CHARACTERIZATION OF KENAF POTENTIAL IN PORTUGAL AS AN INDUSTRIAL AND ENERGY FEEDSTOCK – THE EFFECT OF CROP MANAGEMENT, 2ND YEAR EXPERIMENTS

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ABSTRACT: The purpose of this work was to study the influence of the crop management on the kenaf biomass quality and productivity, in Portugal, namely, the effect of different irrigation and nitrogen fertilization levels, the effect of different varieties, sowing dates, sowing densities and harvest dates. To evaluate the productivity of the crop, the plants were harvested along the growing season and the total aerial dry weight were determined. The quality of the biomass was analysed along the vegetative cycle using the following parameters: organic matter, nitrogen and phosphorus contents. At the end of the growing season, the fiber content, the heat of combustion and the fat content were also determined in order to evaluate the potentiality of this biomass for pulp, fuel and other industrial purposes. Productivity was significantly affected by the sowing date and by the harvest date. Plants sowed earlier presented better productivities than plants sowed later. Highest productivities, in all the fields, were obtained in November. After this date, the productivities maintained or lowered mainly due to the loss of the leaves. The different levels of irrigation and levels of nitrogen fertilization didn't affect the productivities. Nevertheless, higher productivities were obtained in the fields where higher N-fertilizer was applied (150 $kg.ha^{-1}$, N), although without statistical significance. Fields with higher sowing density (40 seeds per m^2) presented also significantly higher productivities than fields with lower sowing density (20 seeds per m^2). Everglades 41 was more productive than Tainung 2, although this difference was not significant. The biomass quality was not affected by the sowing date, the sowing density, the level of nitrogen fertilization or the level of irrigation but the harvest dates affected significantly the quality. November and December harvests provided a biomass with better quality for fuel and pulp purposes than early harvests. No significant differences were observed, between the two varieties, in terms of the biomass quality. Core material of both varieties showed better quality for fuel purposes and bark material of both varieties showed better quality for fibre and pulp purposes. Bark presented higher fat content than core material.
Keywords: kenaf, crop cultivation, biomass composition

1 INTRODUCTION

Kenaf (*Hibiscus cannabinus* L.) is a short day, annual, herbaceous plant producing 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 fibers of the inner core, while high quality paper can be made from the long fibers of the bark [2]. Kenaf, as a high yielding plant, is also a potential energy crop when used as a whole crop. The residues from different industrial processes can be utilized as well 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, in order to access its potential as an industrial and energy feedstock. To do so, the effects of different varieties, sowing dates, sowing densities, harvest dates and different irrigation and nitrogen fertilization levels in the biomass quality and productivity, were studied.

2 MATERIALS AND METHODS

The Portuguese experimental fields are situated in the Peninsula of Setúbal, in the south border of the river Tejo, near the estuary and Atlantic coast (latitude 38º40' N, longitude 9º W, altitude of 50 m), where the climate is warm temperate. During the experimental period, 12th July 2004 – 13th December 2004, the average minimum temperature was 15.1ºC and the average maximum temperature was 23.8ºC, with a total of 198 mm rainfall (2004 autumn was very dry in Portugal).

The experimental plots were established in a dominantly clay and alkaline soil. To study the irrigation and nitrogen fertilization levels effect a factorial scheme 3 (three levels of N-fertilizer) x 4 (four irrigation levels) based in a split-plot design in 3 blocks was used. Standard basic plots had a surface area of 5 x 8 m^2. One kenaf variety was studied, Tainung 2. The fields were sowed at 19th July using a row spacing of 0.50 m and a distance between rows 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. 40 days after sowing, irrigation was differentiated, and four different levels were applied: 0%, 25%, 50% and 100% PET. During the growing season a total of 251, 300, 350 and 448 mm of water were added to the fields. To study the effect of different varieties, sowing dates and sowing densities, a randomized block design with three replications was used. Standard basic plots had a surface area of 4 x 8 m^2. Two kenaf varieties were studied, Tainung 2 and Everglades 41. The fields were sowed at 12th July and at 2nd August. A row spacing of 0.50 m was used and two different distances within row were studied: 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 1 month after sowing). All the fields were fully irrigated in order to compensate the water deficit of the soil, and to prevent water stress.

