Reprinted from: Perspectives on new crops and new uses. 1999.
J. Janick (ed.), ASHS Press, Alexandria, VA.

Effect of Kenaf and Soybean Rotations on Yield Components

Charles L. Webber III

As kenaf (*Hibiscus cannabinus* L., *Malvaceae*) production in the US continues to increase it is essential to integrate this alternative fiber crop into existing cropping systems. Soybean [*Glycine max* (L.) Merr., Fabaceae] is now grown widely in the same production areas where kenaf can be successfully produced. A kenaf/soybean rotational system could have long term economic and pest control advantages, if there are no adverse effects of rotating these two crops. A three-year field study was conducted at Haskell, Oklahoma to determine the effect of six kenaf/soybean rotations on kenaf and soybean yield components. The kenaf cultivar ‘Everglades 41’ and soybean cultivar ‘Forrest’ were planted on a Taloka silt loam soil in mid May and harvested each October. The crops received no irrigation, rainfall was the only source of moisture. The individual kenaf/soybean rotations did not adversely affect the kenaf stalk yields or soybean seed yields. Kenaf stalk yields across all rotational combinations and years averaged 7.9 t/ha, while soybean seed yields averaged 866 kg/ha. Seasonal rainfall affected soybean growth and yields more than any effects due to the cropping sequence. A continuous kenaf rotation produced the greatest kenaf yields (9.4 t/ha) in the final year. It was determined that either a three-year continuous or rotational cropping system can be used for kenaf and soybean production without reducing crop yields.

Kenaf is a warm season annual fiber crop closely related to cotton and okra that can be successfully produced in a large portion of the US, particularly in the southern states. For the last 3000 years kenaf has been used as a cordage crop to produce twine, rope, and sackcloth (Wilson et al. 1965). Kenaf was first domesticated and used in north Africa. India has produced and used kenaf for the last 200 years, while Russia started producing kenaf in 1902 and introduced the crop to China in 1935. The US started kenaf research and production during World War II to supply ropes for the war effort and developed high-yielding anthracnose-resistant varieties, cultural practices, and harvesting machinery (Nieschlag et al. 1960; Wilson et al. 1965; White et al. 1970). Then in the 1950s and early 1960s USDA researchers determined that kenaf was an excellent source for cellulose fibers for a large range of paper products (newsprint, bond paper, and corrugated liner board) with less energy and chemical requirements than standard wood sources. More recent research and development work in the 1990s has demonstrated the plant’s use in building materials (particle boards of various densities, thicknesses, and fire and insect resistance), adsorbents, textiles, livestock feed, and fibers in new and recycled plastics (injected molded and extruded).

As kenaf production in the US continues to increase, it is essential to integrate this alternative fiber crop into existing cropping systems. One practical means of integrating kenaf into existing cropping systems would be the introduction of kenaf into the rotational crop sequences. Crop rotation is an important management strategy which research has demonstrated can provide numerous crop production advantages, including increased pest control (Benson 1985; Edwards et al. 1988), improved soil aggregation resulting in greater wet aggregate stability (Baldock and Kay 1987; Raimbault and Vyn 1991), increased nutrient availability (Adams et al. 1970; Baldock and Musgrave 1980; Asghari and Hanson 1984; Peterson and Varvel 1989b; Varvel and Peterson 1990), increased grain quality (Asghari and Hanson 1984), and increased yields (Crookston et al. 1988; Edwards et al. 1988; Peterson and Varvel 1989a,b,c; Varvel and Peterson 1990; Crookston et al. 1991; Lund et al. 1993).

