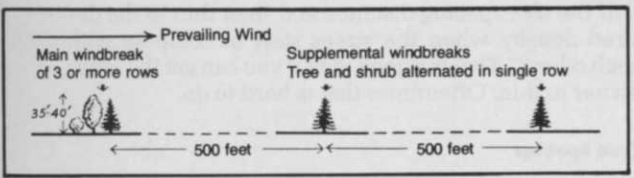

Figure 5

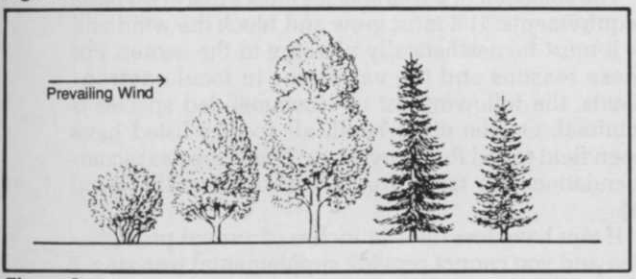

Figure 6

If you have room for only	SELECT	OR SELECT
4 rows	Dense shrub Medium height evergreen Tall evergreen Medium height evergreen	Dense shrub Medium height deciduous Tall evergreen Medium height evergreen
3 rows	Dense shrub Tall evergreen Medium height evergreen	Dense shrub Tall deciduous Medium height evergreen
2 rows	Medium height evergreen Tall evergreen	Dense shrub Tall evergreen
1 row	Medium height evergreen	Tall evergreen

crowded planting, thus making the windbreak much less effective. Three rows with room to develop will give better results than five rows that are seriously overcrowded. A well developed single row can be more satisfactory than three rows with inadequate growing space.

If you must use fewer than five rows, select the following combinations to give the maximum year-round protection for your site:

Please notice I do not recommend a one row deciduous windbreak for year-round protection, even though we see many, many one row lombardy poplar breaks. However, sometimes a tall lombardy poplar is alternated with a dense shrub such as caragana in a single row. I would recommend this arrangement only where evergreens do poorly and protection is needed mainly in the summer.

Tree Spacing

Spacings for windbreak trees vary by the type of tree and/or shrub used because it is very desirable to give trees room to reach mature size. Table 1 gives the *minimum* spacings recommended for windbreak trees. Wider spacing can be used with no disadvantage ex-

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Table 1. Recommended minimum spacings for windbreak trees

	Recommended minimum spacings			
	Irrigated or dryland with 16" or more precipitation.		Dryland plantings with 16" or less precipitation.	
Tree and Shrub types	Multiple-row windbreaks	Single-row wind-breaks	Multiple-row windbreaks	Single-row wind-breaks
	(feet)	(feet)	(feet)	(feet)
All types (between rows)	16		20	
Dense shrub	3	2	4	3
Medium-size deciduous	9	6	10	8
Tall deciduous	12	8	12	10
Medium evergreen	9	6	10	8
Tall evergreen	12	8	12	10

cept that it will take longer to get full protection. I believe you will find these recommended distances appear to be quite large, especially if you are planting small 2-0 or 2-1 stock. Please remember these distances will be adequate for mature trees. Additionally, the spacings recommended between rows and between trees within rows will leave adequate room for use of your tillage equipment; provide your trees with ample room for good growth; avoid wind whipping damage to trees in adjacent rows; and prevent early dieback of the lower limbs.

The question is often asked, "Why not plant at one half the tree spacing distance and then thin to the desired density when the strees start to compete with each other?" That is a good idea *if* you can get the landowner to thin. Oftentimes that is hard to do.

Tree species

The selection of a tree species must satisfy two basic requirements: 1) it must grow and block the wind and 2) it must be aesthetically pleasing to the owner. For these reasons and the variations in local environments, the following list of recommended species is minimal. On the other hand, all species listed have been field tested for many years. These species recommendations are taken from *Trees Against the Wind* (1).

If you have less than 16 inches of annual precipitation and you cannot provide supplemental watering, I recommend using Siberian peashrub, Russian olive, Siberian elm, black locust, ponderosa pine, and Austrian pine.

The most reliable species for high elevation plantings are Siberian peashrub, common lilac, golden willow, hybrid poplar, ponderosa pine, blue spruce, and Rocky Mountain juniper.

