



Cultivation of kenaf and sunn hemp in the mid-Atlantic United States[☆]

Harbans L. Bhardwaj^{a,*}, Charles L. Webber III^b, Glenn S. Sakamoto^c

^a Agricultural Research Station, Virginia State University, Petersburg, VA 23806, USA

^b USDA-ARS, South Central Agricultural Research Laboratory, Lane, OK 74555, USA

^c USDA-NRCS, Plant Materials Center, Hoolehua, HI 96729, USA

Received 12 May 2003; accepted 19 August 2004

Abstract

Sunn hemp (*Crotalaria juncea* L.), a legume plant, has potential in the mid-Atlantic region of the U.S. as a renewable source of fiber and pulp, due to its biological nitrogen fixation capability that can help reduce/eliminate N pollution of Chesapeake Bay. Most research in this region has focused on kenaf (*Hibiscus cannabinus* L.) and little is known about sunn hemp. We evaluated effects of three planting dates (late-May, mid-June, and late-June) and three row spacings (0.3, 0.6, and 0.9 m) on dry matter yields (DMY) of kenaf and sunn hemp during 1997, and 1998 by using three crop treatments (CT1: kenaf grown with 100 kg N ha⁻¹; CT2: sunn hemp grown without inoculation and with 100 kg N ha⁻¹; and CT3: sunn hemp inoculated with *Bradyrhizobium* but without N fertilization). DMY following CT1 and CT3 (7.8 and 6.4 Mg ha⁻¹, respectively) during 1997 were similar and greater than that following CT2 (5.7 Mg ha⁻¹). However, DMY following CT1, CT2, and CT3 were similar in 1998 and ranged from 12.6 to 13.4 Mg ha⁻¹. Kenaf planting date did not affect DMY during 1997 but during 1998 the highest DMY was obtained from kenaf planted in late-May. The optimal planting date for sunn hemp during 1997 was mid-June, whereas in 1998 it was late-May. Row spacing effects on kenaf DMY were not significant. Row spacings of 0.3 m were optimal for DMY of N-fertilized sunn hemp during 1997 and 1998, whereas row spacing did not affect DMY of non-fertilized, but affected inoculated sunn hemp. We conclude that both kenaf and sunn hemp could produce similar dry matter yields in the mid-Atlantic region of U.S.

© 2004 Elsevier B.V. All rights reserved.

Keywords: *Crotalaria juncea* L.; *Hibiscus cannabinus* L.; Nitrogen fertilization; Crop diversification

[☆] Contribution of Virginia State University, Agricultural Research Station Journal Article Series No. 238. The use of trade names or vendors does not imply approval to the exclusion of other products or vendors that may also be suitable.

* Corresponding author. Tel.: +1 804 524 6723; fax: +1 804 524 5950.

E-mail address: hbhardwj@vsu.edu (H.L. Bhardwaj).

1. Introduction

Kenaf and sunn hemp were identified as alternative sources of cordage material for the United States during the Second World War when supplies from overseas were interrupted and an increased need developed for these fibers (Wilson et al., 1965). Kenaf, an an-

nual plant that resembles cotton (*Gossypium hirsutum* L.) and okra (*Abelmoschus esculentus* L.), can be produced in large regions of the United States (Webber et al., 2002) during summer seasons. Sunn hemp, a legume plant, also has great potential as an annually renewable fiber crop and as a green manure and cover crop due to its biological nitrogen fixing capabilities (Cook and White, 1996; Mansoer et al., 1997).

Although both fiber crops possess suitable traits and high yields, kenaf has received more attention than sunn hemp due to its ability to produce consistently greater yields and lower lodging susceptibility (Wilson et al., 1965). Once it was determined that kenaf was a suitable crop for production in the United States, development of high-yielding anthracnose-resistant cultivars and production/harvesting technology soon followed (Nieschlag et al., 1960; Wilson et al., 1965; White et al., 1970). Kenaf has also been identified as an excellent source of cellulosic fiber for the manufacturing of a large range of paper products. Pulping kenaf requires less energy and chemical inputs for processing than standard wood sources (Nelson et al., 1962). Webber and Bledsoe (1993) reviewed the research and development work in the 1990s and concluded that kenaf fiber is suitable for use in building materials, adsorbents, textiles, and composites using new and recycled plastics.

