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Economic Feasibility of Kenaf Production in Three Tennessee Counties

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Since the 1940s, kenaf has been viewed as a potential source of fiber, mainly for newsprint and high quality paper. Kenaf research has once again risen to the forefront due to the recent USDA tobacco buyout. Many states and farmers dependent upon tobacco revenues have been seeking alternative crops for a number of years. This study seeks to expand the current literature by examining the economic feasibility of growing kenaf within three counties in Tennessee. Nitrogen meta-yield response functions for kenaf and four traditional crops were developed for 30 soils through crop growth simulation modeling and used to compare optimal crop budgets for each soil. Results reveal that kenaf would not compete favorably with traditional crops on any soil at prices below $49/ton, while profit-maximizing farmers could supply as much as 1,385,700 tons of kenaf if the price were $55/ton.

Key Words: alternative crop, economic feasibility, enterprise budgeting, kenaf, plant growth modeling, yield response functions

Although agricultural diversification is a natural response to the changing economic and political environments inside and outside the sector, the list of feasible alternatives has changed little in the past several decades for Tennessee farmers. The challenge is to develop agricultural production systems for producing wholesome food and fiber products that the market demands at competitive prices, while preserving a healthy environment for future generations. Diversifying can spread economic risk and offer profitable niche markets, lessen impact on environmental resources strained by monocultural systems, and sometimes offer new opportunities to strengthen communities. The survival and success of farming will depend on insightful and innovative farmers who are willing and able to make production changes.

Tennessee agricultural producers have a variety of livestock, crops, and cropping systems to diversify their operations. Even with this diversity, the pursuit of alternatives to traditional agriculture continues to be of great importance among farmers, land-grant universities, and farm research organizations.

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Kenaf is an alternative crop in the hibiscus family that may be economically feasible to produce in Tennessee. A fiber crop, kenaf can be harvested to make premium quality fine paper, as well as lower grade papers and cordage. Kenaf fibers have also been used to produce rope, canvas, sacking, carpet backing, fishing nets, interior automobile parts such as door panels and headliners, animal bedding, and composite lumber substitutes (EnviroLink, 1999). The stalk of the kenaf plant consists of two types of fiber—outer bast and inner core. The outer fiber, approximately 40% of the plant, is similar to the best softwood fibers used in the production of paper. The whiter inner fiber is similar to hardwood fibers in size and is also suitable for the production of paper (Johnson, 2001). Potential uses for kenaf have been evaluated since the early 1980s, with textiles being identified as an additional potential use (Taylor, 1984). However, one significant challenge to the development of a kenaf market has been the pulp mill industry.

According to the Forest Products Laboratory at the University of Wisconsin-Madison, the number of operational mills declined between 1970 and 2000 from 666 to 530 (Ince et al., 2001). During this same period, the total capacity of all paper, paperboard, and market pulp mills increased from 62 to 114.4 million tons. In 1970, there were 471 mills (out of the 666 mills) with a capacity of less than 100,000 tons per year. In the same year, there were only 14 mills with a capacity greater than 500,000 tons per year. By 2000, only 277 mills had a capacity less than 100,000 tons per year (52%), and 72 mills had a capacity greater than 500,000 tons per year. To summarize these statistics, many mills became significantly larger over the 1970–2000 period, while many smaller mills were closed. In effect, larger mills were replacing smaller mills, and thus capacity actually expanded despite an absolute decline in the total number of mills.

Equipping pulp mills to handle kenaf processing has not been well received because of the large volumes needed for mills to remain competitive and profitable. Like farmers, pulp mill owners do not know the competitive value of kenaf to their operations.

Kenaf can be grown as an alternative crop, but the process of encouraging farmers to substitute kenaf on acreage traditionally planted in crops like corn and cotton has been slow to develop due to the lack of enterprise budget data (Scott and Taylor, 1990). Accordingly, the objectives of this research were: (*a*) to evaluate the economic feasibility of producing kenaf in Carroll, Gibson, and Madison Counties in Tennessee; and (*b*) to determine the kenaf price required to encourage profit-maximizing corn, cotton, wheat, and soybean growers to produce kenaf.

Methods and Procedures

Several steps were taken to examine the economic feasibility of kenaf production in the three-county area. First, after reviewing literature on kenaf production in other states, an initial cost-and-return budget was developed as a starting point. The literature review revealed substantial variation in the assumptions and recommendations for nitrogen fertilization. It also revealed that kenaf yields respond to nitrogen

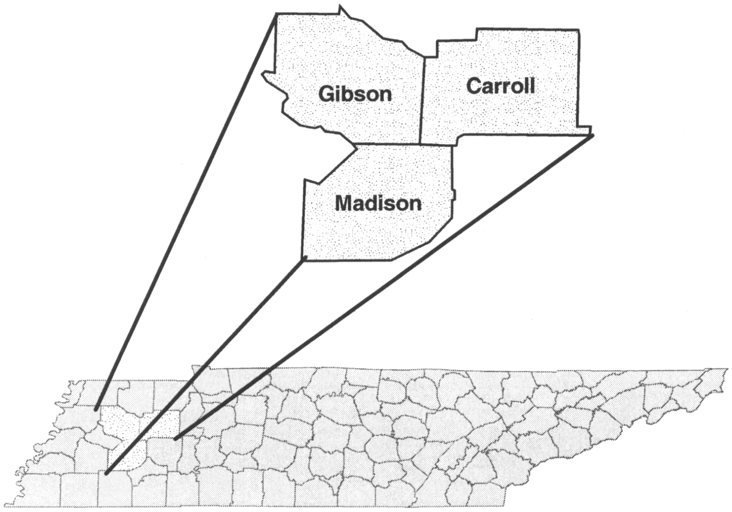

Figure 1. Location of the three Tennessee counties selected for the analysis

fertilization. Consequently, when the initial budget was modified in succeeding steps, economically optimal nitrogen rates and yields for different soil types differentiated the soil-type budgets from the initial budget.

Second, 30 different soil types suited for agricultural production were identified in the three-county area surrounding Milan, Tennessee (figure 1). These counties were selected because they are close to the University of Tennessee's Milan Research and Education Center and the West Tennessee Research and Education Center, where the Tennessee kenaf experiments were conducted. The 30 soil types were identified as soils with the potential for being cropped based on the National Resource Conservation Service's STATSGO database (USDA/National Resource Conservation Service, 2004). The soils identified within each Mapping Unit ID (MUID) were matched with the potential yield file. If a row-crop yield was specified in the database, the soil was assumed to have the potential to be cropped. The area for each soil was matched to the amount of land cropped in the *2002 Census of Agriculture* (USDA/National Agricultural Statistics Service, 2004) and areas uniformly adjusted at the county level, so that the area of cropped land by soil type summed to the acres cropped in 2002 within each of the three counties. These soils were identified as the soils within the three-county region on which kenaf could potentially compete with other crops.

Third, profit-maximizing nitrogen fertilization rates and yields from kenaf meta-yield response functions were determined for each soil type using the Environmental Policy Integrated Climate (EPIC) model (Williams et al., 1989). Crop growth simulation models, such as EPIC, can be used to evaluate the relationships among crop productivity and selected environmental factors. Numerous applications of EPIC have been performed in the United States and in other regions of the world across a broad spectrum of environmental conditions. The flexibility of EPIC has also led to its use within several integrated economic and environmental modeling systems that have been used to evaluate agricultural policies at the farm, watershed, and/or regional scales (Taylor, Adams, and Miller, 1992; Bernardo et al., 1993; Foltz et al., 1995; Babcock et al., 1997). Other examples of crop growth simulation models are CERES (Ritchie et al., 1989) and SOYGRO (Jones et al., 1989). Many of these models were developed for particular localities and were designed to simulate the growth of a single crop. To evaluate the economic feasibility of kenaf production in Tennessee, simulations of multiple crops were required.

