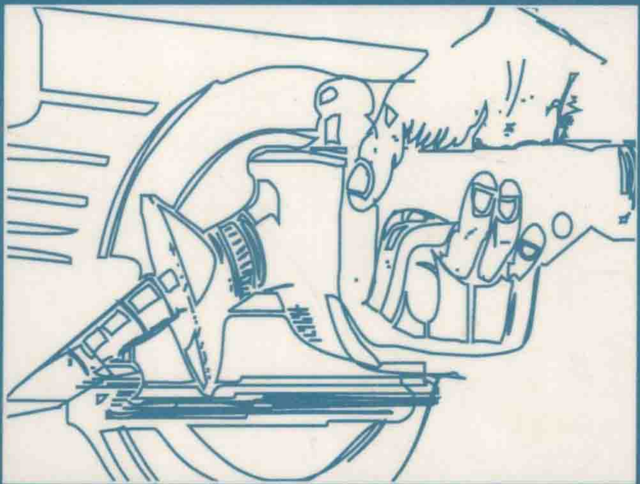
Liquid Fuels from Renewable Resources



Proceedings of an Alternative Energy Conference

14-15 December 1992
Nashville, Tennessee

ASAE
American Society of Agricultural Engineers

Liquid Fuels from Renewable Resources

Proceedings of an Alternative Energy Conference

Edited by
John S. Cundiff

14-15 December 1992
Nashville, Tennessee

Published by
American Society of Agricultural Engineers
2950 Niles Rd., St. Joseph, Michigan 49085-9659 USA

Library of Congress Card Number (LCCN) 92-74909
International Standard Book Number (ISBN) 0-929355-36-9
ASAE Publication 12-92

Foreword

Informed citizens in many countries are concerned about the long-term effect of the release of fossilized carbon into the atmosphere through the combustion of fossil fuels. Of more immediate concern is the degradation of air quality in urban areas due to pollutants in vehicle exhaust. Fuel from renewable resources is a technology that addresses both these concerns. Combustion of annual-growth biomass recycles carbon. Alcohol fuels are blended with petroleum to add oxygen, and the resulting fuel reduces internal combustion engine emissions. Vegetable oil as a replacement for diesel fuel has a similar advantage of reducing engine emissions.

In the United States and many industrialized nations, government is seeking ways to reduce the cost of farm support programs. Liquid fuel and other alternative products from biomass offer a significant new market for agriculture. An ancillary benefit is the opportunity to stimulate depressed rural economies.

The Biomass Energy and Alternative Products Committee (FPE-709) planned the Liquid Fuels from Renewable Resources Conference to provide an opportunity for engineers, scientists, and policy makers with a range of interests and viewpoints to meet together and assess current liquid fuel from renewable resources technology. The planning committee was very gratified to receive papers prepared by engineers and scientists from a broad range of disciplines representing both the feedstock production and conversion groups. It is hoped that interaction of the two groups will highlight systems issues which need to be addressed, and stimulate interest in addressing these issues.

The Biomass Energy and Alternative Products Committee (FPE-709) is pleased to have the cooperation of the Energy Committee (T-11), Solar Energy Committee (SE-414), and Food Processing Waste Management and Utilization Committee (FPE-707) for the planning of this conference. Support from the ASAE Meeting/Conferences Planning staff, specifically Linda Fritsch, is gratefully acknowledged. Appreciation is also expressed to Julia Costello for her assistance in printing these proceedings.

Proceedings Editorial Committee and
Conference Planning Committee

John S. Cundiff, Chairman
Phillip C. Badger
Richard P. Egg
Bryan M. Jenkins
Dennis L. Larson, Liaison SE-414
Abdel Ghaly, Liaison FPE-707

Acknowledgments

The Conference Planning Committee is very grateful for support from the following promotional cooperators.

U.S. Department of Energy — Biofuels Feedstock Development Program
U.S. Department of Energy — Office of National Programs
U.S. Department of Agriculture — Office of Energy
National Wood Energy Association
Tennessee Department of Economic and Community Development

Appreciation is also expressed to the several newsletters and related publications that published articles announcing the conference.

