ΦYTON
REVISTA INTERNACIONAL DE BOTÁNICA EXPERIMENTAL
INTERNATIONAL JOURNAL OF EXPERIMENTAL BOTANY
FUNDACION ROMULO RAGGIO
Gaspar Campos 861, 1638 Vicente López (BA), Argentina
www.revistaphyton.fund-romuloraggio.org.ar

Effects of plant height and row spacing on kenaf forage potential with multiple harvests

Efectos de la altura de planta y el distanciamiento entre surcos sobre el potencial forrajero del kenaf con cosechas múltiples

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Abstract. Kenaf (*Hibiscus cannabinus* L.) forage potential can be enhanced through its regrowth capacity and higher production in narrow rows. A field experiment was conducted in Matamoros, Coahuila, Mexico, during 2 growing seasons (2004 and 2005) to study the effects of plant height and row spacing on kenaf forage potential with multiple harvests. This study evaluated the effects of (1) 2 plant heights at cutting (1.0-1.2 m and 1.8-2.0 m) and (2) 4 inter row spacings (0.19, 0.38, 0.57 and 0.76 m) using a 2 x 4 factorial arrangement of treatments in a completely randomized block design with 4 replications. Dry matter (DM) and crude protein (CP) yields, DM partitioning, neutral detergent fiber (NDF) and CP concentrations were determined. Heights at cutting × row spacing interactions were not significant for the monitored variables ($p>0.05$). Kenaf response to treatments was only relevant for main effects ($p\leq0.05$). Row spacing and plant height affected DM and CP yields ($p\leq0.05$), whereas only plant height affected chemical composition and DM partitioning ($p\leq0.05$). Dry matter (17.0%-26.0%), and CP (12.4%-15.6%) yields were higher ($p\leq0.05$) when plant heights had reached 1.8 to 2.0 m. Row spacing reduction from 0.76 m to 0.38 and 0.19 m increased DM yield (20.4-33.4%) and CP yield (24.2-38.5%) ($p\leq0.05$). Kenaf forage potential increases when planted in narrow rows and harvested 2 or 3 times during the growing season.

Keywords: *Hibiscus cannabinus* L; Chemical composition; Dry matter and crude protein yields; Dry matter partitioning.

Resumen. El potencial forrajero del kenaf (*Hibiscus cannabinus* L.) puede incrementarse aprovechando su capacidad de rebrote y su mayor producción en surcos estrechos. Para estudiar el efecto de la altura de planta y el distanciamiento entre surcos sobre el potencial forrajero del kenaf con múltiples cosechas, se estableció un experimento de campo en 2004 y 2005 en Matamoros, Coahuila, México. Las alturas de planta al corte fueron: (1) 1,0-1,2 m; (2) 1,8-2,0 m. Las distancias entre surcos evaluadas fueron: 0,19; 0,38; 0,57 y 0,76 m. Se utilizó un arreglo de tratamientos factorial 2 x 4 en un diseño experimental de bloques completos al azar con cuatro repeticiones. Se determinaron los rendimientos de materia seca (MS) y proteína cruda (PC), distribución de MS en la parte aérea y concentraciones de fibra detergente neutro (FDN) y PC. Las interacciones altura de planta al corte × distanciamiento entre surcos no fueron significativas para las variables evaluadas ($p>0,05$). La respuesta del kenaf sólo fue significativa para los efectos principales ($p\leq0,05$). Los rendimientos de MS y PC fueron afectados por el distanciamiento entre surcos y la altura de planta; la composición química y la distribución de MS sólo fueron afectados por la altura de planta ($p\leq0,05$). Los mayores ($p\leq0,05$) rendimientos de MS (17,0-26,0%) y de PC (12,4-15,6%) se obtuvieron cuando las plantas fueron cortadas a 1,8-2 m de altura. La disminución del distanciamiento entre surcos de 0,76 a 0,38 y 0,19 m incrementó los rendimientos de MS (20,4-33,4%) y PC (24,2-38,5%) ($p\leq0,05$). El potencial forrajero del kenaf se incrementa cosechando dos o tres veces durante el ciclo de crecimiento y usando surcos estrechos.

Palabras clave: *Hibiscus cannabinus* L.; Composición química; Rendimientos de materia seca y proteína cruda; Distribución de materia seca.

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Recibido / Received 28.XI.2013. Aceptado / Accepted 17.VIII.2014.

INTRODUCTION

Cattle and goat raising are major economic and social activities in arid and semi-arid regions of Mexico. Semi-intensive and intensive goat farming systems tend to increase in numerous agricultural areas, raising the demand for high quality forages (Guerrero-Cruz, 2010). Intensive dairy cattle production systems depend on irrigated forages such as alfalfa, corn, sorghum, and oats. However, low water availability, soil salinity, high ambient temperatures, and a limited number of forage crops restrain forage production in this region (Reta-Sánchez et al., 2008). Sustainable and profitable meat and milk production of both animal species requires increasing forage availability and quality throughout the year. Hence, identification of alternative forage crops with higher water use efficiency is essential.

