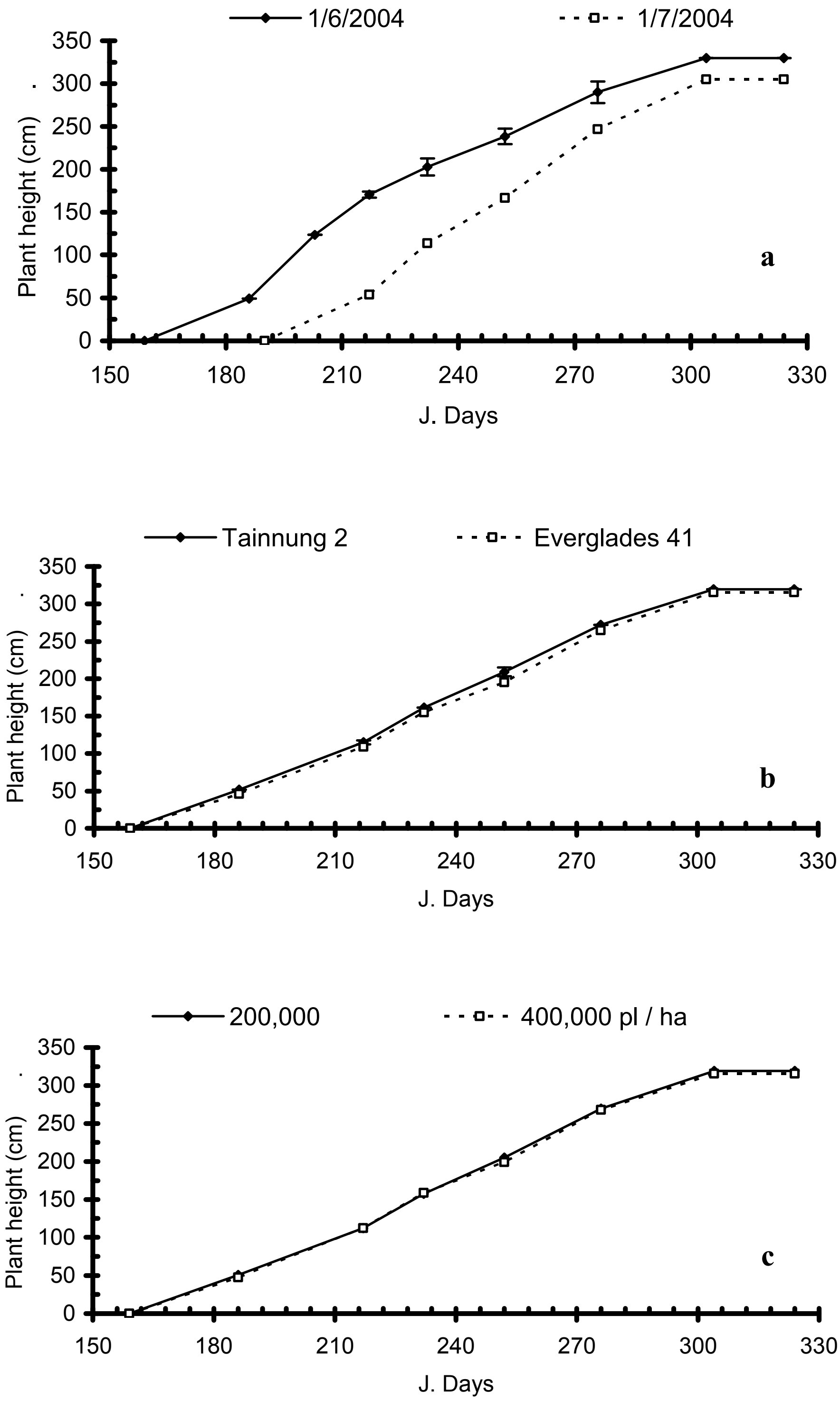

Figure 2: Plant height of Kenaf grown under constraint-free conditions in central Greece in 2004 for the two different a) sowing dates, b) varieties, and c) plant densities. (Vertical lines represent $LSD_{0.05}$ if applicable).

