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Cultivation of kenaf in north-east Greece
Part I - Effect of variety, plant density and irrigation on growth and dry yield

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Abstract

Kenaf is a rapidly growing annual crop that is cultivated mainly for its stem with numerous end uses (paper, insulation mats, oil/chemical absorbent, energy production, etc.). The growth and adaptability of several varieties have already been tested in central Greece for the period 1994-1997. This specific work aimed to evaluate the effect of variety (Tainung 2, Mal 1, Everglades 41), plant density (32 and 17 plants/m^2) and irrigation (100 and 60% of PET) on growth and dry yields of kenaf in north-east Greece (Komotini). After three years of experimentation (1997-1999), it was found that the most productive variety of the three was Tainung 2 with mean peak dry stem yields of 21 t/ha, followed by Mal 1 (19 t/ha) and Everglades 41 (16.7 t/ha). At the same time the mean dry stem yield in the plots with high density was 19.4 t/ha, while in the ones with the low density 18.1 t/ha. Almost the same dry stem yields were recorded for the two irrigation rates with yields of 19.5 t/ha (100% of PET) and 18.1 (60 % of PET). At that time the bark content on dry basis was 39% for Tainung 2, 40% for Mal 1 and 41% for Everglades 41 and the moisture content of the stem was 58%. When the harvesting was postponed 50-60 days after reaching the highest dry stem yields, the moisture content of the harvested material was reduced from 58 to 25% but at the same time the dry yields were reduced 27% (from 18.8 to 13.6 t/ha) and the bark content was 35%, averaged overall treatments.

Key words: Non-food crop, kenaf, late maturity varieties, plant density, irrigation, dry stem yields, bark and core production.

Introduction

Kenaf (*Hibiscus cannabinus* L.) is a rapidly growing annual crop of great interest as a source for low cost natural fiber and as feedstock for energy production. As fibrous crop, kenaf appears to have enormous potential to become a valuable biomass crop for the future. The kenaf stem is composed of an internal core comprising 60-75% of the dry weight and outer bast stem totaling 25-40% [1]. Recent research has demonstrated numerous potential uses for each of these two materials, which often must be separated from each other. Products from the kenaf core include oil/chemical absorbents [2], bedding material for animals [3] and insulation paneling [4]. Apart from the industrial applications the core material can be used for thermochemical process (combustion, gasification and pyrolysis). The main product of kenaf bast fibres is paper, while the whole plant has high protein and good digestibility and may be pelletized and used in animal feeding [5].

A large number of research has been carried out worldwide in order to determine the appropriate plant population that results in maximization of the crop yields. In the view of this, plant populations between 99,000 and 932,000 plants/ha have been tested for several kenaf varieties throughout the world. In most of these researches, the increase of the plant density from 150,000 to 350,000 plants/ha resulted in maximization of the dry matter yields [6-11]. The choice of an optimum population [12-14] must be considered not only through the response of the yield components, but also through its influence on the growth form of the plant in terms of the ease of management. It has been reported that final plant populations of 185,000 to 370,000 plants/ha are desirable for maximum yields and for the production of single stalk plants with very little or no branching [15]. At low plant populations the crop produces plants with multiple branches, rather than the more desirable single plants which are easier to mechanical harvest. If kenaf is planted at plant populations of over 370,000 plants/ha the crop compensates through competition to the available environmental resources (light, soil moisture and nutrients) by reducing the total number of plants to a more desirable population [15].

Kenaf varieties, according to their reaction to flowering are divided to early and late maturity varieties. It has been reported that the late maturity varieties are more productive compared to the early ones due to the fact that they have longer vegetative phase [16-18]. The most known late maturity varieties are Everglades 41, Everglades 71 and Tainung 2. In the majority of the recent researches Tainung 2 produced the highest yields [19, 20]. Dry stalk yields for the afore mentioned varieties normally ranged from 11 to 18 t/ha, and it was found that the key factors that have affected the yields were the length of the growing season, the average day and night temperatures and the adequate soil moisture.