Kenaf (*Hibiscus cannabinus* L.*)* may be a suitable alternative crop to include in crop production systems in arid and semi-arid regions of Mexico. Kenaf displays several advantageous characteristics such as salinity tolerance (Francois et al., 1992), adaptation to irrigated arid environments (Nielsen, 2004), precocity (Reta-Sánchez et al., 2006), and regrowth ability (Nielsen, 2004; González-Valenzuela et al., 2008).

Although scientific research on kenaf as a livestock forage is limited, there is evidence of its potential consumption by cattle (Hancock et al., 1993; Rude et al., 2002; Chantiratikul, 2004) and small ruminants (Wildeus et al., 1995; Phillips et al., 1996; Phillips et al., 2002). Kenaf is used as forage, especially when harvested at early stages (Phillips et al., 1996). Leaf/stem ratio declines as harvesting is delayed, resulting in lower forage quality due to CP content reductions and fiber concentration increase. Several studies have reported CP concentrations ranging from 279 to 154 g/kg in kenaf harvested at 40 to 105 days after sowing (DAS) (Swingle et al., 1978; Phillips et al., 1999; Nielsen, 2004). At 30 to 65 DAS, kenaf neutral detergent fiber (NDF) concentrations ranged from 224 to 286 g/kg (Swingle et al., 1978; Vinson et al., 1979), whereas in kenaf harvested between 80 and 105 DAS, NDF concentrations ranged from 352 to 515 g/kg (Swingle et al., 1978; Phillips et al., 1996).

With a short growing cycle (52-74 DAS) and appropriate CP concentrations (140 to 158 g/kg), kenaf forage, has proved to be a convenient emergency crop for the summer season in the Comarca Lagunera, Mexico. At 52 DAS, 1.18 m plant height on kenaf yielded 3451 kg/ha of DM, with a 158 g/kg CP content. At 74 DAS, kenaf plants reached 1.95 m in height and produced a 6296 kg/ha DM yield, with a 140-g/kg CP content (Reta-Sánchez et al., 2007; Reta-Sánchez et al., 2010). Yet it is desirable to increase its DM yield potential to make kenaf a more interesting forage to farmers. An alternative to achieve it is to take advantage of kenaf's regrowing ability noted by other studies (Nielsen, 2004; González-Valenzuela et al., 2008) to allow multiple spring and summer harvests in this region. According to results reported by fiber production studies (Acreche et al., 2005; Baldwin & Graham, 2006), another alternative is using a narrow row system to increase kenaf yield. The object of this study was to determine the effect of multiple harvestings at different plant heights and row spacings on kenaf forage potential.

MATERIALS AND METHODS

The study was conducted during 2 growing seasons (2004 and 2005) on a clay loam soil, at La Laguna Experimental Station of the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, located in Matamoros, Coahuila, Mexico (25° 32' N, 103° 14' W, 1150 m.a.s.l.). This experimental site has deep soils (> 1.8 m), with a soil/water availability of 150 mm/m (Santamaría-César et al., 2008) and 0.75% organic C content (Santamaría-César et al., 2006).

Soil preparation consisted of plowing, disking, leveling, and layout. Before sowing, 50 kg of N (granulated urea) and 100 kg of P_2O_5/ha (mono-ammonium phosphate) were applied and incorporated through disking. Fertilizers were hand-applied, due to plot size in each row spacing treatment. Sowing was made by hand on a dry soil on 14 May, 2004 and 11 April, 2005. A 200-mm irrigation was applied one day after sowing. 'Everglades 41' kenaf, an intermediate-cycle, photoperiod-sensitive cultivar (Webber et al., 2002) was planted.

Two plant heights at cutting (1.0-1.2 m and 1.8-2.0 m) and four row spacings (0.19, 0.38, 0.57, and 0.76 m) were evaluated in a 2 × 4 factorial arrangement of treatments in a randomized complete block design with 4 replications. When rows were spaced 0.19 m apart, the experimental plot consisted of 22 rows; when rows were spaced at 0.38, 0.57, and 0.76 m, the number of rows per plot was 12, 9, and 6, respectively. Row length was 10 m in all cases. Plot sizes used for measurements were 3 m long and comprised 17, 10, 7, or 4 rows depending on 0.19, 0.38, 0.57 and 0.76 m row spacings, respectively. Seeding rate used was 50% over target plant density, and plants were thinned by hand at 20 DAS to obtain 500000 plants/ha. To define harvesting dates for each plant height treatment, average plant height was determined from 20 randomly selected plants per plot. Cutting height was 0.20 m above ground in all harvests, according to a previous study (González-Valenzuela et al., 2005).

