Kenaf Forage Yield and Quality under Varying Water Availability

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ABSTRACT

A broadleaf forage crop grown in rotation with winter wheat (*Triticum aestivum* L.) would diversify dryland crop rotations in the central Great Plains. Kenaf (*Hibiscus cannabinus* L.) provides good quality livestock forage, but yield and quality have not been evaluated under varying water availability conditions. This study determined kenaf soil water extraction, plant height, regrowth following cutting, dry matter (DM) yield, and forage quality responses to varying water availability. Kenaf was planted on a Weld silt loam (fine, smectitic, mesic Aridic Argiustolls) under a line-source gradient irrigation system. Water conditions ranged from rainfed to full evapotranspiration replacement. Kenaf was harvested in early August and then again in October. Dry matter yield increased linearly with increases in available water and water use, with about 2000 kg ha^{-1} DM yield produced with 274-mm water use increasing to 6000 kg ha^{-1} with 507-mm water use. Crude protein (163 to 279 g kg^{-1}) decreased with increasing water use. Neutral detergent fiber (229 to 478 g kg^{-1}) and acid detergent fiber (168 to 314 g kg^{-1}) increased with increasing water use. Total digestible nutrients (656 to 840 g kg^{-1}) and relative feed value (range 130 to 308) decreased with increasing water use. For a given amount of water use, kenaf DM yield was lower than corn (*Zea mays* L.) silage, but kenaf crude protein production was higher than corn silage (73–215%). Kenaf appears to be a high quality livestock forage that has potential as both an irrigated or dryland crop in the central Great Plains.

The traditional wheat–fallow dryland production system of the central Great Plains is gradually being replaced by cropping systems that include other crops. The diversification of crops includes corn, proso millet (*Panicum miliaceum* L.), sunflower (*Helianthus annuus* L.), and forage and seed legumes (Anderson et al., 1999; Peterson et al., 1996; Nielsen et al., 1999; Nielsen, 2001; Vigil and Nielsen, 1998). Another potential forage crop to diversify cropping systems in this region may be kenaf.

Kenaf is a warm-season annual that, when mature, can produce fiber for rope, carpet backing, and paper. Kenaf could provide a high-protein forage for integrated crop–livestock operations without the multiyear commitment of land and resources required of alfalfa (*Medicago sativa* L.). Some studies have been done showing the forage characteristics of immature kenaf and demonstrating its feasibility as a potential livestock feed. Phillips et al. (1996) observed that lambs (*Ovis aries*) readily consumed leaves, stems, and immature kenaf stalks. Similar results were reported by Bhardwaj et al. (1996) for kenaf consumption by goats (*Capra hicus*).

Unger (2001) in the Texas Panhandle (average annual precipitation = 475 mm; average June through October precipitation = 303 mm) concluded that kenaf had only limited potential as a dryland forage crop on the southern high plains of the United States because of low plant material yields (2300 kg ha^{-1}). On the other hand, he suggested that the high protein content of kenaf [327 g kg^{-1} at 65 d after planting (DAP) declining to 195 g kg^{-1} at 121 DAP], along with its higher potential yield where precipitation was greater, could make it a useful forage crop where precipitation was more reliable. Phillips et al. (1999) in Oklahoma also reported that whole-plant CP of kenaf declined with time from 223 g kg^{-1} at 40 DAP to 154 g kg^{-1} at 101 DAP. Vinson et al. (1979) similarly found CP declined from 246 g kg^{-1} at 30 DAP to 47 g kg^{-1} at 105 DAP for kenaf grown under irrigation in Arizona. Similar results of declining CP with increasing plant age have been reported by Muir (2001), Swingle et al. (1978), Webber (1993), Phillips et al. (1999), Vinson et al. (1979), and Bhardwaj et al. (1996). Changes in kenaf CP with water availability have not been documented in the literature.

Phillips et al. (1999) reported 3-yr average DM yields of 8644 kg ha^{-1} at 101 DAP with about 200 mm of growing season precipitation. Unfortunately, the irrigation amounts applied were not clearly specified. They concluded that harvesting kenaf at 70 to 80 DAP would optimize digestibility and N concentration of the stalks and maximize the proportion of leaf DM in the whole plant. Dicks et al. (1992) stated that the optimum growth period for kenaf to produce maximum leaf/stem ratio and highest quality forage was 60 d. Webber (1993) reported 2-yr average kenaf yields in Texas of 4764 kg ha^{-1}, with 404 mm of precipitation from planting to 76 DAP, and 7512 kg ha^{-1}, with 476 mm of precipitation from planting to 99 DAP. In that study, whole-plant CP was found to be much lower than in many other reported studies (60–80 g kg^{-1}). Muir (2001) in central Texas found a strong kenaf DM increase in response to increased growing season precipitation, but the production function was not calculated. In that study, 2359 kg ha^{-1} was produced after 90 d of growth in a dry year compared with 5064 kg ha^{-1} in a relatively wetter year. Muir et al. (2001) reported a 2-yr average DM yield of 13 762 kg ha^{-1} for kenaf grown with 448 mm of growing season precipitation and 435 mm of supplemental irriga-

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Abbreviations: ADF, acid detergent fiber; CP, crude protein; DAP, days after planting; DM, dry matter; DP, digestible protein; NDF, neutral detergent fiber; RFV, relative feed value; SAI, silhouette area index; TDN, total digestible nutrient.

tion. Phillips et al. (1996) reported NDF concentrations of 429 g kg^{-1} and ADF concentrations of 326 g kg^{-1} for whole-plant kenaf harvested at 80 DAP. Similar values were reported by Phillips et al. (1999). Vinson et al. (1979) found that NDF increased from 224 g kg^{-1} (30 DAP) to 551 g kg^{-1} (105 DAP). Over the same period, they found that ADF increased from 176 to 419 g kg^{-1}. Muir (2002) reported increases in kenaf NDF and ADF concentrations when harvest date increased from 60 to 120 DAP in 1 yr of a 2-yr study. However, in the second year of the study, with no precipitation from 75 to 120 DAP, no changes in ADF between harvests made at 90 and 120 DAP were observed.

Ghebreiyessus et al. (1997) found that kenaf yield was 39% higher when harvested leaving 30 cm of stalk compared with 15 cm of stalk due to better ratooning with the 30-cm stalk. They also found total N decreased with successive cuttings, averaging 287 g kg^{-1} from the first cutting and dropping by 32% for later cuttings.

