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Effect of row spacing and lineal sowing density of kenaf (*Hibiscus cannabinus* L.) yield components in the north-west of Argentina

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Abstract

The plant density and spatial arrangement of kenaf is an important aspect in kenaf fiber production. A field plant density experiment was conducted at Ledesma (Jujuy, Argentina) in 2001 on a sandy loam soil. The treatments used were different combinations of 35 and 70 cm row spacings with lineal sowing densities of 25 and 40 plants m^{-1}, and were applied to the Cuba 108, Endora and Tainung 1 cultivars. Two indices (bark content and bark index) related to fiber yield and useful for the individual selection of plants were measured. The combination of 35 cm row spacing and 25 plants m^{-1} lineal sowing density, representing an initial density of 714,286 plants ha^{-1}, resulted in the best dry bark yield for the three cultivars. As a result of strong intraspecific competition, height and diameter of the plants decreased while plant density increased. The initial lineal density of 40 plants m^{-1} was not advantageous in comparison to 25 plants m^{-1}, because plant survival rates were reduced at 40 plants m^{-1} and yield did not increase linearly.

Additional key words: intraspecific competition, plant density.

Resumen

Efecto del espaciamiento entre líneas y la densidad lineal de siembra en componentes del rendimiento en kenaf (*Hibiscus cannabinus* L.) en el noroeste de Argentina

Un aspecto importante en la producción de fibra de kenaf es la densidad de plantas y su distribución espacial. En un suelo arcillo arenoso (Ledesma-Jujuy, Argentina) se desarrolló en el año 2001 un experimento a campo sobre poblaciones de plantas. Los tratamientos utilizados consistieron en las combinaciones de surcos espaciados a 35 y 70 cm con densidades lineales de siembra de 25 y 40 plantas m^{-1}, y los mismos se aplicaron a los cultivares Cuba 108, Endora y Tainung 1. Se evaluaron dos índices (contenido de corteza e índice de corteza) para la selección de plantas individuales, los cuales están relacionados con el rendimiento en fibra del cultivo. La combinación de surcos espaciados a 35 cm y una densidad lineal de siembra de 25 plantas m^{-1}, correspondiente a una densidad inicial de 714.286 plantas ha^{-1}, resultó con el mayor peso seco de corteza para los tres cultivares. Se observó una fuerte competencia intraespecífica, donde a medida que la densidad de plantas aumentaba, la altura y el diámetro de las plantas disminuían. La densidad lineal inicial de 40 plantas m^{-1} no fue ventajosa en comparación con la de 25 plantas m^{-1}, debido a que en el primer caso la supervivencia de plantas fue reducida y los rendimentos no aumentaron de manera lineal.

Palabras clave adicionales: competencia intraespecífica, densidad de plantas.

Introduction

Kenaf (*Hibiscus cannabinus* L.) is a herbaceous, warm season, annual, autoallogamous plant of the Malvaceae family, well adapted to different environments. In many countries, production has been orientated to obtaining fiber for paper pulp production (Oliveros Alba, 1993). At Ledesma, in north-west Argentina, an agro-industrial demonstration project was started in 1999 to use kenaf for paper pulp and other purposes. Plant density is one of the most important aspects directly related to fiber yield in kenaf. The optimum plant density has not been determined with precision and can vary with the mechanization system available and fiber's use.

Muchow (1979a,b) studied the response of kenaf cv. Guatemala 4 over a range of densities (100,000 to 900,000 plants ha^{-1}) under irrigated tropical conditions

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and did not detect a significant difference for yield. Researchers in Spain reported that the best plant density was 400,000 plants ha^{-1} (Manzanares *et al*., 1991). The optimum plant density to produce the maximum yields can also vary within cultivars. Campbell and White (1982) in Maryland (USA), found that cultivar Cuba 2032 required a plant density of 500,000 to 700,000 plants ha^{-1} for maximum yields, whereas Tainung 1 required 300,000 to 400,000 plants ha^{-1}. Bukhtiar *et al*. (1990) proposed 444,000 plants ha^{-1} as the optimum plant density for fiber production. Webber *et al.* (2001) describing kenaf production, mentioned the final plant density of 185,000 to 370,000 plants ha^{-1} as the desirable for maximum yields.

