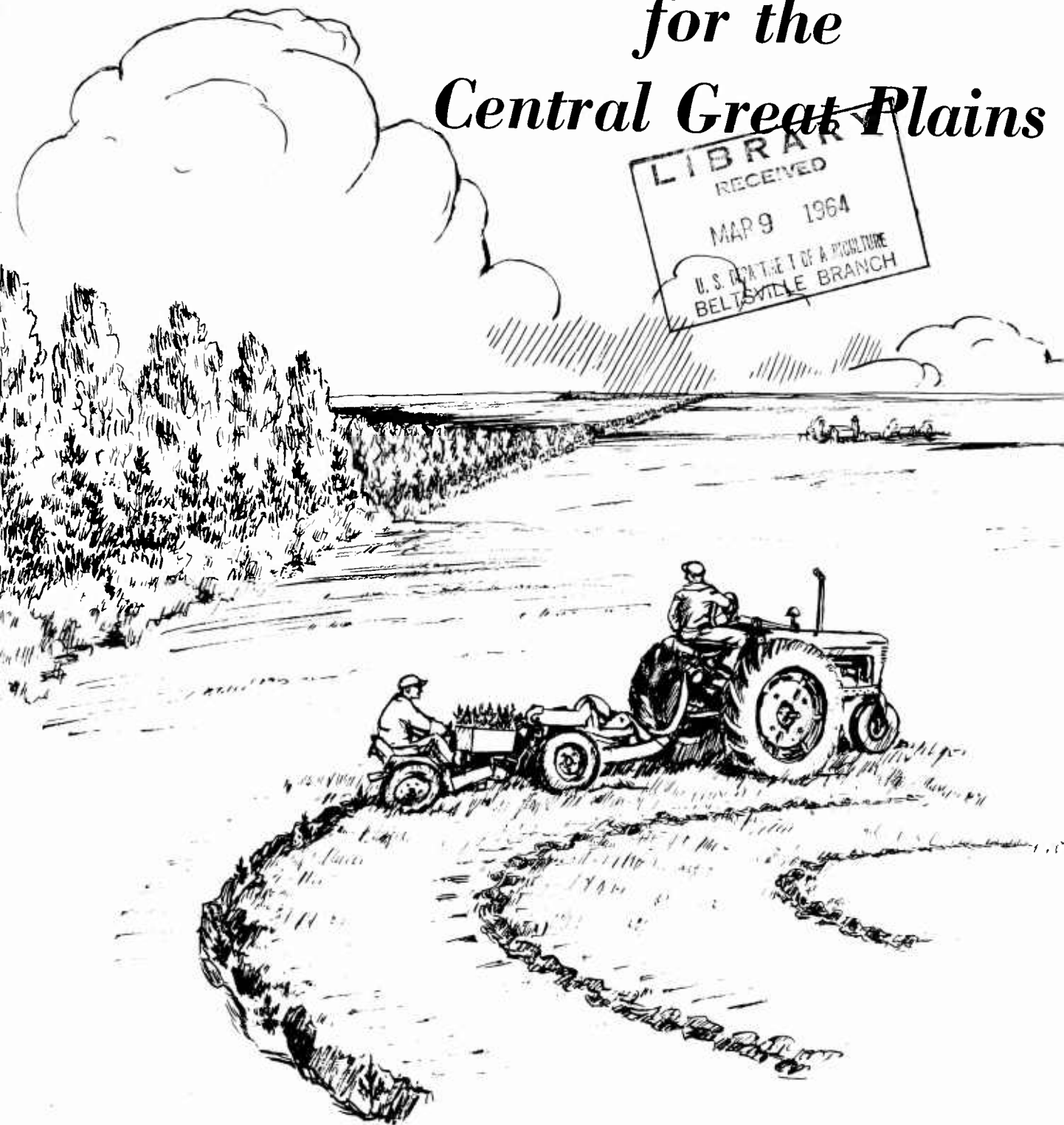


Tree Windbreaks for the Central Great Plains



Agriculture Handbook No. 250

TREE WINDBREAKS FOR THE CENTRAL GREAT PLAINS

Ralph A. Read, Research Forester

**Rocky Mountain Forest and Range Experiment Station
Forest Service, U.S. Department of Agriculture**

**Agriculture Handbook No. 250
U.S. Department of Agriculture**

**February 1964
Forest Service**

Contents

	<i>Page</i>		<i>Page</i>
Introduction.....	1	How to obtain and handle tree planting stock.....	33
Why plant tree windbreaks.....	2	Where to buy planting stock.....	34
How windbreaks affect the environment.....	3	Specify the seed sources.....	34
Effect on wind velocity.....	3	Specify sizes and grades.....	34
Effect on air temperatures and humidity.....	4	Packing and shipping.....	37
Effect on evaporation.....	4	What to do when trees arrive.....	38
Effect on soil temperatures.....	7	Storage.....	38
Effect on soil moisture and snow drifting.....	7	Heeling-in.....	38
Effect on soil properties.....	8	How to plant windbreak trees.....	39
How windbreaks affect plants and animals.....	8	When to plant.....	39
Effect on crops.....	8	Layout.....	39
Effect on farmsteads and livestock.....	8	Planting depth.....	39
How to use windbreaks for protection.....	10	Care of trees during planting.....	40
Single purpose versus many purposes.....	11	Machine planting.....	40
Types of windbreaks and their functions.....	12	Hand planting.....	41
Windbreaks for field protection.....	12	How to cultivate and protect windbreak trees.....	42
Windbreaks for farmstead protection.....	16	Why control of vegetation is important.....	42
Windbreaks for livestock and range protection.....	17	Methods of control.....	42
Windbreaks for protection of public facilities.....	17	Why protection is important.....	45
How to select windbreak trees.....	18	Methods of protection.....	45
What to consider.....	18	How to manage windbreaks.....	53
Select species adapted to planting sites.....	19	Objectives of management.....	53
Select species for windbreak characteristics.....	21	Relieve crowding.....	53
Recommended species.....	22	Release conifers.....	53
How to arrange and space trees in the windbreak.....	25	Add conifers.....	54
Growth and development with age.....	25	Modify low-level density.....	54
Arrangement of species components.....	27	Reduce width.....	54
Spacing between tree rows.....	27	Methods of management.....	54
Spacing between trees in the row.....	29	Thinning and release cutting.....	54
How to prepare land for tree planting.....	29	Coppicing.....	56
Why is land preparation needed?.....	29	Interplanting.....	56
Kinds of land preparation practices.....	30	Use of natural reproduction.....	56
How to decide which practices to use.....	31	Pruning.....	57
General practices for all lands.....	31	Appendix.....	58
Practices depending upon soil and land use.....	31	Examples of effects of windbreaks on field en-	
Recommended practices.....	32	vironment.....	58
When to prepare land.....	32	Examples of effects of windbreaks on crops, live-	
		stock, and farmsteads.....	62
		Literature cited.....	65
		Additional references.....	68

TREE WINDBREAKS FOR THE CENTRAL GREAT PLAINS

By Ralph A. Read, Research Forester*

Introduction

The planting and care of tree windbreaks for protection against climatic extremes and for the improvement of living conditions in the Great Plains of the United States is as old as settlement. In the 1860's homesteaders in the eastern Plains planted trees around their homes and gardens and along their farm boundaries not only to relieve the monotony of the level, treeless plains, but also to slow the force of the wind. In fact, tree planting on the Plains was considered so important to settlement that Congress passed the Timber Culture Act in 1873 to encourage planting of trees on all new homestead lands.

B. E. Fernow, Chief of the U.S. Department of Agriculture's Division of Forestry, the present-day Forest Service, worked with and encouraged State Agricultural Experiment Stations throughout the Plains during the 1890's in establishing tree-planting tests to find out which species were best adapted for plains conditions. The Nebraska National Forest, established in 1902, was the first large-scale demonstration of growing trees in the sandhills. Ranchers and farmers throughout the sandhills have since followed the practice of tree planting around ranches and farmsteads, and especially on range areas for winter protection of livestock. Carlos G. Bates, a pioneer Forest Service researcher, wrote the first comprehensive Department of Agriculture publication on windbreaks and their influence and values. His bulletin, now out of print, was published in 1911.

Field stations of the U.S. Department of Agriculture's Bureau of Plant Industry, now part of the Agricultural Research Service, began tree-planting experiments during the period 1910 to 1920 at locations near Mandan, N. Dak., Cheyenne, Wyo., Akron, Colo., and Woodward, Okla. Enactment of the Clarke-McNary law in 1924 provided Federal assistance to farmers in obtaining trees at cost, through the State and Extension foresters, for planting on farms and ranches in the Great Plains.

The Shelterbelt Project of 1935 to 1942, known after 1937 as the Prairie States Forestry Project,

was the largest windbreak planting project to date. In this project the U.S. Forest Service directly assisted farmers and ranchers in planning and establishing windbreak systems on croplands in the eastern Plains in a belt extending from North Dakota to northern Texas.

Raphael Zon, under whose direction windbreak research by the Forest Service was conducted in the late 1930's, strongly advocated windbreaks for the Plains in the following statement:

Trees grouped together as windbreaks are credited with the improvement of physical conditions, probably most tangibly expressed as protection of crops and cropland. Moreover, a vital value that cannot be expressed in physical terms or realized by those who have not experienced life in the Great Plains region, is the reinforcement of peoples' morale that comes with shelter from the ever-prevailing winds, shade from the sun's glare, the improved appearance of the landscape, a greater pride in ownership, and a real increase in value of property—all culminating in a general sense of being at home on the land. (Slightly edited from "Possibilities of Shelterbelt Planting in the Plains Region," 1935.)

In the century since the first homestead near Beatrice, Nebr., the trial and error experience of thousands of farmer and rancher tree planters, and the work of State and Federal agencies, has provided us with better knowledge of how to plant trees and windbreaks on the Plains.

This handbook summarizes what is known about the influences and values of windbreaks and gives practical recommendations for the planting and care of tree windbreaks in the central Great Plains. This area includes Nebraska, Kansas, eastern Colorado, and southern South Dakota.

Detailed information on species and special types of windbreaks for the northern Plains may be obtained from the U.S. Forest Service research office at Bottineau, N. Dak., the Agricultural Research Service Field Station at Mandan, N. Dak., and from the Soil Conservation Service and State and Extension foresters in both North Dakota and South Dakota.

Information for the southern Plains may be obtained from the Agricultural Research Service Field Station at Woodward, Okla., from the Soil Conservation Service, and State and Extension foresters in Oklahoma and Texas.

*Mr. Read is stationed at Lincoln, Nebr., in cooperation with the University of Nebraska Agricultural Experiment Station.

Why Plant Tree Windbreaks

Tree windbreaks are good investments on farms and ranches of the Great Plains. Windbreaks protect people, farmsteads, gardens, orchards, soils, field crops, livestock, wildlife, and public facilities from the extremes of Plains climate (fig. 1).

These extremes include years of low rainfall and high summer temperatures and years of scanty snowfall and low winter temperatures. Such extremes are accentuated by the persistent, high-velocity winds of Plains climate. Winds are especially persistent and strong during the late fall and early spring when most soils are not protected by growing crops. Wind erosion damages the structure and fertility of soils. Strong wind uncovers and blows away freshly sown seed, causes lodging of grain and corn, degrades fruits and vegetables, and drifts snow and soil across country roads.

In summer, hot, dry winds burn crops, decrease yields, increase water losses during irrigation, and dry out soils. In winter, cold winds make life difficult for people and livestock. Snow drifts into ravines and road ditches, depriving fields of needed moisture and blocking transportation and communication systems.

What can tree windbreaks do to moderate the damaging effects of wind on the Plains? Properly located windbreaks can provide protection in a variety of different ways. On *cultivated fields* they can improve microclimate conditions and crop production by:

1. Reducing wind velocity and soil erosion.
2. Modifying air and soil temperatures.
3. Reducing evaporation and transpiration.
4. Improving distribution of snow and soil moisture.



Figure 1.—Pattern of field and farmstead windbreaks in Oklahoma.

5. Improving distribution of water in sprinkler irrigation.
6. Reducing windburn and wilting of crop plants.
7. Protecting newly seeded crops from blow-out.
8. Protecting mature crops from lodging.

On the *farmstead*, in addition to beautifying surroundings, windbreaks can:

1. Reduce fuel requirements for house heating.
2. Reduce building maintenance costs.
3. Provide personal comfort in working areas.
4. Control snow drifting in work areas and driveways.
5. Protect poultry.
6. Protect sensitive garden and orchard crops.
7. Screen farmhouses from highway noise.

On *livestock range*, and pasture and feeding areas, windbreaks can:

1. Reduce mortality during blizzards.
2. Reduce feed requirements throughout the winter.
3. Maintain productivity and reduce calf losses.
4. Control snow drifting in feeding areas.
5. Improve forage production and quality.
6. Provide shade.

On *public facility* areas, such as along highway and railway rights-of-way, windbreaks can:

1. Protect roads and fences from drifting snow and soil.
2. Protect vehicles from strong, gusty side winds.
3. Protect camping and recreation areas from wind and dust.

In all areas of the Plains, trees and windbreaks can incidentally provide:

1. Beautification and landscaping.
2. Food and cover for wildlife.
3. Small wood products, such as fenceposts and fuel.

HOW WINDBREAKS AFFECT THE ENVIRONMENT

In the sheltered zone on the leeward side of windbreaks, the environment is distinctly different from that on open unsheltered fields exposed to wind. Within the sheltered zone, windspeed is reduced and this causes important changes in air temperature, atmospheric humidity, soil moisture, evaporation, and plant transpiration.

Effect on Wind Velocity

The amount and extent of wind reduction depends upon the characteristics of the tree barriers. Height, density, cross-sectional shape, width,

length, and continuity of barriers all have an important bearing on the extent and degree of protection.

Effect of Height.—Height of trees is probably the most important characteristic, because the distance that protection extends to leeward is proportional to the height of the windbreak. The distance that protection extends is therefore commonly expressed in windbreak heights (H 's). For example, the amount that wind is reduced will differ at leeward distances of 4, 10, or 20 times the average height of barrier, but the percent reduction at 4 H , for example, is the same regardless of barrier height (figs. 2 and 3). When wind direction is at a right angle to the long axis of a barrier, windspeed to leeward is significantly reduced for distances up to 20 times the average height of barrier. Small reductions in velocity extend to 30 H . In addition, there is a small reduction in windspeed at 2 to 5 H windward of certain types of barriers.

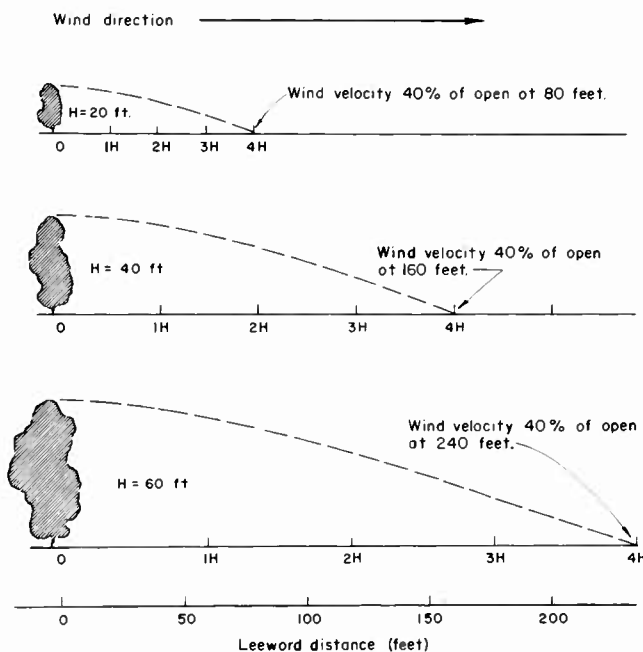


Figure 2.—Leeward distance of wind protection is proportional to height of barrier.

The percentage reduction in wind velocity at any particular H distance from a dense windbreak is relatively constant and does not depend upon how hard the wind blows. A windbreak that reduces a 20-mile-per-hour wind to 10 miles per hour at 8 H , will reduce a 40-mile-per-hour wind to 20 miles per hour at the same point (fig. 3). Although this relationship does not hold for more permeable type windbreaks, it is given here only as a rough guide. More important is the ability of windbreaks to reduce wind to less than 12 to 15 miles per hour, which is the threshold velocity above which soils begin to move.

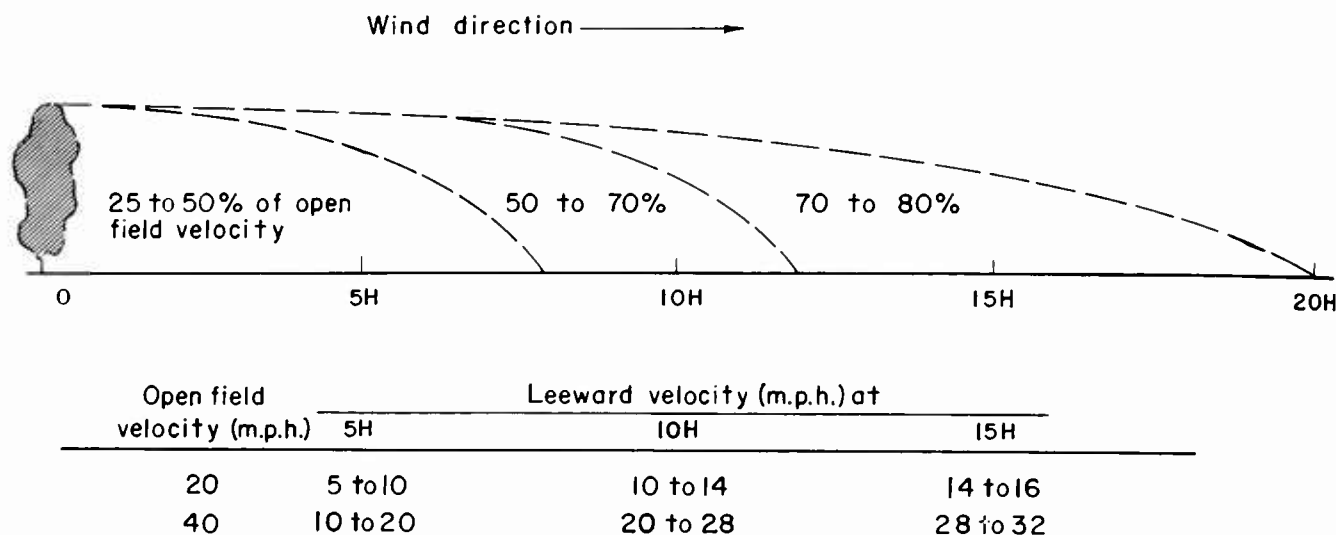


Figure 3.—Zones of reduced wind velocity leeward of barrier as percentage of open field velocity. Examples of actual leeward velocities with open field winds of 20 and 40 m.p.h. Vertical scale exaggerated.

Effect of Density and Width.—Density of a windbreak also influences the reduction of wind velocity. Very dense windbreaks reduce wind-speed in the 0 to 10 H zone more than open ones, but the leeward distance of effective reduction is limited. Moderately dense barriers reduce wind-speed over a greater leeward distance than very dense ones (fig. 4, *C*). Windbreaks with a very permeable lower level do not reduce wind-speed so much as dense ones, but the maximum reduction occurs at a greater distance leeward (fig. 4, *B*). Open or "loose" windbarriers, very permeable from top to ground, provide relatively small reductions near the barrier, and practically none beyond 10 H (fig. 4, *A*). Moderately dense windbreaks, which act as a filter rather than as a solid barrier, are generally considered the best. Density of 50 to 65 percent is considered best for field windbreaks in Denmark, Switzerland, Great Britain, and Russia. However, in Nebraska and South Dakota, the greatest gains in corn yields were produced leeward of windbreaks having a density of about 80 percent.

Narrow windbreaks of moderate density are as effective as wider ones. In fact, windbreaks wider than 5 H may actually be less effective than narrower ones (fig. 5). It should be kept in mind, however, that single rows of one species have no safety factor, because dead trees may leave gaps in a single row and seriously reduce windbreak efficiency.