The objective of this study was to evaluate the potential for kenaf as a dryland or irrigated forage crop under the environment of the central Great Plains. The evaluation was conducted by investigating DM yield, plant height, and forage quality responses to varying water supply; regrowth following cutting; soil water extraction; and ability of postharvest residue to protect the soil from wind erosion. Additionally, the forage productivity of kenaf relative to corn silage was evaluated.

MATERIALS AND METHODS

Studies were conducted with kenaf ('Everglades 41') during the 1997, 1998, and 1999 growing seasons at the USDA Central Great Plains Research Station, 6.4 km east of Akron, CO (40°09′ N, 103°09′ W; 1384 m). The soil is a Weld silt loam (fine, smectitic, mesic Aridic Argiustolls). Before planting, the plot area was tilled twice with a sweep plow equipped with an applicator to apply granules of ethalfluralin [*N*-ethyl-*N*-(2-methyl-2-propenyl)-2,6-dinitro-4-(trifluoromethyl)benzenamine] at a rate of 1.1 to 1.7 kg ha^{-1} (depending on year) for weed control. Additional weed control was performed by hand-weeding as necessary. The plot area was fertilized with 67 kg ha^{-1} N (as ammonium nitrate) before planting to eliminate N fertility as a variable. Soil fertility analysis was not conducted before planting. Kenaf was planted on 9 May 1997, 5 May 1998, and 11 May 1999 at a rate of 269 000 seeds ha^{-1}, with rows spaced 0.76 m apart. A new plot area was used each year, and the preceding crop was always winter wheat harvested for grain.

Variable water availability conditions were created using a gradient line-source solid-set irrigation system throughout the growing season. The plot area for each crop was 24.4 by 61.0 m (Fig. 1). The center section of this area (12.2 by 24.4 m) was bordered by the irrigation lines. This section was uniformly irrigated when the lines were turned on (fully irrigated plot). The irrigation system applied water to this area at the rate of 3.3 mm h^{-1}. On either side of the center section were the two gradient irrigation areas (low gradient and high gradient, 6.1 by 24.4 m, each) where the water applications decreased as distance from the irrigation line increased. The rainfed plots (12.2 by 24.4 m, each), which received no irrigation, were on the outside edges of the gradient irrigation areas. Four soil water measurement sites and irrigation catch gauges were established in each of the areas (i.e., four rainfed sites, four low-gradient sites, four high-gradient sites, and four fully irrigated sites). Only 9 of the 16 sites were available for measurement in 1998 following partial loss of stand due to a late-spring frost (6 June) and insect damage the second week of June (insect not identified). Irrigations were generally applied in the evening when wind speeds were low to minimize differences in water application across the two gradient irrigation areas.

Water use (evapotranspiration) was calculated for each plot by the water balance method using soil water measurements and assuming runoff and deep percolation were negligible (plot area slope was less than 0.5% and amounts of growing

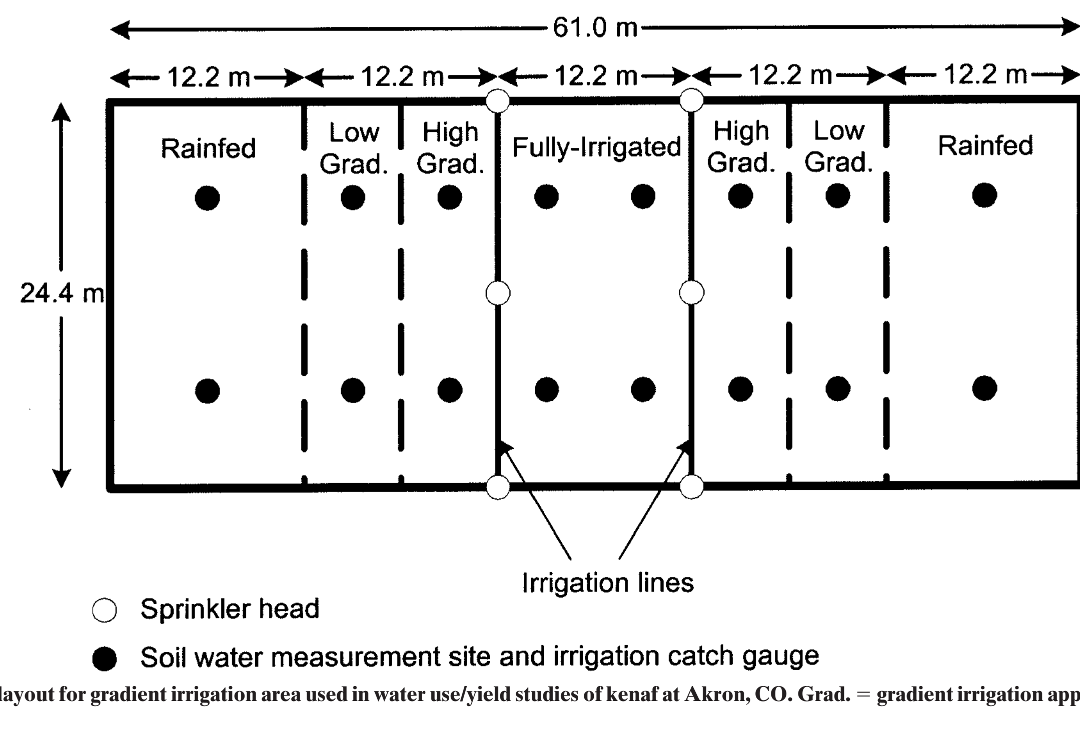

Fig. 1. Plot layout for gradient irrigation area used in water use/yield studies of kenaf at Akron, CO. Grad. = gradient irrigation application section.

season precipitation were generally small). Soil water measurements were made at planting and at harvest at each of the sample sites using a neutron probe at soil depths of 15, 45, 75, 105, 135, and 165 cm.