During the growing season the vegetable material was harvested and the total aerial dry weight, the organic matter, the nitrogen, the phosphorus, the fiber and the fat contents as well as the gross heat of combustion were determined in order to evaluate the productivity and the quality of the biomass. The chemical analyses were performed according to the following analytical procedures: a) organic matter: by calcination at 550ºC for two hours, in a muffler furnace; b) nitrogen content: by the Kjeldahl method; c) phosphorus content: by the ascorbic acid method, after digestion of the sample; d) fiber: by the van Soest method; e) fat: Soxhlet extraction with n-hexane; f) gross heat of combustion: using an adiabatic calorimeter.

3 RESULTS AND DISCUSSION

3.1 Biomass Productivity

Fig. 1-5 show the differences, in terms of the dry matter productivities between fields sowed at two different dates, between fields with different varieties, between fields sowed with different densities, among fields with different nitrogen application and among fields with different levels of irrigation.

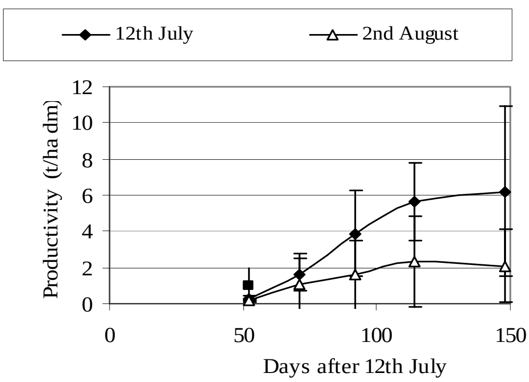

Figure 1: Productivities obtained in fields sowed at two different dates

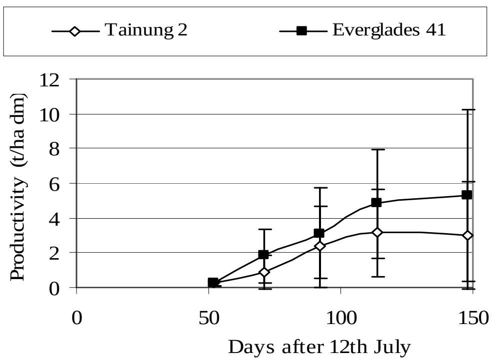

Figure 2: Productivities obtained in fields with different varieties

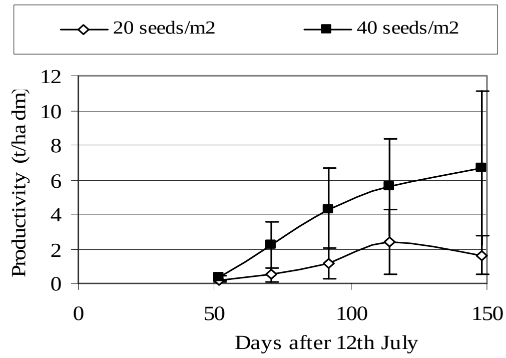

Figure 3: Productivities obtained in fields with different sowing densities

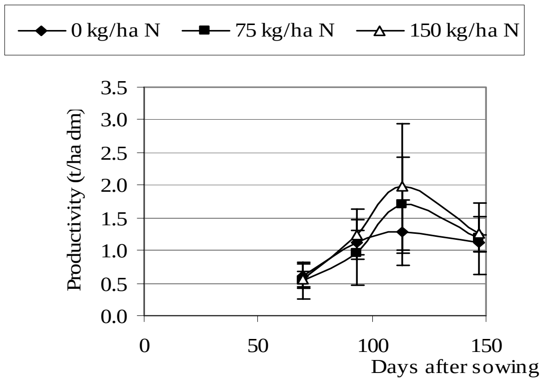

Figure 4: Productivities obtained in fields with different nitrogen application levels

