RESEARCH

Kenaf Forage Yield and Quality as Affected by Population Density

David Guadalupe Reta-Sánchez,* Beatríz Hernández-Dozal, José Antonio Cueto-Wong, Jesús Olague-Ramírez, and J. Santos Serrato-Corona

ABSTRACT

Population density can affect kenaf (*Hibiscus cannabinus* L.) forage morphology, yield, and nutritive value. The impact of plant population density on dry matter (DM) yield, DM partitioning in aerial organs, and forage quality parameters such as crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF) was determined. This study was conducted in Matamoros, Coahuila, Mexico, in the summers (June–September) of 2005 and 2006. Kenaf response to six plant population densities, ranging from 160,000 to 1,860,000 plants ha^{-1}, was determined using a randomized complete block design with four replications. Regression analysis was used to examine the relationship between plant density and parameters measured. Response of DM yield to population density was quadratic with maximum production (7078–7469 kg ha^{-1}) between 920,000 and 1,245,000 plants ha^{-1}. Dry matter yields per plant, number of nodes, and stem diameter declined as population density increased in a quadratic fashion, primarily between 160,000 and 840,000 plants ha^{-1}. Dry matter partitioning into aerial organs and nutritive value were not affected by plant population. To reduce lodging susceptibility due to overly slender stems and to achieve about 95% of maximum yield, the proper population range for kenaf forage harvested at 89 d after sowing would appear to be 343,500 to 637,000 plants ha^{-1}.

D.G. Reta-Sánchez and J.A. Cueto-Wong, Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP). Blvd. José Santos Valdez 1200. Col. Centro. 27440, Cd. Matamoros, Coahuila, México; B. Hernández-Dozal and J. Olague-Ramírez, Instituto Tecnológico de Torreón. Km. 7.5, Carr. Torreón-San Pedro, Ejido Ana, Torreón, Coahuila, México; J.S. Serrato-Corona, Facultad de Agricultura y Zootecnia, Universidad Juárez del Estado de Durango, Domicilio Conocido, Ej. Venecia, Dgo. Apdo. Postal 1-142, Gómez Palacio, Dgo. Received 23 Mar. 2009. *Corresponding author (reta.david@inifap.gob.mx).

Abbreviations: ADF, acid detergent fiber; CP, crude protein; DAS, days after sowing; DM, dry matter; LAI, leaf area index; NDF, neutral detergent fiber.

In dairy production systems settled in arid and semiarid regions of Mexico, herd nutrition relies on good quality forages produced by irrigation. In these regions, traditional cropping systems based on alfalfa (*Medicago sativa* L.), corn (*Zea mays* L.), sorghum [*Sorghum bicolor* (L.) Moench], and oats (*Avena sativa* L.) face multiple problems due to limited water availability and increasing soil salinity and a limited cropping pattern for forage production. Therefore, it is important to search for alternative crops that very efficiently use natural resources for forage production.

Kenaf (*Hibiscus cannabinus* L.) may be a suitable alternative crop for integration into farm production systems in arid and semiarid regions of Mexico. Kenaf displays several beneficial characteristics such as salinity tolerance (Francois et al., 1992), adaptation to irrigated arid environments (Nielsen, 2004), and capacity for growth in warm environments (LeMahieu et al., 1991). In addition, precocity allows harvest at 70 to 83 d after sowing (DAS) (Phillips et al., 1999; Reta et al., 2006).

Published in Crop Sci. 50:744–750 (2010).
doi: 10.2135/cropsci2009.03.0150
Published online 6 Jan. 2010.

Traditionally, kenaf has been cultivated for fiber production (Taylor and Kugler, 1992). However, several studies have demonstrated its potential as a forage crop (Swingle et al., 1978; Rojas et al., 1994), especially when harvested early (Phillips et al., 1989; González-Valenzuela et al., 2008). Several researchers have reported protein concentrations from 154 to 279 g kg^{-1} in kenaf harvested at 40 to 105 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^{-1} and acid detergent fiber (ADF) concentrations ranged from 176 to 236 g kg^{-1} (Swingle et al., 1978; Vinson et al., 1979). However, NDF (352–515 g kg^{-1}) and ADF (294–419 g kg^{-1}) concentrations increased considerably with delayed harvest (80–105 DAS) (Swingle et al., 1978; Vinson et al., 1979; Phillips et al., 1996).

Little information is available regarding kenaf forage response to population density, which affects plant morphology, dry matter (DM) accumulation, and susceptibility to lodging. Previous research has focused primarily on the effect of population density on stem and total DM yield for fiber production (Campbell and White, 1982; Acreche et al., 2005).