Plant height was recorded weekly as the average height of six plants surrounding each soil water measurement site. Forage samples were taken on 14 Aug. 1997, 12 Aug. 1998, and 18 Aug. 1999 when plants in the fully irrigated plot had reached a height of about 135 cm. Plants from a 9.3-m^2 area were hand-harvested, leaving at least two nodes (a stem of 20 cm) for regrowth as suggested by Robinson (1993). Samples were weighed, dried at 55°C to a constant weight, and weighed again to determine moisture content and DM yield. Samples were ground to pass a 1-mm screen and sent to a commercial laboratory (Olsen's Agricultural Laboratory, McCook, NE) for forage analysis. Crude protein concentration was determined by N combustion (Cuniff, 1995); NDF and ADF were determined by refluxing (kettle method, Undersander et al., 1993); digestible protein (DP) was calculated by multiplying CP by the digestible coefficient for alfalfa (Morrison, 1959) although the author does not know of data to confirm that the digestible coefficient for alfalfa would be applicable to kenaf; and TDN was calculated from ADF using a standard calculation (Dr. B. Anderson, Extension Forage Specialist, Univ. of Nebraska, Lincoln, NE, unpublished data, 1985). Other samples were also collected at this time and chopped with a forage chopper. The chopped plant material was then packed in 18.9-L buckets with lids (minisilos) to ensile the kenaf (packing density was not determined).The lids provided an air-tight seal. Samples of kenaf ensilage were removed after 120 d and sent to the same commercial laboratory for forage analysis. Similar procedures were followed when taking the second forage samples from the kenaf regrowth on 9 Oct. 1997 and 13 Oct. 1998, just before a killing frost (13 Oct. 1997, 17 Oct. 1998). No second-cutting forage samples were taken in 1999 due to the loss of plants from hail.

Linear regressions were performed on all water use and yield data collected in 1997 and 1998 to determine the production functions (DM yield vs. water use). The DM yield data from 1999 were not used in the determination of production functions due to the loss of plants from hail on 31 May 1999 and 29 June 1999 that resulted in nonuniform plant stands. Averages and standard deviations of each of the forage quality parameters and water use values were computed at each of the four water gradient positions, and linear regressions were performed on the individual data sets from each year and each cutting and on the data combined over both years within each cutting. Linear regression slopes were judged to be significant when $P \leq 0.10$.

To compare kenaf results with a more commonly grown forage crop, corn (Pioneer Hybrid 34K77) was planted (39 770 seeds ha^{-1}) adjacent to kenaf on 11 May 1999 and harvested on 15 Sept. 1999 at physiological maturity (black layer development). Nitrogen was applied (56 kg N ha^{-1}) as urea ammonium nitrate at planting. Chopped samples were ensiled for 124 d and then sent to the same commercial laboratory as used for the kenaf samples for forage quality analysis.

RESULTS AND DISCUSSION

Precipitation during the first cutting period (early May to mid-August) was nearly the same in 1997 and 1998 and near the 37-yr average of 218 mm (Table 1). Precipitation was 57 mm above the 36-yr average during the first cutting period in 1999. Precipitation during the second cutting period (mid-August to mid-October) was near the 37-yr average of 65 mm in 1997 and 45 mm below the average in 1998. No precipitation values are given for the second cutting period in 1999 as the experiment was discontinued due to nonuniform stand loss caused by hail on 31 May 1999 and 28 June 1999. Although the stand loss caused by the hail created a situation in which the DM yield and water use data in 1999 were not useful for defining the production function for kenaf, plant samples (representative, individual, whole, undamaged plants) were collected so that forage quality analysis could be performed and compared directly with corn forage samples collected in 1999.

Total water received from precipitation and irrigation during the first cutting period ranged from 212 to 301 mm in 1997, 219 to 359 mm in 1998, and 284 to 513 mm in 1999. During the second cutting period, the total water received ranged from 58 to 192 mm in 1997 and 20 to 167 mm in 1998. These differences in growing season water availability caused large differences in plant height (Fig. 2) and DM yield (Fig. 3), with both exhibiting linear increases as water use increased (Table 2). Plant height at the first cutting ranged from 69 to 136 cm in 1997 and from 115 to 137 cm in 1998. Plant height at the second cutting ranged from 30 to 64 cm in 1997 and from 43 to 74 cm in 1998.

Kenaf DM yield increase in response to water use was strongly linear for both the first and second cuttings in 1997 (Fig. 3). The DM yield response to water use

Table 1. Growing season precipitation and irrigation amounts (averaged by gradient position) at Akron, CO.

			Gradient position					
Year	Cutting	Dates	Rainfed	Low gradient	High gradient	Fully irrigated	Precipitation	Precipitation range (1965–2001)
			mm					
1997	First	9 May–14 Aug.	0	27	60	89	212	
	Second	15 Aug.–9 Oct.	0	33	90	134	58	
	Total	9 May–9 Oct.	0	60	150	223	270	
1998	First	5 May–12 Aug.	12	42	107	152	207	
	Second	13 Aug.–13 Oct.	0	27	117	147	20	
	Total	5 May–13 Oct.	12	69	224	299	227	
1999	First	11 May–18 Aug.	9	103	161	238	275	
	Second	N/A†	N/A	N/A	N/A	N/A	N/A	
	Total	N/A	N/A	N/A	N/A	N/A	N/A	
Avg. (1965–2001)	First	7 May–12 Aug.					218	116 to 411
	Second	13 Aug.–14 Oct.					65	6 to 140
	Total	7 May–14 Oct.					283	154 to 495

† N/A, not available; hail on 31 May 1999 and 28 June 1999 reduced kenaf stands so that the experiment was not continued after the first cutting.

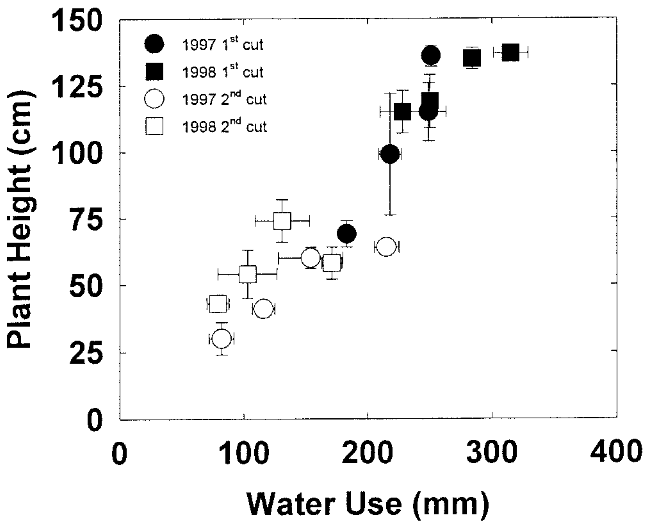

Fig. 2. Kenaf height vs. water use for two cuttings of kenaf grown under an irrigation gradient at Akron, CO, in 1997 and 1998. Bars are ± one standard deviation.

