CHARACTERIZATION OF KENAF POTENTIAL IN PORTUGAL AS AN INDUSTRIAL AND ENERGY FEEDSTOCK – THE EFFECT OF IRRIGATION, NITROGEN FERTILIZATION AND DIFFERENT HARVEST DATES

A. Fernando[1]; P. Duarte[1]; J. Morais[1]; A. Catroga[1]; G. Serras[1]; S. Pizza[2]; V. Godovikova[3]; J. S. Oliveira[1]
[1]Grupo de Disciplinas de Ecologia da Hidrosfera / Unidade de Biotecnologia Ambiental, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Quinta da Torre, 2829-516 Caparica, Portugal; Tel. and fax: 351.21.2948543; e-mail: jfso@fct.unl.pt or ala@fct.unl.pt; [2]Dip. Di Produzione Vegetale, Univ. della Basilicata, Potenza, Italy; [3]Institute of Cytology and Genetics, Russian Academy of Sciences, Novosibirsk, Russia

ABSTRACT: The purpose of this work was the study of the influence, on the kenaf biomass quality and productivity, of different irrigation and nitrogen fertilization levels and the date of harvest, in Portugal. 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 by the following parameters: organic matter content, nitrogen content and phosphorus content. At the end of the growing season, the fiber content and the heat of combustion were also determined in order to evaluate the potentiality of this biomass for pulp and fuel purposes. Productivity was affected by the level of irrigation but not by the level of nitrogen fertilization. Higher productivities were obtained in the fields with 301 and 400 mm of water added. Biomass quality was not affected either by the level of irrigation of the fields or by the level of N-fertilization. Productivity and Biomass quality were affected by the date of harvest. The early January harvest provided a biomass with better quality for industrial purposes but the early November harvest provided better yields.
Keywords: kenaf, crop cultivation, biomass composition

1 INTRODUCTION

Kenaf (*Hibiscus cannabinus* L.) is a short day, annual, herbaceous plant producing a 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, 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, in order to access its potential as an industrial and energy feedstock. To do so, the effects of different irrigation and nitrogen fertilization levels and the date of harvest in the biomass quality and productivity, were studied.

2 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 Atlantic coast (latitude 38º40’ N, longitude 9º W, altitude of 50 m), where the climate is warm temperate. During the experimental period, 4th July 2003 – 8th 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 dominantly clay and alkaline soil. 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 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. 41 days after sowing, irrigation was differentiated, and four diferent levels were applied: 0%, 25%, 50% and 100% PET. During the growing season a total of 204, 253, 301 and 400 mm of water were added to the fields. 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 9 m^2.

During the growing season the vegetable material was harvested and the total aerial dry weight, the organic matter content, 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 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; fiber: by the Weende method; gross heat of combustion: using an adiabatic calorimeter.

3 RESULTS AND DISCUSSION

3.1 Biomass Productivity

Fig. 1 and Fig. 2 show the differences, in terms of the dry matter productivities among fields with different nitrogen application, and among fields with different levels of irrigation.

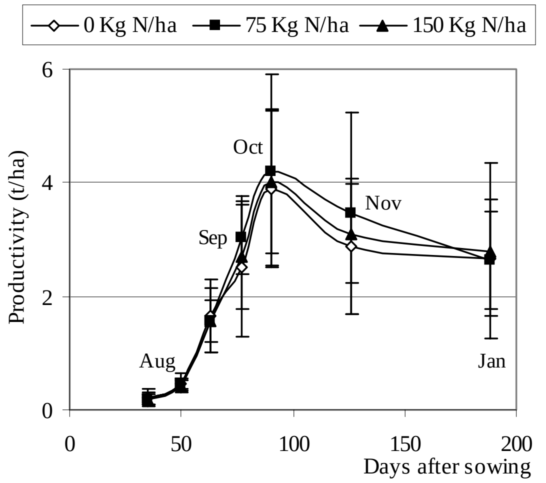

Figure 1: Productivities obtained in fields with different nitrogen application levels

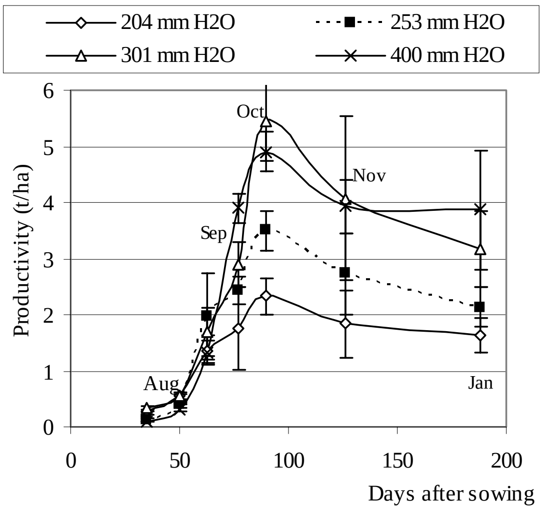

Figure 2: Productivities obtained in fields with different irrigation levels

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 the soil was already rich in nitrogen.