Sunn hemp is also known as Sunnhemp, Indian hemp, Madras hemp, brown hemp, and sannhemp (Duke, 1983). Sunn hemp, a member of the legume family (Fabaceae), has great potential as an annually renewable, multi-purpose fiber crop (Cook and White, 1996). The stems of sunn hemp are composed of two fibers, the bast and woody core. The bast fibers, which are located in the outer bark, are much longer than the core fibers, but the two fiber widths are similar (Cunningham et al., 1978). Duke (1983) observed that bast fiber from sunn hemp is more durable than jute. As the world faces an increased need for fiber, sunn hemp has the potential to be grown on a large commercial scale (Cook and White, 1996). A detailed description of sunn hemp has been provided by Duke (1983) and Cook and White (1996).

Delayed planting reduced dry matter yields of sunn hemp in lower Rio Grande Valley of Texas, especially if planting was delayed by four weeks or longer from late-March to mid-April (Cook et al., 1998), whereas plant population did not influence total stalk yield (Cook and

Scott, 1998). Sunn hemp is highly resistant to root-knot nematodes, but not equally resistant to southern root-knot (*Meloidogyne incognita*) and reniform nematodes (*Rotylenchulus reniformis*). Robinson and Cook (2001) reported that reproduction of reniform nematode on sunn hemp was nearly undetectable, whereas reproduction of southern root-knot nematode was greater than that on resistant cotton. Scott and Cook (1994) compared the dry matter yields of kenaf, roselle (*Hibiscus sabdariffa* L.), and sunn hemp at two locations in Rio Grande Valley of Texas during 1992 and 1993 and reported that sunn hemp produced dry matter yields equal to kenaf during 1992, but not during 1993 when sunn hemp yields were significantly lower than kenaf.

In the mid-Atlantic region of the United States, persistent needs for crop diversification and protection of the Chesapeake Bay from nitrogen pollution suggest that leguminous plants that have the potential of reducing/eliminating the use of inorganic nitrogen fertilizers, such as sunn hemp, be studied. However, information about the production and yield of sunn hemp in the mid-Atlantic region of the United States is lacking, whereas considerable work has been done in kenaf (Bhardwaj and Webber, 1994; Bhardwaj et al., 1995, 1996). Sunn hemp has been researched as a legume cover crop in southeastern U.S. (Mansoer et al., 1997) and as a source of fiber in southern U.S. (Cook and Scott, 1998; Cook et al., 1998; Robinson and Cook, 2001). The objectives of our studies were to identify optimal planting date and row spacing for sunn hemp and to compare the dry matter yields of kenaf and sunn hemp.

2. Materials and methods

The plant material consisted of sunn hemp cv. 'Tropic Sun' and kenaf cv. 'Everglades-41'. Field experiments were conducted during 1997 and 1998 at the Randolph Farm of Virginia State University, located in Ettrick, Virginia (approximately 37°N and 77°W) on an Abel sandy loam (fine loamy mixed thermic Aquatic Hapludult) soil that typically has a pH of 6.1–6.4, P content of 54–77 mg kg⁻¹ and K content of 52–54 mg kg⁻¹. The experimental design was a split-split plot design of three replications with the planting dates as main plots, crop treatments in sub-plots, and row spacings as sub-sub plots. The three crop treatments consisted of: kenaf grown with

100 kg N ha⁻¹, sunn hemp grown without inoculation and with 100 kg N ha⁻¹, and sunn hemp inoculated with *Bradyrhizobium* but without N fertilization. Planting dates for 1997 were 29 May, 12 June, and 28 June, and for 1998 were 30 May, 15 June, and 29 June. Each plot consisted of three rows with 1-m distance between plots and row length of 3 m. Within each planting date, row spacings of 0.3, 0.6, and 0.9 m were evaluated. Approximately 100 seeds were planted in each row at about 0.02-m depth. Other than the treatment variable, these plots received no additional fertilizer applications. Plots received a pre-plant-incorporated treatment of Treflan (trifluralin) herbicide at 0.5 kg/ha a.i.