in 1998 was not strongly defined for either the first or second cuttings although the DM yield produced for a given amount of water use in 1998 was in the range of observed values from 1997. Combining the data for the 2 yr gave a DM yield increase of 16.6 kg ha^{-1} for every millimeter of water use during the first cutting period and 11.3 kg ha^{-1} for every millimeter of water use during the second cutting period (Table 2). Although the rate of increase in DM yield due to water use was lower for the second cutting, the amount of water required to produce 1000 kg ha^{-1} was much less (about 153 mm for the first cutting and about 110 mm for the second cutting). Taking the two cuttings together produced a DM yield production relationship of:

$$\text{kg ha}^{-1} = 17.1(\text{mm} - 157) \quad [1]$$

This relationship indicates that kenaf DM yield increased by 17.1 kg ha^{-1} for every millimeter of water use after 157 mm of water use, with 274 mm of water use required to produce 2000 kg ha^{-1} and 507 mm required to produce 6000 kg ha^{-1}. This DM yield production relationship compares with a relationship for dryland corn in northeastern Colorado of:

$$\text{kg ha}^{-1} = 22.4(\text{mm} - 129) \quad [2]$$

(D.C. Nielsen, unpublished data, 2002). This relationship indicates that corn DM yield increased by 22.4 kg ha^{-1} for every millimeter of water use after 129 mm of water use, with 218 mm of water use required to produce 2000 kg ha^{-1} and 397 mm required to produce 6000 kg ha $^{-1}$. If DM yield in relation to water use is the only productivity characteristic important to a producer, corn appears to have the advantage over kenaf.

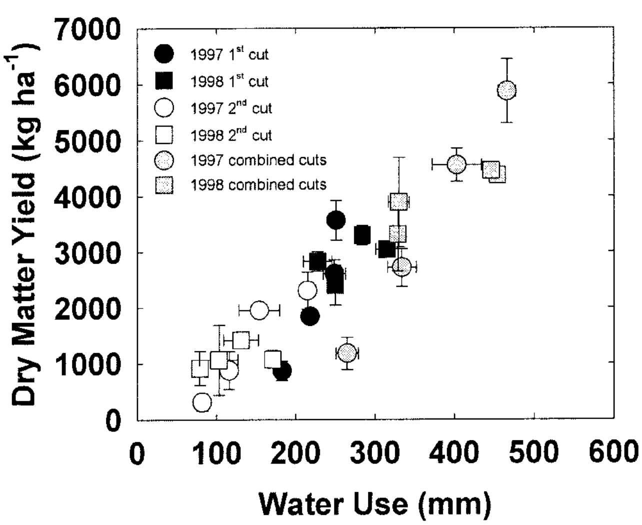

Fig. 3. Dry matter yield vs. water use for two cuttings of kenaf grown under an irrigation gradient at Akron, CO, in 1997 and 1998. Bars are ± one standard deviation.

Table 2. Linear regression equations, coefficients of determination (r^2), and probabilities of type I error (P) for plant height (cm) vs. water use (mm) and dry matter yield (kg ha^{-1}) vs. water use (mm) of kenaf (data combined over 1997 and 1998).

Cutting	Linear regression equation	SE_{slope}	r^2	P
	Plant height (cm) vs. water use (mm)			
1	cm = 0.507 × (mm − 19.18)	0.109	0.78	<0.01
2	cm = 0.202 × (mm + 131.5)	0.093	0.44	0.07
	Dry matter yield (kg ha^{-1}) vs. water use (mm)			
1	kg ha^{-1} = 16.6 × (mm − 93.1)	5.6	0.59	0.03
2	kg ha^{-1} = 11.3 × (mm − 22.0)	3.1	0.69	0.01
Combined	kg ha^{-1} = 17.1 × (mm − 156.6)	3.5	0.80	<0.01

Crude protein in the fresh-cut kenaf samples ranged from 163 to 279 g kg^{-1} (Fig. 4). Crude protein declined with increasing water application and water use in 1997 (Table 3). In 1997, CP was lower in the second cutting of fresh-cut kenaf than in the first cutting, as determined by standard deviation bar overlap (Fig. 5). In 1998, CP was not different between cuttings. In 1997, first-cutting CP was lower in the silage samples than in the fresh-cut samples and showed the same decline with increased water application. As with the fresh-cut samples, CP in the first-cutting silage samples was lower in 1998 than in 1997. Crude protein in the second-cutting silage samples of 1998 was not different from the fresh-cut CP values. Crude protein in the silage samples ranged from 174 to 251 g kg^{-1}. When the 1997 and 1998 data were combined, CP decreased linearly with water use (Table 3) for both cuttings of fresh kenaf and first cutting of silage.

Neutral detergent fiber for the fresh-cut samples ranged from 229 to 401 g kg^{-1} (Fig. 4), increasing with water use for the second cutting of fresh kenaf in 1997 and for the first cutting of kenaf silage in 1997 and 1998. Neutral detergent fiber was lower in the second cutting than in the first cutting in 1998 (Fig. 5) for both fresh-cut and silage samples, which ranged from 287 to 478 g kg^{-1}. When the 1997 and 1998 data were combined, NDF increased linearly with water use for both cuttings of fresh kenaf and first cutting of silage.

Acid detergent fiber also increased with water use for both cuttings of fresh kenaf in 1997 and for the first cuttings of silage in 1997 and 1998 (Fig. 4 and Table 3). Acid detergent fiber in fresh-cut samples was lower in the second cutting than in the first cutting in 1998 (Fig. 5). When the 1997 and 1998 data were combined, ADF increased linearly with water for both cuttings of

