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Second-Year Growth and Productivity for Potential Herbaceous Energy Crops in the Southeast and Midwest/Lake States

A. F. Turhollow

Environmental Sciences Division
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ENVIRONMENTAL SCIENCES DIVISION

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A. F. Turhollow*

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*Energy Division, ORNL

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ABSTRACT

TURHOLLOW, A. F. 1988. Second-year growth and productivity for potential herbaceous energy crops in the Southeast and Midwest/Lake States. ORNL TM-10626. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 32 pp.

The results of the second year of the lignocellulosic energy crop screening projects in the Southeast and Midwest/Lake States of the Herbaceous Energy Crops Program are summarized. Most species being screened are grasses, both annual and perennials, and legumes. Establishment of perennial crops was completed during the second year. Yields were quite variable, ranging from 0 for flatpea at a drought-stricken site in Virginia to as high as 31.9 Mg/ha for a sweet sorghum-rye double crop at a site in Indiana. The yield data collected--along with agronomic input, machinery, and labor requirements--will be combined in the future to help select the best species for further development as energy crops.

INTRODUCTION

The screening and selection of lignocellulosic crops is currently the major focus of the Herbaceous Energy Crops Program (HECP) located at the Oak Ridge National Laboratory. This program is funded by the Biofuels and Municipal Waste Technology Division (BMWTD) of the Department of Energy. Secondary emphases of the HECP are oilseed crops and environmental and economic analyses (Cushman et al. 1987). This report summarizes the crop yield data obtained from the second year of five multiyear herbaceous lignocellulosic energy crop screening and selection projects located in the Midwest/Lake States and the Southeast. These regions were chosen for study because of the abundance of cropland potentially available for energy crop production and the relatively high potential productivity of land.

Lignocellulosic energy crops, which include the traditional forage crops, can be cultivated with machinery commonly used for forage production and can be grown on lands that are either good or marginal for traditional row cropping. In addition, lignocellulosic energy cropping systems that use perennials or combine double cropping of annuals and no-tillage cultivation methods reduce erosional soil losses by providing year-round ground cover. Lignocellulosic crops may serve as energy feedstocks for any of the conversion technologies currently under consideration by BMWTD. A goal of the HECP is to produce, store, and transport lignocellulosic crops to a conversion facility at a cost of \$1.90 to \$2.85/GJ (\$33 to \$50/dry Mg) in the year 2000. A delivered cost in this range appears to be required if fuels produced from lignocellulosic crops are to be competitively priced with conventional fuels in the future. Yields in the year 2000 are expected to be in the range of 13 to 40 Mg ha^{-1} $year^{-1}$. [As a means of reference, a corn grain crop on good land in the Midwest might yield 8.3 dry Mg/ha of grain (150 bushels/acre) and a total biomass amount including grain of about 17 dry Mg/ha.] The best yields will be achieved on high-quality croplands in the Midwest and Southeast. The lowest yields can be expected on the more marginal croplands. Both within and among regions some large variances in yield can be expected because of land quality.

The first steps in achieving this goal are to screen the potential species and to gather the data necessary for evaluating species and cropping systems and establishing conversion linkages. Based on data gathered over a 4- to 5-year period, a number of species will be selected as good candidates for energy crops. Although productivity is a major criterion in selecting species, it must be weighed against the inputs required to achieve the yield as well as the variability of the yield. The system used to grow an energy crop is important. The machinery and labor involved (as well as the required scheduling) and agronomic factors such as fertilizing, harvesting, and storage must all be considered. Generally annual species provide higher yields than perennial species but also require greater inputs. However, perennial species are better adapted to a wider range of sites, especially those sites that can be characterized as erosive or poorly drained. Another important consideration, particularly in the Southeast, is how well a species grows under drought stress.

Field research in lignocellulosic crop production was initiated at five institutions during FY 1985 and continued in FY 1986 (Fig. 1). Projects in the Midwest/Lake States are located at Cornell University, Geophyta (near Vickery, Ohio), and Purdue University. Projects in the Southeast are located at Auburn University and Virginia Polytechnic Institute and State University (Virginia Tech). Additional projects are being started in FY 1988 in the western Corn Belt and the Great Plains.

All projects share common features. Each contains a screening component in which several promising species are grown under a variety of conditions at a number of sites. Some sites have no serious environmental restrictions on growth and productivity, while others have varying factors that can restrict productivity, such as erosiveness or wetness. The species being screened are primarily annual and perennial grasses and perennial legumes, although one annual crucifer species is also being tested (Table 1). The Universal Soil Loss Equation (Wischmeier and Smith 1978) is being used to estimate soil loss on lands used for energy feedstock production. Each project provides crop yield data expressed as mass per unit of area and chemical yields expressed as percent cellulose, hemicellulose, nonstructural carbohydrate, lignin, protein, and ash. Beyond these similarities, each project is unique. Both the meteorological and environmental conditions vary by region. Also the species themselves and the specific growing conditions (e.g., weather, soil, slope) differ at each site. The unique characteristics of each project are detailed below.