Energy Outlook, Virginia Center for Coal & Energy Research
Ag Industrial Materials and Products, New Uses Council, Inc.
Energy Network News, State Energy Programs Division, U.S. DOE
FPEI News, Food and Process Engineering Institute, ASAE
Energy Crops Forum, Biofuels Feedstock Development Program, U.S. DOE
Biomass and Bioenergy, Pergamon Press
SERBEP Update, Southeastern Regional Biomass Energy Program, U.S. DOE

The invited speakers added tremendously to the conference, and their contribution is gratefully acknowledged.

Dr. Donald L. Klass, President, Biomass Energy Research Association

Dr. David L. Greene, Manager, Energy Policy Research Programs, Center for Transportation Analysis, Oak Ridge National Laboratory

Dr. Peter Wittman, Chairman, OO Warenvermittlung, Linz, Austria

Mr. Mark Dungan, Executive Assistant to Secretary of Agriculture-Energy Affairs

Table of Contents

PLANT AND ANIMAL OILS AS VEHICLE FUELS

EVALUATION OF BIOMASS PRODUCTION SYSTEMS FOR THE MIDWEST

E. L. Hunter, I. C. Anderson, and D. R. Buxton*

ABSTRACT

Renewable sources of energy are needed that can be supplied from dedicated biomass crops. This research was conducted on highly productive level soils in central Iowa and a marginally productive sloping soil in southern Iowa to identify species and agronomic practices that result in high yield of biomass. Several cropping systems were evaluated for four years. Perennial crops such as reed canarygrass, big bluestem and switchgrass yielded about 11 Mg ha^{-1} and are well suited for sloping soils. Interplanting rows of a summer annual such as forage sorghum into perennial alfalfa after its first cutting for hay produced 5 Mg ha^{-1} of hay and 10 Mg ha^{-1} of combustible biomass. Sorghums planted alone or double cropped with fall seeded rye, to protect the soil during the winters, yielded over 20 Mg ha^{-1}. Varieties of sweet sorghum from the Gulf Coast have the potential to produce over 4800 L ha^{-1} of ethanol from their readily fermentable stalk sugar. Culture of sweet sorghum for ethanol is discussed.
KEYWORDS: sweet sorghum, switchgrass, corn, cool-season grasses, warm-season grasses, fermentation, ethanol

INTRODUCTION

Renewable sources of energy are needed because fossil fuel supply is finite and concern for the environment continues to increase. Biomass from herbaceous energy crops has the potential to supply much of this renewable source of energy and to pose fewer environmental concerns than fossil fuels. Energy crops have flexibility in that they can be grown where needed and thereby reduce transportation costs. Production of herbaceous energy crops would broaden the crop base in farm communities and improve rural economic conditions.

The research reported here was conducted in the North Central Region of the USA, which is one of the most productive regions in the USA. The study was concerned with developing dependable supplies of low-cost biomass for combustion and liquid fuels. The objective was to identify species and agronomic practices that resulted in high yield of biomass per unit of land area. Prime farmland without erosion potential will support both highly productive perennial sod-forming crops as well as annual row crops. Marginal sloping land, however, is much more suited for cropping systems that feature sod-forming, perennial species.

*Dep. of Agronomy, Iowa State Univ., Ames, IA 50011. D. R. Buxton is USDA-ARS.
Contribution from Iowa Agric. Home Econ. Exp. Stn.