Many factors can be responsible for the positive yield response to crop rotation, but increased nitrogen availability following a legume crop is often the most recognized benefit (Adams et al. 1970; Baldock and Musgrave 1980; Asghari and Hanson 1984; Peterson and Varvel 1989b; Varvel and Peterson 1990). Crop rotations involving legumes such as alfalfa (*Medicago sativa* L.) (Adams et al. 1970; Baldock and Musgrave 1980; Asghari and Hanson 1984; Raimbault and Vyn 1991), red clover (*Trifolium pratense* L.) (Peterson and Varvel 1989b,c; Raimbault and Vyn 1991), and soybean [*Glycine max* (L.) Merr.] (Crookston et al. 1988; Edwards et al. 1988; Peterson and Varvel 1989b,c; Crookston et al. 1991; Lund et al. 1993) have often demonstrated their benefit to non-legume crops such as maize (*Zea mays* L.) (Crookston et al. 1988; Edwards et al. 1988; Peterson and Varvel 1989c; Crookston et al. 1991), and grain sorghum [*Sorghum bicolor* (L.) Merr.] (Peterson and Varvel 1989b).

Soybean, a legume crop grown for its grain, is now grown widely in the same production areas where kenaf can be successfully produced. A kenaf/soybean rotation system could have long term production and economic advantages, if there are no significantly adverse affects of rotating these two crops. At present there is insufficient research concerning the affect of including kenaf into a crop rotation with other existing crops such as soybean. The objective of this research was to determine the affect of a kenaf and soybean rotations on kenaf and soybean yield components.

METHODOLOGY

A 3-yr field study was conducted at Oklahoma State University's Eastern Research Station, Haskell, Oklahoma, to determine the effect of six kenaf/soybean rotation combinations on kenaf and soybean yield components. The 3-yr experimental design was a randomized complete block with four replications.

Plots were 7 m wide (eight 76-cm rows) and 7 m long, and oriented in an east-west direction. Each year prior to planting, fertilizer was applied and incorporated to the kenaf plots at a rate of 168, 22, and 42 kg/ha of N, P, and K, respectively and to the soybean plots at a rate of 0, 22, and 168 kg/ha of N, P, and K, respectively. The kenaf cultivar 'Everglades 41' and soybean cultivar 'Forrest' were planted on a Taloka silt loam soil (fine mixed, thermic Mollic Albaqualf, 0–1% slope) in mid May (May 11, 1989, May 25, 1990, and May 10, 1991) and harvested each October (Oct. 19, 1989, Oct. 26, 1990, and Oct. 16, 1991). The soybean seeds were inoculated with the appropriate *Rhizobium* culture and each crop was planted at a rate of 370,000 seeds/ha.

The day after planting all plots received a pre-emergence application of metolachlor [2-chloro-N- (2-ethyl-6-methylphenyl)-'(2-methoxy-1-methylethyl) acetamide] at 1.7 kg/ha to control weeds. The herbicide was applied using a tractor-mounted sprayer delivering 187 liters/ha at 275 kPa pressure. Fan-tip sprayer nozzles were 0.5 m apart on a 7-m boom. All plots were kept weed free during the growing season by handweeding. The crops received no irrigation, rainfall was the only source of moisture.

The research plots were harvested 161 days after planting (DAP) in 1989, 154 DAP in 1990, and 159 DAP in 1991. A 2.25 m^2 (1.50 by 1.50 m) quadrant was harvested from the center two rows of each plot. All plants were harvested by hand and cut at ground level. Plant counts from the harvest quadrant were used to determine plant populations. Three kenaf plants were selected randomly from the harvested material to determine plant heights and stalk diameters. Calipers were used to measure stalk diameters at 1 m above the base of the kenaf stem.

The kenaf leaves, flowers, and flower buds were removed from the stalks and weighed separately to determine the fresh weight. Plant samples were oven dried at 66°C for 48 h and weighed to determine dry weight. All kenaf weights and percentages were based on oven dry weights. The soybean seeds were weighed and yields adjusted to the standard 13% moisture.

In the final year of the rotational study soil samples (0–15 cm) were collected at planting and harvest to determine soil pH, nitrogen (N), phosphorus (P), and potassium (K) content. Soil and root samples were also collected at planting, mid-season (76 DAP), and harvest to determine nematode populations in the soil. The nematode samples were collected with a soil sampling tube with an inside diameter of 5.2 cm. Soil and nematode samples were processed at Oklahoma State University's analytical and diagnostic laboratories.