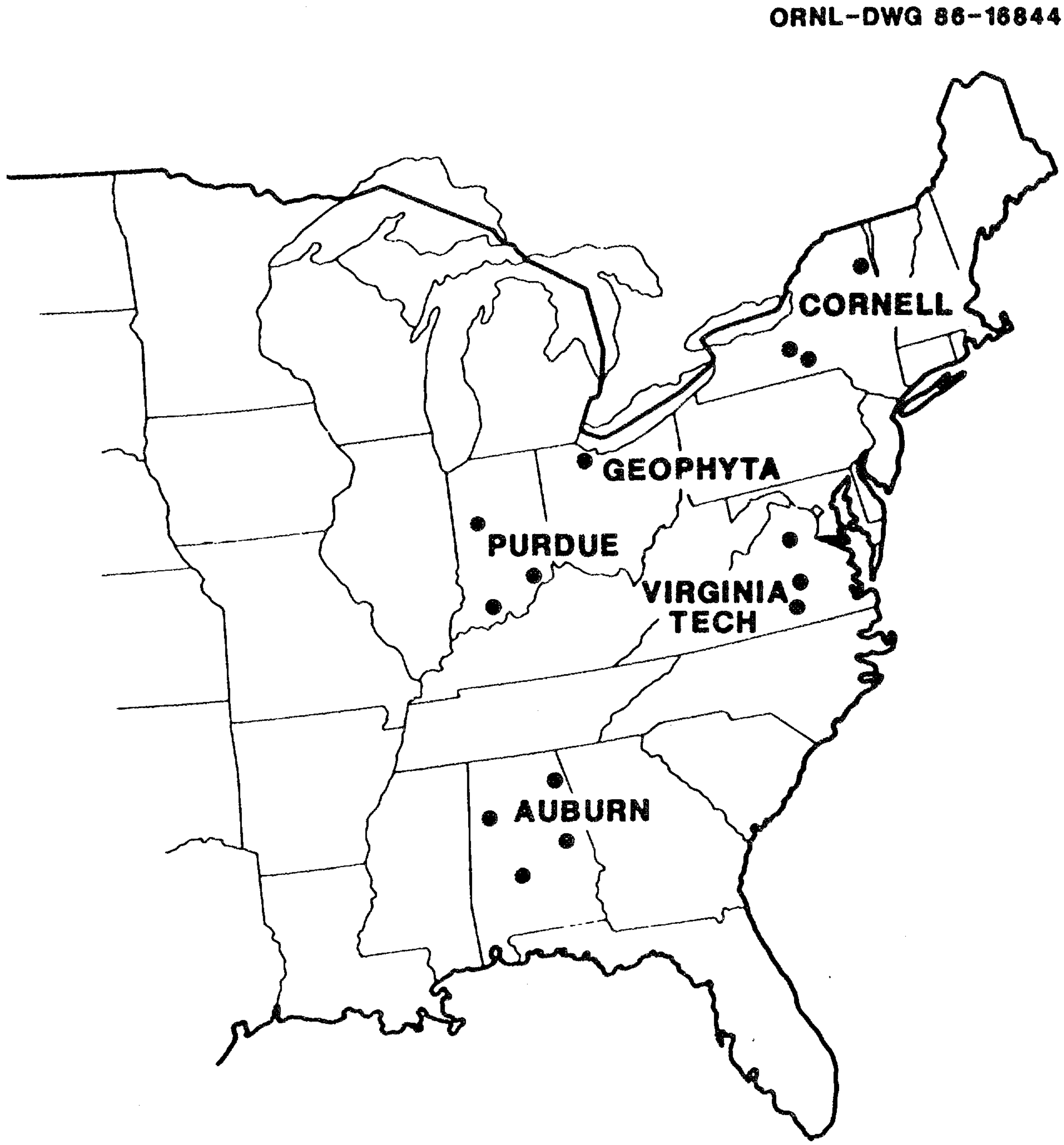

Fig. 1. Locations of the field sites for Herbaceous Energy Crops Program's lignocellulosic crop-screening studies in the Midwest/Lake States (Cornell, Geophyta, and Purdue) and the Southeast (Auburn and Virginia Tech).

Table 1. Lignocellulosic species being screened by herbaceous energy crops projects in the Southeast and Midwest/Lake States regions