Evergreen trees can be called the foundation for windbreaks in all areas where they can be grown satisfactorily as they give year-round protection. They should be included in windbreaks wherever possible. In areas where they do well, evergreens may be used for the entire windbreak. However, a windbreak of mixed species gives some protection against insects or diseases damaging the entire planting.

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Table 2. Recommended windbreak species

DENSE SHRUBS NAME	Mature Height	Crown Width	Minimum Precipitation	Saline Soil Tolerance	Winter Damage Resistance
Siberian peashrub *Caragana arborescens*	(feet) 10	(feet) 10	(inches) 12	Excellent	Good

A dense, attractive, many-stemmed shrub. Makes rapid growth. Has long life, wide range of soil and elevational adaptability. Generally insect and disease free. Sprouts from crown only. Good for dryland or irrigated plantings. Reaches full size on irrigated land in 5 to 7 years, on dryland in 10 to 12 years. Can be trimmed to make an excellent protective hedge. A superior windbreak shrub adaptable to the whole region. It is weakened by repeated 2, 4-D exposures.

Common lilac *Syringa vulgaris*	10	10	15	Good	Excellent

Very dense. Slow to medium growth rate; long lived; wide soils and elevational adaptability. Sprouts heavily, mainly at the root crown, but spreads slowly. Makes excellent hedge or shrub row in windbreak. Has high aesthetic value. Occasionally becomes infested with scale insects; extremely sensitive to 2, 4-D. Has high resistance to drought and cold.

Tatarian honeysuckle *Lonicera tatariea*	8	7	15	Fair	Excellent

Attractive global-shaped, many stemmed shrub. Bears numerous pink or white flowers. Red fruit holds on till fall. Provides good wildlife food and cover. Not commonly subject to insect or disease problems. Does well on most soils.

Common privet *Ligustrum vulgare*	10	8	15	Good	Good

An extremely dense, attractive shrub with medium to rapid growth. Needs well-drained soil. Sprouts only from crown. A nearly ideal plant for low single-row windbreaks, as well as the shrub row in multiple-row plantings.

NAME	Mature Height	Crown Width	Minimum Precipitation	Saline Soil Tolerance	Winter Damage Resistance
Nanking cherry *Prunus tomentosa*	(feet) 6	(feet) 4	(inches) 15	Fair	Good

An attractive upright shrub with a fast growth rate. Produces abundant edible fruit that makes good jelly. Fruit is retained throughout the winter and makes good wildlife food. Some hybrid varieties grow to 10 feet tall. Has fair to good windbreak qualities. No known insect or disease problems. Nanking cherry should not be planted near cherry orchards because it is an alternate host to Western X cherry disease.

Peking Cotoneaster

Cotoneaster acutifolia	5	4	12	Fair	Good

Similar to Nanking cherry. Will grow on severe sites. Moderate growth rate. Withstands drought well. Produces abundant fruit that is retained throughout the winter. An excellent species for adding wildlife value to a windbreak. Few insect or disease problems.

Mugo pine

Pinus mugo	8	8	20	Fair	Fair

An attractive, compact evergreen shrub with moderate growth rate. Does best on fertile, well-drained soils. Performs best as a windbreak shrub at elevations below 4,500 feet as winter burning is a problem over this elevation.

DECIDUOUS TREES

Russian-olive

Eleagnus augustifolia	30	20	12	Excellent	Excellent

A small tree with dense, attractive crown. A superior tree for windbreak, wildlife, and aesthetic values and for drought resistance. Makes a dense hedge when clipped. Its spiny-tipped twigs make a dense planting an almost impenetrable barrier. Considered to be one of the best deciduous species for dryland plantings in the region. Makes very rapid growth especially on good soil with ample moisture. It is adapted to a wide range of soils. Sprouting is negligible, but it spreads by seed where there is adequate soil moisture. More resistant to spray damage than other deciduous species, but not as resistant as evergreens.

Golden willow

Salix alba var. *vitellina*	35	30	15	Good	Excellent

A medium-size tree with good growth form for windbreak use. Bright yellow to orange colored young branches make it attractive in winter. Makes very rapid growth; has wide adaptability to soil and moisture conditions. Sprouts only from crown and does not spread from runners. Subject to severe damage from scale insects and aphids. Should be used in dryland plantings only if supplemental moisture is available. Excellent in the Palouse.