EPIC operates on a continuous basis using a daily time step, and can perform long-term simulations for hundreds and even thousands of years. A wide range of crop rotations and other vegetative systems can be simulated with the crop growth routine used in EPIC. An extensive array of tillage systems and other management practices can also be simulated with the model. To analyze the 1985 Resource Conservation Act, nearly 12,000 100-year EPIC simulations were performed for different crop, tillage, soil, climate, and conservation practice combinations which included economic assessments (Putnam, Williams, and Sawyer, 1988). Detailed discussions of EPIC components and functions are given in Williams, Jones, and Dyke (1984), Williams (1990), Sharply and Williams (1990), and Williams (1995).

A key output provided by EPIC is crop yield predictions. Several studies have been performed in the United States and other countries that focused specifically on testing the accuracy of EPIC crop growth and yield predictions (Williams et al., 1989; Bryant et al., 1992; Gray et al., 1997; Geleta et al., 1994; Sabbagh et al., 1991; Parsons, Pease, and Martens, 1995; Cavero et al., 1998; Cavero et al., 1999; Roloff, de Jong, and Nolin, 1998; Chung et al., 2001; Perez-Quezada et al., 2003; Chung et al., 1999; Martin, Nearing, and Bruce, 1993). The EPIC model has proven to be a robust tool for simulating the effects of crop rotation, tillage, and other management practices, climate, soil, and topography on crop yields, water and wind erosion, nutrient and pesticide losses, and soil organic carbon content. EPIC can simulate production of more than 80 crops, and has been used to evaluate the crops required for this analysis—specifically, corn, cotton, wheat, soybeans, and kenaf. To maintain consistency, and for ease of operation, EPIC was selected as the crop growth simulator.

The meta-response functions were estimated as quadratic-plateau functions from data generated through EPIC simulations. Plateau values were considered to provide the maximum yields for each crop and soil (Cerrato and Blackmer, 1990). Kenaf yields were obtained by increasing the nitrogen rate from zero to 340 lbs./acre in 20 lbs./acre increments. The yield obtained from EPIC for a given nitrogen rate and soil was the average of yields simulated over 100 years. Weather conditions were drawn at random from distributions obtained from the weather station at the University of Tennessee's Milan Research and Education Center.

The EPIC simulations assumed: (*a*) no-tillage production practices, a common tillage practice in the three-county area; (*b*) inputs other than nitrogen were applied as specified in the initial kenaf budget; and (*c*) the rates reflected in the budget for these other inputs were sufficient to eliminate yield reductions from insufficient application. Profit-maximizing nitrogen rates and yields for each soil type were calculated by setting the first derivative of the respective meta-nitrogen yield response function equal to the nitrogen-to-kenaf price ratio and solving for the optimal nitrogen rate. The optimal nitrogen rate was then substituted into the yield response function to determine the optimal yield for the respective soil type.

Fourth, the initial kenaf budget was modified for each of the 30 soil types by replacing the initial nitrogen rate and yield with the profit-maximizing rates and yields, assuming other input costs were constant across soil types. The bottom lines in these modified kenaf budgets estimated returns to land and management for the respective soil types.

Fifth, EPIC simulations similar to the ones for kenaf were used to estimate quadratic-plateau corn, cotton, soybeans, and wheat meta-nitrogen yield response functions for each soil type. No-tillage production practices were assumed and inputs other than nitrogen were as specified in existing University of Tennessee crop budgets (Gerloff, 2004a). The existing crop budgets were modified by replacing the nitrogen rates and yield in the budgets with the resulting profit-maximizing nitrogen rates and yields. Returns to land and management for each competing crop on each soil type were taken from the bottom lines of the modified budgets.

Sixth, returns to land and management were compared for kenaf, corn, cotton, wheat, and soybeans to discover which crop produced the highest return on each soil type. Because nitrogen is not a major input in soybean production, the University of Tennessee soybean budget (Gerloff, 2004a) was used for each soil type with yields adjusted by the 100-year average estimated by EPIC.

Seventh, a kenaf supply curve was mapped for the three-county area by comparing optimal kenaf production for each kenaf price between $35/ton and $75/ton in $10/ton intervals. For each price, optimal kenaf production for a particular soil type was calculated as the product of its acreage and optimal yield. The potential quantity of kenaf supplied for a particular price was optimal kenaf production summed across the soil types for which kenaf was identified as the most profitable crop. The supply curve can help business managers, who demand kenaf as a production input, decide whether sufficient kenaf can be potentially supplied at a price low enough for feasible production of their products.

Results

Initial Cost-and-Return Budget for Kenaf Production in Tennessee

The initial 2004 kenaf budget was developed for Tennessee (table 1) by examining the results of several projects undertaken in the southern United States. Kenaf yields and prices were the most uncertain items in the cost-and-return budgets. They varied widely among the various projects. The initial budget in table 1 included a yield of 7.2 tons/acre, the mean yield obtained from experiments conducted in 2001 through

Table 1. Initial No-Tillage, Farm-Gate Kenaf Budget (38-inch rows), Estimated Costs and Returns per Acre (assuming 12/16-row equipment)

Item	Description	Unit	Quantity	Price	Amount
Revenue:				**Dollars ($)**	
Kenaf	Stalks	ton	7.20	$55.00	$396.00
Variable Expenses:					
Seed	8.5 seed/ft.	pound	6.6	$3.00	$19.80
Fertilizer:					
N (as AN)		pound	80	$0.38	$30.40
P_2O_5		pound	60	$0.28	$16.80
K_2O		pound	90	$0.13	$11.70
Custom Application	Tenn. Farm Coop.	acre	1	$4.00	$4.00
Herbicide:					
Burndown	Generic Glyphosate	gallon	0.21	$16.00	$3.36
	2,4-D for Resistant Horseweed	pint	1	$1.81	$1.81
Pre-emergence	Gramoxone Max	pint	2.2	$4.62	$10.16
	Prowl	quart	1.5	$5.38	$8.07
Post-emergence	Staple	ounce	1.2	$19.10	$22.92
	Surfactant	quart	0.08	$3.50	$0.28
Machinery Repair		acre	1	$3.23	$3.23
Machinery Fuel		acre	1	$1.05	$1.05
Custom Harvesting [a]		acre	1	$45.37	$45.37
Operating Capital	Six Months	acre	205.58	$0.08	$16.45
		Total Variable Expense			$195.40
		Return Above Variable Expense			$200.60
Machinery Fixed Expenses:					
Production		acre	1	$7.36	$7.36
Harvesting [b]		acre	1	$59.57	$59.57
		Total Machinery Fixed Expense			$66.93
		Return to Land, Labor & Management			$133.67
Labor Expenses:					
Production		hour	0.11	$8.00	$0.90
Harvesting [c]		hour	0.66	$8.00	$5.28
		Total Labor Expense			$6.18
		Return to Land & Management			**$127.49**

[a] Custom charge for a corn silage harvester and labor to operate it to harvest kenaf.