On treatments to be harvested when plants reached a height of 1.0 to 1.2 m, five to six 120-mm irrigations were applied during the growing cycle: one before the first harvest, 2 before the second harvest, and 2 or 3 before the third harvest. In 2004, planting was performed 33 days later than in 2005, consequently requiring 3 irrigations to achieve the third harvest, since the growth period extended 61 days. Such irrigations were applied at 33, 55, 80, 102, 123, and 139 DAS in 2004; and at 44, 65, 86, 112, and 133 DAS in 2005. Additional N applications were made at a rate of 100 kg/ha before the first irrigation for the second harvest and before the first 2 irrigations for the third harvest in both years. On treatments harvested when plants reached heights of 1.80 to 2.0 m, 5 irrigations were given during the growing cycle: 2 before the first and 3 before the second harvest. These 120-mm irrigations were given at 33, 55, 80, 102, and 123 DAS in 2004 and at 44, 65, 86, 112, and 133 DAS in 2005. In both growing seasons, before each of all 5 post-planting irrigations, additional N was applied as urea at 100 kg/ha. Irrigation management in both plant heights at cutting was similar to that reported by previous studies conducted at this same locality (Reta-Sánchez et al., 2007; Reta-Sánchez et al., 2010), except in 2004, when the 1.0 to 1.20 m plant height treatment required a third irrigation.

Rainfall was 131.4 mm during the 2004 growing season and 68.1 mm in 2005. In 2004, average maximum, minimum, and mean temperatures were 34.9, 19.0, and 27.0 °C, respectively, and 36.8, 19.2, and 28.0 °C in 2005. Potential evaporation values for the growing seasons were 1222.1 mm and 1273.4 mm in 2004 and 2005, respectively (Table 1). It was necessary to make 1 or 2 insecticide applications to control whitefly (*Bemisia argentifolii* Bellows & Perring). In 2004 and at 31 DAS, Endosulfan 35% C.G. (Velsimex, S.A. de C.V., Mexico D.F.; endosulfan; 6,7,8,9,10,10-hexachloro-1,5,5a,6,9,9a-hexahydro-6,a-methano-2,4,3-benzodi-oxathiepin 3-oxide) was applied at 1.5 L/ha. Subsequently, at 123 DAS, Endosulfan 35% C.G. at 1.5 L/ha and Rescate 20 PS [DuPont Mexico, S.A. de C.V., Mexico, D.F.; acetamiprid; (E)-N^1-[(6-chloro-3-pyridy)methyl]-N^2-Cyano-N^1-methylacetamidine] were applied at 0.400 kg/ha. These same 2 insecticides and doses were administered in 2005 at 107 DAS.

Fresh forage and dry matter yields were determined at harvest time. Dry matter percentage per plot was determined from a 10-plant random sample. These plants were dried at 60 °C in a forced-air oven, until constant weight was attained. Dry matter yield was determined multiplying fresh forage yield by the DM percentage obtained for each plot. Dry matter partitioning into plant aerial organs was also determined at harvest time by a plant sample similar to that used for calculating DM percentage. Aboveground stems, leaves (blades and petioles), and reproductive organs (flowers and fruits) were separated from the whole plant samples; thereafter, these plant organs were dried at 60 °C until constant weight was achieved to determine their dry weight.

The same plants that were sampled to estimate DM percentage were used to determine forage chemical composition in terms of CP and NDF. Dried plants were ground in a Wiley mill (Thomas Scientific, Swedesboro, NJ, USA) to pass through a 1.0 mm screen. These samples were analyzed according to the procedures described by Goering & Van Soest (1970) for NDF and ADF. The Kjeldahl procedure was used to determine N (Bremner, 1996). Crude protein yield per hectare was determined multiplying CP concentration by DM yield in each experimental plot.

Statistical analysis. Since planting dates were not the same in both years of this study, the analysis of all variables measured is presented by year. Analyses of variance comprehended the following variables: DM and CP yields, CP and NDF concentrations, and DM percentages in the plant aerial organs. The analysis of variables considered the first harvests, the sum of regrowth values, and the total growing season values. Dry matter and CP yields of the harvests, determined from the sums of harvests, were taken into account to estimate the weighted averages for the chemical composition of regrowths, and the total growing season values. Weighted least squares regression ($p \leq 0.05$) was used to examine the relationship between DM partitioned into leaf and forage quality parameters (CP and NDF). The Tukey's test served to compare means ($p \leq 0.05$). Data were analyzed through SAS statistical software (SAS Inst., 1990).

RESULTS

No significant row spacing × plant height interaction was evident for any of the assessed variables ($p > 0.05$). Row spacing affected DM and CP yields ($p \leq 0.05$) only, while plant height notably affected forage chemical composition, DM partitioning into plant aerial organs, and DM and CP yields ($p \leq 0.05$).

Growing season and weather conditions. Kenaf's growing seasons were different in both years due to changes in climatic conditions. This was because of the different planting dates for each year, as well as from the year to year weather variability. When plants were cut at plant height 1 (1.0-1.2 m), 3 harvests were performed at 54, 98, and 159 DAS in 2004 and at 63, 105, and 150 DAS in 2005. When plants were cut at plant height 2 (1.8-2.0 m), 2 harvests were done at 74 and 138 DAS in 2004, and at 84 and 148 DAS in 2005 (Table 1).