When the F-test indicated statistical significance ($P < 0.05$), the least significant difference (LSD) test was used to separate means (Snedecor and Cochran 1967). When no significant year by cultivar interactions were indicated, results are reported as averages across years.

EXPERIMENTAL RESULTS

Precipitation was measured during each growing season from May 1 to harvest and totaled 580 mm in 1989, 571 mm in 1990, and 422 mm in 1991 (Table 1). The 20-yr average precipitation (1 May–31 Oct.) for the location was 567 mm. Precipitation in 1989 and 1990 was just above the 20-yr average precipitation of

567 mm, compared to the 1991 precipitation which was 25% less than the 20-yr average. A greater percentage (77%) of seasonal precipitation was received in the first 3 months of 1989 than the first 3 months of either 1990 (48%) and 1991 (51%).

Kenaf Yield Components

First Year. The kenaf stalk yields for the first year ranged from 6.0 to 7.0 t/ha (Table 2). Even though there were no significant differences for kenaf stalk yields, plant populations, and stalk diameters among treatments during the first year, there was a significant difference for plant heights. The first kenaf treatment had significantly greater plant height compared to the third kenaf treatment. A general trend existed between decreasing plant heights and increasing plant populations and stalk yields.

Second Year. The kenaf stalk yields for the second year ranged from 8.0 to 8.3 t/ha (Table 3) with no significant differences among kenaf treatments for stalk yields, plant height, and stalk diameter. Plant population for the kenaf following soybean was significantly less than kenaf following kenaf production. It is unclear why there would be such a significant decrease in kenaf plant population when kenaf was planted the year following a soybean planting. Even with lower plant populations the kenaf treatment following soybean did not have significantly less yields. These results are consistent with earlier research by Higgins and White (1970) and Webber (1993) who reported no significant yield loss from population differences as long as the plant populations remain above a certain limit, 99,000 plants/ha. The kenaf plants often compensate for decreased plant populations by increasing plant height and/or stalk diameters. Although the plant population was the only yield parameter with a significant difference there was a slight inverse trend between decreased plant populations and increased stalk diameters.

Table 1. Precipitation for 1998, 1990, and 1991 for Haskell, Oklahoma. The 20-yr average seasonal (May 1–Oct. 31) precipitation for the research location is 567 mm.

	Precipitation (mm)		
Period	1989	1990	1991
May	214	187	63
June	143	22	145
July	89	67	7
Aug.	65	36	45
Sept.	52	213	135
Oct. 1 to harvest	17	45	28
Total^z	580	570	423

^{z}May 1 to harvest.

Table 2. Kenaf yield components for the first year (1989) of the rotational study.

Plant population (plants/ha)	Plant height (cm)	Stalk diameter (mm)	Stalk yield (t/ha)
213,000	200a^z	11.4	6.0
282,000	195ab	11.6	6.9
309,000	181b	10.8	7.0

^{z}Mean separation in columns by LSD (5% level).

Table 3. Kenaf yield components for the second year (1990) of the rotational study.

Previous crop	Plant population (plants/ha)	Plant height (cm)	Stalk diameter (mm)	Stalk yield (t/ha)
Soybean	151,000b^z	220	14.8	8.1
Kenaf	244,000a	220	14.0	8.3
Kenaf	274,000a	240	13.8	8.0

^{z}Mean separation in columns by LSD (5% level).

Table 4. Kenaf yield components for the third year (1991) of the rotational study.

Previous crops	Plant population (plants/ha)	Plant height (cm)	Stalk diameter (mm)	Stalk yield (t/ha)
Soybean, soybean	381000	184	11.2	8.5
Soybean, kenaf	410000	185	11.0	8.7
Kenaf, kenaf	420000	193	11.9	9.4

Third Year. The kenaf stalk yields for the third and final year of the rotational study ranged from 8.5 to 9.4 t/ha with no significant differences among kenaf treatments for stalk yields, plant population, plant height, and stalk diameter (Table 4). Plant population for the kenaf crops which followed soybean were slightly less, but not significantly less than the continuous kenaf for three years. There was a general trend of increasing stalk yields with increasing plant populations, plant height, and stalk diameter.

