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Herbaceous Energy Crops Program: Annual Progress Report for FY 1986

J. H. Cushman
A. F. Turhollow
J. W. Johnston

ENVIRONMENTAL SCIENCES DIVISION
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J. H. Cushman
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Environmental Sciences Division
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*Energy Division, ORNL

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EXECUTIVE SUMMARY

The availability of biomass feedstocks is a critical constraint on the deployment of biomass energy technologies. This report summarizes the progress for FY 1986 of the Herbaceous Energy Crops Program (HECP), a program supporting research on the production of terrestrial, nonwoody energy crops. HECP is part of the U.S. Department of Energy's Biofuels and Municipal Waste Technology Division, and Oak Ridge National Laboratory provides field management for the program and has overall responsibility for its research.

The overall goal of HECP is to provide the technology base that will allow industry to develop commercially viable systems for producing herbaceous biomass for fuels and energy. Specific objectives include identifying the resources available for biomass production, identifying and improving the species most appropriate for energy crops, defining cost-effective management techniques for energy crops, and establishing the environmental acceptability and economic feasibility of herbaceous energy crops.

HECP supports research in four areas:

1. Lignocellulosic energy crops. Lignocellulosic crops, primarily forage crops, are the main focus of HECP. They are suitable feedstocks for essentially all of the advanced thermochemical and biochemical conversion processes that are now under development. Screening and selection projects began in the Southeast and Midwest-Lake States in FY 1985 and continued in FY 1986.

2. Oilseed crops. Oilseed crops are a secondary emphasis in the program. In cooperation with the U.S. Department of Agriculture's Agricultural Research Service at Tifton, Georgia, HECP is developing winter rapeseed varieties suitable for use as double-cropped winter crops in the Southeast.

3. Exploratory research. The exploratory studies include research on hydrocarbon biosynthesis, tissue culture techniques for sorghums, and wetland systems.

4. Environmental and economic analyses. Work in the environmental and economic analysis area consists of studies supportive of HECP, including resource assessments and analyses of production costs.

MAJOR ACCOMPLISHMENTS IN FY 1986

Lignocellulosic Crops

Five field studies in the Southeast and the Midwest-Lake States designed to screen and select promising perennial and annual lignocellulosic crop species were continued in FY 1986. A range of agronomic management practices, site qualities, and species is being studied.

Yields of some of the annual species have been impressive. Sweet sorghum (Sorghum bicolor) yielded in excess of 25 dry Mg/ha at both the Auburn University and the Purdue University projects. Pearl millet (Pennesitum americana) and sorghum x sudangrass (Sorghum bicolor x Sorghum sudanensis) yields ranged between 12.9 and 20.4 dry Mg/ha. Most of these summer annuals are being double-cropped with a winter annual, usually rye. Average rye yields were about 4.5 dry Mg/ha.

Most perennial species have been successfully established, although stands are not yet adequate at a few sites. Most of the yield data for perennial crops are from their establishment year, a year in which yields are typically low. However, some species did particularly well at some sites. Johnsongrass (Sorghum halapense) yielded 10.8 dry Mg/ha, and switchgrass (Panicum virgatum) and sericea lespedeza (Lespedeza cuneata) yielded in excess of 5 dry Mg/ha at some sites in Alabama.

Fertilizer response tests are part of the screening and selection process. As expected, the nonlegumes exhibited a positive response to fertilizers. The legumes alfalfa (Medicago sativa) and birdsfoot trefoil (Lotus corniculatus) did not respond to potassium, although this is probably because the soils they are grown on already contain adequate potassium.

Crop growth model work is being pursued at Cornell and Purdue universities. Soil resource work is being undertaken at Cornell and Virginia Tech universities.

Oilseed Crops

Middle distillate fuels (diesel and home heating oil) represent the second largest share of the petroleum end-product market. Some vegetable oils may serve as diesel fuel substitutes. Winter rapeseed (Brassica napus) is the oilseed crop being focused on in HECP-supported research focusing on winter rapeseed (Brassica napus) as an oilseed crop. The aim of rapeseed research is to produce high yielding, high oil-content cultivars.

Three projects are being undertaken at the University of Idaho to breed specific characteristics into winter rapeseed: (1) atrazine-resistant winter rapeseed, (2) Canola-quality winter rapeseed (oil with less than 1% erucic acid and meal with less than 0.3% glucosinolates) adapted to the southeastern United States, and (3) dwarf industrial (48 to 62% erucic acid oil) and edible (less than 1% erucic acid oil) lines of winter rapeseed. Two backcrosses were made in the atrazine resistance breeding work. Two generations were screened for characteristics appropriate for double-cropping Canola-quality winter rapeseed in the southeastern United States. The initial cross for dwarf winter rapeseed cultivars was made. In addition to the winter rapeseed breeding work, the University of Idaho also coordinates the National Winter Rapeseed Variety Trials. These trials provide useful feedback for the breeding work.

At Tifton, Georgia, a University of Georgia project is looking at production and harvesting practices for winter rapeseed as a double crop in the southeastern United States. Three varieties of rapeseed are being grown: Dwarf Essex, a winter variety; Westar, a summer variety; and Cascade, one of the edible winter varieties developed by the University of Idaho. Westar has exhibited the earliest maturity and the best yields, followed by Cascade.

The University of Georgia at Athens is examining small-scale extraction of vegetable oil using carbon dioxide as a solvent.

Exploratory Research

The University of Minnesota is working with the wetlands crop *Typha*. Preliminary results from sustained productivity experiments indicate that a single fall harvest of aboveground biomass is better than two harvests per year, although the timing of the midsummer harvest may affect this conclusion. Machine harvest does not negatively affect productivity and tends to enhance productivity in the year following machine harvest. Belowground harvests reduce aboveground productivity in the year following harvest, but productivity may recover in the second year following harvest. Experiments on the water requirements of *Typha* spp. show that continuous flooding provides for the greatest growth but also is the most expensive. Results indicate that a harvesting scenario that does not require fall field-drying is desirable.

Hydrocarbon-bearing plants might provide a liquid fuel that requires only limited refining. However, efforts to increase hydrocarbon production in plants to economic levels have thus far been unsuccessful. Lawrence Berkeley Laboratory is investigating the physiology and biochemistry of plant hydrocarbons using *Euphorbia lathyrus*. This work will lay the foundation for future genetic manipulations and the use of biotechnology to increase plant hydrocarbon production.

Experiments on environmental regulation of hydrocarbon production using either water or salt stress increased the allocation of photosynthate to storage compounds (including hydrocarbons) at the expense of structural components. Experiments on enzymatic regulation seek to identify the structures and enzymatic systems responsible for the allocation of carbon to hydrocarbons.

Research at Texas A&M University is directed toward identifying fundamental biological information and modifying processes that are responsible for in vitro plant regeneration of sorghum (Sorghum bicolor). Callus cultures of eight agronomically important genotypes of sorghum were established and studied to determine biochemical/compositional, histological, developmental, and cytogenic differences that may affect in vitro responsiveness and allow efficient plant regeneration. Attempts to repeat studies reported in the sorghum tissue culture literature uncovered major discrepancies. Three genotypes previously reported to be recalcitrant were regenerated from culture for the first time.

An experiment established at the Oak Ridge National Environmental Research Park in the summer of 1986 in investigating the possibility of using successional vegetation from abandoned fields and pastures as biomass for energy feedstocks. Two sites were chosen, one in a field that had been previously planted to sorghum x sudangrass, wheat, and soybeans and the other in a pasture that has been intermittently mowed over the last 10 years. Treatments include harvest frequency and fertilizer and lime applications.

Environmental and Economic Analyses

The literature on wet soils and species is reviewed in a report entitled "Productivity of Wet Soils" (Johnston, in preparation). Wet soils occupy 105 million ha in the continental United States, with about 40% currently being cropped. About one-quarter of major U.S. crops are grown on wet soils. Two plants that grow well on wetlands are Typha spp. and Phragmites australis. Reed canarygrass (Phalaris arundinacea) is being screened as a lignocellulosic energy crop but it also grows wild on wet soils.

Lignocellulosic crops are a potential alcohol fuel feedstock. A section on the production of lignocellulosic crops was contributed by HECP as part of a Solar Energy Research Institute-coordinated study on fuel alcohol. Estimated in-field production costs for 1985 technology range from $40.60 to $61.50/dry Mg and for year 2000 technology range

HERBACEOUS ENERGY CROPS PROGRAM: ANNUAL PROGRESS REPORT FOR 1986

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ABSTRACT

This report describes the activities and accomplishments of the Herbaceous Energy Crops Program (HECP) for the year ending September 30, 1986. HECP, one of three research programs on the production of biomass energy crops supported by the U.S. Department of Energy's Biofuels and Municipal Waste Technology Division, is devoted to research on the development of terrestrial, nonwoody plant species for use as energy feedstocks. Oak Ridge National Laboratory provides field management for the HECP and has overall responsibility for its research.

HECP emphasizes lignocellulosic forage crops. In FY 1986 screening and selection trials continued on 25 species of perennial and annual grasses and legumes in five projects in the Southeast and the Midwest-Lake States regions. Research also continued on the development of winter rapeseed as a diesel-fuel substitute. Activities in FY 1986 included genetic crosses and selections to incorporate atrazine resistance, development of Canola-quality winter rapeseed for the Southeast, and development of dwarf varieties. Production practices for double-cropped winter rapeseed in the Southeast were also examined.

Exploratory research efforts in FY 1986 included the physiology and biochemistry of hydrocarbon production in latex-bearing plants, the productivity of cattail stands under sustained harvesting, the development of tissue culture techniques for hard-to-culture sorghum genotypes, and the start of a study to measure sustained productivity of old-field successional vegetation. Environmental and economic analyses in FY 1986 included studies on the uses of wetlands and wet soils, the use of lignocellulosic crops as an alcohol feedstock, the potential of direct combustion of lignocellulosic crops, and existing oilseed extraction facilities.

1. INTRODUCTION

Feedstock availability will determine the ultimate contribution of biomass technologies to U.S. energy supplies. In recognition of the critical importance of feedstocks to the development of biomass energy systems, the U.S. Department of Energy (DOE) supports research on a range of aquatic and terrestrial biomass production systems. This report summarizes the progress for FY 1986 in the Herbaceous Energy Crops Program (HECP), a DOE-supported program devoted to research on terrestrial, nonwoody energy crops.

HECP is supported by DOE's Biofuels and Municipal Waste Technology Division (BMWTD). Oak Ridge National Laboratory (ORNL) has been designated the Field Management Office for the program and, thus, is responsible for overall management of its research efforts. At ORNL, HECP is part of the Environmental Sciences Division's Biomass Production Program (Fig. 1).

The purpose of this report is to present an overview of HECP, with emphasis on the research progress in FY 1986. Section 2 briefly describes the relationship of HECP to other BMWTD programs and presents an overview of the program's organization, goals and objectives, and approach to research. Sections 3 to 6 discuss in detail the research projects and progress for FY 1986 in each of HECP's major research areas.

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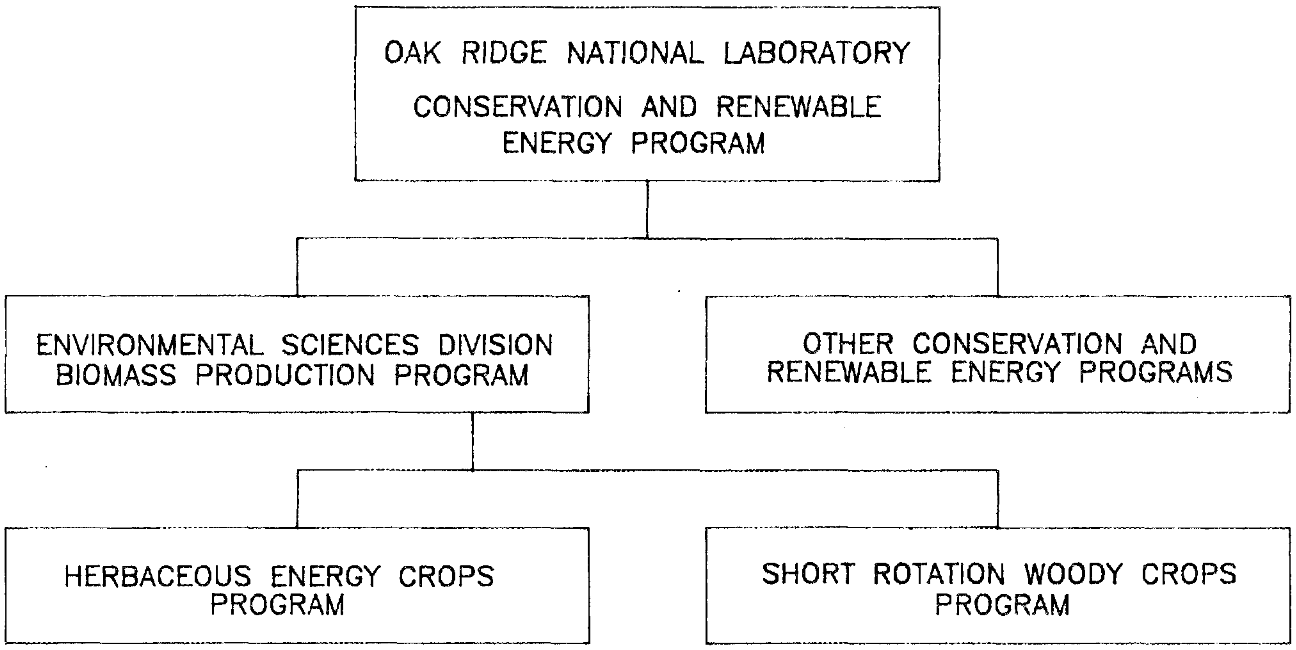

Fig. 1. The Herbaceous Energy Crops Program is one of two biomass production programs managed by ORNL for DOE's Biofuels & Municipal Waste Technology Division.