With a later planting date (May), kenaf plants harvested in 2004 at plant height 1 had a longer growing season, due to the long growth period of the second regrowth which lasted until 21 October, probably as a response to lower mean minimum temperatures than those of 2005 for the same harvest. On the other hand, with an earlier planting date (April), kenaf plants harvested in 2005 at plant height 2 (1.8-2.0 m) had a longer total growing season as a result of a longer period between planting and the first cut. This response was also probably related to lower mean minimum temperatures than those of 2004 for the same developmental morphology period.

Other factors favoring kenaf growth in 2004 were higher rainfall, lower potential evaporation values, and lower mean maximum temperatures than those of 2005 (Table 1).

Forage chemical composition. Plant heights at cutting displayed significant CP and NDF content differences ($p \leq 0.05$). In both growing seasons, at the first harvest plant

Table 1. Growing season and climate characteristics during kenaf development planted on 4 row spacings and harvested at 2 plant heights (1; 2) at cutting during 2004 and 2005.
Tabla 1. Ciclo de crecimiento y factores climáticos durante el desarrollo de kenaf establecido en cuatro distancias entre surcos y cosechado en dos alturas de planta al corte (1; 2) durante 2004 y 2005.

Plant height	**Harvest**	**Growing season (days)**	**Mean temperature (°C)**		**Rainfall (mm)**	**Total evaporation (mm)**
			Minimum	**Maximum**		
2004						
1[‡]	1	54	20.0	36.6	25.2	514.3
	2	44	19.8	34.8	66.8	361.4
	3	61	17.5	33.4	39.4	346.3
	Total or mean	159	19.0	34.9	131.4	1222.1
2	1	74	20.0	36.2	34.6	692.3
	2	64	19.0	33.9	87.0	411.7
	Total or mean	138	19.5	35.1	121.6	1104.0
2005						
1	1	63	16.4	37.3	0	546.0
	2	42	21.8	37.3	9.2	419.7
	3	45	20.7	35.5	58.9	307.7
	Total or mean	150	19.2	36.8	68.1	1273.4
2	1	84	17.6	37.6	0	784.0
	2	64	21.3	35.8	68.1	489.4
	Total or mean	148	19.2	36.8	68.1	1258.2

[‡] Plant height 1 = 1.0-1.2 m; Plant height 2 = 1.8-2.0 m.

Table 2. Effect of plant height at cutting on the chemical composition of kenaf forage planted on 4 row spacings and harvested at 2 plant heights at cutting during 2004 and 2005.
Tabla 2. Efecto de la altura de planta al corte sobre la composición química del forraje de kenaf establecido en cuatro distanciamientos entre surcos y cosechado en dos alturas de planta al corte durante 2004 y 2005.

Plant height	**Crude protein (g/kg)**			**Neutral detergent fiber (g/kg)**		
	Harvest 1	**Regrowth** [±]	**Total** [±]	**Harvest 1**	**Regrowth** [±]	**Total** [±]
2004						
1 [‡]	237 a[†]	177 a	187 a	331 b	420 a	404 b
2	194 b	172 a	180 a	438 a	426 a	431 a
2005						
1	205 a	192 a	194 a	320 b	410 b	395 a
2	177 b	179 b	178 b	356 a	433 a	400 a

† For each year, mean values in each column followed by the same letter are not significantly different (Tukey≤0.05). [‡] Plant height 1 = 1.0-1.2 m; Plant height 2 = 1.8-2.0 m; [±] Weighted average with dry matter yields.

height 1 (1.0-1.2 m) yielded the highest CP contents, presenting values between 205 and 237 g/kg. When cutting was delayed in this first harvest until plants had reached a height of 1.8 to 2.0 m (height 2), CP contents decreased between 28 and 43 g/kg. In 2005, CP content in regrowth forage diminished by 13 g/kg when plants were harvested at height 2. As for NDF values, these ranged between 320 and 430 g/kg for the first harvest, and between 410 and 433 g/kg for regrowth forage in both growing seasons. When cutting was delayed until the crop had reached plant height 2, NDF content in harvest 1 increased between 36 to 107 g/kg. Only in 2005, regrowth forage NDF values increased by 23 g/kg in plant height 2 (Table 2).

With regard to total forage, weighted averages of CP and NDF content also presented significant differences ($p \leq 0.05$) between plant heights. In the first year, there were no CP content differences between plant heights ($p > 0.05$), but in the second year CP content decreased by 16 g/kg in plant height 2 ($p \leq 0.05$). NDF content values increased in plant height 2 by 27 g/kg ($p \leq 0.05$) in 2004, while no significant effects ($p > 0.05$) were observed in 2005 (Table 2).