[b] Includes fixed expenses for two boll buggies, two module builders, the tractors used to pull them, and a module tarp for each module; excludes fixed expense for the silage harvester, which is included in the custom harvesting charge.

[c] Includes labor for operating tractors to pull boll buggies and create modules; excludes labor to operate silage harvester, which is included in the custom harvesting charge.

Table 2. Summary of Previous Studies Reporting Kenaf Yields

Citation	State	Reported Yield (tons/acre)	Type of Study
Neill & Kurtz (1994)	Mississippi	5.53	Experiment
Baldwin (2004)	Mississippi	6.0	Feasibility Analysis
Kalo et al. (1999)	Virginia	3.3 to 7.7	Feasibility Analysis
Pearson (1999)	Colorado	3.02 to 4.99	Experiment
Scott and Taylor (1990)	Texas	6 (dryland); 7.5 (irrigated)	Feasibility Analysis
Webber & Bledsoe (1993)	Texas	3.88	Experiment
Stricker, Prine & Riddle (2001)	Florida	12.1	Experiment
Stricker, Prine & Riddle (2001)	Florida	6.9	Experiment
LeMahieu, Oplinger & Putnam (1991)	Minnesota	2.5	Experiment
LeMahieu, Oplinger & Putnam (1991)	Texas	15	Experiment

2003 for four varieties at the University of Tennessee's Milan Research and Education Center (Milan, TN) (Brown et al., 2003). Data for the same period from experiments conducted at the University of Tennessee's West Tennessee Research and Education Center (Jackson, TN) were also examined. The mean yield from the Milan experiments was used in the initial budget because it more closely reflected the assumptions for nitrogen fertilization found in the review of literature.

Tennessee kenaf yields reported above are within the range of yields reported in other studies (table 2). Mean kenaf yield across 10 varieties for 1990–1993 was 5.53 tons/acre in Mississippi (Neill and Kurtz, 1994), and 6 tons/acre was assumed in a 1997 Mississippi budget (Baldwin, 2004). Kalo et al. (1999) included a range of 3.3 tons/acre to 7.7 tons/acre in their feasibility analysis of kenaf in Virginia. In Colorado, Pearson (1999) found average yields over six varieties of 4.99 tons/acre in 1998, and 3.02 tons/acre in 1999. Scott and Taylor (1990) assumed average yields of 7.5 tons/acre for irrigated kenaf and 6 tons/acre for non-irrigated kenaf in their economic analysis of kenaf for the Lower Rio Grand Valley of Texas. Webber and Bledsoe (1993) found a yield of 3.88 tons/acre averaged over six varieties and three harvest dates for 1989 and 1990 in Ladonia, Texas. Stricker, Prine, and Riddle (2001) reported average yields for 1993–1995 across eight varieties of 12.1 tons/acre in Bartow, Florida, and for 1993 and 1995 across seven varieties of 6.9 tons/acre in Gainsville, Florida. In their review of research plot studies, LeMahieu, Oplinger, and Putnam (1991) reported yields ranging from 2.5 tons/acre at Rosemont, Minnesota to 15 tons/acre at College Station, Texas. As suggested by the wide range of reported yields, a range of yields was used to determine the economic feasibility of kenaf production in Tennessee.

The price of kenaf also varied widely among studies. A wide range of assumed prices is typical in feasibility studies for a crop with an emerging or nonexistent market. Other economic feasibility studies assumed both a base price and a range of possible prices. Kalo et al. (1999) used $75/ton as a base price with a range of $65 to $85/ton. Baldwin (2004) used a base price of $55/ton with a range of $41.25 to $68.75/ton. Stricker, Prine, and Riddle (2001) used a base price of $50/ton and a range of $35 to $65/ton. For our analysis, a base price of $55/ton (table 1) and a range of $35 to $75/ton (see table 8) were used to determine economic feasibility of kenaf production in Tennessee.

The September 2004 seed price of $3/lb. (Anderson and Mullens, 2001) was used in the initial budget (table 1) with a seeding rate of 6.6 lbs./acre (Brown et al., 2003). Seed price could be reduced $1/lb. if purchased in bulk (Rymsza, 2005). The higher price was used in the budget as a conservative estimate. Scott and Taylor (1990) used seeding rates of 8 lbs./acre and 10 lbs./acre depending on the soil. Baldwin (2004) and Kalo et al. (1999) used seeding rates of 8 lbs./acre and 14 lbs./acre, respectively, while Stricker, Prine, and Riddle (2001) used a seeding rate of 10 lbs./acre.

Phosphate (P_2O_5) and potash (K_2O) fertilization rates should be determined by soil testing. These fertilizers have small effects on kenaf yields compared to nitrogen fertilization (Neill, Hovermale, and Kurtz, 1994). Nevertheless, the standard rates for Tennessee cotton production of 60 lbs./acre and 90 lbs./acre, respectively, for P_2O_5 and K_2O (Gerloff, 2004b) were assumed to maintain soil productivity (table 1).

The Tennessee kenaf experiments (Brown et al., 2003) were conducted on Collins (at Milan, TN) and Lexington (at Jackson, TN) silt loam soils. Nitrogen application rates were 40 lbs. N/acre in 2001–2003 at Jackson, and 40, 80, and 60 lbs. N/acre at Milan in 2001, 2002, and 2003, respectively (Brown et al., 2003). In 2002, yields at Milan averaged 3.4 tons/acre higher than at Jackson, which was partly attributed to the 40 lbs. N/acre higher rate (Hayes, 2004). Neill, Hovermale, and Kurtz (1994) recommended a rate of 150 lbs. N/acre based on a literature review and experiments conducted in 1991–1993 at Leverette, Mississippi, on a silt loam soil. In addition, Baldwin (2004) included a nitrogen rate of 96 lbs. N/acre in his Mississippi kenaf budgets, and Stricker, Prine, and Riddle (2001) included 120 lbs. N/acre on phosphatic clay soil and 140 lbs. N/acre on sandy soil. Scott and Taylor (1990) used 18 lbs. N/acre and 100 lbs. N/acre in Texas, and in Colorado, Pearson (1999) pre-plant broadcasted 22 lbs. N/acre. Due to the similar climate and soil characteristics in our three-county area, the initial Tennessee kenaf budget (table 1) included a nitrogen fertilization rate of 80 lbs. N/acre based on the amount applied at Milan in 2002. The custom charge of $4/acre for fertilizer application was obtained from Epps (2005).

A labeled herbicide is not available for no-till kenaf production in Tennessee. Treflan is the only herbicide labeled for kenaf production in Tennessee, and it is labeled only for pre-plant incorporated application. Although no herbicides are labeled for no-till kenaf production in Tennessee, weed control will be required. The kenaf budget included weed control costs to more accurately reflect costs of production (Byrd and Baughman, 2002).

For kenaf production to be feasible in Tennessee, steps should be taken to secure Special Local Need 24(c) Labels for a full complement of herbicides. The herbicides used in table 1 were taken from the University of Tennessee no-till cotton budget (Gerloff, 2004b) and from other sources described below. Generic glyphosate was included because it is increasingly used in place of Roundup as a burndown herbicide in Tennessee (Hayes, 2004). The budget included 2,4-D to control glyphosate-resistant horseweed, which is becoming more prevalent in Tennessee (Hayes, 2004). Gramoxone Max was included as a pre-emergence contact herbicide to control annual grasses and broadleaf weeds, and Prowl was included to control annual grasses and some broadleaf weeds. Staple was included as a post-emergence herbicide to control pigweed and other annual broadleaf weeds. Staple has a Special Local Need 24(c) Label for North Carolina kenaf production for post-emergence control of annual broadleaf weeds. Herbicide rates came from chemical labels published by the manufacturers (Naso, 2004), and prices were taken from the *Weed Control Manual for Tennessee* (Steckel and Breeden, 2004).