Effect of Cross-Sectional Shape.—Cross-sectional shape of tree barriers also influences wind velocities to the leeward. Vertical-side windbreaks appear to provide greater wind reduction over a wider leeward area than windbreaks with inclined slopes. Because some wind is forced directly through the barrier, the area of reduced wind-speed is extended farther to the leeward (fig. 6). A

smooth inclined slope is assumed to offer less resistance to wind. However, results of research on what constitutes the best cross-sectional shape for greatest windbreak effectiveness are contradictory, and no definite conclusions can be stated until more information is available.

Effect on Air Temperatures and Humidity

Air temperatures are modified in the protected leeward zone of windbreaks. In the lee (to the north) of a moderately dense windbreak in central Kansas during July (fig. 7), midday air temperatures 1 to 4 feet above plowed soil in a zone 0 to 4 H from the windbreak were up to 6 degrees warmer than in the open. But in the 6 to 24 H zone they averaged 2 to 5 degrees cooler than over open unsheltered fields. At night, air temperatures near the ground from 0 to 30 H were 1 to 2 degrees warmer than in the open. (See also examples of effects, items 1 to 5, appendix p. 58.)

Air in the sheltered area of windbreaks is generally more humid than on unprotected areas. Averages of 2 to 4 percent higher relative humidity have been recorded in windbreak-sheltered areas as compared with open areas in the Plains of the United States and on the Russian steppe. In dry, hot weather this effect may extend a quarter of a mile from the windbarrier, depending upon its height. (See also examples of effects, items 8-13, appendix pp. 58-59.)

Effect on Evaporation

Evaporation is greatly reduced in the lee of windbreaks, owing to reduced wind movement and air temperature, and increased atmospheric humidity (fig. 8). Evaporation may be reduced

Wind direction $\longrightarrow$

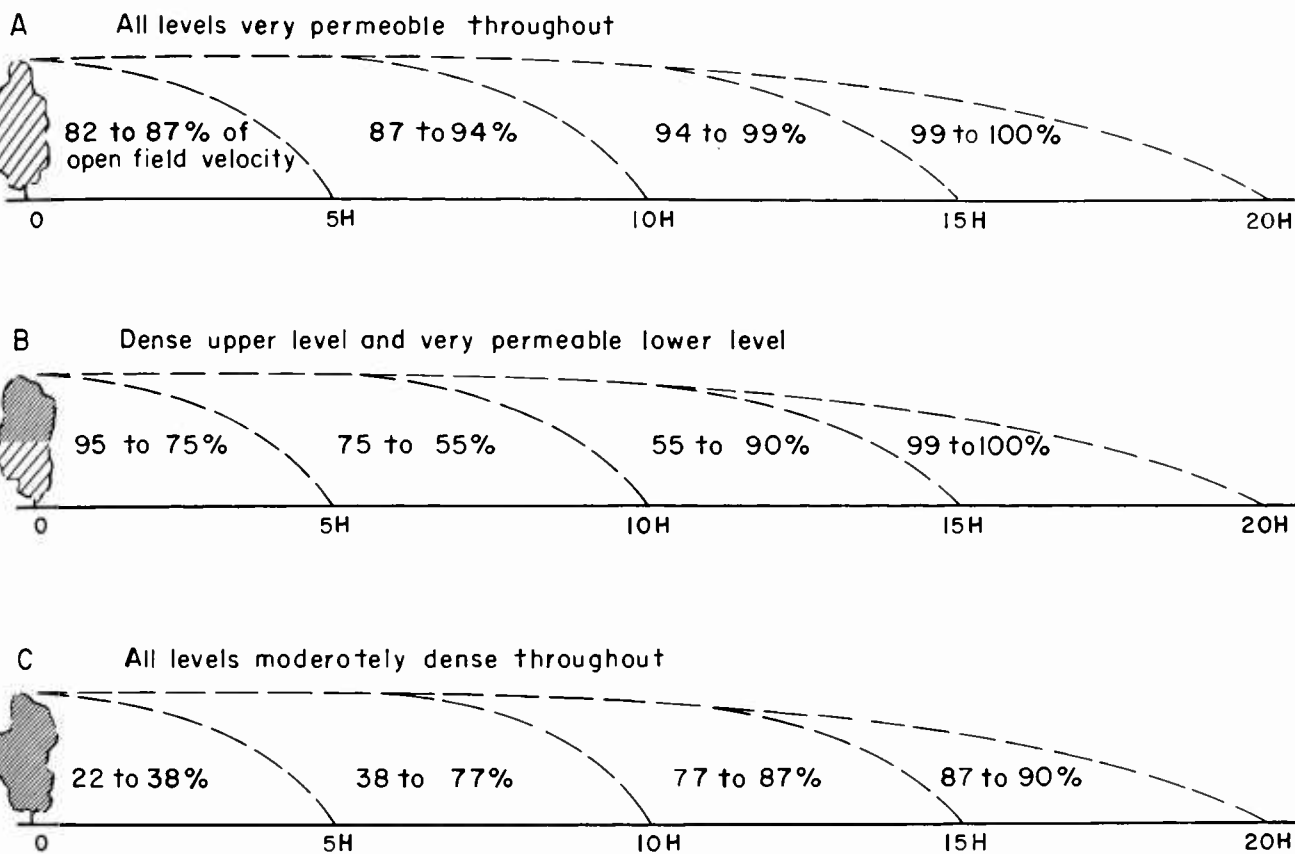


Figure 4.—Zones of reduced wind velocity as percentage of open field wind (5 feet above soil) leeward of barriers of various density. Vertical scale exaggerated. (After Soegaard, 1954.)

Wind direction $\longrightarrow$

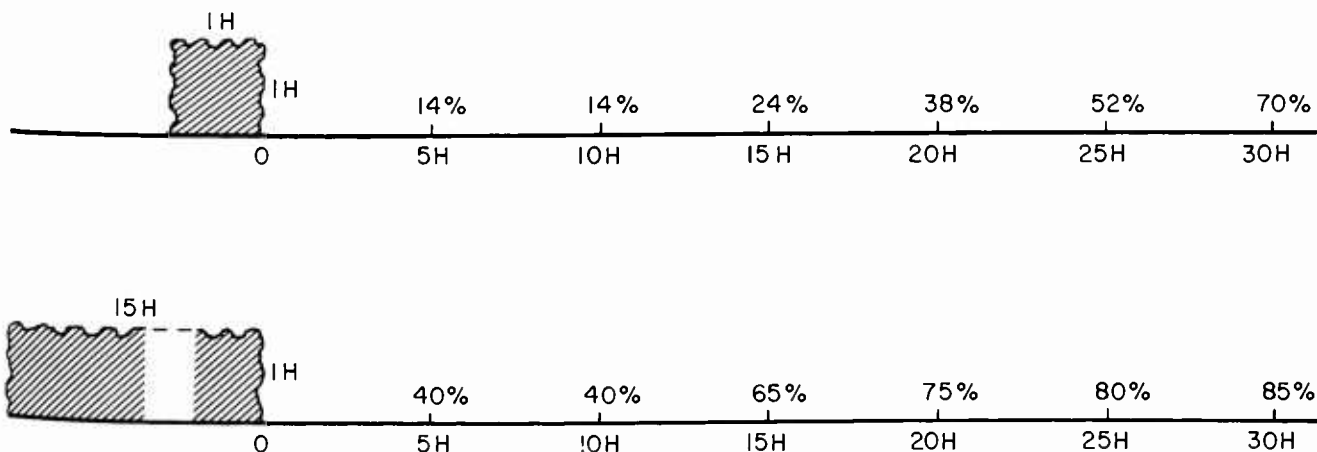


Figure 5.—Zones of reduced wind velocity as percentage of open field wind (at 0.2 H above surface) to leeward of vertical-face artificial barriers of different widths in wind tunnel. Scale of models exaggerated. (After Caborn, 1957.)

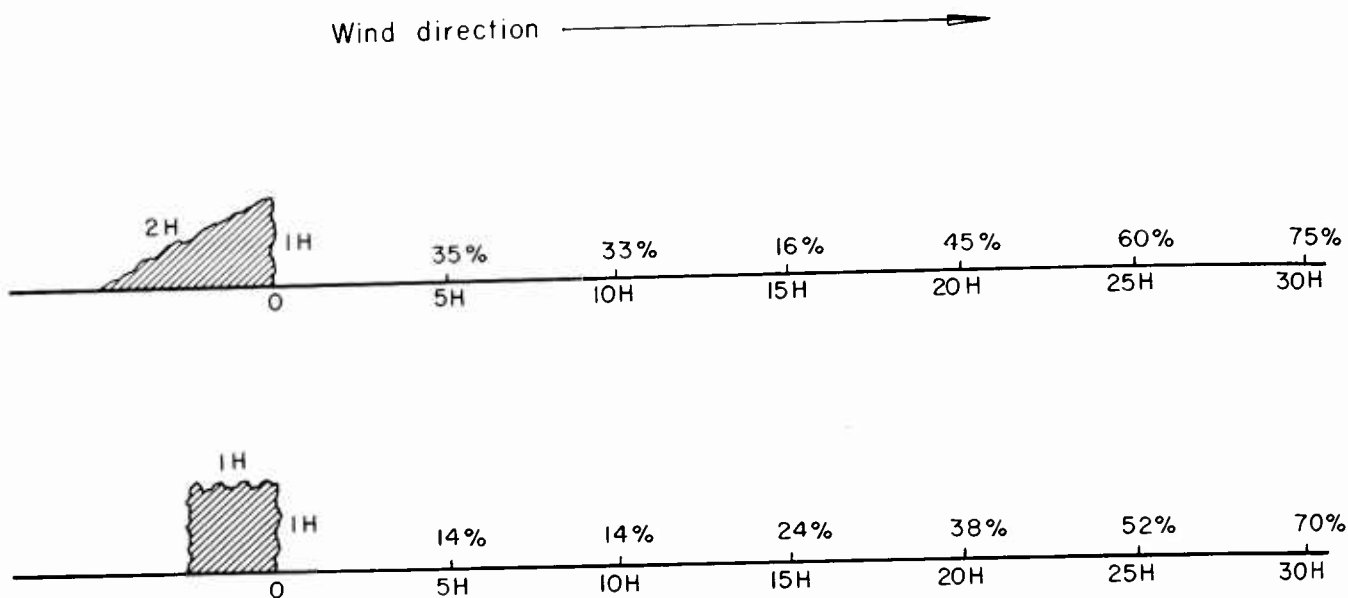


Figure 6.—Zones of reduced wind velocity as percentage of open field wind (at 0.2 H above surface) to leeward of different cross-sectional shaped artificial barriers in wind tunnel. Scale of models exaggerated. (After Caborn, 1957.)

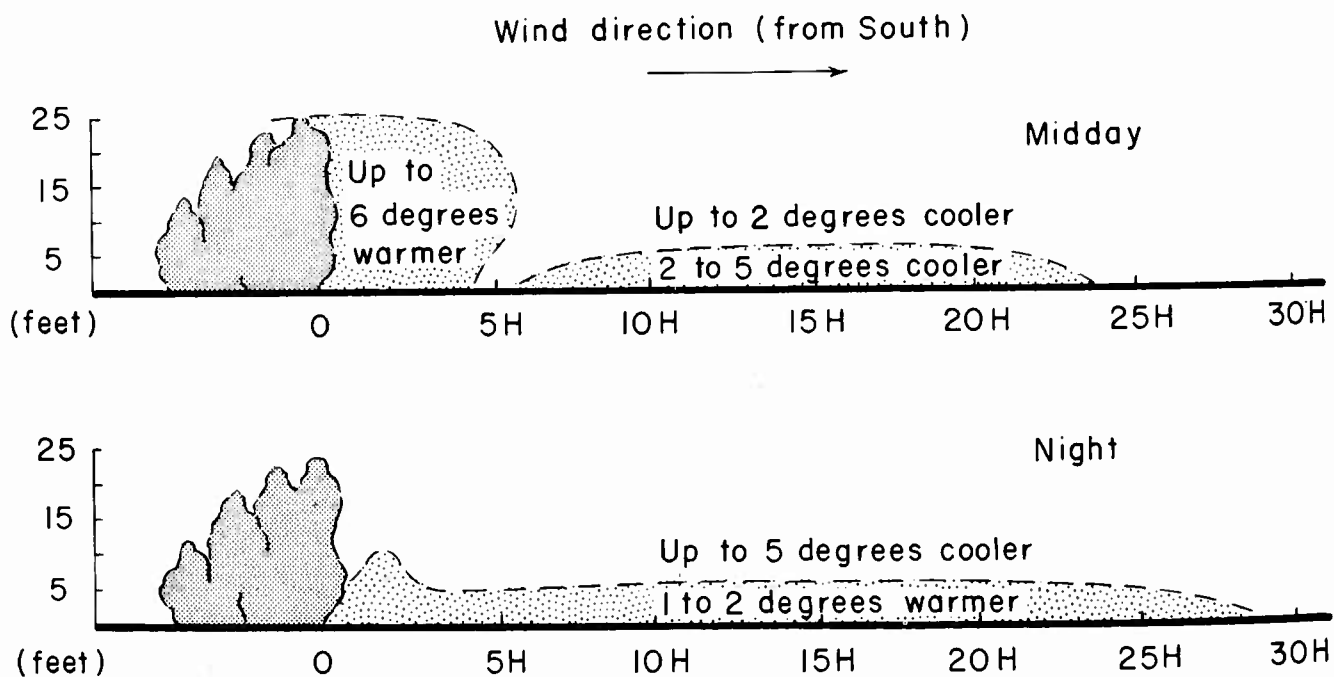


Figure 7.—Air temperature zones leeward of a 25-foot-tall moderately dense windbreak, compared with open field temperatures. Wind at 14 to 20 m.p.h. with open field temperatures ranging from 86° to 110° F. in Kansas during July. Vertical scale exaggerated. (After Woodruff et al., 1959.)

Wind velocity 20 m.p.h. →

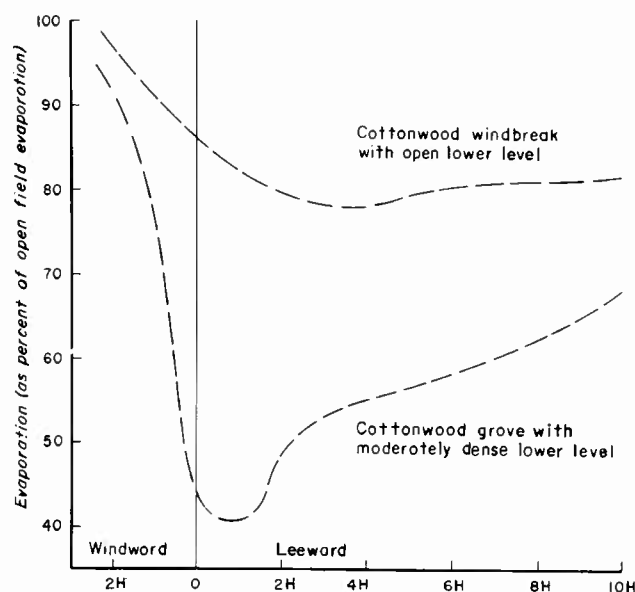


Figure 8.—Percent of open field evaporation windward and leeward of cottonwood windbreaks of different structure. (After Bates, 1911.)

in an area extending 24 H to leeward. Reduced evaporation conserves water during sprinkler irrigation and reduces the loss from reservoirs and ponds. Evaporation is reduced more under fast than under slow wind movement. Reduction in evaporation is proportional to windbreak density, so that permeable barriers, especially those with a sparse lower level, are not so efficient as dense barriers in reducing evaporation (fig. 8). (See also examples of effects, items 14–20, appendix p. 59.)

Effect on Soil Temperatures

Windbreaks influence the temperatures of soils near and directly beneath the trees, but differences at 20-inch depth beyond 1 or 2 H from barriers are negligible. Nevertheless, surface soil temperatures are higher in spring and summer, and lower in fall and winter in the sheltered area than in open, unsheltered areas. (See also examples of effects, items 6–7, appendix p. 58.)

Effect on Soil Moisture and Snow Drifting

Windbreaks conserve soil moisture in their lee by reducing evaporation and transpiration and by controlling distribution of precipitation, especially snowfall. Snow commonly blows off bare open fields and contributes little to field soil moisture. Distribution of snow in sheltered areas depends upon structure of the barrier (fig. 9). Windbreaks with dense lower levels cause snow to drift deeply

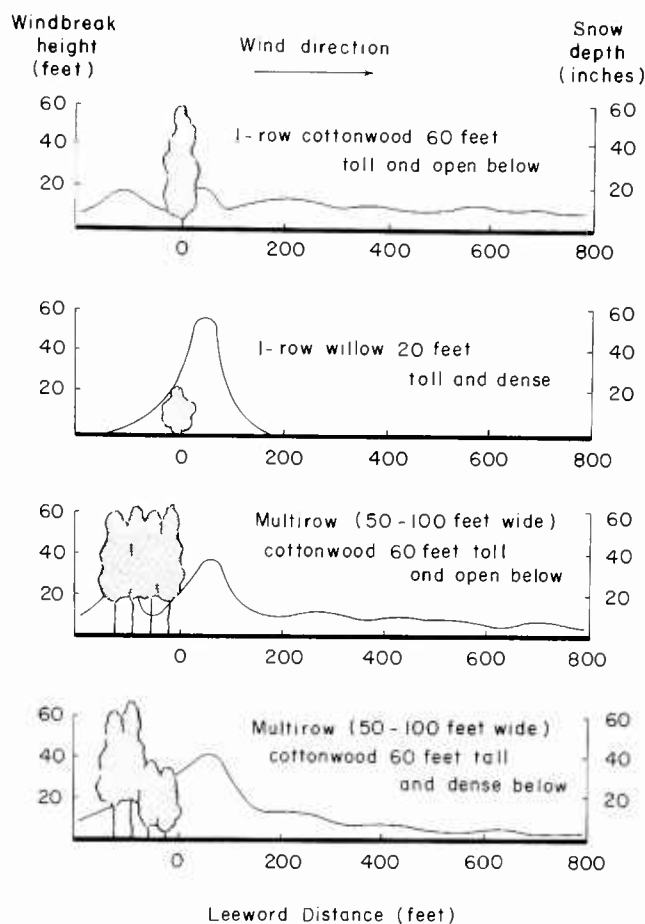


Figure 9.—Profiles of snow depth as influenced by windbreaks of different width and structure. Vertical scales of tree height in feet and snow depth in inches are exaggerated. (After Bates and Stoeckeler, 1941.)

within or near the leeward edge of barriers. Barriers with more permeable lower levels cause 60 to 80 percent of the snow to spread out over leeward fields. Drifting patterns correlate closely with reductions in wind velocity. Windbreaks prolong snowmelt on protected fields and thus reduce moisture loss by evaporation. (See also examples, of effects, items 21–25, appendix pp. 59–60.)

Despite greater water uptake and greater yields by crops on fields protected by shelterbelts, the amount of moisture remaining in soil in some areas has been found to be greater than in unprotected fields. Effects of windbarriers on soil moisture in the area of 0 to 2 H, however, are complicated. Increases due to snow drifting, shading, and reduced evaporation may be offset by moisture utilization by the trees. (See also examples of effects, items 26–33, appendix p. 60.)

Accumulation of snowdrifts within and adjacent to windbreaks results in a larger area of unfrozen or porously frozen soil than open, unprotected areas where soil freezing is deep. This soil condition provides for greater water infiltra-

tion and consequently reduces water loss and soil erosion caused by rapid spring runoff. (See examples of effects, item 34, appendix p. 60.)

Effect on Soil Properties

Windbreaks have improved soil properties in fields as far leeward as 5 to 7 H from the trees. Improvements have been noted in physical and

chemical properties, including increased organic matter, permeability, porosity, aggregation, infiltration, and depths of A horizon. (See examples of effects, items 35-45, appendix p. 61.)