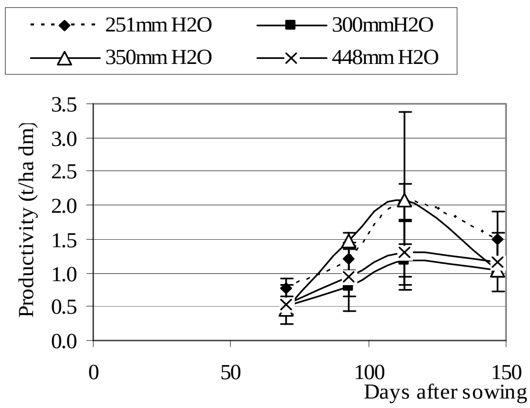

Figure 5: Productivities obtained in fields with different irrigation levels

According to these results there were statistical significant differences between fields sowed at two different dates. Plants sowed earlier (12th July) presented significantly higher productivities than plants sowed later (2nd August). Everglades 41 presented higher productivities than Tainung 2, although this difference was not significant. This result was already expected since both varieties belong to the same group of the late maturity varieties. This group is considered to be more productive than the group of the early maturity varieties, due to the fact that they have a longer vegetative phase [3]. Productivities obtained in the fields sowed with the higher seed density (40 seeds/m^2) were significantly higher than those obtained in the fields sowed with the lower seed density (20 seeds/m^2). This result was expected in the beginning of the vegetative cycle but not in the end of this cycle since kenaf reduces its population during the growing season, being this effect more pronounced in the fields sowed with a higher seed density [4]. But as kenaf was sowed very late (middle July, beginning of August), the growing season was shortened and the reduction of the population was not observed. Higher productivities were obtained in the fields where higher N-fertilizer was applied (150 kg.ha^{-1}, N), but no statistical significance was observed to the other fields with different levels of nitrogen. This non-effect was due probably to the soil richness in nitrogen, even after one year of kenaf culture. There were also no significant differences among productivities obtained in fields with different levels of irrigation. This resulted from the fact that fields were fully irrigated at early stages of growth (when evapotranspiration was higher - August). When irrigation was differentiated evapotranspiration had already diminished and so no observable effects were obtained, in terms of productivity.

The crop grew until 115 days after sowing (beginning of November). After this date, productivities maintained or lowered (mainly due to the loss of the leaves).

At the end of the growing season, the bast fiber represented 30% of the dry weight of the mature defoliated plant and the core represented 70%. The productivities obtained were significantly lower than those obtained by other Mediterranean partners of the Biokenaf project [5]. These lower productivities were mainly due to the late sowing date [6].

3.2 Biomass Quality

Tables I, II and III show the moisture, the nitrogen and the phosphorus contents of the material obtained along the vegetative cycle.

Table I: Moisture content (%) of kenaf, in leaves, core and bark, along the growing season.

Days after sowing	Leaves	Core	Bark
52	88	91	87
71	77	82	77
93	79	74	77
114	81	69	77
148	80	70	75

Table II: Nitrogen content (% dry matter) of kenaf, in leaves, core and bark, along the growing season.

Days after sowing	Leaves	Core	Bark
52	4.33	1.54	1.10
71	1.86	0.40	0.60
93	2.16	0.34	0.68
114	2.30	0.29	0.67
148	2.27	0.35	0.68

Table III: Phosphorus content (% dry matter) of Kenaf, in leaves, core and bark, along the growing season.

Days after sowing	Leaves	Core	Bark
52	0.55	0.27	0.32
71	0.28	0.31	0.28
93	0.41	0.44	0.38
114	0.92	0.84	0.96
148	0.86	0.45	0.58

In terms of moisture, nitrogen and phosphorus contents, there were no statistical significant differences among the plants obtained in fields with different levels of nitrogen, with different levels of irrigation, with different sowing dates and with different sowing densities. No significant difference was observed, also, between Everglades 41 and Tainung 2. Moisture content decreased along the growing season. At the end of the growing season, core presented less moisture than bark material. Leaves were the fraction of the plant that presented the highest humidity. Nitrogen content also decreased along the growing season, due to the dilution effect of the growing crop. Phosphorus content increased along the growing season. Nitrogen content was significantly higher in leaves than in stems. Although not significantly, bark material presented higher nitrogen content than core material. In terms of phosphorus content no significant differences were observed among leaves, core and bark.

The fuel quality of the harvested biomass was evaluated in terms of the organic matter content, analysed along the growing season, and in terms of the gross heat of combustion, analysed at the end of the growing season (Tables IV and V).

Table IV: Organic matter content (% dry matter) of kenaf, in leaves, core and bark, along the growing season.