The machinery used for planting and spraying chemicals included a 215 Hp tractor, a 12-row no-till planter, and a 16-row self-propelled sprayer. Total machinery cost for producing kenaf (excluding harvest cost) was calculated as the sum of fixed and variable costs for operating the machinery. Fixed machinery cost was calculated as the sum of depreciation, interest, taxes, insurance, and storage costs. Variable machinery cost was the sum of repair, fuel, oil, and filter costs. Fixed and variable machinery costs were obtained from the 2004 no-till cotton budget developed by the University of Tennessee (Gerloff, 2004b).

Machinery assumed in calculating the costs of kenaf harvesting and module building included a corn silage harvester, tractor, two boll buggies, two module builders, and tarps. A custom harvesting rate was assumed to capture the fixed and variable costs of the corn silage harvester and the labor used to operate it. A custom harvesting rate of $40/acre was assumed in 1997 (Baldwin, 2004; Kalo et al., 1999; Bowling et al., 1998), and the cost of module building was estimated at $52.52/acre in 1997 (Baldwin, 2004). Custom harvesting and module building costs were inflated to 2004 dollars by the Implicit Gross Domestic Product Price Deflator (U.S. Department of Commerce, Bureau of Economic Analysis, 2000), resulting in a custom harvesting cost of $45.37/acre and a fixed module-building machinery and tarp cost of $59.57/acre (see table 1). Labor hours were calculated as the sum of labor used in kenaf production and module building. Harvesting labor included labor required to pull the boll buggies and create the modules, but excluded labor required to operate the silage harvester, which was part of the custom harvesting charge.

For production operations, labor hours for planting and application of herbicides were assumed to be 1.25 times machine hours (Gerloff, 2004b). Labor hours for module building (tractor operation to pull boll buggies and create modules) were taken from Baldwin (2004). Labor costs for production ($0.90/acre) and module building costs ($5.28/acre) were estimated using a wage rate of $8/hour (Gerloff, 2004b) to give a total labor cost of $6.18/acre (see table 1). The base yield of 7.2 tons/acre and base price of $55/ton used in table 1 resulted in a return to land and management of $127.49/acre.

Returns to Land and Management for Kenaf and Competing Crops

Table 3 presents the 30 soil types and their kenaf meta-yield response functions for nitrogen. At the base prices for kenaf ($55/ton) and nitrogen ($0.38/lb.), economically optimal nitrogen rates ranged from 89 lbs./acre for Falaya soil to 241 lbs./acre on Henry soil, while optimal kenaf yields ranged from 6.2 tons/acre on Bibb soil to 11.4 tons/acre on Memphis soil. The estimated kenaf meta-response function yields resulting from various levels of nitrogen application were found to be within the yield ranges reported from various kenaf studies (figure 2).

EPIC simulation predictions of nitrogen rates and yields were higher than observed farming situations due in part to the modeling assumption that inputs other than nitrogen were applied at sufficient rates to prevent yield reductions from insufficient application. When calibrating competing crops in the EPIC model, the same procedures and calibrations for each crop were made to calculate optimal nitrogen rates and yields, which allowed for direct comparisons among crops. EPIC yield responses across all comparable crops were very close to actual yields in the region. Actual yields of comparable crops in the region were 119, 36, and 35 bushels/acre with EPIC simulated yields of 109, 38, and 30 bushels/acre, respectively, for corn, soybeans, and wheat.

Using the meta-response functions and accounting for harvesting cost changes at a rate of $9.01/ton, the returns to land and management for yields ranging from 60% to 140% of optimal (table 3) were estimated for an average of all meta-response functions and for the highest and lowest yielding soils in the region using prices from $35 to $75/ton in $10/ton increments. The harvest cost of $9.01/ton was derived from the initial budget by summing harvesting machinery costs of $59.57/acre and harvesting labor costs of $5.28/acre and dividing by the average yield of 7.2 tons/acre. At the $35/ton price level, net returns are negative for all levels of yield except when yield is 40% greater than the optimal yield (table 4). At $65/ton, the average meta-response function provides a positive net return over all yield ranges examined.

On the highest yielding soil (Memphis), positive returns are generated at all price levels except $35/ton when yields are equal to the optimal yield level. Even when yields are 80% of the optimal yield level, net returns range from $9/acre to $281/acre when prices are $45/ton and $75/ton, respectively. However, the lowest yielding soil (Bibb) provides positive net returns under this range of prices when yield is 80% of optimal at $65/ton, to a low of $45/ton when yield is 140% of optimal.

Breakeven prices for these same yield levels are also determined (table 5). Breakeven kenaf prices using the average meta-response function ranged from $63.95/ton for a yield of 60% of optimal to $33.45/ton if a yield 140% of optimal is attained. When the expected yield is achieved, the breakeven price over all soils is $42.55/ton and ranges from $53.70/ton for the Bibb soil to $37.27/ton for the Memphis soil. Any price above these breakeven prices would provide the farmer with a positive return to land and management.

Table 3. Kenaf Meta-Yield Response Functions, Economically Optimal Nitrogen Rates and Yields, and Plateau Nitrogen Rates and Yields for 30 Soil Types: Base Nitrogen ($0.38/lb.) and Kenaf ($55/ton) Prices

	Soil Type	Meta-Response Function	Nitrogen Rate (lbs./acre)		Yield (tons/acre)	
			Optimal	Plateau	Optimal	Plateau
1	ADATON	$2.061 + 0.072N - 0.00015N^2$	210	235	10.4	10.5
2	ADLER	$1.827 + 0.070N - 0.00015N^2$	205	230	9.7	9.8
3	ARKABUTLA	$1.235 + 0.063N - 0.00016N^2$	173	196	7.3	7.4
4	BIBB	$2.358 + 0.048N - 0.00014N^2$	139	166	6.2	6.3
5	CALLOWAY	$3.821 + 0.073N - 0.00026N^2$	126	140	8.9	9.0
6	CENTER	$2.846 + 0.074N - 0.00020N^2$	163	181	9.5	9.6
7	CHENNEBY	$2.684 + 0.055N - 0.00016N^2$	149	173	7.4	7.5
8	COLLINS	$2.172 + 0.055N - 0.00016N^2$	153	177	7.0	7.1
9	CONVENT	$0.985 + 0.065N - 0.00013N^2$	222	252	9.0	9.1
10	DICKSON	$0.995 + 0.074N - 0.00015N^2$	217	241	9.9	10.0
11	DULAC	$0.697 + 0.077N - 0.00014N^2$	239	265	10.7	10.8
12	DUBBS	$1.052 + 0.077N - 0.00017N^2$	206	228	9.7	9.8
13	ENNIS	$1.912 + 0.053N - 0.00014N^2$	166	194	6.9	7.0
14	ENVILLE	$0.766 + 0.060N - 0.00013N^2$	196	224	7.4	7.5
15	FALAYA	$5.288 + 0.053N - 0.00025N^2$	89	104	8.0	8.0
16	FALKNER	$1.097 + 0.071N - 0.00014N^2$	225	252	10.0	10.1
17	GRENADA	$0.543 + 0.076N - 0.00015N^2$	232	258	10.2	10.3
18	HENRY	$0.972 + 0.075N - 0.00014N^2$	241	268	10.8	10.9
19	IUKA	$0.911 + 0.058N - 0.00015N^2$	172	197	6.5	6.6
20	LEXINGTON	$1.111 + 0.077N - 0.00017N^2$	203	225	9.6	9.7
21	LORING	$0.880 + 0.075N - 0.00014N^2$	234	261	10.5	10.6
22	MANTACHIE	$2.223 + 0.053N - 0.00016N^2$	145	169	6.6	6.7
23	MEMPHIS	$1.337 + 0.078N - 0.00015N^2$	235	260	11.4	11.5
24	MOUNTVIEW	$1.414 + 0.071N - 0.00017N^2$	193	216	9.0	9.1
25	OCHLOCKONEE	$2.247 + 0.062N - 0.00014N^2$	193	220	8.9	9.0
26	PROVIDENCE	$1.109 + 0.072N - 0.00015N^2$	215	241	9.7	9.8
27	ROUTON	$2.053 + 0.074N - 0.00023N^2$	145	162	7.9	8.0
28	SMITHDALE	$1.618 + 0.062N - 0.00014N^2$	193	219	8.3	8.4
29	VICKSBURG	$2.152 + 0.071N - 0.00029N^2$	111	124	6.5	6.6
30	STEENS	$2.403 + 0.045N - 0.00010N^2$	183	220	7.2	7.4