EXPERIMENTAL PROCEDURES

The studies were conducted at Ames, a central Iowa location on prime row crop land, and at Chariton, a southern Iowa location on marginal sloping land. Thirteen cropping systems were used from 1988-1991. Four perennial crops were grown that do not require annual seeding: alfalfa (variety Arrow), reed canarygrass (Venture), which are two C_3 cool-season crops, switchgrass (Cave-in-Rock), big bluestem (experimental SD-43), which are two C_4 warm-season crops. Alfalfa and reed canarygrass also were grown as perennial crops in which 8-cm wide tilled slots 76 cm apart were made for planting of sweet sorghum (M81E) or sorghum x sudangrass hybrid (FFR201) after the first cutting of alfalfa or reed canarygrass had been removed. The sorghums were harvested in late August and a final harvest of the forage crop regrowth was taken after frost. This perennial prairie system used a cool season crop for growth from early spring until late fall, which was supplemented with a C_4 warm-season sorghum for rapid growth during midsummer when the cool-season crop normally has limited growth. Sweet sorghum and the forage sorghum were planted each year on the same plots in 76-cm rows. The sorghums also were double cropped with fall seeded rye (Aroostook), which was harvested the following May before seeding the sorghum. Sweet sorghum also was grown in a three-year rotation consisting of corn (Pioneer 3377), soybeans (Pella or BSR201), and sole sweet sorghum or sweet sorghum double cropped with rye seeded after soybean harvest. All systems except soybeans and sole alfalfa received four rates of nitrogen fertilizer (0, 70, 140 and 280 kg ha^{-1}). A single yearly harvest was made of all crops except for two or three cuttings per year for alfalfa and reed canary grass.

The experimental design at both locations was randomized complete block with nitrogen treatments as subplots with four replications. Main plots were 6 x 31 m and the subplot 6 x 7 m. Severe droughts occurred in 1988 and 1989. Rainfall in 1990 was much above average and slightly above average in 1991.

RESULTS AND DISCUSSION

Average biomass yields of alfalfa, reed canarygrass, big bluestem, and switchgrass were 11, 11, 10 and 11 Mg ha^{-1} with adequate N fertilizer, respectively. The perennial prairie of alfalfa-sorghums yielded 15 Mg ha^{-1}. The sorghums were not competitive in the reed canarygrass system, which yielded 11 Mg ha^{-1}. Although the biomass from these forage crops could be fermented to ethanol upon saccharification of the celluloses, their most promising use may be as solid fuel for combustion. Compared with coal, they are essentially devoid of sulfur and acid rain potential. With the future mandated lower emissions, coal fired plants either need to use lower sulfur coal or install better emission controls. Coburning of biomass with coal may be a more economical solution. From an energy aspect, 1 Mg of biomass equals 0.6 Mg of coal and low sulfur coal cost about $35 per 0.6 Mg. Therefore, 11 Mg of biomass per hectare should be worth $385. Because of the very low sulfur content of biomass it should be worth more for combustion with coal. The alfalfa-forage sorghum system on marginal land appears attractive because it would provide 5 Mg ha^{-1} of alfalfa hay for cattle associated with farming in those areas and 10 Mg ha^{-1} of fuel from the forage. After the 4th winter of this system, the sorghum has not reduced winter survival and spring regrowth of the alfalfa.

Continuous sweet sorghum yielded 18 Mg ha^{-1} and forage sorghum, using a variety which was too early for our latitude, yielded 16 Mg ha^{-1}. The double crop with rye yielded over 20 Mg ha^{-1} during wet years but less than sole sorghums during dry years.

The sorghums should generally be part of a rotation and if following soybeans or an oat-meadow crop, little fertilizer N is needed. Since the harvest of sorghum leaves the soil bare and vulnerable to water erosion, a cover crop such as rye should be used and the rye chemically killed in the early spring before planting of corn. Forage sorghum or high density seeded Caribbean corn, as we are now using, could be used either for ethanol production or for combustion. We have been successful in harvesting this biomass by driving through the crop with a flail type corn stalk chopper that shreds the plant material to a fluffy mat, which dries rapidly and can be baled. At our latitude, temperatures are low enough by September 20 to decrease growth rates of these C_4 crops so that little potential biomass is lost by harvest at this time and the drying conditions are favorable.