Dry matter and crude protein yields. In both growing seasons, kenaf harvested at plant height 2 (2 cuts) produced more total DM (17%-26%) and CP (12.4%-15.6%) yields ($p \leq 0.05$) than kenaf harvested at plant height 1 (3 cuts). Separate analyses for harvest 1 and regrowth revealed that DM and CP yields in harvest 1 were higher when kenaf was harvested at plant height 2, whereas regrowth yields were higher ($p \leq 0.05$) in kenaf harvested at plant height 1 (Table 3).

Dry matter and CP yields of kenaf produced on narrow rows (0.19, 0.38, and 0.57 m) were higher than those obtained with conventional row spacing (0.76 m) ($p \leq 0.05$). Yield response to row spacing reduction was higher in 2004 than in 2005. In 2005, only those rows 0.19 m apart produced higher yields ($p \leq 0.05$) than conventional rows (Table 4).

In the first harvest of both growing seasons, DM and CP yields produced on 0.19 m spaced rows were higher than those observed on rows 0.76 m apart ($p \leq 0.05$). Comparison among narrow rows (0.19, 0.38 and 0.57 m) did not show any CP yield differences for the 2 growing seasons ($p > 0.05$). However, there were significant DM yield differences among narrow rows only in 2004, when rows spaced 0.19 m apart produced higher yields ($p \leq 0.05$). In the 2004 season, forage obtained from regrowth exhibited higher DM and CP yields on rows spaced at 0.19 m and 0.38 m than those on conventional row spacing (0.76 m). Yet, in 2005 only those rows spaced at 0.19 m produced higher yields than conventional rows ($p \leq 0.05$). In this latter season, comparison among narrow rows showed that yields on rows spaced at 0.19 m were higher ($p \leq 0.05$) than those obtained on 0.38 m row spacing (Table 4).

Dry matter partitioning. Only plant height at cutting significantly affected DM partitioning into plant aerial organs ($p \leq 0.05$). In both growing seasons, plants harvested at plant height 1 (1.0-1.2 m) had higher DM leaf partitioning, and such a response occurred in the first harvests as well as in regrowths. By contrast, higher DM partitioning into stems occurred when harvesting was delayed until plants had reached height 2 (1.8-2.0 m) at cutting. In 2004, plants developed reproductive organs only in the second regrowth harvested

Table 3. Effect of plant height at cutting on dry matter (DM) and crude protein (CP) yields of kenaf forage planted on 4 row spacings and harvested at 2 plant heights at cutting during 2004 and 2005.
Tabla 3. Efecto de la altura de planta al corte sobre los rendimientos de materia seca (MS) y proteína cruda (PC) de kenaf establecido en cuatro distancias entre surcos y cosechado en dos alturas de planta al corte durante 2004 y 2005.

Plant height	DM yield (kg/ha)			CP yield (kg/ha)		
	Harvest 1	Regrowth	Total [±]	Harvest 1	Regrowth	Total [±]
2004						
1 [‡]	2194 b[†]	10090 a	12284 b	520 b	1789 a	2308 b
2	5676 a	8692 b	14368 a	1098 a	1496 b	2594 a
2005						
1	1227 b	6050 a	7277 b	248 b	1160 a	1408 b
2	3916 a	5258 b	9173 a	689 a	938 b	1627 a

[†] For each year, mean values in each column followed by the same letter are not significantly different (Tukey≤0.05).
[‡] Plant height 1 = 1.0-1.2 m; Plant height 2 = 1.8-2.0 m; [±] Sum of all cut yields.

at plant height 1, and this response was due to crop growth extended until 21 October (Table 5).

Regression analysis showed significant linear relationships ($p \leq 0.05$) between leaf proportion in forage and CP and NDF contents. Harvest 1 of those plants harvested at plant height 1 yielded the best forage chemical composition. In such plants, a higher leaf proportion (55%) in forage favored higher CP contents and lower NDF concentrations. When leaf proportion decreased in harvest 1 of plant height 2 (38%-40%) and in regrowths harvested at plant height 1 (45%), the chemical composition showed intermediate values. When leaf proportion decreased to values between 36% and 38%, regrowth harvested at plant height 2 yielded the lowest CP and highest NDF concentrations (Fig. 1).

Table 4. Effect of row spacing (RS) on dry matter (DM) and crude protein (CP) yields of kenaf planted on 4 row spacings and harvested at 2 plant heights at cutting during 2004 and 2005.

Tabla 4. Efecto de la distancia entre surcos (DS) sobre los rendimientos de materia seca (MS) y proteína cruda (PC) de kenaf establecido en cuatro distancias entre surcos y cosechado en dos alturas de planta al corte durante 2004 y 2005.