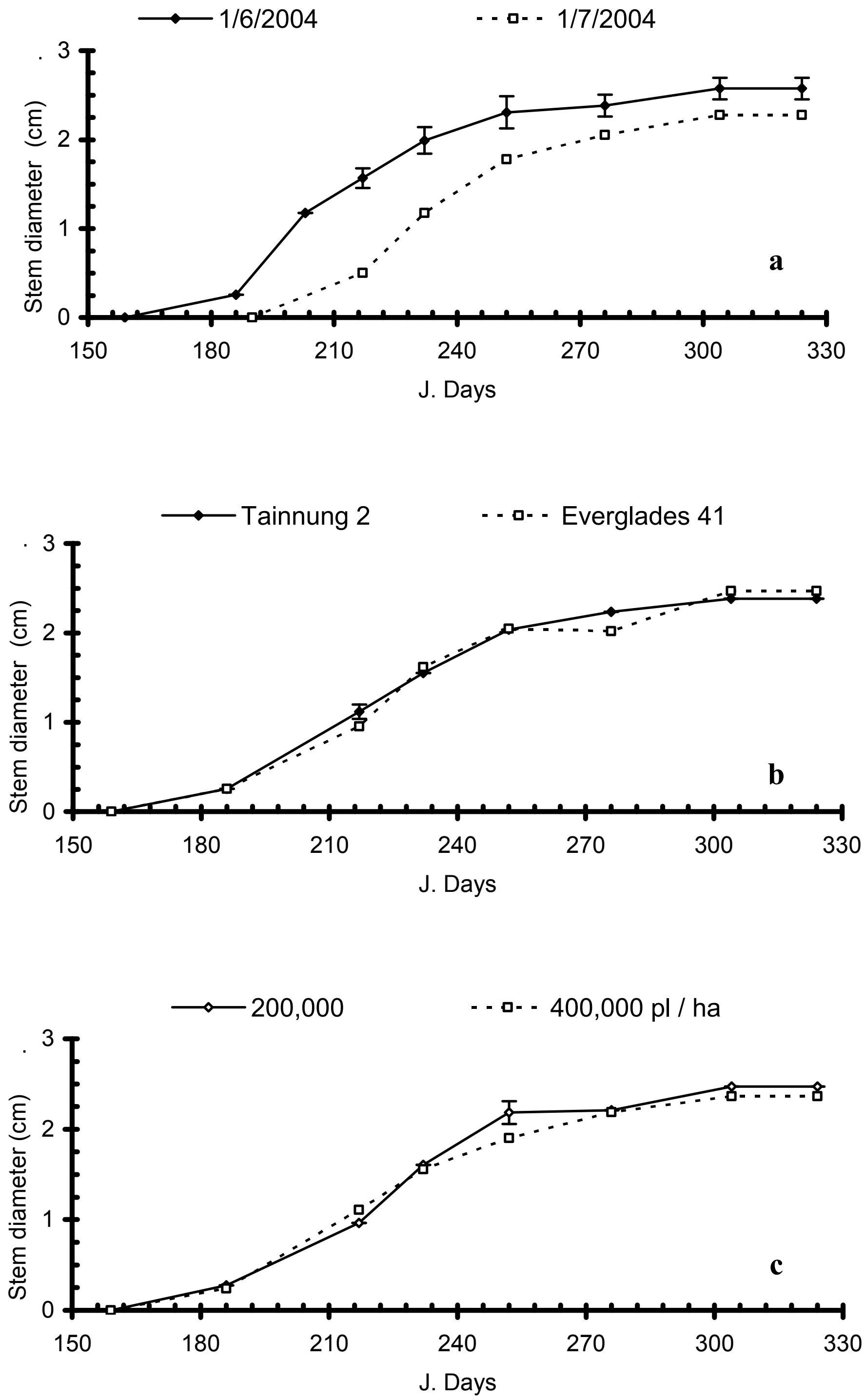

Figure 3: Basal stem diameter of Kenaf grown under constraint-free conditions in central Greece in 2003 for the two different a) sowing dates, b) varieties, and c) plant densities. (Vertical lines represent $LSD_{0.05}$ if applicable).