Increasing kenaf population densities results in greater plant competition for water, light, and nutrients; therefore, plants are typically shorter with smaller stem diameters and are more susceptible to lodging (Higgins and White, 1970; Acreche et al., 2005). At very low planting densities kenaf produces multiple branches, which renders harvesting more difficult (Higgins and White, 1970; Massey, 1973). Optimum population density for DM production varies according to environment, agronomic management, and cultivar. In other studies kenaf plants have displayed high plasticity. Webber et al. (2001) reported from 185,000 to 370,000 plants ha^{-1} as the desirable population density for kenaf. However, due to the influence of different factors such as environment and cultivars, other research suggests optimum population density varies from 400,000 to 700,000 plants ha^{-1} (Campbell and White, 1982; Bukhtiar et al., 1990; Manzanares et al., 1996). The objective of this study was to determine the influence of population density on kenaf DM yields, DM partitioning into aerial organs, and forage quality.

MATERIALS AND METHODS

This study was conducted at La Laguna Experimental Station of the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, located in Matamoros, Coahuila, México (25°32′ N, 103°14′ W and 1150 m altitude above sea level), on a clay loam soil. Soil preparation consisted of plowing, disking, leveling, and layout. Before sowing, 50 kg of N and 100 kg of P_2O_5 ha^{-1} were applied, using granulated mono-ammonium phosphate. Sowing was performed on dry soil on June 21, 2005, and June 20, 2006. One 200-mm irrigation was applied immediately after sowing. Kenaf 'Everglades 41' was used, which is an intermediate-cycle photoperiod-sensitive genotype (Webber and Bledsoe, 1993).

During 2005 the evaluated population densities were 160,000, 500,000, 840,000, 1,180,000, 1,400,000 and 1,550,000 plants ha^{-1}, while in 2006, 200,000, 500,000, 840,000, 1,180,000, 1,520,000, and 1,860,000 plants ha^{-1} were examined. The seeding rate was increased 100% over the target plant population treatments and plants were thinned by hand at 20 and 34 DAS to achieve the desired population densities. Plant densities changed from year to year because self-thinning reduced the stands below the target plant population in 2005. A complete randomized block design with four replications was used. Each experimental plot consisted of six 3-m rows with a row spacing of 0.38 m. To maintain adequate soil moisture, 120-mm irrigation was applied on 17, 37, 57, and 77 DAS. During the first two irrigations, additional applications of 50 kg ha^{-1} of N as urea were made. During the 2005 growing season, a 68-mm rainfall was received compared with 178 mm in 2006. In 2005, average maximum, minimum, and mean temperatures were 36.3, 21.3, and 28.8°C, respectively, and in 2006 these were 32.9, 21.2, and 26.8°C.

Pest control was conducted by means of two insecticide applications at 21 and 56 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-6,9-methano-2,4,3-benzodioxathiepin 3-oxide) at 1.5 L ha^{-1} and Rescate 20 PS {DuPont Mexico, S.A. de C.V., Mexico, DF; acetamiprid; (*E*)-N^1-[(6-chloro-3-pyridyl)methyl]-N^2-cyano-N^1-methylacetamidine} at 0.400 kg ha^{-1} were applied for whitefly (*Bemisia argentifolii* Bellows and Perring) control at 21 and 56 DAS. Weed control was achieved by hand and hoe.

Before harvesting, plant height and stem nodes from five randomly selected plants per plot were recorded. Four 2-m rows located at the center of each experimental plot were used for determining yields. The harvested plants were cut 20 cm above the soil surface, at 87 DAS in 2005 and 89 DAS in 2006, and before flowering. After harvesting, stem diameters were measured on 20 plants per plot. The number of harvested plants per plot were counted as well.

At harvest time, fresh forage yield per plot was determined. Dry matter percentage per plot was calculated using a plant sample from a 2-m row (0.76 m^2). These plants were dried in a forced-air oven at 60°C, until a constant weight was obtained. Dry matter yield was determined multiplying fresh forage yield times the percentage of DM obtained on each plot. Dry matter yield per plant was determined by dividing DM yield by the number of plants harvested on each plot.

Dry matter partitioning into plant aerial organs was also determined at harvest time. To achieve this, one 2-m row (0.76 m^2) from each plot was sampled, and stems and leaves (blades and petioles) were separated. Plants were dried at 60°C until a constant weight was obtained, to determine the dry weight of each aerial organ of the crop. Leaf area index (LAI) was determined for each plot using a LAI-2000 consisting of an optical sensor (LAI-2050) and a control unit (LAI-2070) (LI-COR, 1992). Two readings were recorded in the center of each plot, one was taken above the canopy and the other beneath.

The plants that were sampled to estimate DM percentage were also used to determine forage quality in terms of CP, ADF, and NDF. The dried plants were ground in a Wiley mill to pass through a 1.0-mm screen. These samples were analyzed according to the procedures described by Goering and Van Soest (1970) for NDF and ADF and using the Kjeldahl procedure for N (Bremner, 1996).

All data were analyzed with the General Linear Model using SAS statistical software (SAS Institute, 1985). Data were combined over plant population and years. Weighted least squares regression was used to examine the relationship of the means of each plant density to DM yield, agronomical characteristics, and forage quality parameters. Linear or quadratic equations were selected according to the significance of the regression coefficients. Effects were considered significant in all statistical calculations if P values were ≤ 0.05.