2. PROGRAM DESCRIPTION

To reduce uncertainty to the point at which industry will invest in biomass technology development, BMWTD supports a multifaceted research effort on biomass energy technologies, with the goal of providing a technology base for biomass energy production and conversion. HECP was established in 1984 as one element in the overall BMWTD program. This section describes the relationship of HECP to the other major BMWTD programs and then discusses its goals, objectives, and approach to research.

2.1 ORGANIZATION

HECP, one of three major BMWTD programs devoted to the production of biomass fuels and feedstocks (Fig. 2), is investigating the production of energy crops using terrestrial, nonwoody plant species. The Short Rotation Woody Crops Program emphasizes the production of wood for energy through short-rotation intensive silviculture, and the Aquatic Species Program emphasizes oils from microalgae. The BMWTD conversion programs are exploring advanced technologies for converting biomass feedstocks to useful forms of energy. The regional programs facilitate the deployment of both production and conversion technologies through regional resource assessments and technology transfer.

2.2 GOALS AND OBJECTIVES

The overall goal of HECP is to provide a technology base that will allow industry to develop commercially viable systems for producing herbaceous biomass for fuels and energy feedstocks. The HECP research program primarily seeks to produce energy feedstocks that are suited for liquid and gaseous fuels. Renewable energy resources other than biomass have limited ability to economically produce large quantities of liquid fuels. In addition to providing energy, there are a number of benefits to producing energy from herbaceous energy crops. Herbaceous energy crops provide a domestically produced source of energy that enhances U.S. energy security. The energy markets provide an additional outlet for products that can be produced by a currently depressed and heavily subsidized agricultural sector. In addition, it is possible to develop systems of growing energy crops that have environmentally beneficial effects.

Four objectives have been defined for HECP:

1. Identify the biotic and physical resources available for the production of herbaceous energy crops.

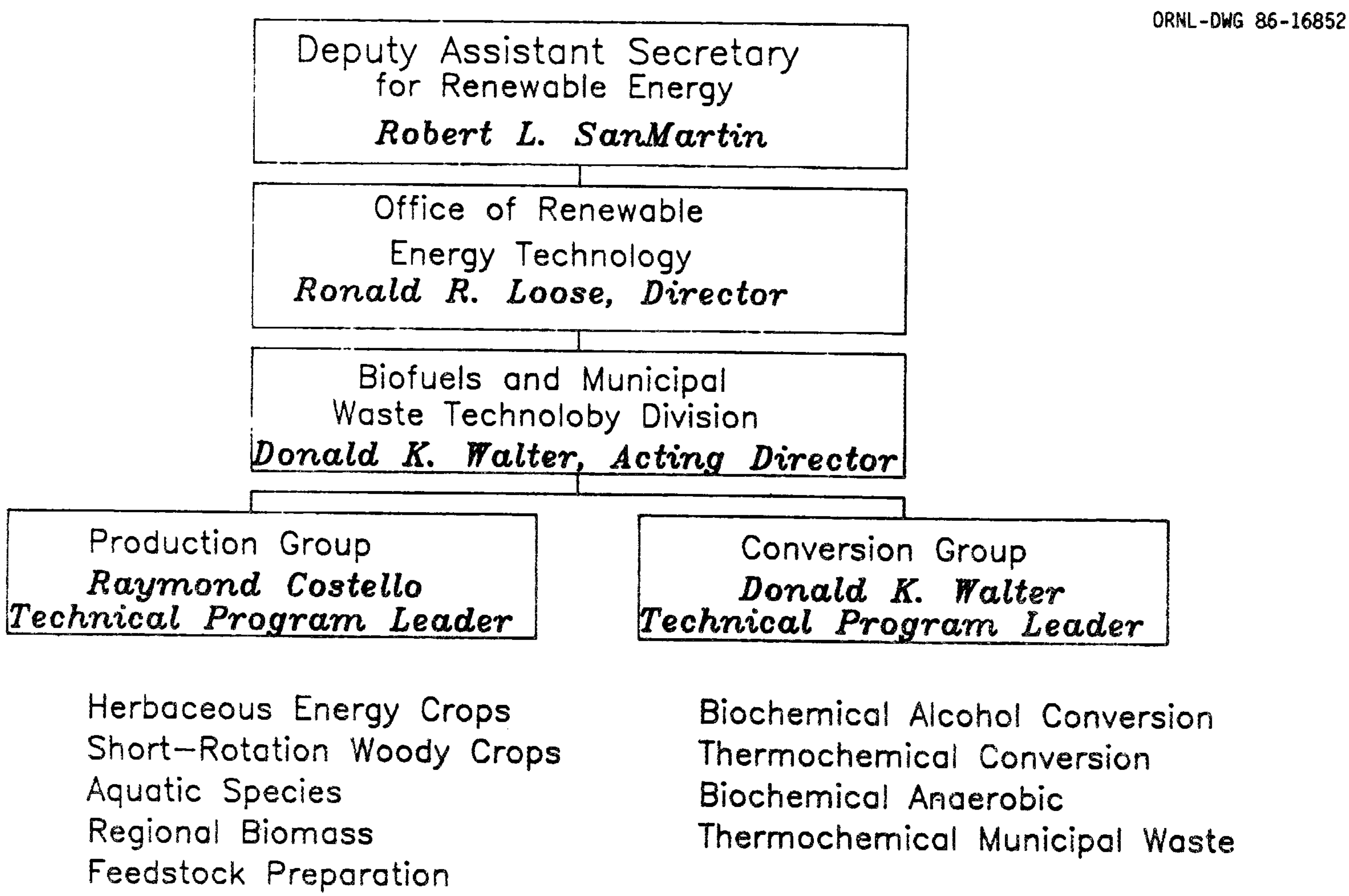

Fig. 2. Biofuels & Municipal Waste Technology Division research programs include both biomass production and conversion technologies.

2. Identify and improve the productivity of the species most appropriate for herbaceous energy crops.

3. Define cost-effective management techniques for the production of herbaceous energy crops.

4. Establish the environmental acceptability and economic feasibility of herbaceous energy crops.

These objectives form a series of steps essential to reaching the HECP's goal of developing commercially viable herbaceous energy crops.

2.3 APPROACH

The Congressional Office of Technology Assessment (1980) and DOE's Energy Research Advisory Board (1981) determined that biomass can make significant contributions to U.S. energy supplies. To exploit the potential contribution by herbaceous energy crops, the research strategy must take into account biotic, economic, and environmental factors; the structure of American agriculture; competing uses for land; and the structure of energy markets. Appropriate systems for producing energy crops must be defined and their attractiveness to potential producers and consumers demonstrated. These factors require the identification and improvement of appropriate species, development of efficient agronomic practices, and development of economic systems of energy crop production.

The American farmer will be the primary producer of herbaceous energy crops. Farmers, like others in the private sector, require profit opportunities to produce specific crops. Currently, markets for food commodities are poor and farmers desire alternative markets for what they can produce. The use of crops for energy represents such an alternative market, and it is a potentially large market. Energy crops will be a viable alternative for farmers only if they can be integrated with present crops and production practices. Low-cost production systems must be developed so that energy feedstocks can be priced low enough to be attractive as energy products, yet the difference between feedstock selling price and cost of production must be great enough to provide a profit margin for the producer. In addition, labor and machinery requirements must be compatible with ongoing agricultural activities.

For most energy products, herbaceous energy crops must be processed in a conversion facility. Supplies of energy feedstocks for a conversion process must be available on a year-round basis which means biomass must be stored if it is not harvested year-round. Producing energy crops for as much of the year as possible will reduce storage requirements. In addition, to improve the economics of the conversion process, the chemical composition of energy crops should be tailored as much as possible to the conversion process under consideration. Therefore, conversion processes must also be considered in the development of herbaceous energy crops.

The United States has 228×10^6 ha of cropland of which 166×10^6 ha are currently cropped, and the remainder is in pasture, range, and forest, or used for other purposes. Cropland varies widely in quality as do climatic conditions. The primary limitations on cropland are erosiveness and wetness, although in most cases, these limitations can be readily overcome with careful crop management. Some land can be tilled on an annual basis, other land should not be.

Because of these varied conditions, no one crop will be best suited for all situations. Therefore, HECP is screening a number of potential energy crop species (primarily grasses and legumes) on a range of cropland types. Annual crops are well suited for better sites, while perennial crops are well suited for good sites as well as marginal and erodible sites. Perennial energy crops would displace more erodible annual crops that encourage erosion from land subject to soil loss, and may, therefore, enhance the productivity of erosive lands over time.

HECP has established priorities for different categories of herbaceous energy crops and production regions. The main emphasis is on herbaceous lignocellulosic crops with a secondary emphasis on winter rapeseed as a winter oilseed crop for the Southeast. The exploratory research component of the program includes smaller research efforts on biotechnology, wetland species, abandoned cropland, and, starting in FY 1987, the effects of feedstock composition on the efficiencies of conversion technologies. Some of the Exploratory Research efforts relate to lignocellulosic crops.

Lignocellulosic crops are emphasized because they have the highest potential for producing significant quantities of fuels or energy feedstocks in the foreseeable future. A wide range of species suitable for perennial and double-cropping systems and adapted to many different sites and climates is available. Screening and selection of lignocellulosic crops is in progress in the two most promising regions, the Midwest-Lake States and the Southeast. These two regions have large amounts of marginal croplands with few extreme restrictions on productivity. The Great Plains states are the next most promising region, and research will begin there in FY 1988. Other regions have more extreme restrictions on their land base or potential productivity.

Lignocellulosic crops are suitable feedstocks for conversion research support by the BMWTD. The liquid fuels from these conversion processes are alcohols, which make good gasoline substitutes. While gasoline is the most important liquid fuel in the United States, in certain critical sectors, such as agriculture, trucking, railroads, and mining, diesel is the primary fuel.

Vegetable oils make good diesel substitutes. Oilseeds could prove to be feasible fuel sources if they can be produced at a low enough cost. Growing oilseeds as a winter crop in a double-crop rotation with a summer food crop appears to be the best way to produce low-cost oilseeds. A double-cropping system reduces land costs of the energy crop, allows greater annual machinery utilization, and provides the positive environmental benefit of a winter ground cover. HECP's efforts in oilseeds concentrate on developing winter rapeseed as a winter double crop for the southeastern United States. Winter rapeseed represents the best possibility for low-cost vegetable oil production, can reduce erosion, and, by virtue of it being a winter crop, extends the land base available for energy crops.

2.4 PROGRAM RESEARCH AREAS

HECP sponsored research in four major areas during FY 1986: (1) lignocellulosic crops, (2) oilseed crops, (3) exploratory research, and (4) environmental and economic analysis.

The lignocellulosic and oilseed crops research areas are directed toward specific types of energy crops. Exploratory research includes several otherwise unrelated research projects on subjects or crop types not currently emphasized but potentially important to HECP. Environmental and economic analysis provides supporting research and analysis for all other program areas, as well as information for overall program planning. Figure 3 shows the subdivisions within each of the major areas. Individual research projects in the subareas are described in the following sections.