Both kenaf and sunn hemp plants matured in the fall of each year and were left in the field during late fall and early winter. During this period, cold temperatures caused defoliation. Whole plants from the middle row of each plot, after excluding border plants, were harvested approximately during the middle of the following January to record dry matter yields. The data were analyzed by PROC GLM procedure in version 6.11 of SAS (SAS, 1996). Serial comparisons of mean squares were made appropriate to a split-split plot design. Fisher's protected least significant difference was used for mean separation with a significance level of 5%.

3. Results and discussion

Analysis of variance, from the data combined over two years, indicated that significant interactions existed between year × planting date, and year × planting date × row spacing for dry matter yield. Analysis of data, separately by years, indicated that either the interaction involving crop treatment or the main effects were not significant. Therefore, the crop treatment means were compared by averaging over planting dates and row spacings (Table 1). However, analysis of data, separately by years, indicated that significant interactions still existed between planting dates and row spacing. Further analysis of data, separately by years and crop treatment, indicated lack of interactions. Therefore, comparisons of planting dates and row spacing means were conducted separately over years and crop treatments (Table 1).

The dry matter yields from whole plants of inoculated sunn hemp (6.4 Mg ha⁻¹) and fertilized kenaf

(7.8 Mg ha⁻¹) were significantly greater than the uninoculated and fertilized sunn hemp (5.7 Mg ha⁻¹) during 1997. However, the dry matter yields of the three cropping treatments during 1998 were not different and varied from 12.6 to 13.4 Mg ha⁻¹. The dry matter yields of sunn hemp in our studies, especially those from 1998 experiments, compared well with those obtained in southern Texas for sunn hemp, which during 1994 and 1995 varied from 9.6 to 18.3 Mg ha⁻¹ (Cook et al., 1998). These observations demonstrate that sunn hemp inoculated with appropriate *bradyrhizobia* can produce as much dry matter as either kenaf fertilized with 100 kg N ha⁻¹ or sunn hemp (non-inoculated and fertilized with 100 kg N ha⁻¹). This result is of significance from the standpoint that the sunn hemp can be grown without nitrogen fertilization and associated run-off.

We are unable to answer the question: "Can native *bradyrhizobia* adequately nodulate sunn hemp?" because our experiments did not include the non-inoculated-non-fertilized sunn hemp treatment. Further studies are needed to resolve this issue. In addition, it may be worthwhile to study the interaction between sunn hemp genotypes and bradyrhizobial strains for their biological nitrogen fixation potential. Existence of interaction between the host plant genotype and the bradyrhizobia strain is known to occur in many symbiotic systems (Robinson et al., 2000).

Kenaf planting date did not affect dry matter yields during 1997, but during 1998 the highest dry matter yield was obtained from kenaf planted in late-May. The optimal planting date for sunn hemp during 1997 was mid-June, whereas that in 1998 was late-May (Table 1). Therefore, it may be desirable to plant kenaf and sunn hemp from late-May to mid-June. Most of the summer crops, such as field corn (*Zea mays* L.), cotton (*G. hirsutum* L.), and soybean (*Glycine max* (L.) Merrill) are planted in early-May to mid-June in the mid-Atlantic region of the U.S. Due to the tropical adaptations, both kenaf and sunn hemp appear to be better adapted to plantings when the soil had sufficiently warmed up by the mid-June.