Species	Project Location				
	Auburn	Va. Tech	Cornell	Geophyta	Purdue
			Grasses		
Bermudagrass (*Cynodon dactylon*)	X[a]				
Johnsongrass (*Sorghum halapense*)	X[a]				
Pearl millet (*Pennisetum americana*)	X[a]				
Redtop (*Argrostis gigantea*)			X[g]		
Reed canarygrass (*Phalaris arundinacea*)			X	X	X[b]
Rye (*Secale cereale*)	X[c]			X[d]	X[e]
Smooth bromegrass (*Bromus inermis*)			X[f]	X	
Sorghum (*Sorghum bicolor*) (sweet or forage varieties)	X[a,c]			X	X[e]
Sorghum X sudangrass (*S. bicolor* X *S. sudanensis*)		X		X[d]	X[e]
Sudangrass (*Sorghum sudanensis*)			X		
Switchgrass (*Panicum virgatum*)	X[a]	X	X	X	X
Tall fescue (*Festuca arundinacea*)	X	X		X	X[b]
Timothy (*Phleum pratense*)			X[g]	X	
Weeping lovegrass (*Eragrostis curvula*)		X			
			Legumes		
Alfalfa (*Medicago sativa*)			X[f]	X	
Arrowleaf clover (*Trifolium vesiculosum*)	X[c]				X
Birdsfoot trefoil (*Lotus corniculatus*)		X		X	X
Crimson clover (*Trifolium incarnatum*)	Xc				
Crownvetch (*Coronilla varia*)		X			
Flatpea (*Lathyrus sylvestris*)		X	X		
Lupine (*Lupinus* spp.)	X[c]				
Red clover (*Trifolium pratense*)			X[g]		
Sericea lespedeza (*Lespedeza cuneata*)	X[a]	X			
Sweet clover (*Melilotus alba*)	X[a]				
Vetch (*Vicia sativa*)	X[c]				
			Other		
Kale (*Brassica oleracea acephala*)			X		

[a]Base species in double-cropping or intercropping system.
[b]Reed canarygrass and tall fescue grown alone and interseeded with sorghums.
[c]Species interseeded on base species in various combinations.
[d]Rye and sudangrass double-cropped (sequentially grown on the same land in the same year).
[e]Rye and sorghums double-cropped.
[f]Mixture (smooth bromegrass with alfalfa).
[g]Mixture (timothy, redtop, and red clover).

The data presented in this report are from the second year of the projects and cover harvests made during 1986. Yields of the annual species are representative of typical yields that can be expected given the climatic conditions. Most perennial species will not reach their maximum levels until their third year. The results are presented by region to follow the geographic organization of the HECP. It is difficult to give conclusions by regions based on only 1 or 2 years of growth data, so conclusions are drawn only for all the projects combined.

MIDWEST/LAKE STATES

The Midwest/Lake States is one of the most highly productive agricultural areas in the world. The region contains a large quantity of highly productive cropland, but even some of this highly productive land has characteristics that may restrict its use. The two major factors that restrict land use are erosiveness due to slope and soil textures and excessive wetness due to poor drainage. Additional factors of importance, especially in combination with eroded soils, are physical and chemical constraints on root penetration that decrease the drought tolerance of crops grown on those soils. Three projects are currently screening lignocellulosic crops for their energy-cropping potential on a variety of good and marginal cropland sites characteristic of the Midwest-Lake States.

Cornell University

The productivities of five species and two species combinations are being determined at eight sites with six different soil series in New York State. The species include two perennial grasses (switchgrass and reed canarygrass), one perennial legume (flatpea), one annual grass (sudangrass), one annual crucifer (kale), and two perennial grass-legume combinations (timothy-red clover and alfalfa-bromegrass). A meadow site is also included. Each site-soil series combination represents a different set of use and production limitations (Table 2). The crops at each site, except Hector, are grown under each of three fertility regimes (Table 3).

Yield results for the species by site, fertilizer rate, and cutting management are shown in Table 4. Some species responded to fertilizer treatments (reed canarygrass, timothy/redtop/red clover, meadow, kale, and sudangrass) while others did not (alfalfa-brome and flatpea). Whether two to three cuttings per year or one cutting per year was better was species and site dependent. Kale gave the highest yield but required 224 kg/ha of nitrogen to achieve that yield. Perhaps the most impressive yields relative to input requirements came from the existing meadow.

<u>Geophyta</u>

Ten forage species including five perennial grasses (reed canarygrass, smooth bromegrass, switchgrass, tall fescue, and timothy); three annual grasses (rye, sorghum, and sorghum X sudangrass); and two perennial legumes (alfalfa and birdsfoot trefoil) are being screened at three sites in north-central Ohio. Three sites in close proximity that exhibit a range of wetness limitations from chronically wet to periodically wet were selected for study. The soils are Toledo and Lucas silty clays. In addition to limitations on crop productivity, these

Table 2. Soil characteristics at Cornell research sites

Site	Soil series	Limitation(s)
Aurora	Honeoye	None
Caldwell Field A	Collamer	No specific limitations
Caldwell Field B	Collamer	Erosiveness (10% slope and texture)
Halme Farm	Erie	Acidic, chronic wetness, stony, low fertility
Hector	Erie	Acidic, chronic wetness
Mt. Pleasant Farm	Mardin	Acidic, low fertility, fragipan
Poole Farm	Honeoye	Erosiveness (10% slope)
Willsboro Farm M	Madalin	Fine texture, poor drainage, chronic wetness
Willsboro Farm R	Rhinebeck	Fine texture, poor drainage, chronic wetness

Table 3. Fertilizer regimes (three application rates of $N-P_2O_5-K_2O$ in kg/ha) by species at Cornell sites (1986)