A total rainfall of 500-625 mm^2, over a period of 5 to 6 months, is essential for a successful production of kenaf fibre. A well distributed rainfall of about 125 mm for each month during the growing season leads to optimum yields [22]. It has been reported that the dry matter yields were higher when the plants were irrigated well [23-26]. Further to that it has been reported that the dry stem yields were linearly associated to the added irrigation water [25, 26].

The main purpose of this research was to test the adaptability and productivity of kenaf in north-east Greece (Thrace). The specific objectives of this work were to test the effect of plant density (170,000 and 320,000 plants/ha) and irrigation (100% of PET and 60% of PET) on the growth and yield of three late-maturity kenaf varieties (Tainung 2, Mal 1 and Everglades 41) for a period of three years (1997-1999) in Komotini, situated in the mentioned area.

Materials and Methods

For a period of three subsequent years (1997, 1998, 1999), three kenaf trials were carried out in north-east Greece (Komotini). The site co-ordinates were latitude 41°5', longitude 25° 20' and an altitude of 37 m above the sea level. A detailed description of the kenaf trials is presented in Table 1.

It is worth of mentioning that apart from the applied irrigation the plants received (during the irrigated period) a total precipitation that was 106 mm in 1997, 179 mm in 1998 and 131 mm in 1999. A drip irrigation system was used for the irrigation water supply, which was also used for the nitrogen fertilization of the crop (N 60 and 120 kg/ha). The nitrogen fertilization was added to the plants 40 to 50 days from the emergence. In all sites the soil type was silty clay (SCL), about neutral to reaction with organic matter content ranging from 1.9 to 2.8%.

Table 1. Description of the kenaf fields (sowing date, irrigation rate, tested factors and experimental layout) in Komotini.

Sowing date	Irrigation rate	Tested factor	Experimental layout
13/5/97	I_1=380 mm I_2=228 mm	<u>Three varieties</u> Tainung 2, Mal 1 and Everglades 41	$3x2^2$ factorial in a randomized complete block design in three replications (36 plots)
2/6/98	I_1=400 mm I_2=240 mm	<u>Two plant densities</u> D_1=320,000 pl/ha D_2=170,000 pl/ha	
15/5/99	I_1=395 mm I_2=237 mm	<u>Two irrigation rates</u> I_1=fully irrigated I_2=3/5 I_1	

Throughout the growing seasons (1997, 1998, 1999) a series of measurements was carried out including canopy height, basal stem diameter, fresh and dry weight of plant parts (stems and leaves), bark and core percentage of the stems on fresh and dry basis and nitrogen content (%) of stems and leaves as well. For the height and stem diameter measurements a total number of ten marked plants per plot were used, while for the yield estimations an area of one square meter plot was harvested regularly throughout the growing period. For the nitrogen analyses, a Kjeldahl digestion was used (Tecator, Kjeltec 1030 autoanalyzer, Sweden).

The effect of the three tested varieties, the two irrigation rates, the two plant populations and their interaction on all measurements was tested by a standard analysis of variance (ANOVA). LSD multiple range tests were used for partitioning the means (statistical significance at the P=0.05). The STATGRAPHICS statistical software was used for carrying out the data analysis.

Results and Discussion

Growth characteristics: The final plant height and basal stem diameter are presented in Table 2. Significant differences (P<0.05) were recorded among the tested varieties for both plant height and stem diameter, while for the other factors (plant density and irrigation) significant differences were recorded between the two plant populations and only for the stem diameter.

Averaged over all years, the variety Tainung 2 had the tallest plants with a mean plant height of 331 cm, followed by 316 cm for Everglades 41 and 306 cm for Mal 1. At the same time the mean plant height was higher in the plots with lower plant density compared to the plots with higher plant density (324 cm versus 311 cm). In the fully irrigated plots, plants were only 2% taller compared to the plants in the plots with the low irrigation rate (321 cm versus 314 cm).