NAME	Mature Height	Crown Width	Minimum Precipitation	Saline Soil Tolerance	Winter Damage Resistance
Black willow	(feet)	(feet)	(inches)		
Salix nigra	40	35	20	Excellent	Excellent

Grows very rapidly under irrigation. Forms broad, global crown that is moderately dense. Usually has several stems from near ground level. Serves well as a middle row in windbreaks. Not very suitable for single row plantings because of its low wide spreading branches. Has performed well in localities with salty soils and high water tables where establishment of other species was difficult. Subject to damage by scale insects.

Black locust

Robinia pseudoacacia	50	40	15	Fair	Fair

Has rapid growth rate. Forms moderately dense crown. Tolerates very hot climates. Adapts to a wide range of soil conditions, but does not stand waterlogging. Seldom damaged by insects or disease. Not recommended for ditch bank or fence row plantings because injured roots produce thickets of sprouts. Confine black locust between other rows of trees to prevent spreading on irrigated land. Suckering is not serious on dryland. Requires little maintenance once it is established. A well-liked and widely used tree with good shade, aesthetic, and wildlife values.

Honeylocust

Gleditsia triacanthos var. *inermis*	40	20	12	Good	Fair

Medium to tall tree. Fairly drought resistant. Withstands alkaline soils well. Attractive zigzag twigs, fine textured leaflets. Two to four inch thorns. Fruit is a large 12" (max.) pod. Winter injury on harsh sites.

Siberian elm

Ulmus pumila	50	30	12	Excellent	Good

Has moderately dense crown and attractive form. Makes rapid growth. Adapted to a wide range of conditions. Branches usually become brittle in irrigated plantings. This often results in breakage and an untidy appearance. Pruning can reduce this. Sprouting is not a problem, but thickets of seedlings often form around irrigated plantings. Severely damaged from repeated exposure to herbicides applied as crop sprays. Sudden fall freezes can cause severe damage. Susceptible to scale insects. Very drought resistant but has not stood up well in Oregon and Columbia Basin. A very acceptable dryland tree in Idaho up to 5,000 feet. (Note: Chinese elm. *U. Parvifolia* is quite similar.) Resistant to Dutch elm disease.

Hybrid poplar

Populus x spp.	50	30	15	Good	Excellent

Makes very rapid growth. Has dense crown and good form. Does best under irrigation, but performs well in dryland plantings with 15" or more annual precipitation. Provides quick protection. Suckers from injured roots. Do not plant near field drains or along irrigation ditches. A well liked tree that is growing in popularity. Susceptible to poplar and willow borer. (Note: There are many hybrid poplars. The one described here is a selection that was made from early Idaho test plantings of hybrid poplars.)

NAME	Mature Height	Crown Width	Minimum Precipitation	Saline Soil Tolerance	Winter Damage Resistance
Green ash	(feet)	(feet)	(inches)		
Fraxinus pennsylvanica var. *lanceolata*	60	40	15	Good	Good

A deep rooted, long lived tree with dense, symmetrical and attractive crown. Growth may be slow at first, but moderate to rapid after becoming established. It will become overtopped by more rapidly growing trees, such as black locust and Siberian elm, if planted too close to them. Sprouting is negligible. An excellent tree for ditch bank and fence row plantings. It is more winter hardy and salt tolerant than black locust. It is damaged by herbicide sprays, but is more resistant than Siberian elm. Subject to damage by scale insects and aphids.