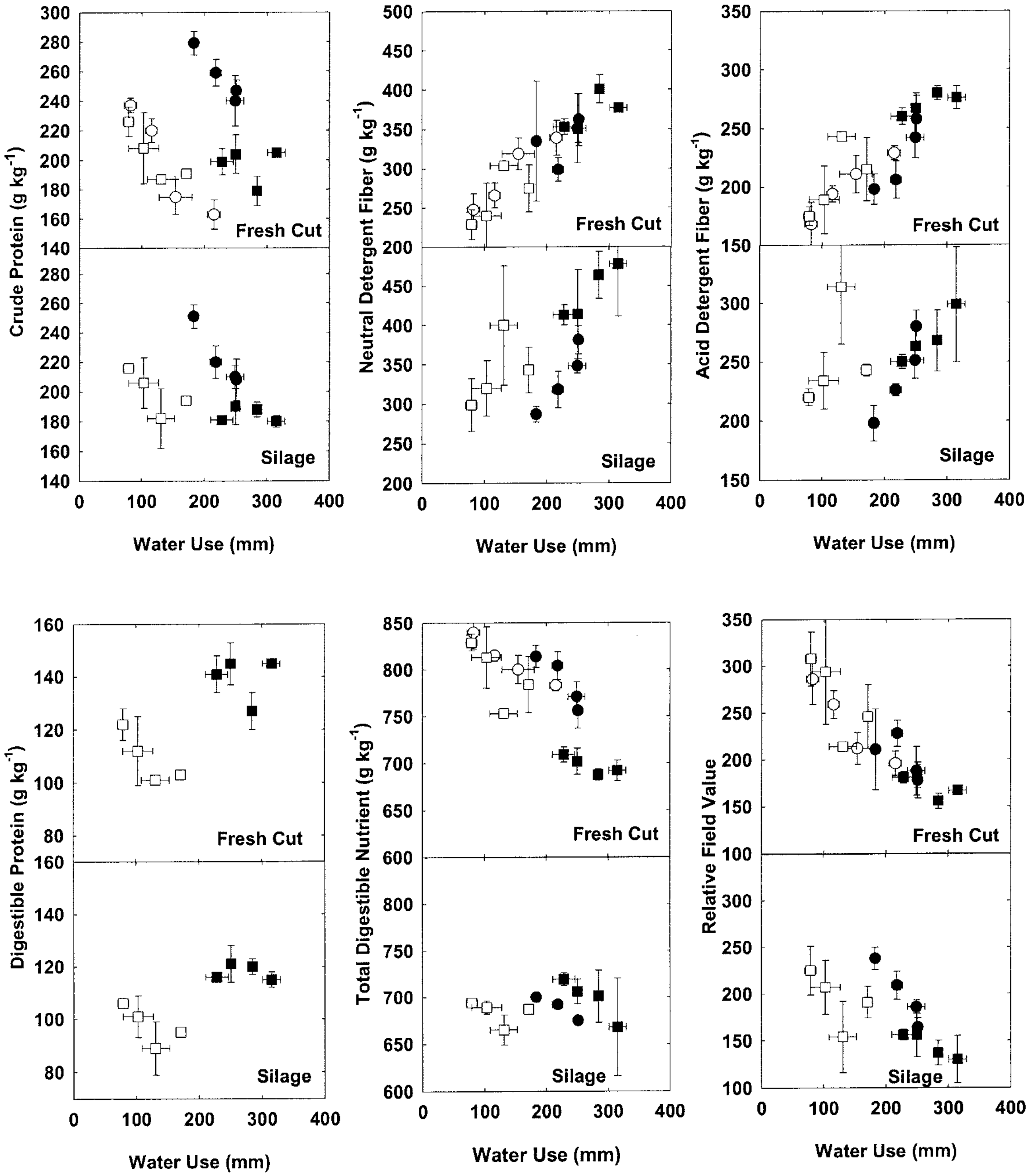

Fig. 4. Influence of water use on concentration of crude protein, neutral detergent fiber, acid detergent fiber, digestible protein, total digestible nutrients, and relative feed value for two cuttings of kenaf grown under an irrigation gradient at Akron, CO, in 1997 and 1998. Bars are ± one standard deviation. ● = 1997 first cutting, ■ = 1998 first cutting, ○ = 1997 second cutting, and □ = 1998 second cutting.

fresh kenaf and the first cutting of silage. Values for the fresh-cut samples ranged from 168 to 310 g kg^{-1} and from 198 to 314 g kg^{-1} for silage samples.

Digestible protein values were available for samples collected in 1998 (Fig. 4). There was no consistent trend in DP in response to water use for either the fresh-cut or silage samples in either cutting. Values ranged from 101 to 154 g kg^{-1} for fresh-cut samples and from 85 to 121 g kg^{-1} for silage samples. For both fresh-cut and silage samples, DP was higher for first-cutting samples than for second-cutting samples (Fig. 5).

Both first and second cuttings of fresh cut kenaf in 1997 decreased in TDN with increasing water use (Fig. 4 and Table 3). The first cutting of silage in 1998 declined in TDN with water use. Total digestible nutrients ranged from 656 to 840 g kg^{-1} for the fresh-cut samples and from 665 to 731 g kg^{-1} for the silage samples.

Relative feed value is an index used to categorize alfalfa hay in inventory management and for grading hay for buying and selling (Kuehn et al., 1999). It has also been used with mixed legume/grass hay. Relative feed value combines the nutritional factors of digestibility and intake into a single value and is calculated from values of NDF and ADF. Values greater than 151 are classified as prime dairy hay. While use of RFV to characterize the nutritional value of kenaf must wait for

Table 3. Linear regression intercepts and slopes, standard errors of intercepts and slopes (SE_{int} and SE_{slope}), coefficients of determination (r^2), and probabilities of type I error (P) for forage quality characteristics vs. water use (mm) of kenaf.