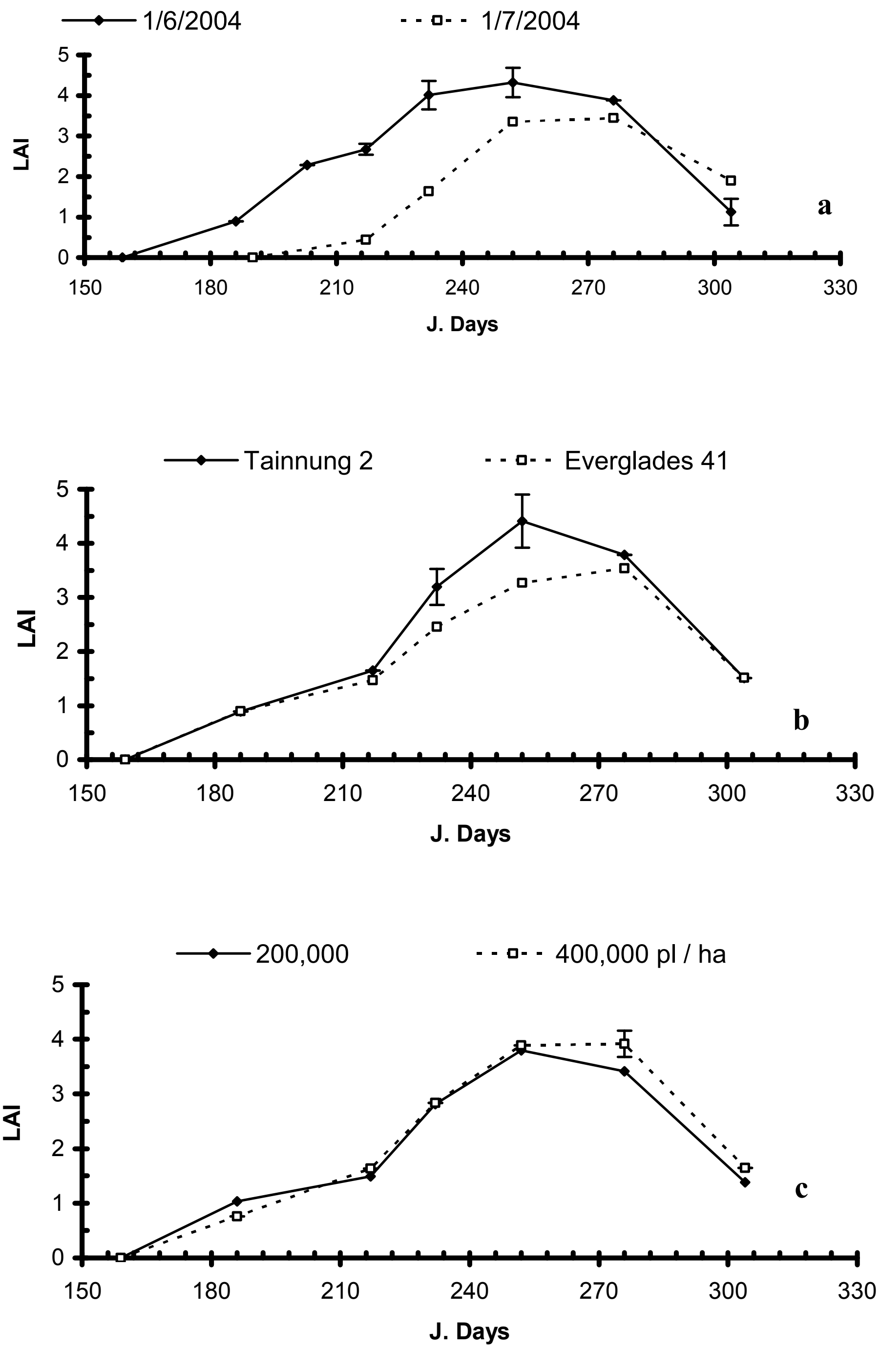

Figure 4: LAI evolution of Kenaf grown under constraint-free conditions in central Greece in 2004 for the two different a) sowing dates, b) varieties, and c) plant densities. (Vertical lines represent $LSD_{0.05}$ if applicable).