Row spacing and lineal sowing density can also be related to availability of the sowing machinery. In the USA, a row spacing of 42 cm was used; in Italy, row spacings of 16.5 and 50 cm were tested with no significant differences (Benati *et al*., 1992). Dempsey (1975) proposed a 15 to 95 cm range between rows. Kenaf yields were 12% higher in narrow rows compared to wide rows, when it was grown in 36 and 71 cm rows (densities of 368,000 and 184,000 plants ha^{-1}) (Massey, 1974). Basal stem diameter was larger in wide rows than in narrow rows, but plant height was not affected by row spacing. Salih (1983) studied cv. Cubano grown at row spacings of 0.2, 0.3 or 0.4 m and plant spacings of 0.025, 0.05, 0.075 or 0.1 m over three years. Stand percentage, stem diameter, and height increased as plant and row spacing increased. Total dry ribbon yields were highest at the intra-row spacing of 0.025 m, but were unaffected by differences in inter-row spacing.

In field trials in the 1990 and 1991 rainy seasons at Ambikapur, Madhya Pradesh (India), seed and fiber yields were not significantly affected by the sowing methods at row spacings of 20 or 30 cm or broadcasting (Bajpai *et al*., 1994).

Apart from the plant density of kenaf, many factors are important in this crop. Webber and Bledsoe (2002), said that it may be advantageous to harvest the kenaf crop earlier than 150 days after planting depending on the harvesting conditions (e.g. soil moisture or equipment availability) or marketing opportunities (price fluctuation or alternative uses).

In this research, the plant density used was a result of the combination of row spacing and lineal sowing density (plant spacing). The objective was to evaluate the effects of row spacings and lineal sowing densities on yield components of three commercial kenaf cultivars.

Material and Methods

A field experiment was conducted at Ledesma (Jujuy, Argentina) in 2001, located at 23º 48' LS, 64º 49' LW and an altitude of 446 m, on a Florencia sandy loam (*Phaeozem haplico*) soil, with pH 7.7 and 2.6% OM. The rainfall during the crop cycle was 740.6 mm and covered the evapotranspiration of the crop, so the crop developed without artificial irrigation. The average minimum and maximum temperatures and monthly cumulative rainfall during the crop season were as described in Table 1.

The experiment was arranged with a fixed model in a three factor randomized complete block design with three replications. Factor A: three high yield potential, photosensitive and long to intermediate cycle cultivars (A_1: Cuba 108; A_2: Endora; A_3: Tainung 1). Factor B: two row spacings (B_1: 35 cm between rows; B_2: 70 cm between rows). Factor C: two lineal sowing densities (C_1: 25 plants m^{-1}; C_2: 40 plants m^{-1}).

The thermal time for the cultivars was calculated for the period between sowing and blooming. A base development temperature of 10ºC (Evans and Hang, 1993) was assumed and the procedure of Ritchie and NeSmith (1991) was followed. The thermal time for the mentioned period for the cultivars Cuba 108, Endora and Tainung 1 were 1,572.3, 1,543.3 and 1,384ºCd (degree days) respectively.

Table 1. Mean daily minimum (Tmin) and maximum (Tmax) temperatures and monthly cumulative rainfall (CR) between the experimental period (December 2000-May 2001)

	Dates					
	12/2000	**01/2001**	**02/2001**	**03/2001**	**04/2001**	**05/2001**
T min (ºC)	20.4	22.8	22.5	21.6	17.6	13.2
T max (ºC)	31.8	33.6	31.9	32.0	25.3	19.7
CR (mm)	42.2	314.7	129.3	99.4	140.9	14.1

Seeds were treated with triadimenol beta-[4-chlorophenoxialfa-(1-1 dimethylethyl)-1 H-1, 2, 4 triazol-1-ethanol] at a rate of 0.2 l 100-kg^{-1} of seeds. Trifluralin [2, 6-dinitro-N, N-dipropyl-4-(trifluoromethyl) benzenamine] and chlorpyrifos (0,0-diethyl 0-3,5,6-trichloro-2-pyridyl phosphortioate) were applied at a rate of 2 l ha^{-1} each one before sowing. In order to achieve maximum potential yield, 95 kg N ha^{-1} were applied as preplant urea, so the crop was non-limiting in water (with the rainfall) and nutrients. Three weeks after sowing, plots were hand-thinned in order to match the theoretical lineal sowing density per row. Plots were kept weed free by hand-weeding until the plants were 1.5 m high.