Site	Species	Fertilizer regime 1	2	3
Aurora	Kale	56-34-34	112-67-67	224-67-67
	Sudangrass	34-34-34	67-67-67	134-67-67
Caldwell A	Alfalfa-brome	0-34-22	0-67-45	0-134-90
	Flatpea	0-34-22	0-67-45	0-134-90
	Switchgrass	22-6-22	45-11-45	90-11-45
	Timothy/redtop/red clover	0-34-22	0-67-45	0-134-90
Caldwell B	Alfalfa-brome	0-34-22	0-67-45	0-134-90
	Flatpea	0-34-22	0-67-45	0-134-90
	Switchgrass	22-6-22	45-11-45	90-11-45
	Timothy/redtop/red clover	0-34-22	0-67-45	0-134-90
Halme	Reed canarygrass	28-17-25	56-34-50	112-34-50
	Sudangrass	34-22-39	67-45-78	134-45-78
	Timothy/redtop/red clover	0-17-34	0-34-67	0-67-134
Hector	Meadow	0-0-0	0-0-0	0-0-0
Mt. Pleasant	Flatpea	0-17-34	0-34-67	0-67-134
	Kale	56-39-39	112-78-78	224-78-78
	Switchgrass	28-17-25	56-34-50	112-34-50
	Timothy/redtop/red clover	0-17-45	0-34-67	0-67-134
Poole	Alfalfa-brome	56-22-22	112-45-45	224-45-45
	Flatpea	0-6-11	56-11-22	112-11-22
	Switchgrass	28-6-11	56-11-22	112-11-22
	Timothy/redtop/red clover	0-6-11	0-11-22	0-22-45
Willsboro M	Kale	56-39-22	112-78-45	224-78-45
	Meadow	0-0-0	0-56-45	56-56-45
	Reed canarygrass	28-28-14	56-56-28	112-56-28
	Timothy/redtop/red clover	9-28-22	0-56-45	0-112-90
Willsboro R	Kale	56-39-22	112-78-45	224-78-45
	Meadow	0-0-0	0-56-45	56-56-45
	Reed canarygrass	28-28-14	56-56-28	112-56-28
	Timothy/redtop/red clover	0-28-22	0-56-45	0-112-90

Table 4. Total annual yields (dry Mg/ha) by species at Cornell sites (1986)

Species	Cuts/year	Fertilizer regime	Site: Aurora	Caldwell A	Caldwell B	Halme	Hector	Mt. Pleasant	Poole	Willsboro M	Willsboro R
Alfalfa-brome	3	1	1.6	2.3				8.6			
		2	1.8	2.3				8.5			
		3	1.8	2.1				9.0			
	2	1	2.0	2.4				8.4			
		2	2.1	2.1				8.8			
		3	2.0	2.4				8.8			
Flatpea	1[a]	1					4.8	4.2			
		2					5.4	4.5			
		3					5.3	3.8			
	1[b]	1					3.5	3.4			
		2					4.4	2.6			
		3					3.9	1.8			
Reed canarygrass	2	1			4.1				1.8	2.2	
		2			5.5				3.3	3.6	
		3			6.9				4.2	4.7	
	1	1			3.9				2.2	2.2	
		2			4.4				3.3	3.2	
		3			4.6				3.8	4.9	
Switchgrass	1[a]	1	0.9				1.1	2.9			
		2	1.2				1.4	2.8			
		3	1.2				2.1	3.9			
	1[b]	1	0.7				0.9	1.2			
		2	0.8				1.1	1.4			
		3	0.7				1.2	1.9			

Table 4 (continued)

Species	Cuts/year	Fertilizer regime	Site: Aurora	Caldwell A	Caldwell B	Halme	Hector	Mt. Pleasant	Poole	Willsboro M	Willsboro R
Timothy/redtop/ red clover	2[c]	1		1.8	2.8	5.6		6.5	7.7	2.2	2.6
		2		1.7	3.0	6.5		6.4	7.2	3.2	5.5
		3		2.1	3.3	6.6		7.2	7.3	4.0	6.2
	2[d]	1		2.0	3.4	6.8		8.4	6.6	2.5	3.4
		2		2.0	3.7	8.1		7.3	7.1	4.8	6.5
		3		1.8	3.3	7.8		7.5	7.6	5.7	7.0
Meadow	2	1					3.6			3.2	2.6
		2								4.7	4.5
		3								5.0	5.6
	1	1					1.8			1.9	2.2
		2								3.2	3.8
		3								4.2	4.8
Kale	1	1	2.5					6.1		2.2	2.4
		2	4.5					8.8		5.1	5.9
		3	8.0					11.6		7.7	7.3
Sudangrass	2	1	3.6			2.0					
		2	4.5			2.2					
		3	5.8			3.6					
	1	1	6.2			2.6					
		2	7.4			3.1					
		3	9.8			5.8					

[a]5 cm stubble height at harvest.
[b]15 cm stubble height at harvest.
[c]First harvest June 10.
[d]First harvest June 25.

low-lying, chronically wet soils cannot be cultivated or harvested with conventional equipment during much of the year. Crop responses to fertilization, weed control, and harvest frequency are additional factors being studied at Geophyta.

Attempts to establish perennial species in 1985 were unsuccessful because of soil crusting and frost heaving. Most perennial species were successfully established in 1986, although some required three tries (Table 5), and provided satisfactory establishment-year yields (Table 6). However, attempts to establish smooth bromegrass failed again at all three sites, and reed canarygrass and tall fescue each failed at one site. Because smooth bromegrass was never successfully established, it has been dropped from consideration as a species being screened in the Geophyta project. The fertilizer levels used, none of which can be considered excessive, are presented in Table 7.