RESULTS AND DISCUSSION

Population density × year interactions for DM yield and LAI were observed, whereas no interactions existed for the other agronomic characteristics and quality forage parameters. Average over years, DM yield, DM yield per plant, number of nodes, stem diameter, LAI, and DM accumulated in stem and leaf were affected by plant population. When averaged across plant population, significant DM yield, stem diameter, and forage quality parameters response was observed due to year (Table 1).

Dry matter yields response to plant population differed between growing seasons, probably due to less favorable weather in 2005, when the trial received less rainfall and maximum and mean temperatures were higher than in 2006. Increases in DM yields due to plant population were higher in 2005 (1123 kg ha^{-1}) than in 2006 (582 kg ha^{-1}). The response of DM yield to population density was quadratic in both years. In 2005 the highest DM production was attained at 1,245,000 plants ha^{-1}, whereas in 2006 the maximum was achieved at 920,000 plants ha^{-1}. Averaged across plant densities and years, DM yields were of 6669 to 7023 kg ha^{-1} (Fig. 1 and Table 2). These production yields are similar to those reported by Reta et al. (2006) with Everglades 41 harvested 83 DAS at the same experimental location (6920 kg ha^{-1}). Studies conducted in the United States by Webber (1993), Muir (2001), and Nielsen (2004) reported production levels of 4764 to 7512 kg ha^{-1}, which were lower or similar to those found in this study.

Dry matter yields per plant, number of nodes, and stem diameter decreased as population density increased in a quadratic model. The main changes occurred when plant density was between 160,000 and 840,000 plants ha^{-1}. Plant height was not affected by population density. Reductions in stem diameter due to population density increases are similar to those found in other studies, resulting from intraspecific competition among plants (Campbell and White, 1982; Acreche et al., 2005). As for the LAI, only in the first year was a positive linear relationship with plant population observed, with an increase rate of 0.157 per 100,000 plants ha^{-1}. In 2006, LAI ranged from 3.6 to 4.0 (Fig. 1 and Table 2).

The plant densities required to achieve the maximum DM yields in this study (920,000 to 1,245,000 plants ha^{-1}) were higher than those reported in studies aimed for fiber production (Webber et al., 2001). However, considering only the part of the curves where the yields reached 95% of maximum yields (Fig. 1; 343,500 to 637,000 plants ha^{-1}), the results are similar to other reports indicating that 400,000 to 700,000 plants ha^{-1} are required to obtain maximum yields (Campbell and White, 1982; Bukhtiar et al., 1990; Manzanares et al., 1996). Although lodging was not observed in this study, due to the effects of plant competition on stem diameter in high plant populations, kenaf plants could be more susceptible to lodging as indicated by Higgins and White (1970) and Massey (1973). Therefore, to determine the optimum plant population, lodging susceptibility aside from DM yields should be considered. Under these conditions, kenaf response indicates that the best plant population could be below 840,000 plants ha^{-1} to avoid an excessive reduction of stem diameter. Assuming a yield of 95% of the maximum to be suitable, the proper population range for kenaf forage harvested at 89 DAS would appear to be between 343,500 and 637,000 plants ha^{-1}.

Dry matter yield response in this study differed from previous trial that reported a lack of response in kenaf DM yields as population density increased above 160,000 plants ha^{-1} (Webber et al., 2001). However, taking into consideration that DM yield increases due to plant population were between 8.4 and 18.9%, the results showed that Everglades 41 plants had high plasticity since they had the capability to compensate for lower number of plants per surface unit at low densities (160,000 and 200,000 plants ha^{-1}) with a

Table 1. *T* values from a combined analysis of variance for dry matter (DM) yields, agronomic characteristics, and quality forage parameters of kenaf at harvest established in six population densities (PDs) in 2005 and 2006 at Matamoros, Coahuila, México.

	Significance‡		
Parameters†	PD	Year	PD × year
DM yield, kg ha^{-1}	0.0030	0.0014	0.0066
DM yield, g plant^{-1}	0.0001	0.4282	0.2390
Plant height, cm	0.1203	0.1974	0.7640
No. of nodes in stem	0.0265	0.3271	0.8252
Stem diameter, cm	0.0011	0.0012	0.5078
LAI	0.0010	0.0955	0.0093
DM in stem, g plant^{-1}	0.0203	0.7283	0.9181
DM in leaf, g plant^{-1}	0.0174	0.8653	0.9053
CP, g kg^{-1} DM	0.2406	0.0013	0.1429
ADF, g kg^{-1} DM	0.8591	0.0046	0.9860
NDF, g kg^{-1} DM	0.8133	0.0002	0.7008

† LAI, leaf area index; CP, crude protein; ADF, acid detergent fiber; NDF, neutral detergent fiber.

‡ Effects were considered significant if T values were ≤ 0.05.