Plots were 2.1 m wide (three or four rows, according to row spacing) and 6 m long. The research plots were sown by hand on January 17, 2001. They were hand-harvested when the paper maturity was reached, at the beginning of blooming, approximately 18 weeks after sowing, on May 28. Plants were cut at ground level from a 1 m^2 (1 × 1 m) quadrant located randomly along the central or two central lines (according to row spacing) of each plot. It is important to note that, although the number of rows per plot seem to be small, the sowing, theoretical lineal sowing density, weeding control, harvesting and other treatments were done with much control by hand. So, the variability was reduced and the results were representative.

In order to facilitate the fiber extraction operation and to assess other attributes, only a representative section of the whole stalk was selected. The sample consisted of 15% of the whole stalk taken from the middle part of each stalk according to Oliveros Alba (1993). Selected stem parts were oven dried at 45ºC to constant weight (around 48 h).

The following variables were measured at harvest:

— Dry bark weight (DBW) (g m^{-2}): total bark weight (bark manual extraction) of the stems collected in the 1 m^2 quadrant.

— Dry stem weight (DSW) (g m^{-2}): total stem weight of the stems collected in the quadrant.

— Bark content (BC): BC (%) = [Dry bark weight per plant (g) / Dry stem total weight per plant (g)] × 100.

— Bark index (BI) (Oliveros Alba, 1993): BI = {Dry bark weight per plant (g) / [Total height per plant (cm) × Stem middle diameter per plant (mm)]} × 1,000.

— Stem height (SH) (cm): average height of the stems collected in the quadrant.

— Stem diameter (SD) (mm): average middle diameter of the stems collected in the quadrant.

— Plant density at harvest (PH) (plants m^{-2}).

The information collected was subjected to analysis of variance. When the *F*-test resulted in statistical significance at the $P = 0.05$ level, a Tukey test was applied in order to differentiate means.

Results and Discussion

Dry bark weight

ANOVAs showed that cultivars, row spacings, and their interaction had significant effects on DBW (Table 2). Table 3 shows that Endora yielded 575.0 g m^{-2} differing significantly from Tainung 1 (451.8 g m^{-2}) and Cuba 108 (438.5 g m^{-2}). The DBW for the 35-cm row spacing was significantly greater than the 70-cm row spacing. However, it is important to note that the widest spacing (70 cm) comprising half of the rows per unit area, only decreased the DBW by 25% (Table 4). These data agree with a previous study (Vincent, 1982)

Table 2. F values and level of significance from the analysis of variance for cultivars, row spacings, lineal sowing densities and their interactions

Factors	DBW (g m^{-2})	DSW (g m^{-2})	BC (%)	BI	SH (cm)	SD (mm)	PH (plants m^{-2})
Cultivars (Cv)	0.0014**	0.0045**	ns	ns	ns	0.0710[a]	ns
Row spacings (Rsp)	0.0001**	0.0003**	0.0155*	0.0002**	0.0005**	0.0004**	0.0001**
Lineal sowing densities (Sden)	ns	ns	0.0091**	0.0004**	0.0001**	0.0002**	0.0001**
Cv * Rsp	0.0482*	0.0411*	ns	ns	ns	ns	ns
Cv * Sden	ns	ns	ns	ns	ns	ns	ns
Rsp * Sden	ns	ns	ns	ns	ns	0.05*	ns
Cv * Rsp * Sden	ns	ns	ns	ns	ns	ns	ns

[a] ($p \leq 0.1$). * ($p \leq 0.05$). ** ($p \leq 0.01$). ns: not significant. DBW: dry bark weight. DSW: dry stem weight. BC: bark content. BI: bark index. SH: stem height. SD: stem diameter. PH: plant density at harvest. ns: not significant.

Table 3. Differences among means for variables with significant variation for cultivars

Cultivars	Variables	
	DBW (g m^{-2})	DSW (g m^{-2})
Endora	575.0 a	1,530.8 a
Tainung 1	451.8 b	1,276.3 b
Cuba 108	438.5 b	1,177.2 b

Means followed by different letters are significantly different ($p \leq 0.05$). DBW: dry bark weight. DSW: dry stem weight.

in which the highest yield was obtained at a row spacing of 30 cm. Nevertheless, Dempsey (1975), Nazirov *et al*. (1976), Salih (1983), Benati *et al*. (1992), and Bajpai *et al*. (1994) could not find differences when examining a range of row spacings.

The analysis of interactions for cultivars and row spacings, determined that the combination of Endora and the 35-cm row spacing was the best yielding combination.