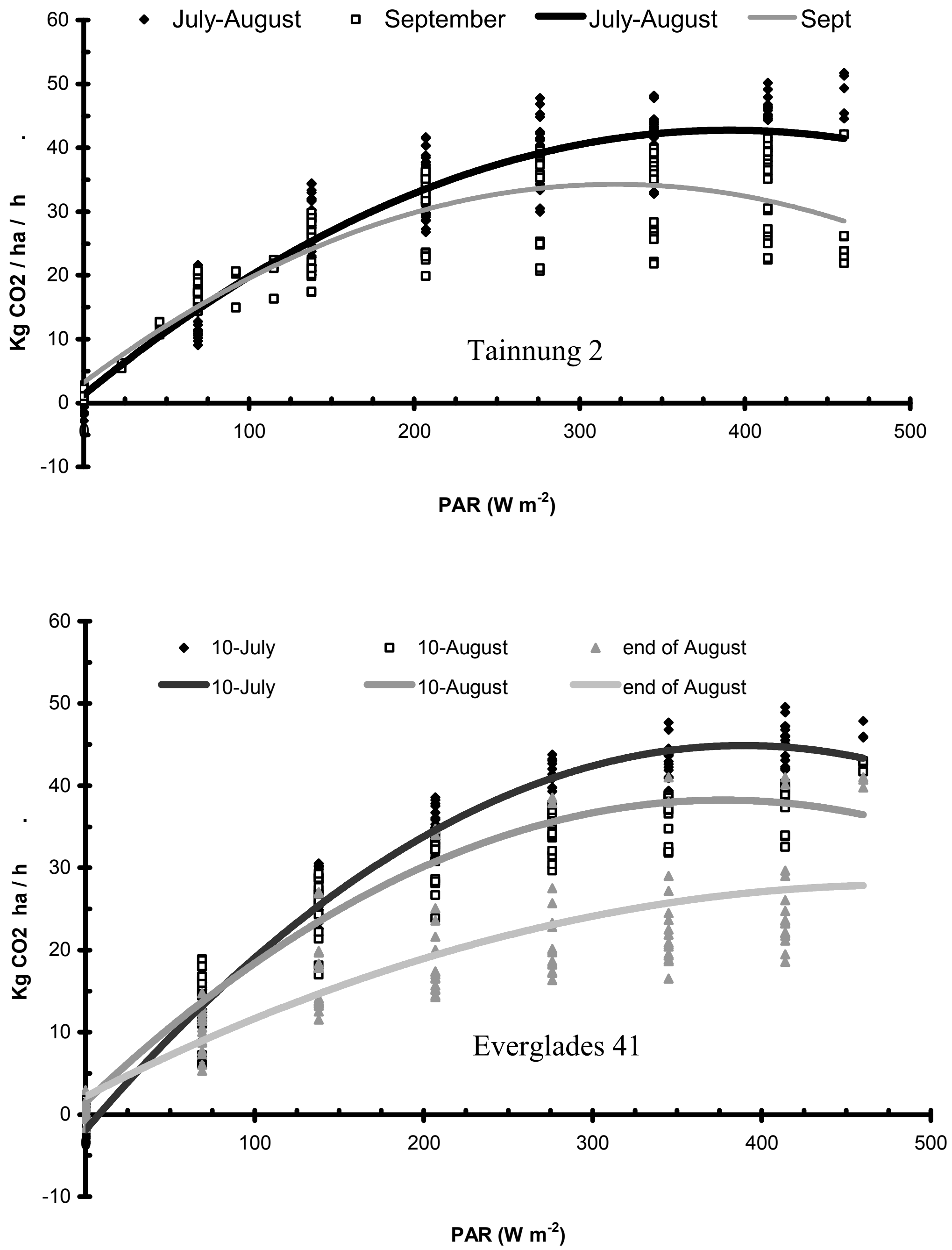

Figure 5: The assimilation-light response curve measured (markers) and plotted (lines) for the two studied kenaf varieties, grown under constrained free conditions in central Greece in 2004 (temperature range 15-28^{o}C).