Typical examples of research on the influences of windbreaks on air and soil temperature, air humidity, evaporation, snow distribution, runoff, soil moisture, and soil structure are listed in the appendix, p. 58. Omission of any items in the listings indicates that no data were available.

How Windbreaks Affect Plants and Animals

The sheltered areas produced by windbarriers are generally more favorable for growth of plants and animals than an open, unsheltered environment. Windbreaks reduce wind movement, daytime air temperatures, and evaporation, and increase atmospheric humidity. These modifications of environment reduce transpiration of field crops and conserve soil moisture. The influences of a windbreak on plant transpiration in Kansas during hot, windy July days has been computed by formula using wind velocity and air temperature data. Transpiration in the lee of the windbreak 0 to 20 H ranged from 79 to 95 percent of open-field rate. The greatest daytime reduction, to 79 percent of open-field transpiration, was found at distances of 2 and 8 H. Beyond 25 H the reduction was negligible. At night the transpiration rate at 2 H leeward was 69 percent of open-field rate.

Plant growth proceeds most rapidly when the cells of growing tissues are full of water. When cell water drops below full capacity from excessive transpiration, unavailable soil moisture, or both, the physical and chemical processes of growth are slowed. At the extreme, plants wilt under stress of limited moisture, especially when accompanied by wind and high temperatures.

Carbon dioxide, which is essential for plant growth, tends to accumulate in areas of reduced wind. Consequently, more carbon dioxide is available for plant growth in the lee of windbreaks than in the open. Furthermore, more is utilized by the plants because the stomata of the leaves, through which the carbon dioxide enters the plants, remain open longer each day when the level of moisture in the plants is high.

Effect on Crops

Greater yields of field crops have been found in the shelter of windbreaks than in the open in many parts of the world (see examples of effects, appendix p. 62). The amount of change in yields varies from test to test because of differences in structure and location of windbreaks used and in climates and weather. Short, permeable wind-

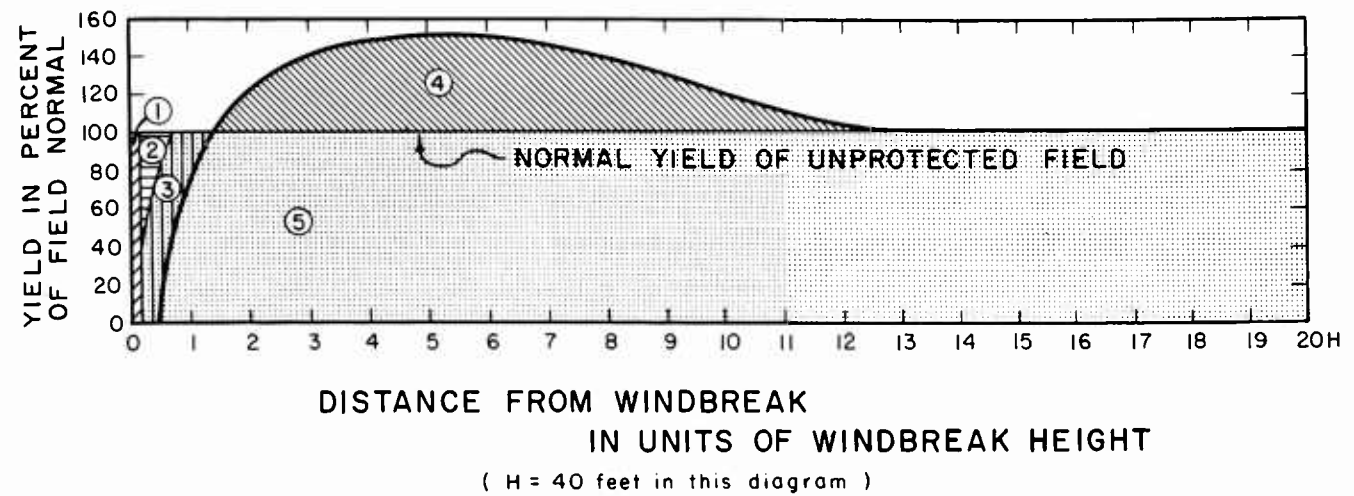
breaks differ in effects from tall, dense ones. Minimum benefits are to be expected in cool, moist climates or seasons that have little wind; maximum benefits in hot, dry, and windy climates or seasons. Despite differences, real benefits have been found in the shelter of many types of windbreaks in many climates. The general effect of field windbreak protection on yields of corn and small grain as derived from data obtained during 1935-41 in the Great Plains region of the United States is shown in figure 10.

A narrow strip of ground about 1 H wide paralleling tree barriers on both sides is often unfavorable for crops (fig. 11). These strips are occupied by tree roots which use soil moisture and nutrients. There is some evidence that this unfavorable effect may also be related to shading and higher air temperatures. Crop yields may be reduced to nothing in these strips. However, the area affected unfavorably is relatively small compared to the area favorably affected by windbreaks (see numbers 3 and 4 of figure 10). Further discussion of this effect will be found in the section on "Limitations," p. 15.

Effect on Farmsteads and Livestock

Properly located tree barriers can improve the local environment of farmsteads, where many daily chores are done. Reduction of winter wind movement permits homes to be kept more comfortable with less fuel. Windbreaks can control snow drifting and provide clear working areas after severe storms (fig. 12, A). Lessened exposure of buildings to the elements reduces maintenance costs for wind damage and paint. Properly arranged and located windbreaks can also reduce dust and soil movement and improve comfort on the farmstead during hot, dry summer weather.

Tree windbreaks about feedlots will protect cattle from winter winds and control drifting of snow (fig. 12, B). Shelter from the cold blizzard winds reduces storm-caused mortality, enables the cattle to maintain better weight with less feed, and reduces calf losses. If snow drifting is controlled, feed areas can be kept free of drifts.



LEGEND

EFFECTS ON OPEN, UNPROTECTED FIELDS

- ① UNPLANTED FIELD BORDERS
- ② NORMAL CROP LOSS AT FIELD BORDERS
- ⑤ NORMAL CROP YIELD OF FIELD

ADDITIONAL EFFECTS ON WINDBREAK PROTECTED FIELDS

- ③ CROP LOSS IN SAPPED STRIP NEAR TREES
- ④ CROP GAIN DUE TO WINDBREAK EFFECT
- ④ - ③ NET WINDBREAK EFFECT

Figure 10.—Cross section of crop yield on a field leeward of a windbreak. (After Stoeckeler, 1962.)



Figure 11.—Unfavorable effect of windbreak on crops shows up on 12 rows of corn in this irrigated western Nebraska field. The main windbreak trees are Siberian elm, 45 feet tall. (Photo courtesy of W. T. Bagley, University of Nebraska.)



F-453801-408999

Figure 12.—A, Properly located windbreaks protect this farmstead winter and summer. B, Beef cattle and sheep feeding in protected leeward space behind a tall, wide windbreak.

The influences of windbreak shelter have been studied in many countries of the world. Results have differed with kind of crop, previous cropping history, moisture, weather, density of windbreak, and other factors. Results of many of these studies are condensed in the appendix, p. 62. The

results show that in the majority of cases, beneficial effects on crops, livestock, farmsteads, and facilities have been demonstrated under windbreak shelter protection in windy agricultural regions throughout the world.

How To Use Windbreaks for Protection

Protection tree plantings on agricultural lands are long-term investments in soil and water conservation. Although tree windbreaks will give some early protection, they normally will require 30 years to reach full protective effectiveness in the central Plains. Since in most situations they will remain useful for another 25 to 30 years, the planting and care of them will span more than a generation. Careful planning is therefore essen-

tial to protect the investment and to insure continued long-term benefits. Mistakes in tree selection, arrangement, spacing, and location can be costly.

Windbreak systems can be fully effective only if used to supplement other soil conservation practices, such as stubble tillage, cover crops, and strip-cropping. Windbreak systems are a part of overall farm planning; the soils and topography of

fields, terraces, waterways, pastures, and other uses will greatly affect and often limit their location. Therefore, the entire plan of farm land use must be considered in locating permanent structures such as tree barriers. The windbreak system should be planned and laid out on a large-scale aerial photograph of the farm or ranch. Using this method (fig. 13), the adequacy of windbreak protection in relation to all land uses can be visualized.

The owner or manager should list the purpose of windbreak protection for each field or unit of land use. It is essential to decide on purpose at the outset, because this will determine what planting specifications are to be used to provide the windbreak structure that will accomplish specific objectives.

As emphasized in the first section, the density of different height levels in windbreaks has an important influence on pattern of wind velocity

reduction to leeward, and consequently on other microclimatic factors. Windbreaks of different structures are required to satisfy different objectives. For example, the wind reduction needed for a farmstead should be greater but over a smaller area than that required for a field windbreak. This difference in objectives will require different kinds and numbers of trees, and different arrangement and spacing intervals between trees, rows, and barriers.

SINGLE PURPOSE VERSUS MANY PURPOSES

Although windbreaks are often planted to serve several purposes, they cannot ordinarily serve all purposes equally well at the same time. As mentioned previously, the patterns of wind reduction required by one objective are often different from



SCS-D-2728

Figure 13.—Windbreak protection patterns should be planned in conjunction with total land use planning for the farm and ranch

those required for another objective. Variations in density, width, and shape of barrier are required to obtain different patterns of wind velocity reduction and their accompanying effects on temperature, evaporation, and snow accumulation. Therefore, if plantings are to provide maximum benefits, the owner's decisions as to specific kinds and arrangements of trees to attain major objectives in structure must take precedence over other considerations.

Multiple-use windbreaks designed to satisfy several objectives have been tried in the past, with only moderate success. Results of such plantings after 20 years do not appear to justify the combination of several objectives into one type of planting. For example, windbreaks intended for field protection should not include trees such as black walnut and apricots, ostensibly for fruit production. Such trees occupy considerable space, yet contribute little to windbreak effectiveness. Again, field windbreaks intended for maximum snow spreading on leeward fields should not include low shrubby species for wildlife food and cover. The ground level density of shrubs, in this instance, will defeat the main objective by creating snowdrifts near the windbreak instead of spreading it over leeward fields.

Windbreaks should ordinarily be planted with one primary purpose in mind. This should determine, within limitations of the soil, the species, their arrangement, and spacing. Variations may be used to fulfill an incidental or subordinate objective, provided this does not interfere with proper functioning for the primary objective. The primary purpose, however, should have exclusive priority in deciding as to species, arrangement, and spacing that will influence windbreak structure.

Recreational, esthetic, and wildlife values are nearly always present as incidental values of tree plantings, regardless of major purposes. Such incidental values therefore need not be of primary consideration in planting field windbreaks, farmstead windbreaks, or livestock and road protection windbreaks. If recreational areas or wildlife habitats are desired as primary reasons for tree planting, these objectives should be so stated, and the plantings made for those purposes, and not for wind protection of fields, homes, etc.

TYPES OF WINDBREAKS AND THEIR FUNCTIONS

Windbreaks may be classified into four general types, according to location and objectives of protection:

1. Field windbreaks, often called shelterbelts—to protect extensive areas of cultivated fields from wind erosion and to provide more favorable environment for growing crops.

2. Farmstead windbreaks—to protect a limited space of living areas in and around the farm home, barnyards, feedlots, and gardens for greater year-round comfort, convenience, and productivity.

3. Pasture and range windbreaks—to protect limited areas in which livestock range and feed, and to provide more favorable environment for forage and animal growth over more extensive areas.

4. Public facility windbreaks—to protect highway and railway travel routes and recreational areas from strong winds, soil blowing, and snow drifting.

Field protection may require several kinds of windbreak structures, depending upon objectives. For example, a barrier for snow distribution should have a different density and spacing interval than a barrier intended to protect crops from hot winds. Moreover, barriers intended primarily for wind erosion control are likely to differ from either of those just mentioned in density and spacing intervals.

The structure of farmstead windbreaks, on the other hand, can be limited to a fairly standard arrangement. There is usually only one objective—providing the greatest reduction in wind velocity around the farm buildings. Influence upon wind and drifting snow over a large leeward area is usually not important in such plantings.

The structure of pasture and range windbreaks may vary, as in the field barriers, because of different objectives. Barriers for maximum protection of livestock in feeding areas must be dense enough to control snowdrifting near them, while barriers to improve snow distribution over grassland require more permeability. For temporary livestock shelter during severe winter storms another type of barrier is needed. Such a windbreak should be very wide in order to accommodate the livestock herd.

The structure of barriers along railways and highways may be fairly standard because the major objective is to control snow and soil drifting.

Windbreaks for Field Protection

Objectives.—Tree barriers on cultivated fields are usually planted for more specific objectives than are barriers in other locations. For one thing, the areas to be protected are larger than farmsteads or livestock feeding areas. Secondly, field barriers may be desired for several different objectives, each requiring a slightly different type of structure.

Some of these different objectives are:

1. To reduce soil movement and damage to crops during windstorms.

2. To protect growing crops from extremely hot and desiccating winds.

3. To provide better retention and distribution of snow on fields.

4. To reduce evaporation and improve distribution of sprinkler irrigation water.

Pattern and Orientation.—In planning windbreaks for field protection, it is desirable to think in terms of patterns for complete protection, not just isolated windbreaks oriented in one direction. The best protection requires a pattern or grid consisting of individual windbreaks oriented in several directions and at close enough intervals to protect all fields.

The maximum protected area leeward of parallel barriers at 20 H intervals occurs when wind blows at right angles to them. A series of such parallel windbreaks, though not providing a cumulative effect, does create a larger area of stilled air than the same number of isolated barriers spaced at greater intervals. However, when wind direction changes, the axis of maximum wind velocity reduction shifts and the area of protection decreases (fig. 14). Snowdrifting patterns and the effects upon soil moisture are shifted in relation to the barriers as prevailing winds change during snowstorms. The area affected by favorable change in temperature, humidity, and evaporation is likewise shifted and reduced in size.

The effect of shifting wind direction can be minimized by establishing complete patterns of windbreaks (fig. 15). Thus windbreaks at intervals not exceeding 20 H and oriented in two directions will create a grid or "baffle" within which the "climate" or environment near the ground is significantly different from that on an open plain. Complete patterns are essential for maximum protection because winds blow from nearly all directions sometime during the year.

The establishment of windbreak patterns in level country presents few problems. Since winds in Nebraska and Kansas prevail from the south during the growing season and from the northwest during fall, winter, and early spring, the basic pattern of barriers should be oriented east-west. Patterns should be completed with north-south barriers at 20 H intervals or less to provide maximum protection.

The cardinal directions are given here merely as examples. Where farm fields are planned for conservation practices such as stripcropping, the pattern of windbreaks should conform with the field margins or subdivisions thereof.

Establishment of patterns in rolling country is more of a problem. Where slopes exceed 5 percent, windbreaks should follow as closely as possible the contours of rolling topography. Contour planting will reduce to a minimum the variations that commonly occur in tree survival and height growth, when part of the windbarrier is on one kind of soil and part on another. Since contour

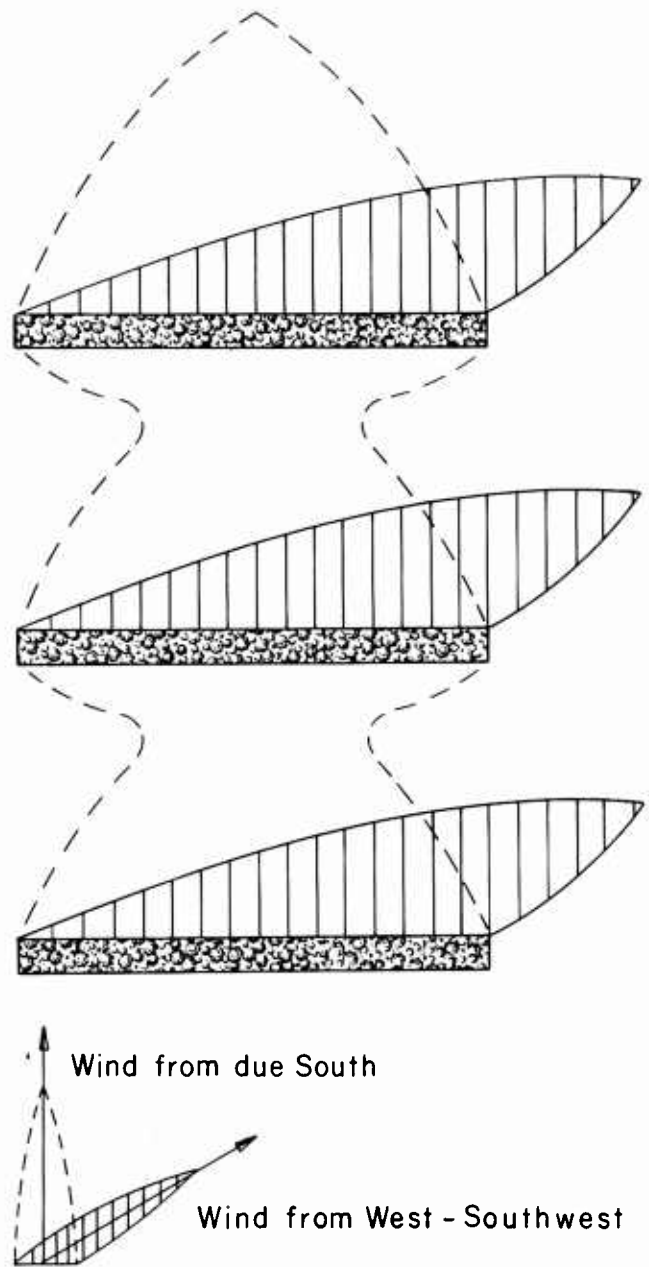


Figure 14.—Comparison of protected areas leeward of parallel barriers when wind direction changes.

windbreaks will not always be oriented to provide maximum protection from prevailing winds, the establishment of supplemental cross barriers should be considered. Cross barriers to complete the patterns of contour-planted windbreaks should not be used on steep slopes, however, unless special practices are undertaken to prevent water erosion. Contour windbreaks should always be planned as part of terracing systems so that trees will have the advantage of extra moisture from the terraces.

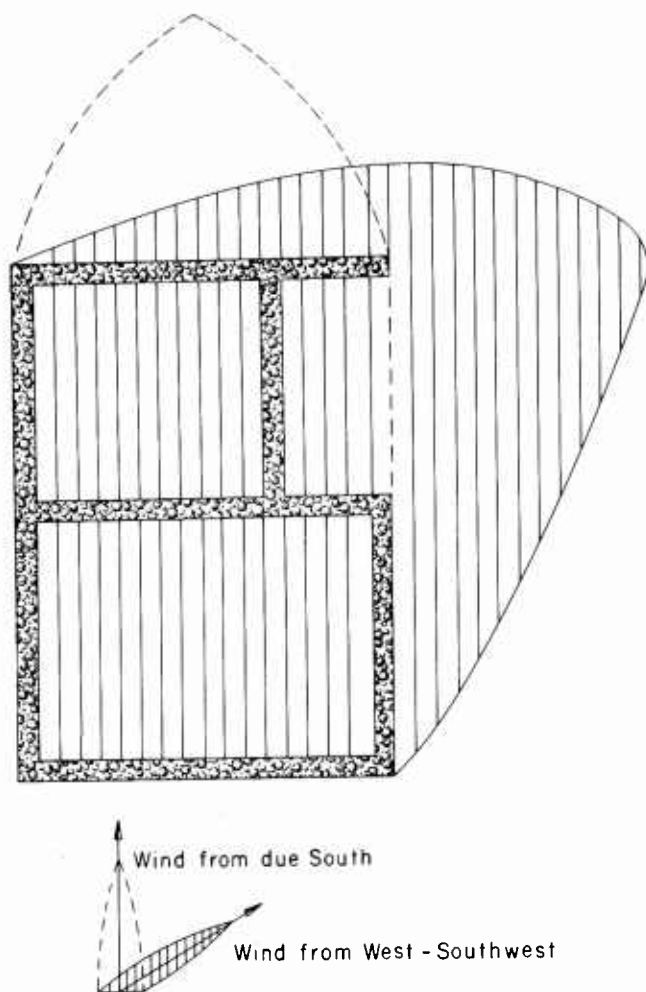


Figure 15.—Comparison of protected areas leeward of a pattern of barriers when wind direction changes.