Row spacing effects on kenaf dry matter yield were not significant. Row spacings of 0.3 m was optimal for dry matter yield of N-fertilized sunn hemp during 1997 and 1998, whereas row spacing did not affect dry matter yields of non-fertilized but inoculated sunn hemp (Table 1). This observation in combina-

Table 1

Crop treatment, planting date, and row spacing effects on whole dry matter yield (Mg ha^{-1}) of kenaf and sunn hemp grown at Ettrick, Virginia during 1997 and 1998

	Kenaf 100 kg N ha^{-1}	Sunn hemp 100 kg N ha^{-1} Un-inoculated	Sunn hemp 0 kg N ha^{-1} Inoculated
1997			
Planting dates			
Late-May ^a	5.82 a ^b	3.68 b	4.84 b
Mid-June	9.67 a	7.95 a	8.36 a
Late-June	7.75 a	5.55 ab	6.00 b
Row spacing			
0.3 m	7.68 a ^b	6.41 a	7.65 a
0.6 m	8.07 a	5.80 ab	6.28 a
0.9 m	7.49 a	4.97 b	5.28 a
Overall 1997 means	7.75 a ^c	5.73 b	6.40 ab
1998			
Planting dates			
Late-May ^a	13.99 a ^b	14.17 a	16.11 a
Mid-June	12.77 b	13.19 a	13.93 ab
Late-June	11.15 c	12.29 a	10.12 b
Row spacing			
0.3 m	11.77 a ^b	14.69 a	12.61 a
0.6 m	13.31 a	12.79 b	14.23 a
0.9 m	12.82 a	12.16 b	13.31 a
Overall 1998 means	12.64 a ^c	13.21 a	13.39 a

^a Late-May plantings on 29 May 1997 and 30 May 1998; mid-June plantings 12 June 1997 and 15 June 1998; late-June plantings 28 June 1997 and 29 June 1998.

^b Means followed by similar letters within columns were not different according to the least significant difference test at 5% level of significance.

^c Overall means of crop treatments, within the rows, followed by similar letters were not different according to the least significant difference test at 5% level of significance.

tion with the high cost of seed for both kenaf and sunn hemp indicates that the desirable row spacing for commercial production of kenaf and sunn hemp may be 0.9 m especially since it is expected that sunn hemp production without N fertilization and with *Bradyrhizobium* inoculation would be preferable in areas in the Chesapeake Bay water shed due N pollution concerns.

During recent years, there has been considerable interest among farming, processing, and scientific communities in North America regarding industrial hemp containing less than 0.3% of delta-9-tetrahydrocannabinol (THC). The dry matter yields of industrial hemp have been reported to be 2.8–6.1 metric tons per acre (approximately $7\text{--}15 \text{ Mg ha}^{-1}$) from Kentucky (ERS, 2000). Given this low dry matter yield and associated legal issues regarding industrial hemp

production in the U.S., the dry matter yields of both kenaf and sunn hemp (approximately 10 Mg ha^{-1}) are impressive. The biological nitrogen fixation capabilities should provide additional incentives for production and utilization of sunn hemp.

4. Conclusions

Our results demonstrate that production of both kenaf and sunn hemp for dry matter production is feasible in Virginia and the mid-Atlantic region of the United States. However, it may be desirable to further study sunn hemp due to its biological nitrogen fixation capabilities. Production of sunn hemp can help in reducing/eliminating use of N fertilizers, and thus, help protect the Chesapeake Bay from pollution.