The effectiveness of weed control varied among sites as well as among species at a site. A one-cut system of sorghum X sudangrass was far superior to a two-cut system. Yields of annual species (Table 8) were much higher than those of perennials. This was not unexpected because it was the establishment year for the perennials. Yields for the perennials should be higher in future years.

Purdue University

Eight species are grown either alone or in winter/summer double-crop combinations at four research sites in Indiana. These include two perennial legumes (alfalfa and birdsfoot trefoil); three perennial grasses (tall fescue, reed canarygrass, and switchgrass); and three annual grasses (rye, sweet sorghum, and sorghum X sudangrass). The sweet

Table 5. Mean populations (in plants/m^2) for spring, early summer, late summer,and fall seedings at Geophyta (1986)

Species	Spring	Early summer	Late summer	Fall
Site 1				
Alfalfa	190			
Birdsfoot trefoil	189			
Reed canarygrass	237			
Sorghum X sudangrass	8[a]	127		
Smooth bromegrass	213[a]	32[a]	122[b]	
Switchgrass	281			
Tall fescue	263			
Timothy	419			
Forage sorghum	38			
Rye				485
Site 2				
Alfalfa	280			
Birdsfoot trefoil	210			
Reed canarygrass	242			
Sorghum X sudangrass	0[a]	75		
Smooth bromegrass	107[a]	21[a]	151[b]	
Switchgrass	356			
Tall fescue	207[a]	6[a]	179[b]	
Timothy	451			
Forage sorghum	9[a]	58		
Rye				367
Site 3				
Alfalfa	245			
Birdsfoot trefoil	209			
Reed canarygrass	134[a]	25[a]	167[b]	
Sorghum X sudangrass	51			
Smooth bromegrass	102[a]	35[a]	167[b]	
Switchgrass	336			
Tall fescue	156[a]	29[a]	221	
Timothy	315			
Forage sorghum	53			
Rye				406

[a]Insufficient population, species reseeded.
[b]Insufficient population, species deleted.

Table 6. Total annual yields (dry Mg/ha) of perennial species in their establishment year at Geophyta (1986)

Species	Weed control With	Weed control Without	Fertilizer level High	Fertilizer level Low	Average
			Site 1		
Switchgrass	5.57	5.02	5.85	4.74	5.30
Reed canarygrass	4.99	5.26	5.82	4.43	5.12
Tall fescue	5.04	5.20	5.94	4.31	5.12
Timothy	3.62	4.00	4.75	2.87	3.81
Birdsfoot trefoil	2.75	3.82	3.35	3.22	3.28
Alfalfa	1.90	3.41	2.60	2.71	2.65
			Site 2		
Switchgrass	5.60	5.82	6.20	5.22	5.71
Reed canarygrass	5.25	4.79	5.68	4.36	5.02
Timothy	3.61	3.60	4.17	3.05	3.61
Birdsfoot trefoil	2.02	3.11	2.91	2.22	2.57
Alfalfa	1.36	2.03	1.72	1.67	1.70
			Site 3		
Switchgrass	4.07	3.38	4.54	2.91	3.72
Timothy	3.28	3.21	4.10	2.39	3.24
Birdsfoot trefoil	1.51	2.16	2.26	1.41	1.83
Alfalfa	1.64	2.34	2.03	1.95	1.99

Table 7. Nitrogen additions and weed control treatments at Geophyta (1986)

Species	Fertilizer Level (kg N/ha)		Weed Control Active ingredient (kg/ha)	
Rye	28	56	2,4-D ester	(1.12)
Alfalfa	11	11	Trifluralin 1,4-DB	(0.56) (1.34)
Birdsfoot trefoil	11	11	Trifluralin 1,4-DB	(0.56) (1.34)
Switchgrass	100	170	Atrazine (fall) 2,4-D amine	(1.68) (0.45)
Forage sorghum	100	170	Metolachlor 2,4-D amine	(1.34) (0.45)
Sorghum X sudangrass (1 cut)	100	170	Metolachlor 2,4-D amine	(1.34) (0.45)
Sorghum X sudangrass (2 cuts)	50+50	85+85	Metolachlor 2,4-D amine	(1.34) (0.45)
Others	100	170	2,4-D amine	(0.45)

Table 8. Total annual yields (dry Mg/ha) of annual species at Geophyta (1986)