Sweet sorghum has potential as a crop for ethanol production. Varieties from the Gulf Coast of USA when grown in the Midwest grow taller than at their latitude of adaptation. When harvested during the middle of September, the grains of the head are at the milk stage. Waconia is the only variety in Table 1 adapted to the Midwest. M81E produces about 8.5 Mg ha^{-1} of soluble sugars, which mainly is sucrose plus some glucose and fructose. At 85% of theoretical yield, multiplication of Mg ha^{-1} of sugars of sweet sorghum by 565 equals L ha^{-1} of ethanol (Smith et al., 1987).

Table 1. Whole plant characteristics of sweet sorghum varieties in 1990 at Ames, using 5 replications.

Variety	Fresh wt. Mg ha^{-1}	Dry wt. Mg ha^{-1}	Sugar Mg ha^{-1}	Ethanol[a] L ha^{-1}	Height m
M81E	103	25.0	8.43	4760	3.26
Wray	102	24.6	7.41	4190	3.35
Theis	98	26.3	7.10	4010	3.57
Dale	87	21.6	6.50	3670	3.29
Rio	82	22.3	5.69	3210	3.29
Cowley	80	22.6	5.45	3080	3.41
Keller	84	22.8	5.34	3020	3.57
Morcane	90	22.2	4.66	2630	2.29
Waconia	73	20.3	5.79	3270	2.62

[a]85% of theoretical yield.

The weight of the freshly chopped whole plant sorghum is near 100 Mg ha^{-1}, which precludes transport to central processing facilities. Also, the plants carry an appreciable lactic acid bacteria inoculum that within less than 1 day can convert about 8-10% of the sugar to lactic acid. This lowers the pH to about 4.7, which causes the forage to become bacteriostatic if kept anaerobic. The main adverse effect of lactic acid is that at this concentration in the forage it is a strong inhibitor of yeast fermentation of sugar to ethanol (de Mancilha et al., 1984). In semisolid-phase fermentation of sweet sorghum similar to that used by Gibbons et al. (1986) and Bryan and Parrish (W. L. Bryan and R. L. Parrish, Winter Meet. Am. Soc. Agric. Eng. 1982, 82-3603), we obtain complete fermentation of sugars within 4-7 days if chopped forage is sprayed with a yeast inoculum and treated with 140 L ha^{-1} of fertilizer grade sulfuric acid ($40 ha^{-1}) to lower the pH to 3.8-4.0 as it is unloaded from the forage wagon. The yeast we use is *S. cerevisiae* NRRL Y-2034, which has activity to pH as low as 2.5 (Gibbons et al., 1986). The fermented silage in anaerobic 50 L plastic containers has been stable in our studies for a year.

Although we have not done the following, we propose on-farm fermentation of the forage in plastic lined trench silos. The liquid of the silage could be flash evaporated as the silage is passed over a hot plate producing a dry residue for heat and ethanol-steam for distillation with a simple horizontal column to produce a 30-50% solution of ethanol that could leave the farm. We are initiating a project to produce lactic acid for biodegradable plastics from sweet sorghum. Tall tanks or silos would be used and the pH of the drainage from the bottom adjusted and returned to the top of the silo to hold the pH of the silo between 5.0-5.5.

Cultural Practices for Sorghum

Until sweet sorghum initiates a head, a portion of the photosynthate is used to form and elongate additional internodes and therefore concentration of sugar increases slowly in the stalk. After head initiation, sugar concentration increases more rapidly, but some sugar is used for elongation of the last five small internodes and for beginning growth of the head (Vietor and Miller, 1990). If the variety is adapted, sugar will be used later for grain formation, and the sugar concentration of the stalk decreases after the milk stage during starch deposition (Hills, et al., 1990). Waconia is the only variety in Tables 1 and 2 adapted to the latitude of Iowa and has a mature seed head by September 15. The seed of Waconia used in 1991 was of poor quality and there was a low and irregular stand so the dry matter yield was low. Brix values for stalk sap of Waconia and Kansas Orange, the second earliest variety, began to decline after early September during starch deposition in the grain (Table 2). The third earliest variety was Sugar Drip. The variety used in most of our studies, M81E, is one of the latest varieties. If harvested during the third week of September its grain is in the milk stage.