Concerning the stem diameter, the highest mean value (1997-1999) was recorded for the variety Everglades 41 (20.2 mm), followed by Tainung 2 (20 mm) and Mal 1 (18.3 mm). As it was already mentioned for the plant height, the mean stem diameter was higher for the low plant density (20.9 mm versus 18.1 mm for the high density). Besides that, between the two irrigation rates the thicker stems were recorded in the fully irrigated plots (19.9 mm versus 19.1 mm).

Table 2. Plant height (cm) and basal stem diameter (mm) at the end of each growing season for the tested factors.

	Plant height (cm)			Basal stem diameter (mm)		
Factor	1997	1998	1999	1997	1998	1999
Variety						
Tainung 2	338b*	323a	331b	20.5b	19.7ab	21.8a
Mal 1	308a	306a	303a	18.3a	17.2a	19.4a
Everglades 41	330b	301a	317ab	19.5ab	18.9b	21.2a
Pl. population						
320,000 pl/ha	321a	300a	313a	18.2a	17.1a	19.1a
170,000 pl/ha	329a	321a	321a	20.8b	20.2b	21.6b
Irrigation rate						
100% of PET	329a	313a	322a	19.8a	19.1a	20.7a
60% of PET	321a	307a	312a	19.1a	18.1a	20.0a
Mean	325	310	317	19.5	18.6	20.4

*Values followed by different letters within the column differ significantly (P<0.05, LSD Test).

Fresh and dry matter yields: As it is presented in Fig. 1 at the early stages of growth (40-80 DAE) the growth rate was rather high in all years. In more details, the growth rate was 1.72 t/ha/day (1997, 73 DAE), 1.27 t/ha/day (1998, 71 DAE) and 1.07 t/ha/day (1999, 83 DAE). Thereafter, the plants continued to increase but with lower growth rates. Further to that in 1997 (115 DAE) the growth rate was 0.58 t/ha/day, in 1998 (95 DAE) 0.66 t/ha/day and 0.65 t/ha/day (116 DAE) in 1999.

Each year, the peak fresh and dry matter yields of the crop were recorded from the beginning to the end of October that corresponded to the flowering phase of the crop (Fig. 1). More specifically, the peak mean fresh biomass yields were 87 t/ha in 1997 (115 DAE emergence), 66.1 t/ha in 1998 (122 DAE) and 66 t/ha (116 DAE) in 1999. Correspondingly, the peak mean dry yields were 22.1 t/ha in 1997 (157 DAE), 20.3 t/ha in 1998 (165 DAE) and 20.4 t/ha in 1999 (177 DAE).