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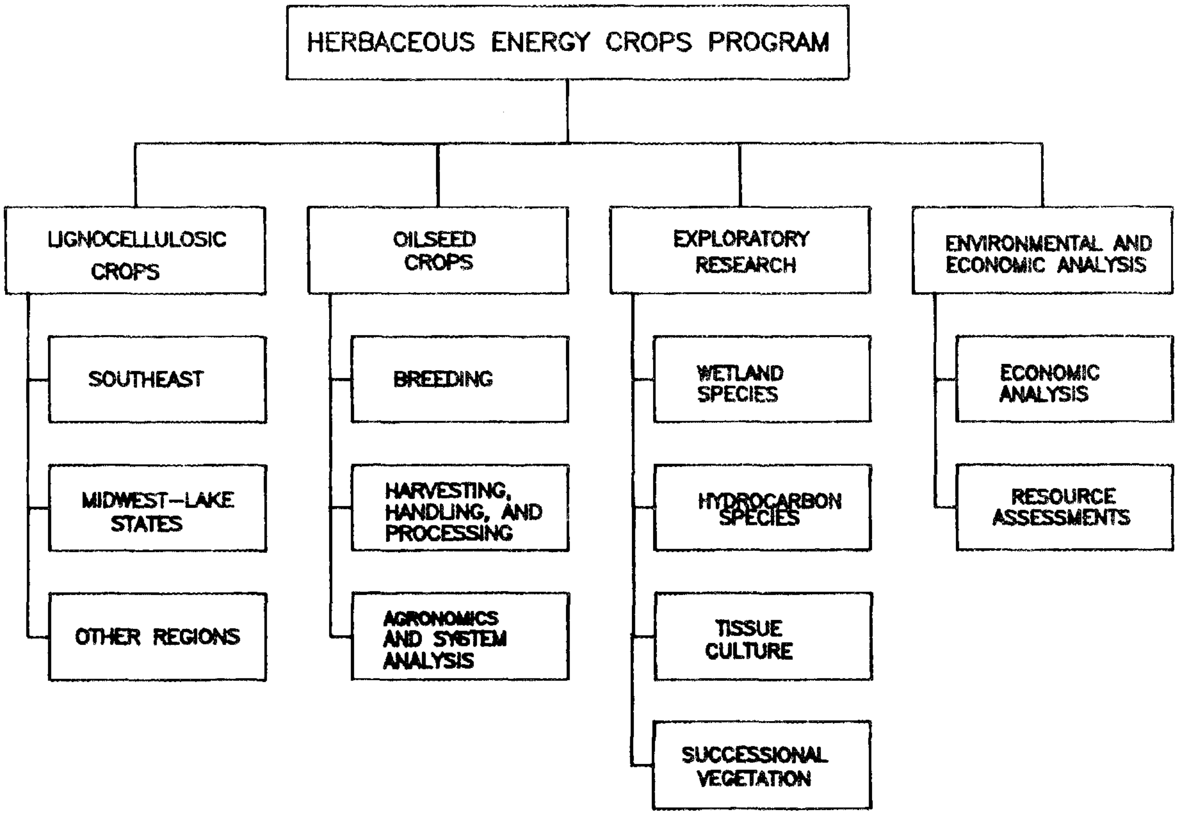

Fig. 3. Subdivision by region or research topic of the four major research areas.

3. LIGNOCELLULOSIC CROPS

Lignocellulosic crops, which include the traditional forage crops, are the main focus of HECP research activities. These crops are suited for production systems that use lands that are either good or marginal for traditional row-cropping. In addition, lignocellulosic cropping systems that use perennials or combine double-cropping with 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 HECP is to produce, store, and transport lignocellulosic crops to a conversion facility for a cost of \$2.10 to \$3.15/GJ (\$33 to \$50/dry Mg) in the year 2000. A delivered cost in this range appears to be required in the future if fuels produced from lignocellulosic crops are to be competitively priced with conventional fuels. 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 9.4 Mg/ha at 88% dry matter [150 bushels/acre], and the total biomass produced by the crop [including grain] is 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 selecting the best species and establishing conversion linkages. Field research in lignocellulosic crop production was initiated at five institutions during FY 1985 and continued in FY 1986 (Fig. 4). Research focused on screening promising lignocellulosic crop species for production of energy feedstocks in the Southeast and Midwest-Lake States regions. 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.

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 restrictions on their productivity, while others have varying degrees of factors that can restrict productivity, such as erosiveness or wetness. The species being screened are primarily perennial grasses and legumes, although several annual grasses and one annual brassica species are 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 lignin, cellulose, hemicellulose, nonstructural carbohydrate, protein, and ash.

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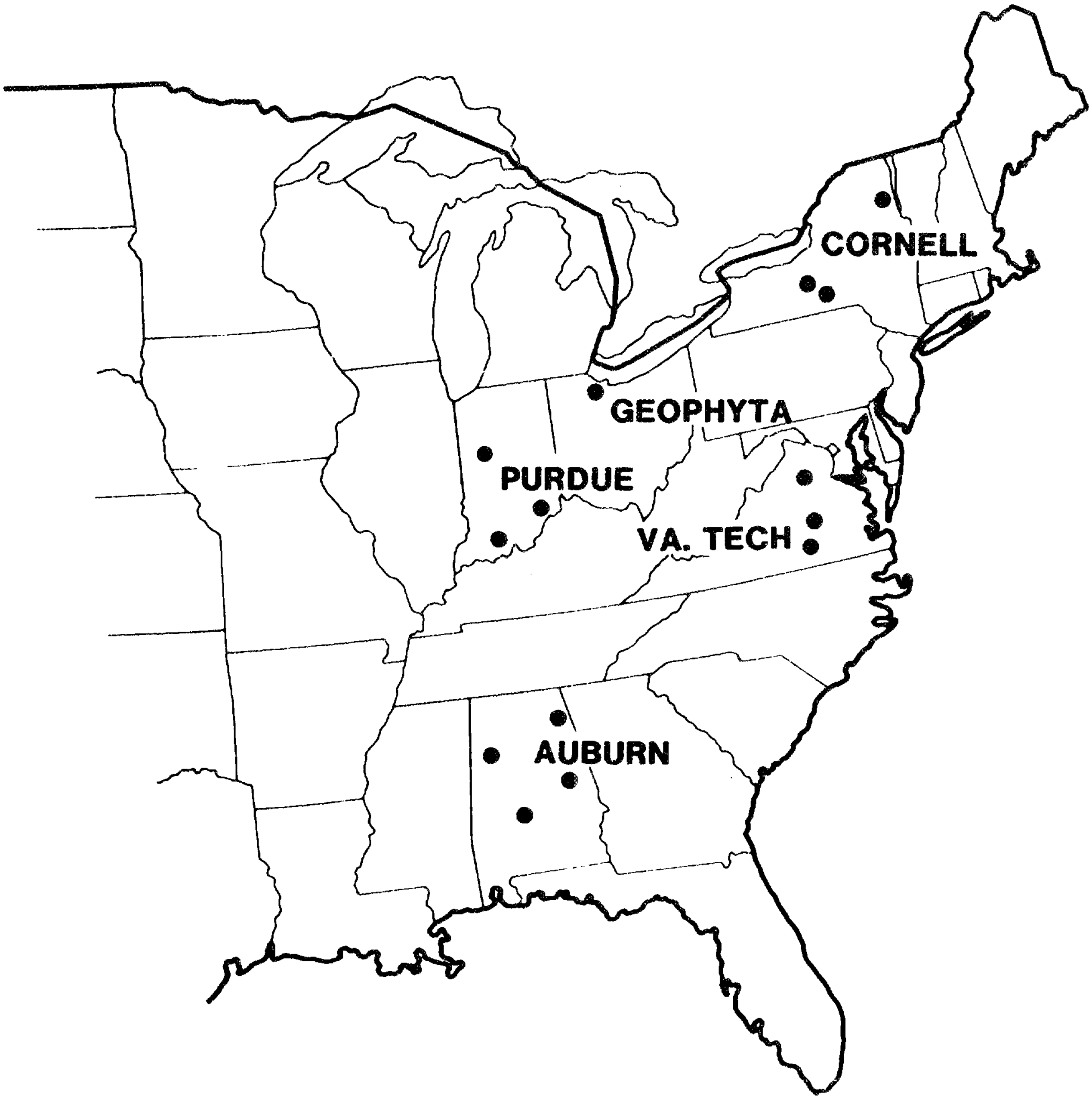

Fig. 4. Locations of the field sites for HECP's lignocellulosic crop screening studies in the Midwest-Lake States (Cornell, Geophyta, and Purdue) and the Southeast (Auburn and Virginia Polytechnic Institute and State University).

Table 1. Lignocellulosic species being screened by HECP projects in the Southeast and Midwest-Lake States regions

Species	Auburn	Va. Tech	Cornell	Geophyta	Purdue
	Grasses				
Bermudagrass (*Cynodon dactylon*)	X[a]				
Johnsongrass (*Sorghum halapense*)	X[a]				
Pearl millet (*Pennisetum americana*)	X[a]				
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[e]
Sudangrass (*Sorghum sudanensis*)				X[d]	
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			
	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*)	X[c]				
Crownvetch (*Coronilla varia*)		X			
Flat pea (*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 will be grown alone and will also be interseeded with sorghums.

[c]Species interseeded on base species in various combinations.

[d]Rye and sudangrass will be double-cropped (sequentially grown on the same land in the same year).

[e]Rye and sorghums will be double-cropped.

[f]Mixture (smooth bromegrass with alfalfa).

[g]Mixture (timothy with red clover).

Beyond these similarities, each project is unique. Specific growing conditions, (e.g., weather, soil, slope) at each site are different, as are the species being grown. Because the research sites are widely dispersed, the meteorological and environmental conditions vary. The unique characteristics of each project are detailed below.

3.1 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 topsoil remaining. This, coupled with 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 the winter component of a double-cropping system with the annual grasses.

The lower coastal plain site is located on a Malbis fine sandy loam with a fragipan overlaying 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.

Virginia Polytechnic Institute and State University (Virginia Tech)

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 sudan); and four perennial legumes (birdsfoot trefoil, crown vetch, flat pea, and sericea lespedeza) were planted. Sites were 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.

3.2 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 factors that primarily 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 sites characteristic of the Midwest-Lake States.

Cornell University

The productivities of four 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 (flat pea), one annual crucifer (kale), and two perennial grass-legume combinations (timothy-red clover and alfalfa-bromegrass). Each site-soil series combination represents a unique set of use and production limitations (Table 2). The crops at each site are grown under each of three fertility regimes: (1) no fertilizer, (2) fertilizer applied at one-half soil-test recommendation, and (3) fertilizer supplied at full soil-test recommendation. Additional efforts at Cornell include (1) development of crop growth models based on physiological responses to meteorological, edaphic, and management input factors; and (2) development of a geographical information data base system for assessing the availability of land in the northeastern and midwestern United States suitable for energy crop production.

Geophyta

Ten forage species including five perennial grasses (reed canarygrass, smooth bromegrass, switchgrass, tall fescue, and timothy); three annual grasses (sorghum, rye, and sudangrass); and two perennial legumes (alfalfa and birdsfoot trefoil) are being screened at three sites in

Table 2. Soil characteristics at Cornell research sites

Site	Soil series	Limitation(s)
Pool Farm	Honeoye	Erosiveness (10% slope)
Mt. Pleasant Farm	Mardin	Highly acidic, low fertility, fragipan
Halme Farm	Erie	Chronic wetness, acidic, stony, low fertility
Caldwell Field I	Collamer	No specific limitations
Caldwell Field II	Collamer	Erosiveness due to slope (10%) and texture
Willsboro Farm I	Rhinebeck	Fine texture, poor drainage, chronically wet
Willsboro Farm II	Madalin	Fine texture, poor drainage, chronically wet

northcentral 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 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 that are being studied at Geophyta.

Purdue University

Eight species are grown either alone or in winter-summer double-crop combinations at three 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 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 has a Zanesville silt loam that is erosive on slopes and is drought-prone due to a fragipan layer that restricts deep rooting. The southeastern site has a Cincinnati silt loam with prior erosion. Two sites differing in slope and prior erosion 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.

3.3 CROP ESTABLISHMENT

The crop establishment phase of the lignocellulosic crop screening effort has been completed at all research sites. All of the candidate species were established, but in some cases establishment proved to be difficult.

In general, there were no difficulties in establishing the annual species in 1985 or 1986 (Table 3). Consistently wet weather, which is the greatest problem for spring-planted annual crops, was not a problem. A sorghum planting in southern Alabama was delayed because of the record-setting drought in that region.

Table 3. Average number of attempts required to attain adequate stands of lignocellulosic crops

Crop	Southeast		Midwest-Lake States		
	Auburn	Va. Tech	Cornell	Geophyta	Purdue
Annual grasses					
Pearl millet	1.0				
Rye	1.0			1.0	1.0
Sweet sorghum	1.0			1.0	1.0
Sorghum x sudangrass		1.0			
Sudangrass				1.0	
Perennial grasses					
Smooth bromegrass			2.2[a]	a,c,d	
Bermudagrass	1.0				
Weeping lovegrass		1.0			
Tall fescue	3.4[b]	1.2[a]		4.0[a,c]	1.8[b]
Switchgrass	1.2[b]	1.0	1.8[a]	2.0[c]	1.3[b]
Reed canarygrass				2.6[c]	2.3[b]
Timothy				2.0[a,c]	
Johnsongrass	1.0				
Perennial legumes					
Crownvetch		1.8[a,b]	.0		
Flat pea		1.8[a,b]	2[a]		
Sericea lespedeza	2.5[b]	1.9[a]			
Birdsfoot trefoil		1.3[a]		2.0[a]	1.0
Lupine	b				
Alfalfa			2.2[a]	2.0[a]	1.0
Sweet clover	2.0[b]				
Red clover	1.0				
Crimson clover			1.5[a]		
Arrowleaf clover	2.0[b]				
Vetch	1.0				
Other					
Kale			1.3		

[a]Establishment failure primarily due to winter damage and frost heaving.

[b]Establishment failure primarily due to drought conditions.

[c]Establishment failure primarily due to unfavorable soil structure and crusting.

[d]Unable to establish adequate stands.