Intervals.—Distance intervals between windbreaks in the pattern depends upon the maximum effective height attainable by the species planted as the tall component. This interval should not exceed 20 times the average height at 20 years, and for best protection it should be about 15 heights.

Since trees do not grow as tall on upland sites as on lowland sites, the actual distance ($20 H$) between windbreaks on uplands will be less. Intervals between windbreaks on sloping ground should be slightly less than on level ground.

Generally, the maximum height attainable by Siberian elm and ponderosa and Austrian pines on upland soils in central and eastern Nebraska and Kansas is about 45 to 50 feet. The elms attain this height in 20 years and the pines in 40 years. This requires a $20 H$ interval not exceeding 800 to 1,000 feet between windbreaks. In the western Plains where maximum tree height on uplands is only 25 to 35 feet, the distance between windbreaks should not exceed 500 to 700 feet.

On lowlands, bottomlands, terraces, and uplands with water table easily accessible to tree

roots, the distance between windbreaks can be as much as 1,200 to 1,500 feet. Cottonwoods on these sites will provide effective heights up to 80 feet. More detailed information on selection of species for height growth on various kinds of soil will be found in the next section.

Where complete protection is wanted before the windbreak trees reach maximum height, the spacing interval should be reduced by one-half, and temporary barriers of fast-growing trees should be planted in the alternate intervals. These should then be removed when the main windbreaks reach maximum height and effectiveness.

Continuity.—If there are gaps in barriers, the wind will stream through them with a jet effect. Velocity through these gaps is usually higher than in the unprotected open fields, but the increased windspeed does not extend far to the leeward (fig. 16).

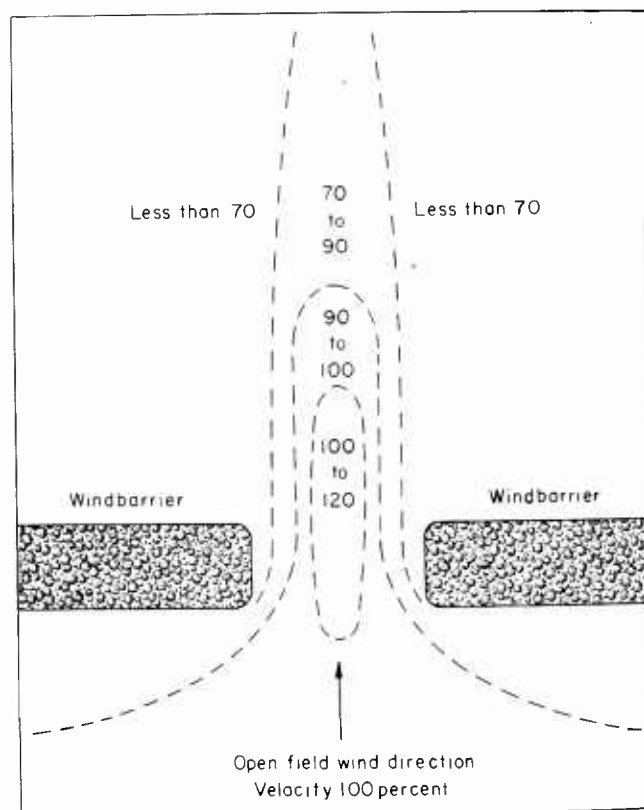


Figure 16.—Percent of open field wind velocity through and leeward of a 30-foot gap in a windbreak. (After Nägeli.)

The danger of increased velocity through gaps and around ends, however, lies in soil erosion and damage to the adjacent edge trees, which are subjected to greater stresses than those of the interior stand. This is one of the reasons that shrubs or conifers are recommended for low-level density at the ends as well as on both sides of windbreaks.

Good windbreak systems have few gaps in them. It is important to plan the location of windbreak patterns to avoid spots of unfavorable soil where trees may die early or not survive at all. Once the plantings are made, it is necessary to replant gaps or fail spots within the first 2 years.

Roadways or lanes through windbreaks wider than 50 feet should be located at an angle through the plantings so that prevailing winds will seldom blow through these gaps (fig. 17). The corners of windbreak patterns, especially those corners subjected to strong northwest winds, should be rounded and reinforced with an extra row of shrubs. Curved rows around a corner are an advantage in cultivation, in addition to maintaining better continuity. The ends of rows should be planted to shrubs and conifers in order to provide low, dense foliage at windbreak ends comparable to the continuity of the frontal faces.

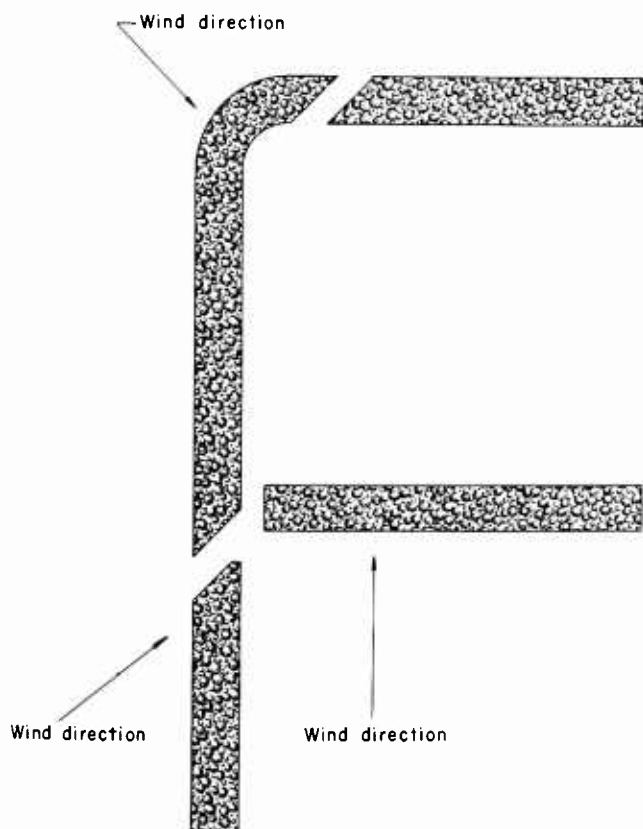


Figure 17.—Examples of roadway or lane location through windbreaks to minimize effect of gaps.

Dimensions.—Length of individual barriers is not important with complete patterns of windbreaks. The effectiveness of any single windbreak in a pattern depends on the orientation, interval, and continuity of others in the system.

Width of field barriers is important only insofar as it affects density. Making windbreaks

wider than is necessary to attain moderate density will have little direct effect in reducing wind velocity.

Barriers on cultivated fields, therefore, should be as narrow as practicable, while containing sufficient tree rows for the required density at all height levels. If moderately dense foliage is required, barriers need be only two to three rows wide. Where greater density is needed at all levels from ground to maximum height, wider barriers of five to seven rows should be used.

Single rows of trees or combinations of trees and shrubs in one row are frequently recommended by the Soil Conservation Service in various areas of the Plains in order to develop complete patterns. When used in patterns at close intervals, single rows of trees and shrubs may furnish a moderate amount of protection. However, single rows do not normally produce the foliage density at all height levels comparable to that attained by several rows of different species of trees and shrubs. Moreover, single rows are more likely to develop gaps that reduce the effectiveness of windbreak systems.

Limitations.—Patterns of field windbreaks will naturally restrict use of farm machinery as compared with its normal use in open fields. This is a limitation only insofar as the landowner wants it to be. Farming with windbreaks requires modification of some practices, as does farming with terraces.

Patterns of field windbreaks will result in strips of land that are unproductive for crops because of competition for moisture and nutrients by tree roots and because of shading. This area must be considered as part of the land devoted to the trees, in exchange for real environmental benefits over a much larger area of cropland. These so-called “sapped” strips may often be used as field roads, or they may be planted to some early-maturing crop that will not be affected by shading and moisture competition.

Field windbreaks should be located where they will provide greatest benefit, yet not interfere with other land uses, travel routes, or public utilities. If they are located too close to road rights-of-way, they create serious problems such as snowdrifting on the road, blind intersections, interference with communication and power lines, and increased likelihood of damage by wildfire. Therefore, windbreaks paralleling roads should be located at least 300 feet from rights-of-way. The corners of windbreak patterns or the ends of individual barriers should not be closer than 300 feet from road intersections.

Location and orientation of windbreak patterns should be planned with as complete a knowledge of soil conditions as possible. Soils may often be the limiting factor in deciding what species to use and where to plant. Location and orientation pattern should avoid certain soils or other local

conditions unfavorable for tree growth. Likewise, a compromise may be needed to take advantage of locating windbreaks on the better soils. Evaluation of sites for determining choice of species for greatest windbreak effectiveness is covered in detail in the next section of the handbook.

Windbreaks for Farmstead Protection

Objectives.—Tree barriers adjacent to the farm and ranch home, about other farm buildings and feedlots (fig. 18), and surrounding orchard or garden areas, have as their major objective the control of wind and temperature. Maximum reduction of wind velocity will normally control snowdrifting. Some of the objectives are:

1. To prevent snowdrifting on driveways and work areas.
2. To reduce fuel requirements for house heating.
3. To reduce weathering of paint and other maintenance expenses.
4. To protect sensitive crops in garden and orchard.
5. To control snowdrifting in livestock feeding yards.
6. To provide more comfortable and quiet working conditions.

Orientation.—Since the area of the farmstead, its miscellaneous buildings, and its garden area is usually rather small compared with that of fields, there is no need for patterns of barriers. Rather it is the location, orientation, and windbreak density in respect to these facilities that is of

greatest importance. Main windbreaks for farmsteads in the central Plains should be oriented in a near north-south direction to the west of, and in an east-west direction to the north of all buildings. In addition, a more permeable type windbreak should be located to the south of farmsteads for protection against hot southerly winds. Farmstead windbreaks need not, however, be restricted to cardinal directions in straight rows, as long as their placement is such that the buildings to be protected are well within the leeward area of winds coming from the north through west to southwest (fig. 19).

Dimensions.—Considerable leeway in width and length of windbreak is allowable for farmstead protection in contrast to field windbreaks. The main requirements are: (1) Adequate low-level density to reduce wind velocity and force snowdrifting close in, (2) adequate height to provide at least 50 percent wind reduction over the farmstead work area, and (3) adequate length to cover most areas as winds shift from north through west to south. The importance of keeping the size and number of gaps at a minimum is just as great as with field windbreaks.

Limitations.—Windbreaks for farmsteads have often been placed too near houses and other buildings. The consequences have been snowdrifting in the very areas that should be free of snow, and oppressive heat during the summer in place of cooling air movement. Windbreaks for farmsteads should be located at least 100 to 150 feet, but not more than 300 to 400 feet, distant from the buildings to be protected.



Figure 18.—Conifer windbreaks protect livestock feeding facilities from strong wind and snowdrifting.

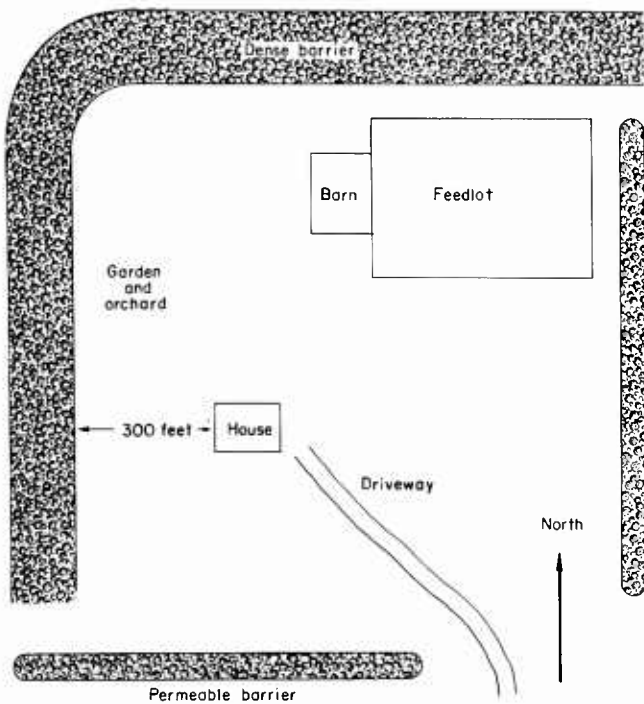


Figure 19.—A suggested plan for windbreak protection of the farmstead.

Farmstead windbreaks should be long enough so that the snowdrifting pattern around the ends of the barrier does not cross driveways or other access roads from the farmstead to the county road, or to feedlots and barns.

Windbreaks for Livestock and Range Protection

Objectives.—There are several objectives in the planting of tree windbreaks on range and pasture land. Of greatest importance is that of providing a protected area for livestock during severe winter storms. One purpose is to provide a haven where animals can get out of strong wind and snow, and thus prevent their drifting with the wind. Another purpose is to maintain an area relatively free from deep snow where hay and other feed is easily accessible.

Shade protection in extremely hot, dry summers may be the objective of some plantings. This is especially necessary for dairy cattle and hogs.

Like windbreaks for increasing crop yields on cultivated fields, barriers may be used for improving hay and grass production over large areas of range, pasture, and meadow land.

Orientation.—As with farmstead windbreaks, complex patterns of windbreaks are not usually needed on pasture and range areas. In extensive areas of grassland range, tree plantings should be in the form of block plantation units located at

strategic places for livestock feeding during the winter. They should be located to take advantage of protection by natural topographic features.

Since protection is most needed during severe snowstorms, the blocks should extend lengthwise from southwest to northeast. Some ranchers have planted U-shaped blocks with the open end to the south or southeast, for maximum protection.

The orientation and location of barriers for range or pasture yield improvement may, however, take the form of field windbreak patterns with the objective of gaining better snow distribution.

Dimensions.—The width and orientation is of most importance in tree plantation blocks intended specifically for protection from winter wind and snow. Barriers similar to farmstead windbreaks are normally dense and tall enough to protect livestock, provided the plantings are not open to stock. Where plantations are to be used as wintering grounds among the trees, the blocks should be several hundred feet wide. The windward north and west sides should be fenced off from stock. Plantations to be used for summer shading should likewise be several hundred feet wide, so as to offset the loss of lower foliage by browsing.

Limitations.—Pasture and range windbreaks for livestock protection should not be located near summer watering or salting areas. Tree plantations near such areas where livestock congregate will be severely damaged by browsing and trampling, and their protective effect will be reduced.

Fencing against normal livestock use is recommended for all windbreaks on range and pasture. Access to winter protection plantations by livestock should be provided only during severe storms. In plantations grown specifically for summer shading, access should be provided only after the trees have reached suitable height for effective shading.

Windbreaks for Protection of Public Facilities

Objectives.—The objective of tree barrier planting along roads and other rights-of-way is to control the drifting of snow or soil so that it does not interfere with the use of the road or railway. Tree plantings for public recreation use along highways, on the other hand, may be established primarily for campers and picnickers. Such areas can provide temporary shelters against strong, hot winds away from highway dirt and noise.

Density, especially near the ground, is essential in structures for snow and soil control. Height is of less importance, though it should be sufficient to contain drifts of 8 to 10 feet deep and still serve as a barrier.

Orientation.—Of course, the direction and pattern of the roads or other rights-of-way to be pro-

tected determines orientation of windbreaks. Generally, the barriers for snow control should be located from 100 to 300 feet north and west of rights-of-way. In some locations where snowdrifting is difficult to control, a series of two or three narrow barriers, 50 to 100 feet apart, should be used. Plantings for recreation purposes should be located at least several hundred feet from highway rights-of-way, and should be oriented to form an enclosure protected on all sides.

Dimensions.—Structures for snow and soil drift control need not exceed two or three rows of trees and can therefore occupy less than 20 feet width. Length depends on specific topographic conditions. Locations of windbreaks should normally be limited to segments of rights-of-way where there are deep cuts or extended low areas to the south and east of higher ground. Recreation area plantings can be long and irregular in shape, but they

should be wide enough to provide space for camping areas.

Limitations.—The most serious limitation appears to be a conflict of land-use objectives. To be of greatest value, windbreaks and recreation enclosures must not be too close to rights-of-way; otherwise they will create rather than solve snow problems. The requirement for such specific locations as snow fences may often put barriers of this kind in places where landowners may not want them. Many landowners do not like to farm around tree strips or blocks located within cropland fields.

The establishment of field windbreak patterns for protection of crops on farmland can normally serve also to protect roadways and other public facilities in the vicinity if this is considered in planning their location. Special-purpose barriers then will not be needed.

How To Select Windbreak Trees

Successful establishment of permanent and effective windbreak systems to fulfill long-term objectives in conservation farming depends a great deal on the choice of species. In addition to the usually dry and windy climate of the Plains, there are many different soils and topographic conditions that limit the choice of trees for planting.

Tree species recommendations given in this handbook apply only to the central Plains area (fig. 20). Recommendations have been adapted from several sources: (1) current technical specifications of the Soil Conservation Service; (2) results of a 1954 survey of shelterbelts in Nebraska and Kansas; (3) results of field testing by Agricultural Research Service field stations at Cheyenne, Wyo., and Akron, Colo.; and (4) past recommendations of State and extension foresters. Tree and shrub recommendations for the northern and southern Plains are given in other publications, some of which are listed in the appendix to this handbook, page 68.

WHAT TO CONSIDER

Environment of the Plains is such as to test the hardiest of tree species. Trees growing outside a forest environment, as in the Plains region, are constantly subjected to unusual stresses of wind, temperature, moisture, evaporation, insects, and diseases. They must be adapted not only to the climate, but also to soil types and competitive vegetation much different from that occurring in naturally forested areas.

Windbreak trees must also fulfill certain functions if they are to be useful in this environment. Survival and growth is not enough. They must

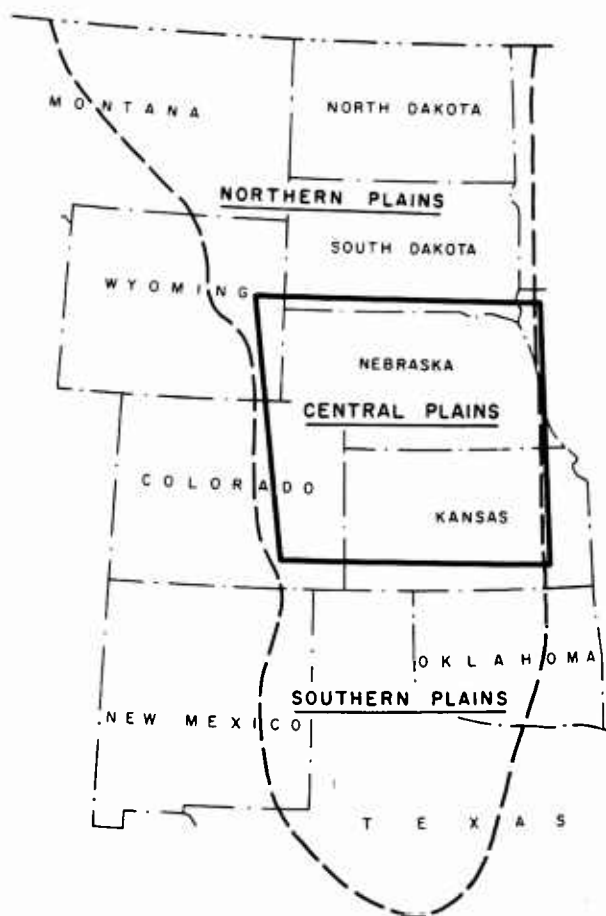


Figure 20.—Central area of the Great Plains to which species recommendations apply.

possess other qualities that enable them to associate perfectly with other adapted species, providing windbarriers of the desired structure. Windbreak trees should also have moderate to dense crowns, stout boles, good retention of lower limbs, and fairly uniform rate of height growth.

