CHARACTERIZATION OF KENAF POTENTIAL IN PORTUGAL AS AN INDUSTRIAL AND ENERGY FEEDSTOCK

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Abstract The purpose of this work was to investigate the influence of crop management on the kenaf biomass quality and productivity, in Portugal, in order to access its potential as an industrial and energy feedstock. To do so, the effects of different varieties, sowing dates, plant populations, different irrigation rates and nitrogen fertilization levels were studied in the biomass quality and productivity. Productivity was affected by the level of irrigation but not by the level of nitrogen fertilization. Higher productivities were obtained in the fields where 301 and 400 mm of water were added. Biomass quality was not affected either by the level of irrigation of the fields either by the level of N-fertilization. Productivity and biomass quality were affected by the sowing date but not by the density of plant population. Plants sowed earlier presented better productivities and better quality for fuel and pulp purposes than plants sowed latter. Tainung 2 and Everglades 41 presented similar productivities and mineral composition. Everglades 41 showed better quality for fuel purposes and Tainung 2 better quality for pulp purposes. Possibilities of industrial utilization under different field conditions were assessed and discussed, in the perspective of sustainable growth and development.

Keywords kenaf, crop management, biomass composition

INTRODUCTION

Kenaf (*Hibiscus cannabinus* L.) is a short day, annual, herbaceous plant processing high quality cellulose. It is a member of the Malvaceae family along with cotton and okra, and is endemic to Africa[1]. The entire plant can be used to produce pulp for the paper industry. Lower quality paper can be made from the short wood fibres of the inner core, while high quality paper can be produced from the long fibres of the bark[2]. Kenaf, as a high yielding plant, can be considered also as a potential energy crop when used as a whole. The residues from its different industrial processes can, as well, be utilized as energy sources[1].

In the scope of the project Biomass Production Chain and Growth Simulation Model for Kenaf (Biokenaf), supported by the European Union, the purpose of this work was to investigate the influence of crop management on the kenaf biomass quality and productivity, in Portugal. As this crop is being introduced in Portugal, as a "new crop", possibilities of industrial utilization under different field conditions are assessed and discussed, in the perspective of sustainable growth and development.

MATERIALS AND METHODS

The experimental fields are situated in the Peninsula of Setúbal, in the south border of the river Tejo, near the estuary and the Atlantic coast (latitude 38º40' N, longitude 9º W, altitude of 50 m). During the experimental period, July 2003 – January 2004, the average minimum temperature was 15.6ºC and the average maximum temperature was 23.0ºC, with a total of 443 mm rainfall.

The experimental plots were established in a clayey and alkaline soil. For the nitrogen and irrigation levels study, only one kenaf variety was studied: Tainung 2. The fields were sowed at 4th July, using a row spacing of 0.50 m and a distance within row of 0.10 m (20 seeds per m^2). P-fertilizer (60 kg $P_2O_5.ha^{-1}$), K-fertilizer (120 kg $K_2O.ha^{-1}$) and ½ N-fertilizer were applied at the time of sowing. The other ½ N-fertilizer was applied when the plants reached approximately 20 cm height (about 1 month after sowing). Three different levels of N-fertilizer were applied: 0, 75 and 150 kg $N.ha^{-1}$. At early stages of growth, all the fields were fully irrigated, in order to compensate the water deficit of the soil and to prevent water stress. 41 days after sowing, irrigation was differentiated, and four diferent levels were applied: 0%, 25%, 50% and 100% PET (Potential Evapotranspiration). During the growing season a total of 204, 253, 301 and 400 mm of water, were added to the fields. A factorial 3 (three levels of N-fertilizer) x 4 (four irrigation levels) split-plot design in 3 blocks was used. Standard basic plots had a surface area of 5 x 9 m^2.