The perennial crops exhibited a broad range of establishment success (Table 3). Soil characteristics related to wetness and texture and meteorological factors related to drought and winter freeze-thaw cycles had the greatest effect on establishment of perennial crops. On chronically wet sites, such as the Geophyta sites and the Halme and Willsboro sites in the Cornell project, winter frost heaving, the result of alternate freezing and thawing, caused upheaval of the roots of newly planted crops. Especially hard-hit were the slowest growing crops, such as flat pea, alfalfa, and smooth bromegrass, probably due to their inability to develop a root system sufficient to deter upheaval. At the Geophyta sites, the heavy clay soils formed a thick crust that inhibited emergence of crops that failed to emerge while the soil surface remained wet. Alfalfa, birdsfoot trefoil, and smooth bromegrass emerged before the crust had fully formed. Fescue and timothy seed persisted in the crust for 33 d and emerged after the next rain. Switchgrass and reed canarygrass did not emerge. It is likely that the delayed emergence due to soil crusting contributed to the frost-heave problems encountered at Geophyta later that winter.

On sites without wetness problems, the greatest deterrents to establishment were drought conditions and winter kill. The continuing drought in the Southeast severely hampered establishment of the lignocellulosic crops in Alabama and Virginia. In addition, warm fall weather in the Southeast did not allow the plants to acclimate for the winter, and an abrupt cold snap in December severely damaged many of the plots at Auburn and Virginia Tech.

These experiences suggest several recommendations for establishing lignocellulosic crops. For excessively wet soils, fall planting must be completed early so that the root systems have time to develop and thereby minimize frost heaving. In addition, the crusting problems encountered at Geophyta indicate that no-till cultivation methods may be the preferable method for planting crops on wet soils.

3.4 CROP PRODUCTIVITY

The productivity of annual crops exceeded those of the perennial crops established in 1985. Annual crops express their maximum growth potential, modified by meteorological and edaphic factors, each year. In contrast, perennial crops require one or more years for establishment before they can express their maximum growth potential. Therefore, comparison of annual and perennial crop productivities must be postponed until data for the 1986 growing season are available.

Annual Crops

Except for the kale grown at three Cornell sites, all of the annual crops currently being grown as part of the HECP screening effort are grasses. Sweet sorghum exhibited the greatest productivity of the annual grasses tested, with dry matter yields in excess of 25 dry Mg/ha in Alabama and Indiana (Table 4). Pearl millet and sorghum x sudangrass hybrids

Table 4. Maximum productivity (dry Mg/ha) of summer annual grasses during calendar year 1985

	Site		
Species	Auburn	Va. Tech	Purdue
Pearl millet	16.4	-	-
Sweet sorghum	25.6	-	25.3
Sorghum x sudangrass	17.6	12.9	20.4

followed with dry matter yields of 16.4 Mg/ha and from 12.9 to 20.4 dry Mg/ha, respectively. These yield values are very encouraging because many of the sites are marginal and optimum management practices for energy crop production are as yet undefined. These annual crops will primarily be grown as the summer component of a double-cropping system. Rye grown as the cool-season component of double-crop systems with sweet sorghum yielded 4.3 dry Mg/ha in Indiana and 4.7 Mg/ha in Alabama (Table 5). In Alabama, combinations of rye with vetch, arrowleaf clover, sweet clover, and lupine yielded an average of 4.8, 5.5, 7.8, and 4.7 dry Mg/ha, respectively, as the cool-season component of double-crop systems with mullet or sweet sorghum (Table 5).

Perennial Crops

Perennial grass and legume crops seldom exhibit maximum annual productivity in their establishment year. The yield results from the 1985 growing season must be interpreted with that fact in mind. Nevertheless, there were excellent yields from some summer perennial crops in their establishment year. Johnsongrass produced 10.8 dry Mg/ha, and switchgrass and sericea lespedeza produced greater than 5 dry Mg/ha at some Alabama sites in their establishment year (Table 6). It is anticipated that significantly greater yields will be measured in subsequent years. Because cool-season grasses and legumes usually require one full year before their first harvest, discussion of the results of that part of the screening effort will be deferred until next year.

Fertilizer Responses

It is anticipated that fertilizer applications will be the most cost-effective input for maximizing the economic return on many of the potential herbaceous energy crops. Preliminary results indicate that most of the candidate energy crop species being considered by the HECP respond positively to addition of nitrogen or N-P-K fertilizers. Yields of sorghum x sudangrass hybrids and switchgrass were increased significantly by additions of nitrogen fertilizers up to 200 kg/ha in Indiana (Figs. 5 and 6, respectively). Similarly, kale yields were increased on a Mardin soil from 5.7 to 9.1 Mg/ha with the addition of the equivalent of 112 kg/ha of N-P_2O_5-K_2O fertilizer (Fig. 7). Perennial legumes were the only crops that consistently did not exhibit productivity increases due to fertilizer applications. The productivities of both alfalfa (Fig. 8) and birdsfoot trefoil were not affected by potassium applications; because legumes can fix atmospheric nitrogen to satisfy most of their nitrogen needs, potassium is the nutrient most often limiting to growth. The cost-effectiveness of fertilizer applications will be determined in the economic assessment component of research scheduled for upcoming years.

Table 5. Mean double-crop yields (dry Mg/ha) for energy-crop combinations in Alabama and Indiana

Crop: Warm season	Crop: Cool season	Number of sites[a]	Warm-season yield	Cool-season yield	Annual yield
		Auburn			
Pearl millet	Rye + vetch	4	13.2	4.8	18.0
Pearl millet	Rye + arrowleaf clover	2	12.7	5.5	18.2
Sweet sorghum	Rye + lupine	3	19.1	4.7	23.8
Sweet sorghum	Rye + sweet clover	4	16.9	7.8	24.7
		Purdue			
Sweet sorghum	Rye	4	22.2	4.9	27.1
Sorghum x sudan	Rye	4	16.4	4.6	21.0

[a]There were four replications at each site.

Table 6. First-year production (dry Mg/ha) of warm-season perennial crops at southeastern U.S. research sites

Species	Site: Auburn	Site: Virginia Tech
Grasses		
Bermudagrass	1.9	a
Weeping lovegrass	3.8	
Switchgrass	5.7	3.5
Johnsongrass	10.8	a
Legumes		
Sericea lespedeza	5.6	b

[a]Crop not grown at this site.
[b]Crop was established, but growth was not sufficient to warrant harvesting.

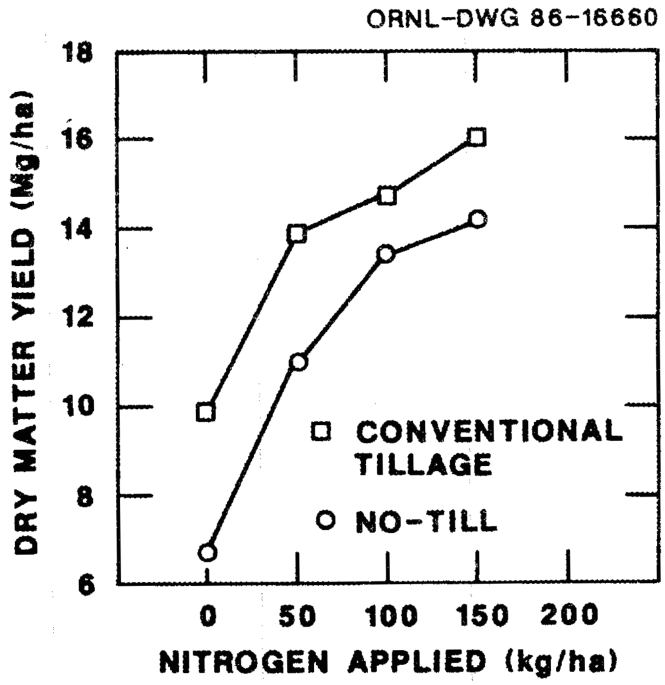

Fig. 5. Yield response of sorghum x sudangrass to nitrogen fertilizer in Indiana (1986).

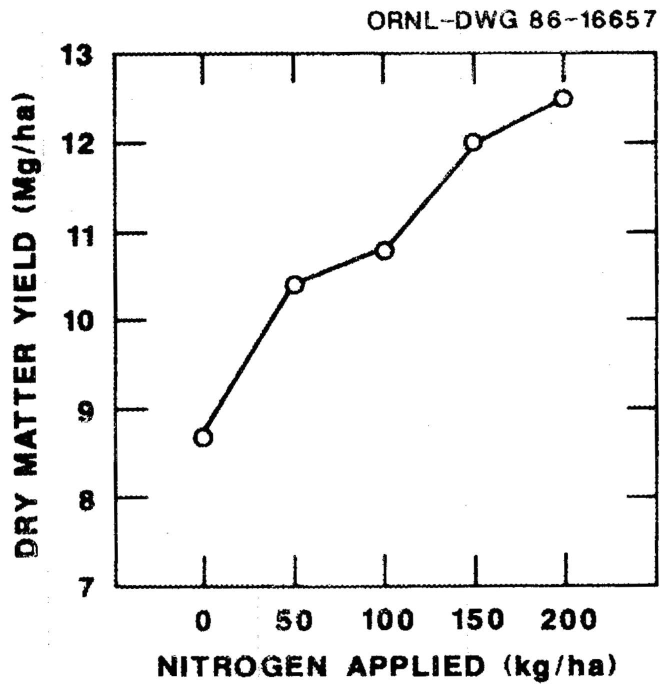

Fig. 6. Yield response of switchgrass to nitrogen fertilizer in Indiana (1986).

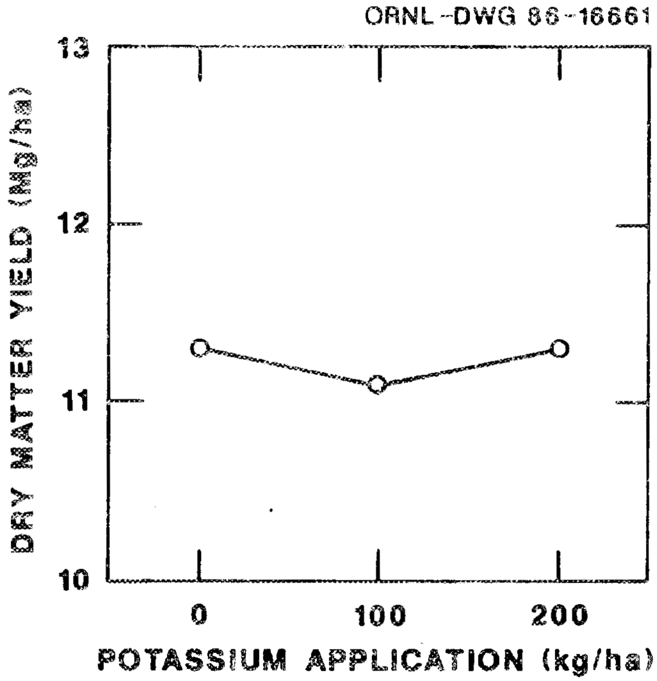

Fig. 7. Yield response of kale to fertilizer on a Mardin soil in west-central New York (1985).

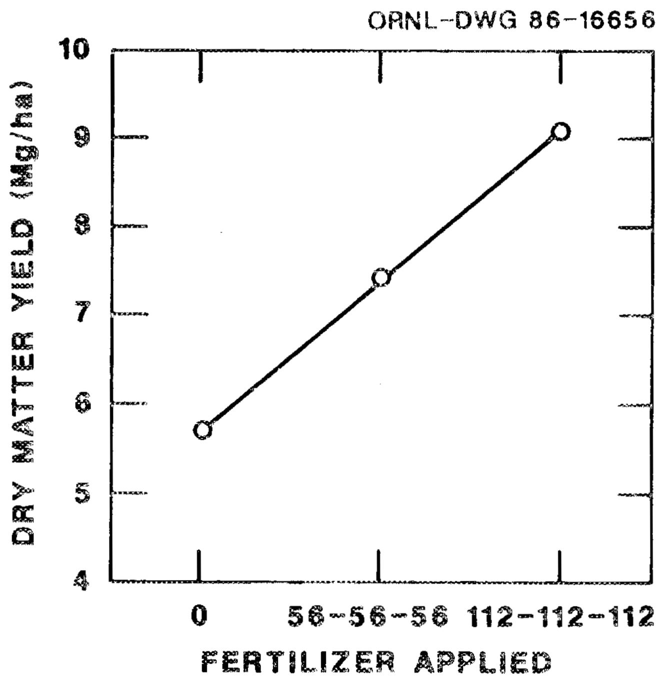

Fig. 8. Yield response of alfalfa to potassium fertilization at four research sites in Indiana (1986).

Chemical Yields

Chemical yields of potential energy crops are available for two annual grasses grown at research sites in Indiana (Table 7). Cellulose, hemicellulose, and nonstructural carbohydrates constituted the highest chemical fractions, followed by lignin and protein. There were statistically significant differences in composition between sweet sorghum and sorghum x sudangrass hybrids. Assuming yields of 20 dry Mg/ha for sorghum x sudangrass hybrids, chemical yields of 6.6, 5.4, and 2.4 dry Mg of cellulose, hemicellulose, and nonstructural carbohydrate per hectare can be expected. These calculations do not take into account the contribution that would be expected from the winter component of a double-crop system.

Tillage Responses

The differences in productivity and response to nitrogen fertilizer of sorghum x sudangrass hybrids under two tillage regimes are shown in Fig. 5. Productivity was greater under conventional tillage, but the response to nitrogen fertilizer was approximately equal under both regimes.