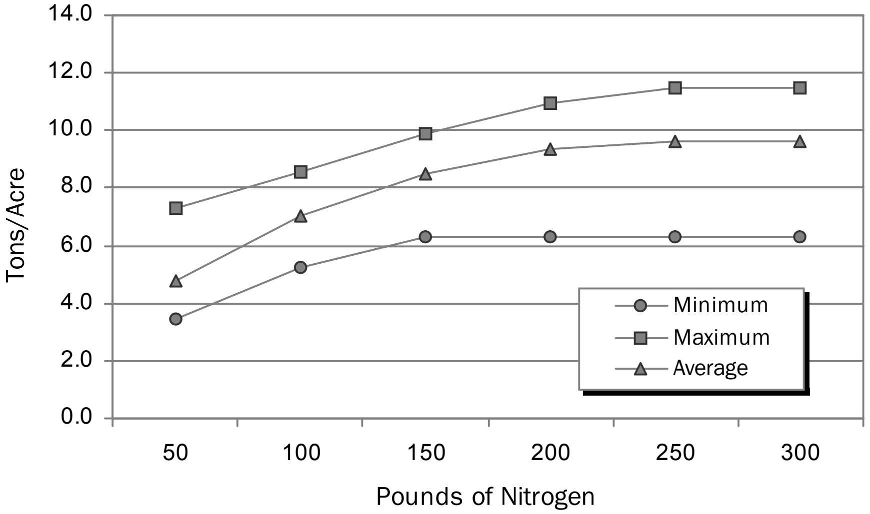

Figure 2. Weighted maximum, minimum, and average yields across all soils for the three-county Tennessee region

Typically, only a portion of a farmer's land is planted to a single crop. Benefits from crop rotations occur and are not captured in this analysis. Crop diversification is used by farmers to decrease production and marketing risk—two factors also not captured in this analysis. While states like Iowa have counties where more than 50% of the cropland is planted in a single crop, this high percentage is not typical of Tennessee counties (table 6) (USDA/National Agricultural Statistics Service, 2004).

Table 7 shows returns to land and management for kenaf and competing crops. Given the base kenaf price of $55/ton, cotton and kenaf consistently compete for the top position as the profit-maximizing crop in the three-county study area. Competing crop returns to land and management were created using 2002–2004 prices and costs (Gerloff, 2004a). Differences in results reported in tables 6 and 7 could be due to higher prices and program payments given to cotton between 2002–2004, as well as a lower estimated cost associated with cotton production in the three-county area due to unknown additional cost to produce cotton on erosive soils (indicative of most soils in the study area). If farmers were to produce kenaf on all soils for which it is the profit-maximizing crop, they would produce 154,930 acres of kenaf on 37% of the 423,825 acres of available cropland in the three-county area, and optimal production on those acres would be 1,385,700 tons. This 37% value is well within the estimated acreage for the crop with the most acreage in the three-county region.

Table 8 and figure 3 illustrate how optimal kenaf production changes as the farm-gate kenaf price increases from $35 to $75/ton and nitrogen price changes from $0.19 to $0.57/lb. Profit-maximizing farmers would not produce kenaf if the farm-gate kenaf price were $49/ton or less. At this price, cotton is the most profitable crop

Table 4. Sensitivity Analysis on the Returns to Land and Management for Kenaf Production for Changes in Yield and Price

	Percent of Optimal Yield				
Kenaf Price ($/ton)	60%	80%	100%[a]	120%	140%
Average over All Soils:		———	($/acre)	———	
$35.00	!151.93	!109.17	!66.41	!23.66	19.10
$45.00	!100.22	!39.31	21.60	82.51	143.42
$55.00	!47.58	31.45	110.48	189.51	268.55
$65.00	5.52	102.66	199.79	296.93	394.06
75.00	58.90	174.12	132.74	404.57	519.79
Memphis Soil:		———	($/acre)	———	
$35.00	!134.62	!80.03	!25.44	29.14	83.73
$45.00	!68.39	9.29	86.98	164.66	242.34
$55.00	!1.13	99.62	200.37	301.12	401.87
$65.00	66.65	190.44	314.24	438.03	561.83
$75.00	134.74	281.56	428.38	575.20	722.02
Bibb Soil:		———	($/acre)	———	
$35.00	!173.25	!143.71	!114.16	!84.62	!55.07
$45.00	!138.14	!95.83	!53.52	!11.20	31.11
$55.00	!101.96	!46.91	8.14	63.19	118.24
$65.00	!65.22	2.54	70.30	138.06	205.82
$75.00	!28.17	52.28	132.74	213.19	293.65

[a] Optimal yield was 8.7 tons/acre averaged over all soils, 11.4 tons/acre for Memphis soil, and 6.2 tons/acre for Bibb soil. Yield sensitivity analysis reflects changes in harvesting costs that might occur on differing productive landscapes. Nitrogen is assumed to be applied at the optimal rate.

Table 5. Breakeven Prices for Alternative Yields on Average, High-Yielding (Memphis), and Low-Yielding Soils (Bibb)

	Percent of Optimal Yield				
Description	60%	80%	100%[a]	120%	140%
		———	($/ton)	———	
Average over All Soils	63.95	50.56	42.55	37.28	33.45
Memphis Soil	55.17	43.97	37.27	32.83	29.67
Bibb Soil	82.58	64.50	53.70	46.50	41.40

Note: The breakeven price reflects the price required to attain $0/acre net return to land and management. If a per acre land charge is known, divide that value by the yield/acre and add the result to the breakeven price.

[a] Optimal yield was 8.7 tons/acre averaged over all soils, 11.4 tons/acre for Memphis soil, and 6.2 tons/acre for Bibb soil.