Days after sowing	Leaves	Core	Bark
52	84	83	87
71	91	90	89
93	91	94	90
114	90	96	90
148	89	95	90

Table V: Gross heat of combustion (kJ.g^{-1} dry matter) of kenaf, in core and bark, at the end of the growing season.

Core	Bark
17.1 ± 0.5	13.7 ± 0.5

In relation to the organic matter content (Table IV), the biomass presented better quality for energy purposes at the end of the growing season when the ash content was lower. According to Tables IV and V, the bark presents an inferior quality for energy purposes than core, due to its lower organic matter content and its lower gross heat of combustion, at the end of the growing season. In terms of organic matter content and in terms of the gross heat of combustion, there were no statistical significant differences among the plants obtained in the different fields.

In order to evaluate the quality of kenaf biomass for fiber and pulp production, hemicelluloses, cellulose and lignin content were determined at the end of the growing season (Table VI). The fat content of the biomass was also determined (Table VI).

Table VI: Fiber content fractionation and fat content (% dry matter) of kenaf, in core and bark, at the end of the growing season.

% dm	Core	Bark
Hemicelluloses	32	23
Cellulose	3	9
Lignin	45	35
Total fiber	81	66
Fat	0.58	0.97

There were no significant differences among plants obtained in the different fields in terms of the fiber and fat content. Bark material presented lower fiber content than the inner core material. But bark material presenting longer fibers contains more cellulose and less lignin than core material. Consequently core may be more difficult to pulp than bark. The potential for mass production of oil as a byproduct of kenaf appears to be poor. The relatively very low fat content of the stems suggests that oil production is not an option for industrial purposes.

3.3 Harvest Date

The selection of the harvest date is very important because, according to the results presented in Figures 1-5 and in Tables I to IV, has strong effects on the biomass productivity and biomass quality. Kenaf biomass is usually harvested after leaf fall, because, unlike traditional agricultural crops, kenaf is grown only for its vegetation stalk. The standing of the kenaf plants in the fields until the defoliation of the stems, also allows the return of nutrients from the fallen leaves (namely, nitrogen, phosphorus and other minerals), back to the soil. According to Figures 1-5, the crop should be harvested November onwards, when productivity is higher and when stems are defoliated.

In order to cover the processing needs, either for the combustion or pulp production, at the moment of harvest, crop should have low mineral and water contents. In terms of the biomass quality, the composition of the biomass changed over the course of the growth period as nitrogen and water content decreased and organic matter increased. The lowest values for the moisture and nitrogen contents were registered November onwards, as well as the highest values for the organic matter content. So, the crop should be harvested November onwards when the biomass presented better quality for fuel and pulp purposes and also when productivity is higher and stems are defoliated.

4 CONCLUSIONS

The results achieved permits us to propose the following considerations:

- Productivity was affected by the sowing date and by the sowing density but not by the level of irrigation or by the level of N-fertilization. Plants sowed earlier (12th July) and with a higher sowing density (40 seeds/m^2) presented higher productivities than plants sowed later (2nd August) and with a lower density (20 seeds/m^2).
- The non observable effect of the irrigation differentiation and the observable effect of the sowing density might be a consequence of the delay on sowing. The lower productivities obtained in all the fields by comparison with other Mediterranean partners might also be due to this delay. Fields were sowed only at the middle of July and beginning of August because a previous sowing (made in May and June) was devastated by rabbits.

The non observable effect of the nitrogen fertilization differentiation might be due to the soil nitrogen richness.

- Biomass quality was not affected either by the level of irrigation, by the level of N-fertilization, by the sowing dates or by the sowing densities.
- Tainung 2 and Everglades 41 presented similar productivities and biomass quality, although Everglades was slightly more productive than Tainung 2.
- Harvest dates affected the productivity and the biomass quality of the crop. Harvest of the biomass material should be performed November onwards when productivities are higher, when stems are beginning to defoliate and when biomass presents the lower moisture and nitrogen contents and higher organic matter content.
- The use of kenaf for fuel or pulp production as well as for other fiber materials production should be considered. In fact, the results obtained in terms of the gross heat of combustion or in terms of the fiber content are considered to be high. Nevertheless it is necessary a more integrated approach between agricultural practices and the industry sector.
- The power and pulp industries, as well as other biomass dependent industries, require quality specifications which, in some cases, are not fully met yet.

5 ACKNOWLEDGEMENTS

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