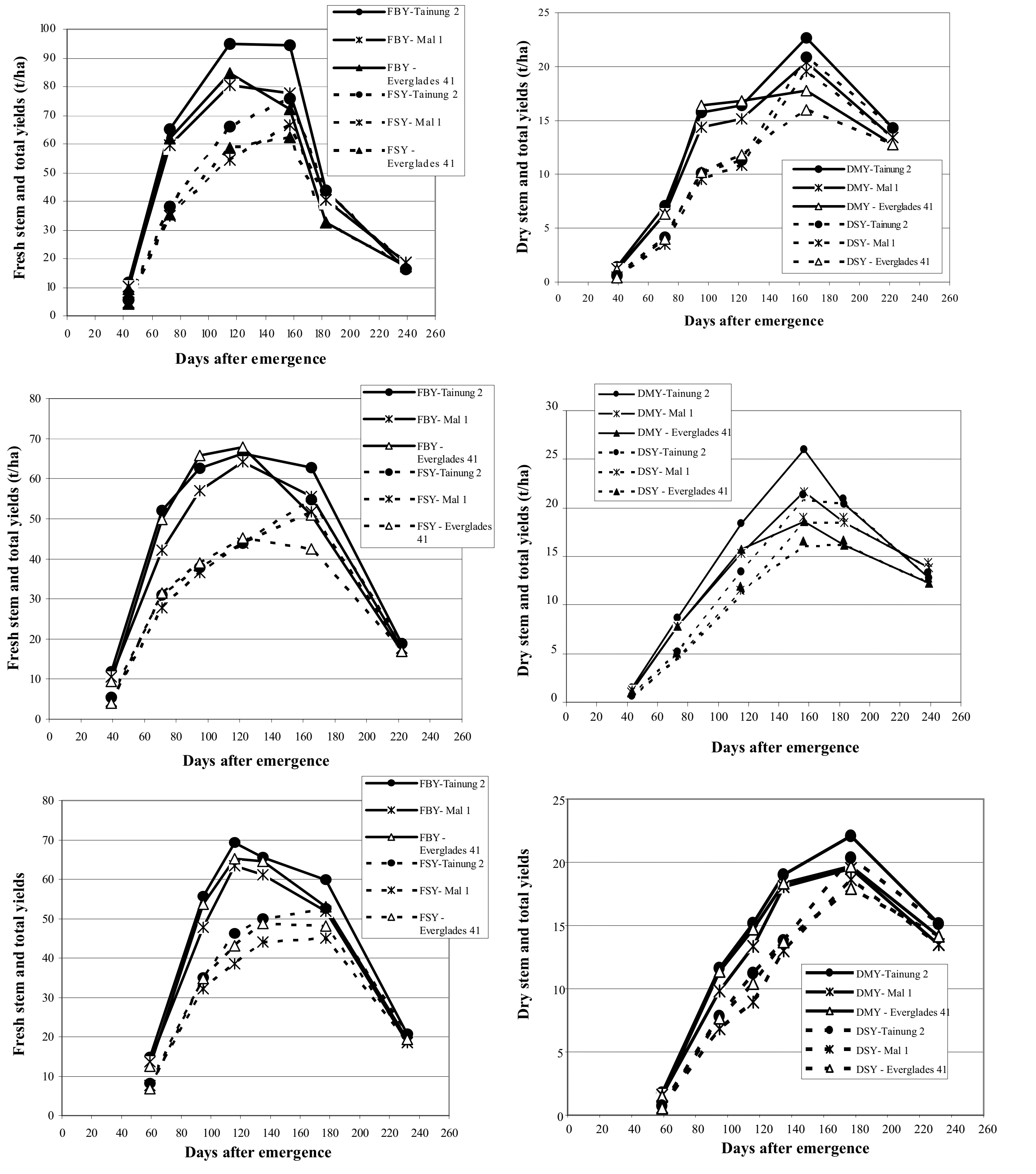

Figure 1. Evolution of fresh and dry matter yields (t/ha) and fresh and dry stem yields for the three tested varieties (Tainung 2, Mal1 and Everglades 41) in all experimental years (1997-1999).

At the early stages of growth, when the crop has a plant height of 80-100 cm, the stem on dry basis represented 40% of the total dry matter yields (Fig. 1). With the progress of the growing cycle this percentage increased and it was found that in the beginning of the flowering phase (middle of September, the crop had a height of 250-280 cm) the stem fraction could reach the 70% of the total dry matter yield, while at the end of the flowering phase (end of October) when the crop had reached its final height (300 to 330 cm) the stem fraction was 76% of the total dry weight.

During all trials the fresh and dry matter yields and yield components that were recorded from the subsequent harvests showed that among the three tested varieties the highest values were recorded by Tainung 2, followed by Everglades 41 and Mal 1 and in many cases significant differences were recorded ($P<0.05$).

Table 3. Maximum fresh and dry stem yields (t/ha) in the middle of November (no leaves on the stems).