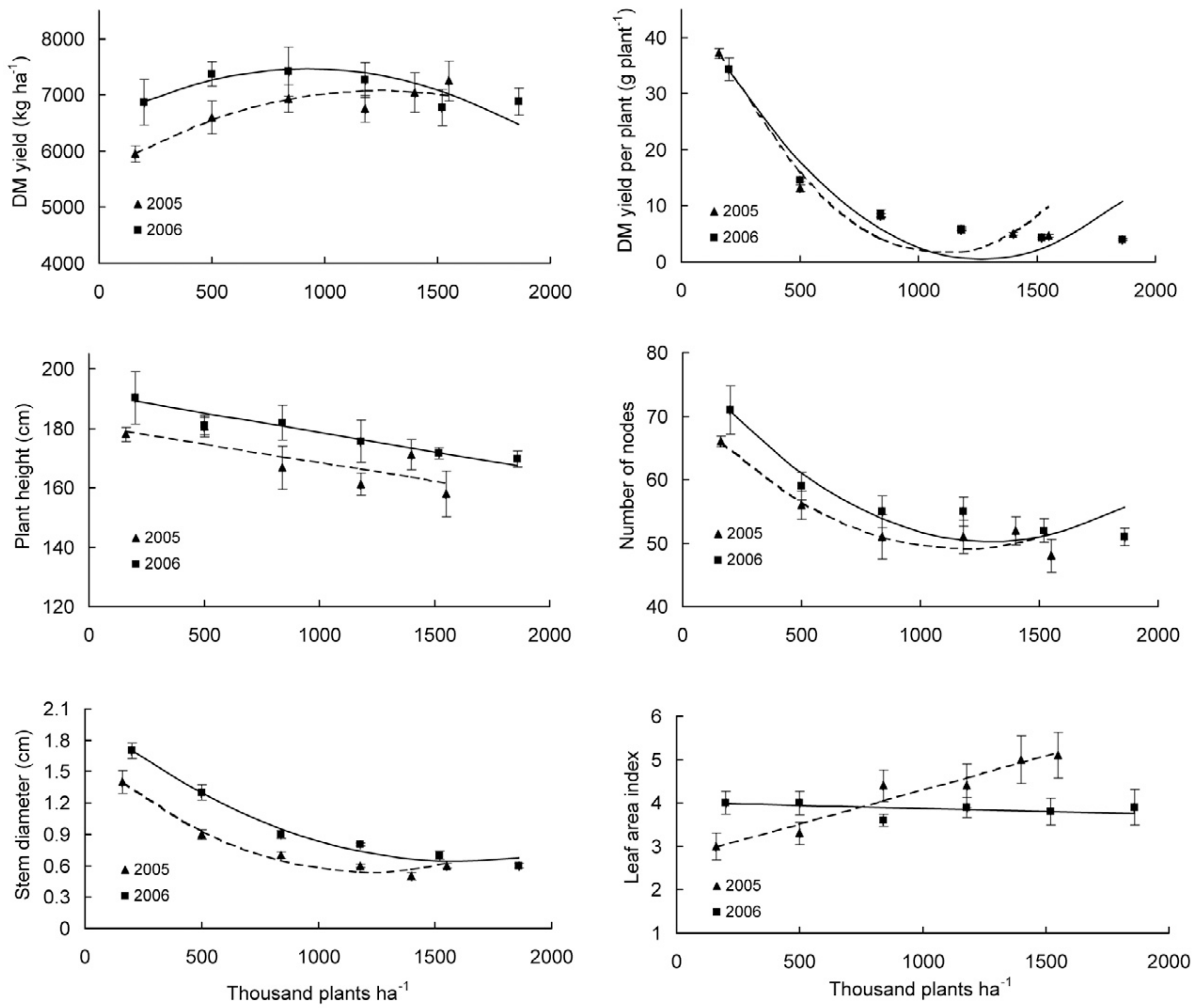

Figure 1. Relationship between dry matter (DM) yields and agronomical characteristics of kenaf at harvest with plant population in 2005 and 2006 at Matamoros, Coahuila, México. Vertical bars indicate standard errors of the mean.

higher DM accumulation per plant and larger diameter stems. Also, the results showed that DM yields began to reduce at high plant populations (Fig. 1). This behavior can favor an adequate stand establishment considering kenaf self-thinning, without detrimental effects on DM yields.

The DM partitioning into kenaf aerial organs per plant as affected by plant density showed a quadratic trend (Fig. 2 and Table 2), in which a greater accumulation of DM can be observed in stems as well as in leaves of lower-density populations. In all cases the primary changes occurred when plant density was increased to between 160,000 and 840,000 plants ha^{-1}. Little differences in DM distribution into the aerial organs of the plants were observed due to a compensatory effect. On average, DM partitioning was between 63 and 66% in stems and between 34 and 37% in leaves (Fig. 3). Dry matter percentages in leaves were slightly above the 32% reported by Bledsoe and Webber (2001) for Everglades 41 harvested at 60 DAS, but similar to 36.2% found by Webber (1993) in kenaf harvested at 76 DAS, 37% observed by Webber and Bledsoe (2002) at 90 DAS, and 35.9% reported by Reta et al. (2006) at 83 DAS.