Table 6. Crop Ranking and Proportion of Planted Acres in Primary Crops Grown in the Three-County Tennessee Area, 2002–2004

	Crop Ranking and Proportion of Acreage				
County	Crop 1	Crop 2	Crop 3	Crop 4	Crop 5
Carroll	Soybeans (34%)	Corn (34%)	Cotton (22%)	Wheat (8%)	Sorghum (0.4%)
Gibson	Soybeans (43%)	Corn (24%)	Wheat (19%)	Cotton (12%)	Sorghum (0.1%)
Madison	Cotton (42%)	Soybeans (32%)	Corn (15%)	Wheat (8%)	Sorghum (1.8%)

Table 7. Comparison of Returns to Land and Management for Kenaf and Competing Crops by Soil Type: Base Nitrogen ($0.38/lb.) and Kenaf ($55/ton) Prices

Soil Type	Crop Land (acres)	Corn ($/acre)	Wheat ($/acre)	Soy-beans ($/acre)	Cotton ($/acre)	Kenaf ($/acre)	Optimal Crop	Kenaf Acreage (acres)
1 Adaton	134	94	!15	91	257	256	Cotton	
2 Adler	118	88	!18	103	264	220	Cotton	
3 Arkabutla	12,946	41	!35	53	125	99	Cotton	
4 Bibb	594	22	!55	28	50	54	Kenaf	594
5 Calloway	8,278	76	!12	61	172	208	Kenaf	8,278
6 Center	7,257	86	!14	71	225	225	Kenaf	7,257
7 Chenneby	39	73	!18	61	203	114	Cotton	
8 Collins	38,588	51	!26	45	138	91	Cotton	
9 Convent	13	67	!25	96	204	174	Cotton	
10 Dickson	89	81	!22	99	229	223	Cotton	
11 Dulac	4,078	95	!21	106	267	261	Cotton	
12 Dubbs	3,422	87	!21	108	264	220	Cotton	
13 Ennis	62	39	!42	48	117	82	Cotton	
14 Enville	3	31	!48	52	89	93	Kenaf	3
15 Falaya	53,147	78	!6	46	164	171	Kenaf	53,147
16 Falkner	287	88	!22	96	259	226	Cotton	
17 Grenada	49,930	85	!24	100	248	237	Cotton	
18 Henry	2,988	74	!23	82	202	267	Kenaf	2,988
19 Iuka	10,316	21	!58	36	54	58	Kenaf	10,316
20 Lexington	53,112	88	!20	107	261	216	Cotton	
21 Loring	53,794	89	!22	107	250	252	Kenaf	53,794
22 Mantachie	318	38	!39	36	100	73	Cotton	
23 Memphis	47,119	117	!17	122	328	299	Cotton	
24 Mountview	55	80	!20	95	241	186	Cotton	
25 Ochlockonee	156	81	!21	102	244	182	Cotton	
26 Providence	29,193	76	!24	102	229	213	Cotton	
27 Routon	18,552	58	!24	30	134	147	Kenaf	18,552
28 Smithdale	21,097	73	!21	84	212	146	Cotton	
29 Vicksburg	7,263	53	!24	52	132	83	Cotton	
30 Steens	878	35	!43	36	109	93	Cotton	
Total:	423,825	33,619[a]	!8,848[a]	35,312[a]	92,093[a]	84,328[a]		154,930

[a] Total return to land and management if all land were planted to the crop in the column ($1,000s).

Table 8. Potential Kenaf Supply Response to Changes in the Farm-Gate Price

Farm-Gate Kenaf Price ($/ton)	Optimal Kenaf Production (nitrogen price = $0.19/lb.)	Optimal Kenaf Production (nitrogen price = $0.38/lb.)	Optimal Kenaf Production (nitrogen price = $0.57/lb.)
		(1,000 tons)	
$35.00	0.0	0.0	0.0
$45.00	0.0	0.0	0.0
$55.00	1,323.8[a]	1,385.7	1,373.4
$65.00	3,937.5	3,921.1	3,893.7
$75.00	3,939.1	3,926.8	3,906.3

[a] At a nitrogen price of $0.19, kenaf is no longer the profit-maximizing crop for the Center soil type. Total kenaf acreage decreases by 7,257 at an optimal yield of 9.51, giving a reduction in production of 69,033 tons. Other than for a kenaf price of $55/ton, kenaf is the profit-maximizing crop on the same soil types for a given kenaf price regardless of the nitrogen price.

on all soil types evaluated. Alternatively, kenaf is the most profitable crop on all soil types when its price is above $67/ton. Increases in optimal kenaf production above $67/ton simply result from higher optimal nitrogen rates, which in turn result in higher optimal yields as farmers maximize profits. For price increases between $49 and $67/ton, kenaf production increases because it becomes the most profitable crop on additional soils, and nitrogen rates and yields increase in response to the profit-maximization criterion.

Results in table 8 suggest that optimal kenaf production is insensitive to changes in the nitrogen price. For example, at a kenaf price of $50/ton, a 50% reduction in the nitrogen price produces a 0.6% increase in kenaf production, and a 50% increase in the nitrogen price produces a 1.2% decrease in kenaf production. Responses to changes in the nitrogen price are even less at higher kenaf prices.

Summary, Conclusions, and Caveats

The economic feasibility of producing kenaf in three Tennessee counties was examined using budgeting, simulation, and breakeven analysis under the assumption of profit maximization. A base budget for kenaf was developed using secondary-source information in combination with information from three-year experiments conducted at the University of Tennessee's Milan and West Tennessee Research and Education Centers. The base budget was compared to budgets for traditional crops. One-hundred-year simulations were conducted for kenaf, corn, cotton, wheat, and soybeans on 30 soil types currently cropped in the three-county area under a range of nitrogen fertilization levels (0 to 340 pounds of elemental N). Response functions for each soil type were estimated and breakeven and sensitivity analyses were conducted.

At base prices for kenaf ($55/ton) and nitrogen ($0.38/lb.), economically optimal nitrogen rates ranged from 89 lbs./acre for Falaya soil to 241 lbs./acre for Henry soil,

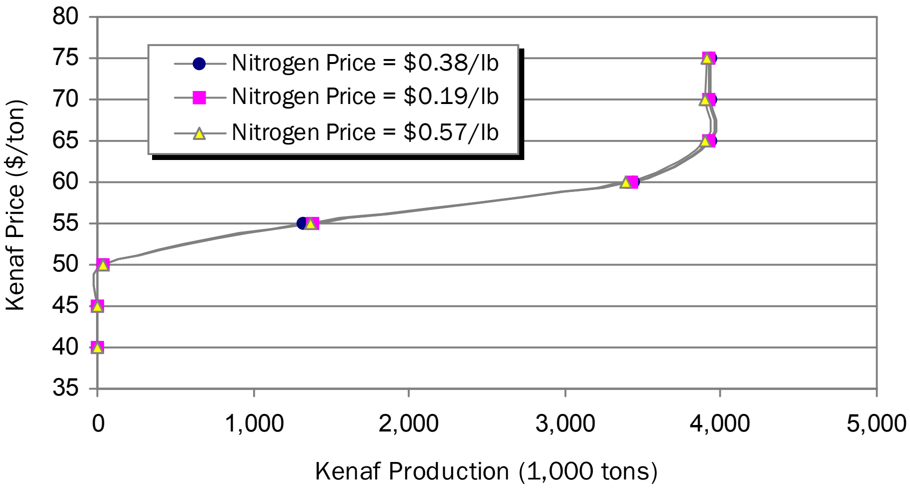

Figure 3. Kenaf potential supply schedule for Carroll, Gibson, and Madison Counties, Tennessee

while optimal kenaf yields ranged from 6.2 tons/acre for Bibb soil to 11.4 tons/acre for Memphis soil. Comparisons of the traditional crops with kenaf showed that cotton and kenaf consistently competed for the top position as the profit-maximizing crop for all 30 soil types in the three-county area. When the kenaf price increased above $67/ton, kenaf was the most profitable crop on all 30 soil types, but when the price fell below $49/ton, it was not the most profitable crop on any soil type. Optimal kenaf production was insensitive to changes in the price of nitrogen fertilizer.