3.5 CROP GROWTH MODELING

Because it is unreasonable to screen all potential crops under all combinations of growth conditions, it is expedient to develop growth models capable of predicting responses of energy crops to different meteorological and crop-management factors. Crop modeling efforts are being initiated at Cornell and Purdue.

The model being developed at Cornell incorporates meteorological and physiological parameters to predict the increase in standing crop over time. Crop responses for different harvest and fertilizer scenarios can be superimposed on the model so that interactions between weather and management practices can be simulated. Physiological response data for sudangrass are being adapted to a model that has been successfully developed and validated for alfalfa.

At Purdue, a spreadsheet growth model for switchgrass is in the validation stage. The model closely follows the GROWIT model, except that senescence has been added as a major factor in the model. Because optimal production of herbaceous energy feedstocks may involve harvesting at frequent intervals, as opposed to forage crops which may be harvested infrequently and before maturity, models that ignore senescence would tend to overestimate harvestable material for late harvests. Using 1983 production data for switchgrass, the model simulated the response of switchgrass to levels of nitrogen fertilization within ±10%. Continuing efforts include adapting the model to second-cutting growth responses, which differ from first-cut responses because the elevated growing point of switchgrass is removed in the first cut.

Table 7. Chemical yield[a] (dry Mg/ha) of two warm-season annual grasses

	Species	
Yield component	Sweet sorghum	Sorghum x sudangrass
Cellulose	5.2	6.6
Hemicellulose	4.4	5.4
Nonstructural carbohydrates	4.5	2.4
Lignin	1.0	1.3
Protein	0.6	0.7
Other	4.3	3.6

[a]Assumes a yield of 20 Mg/ha.

3.6 SOIL RESOURCE INVENTORY

Progress in resource inventories centered on activities at Cornell and Virginia Tech during FY 1986. At Virginia Tech, intensive soil sampling in the lignocellulose production plots was conducted so that specific characteristics that affect crop growth can be identified. In those studies, fragipans, stone lines, and associated lithologic discontinuities that may pose significant limitations on rooting were detected in Appling soils. An example of variability encountered in eroded or erosion-prone soils is shown in Fig. 9. Davidson soils varied in both surface soil and solum depth, primarily because of differences in slope and prior erosion. The Cecil soils were the shallowest, indicating severe erosion in the past, and also showed evidence of subsurface discontinuities. Detailed examination of relationships between soil properties and plant performance at these sites will identify the soil factors that limit plant growth on marginal crop lands. This research will ultimately provide recommendations for activities that will tend to improve the qualities of soils that are classified as marginal for crop production.

The research activities at Cornell approach the topic of soil inventory on a regional basis. A geographic information system approach is being used to prepare an inventory of lands in the Northeast and the Lake States that are suitable for herbaceous biomass production. A crop-specific matching procedure will then be used to correlate crop growth requirements with soil characteristics for the crops being considered for herbaceous energy feedstocks. Using the matching procedure, additional crops can be assessed rapidly and at little additional expense.

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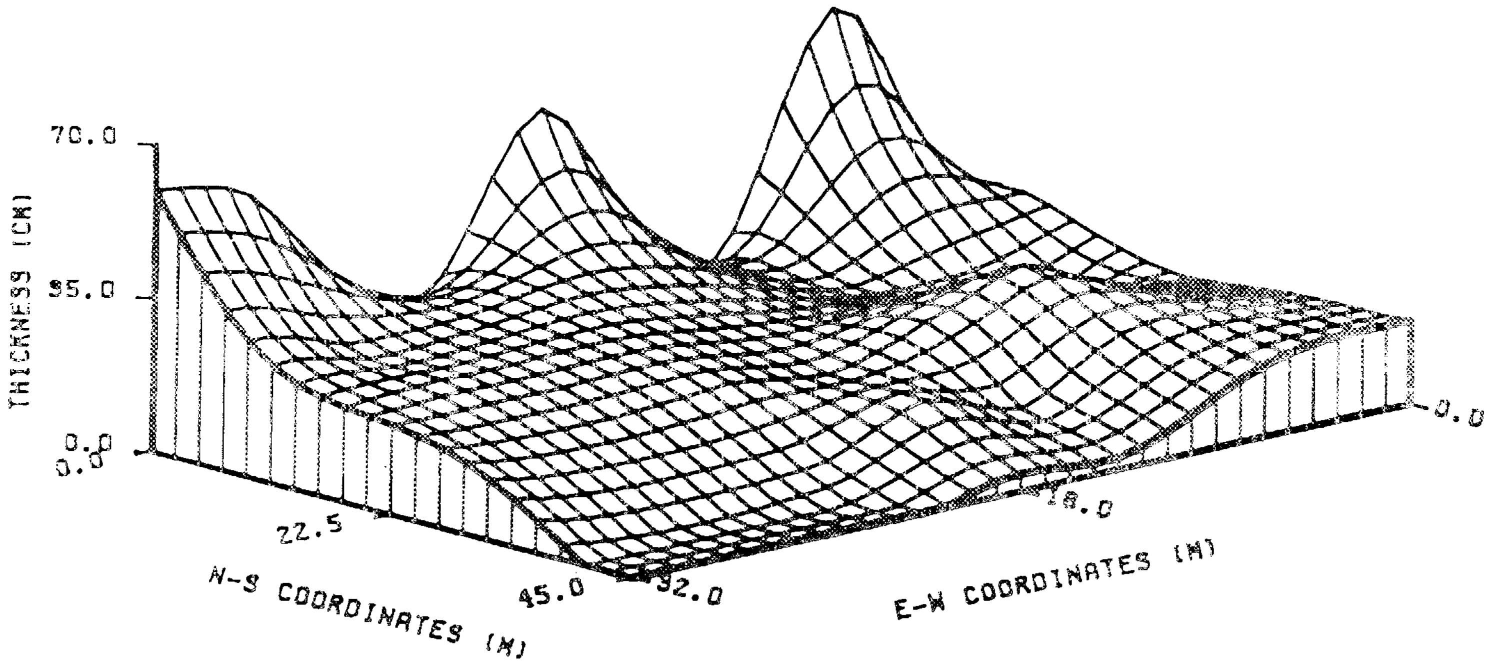

Fig. 9. From this isometric representation of the topsoil thickness at a Lunenburg County, Virginia, research site (Appling sandy loam), high soil-related variability in plant productivity would be predicted because topsoil thickness is often strongly correlated with plant growth performance.

4. OILSEED CROPS

After gasoline, the largest share of the petroleum end-product market is accounted for by middle distillate fuels (diesel and home heating oil). The primary liquid fuels expected to be produced from lignocellulosic crops are alcohols (ethanol and methanol), which make poor substitutes for middle distillates. However, vegetable oils have fuel characteristics very similar to middle distillates and, thus, make good substitutes.

The goal of the HECP work on oilseeds is to produce a substitute for diesel that is competitively priced with diesel. Currently, the cost goal is to produce rapeseed oil at $0.26 to $0.40/L ($1 to $1.50/gal). Some vegetable oils, including rapeseed, require little if any additional processing after being extracted from oilseeds. The degree of postextraction processing is the focus of some research (diesel engine testing and transesterification) at the University of Idaho that is not funded by HECP.

Rapeseed was chosen as the focus of the oilseed effort because it is not widely grown or researched in the United States but is highly productive in other parts of the world, particularly Europe. There is substantial potential to make advances in its production potential. Additionally, it is a winter crop that can be double-cropped in some areas of the United States, which makes the economics of its production potentially very attractive.

In cooperation with the Agricultural Research Service of the U.S. Department of Agriculture, industry, the University of Idaho, and the University of Georgia, HECP is pursuing research on developing winter rapeseed (Brassica napus) as a diesel fuel substitute. At the University of Idaho, research has been under way since December 1978 and focuses on winter rapeseed breeding, field testing, diesel-engine testing, production of methyl ester of rapeseed oil by transesterification, and coordinating nationwide trials of winter rapeseed varieties. Results of this research are summarized in a report issued by the University of Idaho (Auld et al. 1986). Projects at the University of Idaho supported by the HECP involve plant breeding and the nationwide variety trials. Research at the University of Georgia supported by HECP focuses on cultural management practices for winter rapeseed as a double-crop in the southeastern United States and on small-scale extraction of vegetable oils using carbon dioxide as a solvent.

The HECP seeks to develop vigorous, well-adapted, winter rapeseed cultivars that yield between 2800 and 5400 kg/ha of seed (containing 45 to 49% vegetable oil). This yield would provide between 1265 and 2640 L/ha (135 and 282 gal/acre) of diesel-fuel substitute. Much of the research is focused on the Southeast because winter rapeseed has good potential there as a winter double-crop. The University of Idaho breeding projects, the University of Georgia production and harvest research at Tifton, Georgia, and the National Winter Rapeseed Variety

Trials all support the aim of producing vigorous well-adapted winter rapeseed cultivars.

At the University of Idaho, three winter rapeseed breeding projects are funded by HECP: (1) breeding atrazine resistance in winter rapeseed; (2) breeding Canola-quality winter rapeseed adapted to double-cropping in the southeastern United States with oil less than 1% erucic acid and meal with less than 0.3% glucosinolates; and (3) breeding dwarf lines of winter rapeseed. Winter rapeseed lines are classified as edible, industrial, or fuel, but the oil produced by any line can be used as a diesel fuel. Lines that can be used for food or fuel must contain less than 1% erucic acid in the oil and will also be selected for less than 5% linolenic acid. Lines suitable for industrial as well as fuel uses will contain between 48 and 62% erucic acid and less than 5% linolenic acid. Lines useful only as fuel will contain high levels of monounsaturated acids (18:1, 20:1, 22:1) without meeting the criteria for either edible or industrial lines.

Development of atrazine-resistant rapeseed cultivars began in May 1984, when 13 elite winter rapeseed lines were crossed with Triton, one of the first spring rapeseed cultivars developed that produces edible oil and low glucosinolate meal and carries the cytoplasmic gene for atrazine resistance. Atrazine resistance will allow atrazine to be used to kill other undesirable members of the genus Brassica that occur as weeds. During FY 1986 the first backcross (BC_1) and the second backcross (BC_2) were made. This work is expected to culminate in 1989 with the release of atrazine-resistant cultivars.

Development of Canola-quality winter rapeseed for the southeastern United States also began in May 1984, using the crosses of Triton and six of the elite edible winter rapeseed lines. Evaluation of fall-planted spring and winter rapeseed at Tifton, Georgia, over the winter of 1984-1985 indicated that cultivars with intermediate levels of winter hardiness that would flower after only two or three weeks of vernalization were desirable. A longer vernalization period leads to a later start in spring growth resulting in a later harvest and greater pest problems. Rapeseed grows better in cooler weather. A May harvest is required for double-cropping. In FY 1986 the F_3 generation was screened at Tifton for winter survival, adaptation to the Southeast, and early flowering. Based on this screening, 66 lines were selected for further evaluation at Moscow, Idaho, over the spring and summer of 1986. Screening was done for fatty acid content (i.e., erucic acid and linolenic acid) and glucosinolate content. This research should culminate in May 1988 with the release of elite F_5 lines and polycrosses as commercial cultivars.

Winter rapeseed has a low ratio of seed to total plant biomass (harvest index). Developing dwarf varieties will increase seed yield and also reduce lodging which results in loss of yield. Development of dwarf wheat varieties is one of the major ways in which wheat yield has been improved. Development of dwarf cultivars of winter rapeseed began in April 1986 with the crossing of Mikado, a dwarf cultivar from Europe, and

16 elite lines of edible and industrial winter rapeseed. Five of the elite lines are BC_2 progeny which carry atrazine resistance.

The University of Idaho coordinates agronomic field trials known as the National Winter Rapeseed Variety Trials (Fig. 10). Winter rapeseed is planted either in the fall or late summer and harvested either in spring or early summer. Therefore, results of the 1985-1986 trials are not yet available. Results from the 1984-1985 trials are summarized in Table 8. As can be seen from the table, yields varied considerably among locations and also within locations. The severity of winter weather and the speed with which temperatures fall during fall and winter can have a great impact on yields. Experience gained from these trials is useful feedback for the rapeseed breeding work.

The production and harvest practices for winter rapeseed grown as a winter double-crop in the southeastern United States are being examined by the University of Georgia in a project at Tifton, Georgia. Three varieties of rapeseed are being grown: Dwarf Essex, a winter variety; Westar, a summer variety; and Cascade, one of the edible winter varieties developed by the University of Idaho. Three planting dates were used: October 14, October 25, and November 8. (The weather is mild enough in south Georgia that a summer variety can be grown over the winter. The difference between a summer and winter variety is that winter varieties require a vernalization period [i.e., certain number of days below $40^{o}C$, before they will set seed]). On the three experimental plots, 1684 kg/ha of 15-0-15-15 ($\%N-\%P_2O_5-\%K_2O-\%S$) were applied.