			Crude protein						Neutral detergent fiber						Acid detergent fiber					
Year	Cutting	Forage type	Intercept	SE_{int}	Slope	SE_{slope}	r^2	P	Intercept	SE_{int}	Slope	SE_{slope}	r^2	P	Intercept	SE_{int}	Slope	SE_{slope}	r^2	P
1997	1	fresh	*374.2*†	*16.9*	*−0.524*	*0.074*	*0.96*	*0.02*	238.5	119.0	0.436	0.525	0.26	0.42	*39.9*	*55.9*	*0.826*	*0.246*	*0.85*	*0.07*
1998	1	fresh	203.9	60.6	−0.027	0.223	0.01	0.92	255.8	87.2	0.425	0.322	0.47	0.32	215.9	22.6	0.204	0.083	0.75	0.14
1997	2	fresh	*282.2*	*20.8*	*−0.589*	*0.139*	*0.90*	*0.05*	*190.2*	*21.9*	*0.725*	*0.146*	*0.93*	*0.04*	*137.6*	*10.8*	*0.444*	*0.072*	*0.95*	*0.03*
1998	2	fresh	249.9	20.6	−0.387	0.163	0.74	0.14	188.4	54.7	0.608	0.435	0.49	0.30	142.8	49.3	0.518	0.392	0.47	0.32
1997	1	silage	*358.7*	*22.5*	*−0.606*	*0.099*	*0.95*	*0.03*	*65.6*	*67.1*	*1.189*	*0.295*	*0.89*	*0.06*	*6.0*	*58.1*	*1.033*	*0.256*	*0.89*	*0.06*
1998	1	silage	191.9	24.5	−0.026	0.090	0.04	0.80	*214.5*	*47.6*	*0.846*	*0.175*	*0.92*	*0.04*	*131.3*	*33.3*	*0.515*	*0.123*	*0.90*	*0.05*
1998	2	silage	232.0	23.0	−0.269	0.183	0.52	0.28	267.4	81.9	0.604	0.651	0.30	0.45	205.3	87.6	0.390	0.679	0.14	0.63
1997–1998	1	fresh	*378.5*	*61.6*	*−0.615*	*0.246*	*0.51*	*0.05*	*219.2*	*51.4*	*0.543*	*0.206*	*0.54*	*0.04*	*87.6*	*42.1*	*0.650*	*0.168*	*0.71*	*0.01*
1997–1998	2	fresh	*267.3*	*13.2*	*−0.506*	*0.095*	*0.82*	*<0.01*	*181.2*	*24.0*	*0.733*	*0.173*	*0.75*	*0.01*	*146.8*	*20.3*	*0.428*	*0.146*	*0.59*	*0.03*
1997–1998	1	silage	*318.7*	*38.6*	*−0.466*	*0.154*	*0.60*	*0.02*	*18.3*	*78.1*	*1.495*	*0.312*	*0.79*	*<0.01*	*18.3*	*78.1*	*0.722*	*0.312*	*0.85*	*<0.01*
			Digestible protein						Total digestible nutrients						Relative feed value					
1997	1	fresh	—	—	—	—	—	—	*965.7*	*49.1*	*−0.797*	*0.216*	*0.87*	*0.07*	312.9	80.6	−0.496	0.355	0.49	0.30
1998	1	fresh	145.7	42.7	−0.023	0.157	0.01	0.90	756.3	23.5	−0.217	0.087	0.76	0.13	234.7	42.9	−0.235	0.158	0.52	0.28
1997	2	fresh	—	—	—	—	—	—	*868.0*	*10.4*	*−0.413*	*0.069*	*0.95*	*0.03*	*337.2*	*22.5*	*−0.698*	*0.150*	*0.92*	*0.04*
1998	2	fresh	134.8	11.0	−0.209	0.088	0.74	0.14	865.0	54.9	−0.581	0.436	0.47	0.31	363.3	66.1	−0.808	0.526	0.54	0.26
1997	1	silage	—	—	—	—	—	—	310.1	668.7	2.010	2.947	0.19	0.57	*414.6*	*42.3*	*−0.956*	*0.186*	*0.93*	*0.04*
1998	1	silage	123.1	14.3	−0.019	0.053	0.06	0.75	*842.8*	*36.0*	*−0.536*	*0.133*	*0.89*	*0.06*	*235.0*	*17.8*	*−0.335*	*0.066*	*0.93*	*0.04*
1998	2	silage	114.0	11.5	−0.134	0.091	0.52	0.28	697.9	26.9	−0.117	0.214	0.13	0.64	248.1	55.3	−0.445	0.439	0.34	0.42
1997–1998	1	fresh	—	—	—	—	—	—	*986.3*	*81.0*	*−0.988*	*0.324*	*0.61*	*0.02*	*299.2*	*35.9*	*−0.456*	*0.144*	*0.63*	*0.02*
1997–1998	2	fresh	—	—	—	—	—	—	*854.8*	*25.4*	*−0.401*	*0.184*	*0.44*	*0.07*	*352.5*	*26.4*	*−0.766*	*0.171*	*0.73*	*0.01*
1997–1998	1	silage	—	—	—	—	—	—	770.9	262.7	−0.163	1.050	0.00	0.88	*372.9*	*43.1*	*−0.812*	*0.172*	*0.79*	*<0.01*

† Values in italics indicate significant regression slopes ($P \leq 0.10$).