Soybean Yield Components

Soybean seed yields among treatments within years were not significantly different during any year of the 3-yr rotational study and averaged 1.2, 0.73, and 0.67 t/ha, for the first, second, and third year, respectively (Table 5). Soybean yields decreased after the first year independently of the cropping sequence. The soybean yields reflect the greater water available in 1989 during the soybeans initial growth through flowering and podfill, compared to less available water in the first half of the 1990 and 1991 seasons (Table 1).

Soil Analysis

Initial soil analysis of the research plots prior to the first fertilizer application and planting in 1989 had an analysis of 9.0 N, 64 P, and 170 K kg/ha. In the final year of the research, 1991, the soil K content at planting and harvest was significantly different among cropping sequences, while the pH and N were only significantly different for samples collected at harvest (Table 6). When comparing K values between planting and harvest, the cropping sequences with kenaf had the greatest drop in soil K values planting to harvest. Not only did the kenaf crops deplete a greater amount of K during the growing season, but the slight

Table 5. Soybean and kenaf yields by cropping sequence for 1989, 1990, and 1991.

Cropping sequence			Yields (t/ha)					
			1989		1990		1991	
1989	1990	1991	Soybean	Kenaf	Soybean	Kenaf	Soybean	Kenaf
Soybean	Soybean	Soybean	1.2	--	0.8	--	0.6	--
Soybean	Soybean	Kenaf	1.2	--	0.7	--	--	8.5
Soybean	Kenaf	Kenaf	1.2	--	--	8.1	--	8.7
Kenaf	Kenaf	Kenaf	--	6.0	--	8.3	-	9.4
Kenaf	Kenaf	Soybean	--	6.9	--	8.0	0.7	--
Kenaf	Soybean	Soybean	--	7.0	0.7	--	0.7	--

Table 6. Effect of crop sequence on soil analysis (pH, N, P, and K) at planting and harvest during the final year (1991) of rotational research at Haskell, Oklahoma.

Cropping sequence			Planting				Harvest			
1989	1990	1991	pH	N (kg/ha)	P (kg/ha)	K (kg/ha)	pH	N (kg/ha)	P (kg/ha)	K (kg/ha)
Soybean	Soybean	Soybean	5.53	40.9	73.9	170.8ab[z]	5.82ab	5.9b	44.5	159.6b
Soybean	Soybean	Kenaf	5.55	44.0	59.6	209.2a	5.62bc	6.4b	43.7	136.4d
Soybean	Kenaf	Kenaf	5.45	46.8	72.0	180.6ab	5.27d	12.6a	43.1	143.1cd
Kenaf	Kenaf	Kenaf	5.33	35.6	62.4	175.6ab	5.27d	5.6b	46.2	155.7bc
Kenaf	Kenaf	Soybean	5.35	40.3	71.4	172.2ab	5.60c	4.2b	49.3	181.2a
Kenaf	Soybean	Soybean	5.55	36.7	62.2	162.4b	5.85a	5.3b	46.8	165.8b
Main effects		Soybean[y]	5.54a	40.5	65.2	180.8	5.76a	5.1	46.9	168.8a
		Kenaf	5.38b	39.8	68.6	176.1	5.39b	8.2	44.3	145.0b

[z]Means in the column followed by the same letter are not significantly different based on a LSD, 5% level.
[y]Means averaged across the final year's crop.

net gain in K for two of the three soybean sequences indicates that the addition of 42 kg/ha of K at planting served as an adequate soil maintenance application for the soybean crops.