Lombardy poplar					
Populus nigra var. *italica*	70	15	20	Good	Excellent
Grows very rapidly, reaching 40 feet in 12 years under favorable conditions. Has very narrow, though fairly dense, crown. Makes good middle row where fast growth and extra windbreak height are desired. Subject to some canker diseases and heart rot, especially if trees have been damaged by topping, fire, or other causes. Windfirm unless diseased. Susceptible to poplar and willow borer. Competes with nearby crops for soil moisture and nutrients. Short lived.					
EVERGREENS					
Rocky Mountain juniper					
Juniperus scopulorum	20	15	12	Excellent	Excellent
Makes medium to rapid growth. Forms very dense, symmetrical crown. Adapted to wide soil variations. Tolerates high water table. A superior small windbreak tree for this region. Bare-rooted planting stock is difficult to establish on dryland, but does well once established. Subject to damage by spider mites and is sometimes a host to cedar-apple rust.					
Eastern redcedar or Virginia juniper					
Juniperus virginiana	25	15	15	Good	Good
Has moderate to fast growth rate. Similar in appearance to Rocky Mountain Juniper and generally as adaptable. It is easily established except on very dry sites and at high elevations. Well liked for single row screens. Subject to attack by cedar-apple rust. Should not be planted near apple orchards.					
Northern white cedar					
Thuja occidentalis	35	20	20	Good	Good
Moderate growth rate. Forms very dense, attractive crown. Holds lower branches well. Makes a dense single-row windbreak or leeward row in a multiple-row planting. Survives well under irrigation where soils are not highly saline. No known insect or disease problems. Has not been widely used, but existing plantings indicate it is a good tree for many localities. It is well liked in Oregon for single-row screens and windbreaks.					

NAME	Mature Height	Crown Width	Minimum Precipitation	Saline Soil Tolerance	Winter Damage Resistance
Austrian pine	(feet)	(feet)	(inches)		
Pinus nigra	40	30	20	Fair	Good
Has medium growth rate. Develops symmetrical crown that is very dense for a pine. Some maintain the density of one row of Austrian pine is equivalent to that of two rows of ponderosa pine. Holds lower branches well. An excellent tree under irrigation, but has failed in some dryland plantings with low rainfall after 10 to 12 years. If planted without supplemental watering in localities with less than 20-inch annual precipitation, it needs a deep, fertile soil with good moisture holding capacity. Austrian pine is considered an excellent species					

for the Columbia Basin. Ponderosa pine is preferred in Wasco, Gilliam, Sherman, and Morrow counties, Oregon. Usually remains free of insect and disease problems. Susceptile to iron chlorosis.

Scotch pine					
Pinus sylvestris	40	20	15	Fair	Good

Has rapid growth rate. Crown density is usually medium. Lower branches shade out and die if they do not get full sunlight. Adapts to a wide variety of soil conditions. Will withstand permanently moist soil conditions better than ponderosa. Generally easy to establish. A widely used tree for windbreaks. There are many strains of Scotch pine. Some have poor form. Spanish burgo variety does well in Idaho.

Blue spruce					
Picea pungens var. *glauca*	40	25	20	Good	Excellent

Growth rate is unusually slow for first 5 years after planting but has medium growth rate after that. Crown is very dense with attractive pyramidal form. Makes an excellent windbreak species in most of the region. Color varies from green to blue. Sometimes it is difficult to establish. Subject to damage by spider mites, scale insects, and spruce gall aphid.

Norway spruce					
Picea abies var. *bavaria*	60	25	16	Fair	Fair

Makes rapid growth. Develops a very dense crown that extends to the ground unless the base of the crown is in heavy shade. Moisture and soil fertility requirements are higher than for the pines. Does fairly well in dryland plantings if soil is deep and fertile. Subject to spider mite and and spruce bud scale damage. Sometimes becomes stunted in growth due to zinc deficiency.

Ponderosa pine					
Pinus ponderosa	60	30	15	Fair	Good

Has moderate growth rate. Crown is symmetrical and fairly dense. Needs full sunlight for best development so lower branches shade out and die under close spacing. Adapts well to a variety of soil conditions but must have good drainage. Withstands hot, dry sites well. Can be damaged or killed by too much irrigation. Generally free of insect and disease problems. Considered by many to be the most reliable evergreen for windbreaks. Highly preferred in Oregon and in much of the Columbia Basin.