Yields and harvest dates of the three winter rapeseed varieties harvested in 1986 as well as those of Dwarf Essex and Westar during 1985 are shown in Table 9. Yields decreased in both years because the harvest date was delayed to allow crops to mature. The winter of 1985-1986 was milder than the winter of 1984-1985, which accounts for much of the higher yield and earlier harvest date. The harvest dates for Westar in 1986, April 25 to May 10, are quite acceptable for double-cropping. The May 20 to May 30 harvest dates for Cascade are marginal. Cascade has about a 4-week vernalization requirement. If a 2-week vernalization requirement can be developed for winter rapeseed, then harvest can occur earlier than that for Cascade and can better facilitate double-cropping. Because of the later planting date, peanut yield following Dwarf Essex (555 kg/ha) was substantially lower than peanut yield following Westar (3450 kg/ha). These yield data indicate the importance of breeding for early rapeseed maturity. Florunner peanuts were planted on June 4, 1986, following Westar and the early-planted (October 14) Cascade, and Spanish peanuts were planted on June 24, 1986, following the late-planted (November 8) Cascade and Dwarf Essex.

Observations indicate that stand establishment and harvesting techniques need to be improved. These research avenues will be pursued in the coming year.

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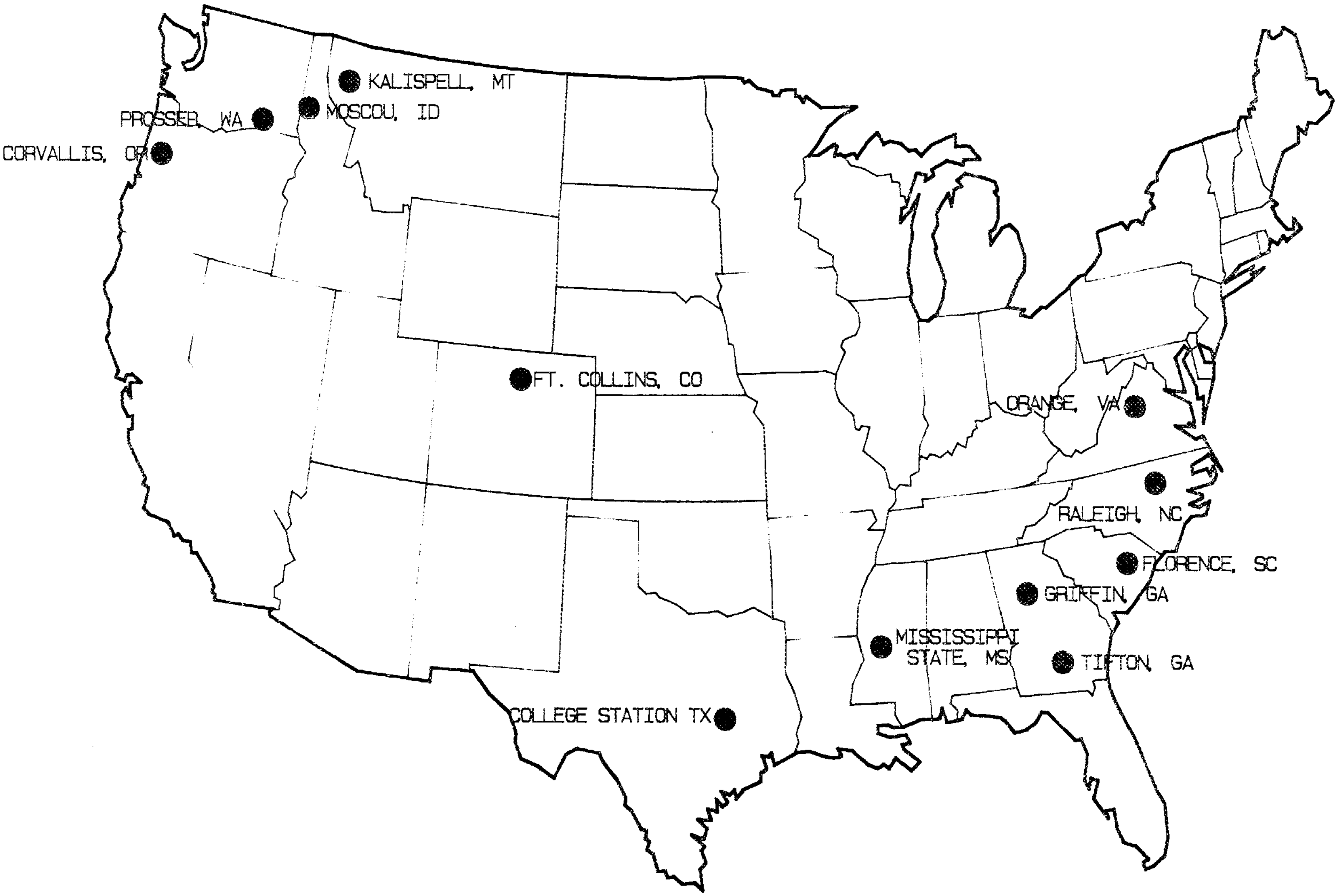

Fig. 10. Locations of National Winter Rapeseed Variety Trials 1986-1987.

Table 8. Yields (kg/ha) from 1984-1985 National Winter Rapeseed Variety Trials

Location	Mean seed yield	Range of seed yield
Moscow, Idaho[a]	2686	1722-3727
Moscow, Idaho[a]	3688	2894-4289
Kalispell, Montana	2868	2151-3364
Ritzville, Washington	2576	1712-3380
Prosser, Washington[b]	2753	1641-4749
Mississippi State, Mississippi	2201	1188-3341
Colby, Kansas	590	305-917
Monitor, Indiana	5745	3765-8267
Florence, South Carolina	830	313-1379
Griffin, Georgia1564	1076-1902	
Orange, Virginia[c]	-	None

[a]Two test blocks were used at Moscow because the number of varieties tested would not permit uniform enough conditions in one large block.

[b]Dryland plot not harvested because of severe wind damage after swathing. Irrigated plot was harvested.

[c]No harvest taken because of severe freeze damage and winterkill.

Table 9. Harvest dates and yields from rapeseed-peanut double-cropping at Tifton, Georgia

	1984-1985		1985-1986		
	Westar	Dwarf Essex	Westar	Dwarf Essex	Cascade
Harvest date	5/20-31	6/10-6/20	4/25-5/10	6/5-6/15	5/20-5/30
Rapeseed yield (kg/ha)	900-1700	90	1700-1900	150-900	550-1350
Peanut yield (kg/ha)	3450	555	b	b	b
Total diesel equivalents (L/ha)[a]	1960-2320	290	b	b	b

[a]Assumes rapeseed and peanut oils have 90% of fuel value of diesel and are 45% oil and that rapeseed oil weighs 0.90 kg/L.

[b]Not available at report time.

The University of Georgia at Athens is examining small-scale extraction of vegetable oil using carbon dioxide as a solvent. Data have been gathered on solubility isotherms and on the effects of particle size, oilseed preparation, temperature, and pressure; kinetics of solvent flow rates; and recycle of carbon dioxide solvent. Tests indicate that a vertical reactor with a downward solvent flow holds the greatest promise for the efficient recovery of peanut oil using carbon dioxide.

5. EXPLORATORY RESEARCH

Exploratory research includes a number of projects of interest to the HECP that do not fit conveniently into the major areas of research emphasis. These projects, which include productivity of wetland systems, physiology and biochemistry of hydrocarbon production in semiarid plants, development of methods for regenerating sorghum plants from tissue culture, and productivity and nutrient cycling of old-field successional vegetation, will be discussed individually below.

5.1 WETLAND PRODUCTIVITY

Previous research has shown that characteristics of *Typha* spp. show considerable potential for its use as an energy crop (Pratt et al. 1984). Yields up to 30 dry Mg/ha have been demonstrated in planted stands (Pratt et al. 1984). Approximately 50% of the total biomass is in the form of an extensive rhizome system that contains 40% fermentable carbohydrates. Most of the remainder of the plant is cellulosic. *Typha* spp. grow naturally in monocultures in wetlands that are not used for other agricultural activity. In Minnesota alone, there are over 4×10^6 ha of wetlands capable of growing *Typha* spp. (Pratt et al. 1984). Current research at the University of Minnesota involves two efforts, sustained productivity and water-use efficiency.

Sustained Productivity

To assess the long-term productivity of *Typha* spp. under various harvesting scenarios, four experiments are being conducted. Three of the experiments involve planted, managed stands and the other involves a natural stand. Diversities of soil type, climatic conditions, water level, and *Typha* species are represented in the experiments so that results will be applicable to a range of applications. Three harvesting scenarios are being studied: (1) a single annual aboveground harvest (October), (2) semiannual aboveground harvests (July and October), and (3) an annual aboveground harvest with biennial belowground harvest (both in October).

Two of the experiments, located at Aitken, Minnesota, are being conducted in managed stands that differ in soil type, species, and harvest scenario. The first uses a stand of mixed *Typha* spp. growing on a peat soil. Because all of the harvest scenarios are represented in this experiment, its results will be highlighted in the discussion that follows. The other Aitken experiment, which uses a pure *T. angustifolia* stand growing on a mineral soil, compares the effects of machine versus hand harvesting. The third experiment in which planted stands are used is located at Crookston, Minnesota. This experiment compares the effects on productivity of annual aboveground harvests versus unharvested stands. The natural stand located at the Twin Cities Army Ammunition Plant, New Brighton, Minnesota, differs from the managed stands in its lack of any method for water control. High water levels in October 1985 forced postponement of the natural stand harvest until entry could be made on the frozen surface during winter.

Productivity in all plots declined during the 3-year duration of this experiment (Table 10). Because control plots responded similarly, it must be presumed that the decline was independent of the treatments that have been applied. Comparison of productivities between plots that were land and machine harvested annually indicates no negative effects of the machine harvests. Cumulative yields differed less than 5% between the two harvest regimes over 3 years. It is apparent that annual biomass removal did not reduce Typha productivity after 3 years.

Although the 3-year cumulative yield was greater in plots harvested twice annually, the long-term effect of this harvesting scenario is probably negative. Yield from the midseason harvest in 1985 was approximately double that from annually harvested plots (Table 10). The reason(s) for this high yield is not currently known. Following the 1985 midseason harvest, subsequent yields in the semiannually harvested plots have been approximately one-half of those harvested annually, and regrowth for fall harvest following midseason harvests was minimal in 1985 and 1986.

The rhizome harvest, conducted in the fall of 1984, reduced regrowth in 1985. Shoots were shorter and weighed less than those from plots that experienced shoot harvests only. Samples of belowground biomass in the fall of 1985 indicated that plots harvested belowground had recovered to preharvest levels. It was also observed during the 1986 growing season that shoot density in belowground-harvested plots was approaching that of other plots. Data from the 1986 belowground harvest were not yet available at the time of this writing (October 1986), so complete assessment of this methodology must be deferred.

To summarize the preliminary results of the sustained productivity experiments, it appears that a single fall harvest of aboveground biomass is preferable to two harvests per year, although the timing of the midsummer harvest may be of great importance to this conclusion. Machine harvesting did not negatively impact productivity. Belowground harvests reduced aboveground productivity in the year following harvest, but shoot density and belowground biomass recovery indicate that aboveground productivity may recover after 2 years.

Water-Use Efficiency

The second effort in the wetland systems project is a study to determine the water requirements of Typha spp. Although Typha spp. grow in wetlands where water is normally abundant, the water table is important in determining the types of harvest equipment that can be used and the timing of the harvests. In managed stands with methods of regulating water levels, expenses related to maintenance of water

Table 10. Annual productivity (Mg/ha) of *Typha* harvested over a 3-year period

Harvest scenario	Year 1984[a]	1985	1986	3-year total
Control[b]	5.96	4.21	3.90	14.07
Annual harvest				
Hand	5.48	4.66	4.42	14.56
Mechanized	5.40	5.52	3.85	14.77
Semiannual harvest[c]				
Midseason	--	8.68	1.54	
Regrowth	6.53	0.43	0.43	
Total	6.53	9.11	1.99	17.63
Annual aboveground and biennial belowground harvest				
Aboveground	7.06	3.77	2.07	
Belowground	3.77	--	N/A[d]	
Total	10.83	3.77	N/A	

[a]Shoots from prior years and weeds added 3.5 Mg/ha to the aboveground measurement in addition to that reported.

[b]The harvested area in control plots measured 1 m^2. Samples were taken from plots from which biomass was not removed during the duration of the experiment. Productivity of control plots provide a measure of growth independent of any harvesting beyond the removal of these small samples.

[c]Mean of mechanized and hand harvests.

[d]N/A means not available.

levels may be avoidable if the plants can continue high levels of productivity with lowered water tables. To determine the levels of water necessary to maximize productivity, experiments are under way to study the effects of different water management strategies on productivity, water-use efficiency, and rates of evapotranspiration.

An experiment using artificial paddies was begun on the University of Minnesota, St. Paul, campus in 1985. Two Typha species (T. angustifolia and T. latifolia) and their hybrid (T. X glauca) were grown under three different water management scenarios (constant flooding, saturated soil, and midseason drawdown). The results of this experiment indicate that continuous flooding is optimal for biomass production but incurs the greatest expense in water usage. Saturated soil may decrease water usage without incurring a large sacrifice in biomass production. Dropping the water level to 45 cm below the soil surface at midseason caused significant productivity reductions. The results of the experiment encourage a harvesting scenario that requires minimal drawdown of groundwater.