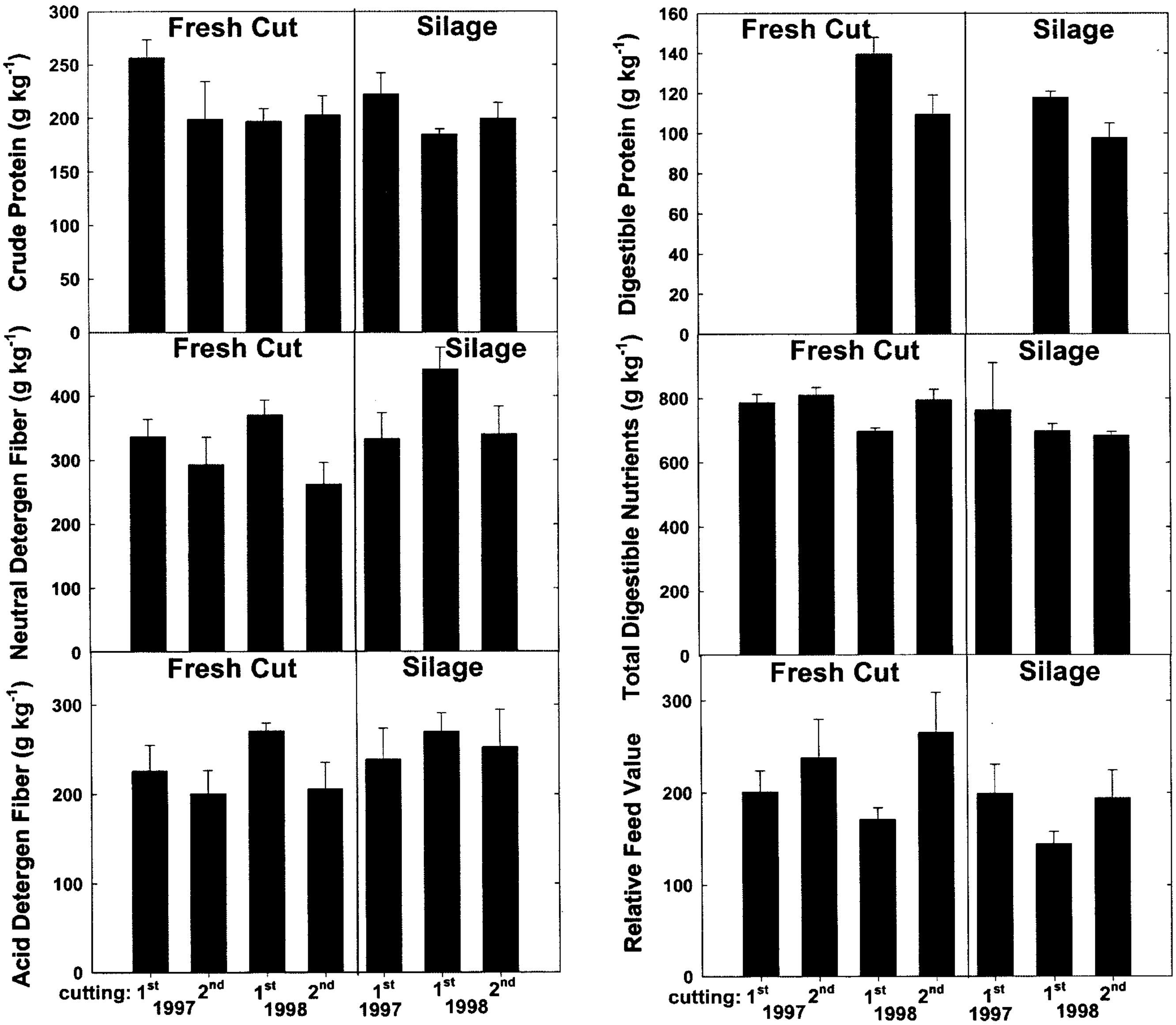

Fig. 5. Concentration of crude protein, neutral detergent fiber, acid detergent fiber, digestible protein, total digestible nutrients, and relative feed value averaged over water gradient positions for two cuttings of kenaf grown under an irrigation gradient at Akron, CO, in 1997 and 1998. Bars are ± one standard deviation.

studies correlating kenaf RFV with intake and animal performance, the fact that kenaf has a similar NDF/ADF ratio as alfalfa (1.2–1.6) suggests that the index may provide some understanding about the relative change in feed quality that occurs when kenaf is grown under different available water conditions.

With the exception of the two highest water values in the first-cutting silage samples in 1998, all kenaf samples had RFV values greater than 151 (Fig. 4). Relative feed value generally declined with increasing water use and was significant for the second cutting of fresh kenaf in 1997 and for the first cutting of silage in 1997 and 1998. When the 1997 and 1998 data were combined, the linear decrease in RFV with water use was significant for both cuttings of fresh kenaf and the first cutting of silage. Relative feed value was higher in second-cutting samples than in first-cutting samples for both fresh-cut and silage samples in 1998 (Fig. 5). Relative feed value ranged from 156 to 308 for fresh-cut samples and from 130 to 238 for silage samples.

Forage quality of kenaf relative to corn silage was compared with data collected in 1999. The hail storms mentioned previously reduced stands in a nonuniform manner such that it was not possible to use the water use and yield data from 1999 with the 1997 and 1998 data for determination of the production function. The 1999 data did not show changes in forage quality characteristics with water use for either kenaf or corn, so data were averaged over all 16 measurement sites. Crude protein, DP, and ADF were lower in corn than in kenaf (as determined by standard deviations, Fig. 6). Corn CP was 39% of the kenaf CP value. Corn DP was 28% of the kenaf DP value. Neutral detergent fiber was the same for both kenaf and corn, but corn ADF was 71% of kenaf ADF. Corn TDN was 10% higher than kenaf TDN.

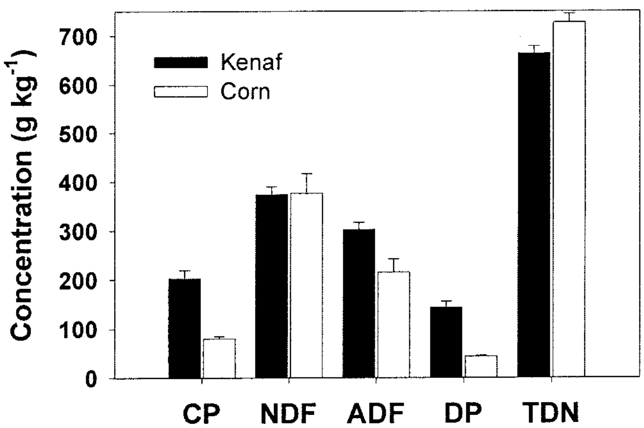

Fig. 6. Comparison of crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), digestible protein (DP), and total digestible nutrients (TDN) between kenaf and corn grown at Akron, CO, in 1999. Bars are ± one standard deviation.

As stated earlier, corn produced more DM yield for a given amount of water use than kenaf. But an assessment of kenaf productivity relative to corn productivity needs to be made relative to production of CP. Using the first- and second-cutting production functions for kenaf (Table 2) and the production function for corn (Eq. [2]), DM yields of kenaf and corn were computed for water use values of 250, 350, and 450 mm (Fig. 7), where two-thirds of the specified water use was assumed to be used to produce the first-cutting DM yield and one-third of the specified water use was assumed to be used to produce the second-cutting DM yield. This distribution of seasonal water use is similar to the average distribution of water use found in the present study. Estimated corn DM yield was 40 to 47% greater than that of kenaf. Applying the CP vs. water use regressions for first and second fresh-cut kenaf combined over 1997 and 1998 (whose slope values are given in Table 3) to the calculated kenaf DM yields and similarly applying CP values obtained from the 1999 corn (85, 79, and 76 g kg^{-1} for the 250-, 350-, and 450-mm water use situations) to the calculated corn DM yields gave estimated CP production that was 73 to 215% greater in kenaf than in corn (231–547 kg ha^{-1} in corn and 498–946 kg ha^{-1} in kenaf). When considered from a CP production viewpoint, kenaf is much more productive under a range of water use conditions than corn for silage.

One of the important pieces of information needed in assessing a new crop's fit into existing dryland crop rotations is the soil water extraction pattern/rooting depth of a crop. While root development and soil water extraction are variable from year to year (depending on soil water content at planting and growing season precipitation timing and amount), Fig. 8 illustrates the soil water extraction capacity of kenaf. The soil water data were taken from the rainfed (unirrigated) plots in 1998 (the driest of the 3 yr), in which only 20 mm of precipitation fell between the first cutting and the second cutting. These data show considerable soil water extraction from the surface down to 105 cm at the time of the first cutting, and measurable but perhaps insignificant soil water extraction at the lowest measurement