Table 2. Mean whole plant yield and stalk brix values of sweet sorghum grown at Ames and Chariton harvested during the first week of October 1991 using 3 replications.

Variety	Fresh wt. Mg ha^{-1}	Dry wt. Mg ha^{-1}	Brix of stalk sap			
			14 Aug	22 Aug	29 Aug	9 Sept
M81E	75	18.2	4.1	4.8	6.1	9.2
Wray	60	16.1	4.7	5.7	7.6	10.8
Theis	57	15.7	4.4	5.1	7.8	10.9
Dale	62	15.5	5.0	6.2	7.6	10.9
Rio	67	16.4	5.4	6.2	9.2	12.5
Cowley	49	13.5	5.0	6.4	9.2	12.7
Keller	56	14.7	4.7	5.4	7.9	10.0
MN1500	77	20.9	4.5	4.9	7.2	10.2
Smith	51	14.7	5.8	7.7	10.1	13.6
Sugar drip	57	15.0	6.0	7.3	10.0	12.6
Kans. Orange	46	13.2	6.6	9.8	13.6	13.3
Waconia	26	6.3	5.5	7.7	9.5	8.1

Sweet sorghum varieties from the Gulf Coast emerge at a similar time as corn when planted in cold soil of early May, but grow very slowly until after July 1 at which time they are less than one-half the height of corn. By the end of July they are equal to corn and during August they exceed the height of corn by 50%. Our greatest dry matter yield of sweet sorghum was during the dry and very high summer temperatures of 1988 at Chariton. Corn grain yield was 2.7 Mg ha^{-1} and total dry matter was one-third that of sweet sorghum which illustrates the drought tolerance of sweet sorghum and its response to warm summer temperatures. Sweet sorghum following a crop of soybeans responds to little additional fertilizer N and uses soil mineralized N (110 kg ha^{-1} for our soils) and residual N of soybeans (60 kg ha^{-1}). Corn under similar conditions would need an additional 140-170 kg ha^{-1} of fertilizer N.

Due to the height of sweet sorghum and profuse tillering, about 30 stalks per m of row length in 76-cm-rows, the crop lodges if exposed to heavy rain storms with wind during July and August. Table 3 shows the effects of spraying sweet sorghum and Caribbean corn with ethephon to reduce plant height and to reduce lodging. The early application shortened length and increased the diameter of internodes 4-10 and the later application had similar effects on internodes 7-13. Ethephon did not appear to reduce total dry matter of either crop.

Table 3. Effects of ethephon on yield and height of sweet sorghum and Caribbean corn in 1991 at Ames, using 2 replications.

		Sweet Sorghum		Caribbean Corn	
Ethephon kg ha^{-1}	Date Treated	Dry Wt. Mg ha^{-1}	Height m	Dry Wt. Mg ha^{-1}	Height m
0	23 July	18.3	3.9	13.3	3.6
0.14	23 July	15.4	3.8	12.8	3.3
0.28	23 July	17.4	3.6	13.5	3.2
0.56	23 July	13.9	3.3	12.2	3.0
0	2 Aug	16.4	3.7	13.6	3.6
0.14	2 Aug	17.2	3.6	13.6	3.4
0.28	2 Aug	18.0	3.2	12.6	3.2
0.56	2 Aug	16.3	3.3	13.3	3.1

Another cultural practice we began investigating in 1991 was spraying sweet sorghum with sugar-ripener chemicals when the head was about 2 cm long. Treatment reduced top growth and plant height. Brix values of the 4th internode was increased 23% and the 8th internode 25% without any apparent reduction in dry matter production.

Preplant application of Dual (metolachlor) herbicide with Concept II (orebetrinil) protected seed has given adequate weed control. Use of proper varieties, planting rate, uniform seed spacing, weed control, lodging control, sugar-ripener effects, and harvest before frost should appreciably increase sugar yield and ethanol potential of sweet sorghum.