The 35-cm row spacing and 25 plants m^{-1} lineal sowing density was the optimum combination to produce maximum bark yield for all cultivars, averaging 488.4 g m^{-2}. This combination corresponds to an initial density of 714,286 plants ha^{-1}. Muchow (1979a,b) could not determine the effect of plant density from 100,000 to 900,000 plants ha^{-1} on DBW. Bukhtiar *et al*. (1990) proposed 444,000 plants ha^{-1} as an optimum plant density to maximize DBW. Benati *et al*. (1992) recommended 300,000 plants ha^{-1} and Manzanares *et al*. (1996) 400,000 to 500,000 plants ha^{-1} to optimize DBW production.

Dry stem weight

Cultivars, row spacings, and their interaction had significant effects on DSW (Table 2).

Results are similar to the ones previously reported for DBW. Endora produced the highest yield (1,530.8 g m^{-2}) (Table 3), the 35-cm row spacing (1,497.7 g m^{-2}) yielded more than the 70-cm (1,158.5 g m^{-2}) (Table 4), and the combination of Endora and the 35-cm row spacing was the best yielding combination.

Bark content

Bark content was significantly affected by row spacings and lineal sowing densities, but not by cultivars (Table 2).

The 35-cm row spacing and the 40 plants m^{-1} lineal sowing density were significantly better (1.9% for both) than the 70-cm row spacing and the 25 plants m^{-1} lineal sowing density respectively. The worth for selection of this trait is expected to increase under the highest plant densities (Tables 4 and 5).

In spite of the fact that BC could be a useful tool to find differences among cultivars or individual plants as shown by Oliveros Alba (1993), no significant differences were found for cultivars in this experiment, possibly explained by their similar yield potential and cycle.

Bark index

Cultivars had no significant effect on BI, but row spacings and lineal sowing density effects were significant as can be seen in Table 2.

Row spacing at 70 cm and a lineal sowing density of 25 plants m^{-1} resulted in a higher mean BI (5.3 for both) than row spacing at 35 cm (4.5) and lineal sowing density of 40 plants m^{-1} (4.6), respectively (Tables 4 and 5). These data suggest the occurrence of higher BI values at lower densities.

As in the case of BC, this trait was mentioned as a useful index for plant comparison and selection, although no significant differences among the cultivars were found in this experiment.

Table 4. Differences between means for variables with significant variation for row spacings

Row spacings (cm)	DBW (g m^{-2})	DSW (g m^{-2})	BC (%)	BI	SH (cm)	SD (mm)	PH (plants m^{-2})
35	557.9 a	1497.7 a	42.2 a	4.5 b	215.9 b	6.3 b	64.7 a
70	419.0 b	1158.5 b	40.3 b	5.3 a	236.8 a	7.4 a	33.5 b

Means followed by different letters are significantly different ($p \leq 0.05$). DBW: dry bark weight. DSW: dry stem weight. BC: bark content. BI: bark index. SH: stem height. SD: stem diameter. PH: plant density at harvest.

Table 5. Differences between means for variables with significant variation for lineal sowing densities

Sowing densities (plants m^{-1})	BC (%)	BI	SH (cm)	SD (mm)	PH (plants m^{-2})
25	40.2 b	5.3 a	238.9 a	7.5 a	42.6 b
40	42.3 a	4.6 b	213.8 b	6.2 b	55.7 a

Means followed by different letters are significantly different ($p \leq 0.05$). BC: bark content. BI: bark index. SH: stem height. SD: stem diameter. PH: plant density at harvest.

Stem height

Row spacing and lineal sowing density factors had a significant effect on SH, but cultivars had no effect on this variable (Table 2).

Row spacing at 70 cm (236.8 cm) and a lineal sowing density of 25 plants m^{-1} (238.9 cm) resulted in taller stems with significant differences compared to a row spacing of 35 cm (215.9 cm) and a lineal sowing density of 40 plants m^{-1} (213.8 cm), respectively (Tables 4 and 5). Massey (1974) could not find differences between row spacings of 36 and 71 cm.

The regressional analysis of SH and PH showed that when plant density at harvest (plants m^{-2}) decreased by one unit, stem height increased 0.83 cm (Fig. 1).

Stem diameter

Row spacings, lineal sowing densities and their interaction had significant effects on SD (Table 2). Cultivars had no significant effect at the 5% level. However, the slight advantage observed for Endora (significant at the 10% level) could be important in determining resistance to lodging (Tables 2 and 6).