For the sowing dates and plant population study, two kenaf varieties were studied, Tainung 2 and Everglades 41. The fields were sowed at 26th June and at 11th July. A row spacing of 0.50 m was used, with two different distances within row: 0.10 m (20 seeds per m^2) and 0.05 m (40 seeds per m^2). P-fertilizer (60 kg $P_2O_5.ha^{-1}$), K-fertilizer (120 kg $K_2O.ha^{-1}$) and ½ N-fertilizer (37.5 kg $N.ha^{-1}$) were applied at the time of sowing. The other ½ N-fertilizer was applied when the plants reached approximately 20 cm height (about one month after sowing). All the fields were fully irrigated in order to compensate the water deficit of the soil and to prevent water stress. A randomized block design with three replications, was used. Standard basic plots had a surface area of 5 x 8 m^2.

At the end of the growing season the vegetable material was harvested and the total aerial dry weight, the nitrogen content, the phosphorus content, the fiber content and the gross heat of combustion were determined, in order to evaluate the productivity and the quality of the biomass. The chemical analysis were performed according to the following procedures: a) nitrogen content: by the Kjeldahl method; b) phosphorus content: by the ascorbic acid method, after digestion of the sample; c) fiber: by the Weende method; d) gross heat of combustion: using an adiabatic calorimeter.

RESULTS AND DISCUSSION

Biomass Productivity

Figure 1 show the differences, in terms of the dry matter productivities, among fields with different nitrogen application and among fields with different levels of irrigation.

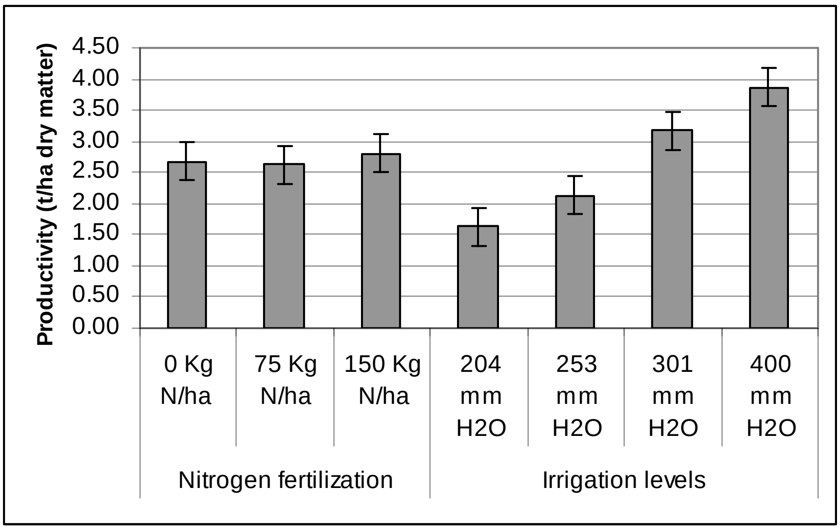

Figure 1. Productivities obtained in fields with different nitrogen application levels and in fields with different irrigation levels

According to these results there were only significant differences among productivities obtained in fields with different levels of irrigation. Higher productivities were obtained for the 50% and 100% PET fields, respectively with 301 and 400 mm of water added. There were no significant differences among productivities obtained in fields with different levels of nitrogen, probably because of the soil availability in nitrogen.

Water use efficiency was obtained as the slope of a linear regression between the irrigation levels and the aerial dry matter obtained at harvest (Figure 2).

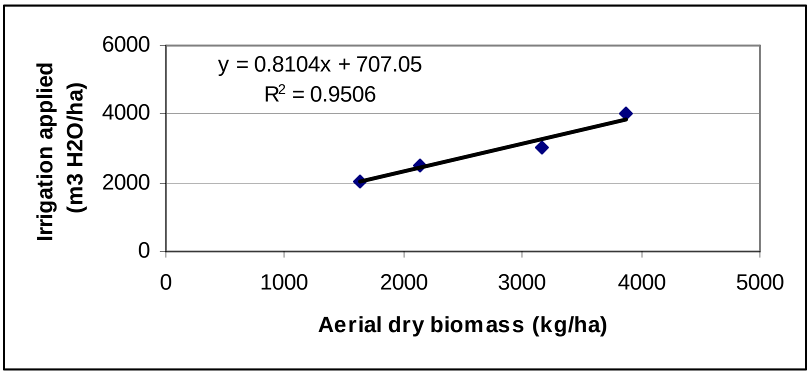

Figure 2. Water use efficiency of Kenaf plants obtained in Caparica in 2003.