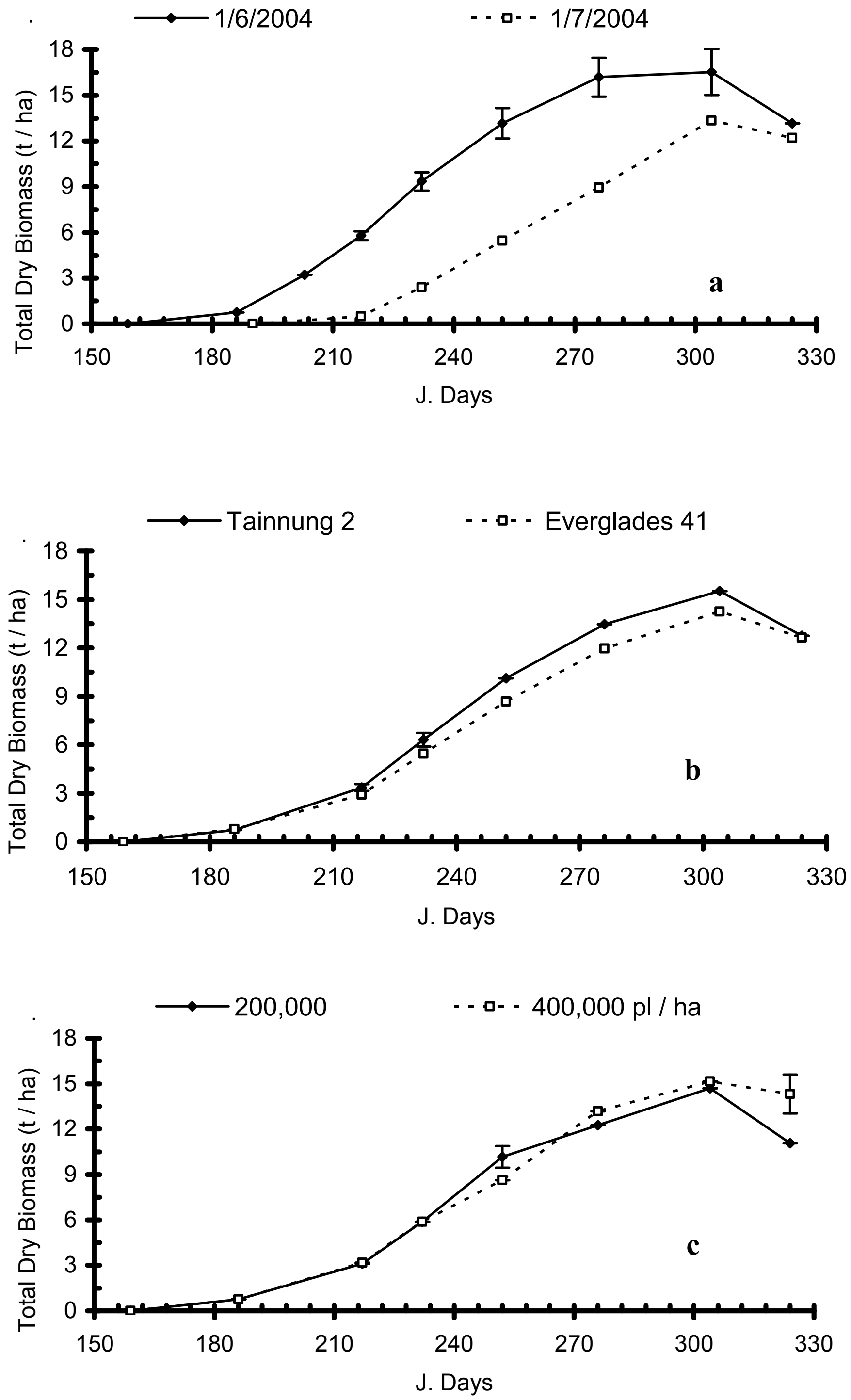

Figure 6: Evolution of total (above-ground) dry biomass of Kenaf grown under constraint-free conditions in central Greece in 2004 for two different a) sowing dates, b) varieties, and c) plant densities. (Vertical lines represent $LSD_{0.05}$ if applicable).