PERSONNEL SAFETY

The equipment for production and harvest of forage crop biomass is common to farmers. For spraying sweet sorghum with growth-controlling chemicals a high clearance sprayer adds some risk. The equipment need for harvesting and ensiling sweet sorghum are those commonly used for corn silage, but some farmers do not have experience with this type of equipment. The most dangerous practice discussed was treating chopped sweet sorghum with fertilizer grade sulfuric acid before ensiling. Because of its unique properties, transport is relatively safe, but special application equipment would be needed.

ACKNOWLEDGEMENT

This research is sponsored jointly by the U. S. Department of Energy under contract with Martin Marietta Energy Systems, Inc., and by the Leopold Center for Sustainable Agriculture at Iowa State University.

REFERENCES

1. Gibbons, W. R., C. A. Westby, and T. L. Dobbs. 1986. Intermediate-scale, semicontinuous solid phase fermentation process for production of fuel ethanol from sweet sorghum. applied and Environmental Microbiology. 51:115-122.

2. Hills, F. J., N. T. Lewellen and I. O. Skoyen. 1990. Sweet sorghum cultivars for alcohol production. California Agriculture 44:14-16.

3. de Mancilha, I. M., A. M. Pearson, H. Momose, and J. J. Pestka. 1984. Increasing alcohol yield by selected yeast fermentation of sweet sorghum. Food Chem. 14:313-318.

4. Smith, G. A., M. O. Bagby, R. T. Lewellan, D. L. Doney, P. H. Moore, F. J. Hills, L. G. Campbell, G. J. Hogaboam, G. E. Coe, and K. Freeman. 1987. Evaluation of sweet sorghum for fermentable sugar production potential. Crop Sci. 27:788-793.

5. Victor, D. M. and F. R. Miller. 1990. Assimilation, partitioning and nonstructural carbohydrates in sweet compared to grain sorghum. Crop Sci. 30:1109-1115.

AGRONOMIC AND ECONOMIC POTENTIAL OF SWEET SORGHUM AND KENAF:

Preliminary Results of the California Industrial Crops Demonstration Program

S. D. Shaffer[1] B. M. Jenkins[2], D. L. Brink[3], M. M. Merriman[4], B. Mouser[5], M. L. Campbell[6], C. Frate[7], and J. Schmierer[8]

ABSTRACT

Sweet sorghum is proving to have excellent potential as a biomass energy crop for the production of fuel alcohol and/or electricity. Its advantages include high biomass and fermentables production per unit area of land, relatively low input requirements, and good suitability to a variety of California growing conditions. Average biomass yield for twelve projects involving nine growers, and eight cultivars was 7.6 bone dry tons per acre(bdt/ac) (17 t/ha) at an average cost of production of $58/bdt ($64/t), ready for harvest. With an ethanol yield of 89 gal/bdt (371 L/t), feed stock costs would be about $0.65/gal ($0.17/L). Improved crop yields at reduced costs can be expected in the future.

Kenaf is a potential paper pulp and fiber feed stock which produces a long bast fiber and a short-fiber core material. About 30% of the stem material is long fiber, and the remaining 70% is short fiber. The current cost of production, given demonstration project yields of 4 bdt/ac (9t/ha) is about $222/bdt ($245/t), and available higher-value uses command prices of $300/bdt ($330/t) for long fiber for cordage and $160/bdt ($175/t) for core material as poultry litter, precluding its use directly as an energy feed stock. However, reusing the poultry litter core material for energy production may be economically feasible. This material may be obtained for about $15/bdt ($17/t), and with an ethanol yield of 34 gal/bdt (142 L/t), feed stock cost may be about $0.44/gal ($0.12/L).
Keywords. sweet sorghum, kenaf, biomass, industrial crops, energy, economics

INTRODUCTION

Several economic and environmental issues may be addressed simultaneously by producing fuels, chemicals, and other petroleum substitutes from indigenous natural resources in California. The production of these bio-derived materials can result in economic development opportunities for all regions of the State, improved energy diversity and security, and environmental benefits, including reduced air pollution, improved soil and water management, and an improved balance in the carbon cycle.