When the cropping sequences were grouped for analysis by their 1991 crop, soybean versus kenaf, the analysis indicated significant differences for pH at planting and harvest, and for K at harvest. The soil analysis at planting in 1991 was an indication of the effect of the proceeding crops, especially the crop grown in 1990. The pH data among cropping sequences had a general trend for lower pH values for those cropping sequences which had kenaf the previous year. The pH at planting compared to harvest is evidence that the cropping sequences influence the soil pH values. The most likely factor within the cropping sequences that would decrease the pH for the kenaf rather than the soybean was the difference in the fertilizer applications for the specific crops. The symbiotic N_2 fixation relationship of soybean and *Rhizobium japonicum* precluded the need N fertilizer applications to the soybean plots, whereas the kenaf production system involved the addition of N fertilizer. The addition of N in the form of ammonium nitrate (NH_4NO_3) to the kenaf plots prior to planting would most likely be responsible for the lower and decreasing pH values in the kenaf plots resulting from nitrification of the ammonium. Another issue that should be investigated is whether kenaf production in itself may reduce soil pH independently of fertilizer applications.

Table 7. Stunt nematode (*Tylenchorhynchus* spp.) means at planting, mid-season (76 DAP), and harvest during the final year.

Cropping sequence			Nematode count (No/100 cm^3)		
1989	1990	1991	Planting	Mid-season	Harvest
Soybean	Soybean	Soybean	44ab[z]	87ab	147ab
Soybean	Soybean	Kenaf	50ab	45ab	15bc
Soybean	Kenaf	Kenaf	14b	41ab	6c
Kenaf	Kenaf	Kenaf	12b	69ab	11bc
Kenaf	Kenaf	Soybean	14b	40ab	68abc
Kenaf	Soybean	Soybean	65a	149a	175a
Main effects		Soybean	41.0a	92.0a	130.0a
(final year)		Kenaf	25.3a	51.7a	10.7b

[z]Means in the column followed by the same letter are not significantly different based on a LSD, 5% level.

Nematodes

A small number of various nematodes (*Pratylenchus* spp., *Helicotylenchus* spp., *Xiphinema americanum*, and *Hoplolaimus galeatus*) were identified on the soybean and kenaf roots or in soil samples collected from the research plots, but stunt (*Tylenchorhynchus* spp.) nematode was the only nematode present throughout all the cropping sequences. Stunt nematode is an ectoparasitic nematode which feeds on a large range of different types of plants including soybean, maize, grain sorghum, alfalfa, wheat (*Triticum aestivum* L.), tobacco (*Nicotiana tabacum*), peanut (*Arachis hypogaea* L.), pearl millet [*Pennisetum glaucum* (L.) R. Br.], and lawn grasses. Stunt nematode populations at planting were the lowest for cropping sequences which followed kenaf (Table 7). When averaged across the previous season's crop, stunt populations where significantly less for kenaf (13.3 nematodes/100 cm^3) than for the soybean (52.7 nematodes/100 cm^3). Stunt nematode populations in the soybean treatments increased from planting through mid-season to harvest, compared to stunt nematode populations in the kenaf treatments which increased from planting to mid-season and then decreased at harvest to levels at or below initial stunt nematode populations. The stunt populations averaged across crops (soybean versus kenaf) followed the same pattern as the individual cropping sequences and resulted in significantly fewer stunt nematodes in kenaf treatments compared to the soybean treatments. These results are consistent with earlier rotational research (Edwards et al. 1988) which reported reduced stunt nematode populations in corn when included in a rotation compared to a continuous corn cropping system.

CONCLUSIONS

The kenaf stalk yields and soybean seed yields in the third and final year of the rotational study were not significantly different as a result of 3-yr cropping sequences. Seasonal rainfall affected soybean growth and yields more than any effects due to the cropping sequence. The pH values in cropping sequences following kenaf were lower at planting and continued to decrease though the growing season for those crop sequences planted in kenaf. The lower pH values did not adversely affect crop yields and could be increased by liming the soil. Including kenaf in a soybean rotation decreased stunt nematodes the following year and produced lower stunt nematodes during a kenaf growing season compared to soybean production. The 3-yr study determined that a kenaf/soybean rotation was successful and did not adversely affect kenaf or soybean yields, but did reduce stunt nematode populations.