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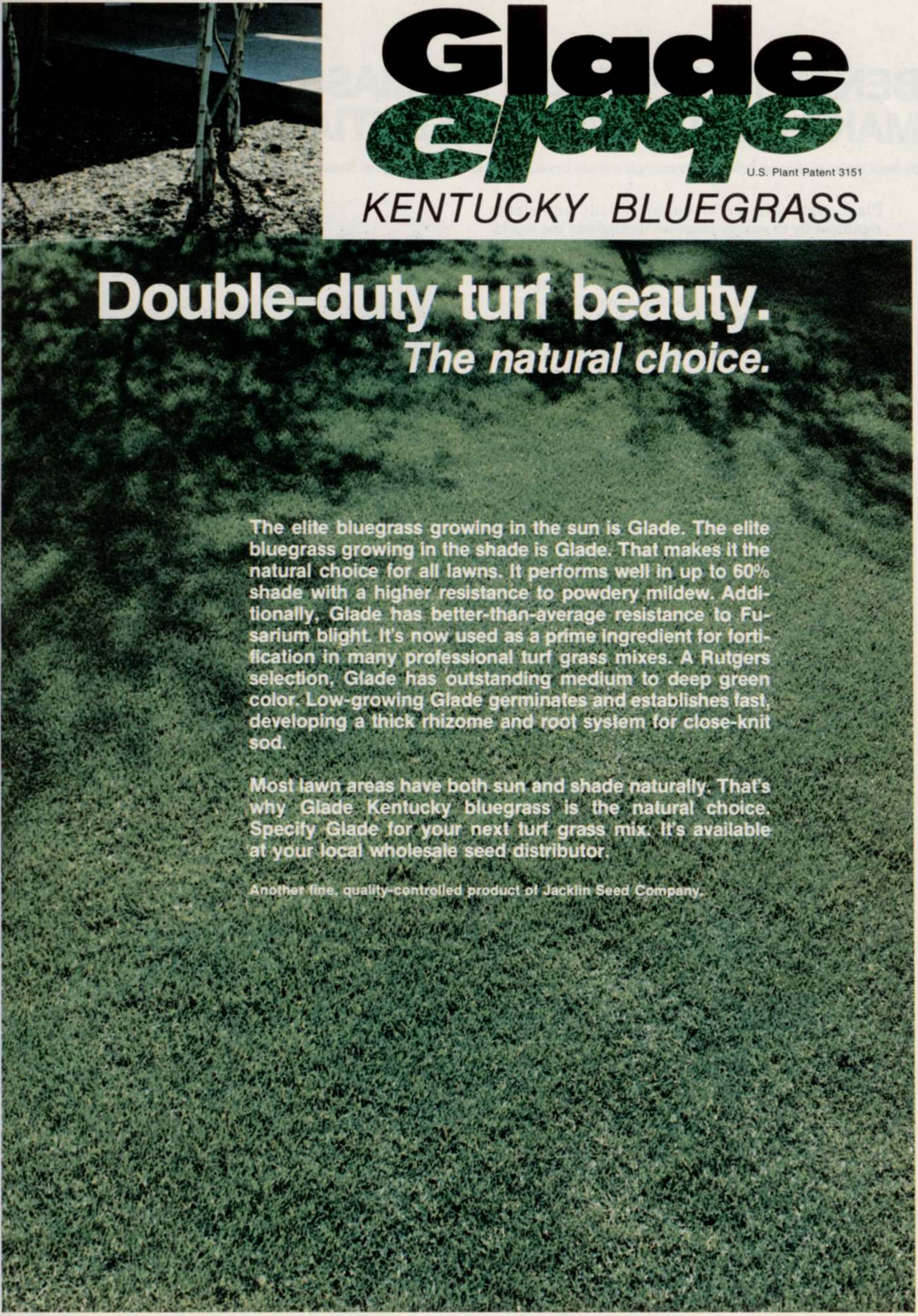

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BENEFITS OF WOOD BIOMASS MAKE CULTIVATION ESSENTIAL

By Paul Heilman, Forest Scientist, Washington State University, Western Washington Research and Extension Center, Puyallup, WA

Plant materials, or biomass, already contribute significantly to energy supplies throughout the world. Even in the United States where such usage is confined primarily to fuelwood and wood wastes burned by wood processing plants, the quantity of energy generated from biomass is important — over 1.5 percent of the total consumption in the U. S. (currently 75 quads of energy). Although significant, such figures show the U. S. to be far from the goal of certain other countries to make biomass fuels a large component of energy use. Some examples:

1. Brazil is attempting with high capitalization and technology to produce ethanol from crops grown for that purpose. The ethanol is intended as a major source of liquid fuels for automobiles. Their program had progressed to the point where several large distilleries are already in production. The crop for this purpose is manioc, a root crop which is adapted to relatively infertile soils and can be grown satisfactorily without irrigation. Livestock production is incorporated into these operations in order to utilize the waste and increase efficiency.
2. Red China has begun a program to provide small scale units on individual farms for production of methane through anaerobic decomposition of farm manure and human wastes. The methane produced would be used at the farmstead for cooking and other purposes.
3. Perhaps the most optimistic program for energy production from biomass is in Sweden. In April, 1980, at a Conference in Atlanta, Georgia, I listened to representatives of that country forecast that by the year 2015 Sweden would have the potential to produce up to 60 percent of its energy from biomass with 45 percent from biomass farms using willows and 15 percent from conventional forestry residues. This would allegedly be achieved with a continued increase in the country's standard of living and yet with only 6 to 7 percent of the total land of Sweden being devoted to the willow plantations.

Potential in the United States

Most analyses show a substantial potential contribution to future U. S. energy consumption from biomass (about 5 percent). Such energy would be in the form of fuelwood for homes; forest and mill wastes used onsite for mill power and cogeneration of electricity for nearby communities; agricultural and food processing wastes used on the farm and at the food processing plants, forest, farm, and city wastes used for electrical production and gasification at central locations; and biomass produced from both terrestrial and aquatic environments also used in central systems for production of electricity and gas.

Within the United States there are considerable differences among regions with respect to options for biomass production and energy recovery. For instance, the Northeast with rural populations, cold winters, and abundant woodlands already uses large quantities for fuelwood for home heating. Also, chips from natural stands of small dimension hardwood stands are likely to be utilized in small centralized systems for energy conversion.

Two clones of poplar hybrids at 1½ years illustrate experimental biomass plantings for energy or fiber. Trees were spaced 4 feet apart.

The Southeast, also with a considerable rural population, has a relatively smaller potential for fuelwood usage. This area also has an abundance of low quality natural hardwood stands which could be chipped and used in central systems. Following the harvest of such forests, the material for such systems could be provided from biomass farms using rapidly growing species.

The Pacific Northwest has a high proportion of productive forest land and also relatively high timber and pulp chip values due primarily to export markets. If these timber values remain high, the region is likely to be hard pressed to provide future fuelwood needs for home heating. Together, the high projected demand for timber, pulp, and firewood in the Pacific Northwest may make high production tree plantations more economically feasible than in other regions. Such plantations could be sufficiently versatile to provide fiber, cordwood, or biomass fuel depending upon needs and markets at harvest. Such plantations are potentially suitable for much of the underused and marginal agricultural lands and certain forest lands in the Pacific Northwest.

Increasing yield potential of woody plants

Rapid growth is not necessarily of adaptive significance to trees; rather, such characteristics as wind firmness, disease and insect resistance, and drought resistance are likely more important in natural selection since with such traits a tree can survive long enough to be effectively reproductive. For instance, we now realize that Douglas fir, although active photosynthetically during the winter months, frequently closes its stomata during warm and sunny periods of the day even though soil moisture supplies may be adequate for continued transpiration and photosynthesis. Consequently, the tree may not fully utilize soil moisture and, thus, may not capitalize fully on periods with high photosynthetic potential.

Furthermore, although conifers are the most productive timber trees in the Pacific Northwest, the growth rate of these species during early years is generally quite slow. For instance, a 26-year-old stand of western hemlock from the Oregon Coast was found to have a current annual biomass production of 11 tons dry weight per acre per year, equal or higher than the most productive world forests, including tropical rain forests. Despite this high rate of production at age 26, the average production for the entire 26-year period of that stand was only 2.9 tons per acre per year. Average production of less rapidly growing stands of conifers would, of course, average even lower.

Several years ago some forest scientists in the Southeast proposed a new approach to forest production for fiber which they called "silage sycamore." The principle of the system was to use a fast-growing tree species, such as sycamore, in very dense plantations with harvest as often as every two years. The advantages of their system as they saw it were that 1) maximum growth rates would be achieved much more rapidly than from conventional forest plantations, 2) elimination of the need to replant after harvest by use of species that would readily resprout following cutting, 3) mechanical harvest with perhaps chipping at time of harvest, thus mechanizing the harvest operation, and 4) production of a relatively uniform product that could be readily transported in vans and could be conveniently handled by conveyor or blower.