The highest productivities, in all the fields, were obtained 90 days after sowing (2nd October 2003). After this date, the productivities lowered mainly due to the loss of the leaves. Although not significant, the degradation of the non-fiber components of bark also contributed to the biomass productivity reduction. At the end of the growing season, the bast fiber represents 38-40% of the dry weight of the mature defoliated plant and the core represents the balance. The productivities obtained were significantly lower than those obtained by other mediterranean partners of the Biokenaf project [3]. These lower productivities were mainly due to the difficulties experienced during the first year of the project, namely, the late sowing date and the heat wave that occurred during the 2003 Summer [4].

3.2 Biomass Quality

Tables I, II and III show the moisture content, the nitrogen content and the phosphorus content 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
35	79 ± 2	89 ± 2	89 ± 2
50	81 ± 2	89 ± 3	85 ± 2
63	85 ± 1	88 ± 3	84 ± 1
77	82 ± 1	83 ± 7	80 ± 2
90	83 ± 1	82 ± 3	79 ± 2
126	-	69 ± 15	62 ± 21
188	-	57 ± 18	38 ± 22

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

Days after sowing	Leaves	Core	Bark
35	3.2 ± 0.6	1.9 ± 0.7	1.9 ± 0.7
50	3.3 ± 1.4	1.0 ± 0.5	1.0 ± 0.3
63	3.0 ± 0.7	0.8 ± 0.4	0.7 ± 0.2
77	2.8 ± 0.4	0.5 ± 0.2	0.5 ± 0.1
90	2.7 ± 0.3	0.4 ± 0.2	0.7 ± 0.2
126	-	0.6 ± 0.3	0.8 ± 0.4
188	-	0.3 ± 0.1	0.7 ± 0.1

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

Days after sowing	Leaves	Core	Bark
35	0.33 ± 0.02	0.24 ± 0.08	0.24 ± 0.08
50	0.36 ± 0.04	0.21 ± 0.06	0.20 ± 0.02
63	0.29 ± 0.04	0.18 ± 0.06	0.33 ± 0.05
77	0.32 ± 0.04	0.14 ± 0.04	0.14 ± 0.03
90	0.36 ± 0.07	0.18 ± 0.03	0.17 ± 0.03
126	-	0.18 ± 0.05	0.27 ± 0.06
188	-	0.12 ± 0.05	0.25 ± 0.09

In terms of moisture, nitrogen and phosphorus contents, there were no statistical significative differences among the plants obtained in fields with different levels of nitrogen and with different levels of irrigation. Moisture content decreased along the growing season, being lower at 188 days after sowing. At this date, bark presented less moisture than core material. Nitrogen and phosphorus contents also decreased along the growing season. Nitrogen and phosphorus contents were significantly higher in leaves than in stems. Although not significantly, bark material presented higher nitrogen and phosphorus contents than core material.

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
35	88 ± 2	82 ± 1	82 ± 1
50	89 ± 1	85 ± 1	88 ± 1
63	90 ± 1	87 ± 2	89 ± 1
77	89 ± 2	91 ± 1	90 ± 1
90	90 ± 2	92 ± 1	90 ± 1
126	-	90 ± 1	89 ± 2
188	-	95 ± 2	89 ± 2

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

Days after sowing	Core	Bark
126	17.5 ± 0.4	12.9 ± 0.4
188	17.6 ± 0.7	13.2 ± 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 significative differences among the plants obtained in the different fields.

In order to evaluate the quality of kenaf biomass for pulp production fiber content was determined at the end of the growing season (Table VI).

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

Days after sowing	Core	Bark
90	37 ± 4	39 ± 2
126	46 ± 3	38 ± 5
188	45 ± 2	41 ± 4

In terms of the fiber content there were no significant differences among plants obtained in fields with different levels of nitrogen and with different levels of irrigation. There were, also, no significant differences between the fiber content of the bark material and the fiber content of the inner core material. There were no significant differences among the fiber content of the biomass obtained at 90, 126 and 188 days after sowing.