RS (m)	DM yield (kg/ha)			CP yield (kg/ha)		
	Harvest 1	Regrowth	Total ±	Harvest 1	Regrowth	Total ±
2004						
0.19	4384 a †	10880 a	15263 a	889 a	1948 a	2837 a
0.38	3849 b	9747 ab	13596 b	822 ab	1756 ab	2578 ab
0.57	3916 ab	9098 bc	13015 b	814 ab	1528 bc	2342 bc
0.76	3591 b	7838 c	11429 c	711 b	1338 c	2048 c
2005						
0.19	3010 a	6115 a	9125 a	571 a	1155 a	1726 a
0.38	2404 ab	5337 b	7741 b	430 ab	1004 b	1433 b
0.57	2635 ab	5820 ab	8455 ab	469 ab	1052 ab	1520 ab
0.76	2236 b	5343 b	7579 b	405 b	986 b	1390 b

† For each year, mean values in each column followed by the same letter are not significantly different (Tukey≤0.05). ± Sum of all cuts yields.

Table 5. Effect of plant height at cutting on dry matter partitioning (%) into plant aerial organs of kenaf planted on 4 row spacings and harvested at 2 plant heights at cutting during 2004 and 2005.

Tabla 5. Efecto de la altura de planta al corte sobre la distribución porcentual de materia seca (MS) en los órganos de la parte aérea de kenaf establecido en cuatro distancias entre surcos y cosechado en dos alturas de planta al corte durante 2004 y 2005.

Plant height	2004		2005	
	Harvest 1	Regrowth	Harvest 1	Regrowth
Stem				
1 ‡	45.0 b †	56.2 b	45.2 b	54.5 b
2	60.1 a	61.3 a	55.2 a	62.1 a
Leaf ±				
1	55.0 a	38.0 a	54.8 a	45.5 a
2	39.9 b	35.8 b	44.8 b	37.9 b
Reproductive organs				
1	-	5.8 a	-	-
2	-	2.9 b	-	-

† For each plant aerial organ, mean values in each column followed by the same letter are not significantly different (Tukey≤0.05). ‡ Plant height 1 = 1.0-1.2 m; Plant height 2 = 1.8-2.0 m;
± Leaf = blade and petiole; Reproductive organs = flowers and developing fruits.