Indeed, the first efforts to evaluate yields under such conditions were very encouraging. So much so that it now appears that the short rotation idea was somewhat oversold. To be sure, early yields are high under such a system, but more recent research with sycamore and other species shows higher yields can be obtained when the harvest cycle is increased from two years or so to eight years and more. Furthermore, at the older ages the yield advantage of close spacing is very much reduced. Also, the cost of stand establishment dictates wider spacing. Nevertheless, with today's interest rates, the advantage of shortening rotation time is obvious. Additionally, for the short term at least, resprouting has become a minor factor, since the rapid gains possible from genetic improvement make replacement of planting stock likely after the first or second harvest.

Research on woody biomass plantings

Use of fast growing hardwood species for maximum biomass production continues to receive major emphasis in work on growing woody biomass. Our research was conducted initially with Dwight Peabody, Western Washington Research and Extension Unit in Mount Vernon, and is now being done with Professor Reinhardt Stettler, forest geneticist, University of Washington, Seattle. The major emphasis of this work is with black cottonwood *(Populus trichocarpa)*, the native cottonwood of the Pacific Northwest and a species highly regarded in Europe where cottonwood planting and culture far predates Pacific Northwest efforts. Our attempts to improve the growth rate of black cottonwood include selection and intraspecific crosses with eastern cottonwood *(P. deltoides)*. One such hybrid planted near Sumner at a 10 x 10 foot spacing without irrigation grew 11 feet the first year from a 20-inch cutting planted 18 inches deep. On August 20th, I measured this tree and it was 14.8 inches in diameter at breast height and 87 feet tall and it won't be 9 years old until this winter. This tree resulted from a cross using pollen collected from a superior *P. deltoides* from Mississippi and a randomly selected *P. trichocarpa* from western Washington. Such crosses with black cottonwood are easily made. Branches containing flower buds from a female *P. trichocarpa* are clipped early in the spring, placed in water and when the buds open they are dusted with the select pollen. Using *P. trichocarpa* as the female parent permits production of viable seeds on the clipped branches. In contrast, branches of *P. deltoides* must be grafted to rooted stock in order for viable seed to be produced.

Our first efforts at systematic selection of black cottonwood involved the collection of cuttings from 50 selected wild trees, 5 trees each from 10 stands located on the South along the Santiam River near Albany, Oregon, to the Chilliwak Valley on the North in southern British Columbia. Flowering branches and later seeds from these stands were also collected. The cuttings were planted on an irrigated site near Sumner, Washington, using 45 20-inch cuttings per clone. These were planted at 4 x 4 foot spacing in nine tree rows with five replications. Additionally, five representatives of the material, including hardwoods that we had been working with for some time, were used in the experiment for comparison. Average height growth of the first year for up to 45 individuals per clone ranged from 5.9 to 10 feet. The cuttings from the hybrid I mentioned earlier grew best but several clones of *P. trichocarpa* grew almost as high and were in fact not significantly different in height from the fastest growing hybrid. On August 20th, the best plants of this hybrid were 24 feet tall. These individuals will still grow another meter in height this year and these plants won't be two years old until this winter.

We intend to select not only for biomass production but also for trunk straightness and small branches because such features are likely to be related to effective utilization of growing space as well as timber quality. Thus, we expect that the materials selected for biomass production will also be suitable for timber production.

A feature of our work that I haven't mentioned is growth of mixed stands, primarily cottonwood-red alder mixture. The purpose of such mixtures is to obtain the benefit of nitrogen fixation by alder and perhaps avoid the need for nitrogen fertilization. Accordingly, we have planted 28 clones in a second experiment to test the effects of alder on cottonwood primarily from the standpoint of total biomass yield of the mixture. Earlier Dean DeBell, forest scientist, U. S. Forest Service, Olympia, Washington, reported benefits of such a mixture in terms of enhanced growth of cottonwood. In our experiment, we found after the first year, a significant, although small, increase in nitrogen content of cottonwood foliage on trees grown with alder. This year we have noted a large increase in both total foliage mass and a darker green foliage color in cottonwood associated with the alder. Such a rapid effect from alder was unexpected since the primary means

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for alder to benefit associated plants has been thought to be through the accumulated forest litter and thus is a longer term process. Although inclusion of red alder in such mixtures shows great promise at this time, we have not begun efforts at genetic improvement of that species.