Selection of tree and shrub species therefore involves two major questions: (1) What species are best adapted to the soil or planting site? (2) Of these adapted species, which have the growth characteristics for producing the types of windbreaks desired?

Select Species Adapted to Planting Sites

Farmers and ranchers have, for years, "selected" the soils for their corn, wheat, alfalfa, pasture, and other crops. A farmer knows which crops grow best on a particular type of soil through the experience of planting and harvesting over a short period of years. Measuring the adaptability and usefulness of tree species on different soils, however, requires a longer period of years. Furthermore, mistakes made in selection of tree species are not as easily corrected as with annual crops.

The environment (site) of a planted tree is made up of climate, soil, topography, and other living organisms. Trees that are not adapted to the site will lack vigor, grow poorly, and may die young. Adapted trees will grow well and thrive for years. Some species and varieties have shown superior adaptation to a wide range of Plains environments, while others are adapted to a very narrow range of conditions.

Climate.—Climate places severe limitations on tree survival and growth in the Plains. The moisture, temperature, and wind environment of planting sites is determined primarily by the prevailing type of climate. This climate in the central Plains ranges from arid and semiarid to subhumid, with wide and rapid fluctuations in temperature and moisture. Strong and persistent winds prevail from the south and the northwest during most of the year. Scanty rain and snowfall, coupled with the high evaporation and transpiration which accompanies strong wind movement, creates great moisture stresses in trees. Severe winter blizzards and hailstorms do much mechanical damage by breaking limbs and bark. Rapid changes in air temperature, such as a drop of 40 to 50 degrees in a few hours, frequently cause dieback and death of trees and shrubs that are slow to reach dormancy in the fall. Trees weakened by such climatic stresses are more susceptible to attack by diseases and insects. Species such as green ash, Siberian elm, caragana, and ponderosa pine are well adapted to cold and snowy locations. Catalpa, locust, tamarix, and shortleaf pine must be restricted to southern areas of the

Plains for best growth. In addition, certain races or strains are often better adapted than others of the same species.

Soil.—Soils place a second limitation on choice of tree species, for the ways in which climate affects tree growth are often modified by texture and depth of soil and configuration of the land surface. Depth, texture, fertility, acidity, and moisture relations of the soil are all important factors in tree survival and growth (fig. 21). Nearly all trees grow well on deep, moist, fertile soils. Relatively few species, however, can tolerate alkaline, very acid, or very stiff, impermeable soils. Some trees grow well on shallow soils for a short period of years, then cease growth and die. Choice of species becomes more limited as soil conditions become more adverse. Cottonwood and willows require moist locations and consequently do well where the water table is close to the surface. They are short lived on upland where water tables are far from the surface. Junipers, ponderosa pine, and certain broadleaf species can make respectable growth and live a long time on relatively shallow soils and dry sites. Russian-olive is probably better adapted than other species for extremely alkaline or saline soils.

Topography.—Topography places a third limitation on choice of trees, for the lay of the land greatly influences soil moisture and wind conditions. In a river or creek bottom land, for example, where ground water is close to the surface, most tree species grow well (fig. 22). On a flat upland far from the water table, choice is restricted and all species are apt to grow more slowly. Uplands are more exposed than lowlands to all climatic elements, especially wind. On an exposed windy plain, trees grow less well than in a more protected area of lowland, even though the soil may be as deep and fertile. Protection by natural topographic features should be utilized when possible in planning the location and orientation of tree plantings. Locations to the leeward of ridges, knolls, and dunes are favorable owing to extra moisture from snow accumulation.

Other Organisms.—A fourth limitation on choice of species may be the other living organisms with which trees are associated. Diseases, insects, animals, other vegetation, and even man all have a bearing on survival and growth of trees. This is the only factor than man can readily modify by taking positive control measures.

Ideally, selection of species or strains should be limited to those with most resistance to insects and diseases. However, some species with low resistance may be used because they have other desirable characteristics. Generally, species that are highly susceptible to major diseases and insects, such as American elm, should be avoided. Susceptibility to minor pests need not limit choice of species.



F-485736-783

Figure 21.—Variations in soils have affected survival and height growth of different species in these 16-year-old windbreaks: A, Survival and growth of tall, fast-growing species in the right half of this windbreak have been reduced by unfavorable soil conditions; conifers were not affected. B, Small spots of unfavorable soil have caused gaps to appear in the upper level of this windbreak.



F-485773-782

Figure 22.—Topography—upland, lowland, or slope—has affected survival and height growth of different species in these 16-year-old windbreaks: A, Cottonwoods are 60 feet tall on lowland site (right), but are nearly all dead on higher ground (left). B, Cottonwoods and elms have died on the knolls of deep sandy soils on undulating topography. Survival and growth is good in the lower places.

Use of windbreaks as shade and stomp lots for livestock, surveys have shown, is the principal factor in reducing the effectiveness and overall usefulness of tree plantings. Nearly one-third of the Prairie States shelterbelts are being seriously damaged. Some species more than others are damaged by trampling, direct browsing, or nibbling by large animals and rodents. Since such damage can be controlled, however, proneness to injury by animals should not influence choice of species.

Select Species for Windbreak Characteristics

The capacity of a tree planting to furnish protection depends on the sum total of all tree and shrub foliage making up windbreak height, density, and continuity. Windbreaks ordinarily require several kinds of trees with different growth characteristics so as to provide foliage density at various height levels over a period of years. As trees grow older their form and crown characteristics change. For example, young eastern redcedars provide very dense foliage near the ground; but as they grow older the lower limbs die and density of foliage shifts to a higher level. Fast-growing cottonwoods provide dense foliage at low to medium heights when young; but with time, foliage density shifts to the upper level. Some fast-growing broadleaf trees develop very loose, open crowns in middle age, and consequently are worthless for windbreaks. Shrubs usually retain dense foliage near the ground throughout their lifetime, especially if they are cut back periodically.

Maintenance of the sheltering effect of windbreaks over a useful span of years depends on the relative life spans of the trees and shrubs planted. Selection of species for their longevity must first fit the limitations of the planting site.

Height.—Height, the most important of windbreak characteristics, influences the extent of the protected area. The effect of height on leeward shelter distance was explained in the first section, and is generally agreed to be significant for 15 to 20 windbreak heights. Therefore, it is well to choose trees that grow as tall as the planting site will allow. For quick effect, fast-growing trees that reach maximum height in a short time are the first choice. Since these fast growers are likely to be short lived even on favorable sites, slower growing tall trees that mature later and remain effective for a long time should be used also. Examples of fast-growing tall trees are cottonwood, sycamore, and Siberian elm. Slower growing tall trees are ponderosa pine and Austrian pine for the central Plains; shortleaf pine for the southern Plains.

Foliage Characteristics.—Density or penetrability also influences the extent of leeward protection. This characteristic depends on width of windbreak, arrangement and spacing of species, and crown height of the different species at various ages. These determine cross-sectional shape and foliage density at various height levels in the windbreak. Such characteristics will naturally change with time as temporary species die and more permanent species reach full crown growth and maximum height.

As explained in the second section, the required density of various height levels will vary depending upon the objectives of protection. Windbreaks of moderate density at all heights provide a wider area of protection than those of greater density. For greatest wind velocity reduction over the greatest area, therefore, trees that maintain medium density at all height levels throughout the growing season are ideal.

The density of a windbreak composed entirely of broadleaf species, or in combination with conifers, changes from season to season as the deciduous foliage grows and drops (fig. 23). Windbreaks composed entirely of conifers do not change density and therefore provide the same degree of protection the year around.

Upper level density depends on the crowns of the tall trees. At least two rows of tall trees are necessary for adequate upper density, since the other shorter tree rows do not contribute to this level.

Middle level density during the first 15 years depends on the medium to slower growing broadleaf trees. After that, the pines and redcedars provide most of the middle level density, with the taller growing pines beginning to form the upper level.

Lower level density is provided by all rows during the first 15 years. After 20 to 30 years, most conifers and broadleaf trees will lose their lower foliage. An exception is eastern redcedar which retains its lower foliage when not crowded. Thereafter the low density must be provided by thick-growing shrubs not exceeding 8 to 10 feet in height, and preferably less than 5 feet tall.

Continuity.—Continuity of windbreaks also influences the extent of protected area. Gaps or openings caused by tree failure in any part of a windbreak destroy uniformity of the structure and reduce efficiency. Gaps also invite encroachment of herbaceous vegetation into windbreaks, with consequent competition and weakening of the entire tree stand.

Protective windbreak systems provide maximum benefits when fields are completely surrounded by barriers, so that a minimum of area is exposed to open field environment. Therefore, the rule is to choose trees that are so adapted to the particular soils that practically all of them survive



Figure 23.—Change in foliage density from summer to winter in a 20-year-old windbreak of conifers and broadleaf trees: A, Effective height in summer is 65 feet. B, Loss of broadleaf foliage during winter reduces effective height to 20 feet.

and grow well if given proper care. If there are several different soil types in the planting area, the best species for each soil should be selected. The occurrence of gaps can be prevented by replacing dead or dying trees with the same species the following season.

Longevity.—Because of the large initial investment in tree planting, the backbone of windbreaks should be the long-lived tree species that provide effective protection for at least 50 years. Protection on farms and ranches in the Plains will be needed just as much 50 to 100 years from now as within the next decade. Plains environment tends to shorten the lives of trees, but some species can live and remain thrifty longer than others. Since these longer lived species will provide an effective windbreak for a longer period of years, they constitute a better investment.

RECOMMENDED SPECIES

Tree and shrub species suitable for windbreaks on six different kinds of sites in the central Plains are given in table 1. Expected maximum heights

at maturity, rate of height growth, and longevity are also given. The three longevity (useful life) classes in the tables are broad and overlapping. Short-lived trees may live from 10 to 40 years; medium from 20 to 60 years; and long-lived trees from 50 to 80 years or more. Longevity is influenced by site, as well as by inherent species characteristics, care, and management. Relative longevity may therefore differ by sites. Other important characteristics of each species are given in table 2, and scientific names in table 3. The section "Why Protection Is Important," page 45, gives information on insects and diseases likely to attack different tree and shrub species.

The kinds of trees in a windbreak should be kept to a minimum, including only those needed to provide the structure for the main objective. For example, if cottonwood is selected as the tall, fast grower, another tall, fast grower such as Siberian elm should not be added. From the tables presented here, trees should be selected tentatively for the soil and site condition most similar to the prospective planting location (table 1). Then from the tentative list, those species having

the desired characteristics such as crown density and drouth resistance should be selected with the aid of table 2.

Many tree and shrub species not recommended in this handbook have been tried and tested. While some of them are without doubt adapted and useful under certain conditions, they cannot be generally recommended for the variety of conditions encountered in the central Great Plains. Other species that have been used extensively in the past, such as American elm, are not recommended because of impending disease or insect conditions. Honeylocust is not recommended because it has an open crown habit not suitable for creating maximum foliage density in windbreaks.

TABLE 1.—*Recommended tree and shrub species for six kinds of sites in the central Plains*

DEEP, MOIST, PERMEABLE SOILS (RIVER AND CREEK LOWLANDS)

Mature size and common name	Maximum height (feet)	Height growth	Useful life
Tall trees:			
Cottonwood.....	80	Fast.....	Medium.
White willow.....	50	do.....	Do.
Siberian elm.....	60	do.....	Do.
Sycamore.....	60	Medium.....	Do.
Shortleaf pine (south only).	60	do.....	Do.
Ponderosa pine.....	60	Slow.....	Long.
Austrian pine.....	60	do.....	Do.
Medium trees:			
Northern catalpa.....	40	Fast.....	Medium.
Black willow.....	40	do.....	Short.
Golden willow.....	30	do.....	Do.
Green ash.....	45	Medium.....	Medium.
Hackberry.....	45	do.....	Do.
Bur oak.....	45	Slow.....	Long.
Scots pine.....	45	Medium.....	Medium.
Jack pine.....	45	do.....	Do.
Eastern redcedar.....	45	Slow.....	Long.
Short trees:			
Boxelder.....	25	Fast.....	Short.
Russian-olive.....	25	do.....	Medium.
Diamond willow.....	15	Medium.....	Short.
Russian mulberry.....	20	do.....	Medium.
Osage-orange.....	25	do.....	Long.
Rocky Mtn. cedar.....	25	Slow.....	Do.
Shrubs:			
American plum.....	10	Fast.....	Medium.
Chokecherry.....	10	do.....	Do.
Tamarisk (south only).	10	do.....	Short.
Purple willow.....	6	do.....	Do.
Common lilac.....	8	Medium.....	Medium.
Honeysuckle (north only).	8	do.....	Short.
Caragana (north only).	10	do.....	Medium.

MEDIUM TO DEEP UPLAND SOILS (SILTY OR CLAYEY LOAMS)

Mature size and common name	Maximum height (feet)	Height growth	Useful life
Tall trees:			
Siberian elm.....	45	Fast.....	Medium.
Shortleaf pine (south only).	45	Slow.....	Do.

TABLE 1.—Continued

MEDIUM TO DEEP UPLAND SOILS (SILTY OR CLAYEY LOAMS)—continued

Mature size and common name	Maximum height (feet)	Height growth	Useful life
Tall trees—Continued			
Ponderosa pine.....	50	do.....	Long.
Austrian pine.....	45	do.....	Medium.
Medium trees:			
Green ash.....	35	Medium.....	Do.
Hackberry.....	35	do.....	Do.
Bur oak.....	35	Slow.....	Long.
Eastern redcedar.....	35	do.....	Do.
Short trees:			
Boxelder.....	25	Fast.....	Short.
Russian-olive.....	25	do.....	Do.
Russian mulberry.....	20	Medium.....	Do.
Osage-orange.....	25	do.....	Long.
Rocky Mtn. cedar.....	25	Slow.....	Do.
Shrubs:			
American plum.....	10	Fast.....	Medium.
Chokecherry.....	10	do.....	Do.
Tamarisk (south only).	10	do.....	Short.
Common lilac.....	8	Medium.....	Medium.
Caragana.....	8	do.....	Do.
Skunkbush sumac.....	6	Slow.....	Do.

MEDIUM TO DEEP UPLAND SOILS (SANDY LOAMS AND LOAMY SANDS)

Mature size and common name	Maximum height (feet)	Height growth	Useful life
Tall trees:			
Cottonwood.....	60	Fast.....	Short.
Siberian elm.....	50	do.....	Medium.
Shortleaf pine (south only).	50	Medium.....	Do.
Ponderosa pine.....	60	Slow.....	Long.
Austrian pine.....	50	do.....	Do.
Medium trees:			
Green ash.....	30	Medium.....	Medium.
Bur oak.....	35	Slow.....	Long.
Eastern redcedar.....	35	do.....	Do.
Short trees:			
Boxelder.....	20	Fast.....	Short.
Russian-olive.....	20	do.....	Do.
Russian mulberry.....	15	Medium.....	Do.
Osage-orange.....	20	do.....	Long.
Rocky Mtn. cedar.....	25	Slow.....	Do.
Shrubs:			
American plum.....	8	Fast.....	Medium.
Chokecherry.....	8	do.....	Do.
Common lilac.....	8	Medium.....	Do.
Skunkbush sumac.....	5	Slow.....	Do.

SANDHILL UPLANDS

Mature size and common name	Maximum height (feet)	Height growth	Useful life
Tall trees:			
Ponderosa pine.....	50	Slow.....	Long.
Austrian pine.....	40	do.....	Medium.
Medium trees:			
Scots pine.....	40	Medium.....	Do.
Jack pine.....	40	do.....	Do.
Eastern redcedar.....	30	Slow.....	Long.
Short trees: Rocky Mountain cedar.	20	do.....	Do.
Shrub: Chokecherry	6	Medium.....	Medium.

TABLE 1.—Continued

MEDIUM TO SHALLOW UPLAND SOILS

(Underlain by coarse sand, gravel, impermeable claypan, or bed rock.)

Mature size and common name	Maximum height (feet)	Height growth	Useful life
Tall trees:			
Siberian elm.....	25	Medium.....	Short.
Ponderosa pine.....	35	Slow.....	Medium.
Medium trees:			
Bur oak.....	30	do.....	Do.
Eastern redcedar.....	25	do.....	Long.
Short trees:			
Osage-orange.....	20	Medium.....	Medium.
Rocky Mtn. cedar.....	15	Slow.....	Long.
Shrubs:			
American plum.....	5	Medium.....	Short.
Tamarisk South only).	5	do.....	Do.
Common lilac.....	5	Slow.....	Do.
Skunkbush sumac.....	5	do.....	Medium.

VERY WET, POORLY DRAINED SOILS (SALINE OR ALKALINE UPLANDS AND LOWLANDS)

Tall trees:			
Cottonwood.....	45	Medium.....	Short.
White willow.....	30	do.....	Do.
Siberian elm.....	25	do.....	Do.
Medium trees:			
Golden willow.....	20	do.....	Do.
Green ash.....	20	Slow.....	Do.
Short trees:			
Russian-olive.....	15	Medium.....	Do.
Diamond willow.....	5	do.....	Do.
Shrub: Purple willow.....	5	do.....	Do.

TABLE 2.—Crown, root, and drouth characteristics of tree and shrub species recommended for planting in the central Plains

Mature size and common name	Crown density	Root habit	Drouth resistance
Tall trees:			
Cottonwood.....	Medium.....	Shallow.....	Low.
White willow.....	do.....	do.....	Do.
Siberian elm.....	Dense.....	Medium.....	Medium.
Sycamore.....	do.....	do.....	Low.
Shortleaf pine.....	Medium.....	do.....	High.
Ponderosa pine.....	do.....	Deep.....	Do.
Austrian pine.....	do.....	do.....	Medium.
Medium trees:			
Northern catalpa.....	Medium.....	Shallow.....	Low.
Black willow.....	do.....	do.....	Do.
Golden willow.....	Dense.....	do.....	Do.
Green ash.....	Medium.....	Medium.....	Medium.
Hackberry.....	do.....	Deep.....	High.
Bur oak.....	Dense.....	do.....	Do.
Scots pine.....	Medium.....	do.....	Medium.
Jack pine.....	do.....	Medium.....	Do.

TABLE 2.—Continued

Mature size and common name	Crown density	Root habit	Drouth resistance
Medium trees—Con.			
Eastern redcedar.....	Dense.....	Deep.....	High.
Short trees:			
Boxelder.....	do.....	Medium.....	Medium.
Russian-olive.....	Medium.....	do.....	Do.
Diamond willow.....	do.....	Shallow.....	Low.
Russian mulberry.....	Dense.....	Deep.....	Medium.
Osage-orange.....	do.....	do.....	High.
Rocky Mtn. cedar.....	do.....	Medium.....	Do.
Shrubs:			
American plum.....	do.....	Shallow.....	Medium.
Chokecherry.....	do.....	do.....	High.
Tamarisk.....	Medium.....	do.....	Medium.
Purple willow.....	do.....	do.....	Low.
Common lilac.....	Dense.....	do.....	High.
Honeysuckle.....	do.....	do.....	Medium.
Caragana.....	Medium.....	do.....	High.
Skunkbush sumac.....	Dense.....	Medium.....	Do.