Species	Annual yield				
	Weed control		Fertilizer level		
	With	Without	High	Low	Average
Site 1					
Sorghum X sudangrass (1 cut)-rye double crop					
Rye	5.16	5.06	5.51	4.71	5.11
Sorghum X sudangrass	17.85	19.03	19.04	17.84	18.44
Total	23.01	24.09	24.55	22.55	23.55
Sorghum X sudangrass (2 cuts)-rye double crop					
Rye	4.97	5.51	5.98	4.50	5.24
Sorghum X sudangrass (1st cut)	4.34	4.65	4.93	4.07	4.50
Sorghum X sudangrass (2nd cut)	2.79	2.82	3.07	2.55	2.81
Total	12.10	12.98	13.98	11.12	12.55
Forage sorghum (1 cut)	24.06	19.90	24.42	19.54	21.98
Site 2					
Sorghum X sudangrass (1 cut)-rye double crop					
Rye	5.03	4.95	5.75	4.22	4.99
Sorghum X sudangrass	17.47	16.94	17.09	17.31	17.20
Total	22.50	21.98	22.84	21.53	22.19
Forage sorghum (1 cut)	17.91	14.52	17.25	15.17	16.21
Site 3					
Sorghum X sudangrass (1 cut)-rye double crop					
Rye	3.03	4.35	4.28	3.10	3.69
Sorghum X sudangrass	21.27	15.86	19.94	17.19	18.56
Total	24.30	20.21	24.22	20.29	22.25
Forage sorghum (1 cut)	19.81	7.93	16.76	10.98	13.87

sorghum and the sorghum X sudangrass are grown as the summer component of a double-crop system with rye as the winter component. The southern site, at the Southern Indiana Purdue Agricultural Center (SIPAC), has a Zanesville silt loam with 8 to 12% slope and prior erosion. The soil is erosive on slopes and is drought prone due to a fragipan layer that restricts deep rooting. The southeastern site, at the Southeast Purdue Agricultural Center (SEPAC), has a Cincinnati silt loam with 8 to 10% slope and prior erosion. Two sites at the Throckmorton Research Farm, one flat with a 0 to 2% slope (T-flat) and one sloping with 6 to 8% slope and with prior erosion (T-slope), were chosen at the west-central location. Both have Sidell silt loams, which are excellent agricultural soils where erosion due to slope is not a problem.

In addition to the screening efforts, the effects of several cultural variables are also being studied. Several levels of nitrogen (grasses) and potassium (legumes) fertilizers are being applied. Yield response of the summer annual grasses to conventional versus minimum tillage techniques will also be determined. In another study, cool-season perennial grasses will be "set back" by a herbicide application to reduce competition with interseeded annual warm-season grasses. It is hoped that competition can be reduced without eliminating the cool-season species, therefore taking better advantage of the midsummer period during which cool-season crops experience a lull in productivity.

Yields at the Purdue University sites in 1986 (Table 9) were generally good. The sweet sorghum-rye double-crop yields were impressive, with mean yields by site ranging from 19.1 to 26.7 Mg/ha.

Table 9. Total annual yields (dry Mg/ha) by Purdue University site (1986)

Site[a]	Alfalfa	Birdsfoot trefoil	Tall fescue	Reed canarygrass	Switch-grass	Rye	Sorghum X sudangrass	Sweet sorghum
T-flat	14.56	3.96				5.95	14.19	20.24
T-slope	13.19	5.28				4.80	12.67	18.35
SEPAC	9.29	7.31	6.16	7.20	10.89	4.35	8.96	14.77
SIPAC	7.89	6.21	6.08			3.81	14.56	22.85

[a]Yields are averaged over fertilizer treatments.

The highest yield was recorded at the SIPAC site, which is considered marginal agricultural land. There, with 150 kg/ha of nitrogen, sweet sorghum yielded 27.5 Mg/ha, and the sweet sorghum-rye double crop yielded 31.9 Mg/ha. At the T-flat and T-slope sites, the perennial grasses were not well enough established to be harvested, but alfalfa yielded over 13 Mg/ha. Birdsfoot trefoil yields were much lower. At the SEPAC site all perennial grasses were well enough established and grew enough biomass to be harvested. At the SIPAC site tall fescue was the only perennial grass harvested. The switchgrass at the SEPAC site had a respectable yield of 10.9 Mg/ha. Reed canarygrass yielded 7.2 Mg/ha at SEPAC, and tall fescue yielded 6.2 and 6.1 Mg/ha at SEPAC and SIPAC, respectively. Grasses showed the most significant yield responses (approximately 75% for tall fescue and reed canarygrass) to the first 50 kg/ha of nitrogen (Table 10). The data indicate that 0 kg/ha is not an appropriate treatment for tall fescue and reed canarygrass because of low yields. Some preliminary economic evaluations of switchgrass based on data obtained from this and previous studies at the SEPAC and SIPAC sites indicate that 0 kg/ha of N is optimal for switchgrass (Lowenberg-DeBoer and Cherney 1987). The legumes on these sites did not respond to added potassium because the sites were already high in available potassium.