Factor	Fresh stem yield (t/ha) 1997	1998	1999	Dry stem yield (t/ha) 1997	1998	1999
Variety						
Tainung 2	75.7b	54.8a	52.6a	20.8b	20.9a	20.4a
Mal 1	66.3a	51.7a	45.1a	18.5ab	19.6a	18.6a
Everglades 41	62.3a	42.5a	48.1a	16.1a	16.0a	17.9a
Pl. population						
320,000 pl/ha	68.4a	50.0a	49.6a	18.5a	19.3a	19.5a
170,000 pl/ha	67.9a	49.3a	47.6a	18.4a	18.4a	18.4
Irrigation rate						
100% of PET	70.5a	49.8a	49.9a	18.5a	19.2a	19.8a
60% of PET	65.7a	49.5a	47.3a	18.4a	18.5a	18.2a
Mean	68.1	49.7	48.6	18.5	18.8	19.0

*Values followed by different letters within the column differ significantly (P<0.05, LSD Test).

Table 4. Fresh and dry stem yields (t/ha) at the end of each growing season (January).

Factor	Fresh stem yield (t/ha) 1997	1998	1999	Dry stem yield (t/ha) 1997	1998	1999
Variety						
Tainung 2	16.4a	18.9a	20.6a	12.8a	14.3a	15.1a
Mal 1	18.5a	17.8a	18.5a	13.8a	13.5a	13.5a
Everglades 41	17.0a	16.9a	19.4a	12.3a	12.8a	14.2a
Pl. population						
320,000 pl/ha	17.5a	18.2a	19.9a	13.3a	13.6a	14.3a
170,000 pl/ha	17.1a	17.6a	19.1a	12.6a	13.5a	14.2a
Irrigation rate						
100% of PET	17.9a	18.0a	19.6a	13.5a	13.6a	14.4a
60% of PET	16.7a	17.8a	19.4a	12.4a	13.4a	14.1a
Mean	17.3	17.9	19.5	13.0	13.5	14.3

*Values followed by different letters within the column differ significantly (P<0.05, LSD Test).

At the same time, the plots with the high plant density (32 plants/m^2) gave higher yields which in some cases differed significantly to the yields that were recorded for the low density plots (17 plants/m^2). On the other hand, the superiority of the high irrigation rate over the low one was so small that only in very few cases showed significant differences (Tables 3 and 4).

In the middle of November in all years after a killing frost the stems were defoliated. The fresh and dry stem yields at two times, in the second part of November and beginning of January, are presented in details in Tables 3 and 4 . In November the moisture content of the stems was 58%, averaged overall years and treatments. When the harvesting was postponed 50-60 days after reaching the highest dry stem yields, the moisture content of the harvested material was reduced from 58 to 25%, but at the same time the dry yields were reduced 27% (from 18.8 to 13.6 t/ha), averaged overall treatments.

Stem components (bark and core): During the flowering phase the bark percentage, averaged overall treatments, was quite high up to 40%. Thereafter, it started to decline and at the time of the dry stem weight maximization (middle of November), the bark represented 38% of the total dry stem weight. At that time the highest bark percentage was recorded among varieties for Mal 1 (39%), while a small superiority of the high over the low plant density and of the high over the low irrigation was recorded.

When the final harvest was postponed until the middle of January, the mean bark percentage was further reduced to 35% but the effect of treatments was almost the same with a superiority of Mal 1 among varieties, of high plant density over the low one and of high irrigation over the low one in terms of bark percentage (Fig. 2). The decline of bark percentage on the frost-killed kenaf plants is mainly referring to losses of the non-fiber components of the bark (primary epiderm and cortex associated with the outer bark) while the fiber losses are not significant.

In Table 5 the bark and core yields and the bark:core ratio in the middle of January for all years are presented. The mean dry bark yields were 4.7 t/ha in 1997 and 1998 and 5 t/ha in 1999, while the corresponding values for the core were 8.2, 8.8 and 9.3 t/ha. It is also clear that significant differences were recorded only among the tested varieties in terms of bark yields in 1998 and 1999.

Nitrogen content in plant parts: In leaves and stems the nitrogen content decreased as the kenaf biomass increased in height and maturity. It should be pointed out that the nitrogen content of the leaves in most measurements was 5 times higher compared to the values of stem. It should also be emphasized that between the two stem fractions (bark and core) higher nitrogen content was always recorded for the bark. The superiority of bark over core in terms of nitrogen content was quite small up to 100 days from emergence (6%) and thereafter this difference gradually increased to 27% in the middle of November and at the final harvest (January) came up to 43% (Figs 3 and 4).