TABLE 3.—Common and scientific names of tree and shrub species recommended for planting in the central Plains

Mature size and common name	Scientific name
Tall trees:	
Cottonwood.....	<i>Populus deltoides</i>
White willow.....	<i>Salix alba</i>
Siberian elm.....	<i>Ulmus pumila</i>
Sycamore.....	<i>Platanus occidentalis</i>
Shortleaf pine.....	<i>Pinus echinata</i>
Ponderosa pine.....	<i>P. ponderosa scopulorum</i>
Austrian pine.....	<i>P. nigra</i>
Medium trees:	
Northern catalpa.....	<i>Catalpa speciosa</i>
Black willow.....	<i>Salix nigra</i>
Golden willow.....	<i>S. alba vitellina</i>
Green ash.....	<i>Fraxinus pennsylvanica</i>
Hackberry.....	<i>Celtis occidentalis</i>
Bur oak.....	<i>Quercus macrocarpa</i>
Scots pine.....	<i>Pinus sylvestris</i>
Jack pine.....	<i>P. banksiana</i>
Eastern redcedar.....	<i>Juniperus virginiana</i>
Short trees:	
Boxelder.....	<i>Acer negundo</i>
Russian-olive.....	<i>Elaeagnus angustifolia</i>
Diamond willow.....	<i>Salix missouriensis</i>
Russian mulberry.....	<i>Morus alba tartarica</i>
Osage-orange.....	<i>Maclura pomifera</i>
Rocky Mtn. cedar.....	<i>Juniperus scopulorum</i>
Shrubs:	
American plum.....	<i>Prunus americana</i>
Chokecherry.....	<i>P. virginiana</i>
Tamarisk.....	<i>Tamarix pentandra</i>
Purple willow.....	<i>Salix purpurea</i>
Common lilac.....	<i>Syringa vulgaris</i>
Honeysuckle.....	<i>Lonicera tatarica</i>
Caragana.....	<i>Caragana arborescens</i>
Skunkbush sumac.....	<i>Rhus trilobata</i>

How To Arrange and Space Trees in the Windbreak

Determination of spacings and arrangements of trees for best growth has been the aim of a number of experiments in the Plains for five or six decades. These studies have led to recommendations of different spacings and arrangements depending on location within the region, whether in the arid western or more humid eastern zones. Most of these studies, however, have dealt with the effects of space and arrangement on individual tree growth, rather than the effects on windbreaks structure.

The Plains tree planter should keep in mind that windbreaks are not planted simply for the best growth and development of individual trees. They are planted for mass effect against the wind. Therefore, spacings and arrangements recommended solely on the basis of individual tree growth, with no regard for the type of structure desired, are of doubtful value in producing effective windbarriers. On the other hand, arrangement and spacing of windbreak trees must often be a compromise between requirements for individual tree growth and requirements for growing a stand of trees that will produce the type of structure needed for protection.

One-row windbreaks have free growing space for trees on two sides and obviously create no problem of crowding between rows. Research has shown, however, that single rows of trees do not provide sufficient density for maximum wind reductions over extended leeward areas, although the amount of reduction close to the barrier may

be satisfactory. Single rows of trees have no safety factor against occurrence of gaps; for example, the failure of several consecutive trees can seriously impair the continuity of barriers (fig. 24). More than one row of trees is therefore recommended to produce windbarriers of effective density and height.

Machine planting and cultivation have greatly influenced row spacing recommendations. Close spacings between trees and rows are possible when hand planting and cultivation are used, but machine planting and cultivation now require row spacing of at least 8 feet and ranging up to 24 feet. Widely spaced rows are required to accommodate the large cultivation equipment in common use on western Plains wheat farms.

GROWTH AND DEVELOPMENT WITH AGE

It is important to understand the growth phases of windbreak trees in order to decide on proper arrangement and spacing of the various species components. Above all, it should be kept in mind that the height, density, cross section, and profile of tree windbreaks changes with time. These changes will greatly affect the structure and efficiency of the windbreaks.

Hypothetical examples in development of two five-row windbreaks composed of different species



F-485082

Figure 24.—Although single-row windbreaks are fairly easy to establish compared with windbreaks of several rows, they do not provide the density and continuity required for best protection of cropland.

over a 40-year period are given in figures 25 and 26. A significant change takes place between the 20th and 40th year. In the conifer windbreak (fig. 25) the slower growing pines and redcedars reach mature height after 30 to 40 years, at which time the fast-growing elms begin to deteriorate. This illustrates development of an effective long-lived windbreak through use of conifers. In the

windbreak composed exclusively of broadleaf trees (fig. 26) most species begin to decline and the windbreak loses its effective height and density between the 20th and 40th year. Earlier deterioration of broadleaf species as compared to conifers has occurred in many plantations throughout the Great Plains.

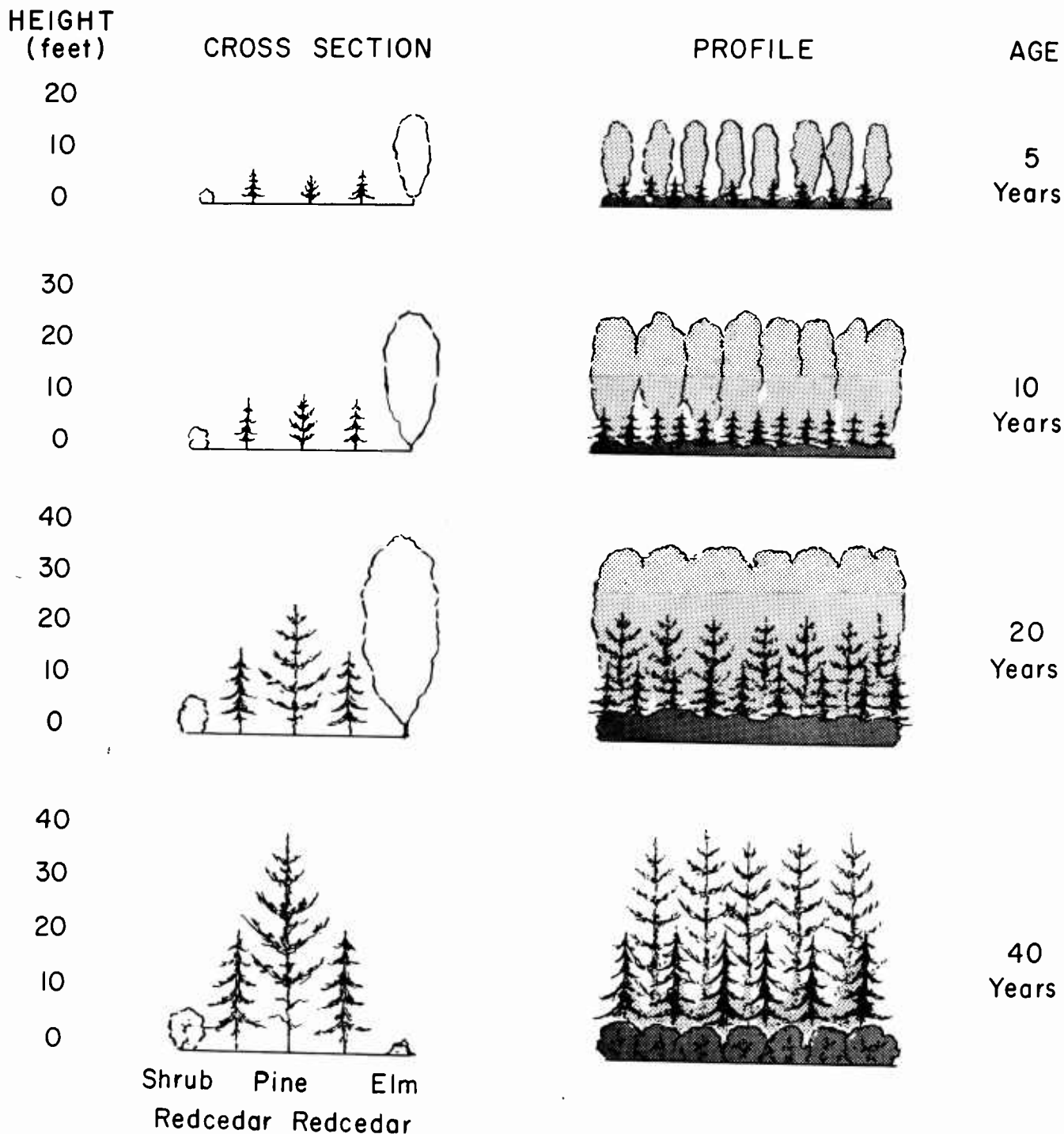


Figure 25.—Cross-section and profile characteristics of a five-row conifer windbreak as influenced by growth and development during 40 years.

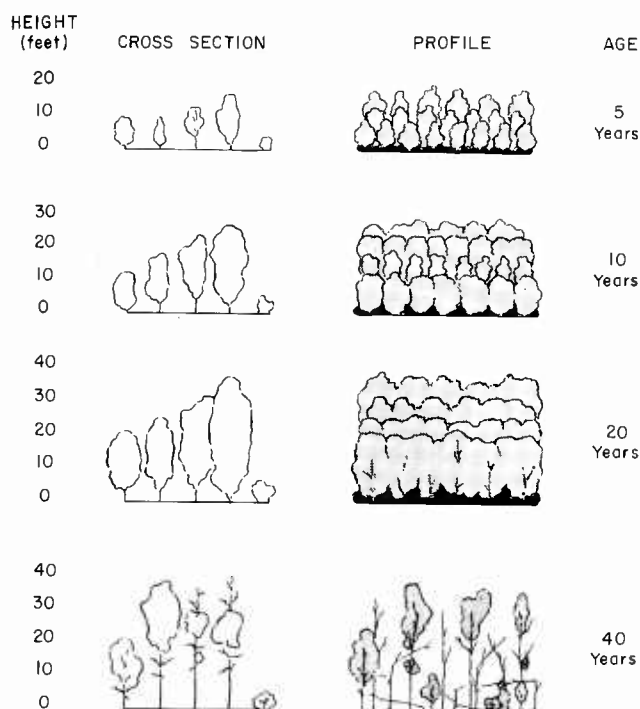


Figure 26.—Cross-section and profile characteristics of a five-row broadleaf windbreak as influenced by growth and development during 40 years.

Growth and development of windbreak trees and shrubs can be controlled and modified to some extent, to produce a barrier with certain characteristics. Shrubs, for example, may be cut back to the ground and allowed to sprout, so as to increase ground level density. Much research is needed, however, to determine more specifically how to manage the components of windbreaks by means of silvicultural cutting practices. With proper silvicultural care, it may be possible to prolong the effectiveness of broadleaf windbreaks such as that illustrated in figure 26. At present, however, a minimum of two rows of conifers is recommended for all windbreaks, to provide longevity and protection against soil blowing in late fall, winter, and early spring, when broadleaf trees are bare. Pines and junipers are particularly well suited for this purpose.

ARRANGEMENT OF SPECIES COMPONENTS

The arrangement and row spacing of different tree species determines the cross-sectional shape of a windbreak. With normal survival and growth of species of known height and crown growth habits, this shape may be easily predicted for any age.

Species arrangements which provide a moderately dense lower level are generally better than

very dense or very open barriers. Barriers with an abrupt or nearly vertical cross section are better than those with a gently sloping cross section.

Species arrangement should therefore provide not only for the best tree-row development, but also for moderate density and a fairly abrupt cross-sectional face. Slower growing species such as pine and redcedar intended for future effective height and longevity should not be placed in a position where they will be overtopped by fast-growing species.

A tree row should be of one species from end to end, except where soil differences dictate a change as described in the previous section. A mixture of species within tree rows, alternating short and tall, is not recommended. Failure of one or the other species will leave within-row openings along the windbreak axis that weaken the entire structure. Failure of an entire row is much easier to correct by replanting than scattered failures within rows.

Arrangement of medium and tall trees may be varied to some extent. The shrub and pine rows, however, should always be at least 20 feet distant from tall, fast-growing trees. This is necessary not only for best height growth, but also to maintain crown vigor to the ground level. Both sides of windbreaks should contain rows of trees or shrubs that will remain dense near the ground. Fast-growing but short-lived trees should always be in the outside rows, where they may be removed after 20 to 25 years with minimum interference to the remainder of the windbreak.

SPACING BETWEEN TREE ROWS

Very wide spacing between tree rows is believed by some observers to be necessary for tree survival in the drier parts of the Plains. There are many excellent windbreak plantings at row spacings of 20 to 30 feet. On the other hand, there are also examples of vigorous 20- to 40-year-old conifer windbreaks in the high Plains at row spacings of 8 to 10 feet.

A windbreak is most efficient when the wind is blowing from either of the two directions perpendicular to the long axis of the barrier. Therefore, the profile or frontal view is the most important aspect to consider in terms of wind reduction effect. Density of this profile is determined primarily by (1) species, (2) spacing between trees *in the row*, and (3) number of rows.

Distance between tree rows can be varied considerably without appreciably affecting the density, height, and continuity of windbreaks. Variations in row spacing between 10 and 20 feet have little effect on wind velocity reduction, since the frontal face of the windbarrier presents to the

wind approximately the same height and density, regardless of distance between tree rows (fig. 27).

The advantages and disadvantages of close versus wide row spacing as it affects tree growth and windbreak maintenance should be considered. The chief disadvantage of widely spaced rows is that plantings must be maintained by cultivation for an indefinite number of years, because the tree crowns never close and shade out herbaceous vegetation. Another disadvantage is that widely spaced rows occupy more land than necessary for a windbreak of the required density.

An advantage of widely spaced rows is that larger tree crowns develop and maintain lower foliage density for many more years than closely spaced trees. This advantage is not essential, however, since with proper composition of the windbreak, low level density can be provided as well or better with shrubby species. Then too, large-crowned trees require more moisture and may be more subject to dieback during drouth.

The advantage of closely spaced rows (not less than 8 feet apart, however) is early crown closure and completion of the cultivation job. A disadvantage of closely spaced tree rows is that compe-

tition among trees starts very early. Unless thinning and release cuttings are planned and carried out, the vigor of trees is likely to decline.

Minimum spacing between rows may sometimes have to be determined by the size of cultivation equipment available. The minimum spacing should be 3 to 4 feet wider than the implement, to avoid mechanical damage to the trees.

Current tree row spacing recommendations for eastern Nebraska and Kansas are 10 to 16 feet, and for western parts of these States 12 to 18 feet. Across the Nebraska and Kansas line in eastern Colorado, the recommended row spacing on drylands ranges from 12 to 20 feet; on irrigated lands 10 to 14 feet. To the north in South Dakota, the statewide recommendation is 10 to 14 feet, (18 feet by current Soil Conservation Service technical guides) with slightly wider spacings for very heavy soils and in areas of very low rainfall.

Since a range in spacing between tree rows from 10 to 20 feet is not critical from the standpoint of producing an effective windbarrier, the landowner should choose whatever spacing best fits his cultivation equipment and his intentions as to later cultivation, thinning, and management.

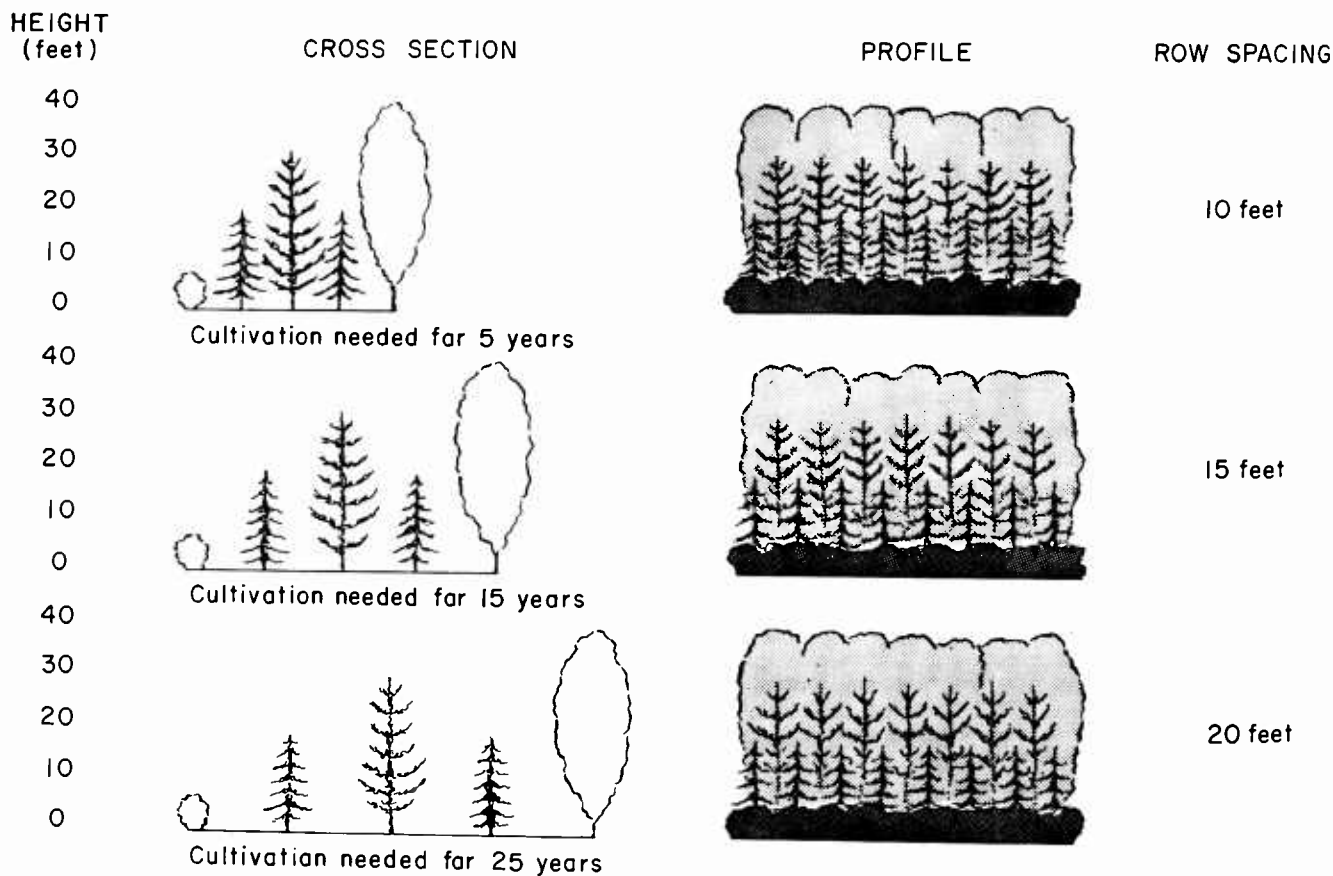


Figure 27.—Cross-section and profile characteristics of a 25-year-old five-row windbreak as influenced by spacing between rows.

SPACING BETWEEN TREES IN THE ROW

Whereas variations in row spacing make little difference in windbreak effectiveness, the spacing between trees within rows makes considerable difference.

Spacing between trees in the row directly affects the frontal and interior density of the barrier (fig. 28). In the low level portion of a barrier the distance between shrubs determines the density and continuity of that level. Similarly at other levels from medium to tall heights, the distance between trees will at any age affect the density of barrier. Number of tree rows contributing to a height level, of course, has an additional effect on density.

Recommended spacing for shrubs or conifers for low level density is between 3 and 5 feet. Under most conditions this spacing will provide a dense barrier from the ground level to 3 or 4 feet high. Shrubs such as caragana will provide effective height to 10 or 12 feet.

Spacing between the tall, fast-growing trees such as cottonwood, willows, or Siberian elm should be from 6 to 12 feet. If the owner definitely intends to thin tree rows after 5 to 10 years, these tall fast growers can be planted at 6-foot spacing, in order to provide an effective barrier during early years. The tall fast growers, however, should be spaced 10 to 12 feet apart if no thinning is to be done.