Increases in population density were not related to kenaf nutritive value in terms of crude protein (CP) and fiber concentrations (Table 2). In 2005, average CP, ADF, and NDF concentrations were 177, 453, and 524 g kg^{-1}, respectively; while in 2006 these values were 126, 497, and 613 g kg^{-1}, respectively (Fig. 4). This response is probably predictable when considering that density increase did not modify the forage leaf and stem proportions, which are related to forage quality in terms of CP and fiber concentrations (Swingle et al., 1978).

Nutritive-value parameters obtained were similar to those found by Reta et al. (2006) on Everglades 41 established in the same location with a population density of 160,000 plants ha^{-1} and harvested at 83 DAS during its flowering phase. Swingle et al. (1978) and Muir (2002) reported higher CP concentrations (192 g kg^{-1}) and lower ADF (280 to 290 g kg^{-1}) and NDF (350 to 380 g kg^{-1}) concentrations in studies conducted in the United States, harvesting between 80 and 90 DAS, than those found in this experiment, probably due to an earlier phenological phase at harvesting. This behavior is observed in kenaf

Table 2. Regression equations for dry matter (DM) yields, agronomic characteristics, and quality forage parameters of kenaf at harvest established in six population densities in 2005 and 2006 at Matamoros, Coahuila, México.

Parameters†	Year	Regression equation	Significance‡		
			b	c^2	R^2
DM yield, kg ha^{-1}	2005	$y = 5599.82 + 2.37x\text{-}95E\text{-}05x^2$	0.01	0.05	0.97
	2006	$y = 6519.18 + 2.06x\text{-}11E\text{-}04x^2$	0.02	0.03	0.88
DM yield, g plant^{-1}	2005	$y = 50.30 - 0.09x + 41E\text{-}06x^2$	0.01	0.01	0.98
	2006	$y = 47.91 - 0.08x\text{-}30E\text{-}06x^2$	0.01	0.02	0.97
Plant height, cm	2005	$y = 180.93 - 12E\text{-}03x$	0.04	–	0.71
	2006	$y = 191.72 - 13E\text{-}03x$	0.01	–	0.91
No. nodes in stem	2005	$y = 71.73 - 0.04x + 16E\text{-}06x^2$	0.01	0.01	0.99
	2006	$y = 79.01 - 0.04x + 17E\text{-}06x^2$	0.01	0.04	0.96
Stem diameter, cm	2005	$y = 1.68 - 19E\text{-}04x + 77E\text{-}08x^2$	0.01	0.01	0.99
	2006	$y = 2.02 - 17E\text{-}04x + 54E\text{-}08x^2$	0.01	0.01	0.99
LAI	2005	$y = 2.73 + 16E\text{-}04x$	0.01	–	0.96
	2006	$y = 4.01 - 14E\text{-}05x$	0.27	–	–
DM in stem, g plant^{-1}	2005	$y = 28.05 - 0.05x + 22E\text{-}06x^2$	0.01	0.03	0.96
	2006	$y = 33.03 - 0.05x + 21E\text{-}06x^2$	0.01	0.02	0.97
DM in leaf, g plant^{-1}	2005	$y = 18.30 - 0.03x + 16E\text{-}06x^2$	0.01	0.03	0.96
	2006	$y = 20.94 - 0.04x + 14E\text{-}06x^2$	0.01	0.03	0.96
CP, g kg^{-1} DM	2005	$y = 168.4 + 90E\text{-}04x$	0.30	–	0.26
	2006	$y = 139.2 - 13.8E\text{-}03x$	0.03	–	0.75
ADF, g kg^{-1} DM	2005	$y = 459 - 34.9E\text{-}03x + 23.4E\text{-}06x^2$	0.18	0.21	0.50
	2006	$y = 497 + 21.5E\text{-}04x$	0.76	–	0.02
NDF, g kg^{-1} DM	2005	$y = 529.6 - 58.4E\text{-}04x$	0.63	–	0.06
	2006	$y = 607.2 + 57.3E\text{-}04x$	0.55	–	0.09

† LAI, leaf area index; CP, crude protein; ADF, acid detergent fiber; NDF, neutral detergent fiber; *x*, thousand plants ha^{-1}.

‡Effects were considered significant if *T*-values $\leq$ 0.05.

forage harvested at 52 DAS, at an average plant height of 1.0 to 1.20 m, making it possible to reach concentrations of up to 169 g kg^{-1} CP, 373 g kg^{-1} ADF, and 408 g kg^{-1} NDF with Everglades 41 under similar conditions to those of the present experiment (Reta et al., 2007). Swingle et al. (1978) reported concentrations of 110 g kg^{-1} CP, 520 g kg^{-1} NDF, and 412 g kg^{-1} ADF in kenaf harvested at 130 DAS.