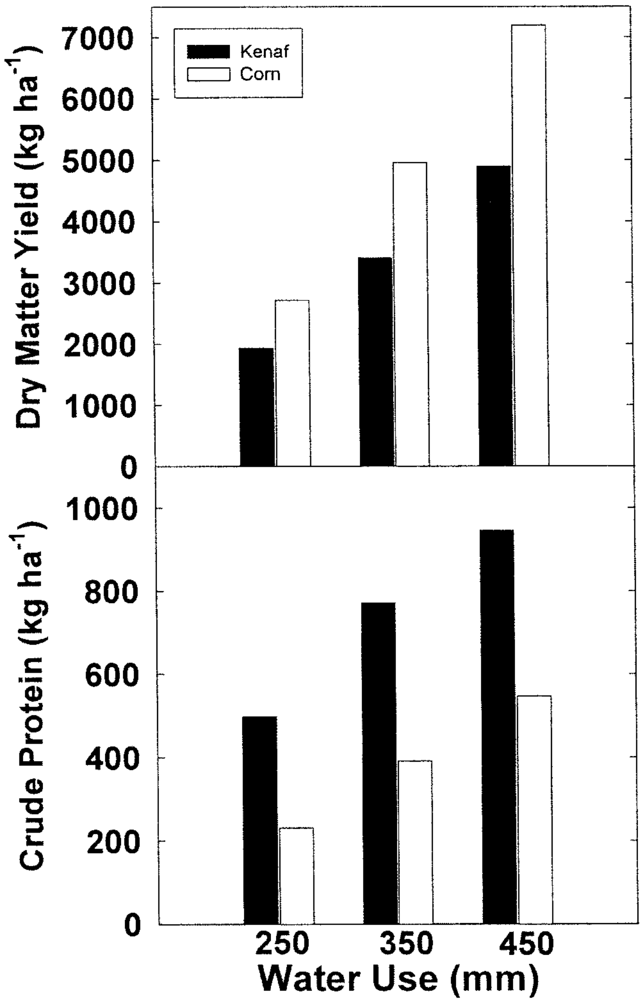

Fig. 7. Estimated kenaf and corn dry matter yield and crude protein production under three water use conditions at Akron, CO.

depth (165 cm) by the time of the second cutting. From planting to second cutting, soil water under kenaf declined by 138 mm, by root extraction, evaporation, or gravitationally driven movement below the root zone.

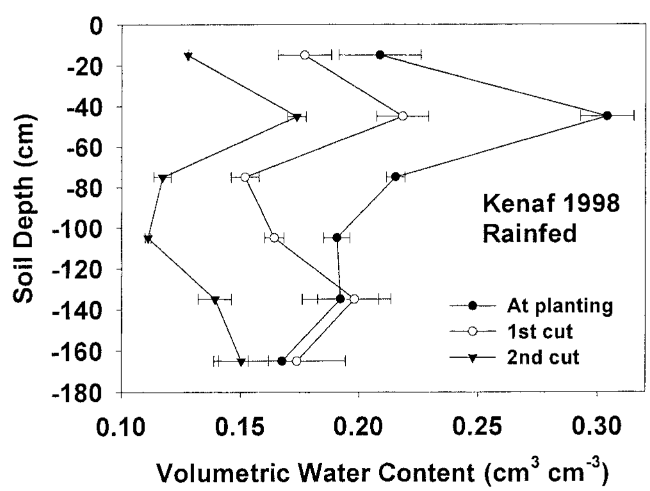

Fig. 8. Volumetric water content of rainfed plots in 1998 at planting and two harvest dates for kenaf on Weld silt loam at Akron, CO. Bars are ± one standard deviation.

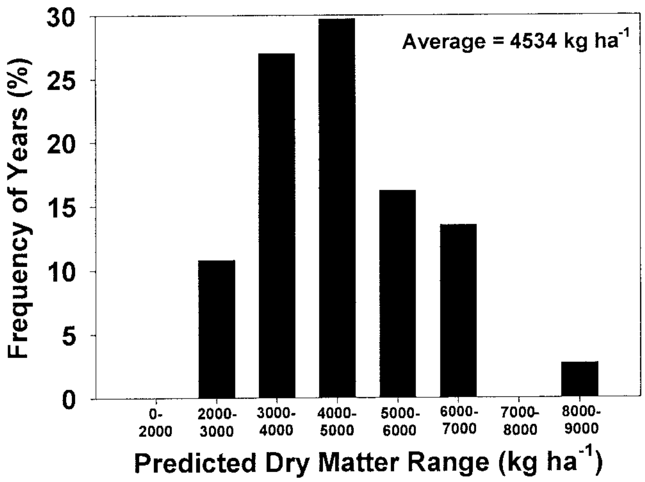

Fig. 9. Frequency distributions of kenaf dry matter yields estimated from production functions for combined first and second cuttings, soil water use of 138 mm, and historical precipitation records (1965–2001) from Akron, CO.

The distribution of dryland kenaf forage production due to varying rainfall can be estimated from the 1965–2001 precipitation record from 7 May to 14 October, assuming a soil water use of 138 mm and the production function for first and second cuttings combined (Eq. [1]). The frequency distribution of predicted forage DM yields (Fig. 9) shows the most frequently predicted yield range (4000–5000 kg ha^{-1}) occurred for nearly 30% of the years of record. The precipitation record predicted a mean yield of 4534 kg ha^{-1}. In 63% of the years, there was enough growing season precipitation to give a yield of at least 4000 kg ha^{-1}. In 17% of the years, there was enough growing season precipitation to give a yield of at least 6000 kg ha^{-1}.

An important consideration in growing kenaf for forage in the central Great Plains is how the remaining stalk residue following harvest affects the potential for soil erosion by wind and possible soil water recharge over winter by snow. To assess these two factors, the silhouette area index (SAI = stalk height × diameter × population) was calculated for a typical kenaf field after harvest. A stalk population of 215 000 stalks ha^{-1} with a height of 20 cm and stalk diameter of 1.5 cm gives an SAI of 0.065. Nielsen and Aiken (1998) showed that this value of SAI in similarly structured sunflower residue reduced the erosion ratio to near 0, effectively eliminating the possibility of soil movement. Additionally, Nielsen (1998) showed that, under average or above-average winter snowfall conditions in northeastern Colorado, an SAI of 0.065 in sunflower residue could be expected to increase soil water over winter by about 170 mm. This was the result of effective snow capture and snow melt during nonfrozen soil periods. Similar soil water recharge in kenaf residue could be expected considering the similar nature of the residue. This recharge would be extremely important to the productivity of crops following kenaf in rotation.

CONCLUSIONS

Kenaf DM yield increased linearly with increasing water use. With two cuttings of kenaf for forage during a growing season, average DM yield would be about 4500 kg ha^{-1}. The production of kenaf DM yield for a given unit of water use is lower than DM yield production by corn silage, but because of the higher CP content of kenaf, production of CP for a given unit of water is estimated to be higher with kenaf than with corn silage. Other forage quality characteristics of kenaf are similar to corn silage. Kenaf stalks remaining after harvest present a sufficient SAI to effectively control wind erosion of soil and to aid in soil water recharge by snow catch during the noncrop period. Kenaf appears to be an agronomically viable alternative forage crop for the central Great Plains.

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