REFERENCES

Adams, E., H.D. Morris, and R.N. Dawson. 1970. Effect of cropping systems and nitrogen levels on corn (*Zea mays*) yields in the southern piedmont region. Agron. J. 62:655–659.

Asghari, M. and R.G. Hanson. 1984. Nitrogen, climate, and previous crop effect on corn yield and grain N. Agron. J. 76:536–542.

Benson, G.O. 1985. Why the reduced yields when corn follows corn and possible management responses? p. 161–174. In: D. Wilkerson (ed.), Proc. 40th Annual Corn and Sorghum Research Conference. Chicago, IL., Dec. 11–12, 1985. Am. Seed Trade Assoc., Washington, DC.

Baldock, J.A. and B.D. Kay. 1987. Influence of cropping history and chemical treatments on the water-stable aggregation of a silt loam soil. Can. J. Soil Sci. 76:501–511.

Baldock, J.O. and R.B. Musgrave. 1980. Manure and mineral fertilizer effects in continuous and rotational crop sequences in Central New York. Agron. J. 72:511–518.

Crookston, R.K., J.E. Kurle, P.J. Copeland, J.H. Ford, and W.E. Lueshen. 1991. Rotational cropping sequence affects yield of corn and soybean. Agron. J. 83:108–113.

Crookston, R.K., J.E. Kurle, P.J. Copeland, and W.E. Lueshen. 1988. Relative ability of soybean, fallow, and triacontanol to alleviate yield reductions associated with growing corn continuously. Crop Sci. 28:145–147.

Edwards, J.H., D.L. Thurlow, and J.T. Eason. 1988. Influence of tillage and crop rotation in yields of corn, soybeans, and wheat. Agron. J. 80:76–80.

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

Lund, M.G., P.R. Carter, and E.S. Oplinger. 1993. Tillage and crop rotation affect corn, soybean, and winter wheat yield. J. Prod. Agr. 6:207–213.

Nieschlag, H.J., G.H. Nelson, I.A. Wolff, and R.E. Perdue, Jr. 1960. A search for new fiber crops. TAPPI 43:193–201.

Peterson, T.A. and G.E. Varvel. 1989a. Crop yield as affected by rotation and nitrogen rate. I. Soybean. Agron. J. 81:727–731.

Peterson, T.A. and G.E. Varvel. 1989b. Crop yield as affected by rotation and nitrogen rate. II. Grain sorghum. Agron. J. 81:731–734.

Peterson, T.A. and G.E. Varvel. 1989c. Crop yield as affected by rotation and nitrogen rate. III. Corn. Agron. J. 81:735–738

Raimbault, B.A. and T.J. Vyn. 1991. Crop rotation and tillage effects on corn growth and soil structural stability. Agron. J. 83:979–985.

Snedecor, G.W. and W.G. Cochran. 1967. Statistical methods. 6th ed. Iowa State Univ. Press, Ames.

Varvel, G.E. and T.A. Peterson. 1990. Residual soil nitrogen as affected by continuous, two-year, and four-year crop rotation systems. Agron. J. 82:958–962.

Webber, C.L. III. 1993. Yield components of five kenaf cultivars. Agron. J. 85:533–35.

White, G.A., D.G. Cummins, E.L. Whiteley, W.T. Fike, J.K. Greig, J.A. Martin, G.B. Killinger, J.J. Higgins, and T.F. Clark. 1970. Cultural and harvesting methods for kenaf. USDA Prod. Res. Report 113. Washington, DC.

Wilson, F.D., T.E. Summers, J.F. Joyner, D.W. Fishler, and C.C. Seale. 1965. ‘Everglades 41’ and ‘Everglades 71’, two new varieties of kenaf (*Hibiscus cannabinus* L.) for fiber and seed. Florida Agr. Expt. Sta. Cir. S-168.