Slower growing trees should be planted 6 to 10 feet apart within rows. Pines and junipers both grow well at this spacing for the first 20 years. As the pines reach 20 feet in height, they will need more space. Pines should then be thinned to a

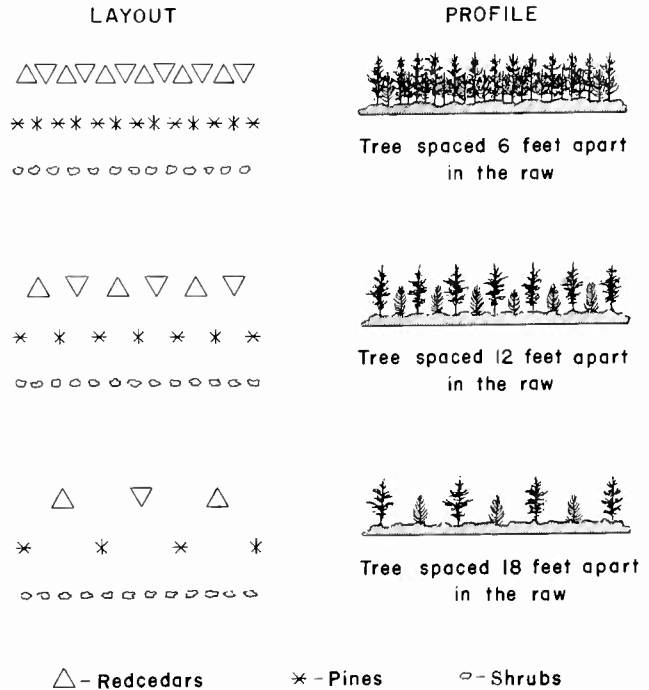


Figure 28.—Windbreak profiles at age 15 years with different tree spacings in the row. Shrubs spaced 3 feet and rows 12 feet apart.

spacing of 15 to 20 feet within the rows. This should be done before the lower limbs begin to die.

Staggering or alternating the position of trees in adjacent rows is desirable where tree spacing in the rows is the same. This will not only help to cover up gaps caused by mortality but will also provide a more uniform density of windbreak profile.

How To Prepare Land for Tree Planting

WHY IS LAND PREPARATION NEEDED?

Preparation of land for tree planting in the Plains is needed for the same reasons that land is prepared for any agricultural crop. Land preparation does the following:

1. Increases survival and growth of trees by:
 - (a) Destroying weed competition.
 - (b) Reducing subsequent weed crops.
 - (c) Increasing soil moisture storage.
2. Reduces likelihood of wind erosion damage by:
 - (a) Providing a growing cover crop.
 - (b) Maintaining a rough soil surface.

3. Controls the amount of previous plant residues that would otherwise interfere with machine planting.

Past experience and research in the Plains have shown repeatedly that trees survive very poorly when planted with no prior soil preparation on land occupied by grass or alfalfa. This is especially true in the drier areas of the western Plains. Land is plowed and summer fallowed for grain and other crops in order to store moisture and to control herbaceous vegetation. This practice is just as important for trees. Even in the sandhills grasslands where a minimum of soil preparation is recommended because of their light, unstable soils, some preparation for trees is necessary and beneficial.

The natural vegetation of the Plains is predominantly grass, with smaller amounts of forbs, including many vigorous weeds. This vegetation is well adapted to Plains climate and soils. It naturally has a great advantage over small trees, at least for the first few years after planting. The native grasses and weeds and some very aggressive introduced weeds grow vigorously on most soils.

The highly vigorous growth of herbaceous vegetation which characterizes the Plains region often completely occupies the sites intended for windbreaks. Available moisture in the soil is rapidly used by this vegetation. If there is to be moisture available for new trees, this vegetation must be controlled, at least until the tree roots become established at a depth below roots of natural vegetation. Following are some specific reasons for controlling the competing plants.

1. Young trees, whether bare-root or potted seedlings and transplants, need plenty of moisture for the first year or two in the field until roots have become well established.

2. Moisture must be available in the top 2 to 3 feet of soil.

3. Heavy stands of weeds, grass, or crops deplete the surface soil of moisture.

4. Young trees weaken and die when competition for available moisture in the surface soil is too great, as from fast-growing weeds and grasses.

5. Young trees weaken and die when they are overtopped or heavily shaded by fast-growing weeds and grasses.

KINDS OF LAND PREPARATION PRACTICES

Practices of preparing land for tree planting are all aimed toward more favorable conditions for tree survival and growth. The following brief descriptions of land preparation practices and their purposes will be helpful in deciding which should be used in a particular case.

Contour terracing.—To provide extra moisture for trees planted on the contour adjacent to or on terraces. Terraces also reduce water erosion within tree plantings.

Diversion ditches.—To provide for diversion of runoff water from adjacent fields or road ditches to the planting area either by spreading or along the tree rows.

Snow fence barrier.—To catch and hold snow on land to be planted the following spring (fig. 29). This is of greatest importance in dryland areas where additional subsoil moisture can benefit trees.

Subsoiling.—Loosening of a narrow strip of soil to a depth of 2 to 3 feet for the purpose of breaking up a hard layer of plowsole or a naturally impermeable subsoil. This practice provides for deeper penetration of moisture and tree roots into heavy-textured subsoils. Subsoiling has increased tree survival on hardpan soils by one-third. It has increased (1) planting efficiency, (2) height and root development, and (3) vigor.



Figure 29.—Snow fencing put up the previous fall will accumulate snow to give extra moisture for a new windbreak planting.

Summer fallow.—Clean cultivation of soil throughout a growing season. It accomplishes two important things: (1) Accumulation of moisture, and (2) accumulation of nutrients. Summer fallow prevents growth of weeds and grass that would otherwise deplete surface soil moisture and nutrients. It allows accumulation of nutrients from decomposition of organic materials in the soil.

Stubble-mulch or trashy fallow.—An adaptation of summer fallow in which protective organic materials are maintained on the soil surface by use of special tillage implements.

Summer cover crop.—A close-growing grain, sorghum, or sudan crop planted on sandy land in late summer prior to tree planting, to remain through the fall and winter for protection against wind erosion.

Fall plowing.—Loosening of soil to provide better reception and holding of moisture throughout the winter, and to bring soil into better tilth for spring tree planting. It should be deeper for trees than for crops.

Fall cover crop.—A close-growing crop of oats or barley planted in the early fall prior to spring tree planting. The cover protects the soil and catches and holds snow.

Spring disking and harrowing.—Smoothing of the site to facilitate tree planting and to kill early-germinating weeds and grasses. This should be done 3 to 4 weeks before planting so that early spring rains will settle the soil.

Spring cover crop.—A close-growing crop of sorghum, sudan, or grain planted in early spring at tree planting time, to provide protection for trees and sandy soils.

Spring furrow.—The removal of a strip of sod, 1½ to 2 feet wide and several inches deep, to facilitate planting of trees on light sandy soil which cannot otherwise be prepared by ordinary clean cultivation.

HOW TO DECIDE WHICH PRACTICES TO USE

Preparation of land for tree planting includes several important steps. All are aimed toward providing the most favorable soil conditions for receiving transplants, so that there is the greatest possible opportunity for young trees to survive and grow.

The method of preparation will naturally differ according to:

1. Kind of soil—whether a loose sandy soil subject to blowing, or a silty clay soil somewhat impermeable to roots.
2. Present cropping practice or vegetation cover.
3. The likelihood of spring rains following planting, and other factors of climate.

General Practices for All Lands

The following practices should be applied to most lands for tree planting, as important supplemental measures to improve moisture conditions of the planting site. Such practices are, for the most part, permanent conservation practices. They are here considered as land preparation practices, because for greatest benefits they should be put into effect a year or so before tree planting.

Contour terracing.—Whenever terracing is recommended, the planting of windbreaks should fit the terracing pattern. Contour tree planting, especially on rolling land where tree sites are likely to be variable, provides additional moisture for increased and more uniform tree growth.

Diversion ditches.—As with contour terracing, securing additional moisture from field diversion will result in increased and more uniform tree growth.

Irrigation.—If trees can be irrigated, the advantages are similar to those for any crop.

Snow fence barrier.—The increase of moisture on tree planting areas brought about by snow drift fences will assure greater tree survival and growth.

Practices Depending Upon Soil and Land Use

Present land preparation recommendations for tree planting are similar among States in the Plains region. Recommendations vary, however, according to soil texture, erodibility, and land use. The combination of these factors will likely determine the appropriate land preparation practices.

Kind of Soil.—Practices for sandy soils, especially very sandy textures, must provide a means for maintaining vegetation cover within and on the soil surface. Without adequate cover these lighter texture soils are apt to be damaged severely by wind erosion. Practices for sandy soil should ordinarily cause a minimum of disturbance to vegetation cover. If cover is inadequate under previous land use, cover crops should be established.

Medium to heavier textured soils are less subject to wind erosion, but they require more intensive weed control to conserve moisture. The use of summer fallow should be regarded as a standard treatment for the heavier soils, except perhaps on corn land in the eastern areas of the Plains where moisture availability is not so critical.

Present Crop or Vegetation Cover.—The present use of land to be tree planted naturally determines to a large extent what can be done in the way of preparation. Grass and alfalfa land should be prepared a year in advance, except on highly erodible soils. However, the presence of other crops on land to be tree planted frequently forces land preparation for trees into a rather tight schedule.

Grassland.—Sod on medium to heavy soils should be plowed deeply and worked until it is well decomposed. Preparation of grassland, on all but loose sandy soils, should begin at least 1 year before planting trees. During very drouthy seasons 2 years of summer fallow after plowing may be necessary. The roots of natural vegetation completely occupy the site and are highly competitive for moisture. When this vegetation is reduced or destroyed and the organic materials from it partly decomposed, the soil will be in best tilth for planting. Soil will be moist and free of fresh organic matter that would otherwise clog planting machines, and require moisture and nutrients for decomposition.

In contrast, grassland on light sandy soils cannot be prepared ahead of time because of the risk of wind erosion. In this case, the vegetation is scalped and turned over in a narrow strip 1½ to 2 feet wide at the time of tree planting.

Alfalfa fields.—Alfalfa fields should be prepared for tree planting in the same way as grasslands, except on light sandy soils.

On the sandy soils, alfalfa should be plowed 1 year before tree planting, and an annual crop planted in its place for temporary cover during the growing season. Trees can then be planted directly in the stubble with no further preparation.

Small grain fields.—Stubble of small grain normally furnishes adequate cover until tree planting time the next spring. In light, sandy soils trees can then be planted in stubble with no further preparation. In heavier soils, however, stubble should be plowed and disked the fall before planting.

Where stubble is not adequate, or if soil moisture is low, heavier soils should be summer fallowed and seeded to oats in the fall. Sandy soils should be planted to a late summer cover crop.

Corn fields.—On heavier soils the only preparation needed is to cut cornstalks and disk in the fall. Sandy soils, however, should be fall seeded to grain if the field lacks cover.

Noxious weeds, such as bindweed (creeping jenny), leafy spurge, thistle, and quackgrass, should be killed by cultivation and/or chemical sprays *before* trees are planted on any lands.

Recommended Practices

Minimum land preparation practices according to broad soil texture classes and land use are summarized below. The recommendations are adapted from two sources: (1) Soil Conservation Service technical specifications for Nebraska, and (2) recommendations of various State and extension foresters in the Plains. It is emphasized that these recommendations are minimum practices and intended only as a general guide. Detailed recommendations by specific soil types and different

vegetation covers have been developed for most local areas in the central Great Plains, and these will be used by soil conservation and forestry technicians.

RECOMMENDED MINIMUM LAND PREPARATION FOR TREE PLANTING ACCORDING TO SURFACE SOIL TEXTURE AND LAND USE

Sandy to very sandy soils

Grassland-----	Scalp a 20-inch band of sod just before planting; plant trees in narrow furrow.
Alfalfa-----	Plow 1 year before; plant summer annual cover crop; plant trees in cover crop stubble.
Small grain-----	Do not disturb if good stubble; plant trees in narrow furrow. Plow if poor stubble; plant summer cover crop; plant trees in cover crop stubble.
Corn-----	Fall disk cornstalks; plant small grain cover crop; plant trees in cover crop stubble.
IMPORTANT-----	After planting, do not cultivate between the tree rows on any sandy soils; just keep the weeds and grass mowed.

Medium to heavy soils

Grassland-----	Plow 1 year before; summer fallow; fall seed small grain for cover; spring disk and plant trees.
Alfalfa-----	Same as for grassland.
Small grain-----	Fall plow and disk if good moisture and stubble; plant trees in undisturbed soil. Plow stubble and summer fallow if poor moisture and stubble; fall seed small grain for cover; spring disk and plant trees.
Corn-----	Fall disk cornstalks; plant trees in undisturbed soil.

WHEN TO PREPARE LAND

Preparation of land well ahead of planting is an essential part of tree planting know-how in the Plains.

1. Lay out terraces 1 year before planting.
2. Subsoil areas with tight impermeable layers 1 year before planting.
3. Plow grassland and alfalfa stands, except on light sandy soils, at least 1 year in advance to allow for partial decomposition of organic materials.
4. Summer fallow plowed grass and alfalfa during the growing season before planting.
5. On light sandy cultivated soils, maintain as much coarse litter as possible on and in the surface the growing season and winter before planting.
6. If light sandy cultivated soils lack cover, plant a close-growing temporary crop the summer before and leave stubble undisturbed.
7. Erect snow fence barriers to windward of area the fall before planting.

8. When planting in spring-seeded grain, cultivate a narrow 4-foot strip for planting.

A time schedule for the various practices, by kind of soil and present land use, is suggested in the following checklist.

Practice	Sandy soils				Medium to heavy soils			
	Orass	Alfal-fa	Orain	Corn	Orass	Alfal-fa	Orain	Corn
One year before:								
Build terraces	X	X	X	X	X	X	X	X
Diversion ditches	X	X	X	X	X	X	X	X
Plow		X			X	X		
Subsoil					X	X	X	X
Summer before:								
Fallow					X	X	(*)	
Stubble mulch							(*)	
Leave stubble			X				X	
Disk stubble			(*)					
Plant oats		X	(*)					

Practice	Sandy soils				Medium to heavy soils			
	Grass	Alfal-fa	Orain	Corn	Orass	Alfal-fa	Orain	Corn
Fall before:								
Leave stubble	----	X	X	X	----	----	X	X
Plow	----				----		(*)	(*)
Disk	----		(*)	X	----		(*)	X
Plant oats	----		(*)	X	X	X	(*)	----
Snow fence	X	X	X	X	X	X	X	X
Spring:								
Leave stubble	----	X	X	X	----		X	----
Disk and harrow	----	(*)	(*)	(*)	X	X	(*)	(*)
Plant oats	----	(*)	(*)	(*)				----
Plant trees in:								
Firm fresh soil	----				X	X	(*)	(*)
Stubble	----	X	X	X			X	X
Grain	----	(*)	(*)	(*)	----			
Scalped furrow	X				----			

*Alternative practice if poor stubble cover or low moisture.

How To Obtain and Handle Tree Planting Stock

Because of the unfavorable conditions for germinating tree seed and tending small seedlings directly on planting sites in the Plains, the most practical method of establishing plantings is to transplant small trees. Large quantities of tree seedlings are produced in special nurseries (fig. 30) where the small delicate plants may be spaced, watered, fertilized, and weeded according to their needs. The 1- to 4-year-old seedlings or transplants are then shipped to the tree planter.

The average landowner tree planter must depend upon these special nurseries for his planting stock. These are operated by private commercial companies or by State and Federal agencies. Choice of species is therefore limited to those produced by these nurseries. In some years nursery failures further limit the kinds of trees and shrubs available.

Some species can be home grown by the farmer willing to devote some extra time to the job. Thus, species not generally available from nurseries may be produced for windbreak planting. If the farmer has had no previous experience in raising trees from seed, however, it will probably not pay him to try it for large quantities of planting stock. The cost of good-quality 1- to 4-year-old tree planting stock is well within the means of most landowners. For farmers interested in growing their own stock from seed, the following publications are recommended:

Woody-Plant Seed Manual.

U.S. Dept. Agr. Misc. Pub. 654. 1948.

Nursery Practice for Trees and Shrubs Suitable for Planting on the Prairie-Plains.

U.S. Dept. Agr. Misc. Pub. 434, 1941.

(Out of print; may be seen in libraries.)

Forest Nursery Practice in the Lake States.

U.S. Dept. Agr., Agr. Handbook 110. 1957.

Planting the Southern Pines.

U.S. Dept. Agr., Agr. Monograph 18. 1954.

Another method of obtaining tree planting stock is to dig small naturally grown seedlings from within well-established windbreaks, other plantations, or woodlands. These small wild seedlings, if top-pruned to balance the size of the root system excavated, can be transplanted in the same manner as nursery-grown seedlings. This is a practical method of obtaining small quantities of stock, but is not likely to be economical for 500 or more tree seedlings.

The purchasing and handling of tree-planting stock must be regarded as equal in importance to other phases of tree planting. Selection of recommended species will improve chances of success. However, variations in adaptability, growth, form, and insect and disease resistance will depend upon the parent trees or stands from which the seeds were collected (fig. 31). Source of seed materials is second only in importance to species selection itself. Much improvement in seed sources is anticipated in the future, but will require time for selection, breeding, and testing.

Proper handling of stock from the time it leaves the nursery until it is planted in the field is of



F-503712

Figure 30.—Tree nursery showing pine and redcedar seedling stands, sprinkling system, and snow fences for wind and snow control. Each foot of row contains about 20 seedlings.

utmost importance. This is the only time during the life of trees when the roots are exposed to abnormal conditions of temperature, moisture, and light. Therefore, with bare-rooted trees, careless handling even for a few minutes under dry, windy conditions can easily cause death of the trees.

WHERE TO BUY PLANTING STOCK

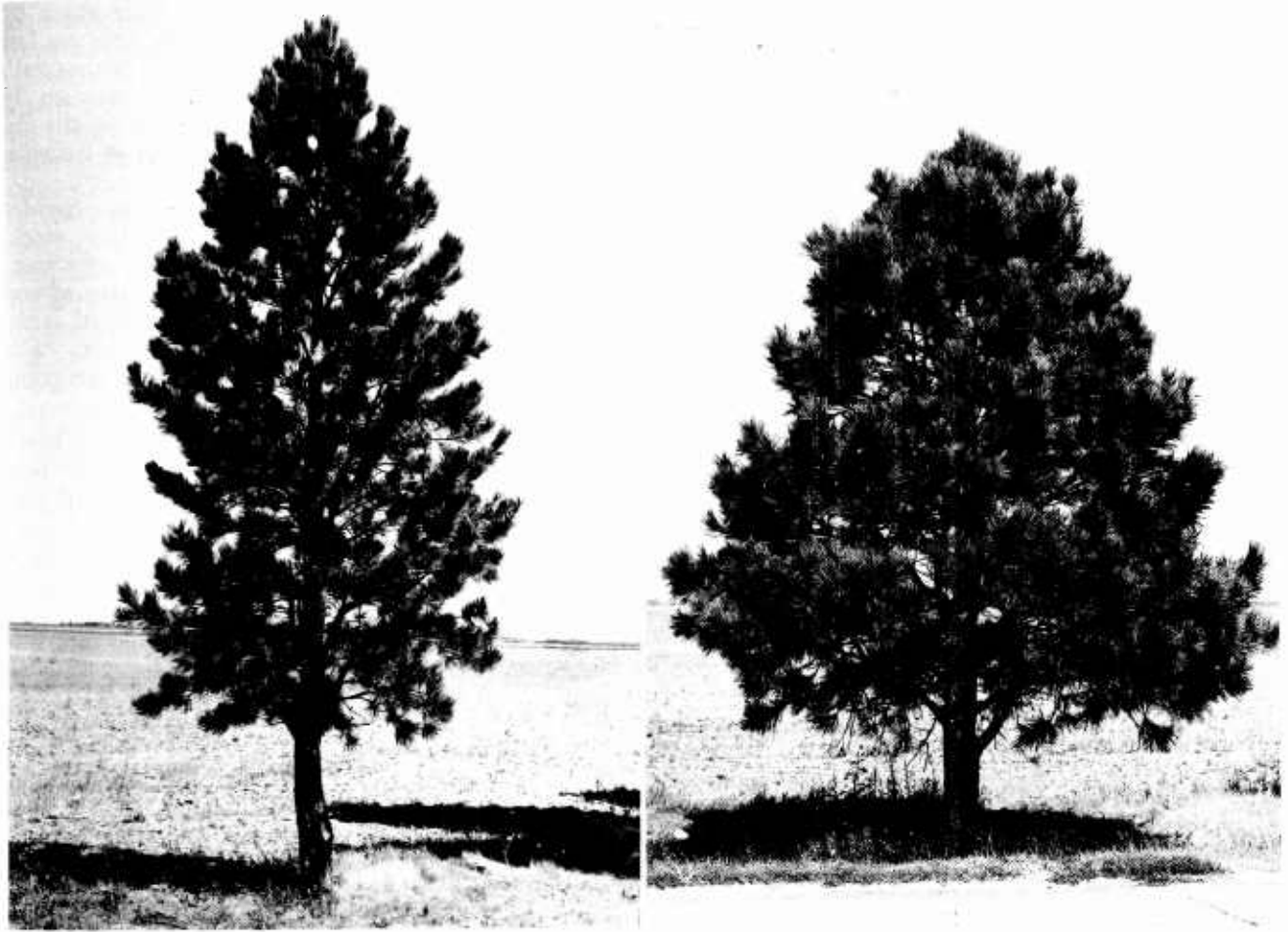
Planting stock for windbreaks is produced in about 20 nurseries in the Great Plains States. Of these, 10 are private commercial nurseries and 8 are State or soil conservation district nurseries. The two U.S. Forest Service nurseries, which also produce stock for National Forest planting, do not accept orders directly from landowners; they supply seedlings through State foresters, extension foresters, or Soil Conservation Districts for farm and ranch planting.