In more details, at the early stages of growth (70-80 DAE) the nitrogen content of the leaves ranged from 4.95 (Everglades 41, 1999) to 5.15% (Mal 1, 1998). The corresponding values for the bark varied from 1.2 (Mal 1, 1999) to 1.34% (Everglades 41, 1998), while for the core values ranged from 1.16 (Tainung 2, 1999) to 1.34% (Everglades 41, 1998). At the flowering phase (50%) the nitrogen content of the leaves varied from 3 to 3.7%, of the bark from 0.84 to 1.09% and of the core from 0.65 to 0.87%. After the stem defoliation the nitrogen content was further declined and at the final harvest the mean nitrogen content of the bark was 0.78% and of that of the core 0.44% (Figs 3 and 4).

Table 5. Dry bark and core yields (t/ha) and bark:core ratio at the end of the growing season.

Factor	Dry bark yields (t/ha) 1997	1998	1999	Dry core yields (t/ha) 1997	1998	1999	Bark:core (on dry yields) 1997	1998	1999
Variety									
Tainung 2	4.3a	5.1b	5.4b	8.5a	9.3a	9.8a	0.51a	0.54a	0.55a
Mal 1	5.3a	4.8ab	4.7a	8.5a	8.7a	8.8a	0.63a	0.55a	0.53a
Everglades 41	4.4a	4.4a	5.0ab	7.9a	8.4a	9.5a	0.56a	0.54a	0.55a
Pl.population									
320,000 pl/ha	4.6a	4.6a	5.2a	8.1a	8.9a	9.2a	0.56a	0.52a	0.56a
170,000 pl/ha	4.6a	4.9a	4.9a	8.7a	8.7a	9.3a	0.54a	0.57a	0.52a
Irrigation rate									
100% of PET	4.8a	4.8a	5.1a	8.7a	8.9a	9.4a	0.56a	0.55a	0.54a
60% of PET	4.5a	4.7a	4.9a	7.8a	8.7a	9.1a	0.58a	0.51a	0.54a
Mean	4.7	4.7	5.0	8.2	8.8	9.3	0.57	0.54	0.54

*Values followed by different letters within the column differ significantly (P<0.05, LSD Test).

Conclusions

After three years of experimentation in Komotini it was found that regarding the tested late-maturity kenaf varieties dry stem yields up to 21 t/ha can be achieved (at the end of autumn) and are quite high compared to the stem yields reported in the international literature. Among the tested varieties, the most productive proved to be Tainung 2 that gave 9% higher yields

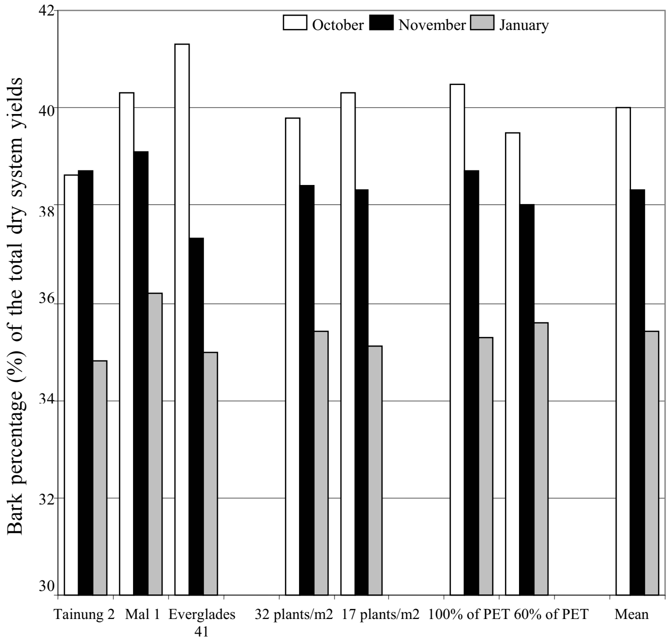

Figure 2. Mean bark percentage for all the tested factors (variety, density, irrigation) at three times through growing period (October, November, January).