The results of this research include the implicit assumption that marketing costs incurred by farmers for kenaf and competing crops are equal. In kenaf's competition with cotton as the most profitable crop, a higher marketing cost compared to cotton would reduce the competitive position of kenaf. For example, if the marketing cost for kenaf were $5/ton more than the marketing cost for a competing crop, a $55/ton farm-gate price would be equivalent to a $50/ton farm-gate price when comparing returns to land and management. Differences in marketing costs would change the optimal supply of kenaf and should be considered by potential kenaf producers and industrial users when making production and marketing decisions.

Implicit in the assumptions of this analysis is that farmers are profit maximizers who produce the profit-maximizing crop regardless of risk. As a new crop without an established market and with uncertain production methods and costs compared to traditional crops, kenaf would be more risky to produce than traditional crops. In addition, farmers attempt to reduce production and marketing risk by growing crops in rotation and through diversification of crop production. The introduction of risk would reduce kenaf produced by risk-averse farmers at each price compared to what is reported in table 7. If farmers perceive there is more risk involved in producing kenaf than the other crops, as might be the case with a new crop and market, the estimated acreage converted to kenaf production is probably high, and a risk premium might be determined and employed in future analyses of kenaf production. The use of contracts and other guarantees by industrial users of kenaf would reduce the risk to farmers associated with growing kenaf and increase its supply for industrial use.

Finally, this analysis assumes that a market exists for the product grown. As asserted by Noelie Bertoniere of the Agricultural Research Service, "Farmers won't grow it unless they are guaranteed a market.… so it's a chicken-and-egg situation" (EnviroLink, 1999).

References

Anderson, J. B., and D. B. Mullens, Jr. (2001). "KenafSeed.Com." Jupiter Seed Company and D.B.M. Farms, Inc. Online. Available at http://www.kenafseed.com/us2001pricesheet.htm. [Retrieved September 17, 2004.]

Babcock, B. A., J. Wu, T. Campbell, P. W. Gassman, P. D. Mitchell, T. Otake, M. Siemers, T. M. Hurley. (1997). "RAPS 1997: Agriculture and the environmental quality." CARD, Iowa State University, Ames.

Baldwin, B. (2004, September 15). Associate Professor, Mississippi State University. "Kenaf Costs and Returns Budgets for South Mississippi for 1997." Personal communication by fax.

Bernardo, D. J., H. P. Mapp, G. J. Sabbagh, S. Geleta, K. B. Watkins, R. L. Elliott, and J. F. Stone. (1993). "Economic and environmental impacts of water quality protection policies 2: Application to the Central High Plains." *Water Resources* 29(9), 3081–3091.

Bowling, R. G., D. L. Hunter, R. M. Millsaps, and J. Stokes. (1998). "Farm machinery custom rates by crop reporting districts in Tennessee, 1997." Pub. No. PB 1085-1M-5/98 (Rep), University of Tennessee Extension Service, Knoxville.

Brown, B., J. Williams, J. McClure, G. Percell, and R. Hayes. (2003). "Kenaf variety and date of planting study: West Tennessee and Milan Experiment Stations, 2001–2003." Unpublished data. Tennessee Agricultural Experiment Station, Knoxville.

Bryant, K. J., V. W. Benson, J. R. Kiniry, J. R. Williams, and R. D. Lacewell. (1992). "Simulating corn yield response to irrigation timings: Validation of the EPIC model. *Journal of Production Agriculture* 5, 237–242.

Byrd, J., Jr., and T. Baughman. (2002, December 3). "Kenaf weed control recommendations." Information Sheet No. 1528, Mississippi State University Extension Service. Online. Available at http://msucares.com/pubs/infosheets/is1528.htm. [Retrieved May 3, 2005.]

Cavero, J., R. E. Plant, C. Shennan, D. B. Friedman, J. R. Williams, J. R. Kiniry, and V. W. Benson. (1999). "Modeling nitrogen cycling in tomato-safflower and tomato-wheat rotations." *Agricultural Systems* 60, 123–135.

Cavero, J., R. E. Plant, C. Shennan, J. R. Williams, J. R. Kiniry, and V. W. Benson. (1998). "Application of the EPIC model to nitrogen cycling in irrigated processing tomatoes under different management systems." *Agricultural Systems* 56, 391–414.

Cerrato, M. E., and A. M. Blackmer. (1990). "Comparison of models for describing corn yield response to nitrogen fertilizer." *Agronomy Journal* 82, 138–143.

Chung, S. W., P. W. Gassman, D. R. Huggins, and G. W. Randall. (2001). "Evaluation of EPIC for tile flow and tile nitrate losses from three Minnesota cropping systems." *Journal of Environmental Quality* 30(3), 822–830.

Chung, S. W., P. W. Gassman, L. A. Kramer, J. R. Williams, and R. Gu. (1999). "Validation of EPIC for two watersheds in southwest Iowa." *Journal of Environmental Quality* 28(3), 971–999.

EnviroLink. (1999, March). "Kenaf: On the fence." *Envirolink: The Online Environmental Community.* Online. Available at http://www.envirolink.org/articles/mar99-2.html. [Retrieved August 2, 2005.]

Epps, B. (2005, January 28). Fertilizer Department, Tennessee Farmers Cooperative, LaVergne, TN. Personal communication by telephone.

Foltz, J. C., J. G. Lee, M. A. Martin, and P. V. Preckel. (1995). "Multiattribute assessment of alternative cropping systems." *American Journal of Agricultural Economics* 77, 408–420.

Geleta, S., G. J. Sabbagh, J. F. Stone, R. L. Elliot, H. P. Mapp, D. J. Bernardo, and K. B. Watkins. (1994). "Importance of soil and cropping systems in the development of regional water quality policies." *Journal of Environmental Quality* 23, 36–42.

Gerloff, D. C. (2004a). "Field crop budgets for 2004." Information Series AE 04-29, Department of Agricultural Economics, University of Tennessee Agricultural Extension Service, Knoxville.

———. (2004b). "Cotton budgets for 2004." Information Series AE 04-30, Department of Agricultural Economics, University of Tennessee Agricultural Extension Service, Knoxville.

Gray, A. W., W. L. Harman, J. W. Richardson, A. F. Weise, G. C. Regier, P. T. Zimmel, and V. D. Lansford. (1997). "Economic and financial viability of residue management: An application to the Texas High Plains." *Journal of Production Agriculture* 10, 175–183.

Hayes, R. M. (2004, August 27). Superintendent of the West Tennessee Experiment Station, Jackson, TN. Personal communication by email.

Ince, P. J., X. Li, M. Zhou, J. Buongiomo, and M. R. Reuter. (2001). "United States paper, paperboard, and market pulp capacity trends by process and location, 1970–2000." Research Paper No. FPL-RP-602, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, University of Wisconsin, Madison.

Johnson, J. (2001, April). "What is kenaf?" Rural Enterprise and Alternative Development Initiative, Report No. 1, Southern Illinois University, Carbondale.