3.3 Harvest Date

The selection of the harvest date is very important because, according to the results presented in Figures 1 and 2 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 and 2, and although the highest productivity was obtained 90 days after sowing (2nd October), the crop should only be harvested after this date, when all the leaves have already fallen. From the results obtained, we may conclude that the productivity was higher 126 days after sowing than 188 days after sowing, but this difference was not significant.

In order to cover the processing needs, either for the energy or for 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, phosphorus and water content decreased and organic matter increased (Tables I to IV). The lowest values for the moisture content and for the minerals contents were registered 188 days after sowing, but differences were not significant in relation to the results obtained 126 days after sowing. In relation to the fiber content and to the heat of combustion there were no significant differences between the 126th day after sowing (early November) and the 188th day after sowing (early January).

So, the highest quality of the kenaf biomass, for fuel and pulp purposes, can be obtained at the beginning of January, but highest productivities can be obtained at the beginning of November. To make a decision about the preferable harvest date, nitrogen, phosphorus, fiber and heat of combustion offtakes, were calculated for the 126th day after sowing and for the 188th day after sowing.

Table VII: Nitrogen offtake ($kg.ha^{-1}$ dry matter) of Kenaf, in core and bark, at the 126th day after sowing and at the 188th day after sowing.

Irrigation	Core		Bark	
	126th	188th	126th	188th
204 mm H_2O	4	4	5	4
253 mm H_2O	15	4	5	7
301 mm H_2O	13	5	17	8
400 mm H_2O	13	9	16	11

Table VIII: Phosphorus offtake ($kg.ha^{-1}$ dry matter) of Kenaf, in core and bark, at the 126th day after sowing and at the 188th day after sowing.

Irrigation	Core		Bark	
	126th	188th	126th	188th
204 mm H_2O	1.8	1.3	2.2	1.5
253 mm H_2O	3.6	1.2	2.0	1.9
301 mm H_2O	3.4	1.9	4.1	2.9
400 mm H_2O	4.0	3.9	4.8	4.3

Table IX: Fiber offtake ($t.ha^{-1}$ dry matter) of Kenaf, in core and bark, at the 126th day after sowing and at the 188th day after sowing.

Irrigation	Core		Bark	
	126th	188th	126th	188th
204 mm H_2O	0.4	0.5	0.4	0.3
253 mm H_2O	0.8	0.6	0.2	0.3
301 mm H_2O	1.2	0.9	0.7	0.5
400 mm H_2O	1.0	1.0	0.6	0.6

Table X: Heat of combustion offtake (GJ.ha^{-1} dry matter) of Kenaf, in core and bark, at the 126th day after sowing and at the 188th day after sowing.

Irrigation	Core		Bark	
	126th	188th	126th	188th
204 mm H_2O	16	18	12	8
253 mm H_2O	29	24	9	11
301 mm H_2O	44	35	20	15
400 mm H_2O	39	42	22	20

According to the offtake results, it is possible to conclude that in terms of biomass quality, the best harvest day would be in the early January (188th day after sowing). But, at this date, small, although not significant, losses in fiber offtake and in heat of combustion offtake would be observed. Requirements of the energy and pulp production sectors, aim preferably a better biomass quality than better biomass yields. So, we think that early January, is the most promising harvest date. This is completed by the fact that at this moment the moisture content of the biomass is lowest.

4 CONCLUSIONS

The results achieved permits us to propose the following considerations:

- 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 affected either by the level of irrigation or by the level of N-fertilization.
- Productivity and Biomass quality were affected by the date of harvest. The early January harvest provided a biomass with better quality but the early November harvest provided better yields. Regarding the requirements of the energy and pulp production industries, the early January harvest date (188th day after sowing) should be chosen.
- It should be also interesting to study other harvest dates, like, for example, a harvest in early March, to study if the extension of the vegetative growth of kenaf plants in the fields could contribute to a better biomass quality, in an annual base.

Before taking a decision concerning industrial utilization, assays at pilot level should be done. Figures obtained concerning actual quality values of the crops tested must be considered as indicative ones.

Integration of agricultural practices and the energy and pulp production sectors, are necessary. Energy crops for power and pulp purposes require quality specifications which, in some cases, are not yet fully met.

5 ACKNOWLEDGEMENTS

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