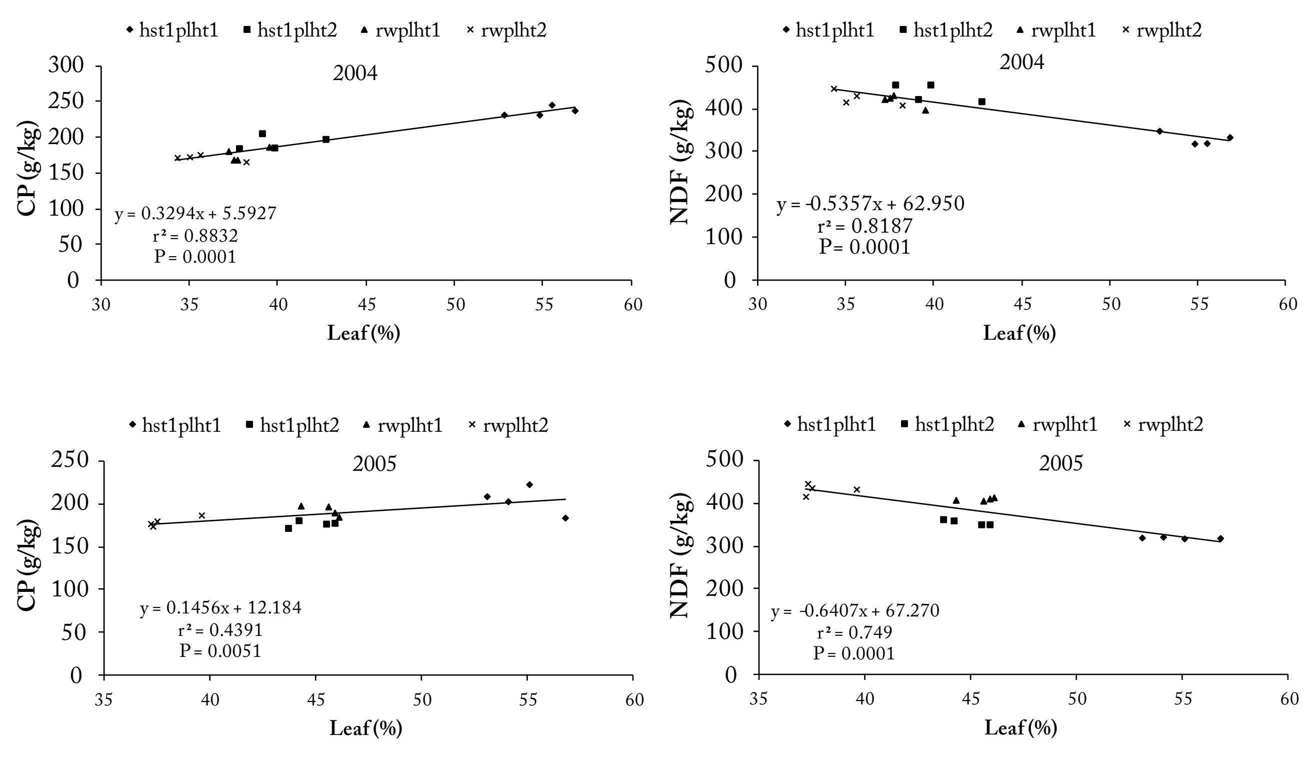

Fig. 1. Relationship between proportion of leaf in forage *versus* crude protein (CP) and neutral detergent fiber (NDF) contents of kenaf planted on 4 row spacings and harvested at 2 plant heights (plht) at cutting during 2004 and 2005. plht1 = 1-1.2m; plht2 = 1.8-2.0 m; hst1plht1 = harvest 1 of plht1; hst1plht2 = harvest 1 of plht2; rwplht1 = regrowth of plht1; rwplht2 = regrowth of plht2.

Fig. 1. Relación entre la proporción de hoja en el forraje *versus* los contenidos de proteína cruda (PC) y fibra detergente neutro (FDN) del kenaf establecido en cuatro distancias entre surcos y cosechado en dos alturas de planta al corte (Altpl) durante 2004 y 2005. altpl 1 = 1-1.2m; altpl 2 = 1.8-2.0 m. cos1altpl 1 = cosecha 1 de la altpl 1; cos1altpl 2 = cosecha 1 de la altpl 2; rbaltpl1 = rebrotes de la altpl 1; rbaltpl2 = rebrotes de la altpl 2.

DISCUSSION

Response of kenaf as a multiple harvest crop. Kenaf showed good regrowth ability, as also observed by other researchers (Nielsen, 2004; González-Valenzuela et al., 2005; González-Valenzuela et al., 2008). This response allowed production of good quality forage in 2 or 3 harvests over a period of 138 to 159 days, according to the plant height at cutting. In all harvests, plants were cut at 0.20 m stubble height; good regrowth attained in this study proves this cutting height would be an adequate management practice, which agrees with previous studies (González-Valenzuela et al., 2005).

In early sowing of kenaf (April 2005), growing periods of both evaluated plant heights were similar (148 to 150 days). However, when planting was delayed until May (2004), the plant height 1 season period (159 days) was longer than that for plant height 2 (138 days), since the second and last regrowth plants harvested at height 1 had a longer growing period because of the lower mean temperatures during September and October (Table 1). Due to such a longer growing season, one additional irrigation had to be applied, for a total 920-mm irrigation depth, in comparison to total irrigation depths of 800 mm more on the other cuts (plant height 2 in 2004 and plant heights 1 and 2 in 2005).

Chemical composition of forage. Row spacing reduction did not affect chemical composition of kenaf forage (p>0.05). On the contrary, plant height at cutting influenced forage chemical composition with lower CP contents and higher NDF values (p≤0.05) when kenaf plants were harvested when they reached height 2 (1.8-2.0 m). These responses are predictable because plant age decreased leaf content and increased the stem proportion in forage. In this way, forage chemical composition was modified, as proved by the significant linear relationship between leaf proportion and CP and NDF concentrations (Fig. 1). This response agrees with results from several other studies on kenaf (Swingle et al., 1978; Reta-Sánchez et al., 2010). It is related to the fact that kenaf leaves at any age have higher CP contents, over 220 g/kg, whereas stem CP concentration decreases to levels below 100 g/kg at 80-90 DAS (Phillips et al., 1999).

Weighted averages of CP and NDF concentrations in total harvested forage were similar to the values obtained in regrowth harvests because regrowths contributed a higher amount of forage than first harvests. Due to higher leaf proportion (39.9%-55.0%), first harvests yielded the best forage chemical composition; however, when leaf proportion decreased (35.8%-45.5%) and stem content increased (54.5% to 62.1%) CP concentration in regrowths declined and NDF content increased. Nevertheless, average values observed for CP (178 to 194 g/kg) and NDF (395 to 431 g/kg) were better than those previously found during the summer season by Reta-Sánchez et al. (2010) in the same locality. In such trial, kenaf produced single harvests at 66 and 74 DAS, with CP and NDF concentrations ranging from 135 to 158 g/kg, and from 421 to 595 g/kg, respectively. Dry matter partitioning values in aerial organs were 31.5% to 46.0% in leaves, 53.2% to 66.8% in stems and 0.7% to 1.6% in reproductive organs. We obtained a higher leaf proportion than that in the study of Reta-Sánchez et al. (2010). This was because plants remained at a vegetative developmental morphology stage during the growing season in most treatments. In the study conducted during the summer season, reproductive organs developed when photoperiods were less than 12.5 hours (Webber et al., 2002) at the end of September (Reta-Sánchez et al., 2008), which increased forage stem content.