Jones, J. W., K. J. Boote, G. Hoogenboom, S. S. Jagtar, and G. G. Wilkerson. (1989). "SOYGRO V5.42." Department of Agricultural Engineering and Department of Agronomy, University of Florida, Gainesville.

Kalo, A., S. B. Sterrett, P. H. Hoepner, F. Diem, and D. B. Taylor. (1999). "Feasibility of adopting kenaf on the eastern shore of Virginia." In J. Janick (ed.), *Perspectives on New Crops and New Uses* (pp. 311–315). Alexandria, VA: ASHS Press.

LeMahieu, P. J., E. S. Oplinger, and D. H. Putnam. (1991). *Alternative Field Crops Manual: Kenaf.* Online. Available at http://www.hort.purdue.edu/newcrop/afcm/kenaf.html. [Retrieved August 24, 2004.]

Martin, S. M., M. A. Nearing, and R. R. Bruce. (1993). "An evaluation of the EPIC model for soybeans grown in Southern Piedmont soils. *Transactions of the American Society of Agricultural Engineers* 36(5), 1327–1331.

Naso, V. (2004). "Crop Data Management Systems, Inc. Web Site." Online. Available at http://www.cdms.net/manuf/manuf.asp. [Retrieved September 15, 2004.]

Neill, S. W., C. H. Hovermale, and M. E. Kurtz. (1994). "Fertility and row spacing for kenaf productions." In C. E. Goforth and M. J. Fuller (eds.), *A Summary of Kenaf Production and Product Development Research 1989–1993* (pp. 7–8). Bulletin No. 1011, Mississippi Agricultural and Forestry Experiment Station, Mississippi State University.

Neill, S. W., and M. E. Kurtz. (1994). "Agronomic research for kenaf crop production in Mississippi." In C. E. Goforth and M. J. Fuller (eds.), *A Summary of Kenaf Production and Product Development Research 1989–1993* (pp. 1–2). Bulletin No. 1011, Mississippi Agricultural and Forestry Experiment Station, Mississippi State University.

Parsons, R. L., J. W. Pease, and D. C. Martens. (1995). "Simulating corn yields over 16 years on three soils under inorganic fertilizer and hog manure fertility regimes." *Communications in Soil Science and Plant Analysis* 26(7/8), 1133–1150.

Pearson, C. H. (1999). "Economic performance of kenaf varieties in the Grand Valley of western Colorado." Online. Available at http://www.colostate.edu/programs/wcrc/annrpt/99/Kenafproceedings.htm. [Retrieved August 21, 2004.]

Perez-Quezada, J. F., J. Cavero, J. Williams, A. Roel, and R. E. Plant. (2003). "Simulation of within field yield variability in a four-crop rotation field using SURRGO soil-unit definitions and the EPIC model." *Transactions of the American Society of Agricultural Engineers* 46(5), 1365–1374.

Putnam, J., J. Williams, and D. Sawyer. (1988). "Using the erosion-productivity impact calculator (EPIC) to estimate the impact of soil erosion for the 1985 RCA appraisal." *Journal of Soil and Water Conservation* 43(4), 321–326.

Ritchie, J. T., U. Singh, D. Godwin, and L. Hunt. (1989). *A User's Guide to CERES–Maize V. 2.1.* International Fertilizer Development Center, Muscle Shoals, AL.

Roloff, G., R. de Jong, and M. C. Nolin. (1998). "Crop yield, soil temperature, and sensitivity of EPIC under central-eastern Canadian conditions." *Canadian Journal of Plant Science* 78(3), 431–439.

Rymsza, T. A. (2005, July 19). President, Vision Paper, Albuquerque, NM. Personal communication by email.

Sabbagh, G. J., S. Geleta, R. L. Elliott, J. R. Williams, and R. H. Griggs. (1991). "Modification of EPIC to simulate pesticide activities: EPIC-PST." *Transactions of the American Society of Agricultural Engineers* 34(4), 1683–1692.

Scott, A. W., Jr., and C. S. Taylor. (1990). "Economics of kenaf production in the Lower Rio Grande Valley of Texas." In J. Janick and J. E. Simon (eds.), *Advances in New Crops* (pp. 292–297). Portland, OR: Timber Press.

Sharpley, A. N., and J. R. Williams, eds. (1990). *EPIC–Erosion/Productivity Impact Calculator: 1. Model Documentation.* Technical Bulletin No. 1768, U.S. Department of Agriculture, Washington, DC.

Steckel, L., and G. K. Breeden. (2004). *2004 Weed Control Manual for Tennessee.* Pub. No. PB 1580, University of Tennessee Extension, Knoxville.

Stricker, J. A., G. M. Prine, and T. C. Riddle. (1998, February / revised 2001, July). "Kenaf—A possible new crop for central Florida." Pub. No. SS-AGE-68, Agronomy Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville.

Taylor, C. S. (1984, May). "A systems approach to commercialization of kenaf." Unpublished Ph.D. dissertation, Department of Agricultural Economics, University of Missouri, Columbia.

Taylor, M. L., R. M. Adams, and S. F. Miller. (1992). "Farm-level response to agricultural effluent control strategies: The case of the Willamette Valley." *Journal of Agricultural and Resource Economics* 17(1), 173–183.

U.S. Department of Agriculture, National Agricultural Statistics Service. (2004). "Tennessee state and county data." *2002 Census of Agriculture*, Vol. 1, Geographic Area Series, Part 42. U.S. Department of Agriculture, Washington, DC.

———. (2005). *Quick Stats: Agricultural Statistics Database*. U.S. Department of Agriculture, Washington, DC. Online. Available at http://151.121.3.33:8080/QuickStats/. [Retrieved July 29, 2005.]

U.S. Department of Agriculture, National Resource Conservation Service. (2004). *State Soil Geographic* (*STATSGO*) *Database.* U.S. Department of Agriculture, Washington, DC. Online. Available at http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/. [Retrieved September 30, 2004.]

U.S. Department of Commerce, Bureau of Economic Analysis. (2000). "Table 1.1.9., Implicit price deflators for gross domestic product [index numbers, 2000 = 100] seasonally adjusted." Bureau of Economic Analysis, Washington, DC. Online. Available at http://www.bea.gov/bea/dn/nipaweb/TableView.asp?SelectedTable=13&FirstYear=2002&LastYear=2004&Freq=Qtr. [Retrieved February 1, 2005.]

Webber, C. L., III, and R. E. Bledsoe. (1993). "Kenaf: Production, harvesting, processing, and products." In J. Janick and J. E. Simon (eds.), *New Crops* (pp. 416–421). New York: John Wiley.

Williams, J. R. (1990). "The erosion productivity impact calculator (EPIC) model: A case history." *Philosophical Transactions of the Royal Society of London* 329, 421–428.

———. (1995). "The EPIC model." In V. P. Singh (ed.), *Computer Models of Watershed Hydrology* (pp. 909–1000). Highlands Ranch, CO: Water Resources Publications.

Williams, J. R., C. A. Jones, and P. T. Dyke. (1984). "A modeling approach to determining the relationship between erosion and soil productivity." *Transactions of the American Society of Agricultural Engineers* 27(1), 129–144.

Williams, J. R., C. A. Jones, J. R. Kiniry, and D. A. Spaniel. (1989). "The EPIC growth model." *Transactions of the American Society of Agricultural Engineers* 32, 479–511.