References

- Bhardwaj, H.L., Rangappa, M., Webber III, C.L., 1995. Potential of kenaf as a forage. In: Proceedings of the International Kenaf Association Conference, Irving, TX 7, 9–10 March, pp. 95–103.
- Bhardwaj, H.L., Webber III, C.L., 1994. Seasonal variation in kenaf yield and quality. In: Proceedings of the International Kenaf Association Conference, Irving, TX 6, 8–10 March, pp. 150–154.
- Bhardwaj, H.L., Rangappa, M., Webber III, C.L., 1996. Effects of row spacing, fertilizers, and varieties on kenaf yield in Virginia. In: Proceedings of the International Kenaf Association Conference, Albuquerque, NM 8, 21–23 March, pp. 23–26.
- Cook, C.G., White, G.A., 1996. *Crotalaria juncea*: a potential multi-purpose fiber crop. In: Janick, J. (Ed.), Progress in New Crops. ASHS Press, Alexandria, VA, pp. 389–394.
- Cook, C.G., Scott Jr., A.W., 1998. Plant population effects on stalk growth, yield, and bark fiber content of sunn hemp. Ind. Crops Prod. 8, 97–103.
- Cook, C.G., Scott Jr., A.W., Chow, P., 1998. Planting date and cultivar effects on growth and stalk yield of sunn hemp. Ind. Crops Prod. 8, 89–95.
- Cunningham, R.L., Clark, T.F., Bagby, M.O., 1978. *Crotalaria juncea*—annual source of papermaking fiber. TAPPI 61, 37–39.
- Duke, J.A., 1983. *Crotalaria juncea* L. Handbook of Energy Crops (Unpublished). Available at http://www.hort.purdue.edu/newcrop/duke_energy/Crotalaria_juncea.html (viewed 2 June, 2004).
- ERS, 2000. Industrial Hemp in the United States: Status and Market Potential. ERS AGES No. 001. 43 pp. Available at <http://www.ers.usda.gov/publications/ages001e> (viewed 2 June, 2004).
- Mansoer, Z., Reeves, D.W., Wood, C.W., 1997. Suitability of sunn hemp as an alternative late-summer legume cover crop. Soil Sci. Soc. Am. J. 61, 246–253.
- Nelson, G.H., Nieschlag, H.J., Wolff, I.A., 1962. A search for new crops. V. Pulping studies on kenaf. TAPPI 45, 780–786.
- Nieschlag, H.J., Nelson, G.H., Wolff, I.A., Perdue, R.E., 1960. A search for new fiber crops. TAPPI 43, 193–201.
- Robinson, A.F., Cook, C.G., 2001. Root-knot and reniform nematode reproduction on kenaf and sunn hemp compared with that on nematode resistant and susceptible cotton. Ind. Crops Prod. 13, 249–264.
- Robinson, K.O., Beyne, D.A., van Berkum, P., Knight-Mason, R., Bhardwaj, H.L., 2000. Variability in plant-microbe interaction between *Lupinus* lines and *Bradyrhizobium* strains. Plant Sci. 159, 257–264.
- SAS, 1996. SAS System for Windows, Version 6.11. SAS Inst. Inc., Cary, NC.
- Scott Jr., A.W., Cook, C.G., 1994. Kenaf, crotalaria, Roselle—two year comparison in South Texas. In: Proc. Int. Kenaf Assoc. Conf., Irving, TX 6, pp. 97–101.
- Webber III, C.L., Bledsoe, V.K., 1993. Kenaf: production, harvesting, and products. In: Janick, J., Simon, J.E. (Eds.), New Crops. Wiley, New York, pp. 416–421.
- Webber III, C.L., Bhardwaj, H.L., Bledsoe, V.K., 2002. Kenaf production: fiber, feed and seed. In: Janick, J., Whipkey, A. (Eds.), Trends in New Crops and New Uses. ASHS Press, Alexandria, VA, pp. 327–339.
- White, G.A., Cummins, D.G., Whiteley, E.I., Fike, W.T., Greig, J.K., Martin, J.A., Killinger, G.B., Higgins, J.J., Clark, T.F., 1970. Cultural and harvesting methods for kenaf. USDA Prod. Res. Report 113. Washington, D.C.
- Wilson, F.D., Summers, T.E., Joyner, J.F., Fishler, D.W., Seale, C.C., 1965. ‘Everglades 41’ and ‘Everglades 71’, two new cultivars of kenaf (*Hibiscus cannabinus* L.) for the fiber and seed. Florida Agric. Expt. Sta. Cir., S168.