5.2 HYDROCARBON PRODUCTION

Latex-bearing plants such as Euphorbia lathyrus produce hydrocarbons that, with extraction and some refining, may be used as a liquid fuel. Unfortunately, efforts to increase the production of hydrocarbons in these plants to economically viable levels have been unsuccessful (Kingsolver 1982). The recent advances in biotechnology show promise for providing techniques that could be used to enhance hydrocarbon production in plants. However, before genetic manipulations can be used to create plants that produce greater amounts of hydrocarbon compounds, the physiology and biochemistry of hydrocarbon production must be more fully understood.

The goal of the hydrocarbon production project at Lawrence Berkeley Laboratory is to develop a sufficient understanding of the processes involved in hydrocarbon production so that plants or their environment can be manipulated to enhance energy feedstock production. HECP-funded research addresses two approaches for attaining that goal: (1) increasing the allocation of photosynthate to hydrocarbon synthesis pathways, and (2) defining the pathways and enzyme systems that are responsible for hydrocarbon synthesis. Euphorbia lathyrus, a plant that produces a hydrocarbon-rich latex, is being used as the test species in both approaches.

Environmental Regulation

Hydrocarbon biosynthesis represents only one of many carbon sinks in plants. If means could be found to alter the patterns of photosynthate allocation, plants could be manipulated to produce increased amounts of selected chemicals of economic importance. Experiments are in progress to determine how plants, specifically E. lathyrus, alter patterns of carbon allocation in response to environmental stresses, with an emphasis on pathways that lead to hydrocarbon biosynthesis.

Experiments were conducted to determine the responses of E. lathyrus to water and salinity stresses. The rationale behind these experiments was that the stresses would decrease growth processes such as cell division and expansion before the rate of photosynthesis was affected. Therefore, the plant would have photosynthate available for allocation to storage pathways, which are dominated by those for carbohydrate and hydrocarbon compounds. Plants were grown hydroponically in growth chambers at osmotic stress levels equivalent to 25 to 100 mM of NaCl. Polyethylene glycol and NaCl were used in the water and salt stress experiments, respectively.

Results indicated that both stresses induced increased allocation of photosynthate to storage compounds at the expense of structural components. In one of the water stress studies, the hydrocarbon content (heptane fraction) increased 50%, while the sugars and amino acids (methanol fraction) and the dry weights were not significantly affected (Table 11).

In salt stress experiments, even low levels of salinity (25 mM NaCl) caused reduced growth (Table 12). Salinity at 50 mM NaCl concentration caused a slight increase of the proportion of photosynthate allocated to hydrocarbons and a larger increase in the proportion allocated to sugars and amino acids, when compared to the control treatment. Although the reduced growth of plants exposed to the salinity stress treatments offset the increased proportion of photosynthate allocated to the hydrocarbon and sugar-amino acid fractions, the pattern of allocation was altered and both systems (water and salt stress) will be useful in mechanistic studies to determine ways to manipulate the enzymatic controls that influence allocation patterns.

Enzymatic Regulation

Research to identify the structures and enzymatic systems responsible for the allocation of carbon to the hydrocarbon fraction in E. lathyrus plants continued during FY 1986. The six major hydrocarbon components of latex were identified: lanosterol, 2,4-methylenelanosterol, cycloartenol, 24-methylenecycloartenol, euphol, and butyrospermol.

Research to determine the role of hydroxymethyl glutaryl coenzyme A reductase (HMGR) in hydrocarbon biosynthesis continued during FY 1986. From a comparison of the reaction rates of the steps in hydrocarbon synthesis from acetate, the conversion of hydroxymethyl glutaryl coenzyme A (HMG-CoA) to mevalonic acid (MVA) was identified as the probable rate-limiting step. HMGR is the enzyme responsible for the catalysis of that reaction. Current research activity includes efforts to isolate and purify the enzyme so that the reaction kinetics can be more fully understood.

Table 11. Effect of water stress on growth, chlorophyll, and selected chemical fractions of *Euphorbia lathyrus*[a]

	Treatment	
	Control	75mM PEG[b]
Dry weight (g)	17A(100.0)[c]	15A(100.0)[c]
Chlorophyll (mM/mm^2)	0.698A	0.705A
Hydrocarbon (g) (heptane fraction)	1.02A(6.0)	1.35B(9.0)
Nonstructural carbohydrate (methanol fraction)	4.08A(24.0)	3.80A(25.3)
Residual	11.90(70.0)	9.85(65.7)

[a]Means in a row that are followed by the same capital letter are not significantly different (P = 0.05).
[b]PEG = polyethylene glycol.
[c]Percent of dry weight in parentheses.

Table 12. Effect of salinity on growth, chlorophyll, and selected chemical fractions of *Euphorbia lathyrus*[a]

	Treatment		
	Control	25mM NaCl	50mM NaCl
Dry weight (g)	26.1A(100.0)[b]	14.9B(100.0)	17.5AB(100.0)
Chlorophyll (mM/mm^2)	0.70A	0.71A	0.69A
Hydrocarbon (g)	1.07A(4.1)	0.72B(4.8)	0.98A(5.6)
Nonstructural carbohydrate (g)	3.24A(12.4)	2.40A(16.1)	3.57A(20.4)
Residual (g)	21.8(83.5)	11.8(79.2)	13.0(74.0)

[a]Means in a row that are followed by the same capital letter are not significantly different (P = 0.05).
[b]Percent of dry weight in parenthesis.

Studies were also conducted to determine the organelle(s) on which the enzymes responsible for hydrocarbon synthesis reside. Various methods were employed to isolate particles that exhibit enzymatic activity. A major peak of sterol synthetic activity was isolated by fractionating latex by isopycnic centrifugation on Percol gradients. To date, no unique structure has been found in the region of the gradient known to carry out the conversion of MVA to sterols.

5.3 REGENERATION OF SORGHUM

The goal of the in vitro plant regeneration research at the Texas Agricultural Experiment Station at Weslaco, Texas, is to identify fundamental biological information and modify processes that are responsible for in vitro plant regeneration of sorghum (Sorghum bicolor). Callus cultures of eight agronomically important genotypes of sorghum were established through the utilization of various explant sources, callus induction media formulations, pretreatments, and incubation conditions. Following establishment, callus cultures were studied to determine biochemical/compositional, histological, developmental, and cytogenetic differences which may confer in vitro responsiveness and allow efficient plant regeneration. Activities focused on empirical investigations directed at obtaining definitive proof of responsiveness or recalcitrance of specific sorghum genotypes. Following an in-depth review of previous sorghum tissue-culture literature, attempts were made to repeat the studies that had been reported. Major discrepancies in the literature were found, including the use of questionable methods and little quantification of regeneration rates.

Three genotypes previously reported to be recalcitrant were regenerated from culture for the first time during FY 1986. MN1500 is one of the most important biomass energy types and BTx399 and RTx430 serve as parents for many of the high-yielding grain sorghums grown in the southern Great Plains.

Biochemical characterization of callus cultures were conducted in an effort to correlate responsiveness with specific chemical markers. Organogenic, embryogenic, and undifferentiated callus along with four developmental classes of immature embryos were analyzed with gel electrophoresis techniques. Results showed no qualitative differences in proteins in the different classes of embryos of the four genotypes that have been most intensively studied thus far (RTx430, CS3541, Hegari, and ATx299 X RTx430). In isozyme electrophoresis assays for esterase and alcohol dehydrogenase, no differences in alcohol dehydrogenase isozymes among the four size classes of the genotypes listed above, or among seven Hegari callus types were found. Differences in esterase isozymes were evident for the four genotypes and for some of the callus types of Hegari, suggesting that isozymes may serve as biochemical markers useful in the identification of embryogenic cultures of sorghum. Biochemical differences between embryogenic and nonembryogenic cultures could increase the understanding of processes that underlie somatic embryogenesis.

5.4 PRODUCTIVITY OF SUCCESSIONAL VEGETATION

The earliest phases in secondary plant succession of croplands are dominated by the unwanted weed species that invade and compete with crop plants. These weeds are one of the greatest problems encountered when attempting to establish crops. Their relatively fast growth, tolerance of environmental stresses, and persistence make them aggressive competitors for growth resources, and without a vigorous control program weeds become the dominant vegetation on agricultural sites. These factors make successional vegetation a potentially useful energy feedstock.

Most research on successional vegetation has been either ecologically or agriculturally oriented. In ecological research, changes in the species composition of the plant community was the primary interest. In agricultural research, the primary objective was to devise ways to control the invasion of successional vegetation. As a consequence, there is little information available concerning the production potential of successional vegetation or its responses to fertilizers or harvesting scenarios.

An experiment was established at the Oak Ridge National Environmental Research Park, Roane County, Tennessee, during the summer of 1986 to explore the possibility of using successional vegetation in abandoned fields and pastures as a source of biomass for energy production. Two types of abandoned cropland were chosen. The first was a field that had been cultivated the previous 5 years for sorghum X sudangrass, wheat (*Triticum aestivum*), and soybean (*Glycine max*) crops. The last crop was soybeans in 1984. The second site was an abandoned pasture that had been mowed occasionally over the last 10 years to inhibit the influx of woody vegetation. Each site was divided into four blocks, each with eight 3.1-m^2 plots. Four additional plots were marked on each end of both sites for establishment of tall fescue and switchgrass so that the productivity of successional vegetation could be compared with that of other lignocellulosic energy-crop candidates on the same site. Within each block, experimental treatments were randomly assigned to each plot. In the abandoned soybean field, the treatments included four fertilizer treatments and two harvest frequencies (once or twice annually) in a 4 x 2 factorial experiment. In the abandoned pasture, the treatments included two lime treatments, two fertilizer treatments, and two harvest frequencies in a 2 x 2 x 2 factorial experiment. Parameters to be measured in this experiment include total biomass production, productivity of selected individual species, changes in species composition, and plant and soil chemical compositions. Data collection from the first year's effort will be completed during November 1986.

6. ENVIRONMENTAL AND ECONOMIC ANALYSES

Four studies were completed in FY 1986: an examination of the productivity and present uses of wet soils, an analysis of the use of lignocellulosic crops for alcohol fuel production, an evaluation of the use of present oilseed extraction facilities to produce vegetable oil for use as a diesel-fuel substitute, and an evaluation of the possibility of using lignocellulosic crops for direct combustion.

Wet soils occupy about 105 x 10^6 ha in the continental United States. Wetlands are highly productive and may have the potential to contribute significantly to energy crop production. A report entitled "Productivity of Wet Soils" by C. A. Johnston surveys wet soils, their native vegetation, and present commercial agricultural uses. Between the mid-1950s and mid-1970s a net loss of 4.5 x 10^6 ha of wetlands occurred, with about 80% of the loss accounted for by conversion to agriculture. About one-quarter of major U.S. crops are grown on wet soils, and about 40% of the wet soils are cropped. Specialized crops that require wet soils include rice (wild and domesticated) and cranberries. Wet soils that are adequately drained can be particularly productive for commercial crops such as corn, soybeans, and cotton. "Muck farms" produce high-value specialty crops on organic soils.

Plants that grow well on wetlands include cattail (Typha spp.) and common reed (Phragmites australis). Both are widely adapted across the United States, and measurements of productivity have been taken in both natural and managed stands. For Typha, aboveground productivity values average up to 12 dry Mg ha^{-1} $year^{-1}$, while total productivity (both aboveground and belowground) averages up to 26 dry Mg ha^{-1} $year^{-1}$. For managed Typha stands planted in wetland fields, reported yields have been only about one-half those for natural stands. Research currently ongoing for Typha is reported in Section 5.1.

Phragmites is found throughout the United States except in seven southeastern states. It has a similar growth pattern to that of Typha, with aboveground biomass peaking in August or September. Reported rates of maximum daily aboveground productivity are greatest for any temperate wetland herbaceous species. Average net aboveground productivity in research plots is about 14 dry Mg ha^{-1} $year^{-1}$. Belowground standing crop is reported to be from 1.4 to 9.9 times higher than aboveground standing crops.

Reed canarygrass (Phalaris arundinacea) is indigenous to the temperate regions of the world and is found in all but the southernmost United States. It grows commonly on wet soils, in moist uplands, and in standing water. Mature reed canarygrass is capable of surviving up to seven weeks of spring flooding. Net aboveground productivity of unmanaged stands averages 9.5 dry Mg ha^{-1} $year^{-1}$. It is one of the species being screened as a lignocellulosic energy crop.

Other species mentioned in the report include sedges (Carex spp.), river bulrush (Scripus fluviatilis), prairie cordgrass (Spartina pectinata), and bur-reed (Sparganium eurycarpum).

As part of a fuel-alcohol technical and economic evaluation study coordinated by the Solar Energy Research Institute, a section on the production of lignocellulosic crops was contributed by the HECP. Species selected from regions that are considered to have a good potential for growing herbaceous energy crops in the eastern United States include: napier grass (Pennisetum purpureum), bermudagrass (Cynodon dactylon), sericea lespedeza (Lespedeza cuneata), switchgrass (Panicum virgatum), reed canarygrass (Phalaris arundinacea), tall fescue (Festuca arundinacea), and sweet sorghum (Sorghum bicolor) (Fig. 11). Sweet sorghum is an annual, the rest are perennials. Reed canarygrass and tall fescue are cool-season species, the rest are warm-season species. Sericea lespedeza is the only legume, the rest are grasses.