According to Figure 2, the water use efficiency was 810 l per kg of dry biomass. Compared with literature values for sorghum[1] (180-190 l/kg dry biomass), kenaf presents lower water use efficiency. But, in 2003, productivities obtained were significantly lower than those obtained by other Mediterranean partners of the Biokenaf project[3]. These lower productivities were probably due to the difficulties experienced during the first year of the project, namely, due to the late sowing date and especially to the heat wave experienced during the 2003 Summer[4] (Table 1). With better productivities, this value can decrease significantly.

Table 1. Average daily temperature, average maximum daily temperature, maximum absolute temperature, average relative humidity (at 9.00h) and minimum absolute relative humidity (at 9.00h), for the months of July, August and September of 2003

	July	August	September
Average daily temperature	21.8ºC	24.8ºC	22.8ºC
Average maximum daily temperature	27.5ºC	29.8ºC	28.1ºC
Maximum absolute temperature	39.4ºC	38.2ºC	37.2ºC
Average relative humidity at 9.00h	77.8%	76.0%	78.4%
Minimum absolute relative humidity at 9.00h	60.4%	56.5%	50.5%

Nitrogen fertilizer use efficiency was obtained as the slope of a linear regression between the aerial dry matter obtained at harvest and the nitrogen fertilization applied (Figure 3).

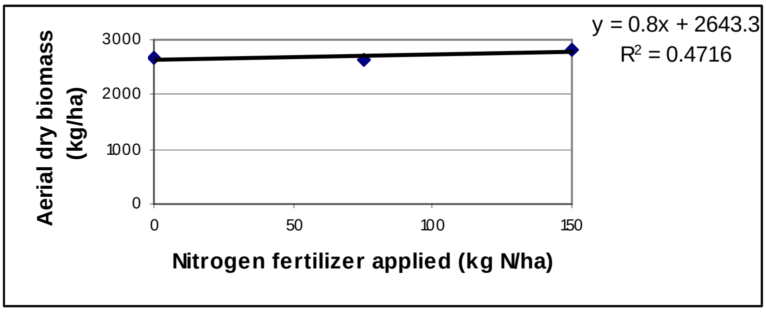

Figure 3. Nitrogen fertilizer use efficiency of Kenaf plants obtained in Caparica in 2003.

According to Figure 3, the nitrogen fertilizer use efficiency was very low, only 0.8 kg dry biomass per kg N-fertilizer. Figure 3 also shows what was previously observed in Figure 1: that there were no significant differences among productivities obtained in fields with different levels of nitrogen fertilizer. This can be explained by high soil nitrogen reserves. In fact, soil nitrogen content before ploughing and sowing was 0.25%[4]. With a soil bulk density of 1.3 kg/dm^3 [4] and assuming that only the nitrogen at the first 20 cm layer of soil would be used by the plants, then soil nitrogen reserves were as high as 6500 kg/ha.

Figure 4 show the differences, in terms of the dry matter productivities between fields sowed at two different dates, between fields with different varieties and between fields sowed with different plant densities.