Yields and cultural practices

Highest yields reported to date are from willows in Sweden where 14 dry tons per acre per year are claimed. With irrigation we expect our best cottonwood clone to give similar yields, since our estimated production was 10 tons per acre for the first year. Without irrigation our best yield from wild stock black cottonwood at 4 x 4 foot spacing and for a four-year cutting cycle has been 4.1 dry tons per acre per year. The same material on a drier site with some grass competition gave 2.6 tons per acre per year at the same spacing and harvest cycle.

For satisfactory results, weeds and grass must be controlled at least during the first growing season. We have been satisfied with preplant herbicides or summer fallow together with minimal cultivation the first season. Dwight Peabody at Mount Vernon has tested many herbicides and has only recently had results showing some selectivity for two materials.

Best spacing depends upon rotation age. We recently obtained yields from a single harvest after eight years which averaged 40 percent more than from the combined yields from two four-year harvests. At eight years, yields were relatively independent of spacing up to 4 x 6 foot; whereas, with shorter rotations (four years or less) spacing is very important in the first harvest but less so in subsequent harvests. The major factor determining spacing and rotation age is size of material desired at harvest and this will vary according to harvest methods, markets, and so forth. We expect wide variation in such factors among regions and locations.

All planting is with cuttings, although stands can be readily produced using seedlings. With black cottonwood, cuttings can be of any age material, i.e., branches or sprouts. We use material from 3/8 to 1 1/4 inches in diameter. Cuttings are about 18 inches long and are placed in subsoiling trenches with about 2 inches left above ground. Such cuttings are collected in the winter months. Survival is high but can be improved for cuttings that have been stored by a 48-hour soak in water. Survival of certain of the hybrids with *P. deltoides* can be much lower, and soaking of these materials is recommended. Mid-season pruning to a single stem is also recommended, although it is not required for short rotation biomass plantings.

Fertilization with nitrogen is required on low organic matter status soils although we have not seen much response to fertilizer in the few instances where we have tried it. We are currently developing foliar analysis guidelines for use in determining nitrogen fertilization requirements.

Diseases have so far not been a problem as long as westside *P. trichocarpa* has been used. Eastside *P. trichocarpa* is not satisfactory for the westside because of the high susceptibility of these materials to a leaf rust under the more humid climate. Insects chew on these plants, but to date we have not felt the need for spraying. Distressed plants—from weed competition, dry soils, and newly planted seedlings—set their buds early in the season and can be severely affected by a bud infesting midge. More vigorous plants set buds much later, especially the terminal bud and by this means appear to avoid being infested.

Conclusions

1. Technology for several processes and end products using biomass to capture solar energy is being developed with the feasibility of each varying with specific growing conditions, needs, and other characteristics of a region or country.
2. Woody plant material is likely to represent a significant portion of the biomass used for energy in most areas.
3. Production of woody biomass offers diversification of markets, including not only energy uses but also pulp chips, cordwood, and timber.
4. Woody species plantations for biomass will likely vary from extensive plantations growing small dimension material in relatively short rotations, such as are planned for Sweden, to small wood lots and fence rows on small ownerships. In these cases, larger dimension trees will likely be grown at longer rotations and wider spacings.
5. Nitrogen fixing plants including trees such as red alder will be utilized in both pure stands and in mixtures with other trees.
6. Tree improvement programs will result in continually improved planting materials with selections and hybrids being developed for specific soil and site conditions.
7. The substantial requirements in land and water to bring about a significant increase in woody biomass production can result only from a new concern for conservation of land and water resources. Loss of productive lands to urbanization and other causes and the generally wasteful usage of irrigation water in this country cannot continue even without the additional water and land needs for biomass plantations. Uncommitted sources of irrigation water including waste water can be used for energy plantations, but a new land and water conservation emphasis will be required if biomass is to be a significant factor for future energy supplies. **WTT**