The Industrial Crops Demonstration Program in the California Department of Food and Agriculture (CDFA) was created to address these challenges and opportunities in an effective integrated approach. Thus far, the program has conducted demonstrations on four crops: sweet sorghum, kenaf, Canola, and lupine. Documented results have so far been obtained for sweet sorghum and kenaf.

---

[1]Research Analyst, California Department of Food and Agriculture, Sacramento
[2]Associate Professor, Biological and Agricultural Engineering Department, University of California, Davis
[3]Professor Emeritus, University of California Forest Products Laboratory
[4]Specialist, University of California Forest Products Laboratory
[5]Professor Emeritus, California State University, University Farm, Chico
[6]Farm Advisor, University of California Cooperative Extension, Stanislaus County
[7]Farm Advisor, University of California Cooperative Extension, Tulare County
[8]Farm Advisor, University of California Cooperative Extension, Lassen County

METHODS

The California Department of Food and Agriculture (CDFA) initiated the Industrial Crops Demonstration Program in 1990. The $115,000 program was funded by Petroleum Violation Escrow (Exxon Oil overcharge) funds which were passed through from the United States Department of Energy (USDOE) to the California Energy Commission (CEC), and by state legislation to the CDFA. The goal of the program is to aid the commercialization of crops for energy and other industrial markets. The objectives of the program are to demonstrate potential energy and industrial crops under commercial conditions; familiarize growers with these crops; determine the suitability of these crops for various energy and industrial markets; determine costs and energy balance of production; and identify barriers to commercialization.

The program consists of several components. First a nine member advisory committee comprised of two growers, two agronomists, a soil scientist, an agricultural energy specialist representing the CEC, an environmental scientist representing the Environmental Defense Fund, an agricultural engineer representing the CDFA, and a USDA-SCS Area Conservationist, was assembled to set criteria for crop selection and review potential crops. Next grower-cooperators were identified and contracted to produce a crop on a pre-commercial basis and record activities and costs associated with crop production. Concurrently a Farm Advisor or other technical support person provided technical assistance and independently monitored, evaluated, and reported on each project. Finally, samples of the crop were collected and submitted for laboratory analysis to determine the appropriate physical and chemical characteristics in order to evaluate market potential.

Several crops were identified by the advisory committee (Table 1) and to date four have been included in the program. The selection was based on considerations of planting material availability, equipment availability, long-term impacts, potential for integration into conventional cropping systems, low or reduced inputs of water, fertilizer, and other chemicals, product marketability including possible multiple uses, and crop adaptability to a wide range of climatological and agronomic conditions found in the state. The four crops (sweet sorghum, kenaf, Canola or rapeseed, and lupine) have met the program requirements which include commercial agronomic status, evident grower interest, private sector support, and identifiable potential markets.

Table 1. Selected Potential Crops for the CDFA Industrial Crops Demonstration Program.

Crop Common Name	Crop Latin Name	Type/Product/Use
amaranth	*Amaranthus cruentus* *A. hypocondriacus*	grain, oil, biomass
buffalo gourd	*Cucrbita foetidissima*	starch, oil, forage
cuphea	*Cuphea* spp.	oil, feed
fodder beets	*Beta vulgaris*	sugar, feed
grindelia	*Grindelia camporum*	resin, biomass
guar	*Cyamopsis tetragonoloba*	(legume) gum, biomass
kenaf	*Hibiscus cannabinus*	fiber, forage, biomass
lupine	*Lupinus angustifolia*	(legume) feed, biomass
meadowfoam	*Limnanthes* spp.	oil, feed
pearl millet	*Pennisetum* spp.	starch, biomass, forage
rapeseed	*Brassica napus*	oil, fiber, biomass
sweet sorghum	*Sorghum bicolor*	sugar, biomass, forage
tumbleweed	*Salsola kali*	biomass