SOUTHEAST

The southeastern United States is characterized by long hot summers and mild winters. The rolling terrain has led to intense soil erosion during the long agricultural history of the region. As a consequence, the soils often have little or no remaining topsoil. This, coupled with

Table 10. Total annual yields (dry Mg/ha) at Purdue University sites by fertilizer rate (1986)

Fertilizer rate[a]	Alfalfa	Birdsfoot trefoil	Tall fescue	Reed canarygrass	Switch-grass	Rye	Sorghum X sudangrass	Sweet sorghum
0 kg/ha K	11.30	5.73						
100	11.10	5.82						
200	11.31	5.53						
0 kg/ha N			2.93	4.19	8.74	4.51[b]	8.74	13.79
50			5.12	7.28	10.40	4.72[b]	12.42	19.45
100			5.92	6.74	10.80	4.74[b]	14.08	20.54
150			7.56	8.11	12.00	4.95[b]	15.13	22.43
200			9.05	9.67	12.50			

[a]Yields are averaged over sites.
[b]Amount of N applied to preceding sorghum crop. Although 50 kg/ha N was applied to each rye crop, the differing amounts of N applied to the preceding sorghum crop affected the yield.

fragipan layers that further restrict the rooting zone, causes water stress and to a lesser extent soil fertility to be the most important limitations to plant productivity in the region. The long growing season is conducive to high productivity for species adapted to the hot and often dry midsummer conditions. Two projects are screening lignocellulosic crops for energy feedstock production in the Southeast.

Auburn University

Productivity of seven grasses and six legumes, either alone or in selected combinations, is being measured at sites in four regions of Alabama. Four of the grasses (Bermudagrass, Johnsongrass, switchgrass, and tall fescue) are perennials and three (pearl millet, rye, and sweet sorghum) are annuals. With the exception of sericea lespedeza, the legumes (arrowleaf clover, crimson clover, sweet clover, lupine, and vetch) are used as a winter component of a double-cropping system with the grasses. The summer annuals, sweet sorghum and pearl millet, were double-cropped with rye and legumes, and perennial warm-season grasses and sericea lespedeza were overseeded with rye and legumes. Tall fescue, a cool-season perennial, was not overseeded.

The lower coastal plain site is located on a Malbis fine sandy loam with a fragipan overlying acidic subsoil. This soil is erosion prone when slopes are cultivated, and root zone restrictions cause drought sensitivity for crops grown there. The upper coastal plain site is located on a Savannah loam that has a fragipan and is erosive. The Piedmont site is located on a Cecil sandy loam that is acidic and erosive. The Sand Mountain site has a Hartsells fine sandy loam that is erosive. All of these soils are considered to be adequate for crop production if appropriate management and conservation practices are used. Research in the Auburn project focuses on the use of double-cropping systems with cool- and warm-season crops to lengthen the period of time in which high productivities can be achieved.

Yields in 1986 at the Auburn University sites varied among species and sites. Yields were reduced by the severe drought that lasted through most of the growing season. Table 11 shows the yields of the cool-season species as well as lists the warm-season species they supplemented. Some of the rye and rye-legume mixtures produced good yields for winter crops, with many in the 5.0 to 9.5 Mg/ha range. Most of the yield in the mixtures was contributed by rye.

Yields of warm-season species are shown in Table 12. The combined yields of the warm- and cool-season species are presented in Table 13. Sweet sorghum was superior to pearl millet at all sites. Sweet sorghum gave excellent yields (23.6 Mg/ha) at the upper coastal plain site. Of the warm-season grasses, Johnsongrass had the best yield (11.8 Mg/ha), but switchgrass also had adequate yields ranging up to 7.0 Mg/ha. Tall fescue, the only cool-season perennial in the tests, performed poorly at all sites.

Virginia Polytechnic Institute and State University

Eight herbaceous species were established by no-tillage methods at each of three sites in the Piedmont of Virginia. Three perennial grasses (switchgrass, tall fescue, and weeping lovegrass); one annual grass (sorghum X sudangrass); and four perennial legumes (birdsfoot trefoil, crown vetch, flatpea, and sericea lespedeza) were planted. Sites were

Table 11. Total annual yields (dry Mg/ha) of cool-season species grown at Auburn sites (1986)

Cool-season species	Warm-season species	Site: Lower coastal plain	Site: Sand Mountain	Site: Piedmont	Site: Upper coastal plain
Rye-crimson clover	Bermudagrass	7.3	2.6	6.4	4.1
Rye-vetch	Switchgrass	6.9	1.5	6.5	5.1
Rye-vetch	Pearl millet	7.3	3.3	6.1	3.5
Rye-arrowleaf clover	Pearl millet	7.0	1.1		
Rye-arrowleaf clover	Johnsongrass				6.0
Rye-sweet clover		8.4	5.0		8.2
Rye-sweet clover	Sweet sorghum			9.5	
Rye-lupine	Sweet sorghum	6.5	2.1	6.0	
Rye	Sericea lespedeza	7.3	4.5	7.8	4.1
Tall fescue	Tall fescue			2.3	2.6
Rye-lupine	Sweet sorghum	6.5	2.1	6.0	
Rye	Sericea lespedeza	7.3	4.5	7.8	4.1
Tall fescue				2.3	2.6

Table 12. Total annual yields (dry Mg/ha) of warm-season species grown at Auburn sites (1986)

Warm-season species	Cool-season species	Site: Lower coastal plain	Site: Sand Mountain	Site: Piedmont	Site: Upper coastal plain
Bermudagrass	Rye-crimson clover	1.2	3.0	3.4	4.1
Switchgrass	Rye-vetch	2.2	4.2	6.6	7.0
Pearl millet	Rye-vetch	3.1	3.7	6.5	5.2
Pearl millet	Rye-arrowleaf clover	3.2	3.7		
Johnsongrass	Rye-arrowleaf clover				11.8
Sweet sorghum	Rye-sweet clover	6.6	12.2	8.6	
Sweet sorghum	Rye-lupine	7.0	5.5	10.3	23.6
Sericea lespedsza	Rye	1.8	4.8	5.4	5.0