Based on a number of assumptions, the most important of which are listed in Table 13, cost estimates were made for each species in the indicated region. The yields used are hypothesized yields. The regional cost differences based on the hypothesized yields are more important than attaching cost to a particular species. In-field production cost estimates for what could be achieved in 1985 and what is possible in 2000 are presented in Table 14.

Transportation costs from the field to the alcohol conversion facility are significant. It was assumed that a 30-d supply of feedstock is maintained at the alcohol plant, with additional feedstock being stored where it was grown. Transportation costs are a function of the distance transported, which depends on the alcohol plant size, crop yield, and the density of feedstock production. Costs were calculated using a cost function of \$1.58/Mg plus \$0.0975/Mg-km one way. Two plant sizes, 95 x 106 L/year and 568 x 10^6 million L/year, and a feedstock requirement of 6 kg/L in 1985 were assumed. For the 95 x 10^6 L/year plant, transportation costs ranged from \$1.70 to \$7.82/Mg and for the 568 x 10^6 L/year plant, from \$4.09 to \$16.64/Mg.

The HECP funds research on the production of winter rapeseed for a diesel-fuel substitute. Some economically important questions regarding the availability of oilseed crushing mills to produce vegetable oil for diesel fuel were addressed in a study entitled "Assessment of Potential for Coproducing Edible and Fuel Vegetable Oil in Existing Vegetable Oil Processing Facilities" (JAYCOR 1987). The primary oilseeds grown in the United States are soybeans, cottonseed, sunflowers, peanuts, safflower, and flax. The study identified 165 mills in the United States (Table 15). Mills extract the oil in one of three ways: mechanical press, prepress plus solvent extraction, and solvent extraction. Mechanical presses are usually used in smaller facilities (100-150 Mg/d), prepress-plus-solvent extraction in moderate-sized facilities (300-500 Mg/d), and solvent extraction in the larger facilities (1000-3000 Mg/d). Solvent

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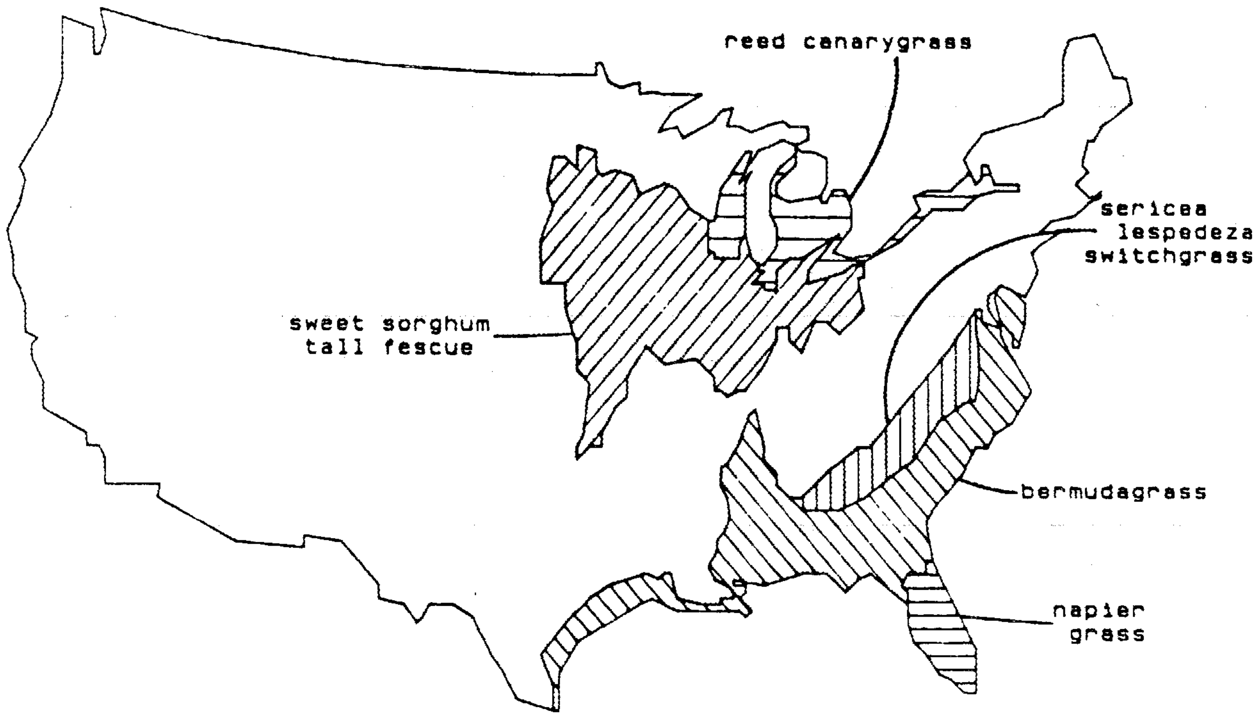

Fig. 11. Representative regions for lignocellulosic crops used in fuel alcohol study.

Table 13. Most important assumptions used in cost estimates for lignocellulosic energy crops

81 ha of a 162-ha farm in lignocellulosic energy crop

Harvest twice a year using large, round bale, haying system, except napier grass which is harvested once a year and sweet sorghum which is harvested once a year using a silage system

Fertilizer applied replaces nutrients removed in harvest
In 1985 harvested crop assumed to be 1.5%N, 0.3%P, 1.5%K
In 2000 harvested crop assumed to be 1.0%N, 0.2%P, 1.0%K
Sericea lespedeza requires no N.

Fertilizer costs \$0.53/kg N, \$.049/kg P_2O_5, \$0.19/kg K_2O

Establishment costs are \$370/ha for perennial crops, no harvest in establishment year

Storage loss of 14%

Table 14. Estimated in-field production costs for lignocellulosic energy crops

Region (crop)	1985 Hypothesized yield (Mg/ha)	1985 Cost[a] ($/Mg)	1985 Cost[a] ($/GJ)	2000 Hypothesized yield (Mg/ha)	2000 Cost[a] ($/Mg)	2000 Cost[a] ($/GJ)
Subtropics (napier grass)	18.0	42.10	2.40	27.0	29.50	1.70
Southeast (bermudagrass)	18.0	40.60	2.30	27.0	28.50	1.60
Piedmont (switchgrass)	9.0	61.50	3.50	13.5	41.40	2.40
Piedmont (sericea lespedeza)	9.0	51.30	2.90	13.5	34.60	2.00
Lake States (reed canarygrass)	12.0	49.60	2.80	18.0	34.20	2.00
Midwest (tall fescue)	15.0	49.30	2.80	22.5	34.40	2.00
Midwest (sweet sorghum)	18.0	58.20	3.30	27.0	38.80	2.20

[a]Includes no transportation cost and allows for 14% storage loss.

Table 15. Oilseed crushing mills in the United States

Primary oilseed crushed	Number of mills
Soybeans	84
Cottonseed	63
Sunflowers	8
Peanuts	8
Safflower	2
Total	165

extraction is generally used for oilseeds with less than 20% oil (soybeans and cottonseed) and press or prepress-plus-solvent extraction is used for oilseeds with higher oil contents. Most soybean mills run all year. The mills that might be available to crush oilseeds for fuel oil production are those that currently process oilseeds other than soybeans and use either mechanical presses or prepress-plus-solvent extraction technology. These mills generally do not operate all year and can be modified to handle a variety of oilseeds, such as winter rapeseed. These mills are located primarily in the southern United States, Minnesota, North Dakota, and California (Fig. 12). The number of mills in the southeastern United States is especially conducive to the establishment of a fuel oil industry with double-cropped winter rapeseed in that region.

A study entitled "Herbaceous Energy Crop Assessment for Direct Combustion Applications" by JAYCOR examined economic and technical issues associated with combusting lignocellulosic energy crops. Because biomass, in general, is a dispersed resource, the size of a facility that would burn biomass is limited by economic more than technical constraints. Transportation costs increase quickly with haul distance.

Most solid fuel combustion systems are designed for coal or wood. On a limited scale, some agricultural wastes, such as rice hulls, wheat straw, cotton gin trash, and corn cobs, have been burned at processing plants and on farms. A review of the current use of solid fuels surveys wood use excluding the forest products industry; coal use excluding electric utilities, coke plants, and residences; and agricultural wastes and residues. Most of the facilities reviewed that combust solid fuels are small, but it is thought that these are the facilities that would be most likely to combust herbaceous energy crops. The wood-burning facilities included account for less than 5% of the total wood used in the industrial, commercial, and municipal sectors, and the coal-burning facilities account for about 10% of total coal consumption in the United States. Based on the characterization of wood and coal users, the eight Standard Industrial Code sectors having potential for herbaceous energy crop combustion include: 20 (food products), 22 (textile products), 28 (chemicals), 30 (rubber and plastics), 32 (stone, clay, glass, and concrete products), 80 (health services), 82 (educational services), and 92 (justice, public order, and safety).

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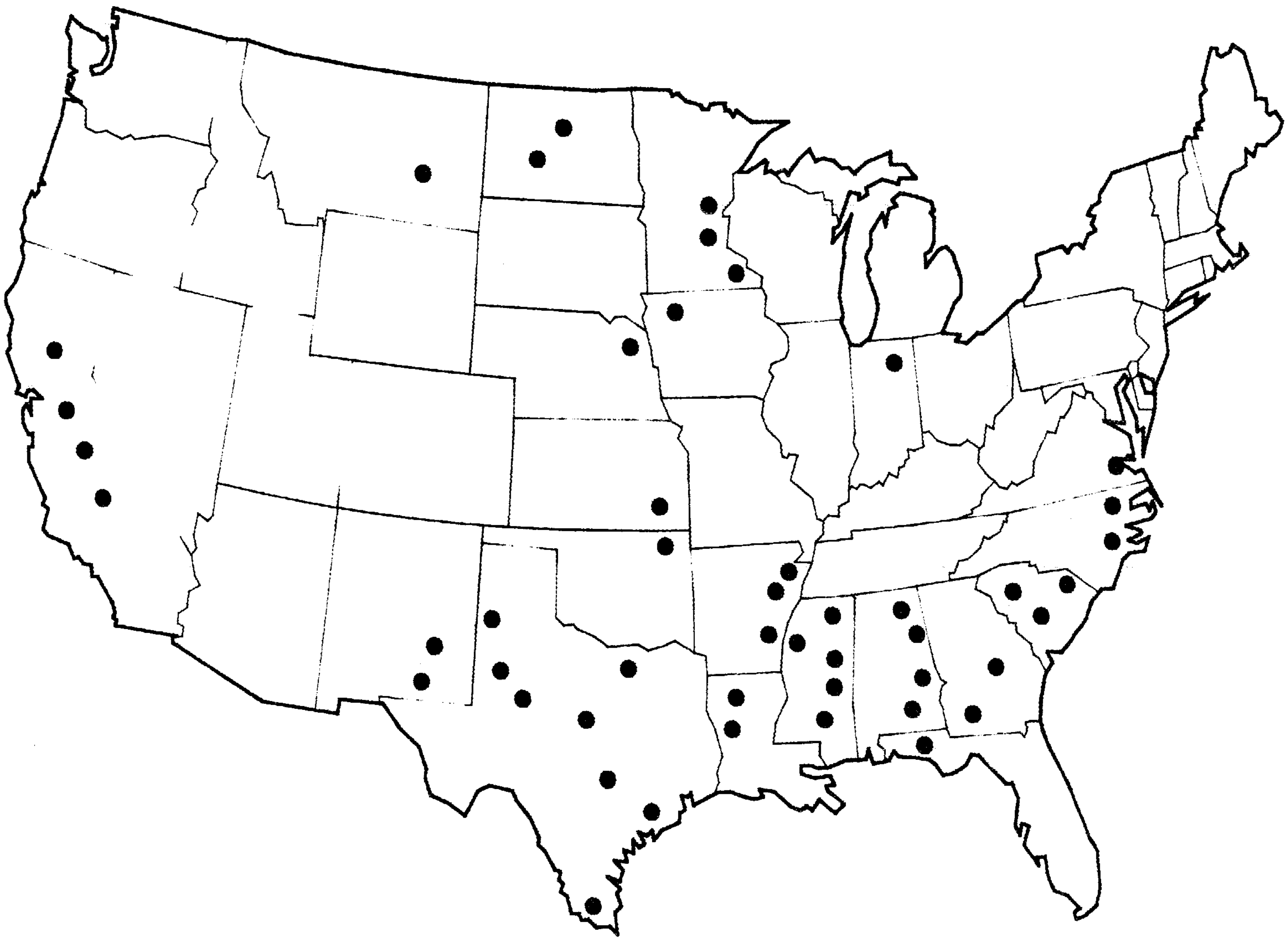

Fig. 12. Facilities suitable for coproducing edible and fuel vegetable oils.

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APPENDIX
Conversion Factors

1 Mg = 1.10 tons

1 ha = 2.47 acres

1 Mg ha^{-1} = 0.446 tons $acre^{-1}$

1 kg = 2.2 lb

1 kg ha^{-1} = 0.893 lb $acre^{-1}$

1 L = 0.264 gal

1 L ha^{-1} = 0.107 gal $acre^{-1}$

1 km = 0.62 miles

1 Mg-km = 0.685 ton-miles

1 GJ = 0.95 million Btu

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