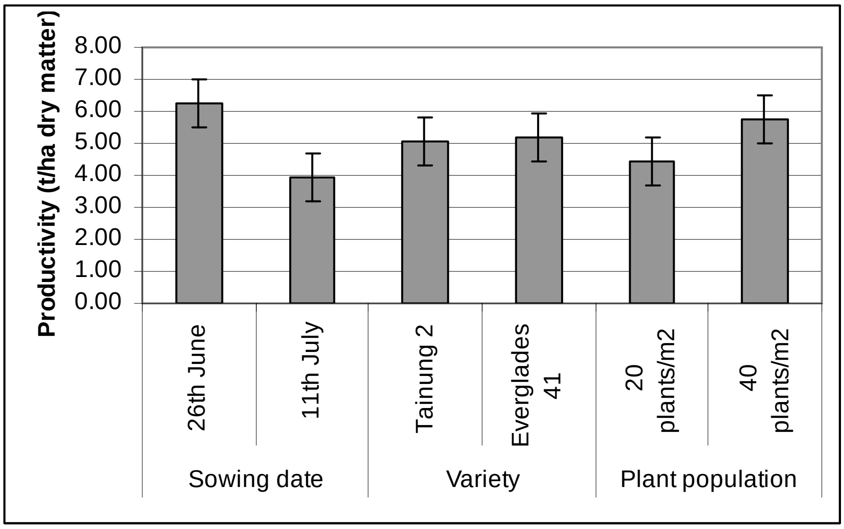

Figure 4. Productivities obtained in fields sowed in two different dates, in fields with different varieties and in fields sowed with different plant densities

According to these results, there were observed only statistical significant differences between fields sowed at two different dates. Plants sowed earlier (26^{th} June) presented significantly higher productivities, than plants sowed 15 days later (11^{th} July). Everglades 41 presented higher productivities than Tainung 2, although this difference was not significant. This result was expected, since both varieties belong to the same group of late maturity varieties. Productivities obtained in the fields sowed with the higher plant density (40 plants/m^2) were higher than those obtained in the fields sowed with the lower density (20 plants/m^2). However, this difference was not significant, chiefly because Kenaf reduces the number of its population during the growing season, being this effect more pronounced in the fields sowed with a higher density[5].

These productivities were, as for the fields with different nitrogen application levels and with different irrigation levels, significantly lower than those obtained by other Mediterranean partners of the Biokenaf project[3] and probably due to the same reasons.

Biomass Quality

In order to answer to the processing needs, by the time of harvest, either for the energy sector or for the pulp production sector, the crop material should present low mineral and water contents. Kenaf biomass is usually harvested after leaf fall, allowing the return of nutrients from the fallen leaves, namely, nitrogen, phosphorus and other minerals, back to the soil. Table 2 show the results obtained concerning the moisture content, the nitrogen and the phosphorus contents, of the kenaf biomass obtained in the experimental fields.

Table 2. Moisture content, nitrogen content and phosphorus content of core and bark of Kenaf biomass obtained in the experimental fields

	Core	Bark
Moisture (%)	53 ± 18	36 ± 20
Nitrogen (% dry matter)	0.4 ± 0.3	0.9 ± 0.3
Phosphorus (% dry matter)	0.13 ± 0.06	0.25 ± 0.08

In all the fields, the only variable that showed some influence on the biomass quality was the sowing date. Effectively, in terms of nitrogen content, plants sowed first, presented significant lower nitrogen content than plants sowed fifteen days later. Nevertheless no influence was observed as for the moisture content as for the phosphorus content. No statistical significant differences were observed between the two varieties (Tainung 2 and Everglades 41), between plants obtained in fields sowed with two different plant densities, among the plants obtained in fields with different levels of nitrogen and in fields with different levels of irrigation. Bark presented less moisture than core material and, although not significantly, higher nitrogen and phosphorus content than core material.

Table 3 shows for all the fields, the biomass nitrogen and phosphorus uptake.

Table 3. Kenaf biomass nitrogen and phosphorus uptake obtained in the experimental fields

Treatments		N uptake (kg N/ha)	P uptake (kg P_2O_5/ha)
Irrigation levels	204 mm H_2O	8	6
	253 mm H_2O	10	7
	301 mm H_2O	12	11
	400 mm H_2O	20	18
Nitrogen fertilization	0 kg N/ha	12	12
	75 kg N/ha	11	12
	150 kg N/ha	15	8
Sowing date	26th June	29	25
	11th July	43	16
Variety	Tainung 2	36	21
	Everglades 41	36	19
Sowing density	20 plants/m^2	29	22
	40 plants/m^2	43	18

According to these results, in all the fields, N and P uptake by Kenaf biomass always showed lower figures than what was applied in the fields. This indicates that Kenaf has low nitrogen and phosphorus requirements, not depleting the soil.