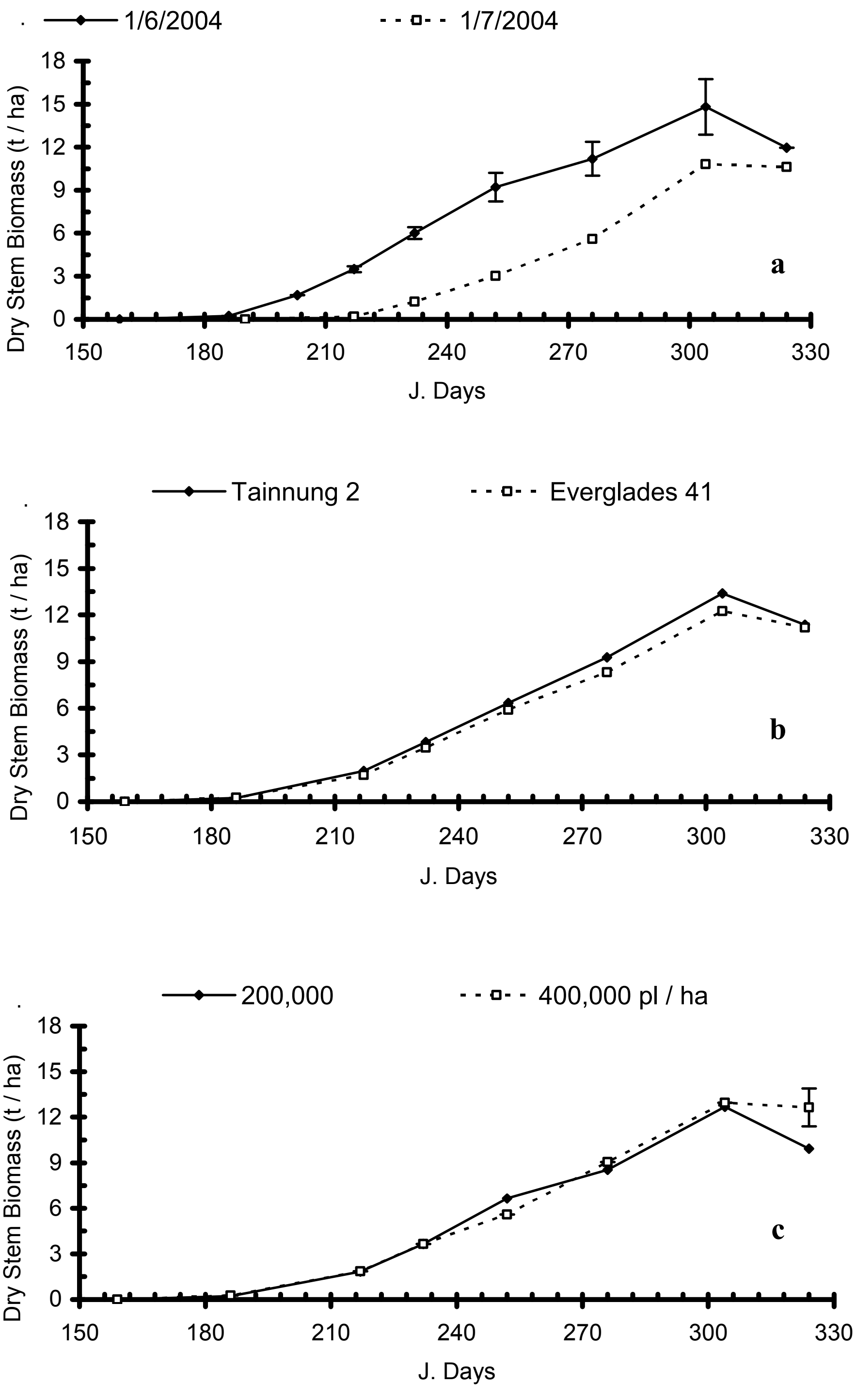

Figure 7: Evolution of dry stem weight of Kenaf grown under constraint-free conditions in central Greece in 2004 for two different a) sowing dates, b) varieties, and c) plant densities. (Vertical lines represent $LSD_{0.05}$ if applicable).