CONCLUSIONS

Nutritive value and DM yield of kenaf forage harvested at 89 DAS, showed a high plasticity in response to plant population. Nutritive value in terms of CP, ADF, and NDF was not modified by plant population. In DM yield, the response to population density was quadratic, with a large plant population interval with high DM yields. Considering only the part of the curves where yield reached 95% of maximum yields, the proper population range for kenaf forage would appear to be 343,500 to 637,000 plants ha^{-1}. The high plasticity of kenaf forage can be an important characteristic because it allows adjusting seeding rates to ensure adequate stands considering self-thinning, without detrimental effects on yield and nutritive value.

Acknowledgments

This research was funded by the Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (México); Consejo Nacional de Ciencia y Tecnología (Mexico); Patronato para La Investigación, Fomento y Sanidad Vegetal de la

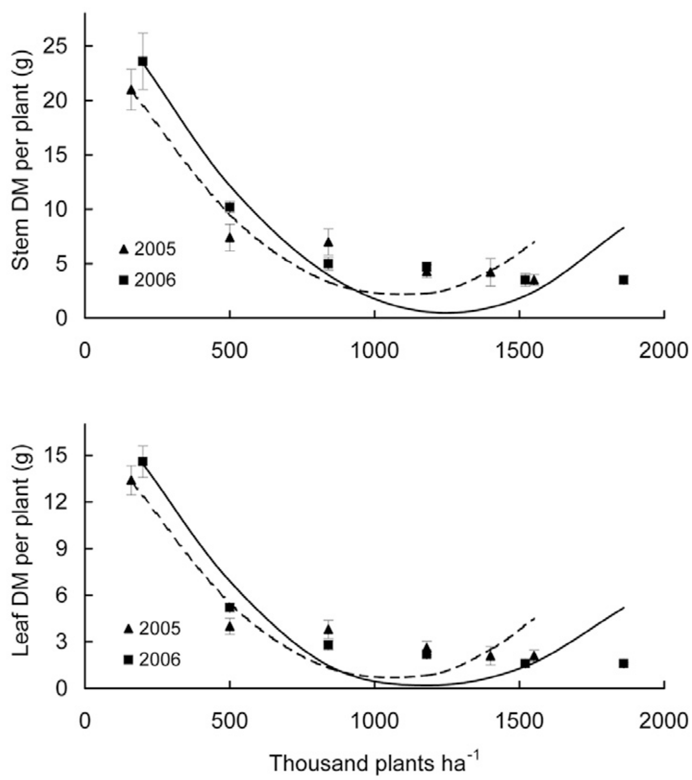

Figure 2. Kenaf stem and leaf dry matter (DM) yield per plant in relation to plant population in 2005 and 2006 at Matamoros, Coahuila, México. Vertical bars indicate standard errors of the mean.

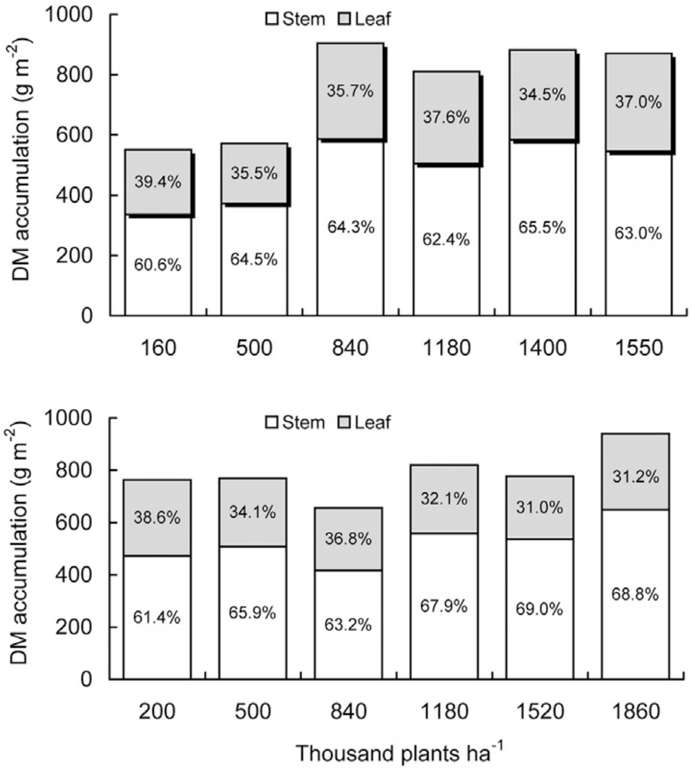

Figure 3. Dry matter (DM) partitioning among leaf and stem of kenaf established in six population densities in 2005 and 2006 at Matamoros, Coahuila, México.