Potential Energy Production

The potential energy produced during combustion of the harvested biomass was evaluated as the productivity (t/ha) x gross heat of combustion (GJ/t) (Tables 2 and 3).

Table 2. Potential energy production (GJ/ha) of core and bark of Kenaf biomass obtained in fields with different nitrogen application levels and in fields with different irrigation levels

Irrigation Level	Nitrogen Fertilization	Core	Bark	Total
204 mm H_2O	0 kg N/ha	14	7	21
	75 kg N/ha	18	9	27
	150 kg N/ha	21	9	30
253 mm H_2O	0 kg N/ha	28	12	40
	75 kg N/ha	21	12	33
	150 kg N/ha	23	8	31
301 mm H_2O	0 kg N/ha	42	16	58
	75 kg N/ha	39	17	56
	150 kg N/ha	25	13	38
400 mm H_2O	0 kg N/ha	37	16	53
	75 kg N/ha	35	17	52
	150 kg N/ha	53	26	79

In terms of gross heat of combustion, there were no statistical significant differences among the plants obtained in fields with different levels of nitrogen and with different levels of irrigation. Then, in terms of the potential energy production, differences among the fields were observed, namely among the different levels of irrigation, mainly due to the differences in the productivities. Highest values were obtained in the most irrigated fields, with 301 mm and 400 mm H_2O. No statistical significant differences were observed among levels of nitrogen fertilization.

Table 3. Potential energy production (GJ/ha) of core and bark of Kenaf biomass obtained in fields sowed in two different dates, in fields with different varieties and in fields sowed with different plant densities

Sowing date	Variety	Plant population	Core	Bark	Total
26th June	Tainung 2	20 seeds/m^2	60	26	86
		40 seeds/m^2	88	26	114
	Everglades 41	20 seeds/m^2	80	20	101
		40 seeds/m^2	80	34	114
11th July	Tainung 2	20 seeds/m^2	32	14	46
		40 seeds/m^2	50	22	72
	Everglades 41	20 seeds/m^2	34	19	54
		40 seeds/m^2	46	24	69

The potential energy production was considerably higher in the fields sowed first than in the fields sowed fifteen days later, mainly due to the highest productivities obtained in those fields but also due to the highest gross heat of combustion of the plants harvested from those earlier fields. Although not statistically significant, higher potential energy production was also observed in the fields sowed with a higher plant population. This resulted from the higher productivities obtained in those fields because, in terms of the gross heat of combustion, no significant differences were observed between plants obtained in fields sowed with two different plant densities. The bark of Everglades 41 presented a higher gross heat of combustion than the bark of Tainung 2. No differences were obtained between the inner core of both varieties. But, in terms of potential energy production no significant differences were observed.

In all the experimental fields, the bark presented lower quality and quantity for energy purposes than core, due to its lower gross heat of combustion and to its lower productivity.

Potential Pulp Production

The potential pulp produced after the harvest of the biomass was evaluated as the productivity (t/ha) x fiber content (% dry matter)/100

(Tables 4 and 5).

Table 4. Potential pulp production (t/ha) of core and bark of Kenaf biomass obtained in fields with different nitrogen application levels and in fields with different irrigation levels

Irrigation Level	Nitrogen Fertilization	Core	Bark	Total
204 mm H_2O	0 kg N/ha	0.36	0.22	0.58
	75 kg N/ha	0.42	0.28	0.70
	150 kg N/ha	0.53	0.30	0.83
253 mm H_2O	0 kg N/ha	0.68	0.36	1.04
	75 kg N/ha	0.58	0.38	0.96
	150 kg N/ha	0.56	0.18	0.74
301 mm H_2O	0 kg N/ha	1.15	0.51	1.66
	75 kg N/ha	1.04	0.56	1.60
	150 kg N/ha	0.63	0.45	1.08
400 mm H_2O	0 kg N/ha	0.90	0.43	1.33
	75 kg N/ha	0.88	0.41	1.29
	150 kg N/ha	1.37	0.85	2.22

In terms of fiber content, there were no statistical significant differences among the plants obtained in fields with different levels of nitrogen and with different levels of irrigation. Then, in terms of the potential pulp production, differences among the fields were observed, namely among the different levels of irrigation, only due to the differences in the productivities. Highest values were obtained in the most irrigated fields, with 301 mm and 400 mm H_2O. No statistical significant differences were observed among levels of nitrogen fertilization.

