The Use and Selection of Trees for Energy and Chemicals

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Abstract - High costs and unreliable availability of fossil fuels and petroleum-based chemicals have caused consideration of growing and using woody biomass as a source of energy and chemical feedstocks. Woody biomass is displacing or supplementing conventional fuels for many forest industries and some non-forest industries. Long range energy and chemical production will involve greater utilization of existing forests and short rotation plantations. Ideally, species used in these plantations should be selected for survival, growth and optimum energy and chemical yields. In practice, however, priority will be given to species and individuals that have already been selected for their growth, form, and wood properties. This paper considers the selection options and summarizes the current work being done through Department of Energy projects and commensurate work at N. C. State University.

Coping with the "energy crisis" has become a way of life in today's world. High fuel prices and shortages are readily apparent and the supply of petroleum-based chemical feedstocks is shrinking with accompanying higher prices for products derived from those feedstocks. An inexpensive, environmentally acceptable and renewable energy and chemical feedstock resource is needed to replace our traditional fossil fuel sources.

Wood is our greatest source of biomass and has potential to partially reduce our dependence on fossil fuels. Residues from many wood processing plants are being utilized as energy sources and numerous non-forest industries are converting to wood energy. Also, a considerable quantity of chemicals derived from wood--termed "silvichemicals"--are in use today (Bratt 1979). Numerous short and long term sources of woody biomass will be needed if a stable energy and chemical dependence is to be achieved. Already most forest residues are committed and low grade standing forests are being considered for short term biomass supplies.

Intensively cultured plantations using selected tree species are likely to become an important woody biomass source in this country (Fege et al. 1979). In South America, the largest energy plantation program in the world, over 200,000 acres (81,000 ha) per year is being established using various *Eucalyptus*

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spp. specifically selected for high energy yields. Trees are being grown on short seedling rotations with replanting done using genetically improved material rather than depending on coppice. Wood from these plantations is converted to charcoal for use in steel mill blast furnaces. Planting programs of this magnitude may occur in the United States if accelerated energy and chemical consumption continues.

This paper discusses the current status and potential of genetic selection to increase energy and chemical production from trees used in plantation culture in the Southeast.

Species Selection

Establishing plantations to maximize production of woody biomass for energy or chemical feedstock production will require unconventional thinking. Characteristics such as wood color, working properties, or dimensional stability which in the past made certain species desirable are less or not at all important in energy or chemical production (Steinbeck 1978). Rather, the total above ground woody biomass produced per acre per year should be the primary species selection criterion. Other, less important tree characteristics related to end use include BTU yields, alpha cellulose content, and certain fiber characteristics. These attributes may be common to commercial species of timber value or to noncommercial species of indigenous and exotic origin. Both conifers and hardwoods have advantages and each will be used under certain conditions. Numerous species selection programs are underway to identify the best species for energy and chemical production (Bente 1979). Fast growing species such as green ash (*Fraxinus pennsylvanica* Marsh), red maple (*Acer rubrum* L.), water oak (*Quercus nigra* L.). willow oak (*Q. phellos* L.), sycamore (*Platanus occidentalis* L.), and loblolly pine (*Pinus taeda* L.) which have relatively high specific gravity and low moisture content are good candidate species (Kellison and Zobel 1971, Zobel et al. 1969). The physical characteristics and growth potential of the eucalypts and European black alder (*Alnus glutinosa* L. (Gaertn.)) make them particularly desirable for energy and chemical production in the South (Frederick et al. 1979). In general, species should exhibit rapid juvenile growth, adaptability to a variety of sites, low susceptibility to insects and disease and high genetic variability to maximize selection opportunities.

Site Selection

The next critical step to optimize production of woody biomass is matching species to site. As forestry is forced onto sites that are less than optimal, trade-offs must be made. Strains and species of trees must be identified and developed that are best suited for thse suboptimal sites--the swamps, ridges, and other areas unsuitable for agriculture. The Hardwood Research Cooperative

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2/ The N. C. State Hardwood Research Cooperative consists of 19 forest industries and the N. C. Forest Service who own or control about 15 million acres (6 million ha) of land in the South from Delaware to Louisiana.