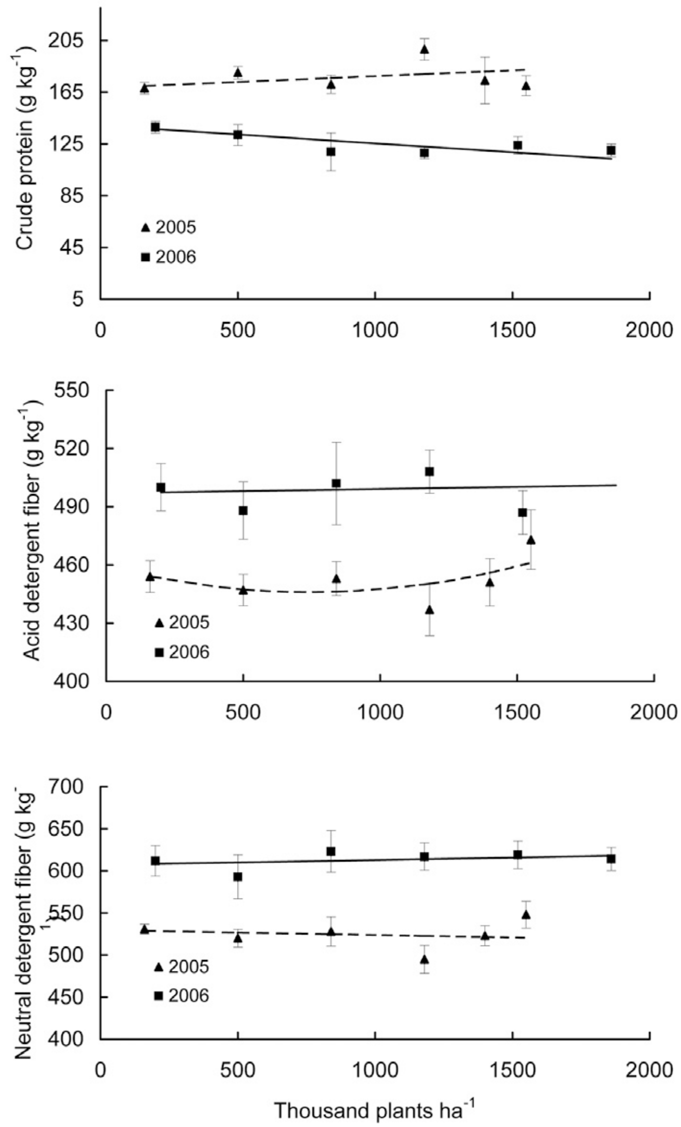

Figure 4. Relationship between forage quality parameters of kenaf at harvest with plant population in 2005 and 2006 at Matamoros, Coahuila, México. Vertical bars indicate standard errors of the mean.

Comarca Lagunera; Fundación Produce Coahuila, A.C.; and Fundación Produce Durango, A.C.

REFERENCES

Acreche, M.M., L.N. Gray, N.G. Collavino, and J.A. Mariotti. 2005. Effect of row spacing and lineal sowing density of kenaf (*Hibiscus cannabinus* L.) yield components in the north-west of Argentina. Span. J. Agric. Res. 3:123–129.

Bledsoe, V.K., and C.L. Webber, III. 2001. Crop maturity and yield components. p. 64. *In* 5th. Natl. Symp., New Crops & New Uses: Strength in Diversity, Atlanta, GA. 10–13 Nov. 2001. Conf. Program and Abstracts. ASHS Press, Alexandria, VA.

Bremner, J.M. 1996. Nitrogen—Total. p. 1085–1121. *In* D.L. Sparks (ed.) Methods of soil analysis. Part 3. SSSA Book Ser. 5. SSSA, Madison, WI.

Bukhtiar, B.A., M.A. Iqbal, M. Idris, I. Ahmadi, and A.G. Kausar. 1990. Effect of sowing date and plant population on fibre yield of kenaf (*Hibiscus cannabinus* L.). J. Agric. Res. Lahore. 28:99–105.

Campbell, T.A., and G.A. White. 1982. Population density and planting date effects on kenaf performance. Agron. J. 74:74–77.

Francois, L.E., T.J. Donovan, and E.V. Maas. 1992. Yield, vegetative growth, and fiber length of kenaf grow on saline soil. Agron. J. 84:592–598.

Goering, H.K., and P.J. Van Soest. 1970. Forage fiber analysis (apparatus, reagents, procedures, and some applications). Handbook 379. USDA-ARS, Washington, DC.

González-Valenzuela, E.A., J.M. Avila-Curiel, J.A. Ortega-S., M.A. Gonzalez-Padrón, and J.P. Muir. 2008. Harvesting interval changes yield and nutritive value of kenaf in a dry tropical climate. Agron. J. 100:938–941.

Higgins, J.J., and G.A. White. 1970. Effects of plant population and harvest date on stem yield and growth components of kenaf in Maryland. Agron. J. 62:667–668.