Table 13. Combined total annual yields (dry Mg/ha) of warm- and cool-season species grown at Auburn sites (1986)

Warm-season species	Cool-season species	Site: Lower coastal plain	Sand Mountain	Piedmont	Upper coastal plain
Bermudagrass	Rye-crimson clover	8.5	5.6	9.8	8.1
Switchgrass	Rye-vetch	9.1	5.7	13.0	12.1
Pearl millet	Rye-vetch	10.4	6.9	12.6	8.6
Pearl millet	Rye-arrowleaf clover	10.2	4.8		
Johnsongrass	Rye-arrowleaf clover				16.8
	Rye-sweet clover	8.4	5.0		8.2
Sweet sorghum	Rye-sweet clover	6.6	12.2	18.1	
Sweet sorghum	Rye-lupine	13.4	7.6	16.4	23.6
Sericea lespedeza	Rye	9.1	9.2	13.2	9.1
	Tall fescue			2.3	2.6

selected in three of the major Piedmont soil types. Appling sandy loam, Cecil sandy loam, and Davidson clay loam soils at the Lunenburg, Amelia, and Orange County sites, respectively, are strongly acidic, highly erosive soils. Three sites for each soil type were chosen on the basis of slope (9 to 12%) and aspect (southeasterly face). Three additional Cecil sandy loam sites with northwest-facing slopes were selected for determination of the effect of aspect on productivity. Research in the Virginia Tech project includes a detailed soil analysis component to link differences in crop productivity in experimental plots to specific soil characteristics. Once the specific edaphic factors that limit crop productivity have been identified, recommendations for remedial actions for improving soil characteristics and enhancing productivity can be made.

Growth at all the Virginia Tech sites was reduced by the drought that affected the entire Southeast during 1986. Yields for eight species at four sites are shown in Table 14. Two warm-season grasses, weeping lovegrass and switchgrass, did very well considering the drought. Yields for switchgrass ranged from 4.2 to 8.0 Mg/ha. Weeping lovegrass yields at the same sites ranged from 5.6 to 8.2 Mg/ha. The annual sorghum X sudangrass did only marginally better than the weeping lovegrass and switchgrass, yielding 3.8 to 8.0 Mg/ha.

CONCLUSIONS

Two years of data have been accumulated on the growth of lignocellulosic crops in the Midwest/Lake States and the Southeast. A severe drought affected the entire Southeast in 1985 and 1986. At many sites, stands of the perennial species were not well established in 1985,

Table 14. Total annual yields (dry Mg/ha) at Virginia Tech sites (1986)

Species	Site			
	Orange Co.	Amelia Co. (SW)	Amelia Co. (NE)	Lunenburg Co.
Sorghum X sudangrass	6.6	8.9	8.4	3.8
Weeping lovegrass	5.6	6.4	8.2	7.6
Switchgrass	5.8	6.7	8.0	4.2
Tall fescue	0.8	2.2	2.0	0.8
Crownvetch	0.3	1.0	0.0	0.0
Birdsfoot trefoil	0.4	1.4	1.0	0.3
Flatpea	0.0	1.4	1.2	0.0
Sericea lespedeza	2.4	3.7	3.9	0.0

and maximum yields were not expected in 1986. However, even with these limitations, some species showed good yields and are emerging as good candidates for energy crops. Among these are the warm-season perennials switchgrass and weeping lovegrass. When considering biomass yield, the double-crop rotation of the annuals sweet sorghum and rye looks promising. However, while total biomass yield is often greater for annuals than for perennials, annuals require more agronomic inputs. Whether cultivation of annuals is justified economically depends on the value of the additional yield compared with the cost of additional inputs.

Results from the lignocellulosic screening and selection projects are being used to modify the research conducted in these projects. Because of establishment problems, smooth bromegrass has been dropped as a species at Geophyta. At all four Auburn sites, sweet sorghum has consistently outyielded pearl millet, so pearl millet has been dropped from consideration. Switchgrass and weeping lovegrass have done relatively well at all the Virginia Tech sites, so more intensive research is being performed on these species. Switchgrass will be subjected to varying rates of nitrogen fertilizer and to overseeding with rye, crimson clover, arrowleaf clover, and hairy vetch. (Some switchgrass will not be overseeded.) Both switchgrass and weeping lovegrass will be subjected to two harvest treatments. At Cornell the kale has not done as well as expected, so three varieties of rapeseed (*Brassica napus*), which is similar to kale, are being tested.

Crop budgets, which estimate the cost of producing biomass, will be developed from the yield and input data gathered from these projects. These data will also be used to do farm-scale linear programming to determine how the production of energy crops could fit into farming operations. The data will also be used in conjunction with crop simulation models to extend the range of sites over which information on energy crop production is available. The data gathered from the projects will be used to select which species will be enhanced as energy crops through crop breeding and more effective agronomic practices.

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