N. C. State University has been testing numerous commercial species for site adaptability for several years and evaluating their suitability for plantation management (Kellison et al. 1979). Results show loblolly pine superior in biomass production on most sites in the South with sycamore, sweetgum, willow oak, water oak, and green ash showing good potential for plantation management on many sites types. This type of testing must be continued and expanded to include the numerous noncommercial and exotic species as well. Our quickest and easiest gains in biomass yields will come from matching species to site.

Selection Within Species

Plantations of trees specifically grown for energy or chemical feedstock production will be established primarily on lands unsuited for agriculture or production forestry. However the increasing value of woody biomass for energy and chemicals may dictate expanded planting on the better sites. This fact is of particular concern because it may have far reaching effects on timber supplies and possibly food production.

Traditional tree selection programs have emphasized well-formed crowns, straight boles, and clean pruning for fiber and solid-wood products (Table 1).

Table 1. Superior phenotypes of southern hardwoods selected within the Hardwood Research Program.

Species	No. Graded	Species	No. Graded
Sycamore	149	Tupelo gum (*Nyssa aquatica* L.)	11
Sweetgum	129	Chestnut oak (Q. *prinus* L.)	8
Yellow poplar (*Liriodendron tuliplfera* L.)	65	Black oak (Q. *velutina* Lam.)	8
Green ash	75	White oak (Q. *alba* L.)	8
Red maple	27	Scarlet oak (Q. *coccinea* Muenchh.)	7
Willow oak	21	Swamp blackgum (*Nyssa sylvatica* Marsh.)	6
Water oak	20	Sugar maple (*Acer saccharum* Marsh.)	5
Northern red oak (*Quercus rubra* L.)	18	Southern red oak (Q. *falcata* Michx.)	5
Black cherry (*Prunus serotina* Ehrh.)	17	White ash (*Fraxinus americana* L.)	3
Black walnut (*Juglans nigra* L.)	12		
Cherrybark oak (Q. *falcata* var. *pagodaefolia* ELL.)	11		

Now these characteristics may be of minor importance in the production of woody biomass. In fact some researchers have expressed concern that traditional selection criteria have compromised or even had a negative effect on BTU and chemical yields from forest plantations (Kellison 1978).

Selection Criteria for Chemicals

Wood is a mixture of three natural polymers: cellulose 50%, hemicellulose, 25%, and lignin 25%. The exact percentage depends on species and genetic differences within species. Therefore, selection could be directed toward increasing that component which is most useful for producing chemical feedstocks. Cellulose content is most important in chemical yields because it makes up the largest component of wood and is the feedstock base for the most important chemicals. For example, cellulose can be converted to glucose and further fermented to ethanol which is an important industrial chemical and can be used for fuel. The conversion of glucose via ethanol to ethylene and butadiene represents the greatest potential utilization of cellulose for chemicals because of the importance of ethylene as the largest volume organic chemical and as a building block for petrochemicals and plastics, and of butadiene in the production of synthetic rubber (Goldstein 1978).

Likewise, a higher hemicellulose content which will yield primarily xylans from deciduous trees and glucomannans from conifers may be valuable. Lignin which will yield phenols may also be selected for but it is likely that selection for cellulose content will be most productive.

Invariably, the chemical industry must turn to a renewable chemical feedstock source and genetic selection programs will surely become important if tree plantations become the source of that resource.

Selection Criteria for Energy

Some of the characteristics desirable for chemical production are also desirable for energy yields, e.g., high cellulose or lignin content. However, BTU yield per unit volume appears to affect energy yields more than any other variable. Traits within and among species that affect BTU yields include specific gravity, moisture content, resin content, and extractive content among others.

Considerable variation in energy yields occurs between species but little is known about variation within species. Given the traits that influence BTU yield and knowing the variation of those traits within selected species (Table 2), it is assumed that breeding for gains in energy yields could be a profitable venture.

Fast growing trees traditionally selected for fiber and solid wood products will continue to be most desirable if the objective is total biomass production. However, this growth need not be concentrated in the bole as would be most desirable for solid wood products. Rather, a high biomass producing select tree may have numerous heavy branches and accompanying large widespreading crown and may even be multiple stemmed. Trees used for energy or chemicals will most

Table 2. Range in specific gravity and moisture content and average energy yields of selected Southeastern species.