Table 5. Potential pulp production (t/ha) of core and bark of Kenaf biomass obtained in fields sowed in two different dates, in fields with different varieties and in fields sowed with different plant densities

Sowing date	Variety	Plant population	Core	Bark	Total
26th June	Tainung 2	20 seeds/m^2	1.09	0.75	1.84
		40 seeds/m^2	2.04	0.79	2.83
	Everglades 41	20 seeds/m^2	1.83	0.47	2.30
		40 seeds/m^2	1.49	0.73	2.22
11th July	Tainung 2	20 seeds/m^2	0.86	0.42	1.28
		40 seeds/m^2	1.46	0.70	2.16
	Everglades 41	20 seeds/m^2	0.80	0.45	1.25
		40 seeds/m^2	1.21	0.56	1.77

The potential pulp production was considerably higher in the fields sowed first than in the fields sowed fifteen days later, mainly due to the highest productivities obtained in those fields because in terms of the fiber content, there were no significant differences between plants obtained in fields sowed at two different dates. Although not statistically significant, higher potential pulp production was also obtained in the fields sowed with a higher plant population. This resulted from the higher productivities obtained in those fields because, in terms of the fiber content, no significant differences were observed between plants obtained in fields sowed with two different plant densities. The bark of Tainung 2 presented a higher fiber content than the bark of Everglades 41. No differences were obtained between the inner core of both varieties. But, in terms of potential pulp production no significant differences were observed.

In all the experimental fields, the bark presented lower quantity for pulp purposes than core, due to its lower productivity, but a better quality for pulp purposes due to a lower content in lignin.

CONCLUSIONS

Productivity was affected by the level of irrigation of the fields but not by the level of N-fertilization. Better productivities were obtained with the highest irrigation levels, namely 301 mm and 400 mm H_20. Biomass quality was not apparently affected either by the level of irrigation either by the level of N-fertilization.

Productivity and biomass quality were affected by the sowing date but not by the plant population. Plants sowed earlier (26th June) presented better productivities and better quality for fuel and pulp purposes than plants sowed latter (11th July). Tainung 2 and Everglades 41 presented similar productivities and in terms of mineral composition there were no differences between the two varieties. The inner core material of the two varieties, presented also, the same quality for energy and pulp purposes. However, the bark of Everglades 41 presented a higher calorific value than the bark of Tainung 2 and the bark of Tainung 2 a higher fiber value than the bark of Everglades 41.

In the perspective of a sustainable growth and development, for the production of Kenaf in the Portuguese climatic conditions, fields should be irrigated with an amount equivalent to 50 % PET. Irrigation with 100% PET, although giving better productivities, can contribute to a depletion of the water resources. Because of the ability of kenaf to mobilise soil nitrogen, nitrogen fertilization does not need to exceed 75 kg/ha and should be adjusted taking in attention soil contribution possibilities.

Still in the perspective of a sustainable growth and development, it is not justificable to choose the highest plant population density (40 plants/m^2). In fact, no significant differences were observed in terms of the productivities, the potential energy production and the potential pulp production, in relation to the fields with the lower plant density (20 plants/m^2). Overall, higher plant density fields are more costly, economically and environmentally, due to the high market price of the seeds and due to the higher content of fossil fuel necessary for its production.

Considering the potential energy production and the potential pulp production, any of the varieties studied can be used, since no significant differences were observed in terms of this production parameters.

Considering the results obtained, fields should be sowed, at latest, at 26th June. A later sowing can compromise the productivities and, therefore, the net economical and environmental gain of this crop. Sowing at middle of May can be considered as a good hypothesis to be studied and applied.

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