The diameters at the 70-cm row spacing and 25 plants m^{-1} lineal sowing density were significantly higher than the ones found at the 35-cm row spacing and 40 plants m^{-1} lineal sowing density, respectively (Tables 4 and 5). These results are consistent with Massey (1974), who found the largest diameters at the 71-cm row spacings compared to 36-cm row spacings. Salih (1978) suggested 20 or 30-cm row spacings in order to produce the largest diameters. In addition, the combination of 35-cm row spacing and 25 plants m^{-1} lineal sowing density (initial plant density of 357,143 plants ha^{-1}) resulted in the largest diameter. This data is in agreement with Manzanares *et al.* (1996) and Salih (1978) who proposed 400,000 or a range of 200,000 to 500,000 plants ha^{-1}, respectively, as the best density to prevent lodging, but differs with Massey (1974), who found that the best range was 132,000-262,000 plants ha^{-1}.

It is important to note that the highest yield did not correspond to the largest diameter and height, which could favour lodging.

Table 6. Differences among means for stem diameter with significant variation for cultivars

Cultivars	Stem diameter (mm)
Endora	7.3 a
Tainung 1	6.7 a b
Cuba 108	6.6 b

Means followed by different letters are significantly different ($p \leq 0.1$).

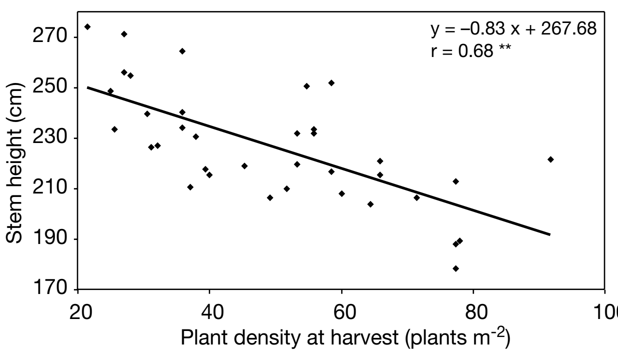

Figure 1. Effect of plant density at harvest on stem height.

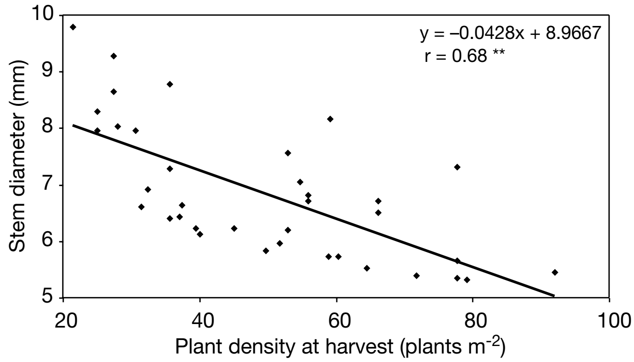

Figure 2. Effect of plant density at harvest on stem diameter.

Table 7. Means values of initial and final plant densities

Row spacings (cm)	Lineal sowing densities (plants m^{-1})	Initial plant density (plants m^{-2})	Plant density at harvest (plants m^{-2})	Final established plant percentage
35	40	114.3	72.9	63.8
35	25	71.4	57.0	79.8
70	40	57.1	38.6	67.6
70	25	35.7	28.8	80.7

The regressional analysis of SD and PH showed that stem diameter decreased 0.428 mm when plant density at harvest (plants m^{-2}) increased 10 units. Therefore, high plant densities at harvest would increase the tendency of lodging (Fig. 2).

Plant density at harvest

ANOVAs showed that row spacings and lineal sowing densities had significant effects on PH, while cultivars had no significant effect on this variable (Table 2). Results indicate that an increased plant density at harvest were related to higher initial density (35 cm row spacing and 40 plants m^{-1} lineal sowing density, respectively) (Tables 4 and 5). Nevertheless, as a result of the suspected high intraspecific competition exhibited by the crop, a larger final established plant percentage was obtained at 25 plants m^{-1} lineal sowing density (Table 7). For this reason, 40 plants m^{-1} does not seem to be justified.

The optimum plant density for kenaf remains to be established. Previous research and the results in this report suggest the inconvenience of defining a single optimum density for the crop. Instead, attention should be given to the suspected intraspecific competition and compensatory mechanisms involving diameter, height and dry bark weight, which in time, compose the bark index (Tables 4 and 5). Therefore, the plant density should also be adjusted according to the crop purpose, taking into account the harvesting system, fiber extraction procedures and application of the final products.

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