LeMahieu, P.J., E.S. Oplinger, and D.H. Putnam. 1991. Kenaf. Alternative field crops manual. Available at www.hort.purdue.edu/newcrop/afcm/kenaf.html (verified 3 Dec. 2009). Univ. of Wisconsin Cooperative Extension Service, Madison, WI, and the University of Minnesota Extension Service and the Center for Alternative Plant and Animal Products, St. Paul, MN.

LI-COR. 1992. LAI-2000 plant canopy analyzer operating manual. LI-COR, Lincoln, NE.

Manzanares, M., J.L. Tenorio, and L. Ayerbe. 1996. Sowing time, cultivar, plant population and application of N fertilizer on kenaf in Spain's Central Plateau. Biomass Bioenergy 12:261–271.

Massey, J.H. 1973. Effects of plant density on two varieties of kenaf in the Georgia Piedmont region. Agron. J. 65:848–849.

Muir, J.P. 2001. Dairy compost, variety, and stand age effects on kenaf forage yield, nitrogen and phosphorus concentration, and uptake. Agron. J. 93:1169–1173.

Muir, J.P. 2002. Effect of dairy compost application and plant maturity on forage kenaf cultivar fiber concentration and in sacco disappearance. Crop Sci. 42:248–254.

Nielsen, D.C. 2004. Kenaf forage yield and quality under varying water availability. Agron. J. 96:204–213.

Phillips, W.A., F.T. McCollum, and C.Q. Fitch. 1999. Kenaf dry matter production, chemical composition, and in situ disappearance when harvested at different intervals. Prof. Anim. Sci. 15:34–39.

Phillips, W.A., S. Rao, D.L. Von Tungeln, and G.Q. Fitch. 1996. Digestibility of freshly harvested, ensiled and mature kenaf by sheep. Prof. Anim. Sci. 12:99–104.

Phillips, W.A., C.R. Srinivas, and T.H. Dao. 1989. Nutritive value of immature whole plant kenaf and mature kenaf tops for growing ruminants. p. 17–22. *In* Proc. Assoc. Adv. of Industrial Crops, Peoria, IL. 5 Oct. 1989. USDA-ARS, Peoria, IL.

Reta S., D.G., J. Santamaria C., J.A. Cueto W., J.S. Serrato C., R. Figueroa V., J.F.J. Chavez G., S. Berumen P., and J.I. Romero P.R. 2007. Potencial de kenaf como cultivo forrajero durante el ciclo de verano en la Comarca Lagunera. Folleto Técnico Núm. 15. INIFAP-CIRNOC-CELALA. Matamoros, Coah., Mexico.

Reta S., D.G., J.S. Serrato C., J.A. Cueto W., J. Santamaria C., J.F.J. Chavez G., and J.I. Romero P.R. 2006. Rendimiento y calidad de forraje de kenaf y sorgo nervadura café en unicultivo y en asociación con maíz. Rev. Fitotec. Mex. 29:91–95.

Rojas, A., H. Dormond, and E. Vazquez. 1994. Valor potencial del kenaf (*Hibiscus cannabinus*) para la alimentación de rumiantes en el trópico. Agron. Costarricense 18:141–145.

SAS Institute. 1985. SAS user's guide: Statistics. Version 5.0. 5th ed. SAS Inst., Cary, NC.

Swingle, R.S., A.R. Urias, J.C. Doyle, and R.L. Voigt. 1978. Chemical composition of kenaf forage and its digestibility by lambs and in vitro. J. Anim. Sci. 46:1346–1350.

Taylor, C.S., and D.E. Kugler. 1992. Kenaf: Annual fiber crop products generate a growing response from industry. p. 92–98. *In* 1992 Yearbook of agriculture. Office of Publishing and Visual Communication, USDA, Washington, DC.

Vinson, H.W., R.S. Swingle, and R.L. Voigt. 1979. Nutritive value and yield of kenaf (*Hibiscus cannabinus*) grown for forage compared with conventional annual forages. Proc. Western Sect. Am. Soc. Anim. Sci. 30:194–197.

Webber, C.L., III. 1993. Crude protein and yield components of six kenaf cultivars as affected by crop maturity. Ind. Crops Prod. J. 2:27–31.

Webber, C.L., III, H.L. Bhardwaj, and V.K. Bledsoe. 2001. Kenaf production: Fiber, feed and seed. p. 315–327. *In* Proc. V National Symposium, New Crops and New Uses: Strength in Diversity, Atlanta, GA. 10–13 Nov. 2001. ASHS Press, Alexandria, VA.

Webber, C.L., III, and R.E. Bledsoe. 1993. Kenaf: Production, harvesting, processing, and products. p. 416–421. *In* J. Janick and J.E. Simon (ed.) New crops. John Wiley & Sons, New York.

Webber, C.L., III, and V.K. Bledsoe. 2002. Kenaf yield components and plant composition. p. 348–357. *In* J. Janick and A. Whipkey (ed.) Trends in new crops and new uses. ASHS Press, Alexandria, VA.