Grower-cooperators were paid $175 to $350/ac ($430 to $865/ha) to grow 2 to 20 ac (1 to 8 ha) of a crop. The grower submitted a report on growing the crop, including procedures, costs, and observations. Growers could sell, use, or dispose of the crop at their discretion, except for samples taken for laboratory and field analysis. In many instances, cooperators participated in field demonstrations and workshops to disseminate information, especially to other farmers, concerning these crops. To date there have been 25 grower demonstrations, resulting in nearly 250 acres planted and monitored (Table 2).

Table 2. Summary of Projects, Industrial Crops Demonstration Program, 1990 -1992.

Year	Crop	Grower	Area (ac)	County
1990	Sweet Sorghum	Babcock	20.4	Stanislaus
1990	Sweet Sorghum	Diener	5.0	Fresno
1990	Sweet Sorghum	Mouser	15.0	Butte
1990	Sweet Sorghum	Traenor	12.0	Yuba
1990	Kenaf	Fisher	20.0	Tulare
1990	Kenaf	Britz	10.0	Fresno
1990	Lupine	Brohard	10.0	Stanislaus
1990	Canola	Durst	20.0	Yolo
1990	Canola	Hayes	10.0	Yolo
1990	Canola	Rivers	5.0	San Luis Obispo
1990 Total			127.4	
1991	Sweet Sorghum	Babock	18.0	Stanislaus
1991	Sweet Sorghum	Bhangoo	3.0	Fresno
1991	Sweet Sorghum	Daddow	10.0	Sutter
1991	Sweet Sorghum	Fry	17.0	Madera
1991	Sweet Sorghum	Mouser	20.2	Butte
1991	Sweet Sorghum	Schmierer	0.2	Lassen
1991	Sweet Sorghum	Toy	5.0	San Luis Obispo
1991	Sweet Sorghum	Traenor	12.0	Yuba
1991	Kenaf	Fisher	20.0	Tulare/Kings
1991	Kenaf	Britz	10.0	Fresno
1991	Lupine	Brohard	10.0	Stanislaus
1991 Total			125.4	
1992	Sweet Sorghum	Mouser	10.0	Butte
1992	Sweet Sorghum	Fisher	3.0	Tulare/Kings
1992	Kenaf	Fisher	20.0	Tulare/Kings
1992 Total			33.0	
Program Total			285.8 (115.6 ha)	

Laboratory analyses were performed under the direction of the University of California, Davis, Department of Biological and Agricultural Engineering, and the University of California Forest Products Laboratory to determine biomass composition, sugar composition, moisture content, properties of combustion, proximate and ultimate analysis, ash content, and other appropriate properties. Additionally, preliminary fermentation studies of sweet sorghum stalk juice and feeding trials of sweet sorghum silage and sweet sorghum bagasse silage are being performed at California State University, Fresno.

RESULTS

Sweet Sorghum [*Sorghum bicolor* (L.) Moench] was grown in 1990 and 1991 by twelve different farmers, in eight different counties in California, ranging from the southern San Joaquin Valley to the central coast, to the northern Sacramento Valley, to the high plains of Lassen county in the northeast corner of the State. Nine different cultivars including seven hybrids and two open-pollinated varieties were demonstrated. An additional open-pollinated variety is being grown as part of two projects in 1992. Plantings ranged from 0.2 to 20 ac (0.1 to 8 ha). Total biomass yields ranged from 1.6 to 13.5 bdt/ac, (3.6 to 30.3 t/ha) with an average of 7.6 bdt/ac (17 t/ha) for all projects over both years. Yield data are summarized in Tables 3 and 4. Two demonstrations, each involving four cultivars, are being conducted during the 1992 growing season.

Cost of production up to harvest ranged from $32 to $82/bdt ($35 to $90/t) including both fixed costs and operating costs, with ultimate biomass yield a primary factor in determining the cost of