Species	Specific Gravity	Moisture Content (Percent)	Energy yield(Dry) (BTU/lb)
Sycamore	0.41 - 0.49	76 - 138	8000
Sweetgum	0.41 - 0.53	98 - 145	7540
Green ash	0.48 - 0.66	41 - 68	8400
Red maple	0.40 - 0.58	55 - 100	8300
Water-willow oak	0.52 - 0.63	68 - 95	8000
Loblolly pine	0.42 - 0.68	70 - 160	8600

likely be whole-tree chipped so only total biomass production is important. Also,.sprouting ability may become an important selection characteristic for hardwoods if repeated crops are to be grown on short rotations. However, if greater production gains can be achieved through breeding programs as compared to coppice rotations, coppicing may not be as important as many people have suggested. From Cooperative studies, we have found gains in volume production from use of genetically improved hardwood seed will exceed the commercial check by twenty-five percent (Zobel 1975). Similar gains have been reported for the Southern pines for which coppice management is obviously not an option.

A breeding program for developing species best suited for plantation culture might best be established by open-pollinated progeny tests of parent trees which had been identified by mild phenotypic selection. Members in the N.C. State Hardwood Research Cooperative have established seed orchards for a limited number of species which have plantation management potential in the Southeast (Table 3). Jettand Weir (1975) reported that the greatest volume gains of commercial hardwoods could be realized through a program of family and within-family selection followed by inclusion of the select trees in clonal seed orchards. An illustration of the potential gain to be realized from family and within-family selections is provided by Webb, et al. (1973) for a young sycamore plantation in Georgia. Of 64 families, tested, the two best produced 60% more dry matter than the plantation average while the two poorest produced 35% less than the average. Individual selection within these and other good families would result in even greater gain. A further finding was high genetic correlation between root collar diameter and dry weight per tree. This parameter could be used for initial selection while other traits are being evaluated in long term breeding programs.

At present, specially adapted sources of loblolly and sand pines _(Pinus clausa_ (Chapm.)) Vasey have been developed for droughty sites in the South. Also, specially selected sources of loblolly and pond pine _(Pinus serotina_ Michx.) have been found very adaptable to wet sites (Zobel 1979). Numerous other southeastern species have sufficient variability for selection of desirable energy and chemical characteristics or adaptability to specific sites.

Table 3. Hardwood seed orchards by species and acreage in the Hardwood Research Program.

	No. Orchards by Type		Acreage of Orchard by Type	
Species	Clonal	Seedling	Clonal	Seedling
Eucalyptus	1	2	1	2
Green ash	1	-	2	-
Sweetgum	6	1	37	4
Sycamore	8	2	18	6
Water-willow oak	5	1	15	3
Yellow poplar	1	-	6	-
Total	22	6	79	15

CONCLUSIONS AND SUMMARY

New sources of energy and chemical feedstocks are needed to replace expensive and rapidly diminishing pretroleum reserves. Woody biomass is expected to partially displace these raw materials now and in the future. Short rotation plantations, selected specifically for BTU yields or extractive content, may supplement forest residues and low quality stands to meet this objective.

Selections for short rotation plantations should be chosen and evaluated at an early age. Growth curves for individuals often change over time. Mild phenotypic, selection in young, uniform stands should be used to select parent candidates that would be evaluated in open-pollinated progeny tests. The best individuals from the best families would form the breeding base for short rotation plantations.

Selection criteria for species and individuals to be included in these plantations will differ from those for trees selected for quality timber production. Most emphasis should be placed on proper species selection and matching species to sites. Individual traits of most importance are fast growth, followed by specific gravity and moisture content. High cellulose, lignin or extractive content may be selected for chemical production.

Wood is currently being utilized on a relatively small scale for energy and chemical production. As oil prices escalate, more emphasis will be focused on woody biomass for these uses. In the future, short rotation plantations may be established specifically for these end products. A breeding program for energy or chemicals should prove both feasible and economical.

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