Results indicated that kenaf may provide a high-protein forage (178 to 194 g/kg CP), with relatively low NDF levels (395 and 431 g/kg). As compared to alfalfa forage, kenaf forage CP values were slightly lower than those frequently observed during the spring and summer (210 g/kg), whereas NDF contents were similar in both species (400 g/kg) (Reta-Sánchez et al., 2011). Corn and sorghum forage produced during the spring and summer seasons showed concentrations of 58.8-67.8 g/kg for CP, and 612-676 g/kg for NDF (Reta-Sánchez et al., 2011). In comparison to values reported by these authors in corn and sorghum, our average values found on kenaf were better for both CP and NDF contents. Núñez-Hernández et al. (2001) reported concentrations between 74 and 95 g/kg for CP, and 447 to 633 g/kg for NDF in corn and sorghum forages.

Dry matter and crude protein yields. In terms of production potential, kenaf regrowth capacity allowed to produce over 228% more DM yields than kenaf with a single harvest (6296 kg/ha) (Reta-Sánchez et al., 2007; Reta-Sánchez et al., 2010). This yield increase required a prolongation of the growing season from 74 to 150 days, and an increase in the total irrigation depth, from 500 mm to 800 mm. The evaluation of both plant heights at cutting evidenced this response. There was also a DM yield increase due to row spacing reduction without affecting the forage chemical composition, thereby increasing CP yields also.

Results indicated kenaf with 2 harvests at plant height 2 (1.8-2.0 m) showed higher DM (17.0% to 26.0%) and CP (12.4% to 15.6%) yields, and better adaptation to the available growing period than kenaf with 3 harvests at plant height 1 (1.0-1.2 m). In both years, kenaf harvested at plant height 2 adapted better to the available growing period in the spring and summer seasons, reaching final harvesting in early September. In comparison, prolongation of the second regrowth cutting interval in the first year of kenaf harvested at plant height 1 delayed final harvesting until October. These results suggest kenaf can be harvested at either evaluated height, provided that an early planting date is considered (April), when plant height 1 is to be used as the criteria for harvesting.

Row spacing reduction from 0.76 m (conventional) to 0.19 m increased DM yields between 20.4% and 33.6%, and CP yields between 24.2% and 38.5%. These results are similar to those reported for kenaf for fiber production, which evidenced DM yield increases in narrow rows (Acreche et al., 2005; Baldwin & Graham, 2006). In the present study, since row spacing did not affect DM partitioning or forage chemical composition, DM yield increases also allowed CP yield increments in narrow rows. The best results were obtained in rows spaced 0.19 m and 0.38 m apart. The use of narrow-row production advantages will depend on chemical weed control alternatives, since mechanical weed control cannot be practiced in such narrow row spacings.

Kenaf yield in comparison with conventional crops. Major forage crops in the Comarca Lagunera region during the spring and summer seasons are alfalfa, corn, and sorghum. During the available period of both seasons (205-245 days), these crops produced 16916, 28134, and 30938 kg/ha DM yields, respectively, and 3552, 1850, and 1802 kg/ha CP yields, respectively (Reta-Sánchez et al., 2011). Dry matter yields of conventional crops are higher than those found for kenaf in this study. However, in CP production, kenaf's maximum yields (2594 kg/ha) were higher than those frequently obtained from corn and sorghum. In addition, kenaf forage showed a shorter growing season (138-159 days) and required less irrigation depth (800-960-mm) than conventional crops. To achieve the above-mentioned results, alfalfa requires a growing season of 245 days and 1680 mm of irrigation water, while corn and sorghum forages require 205 days to complete their growing seasons, and irrigation depths of 1270 mm (Reta-Sánchez et al., 2011). These results indicate that, compared to alfalfa, kenaf produced 85% of DM yields and 73% of CP yields in a 95-day shorter growing season, needing only a 53% total irrigation depth. Similarly, when compared with corn and sorghum planted in spring and summer seasons, kenaf produced between 46% and 51% of DM yields, and between 140% and 144% of CP yields, with a growing season 55 days shorter and demanding only 65% total irrigation depth.

CONCLUSIONS

Results evidence that kenaf forage potential increases when established on narrow rows and with multiple harvesting. In a 138 to 159-day growing period, kenaf's regrowth ability after cutting allowed 3 harvests when plants were cut at height 1.0-1.2 m (plant height 1), and 2 harvests at height 1.8-2.0 m (plant height 2). When harvested at plant height 2, DM and CP yields increased by 17.0%-26.0% and 12.4%-15.6%, respectively. In addition, crop development adaptated better to the available growing period. Row spacing reduction, from 0.76 m (conventional) to 0.38 m and 0.19 m, increased DM yields between 20.4% and 33.4%, without affecting forage chemical composition. Due to this response, CP yields increased between 24.2% and 38.5% in kenaf planted on narrow rows. In general, kenaf can be a good alternative forage crop on account of its efficient water use and nutrients content.

ACKNOWLEDGEMENTS

This research was funded by Consejo Nacional de Ciencia y Tecnología, Fundación Produce Coahuila, A.C., Fundación Produce Durango, A.C., and Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (México).

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