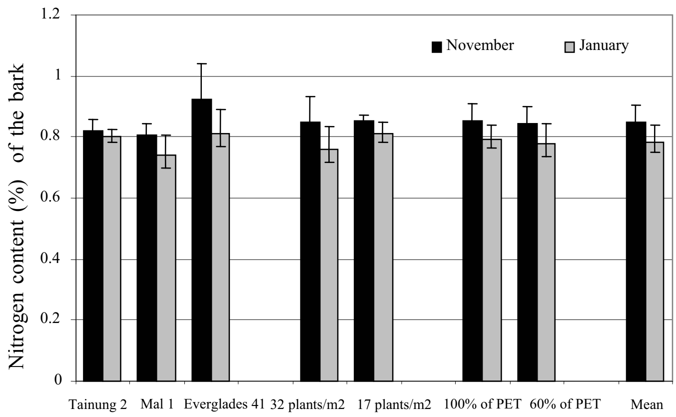

Figure 3. Mean nitrogen content (%) of the bark for all the tested factors (variety, density, irrigation) in November and January.

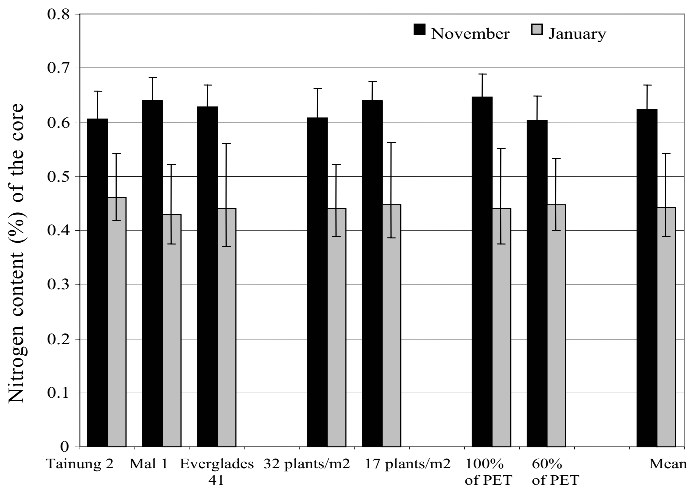

Figure 4. Mean nitrogen content (%) of the core for all the tested factors (variety, density, irrigation) in November and January.

compared to Mal 1 and 19% higher compared to Everglades 41.

The plant density did not play an important role on the kenaf yields. It was only found that a small superiority in terms of dry yields of the high over the low plant density was recorded and at the time of the dry stem maximization came up to 7%. The plots with the high plant density were sensitive to lodging. Thus, for the site of the trial a plant density from 170,000 to 300,000 plants/ha can be suggested that secure single stems (no branches) with high dry stem yields.

Regarding irrigation, it was found that between the two applied irrigation rates no significant effects on growth and yield were recorded except for a small superiority of the high over the low irrigation in terms on growth and dry yields. It can be concluded that the total quantity of water that the plants received from the low irrigation (220-240 mm) in combination with the rainfalls (106-179 mm) resulted to total water supply from 334 to 419 mm that could be adequate to secure a good development of the crop which leads to high stem yields. Further investigation is needed in order to test the crop at lower irrigation rates in order to have a clear picture of the irrigation effect on growth and yields.

When the final harvest was postponed 50-60 days after the maximization of the dry stems yield, the recorded yield had a reduction of 27%. At the same time the moisture content of the harvested material was sharply reduced from 58 to 25%. The bark content declined from 38 to 35% and the nitrogen content of bark and core was reduced (0.78 and 0.44%, respectively). For the specific climatic conditions of the trial site and when the quality of the harvested fiber is not a crucial factor, the harvesting should take place in December when the frost-killed crops had managed to loss moisture content but the dry stem losses are still small.

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