The common way of obtaining large quantities of tree-planting stock for windbreaks is through

an agricultural agency. Tree orders are processed in several ways: (1) Through county agricultural agents to the extension forester's office, (2) through district foresters to the State forester's office, and (3) through Soil Conservation District offices. These agencies accept orders and consolidate them before sending them to the various private, State, or Federal nurseries. Tree orders can also be mailed directly to any private commercial nurseryman.

Specify the Seed Sources

Studies in genetic variation of trees emphasize the importance of careful selection of seed sources for successful plantation establishment. Most tree species have a wide range of genetic variation. Best success may depend largely upon use of selected stock which has been grown from seed of parent trees of known adaptability and resistance to insects and diseases.



F-503713, 721

Figure 31.—Ponderosa pines of distinctly different crown form, branch angle, and foliage density. These different traits are inherited from the parent stocks.

Cost of planting stock should not be a primary consideration in a long-term investment such as windbreaks. It is better to pay for stock of known adaptability than to pay less for untried and poorly adapted stock. The cheaper plant materials may prove to be expensive in the long run, because of poor survival.

Special selections of two species recommended for Plains windbreaks are presently available. Chinkota elm, a selection of Siberian elm, has proved to be more winter hardy than the general run of Siberian elm available in most nurseries. This selection was developed by research scientists at South Dakota State College and certified for use in South Dakota. A selection of cottonwood, known as Siouxland, is faster growing, more vigorous, and more resistant to leaf rust than the general run of common cottonwood (fig. 32). It was developed by Dr. C. M. Nagel, a plant pathologist in South Dakota.

A general recommendation in specifying source of seed for planting stock is that it should origi-

nate within a range in latitude of 100 miles north and south of the planting site.

Progress is being made toward identifying and propagating individuals and sources of trees that have superior characteristics for windbreak use. Progress will be encouraged if orders for trees specify where they are to be planted and what is desired in terms of tree growth rate, form, disease and insect resistance, and other special characteristics.

Specify Sizes and Grades

In any bed or lot of nursery-grown stock there are some small, deformed, or damaged seedlings not suitable for field planting. These should be discarded by the nurseryman, but sometimes are shipped out to planters. Planters should discard all small-grade cull stock. Experience and research have demonstrated that certain sizes and grades of planting stock are required to obtain satisfactory survival and growth of trees on

Plains planting sites. These sizes usually average somewhat larger than is required in stock for the more humid forested regions.

Caliper or diameter of stem 1 inch above the ground line is a good measure of the ability of planting stock to survive. Large-caliper stock gives highest survival in normal to dry seasons. Slightly smaller caliper stock will do well during seasons of above-average rainfall in April and May.

Minimum stem caliper for trees to be planted in the Plains should be one-fourth inch for both conifers and broadleaf species. Two to three years are required to grow junipers and pines to this size; one year for most broadleaf species.

Size of top is of less importance than stem caliper, although many nurseries list their stock by top size only. Conifers should have tops no less than 8 inches and no more than 15 inches tall. Broadleaf seedlings should average between 18 and 30 inches in height. For most species, the top size will be correct if the stem caliper is between $\frac{1}{4}$ and $\frac{3}{8}$ inch.

Grading of seedlings and transplants provides the greatest assurance of good-quality stock. Grading takes into consideration not only stem caliper and top height, but also the ratio of top to root size, root damage, size of terminal buds, occurrence of disease, color of foliage, etc. The use of top-root ratio by weight can make the grad-

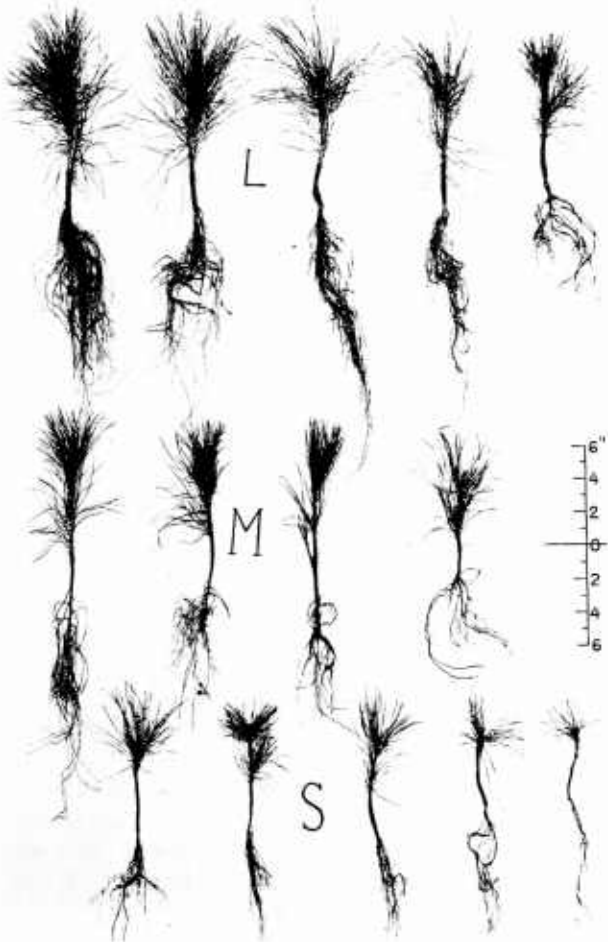


Figure 32.—Siouxland, rust-resistant cottonwood 40 feet tall at 7 years of age, Lincoln, Nebr.

F-503714

ing process more accurate and selective, since it expresses favorable or unfavorable balance. Seedlings having a large root system for an average or better top will survive better than those with a small root system. Shearing or cutting back the top growth of seedlings is often practiced in the nursery to obtain a more favorable top-root balance. This should be done by the tree planter if he receives trees that are poorly balanced. For conifers a 3 to 1 ratio of top to root weight is desirable; a 3 to 2 ratio is better.

There are at present no standard grading rules for any species used in Plains planting. If "grading" is being done, it is merely a matter of culling, rather than sorting trees into small, medium, and large grades. The mass of evidence, however, from all regions of this country and the world, and with most tree species, supports the practice of grading for best results. The medium and large grades of stock (fig. 33) consistently give the highest survival and growth.



F-503715

Figure 33.—Specimens of nursery bedrun, 3-year-old ponderosa pine, showing large (L), medium (M), and small (S) grades of planting stock. The small grade trees are culls for Plains planting. Scale in inches.

PACKING AND SHIPPING

Although packing and shipping will normally be done by experienced nurserymen or foresters, the landowner or technician receiving trees should be aware of proper packing and shipping procedures. He should notify the agencies responsible of any serious deficiencies in packing methods.

The period of time during which bare-rooted trees are kept out of the soil is probably the most critical time for them between germination and maturity. Conifers are more sensitive to poor care of the roots than most broadleaf species.

Packing and shipping must therefore be accomplished with little delay and by methods that will maintain proper moisture and temperature about the root systems until trees reach their destination. Once tree roots are damaged or become dry, no amount of watering or care is likely to make them grow.

Trees are packed in various ways depending on the preferences of nurserymen and agencies responsible for distribution. Packing is usually done inside a building that is kept rather cool, not over 50° to 60° F.

Sphagnum moss and shingletow are the most commonly used packing materials. This material is allowed to soak up as much water as it will hold. It is then spread out in the center of the wrapping material and trees placed on it with roots to the center. More moss or shingletow is placed on the roots and the spread is then rolled into a compact bundle. Wrapping materials may be ordinary burlap, burlap-backed paper, asphalt-impregnated paper, or crinklekraft paper. Bundles are tied with twine, wire, or steel strap.

Some agencies used corrugated paperboard cartons lined with wax to preserve the useful life of the carton containing the damp packing material. These are closed with gummed tape or large staples. With wax-lined cartons inner wrapping paper is not used; the trees and packing materials are put directly into the box.

Larger tree orders are often put up in bales either in the field or packing shed. Such bales may contain 1,000 to 2,000 trees, and generally contain a smaller quantity of packing materials in proportion to tree roots than the smaller bundles. Field baling is not ordinarily done during hot, windy weather. Bales are usually watered with a probe if stored for any length of time before shipment. Once dug from the nursery beds, all conifers whether in bales or loose in field carry boxes are stored in refrigerated rooms at 40° F. when not actually being counted, graded, packed, or transported.

Trees in bales or boxes are shipped 50 to several hundred miles by various means. Planters living within 50 miles of the nursery often pick up trees to reduce the time in transit. Railway parcel post or express is the predominant mode of tree ship-

ping, although trucks are increasingly used. Refrigerated trucks are preferred for longer hauls requiring more than a half day or if freezing weather is likely. Air freight, available at a limited number of points, provides shipment with the least delay, though at higher cost. Trees shipped by air reach their destination in several hours and are practically as fresh as when shipped.

WHAT TO DO WHEN TREES ARRIVE

When tree planting stock is received at the farm or ranch, the bale or carton should be opened for inspection without delay. If trees have been packed properly to keep roots moist and cool, have been in transit no more than 2 or 3 days, and have not been subjected to either freezing or high temperature, they will be in good condition for planting.

If trees are to be planted within 2 weeks from the time of arrival, they can be left in the box or bale. They should be watered each day, and kept in a cool place out of the sun and wind.

In contrast, if roots are dry or barely moist and noticeably warm or moldy, trees should not be planted. The office through which the tree order was given should be notified. The tree-distribution people and nurserymen want to know about the condition of trees after shipment, and prompt notification of poor conditions will aid them in improving packing and shipping methods.

Planting stock should also be inspected for size and grade. If the shipment contains more than 5-percent cull or very small trees, the tree-distribution people should be notified. The small trees should not be planted.

Storage

If moist cold storage at temperatures of 33° to 40°F. is available, trees should be so stored until planting time. The bales should be opened and the packing material moistened thoroughly by sprinkling. The bales should then be retied loosely and watered often to maintain moderate moisture. The cold storage will keep trees dormant for several weeks until planting can be done.

Heeling-In

If planting is to be delayed longer than 2 weeks after arrival of the trees, and if moist cold storage is not available, trees should be heeled-in the soil in a shady, cool place.

Heeling-in is done by digging a V-shaped trench (fig. 34) deep enough to accommodate the



F-345374

Figure 34.—A properly made heel-in trench for temporary storage of seedlings and transplants.

full spread of tree roots against the bare soil. A bundle of seedlings is untied and spread out on the sloping side of the heel-in trench, so that each tree root system will be in contact with soil. The trench is then filled with soil, packed and watered so that there will be no air spaces among the roots.

Heel-in trenches should be deep enough to accommodate roots without their being bent or curled upward. Following are detailed directions for storing seedlings in trenches. Throw in pulverized soil on the first layer of tree roots until the roots are covered by an inch or two of soil. Then start another layer of trees. No part of the green tops of conifers should be covered with soil. Check soil moisture each day and sprinkle if necessary. Trees should be removed from the heel-in beds and planted before buds burst and new growth has started.

How To Plant Windbreak Trees

Twenty-five years ago most tree planting was done by hand; 500 trees per man on Plains sites was a good day's work. Many plantings of less than 500 trees are still planted by hand, and generally this is the cheapest and most efficient way to establish small plantings.

Complete windbreak systems for most farms nowadays require several thousand trees. Furthermore, weather conditions and the pressure of other work at tree-planting time often demand that the job be done as quickly as possible. Tree-planting machines are therefore used to do the job quickly and efficiently. A 3-man crew with planting machine can plant up to 8,000 trees a day.

A word of caution regarding machine planting. Even with a machine working properly and an experienced crew, it is better to plant fewer trees and plant them well, than to set a speed record and later find less than half of them alive, because of a poor job of handling and planting.

WHEN TO PLANT

Trees are best planted in the 3 to 4 weeks of early spring after the frost is out of the ground, but before the tree buds begin to swell. In eastern Nebraska in average years this period falls between April 10 and May 10. Planting in western Nebraska is usually 1 to 2 weeks later. Tree planting in southern Kansas may begin in mid-March, 2 to 3 weeks earlier than in eastern Nebraska.

Bare-rooted trees should not be field planted after they have started new top growth, since many of them will die with such treatment. Potted trees should likewise be planted before growth starts. However, if delay in planting is unavoidable, potted trees can be field planted throughout the growing season, if they are watered on planting.

Fall planting is not recommended. Experience has shown that mortality of fall-planted trees is likely to be high, owing to excessive moisture loss during winter before trees can establish a new root system. There is also danger of frost heaving in heavier soils. Fall-planted trees are apt to suffer higher mortality from rodent damage, since they lack a well-established root system and hence the capacity to recover.

Other recommendations concerning techniques of planting are as follows. Choose calm, cloudy days for planting, when possible. Plant even during rain on sandy soils where equipment can be operated in wet weather. Defer planting when wind velocity exceeds 15 m.p.h. If spring planting conditions are too unfavorable, i.e., with excessive wind, heat, and dry soils, line out trees a foot apart near the farmstead where they can be irrigated and tended for a season. Dig them before growth starts the following spring and transplant by hand or machine to the field location.

LAYOUT

The District Forester or Soil Conservation District technician will assist in preparing planting layout plans. Copies of the layout, including number of rows, species arrangement, spacing, etc., are furnished as a guide to the farmer and tree-planting foreman.

The planting layout in the field should be completed before any trees are moved. Distance between rows should be staked with flags or laths. Then the tractor driver pulling the tree planter can line up the machine without delay. Sufficient space for cultivation should be left between tree rows and existing fences.

Rows should be laid out in advance if a row marker on the machine is not used. Stakes should be set close enough (not more than 150 to 200 feet apart) in each row so that tree rows are parallel. Crooked and nonparallel rows can cause trouble in cultivation. Where rows curve or turn corners, more stakes should be set so that a smooth curve is made. The most timesaving and accurate method of making parallel rows is to use a row marker attached to the tractor or the planter (fig. 35).

In advance, the first stake in each row should be labeled clearly to identify the species to be planted. Intermediate stakes where a change in tree species is required should be similarly labeled. This is important, to make sure the different species are planted in the arrangement that was planned. Obviously, mistakes are not easily corrected after the trees are planted.

Distance between trees in the rows can be estimated by pacing when hand planting. In machine planting, the proper distance can be governed by speed of the machine and timing of the planters. A flagged spacing stick can be fastened to the tail end of the planting machine to help the planters estimate distance between trees.

PLANTING DEPTH

Trees should be planted in the field at approximately the same depth as they grew in the nursery. A frequent mistake in present-day planting practice is setting trees too deep. This mistake is sometimes compounded later by close cultivation which tends to cover the trees even more. Planting too deeply is more damaging to conifers than to broadleaf species. A good rule is not to cover any lower branches.

It is also a mistake to plant too shallow unless a cultivator following immediately will throw soil toward the trees. Shallow planting is likely to expose part of the roots to drying and also will result in trees being blown over. It is better to



SCS-545

Figure 35.—Tractor-drawn tree-planting machine with row marker in carry position. In use, the long bar swings out at a right angle to line of travel and marks the next row to be planted.

plant at the proper depth in the first place, then keep cultivation equipment at least a foot away from the trees.

Conifers and most broadleaf trees will normally be planted as they come from the nursery. Shrubs, however, can be top-pruned to force low branching. Broadleaf species and eastern red-cedar exceeding 20 inches in top length should also be top-pruned. This will improve top-root ratio and assure better growth the first season.

CARE OF TREES DURING PLANTING

Tree roots should never be allowed to dry, even slightly. On the planting site, all trees excepting the ones needed for a complete round or pass through with the planter should be kept wrapped in cool, moist condition in the shade of other trees or beneath a vehicle. If the roots of trees in a bundle are tangled together, each tree should be carefully separated so that roots are not stripped during the fast pace of machine planting.

In both machine and hand planting, trees should always be carried with their roots in water, moist moss, sand, or burlap. No delay or interruption should occur in moving trees from the moist bales or heel-in beds to planting containers.

MACHINE PLANTING

The very speed that enables the planting of several thousand trees per day is one of the disadvantages of machine planting. In most instances the greater speed results in less attention being given to the condition of the individual tree than with hand planting. And yet each tree has an important function in the windbreak.

Therefore, a special effort should be made to carefully check the following items by frequent sampling:

1. Proper planting depth.
2. Roots not doubled up.
3. Roots not stripped.
4. Soil well packed about roots.
5. Trash not mixed in with roots.
6. Top not mechanically damaged.
7. Tree vertical.

Each tree row should be "walked" to check these items following planting. The "walker" should firm the soil about each tree with his feet, if the packing wheels are not operating properly. It may be desirable to stop the planting, make adjustments, and then resume at a speed that will give the best planting job.



F-323445-46-47-49-51-52-54

Figure 36.—Steps in hand planting by the Prairie States Forestry Project method: A, Remove debris and dry soil; B, position of shovel for first insertion; C, shovel handle pushed forward to break out soil behind blade; D, after pulling loose soil from hole, the shovel is inserted a second time to make a firm vertical wall; E, tree roots are placed against vertical wall, and loose soil pushed against them; F, hole is half filled with loose, moist soil and firmed against roots with the foot; G, hole is filled with soil and firmed about the tree with the feet.

HAND PLANTING

Hand planting, in contrast to machine planting, makes it possible to give maximum individual attention to each planted tree. Detailed directions are as follows.

All trash should be scraped off the planting spot. Dig the hole deep enough to accommodate most of the roots, leaving one side of the hole smooth and vertical. Holding tree with one hand at proper depth against the vertical side of hole, throw in moist, loose soil against the lower root



system and pack firmly with the fist or heel. Continue to add loose soil (no trash) and pack firmly until the hole is filled. Step on loose soil with heel to settle it, and add more soil to fill flush with surrounding ground. Kick a mulch of trash or loose soil around the tree.

An improved method of hand planting, devised by the Prairie States Forestry Project, uses a long-handled, round-pointed shovel with a straight shank (fig. 36). With this method a minimum of soil is moved and speed of planting is increased.

How To Cultivate and Protect Windbreak Trees

Failure to cultivate and protect windbreaks has resulted in thousands of mediocre to worthless tree plantings in the Great Plains. The presence of such examples tends to discourage rather than promote the planting of trees for windbreaks.

Lack of grass and weed control can completely nullify the initial success of a good tree-planting job using high-quality stock. This point has been repeatedly emphasized in practically every bulletin, circular, news article, and leaflet written about planting trees on the Plains. Reasons for control of herbaceous vegetation were stressed in the section on land preparation. Vegetation control after tree planting is just as important and is covered in detail in this section.

In Plains tree plantations, protection measures are as important as cultivation. Lack of protection against rodents, livestock, fire, insects, and diseases can nullify in short order all previous care in selection of trees, planting, and cultivation.

WHY CONTROL OF VEGETATION IS IMPORTANT

Methods of vegetation control may vary, but all are aimed at reducing the amount of herbaceous plants likely to compete with trees for moisture, and to prevent the shading and smothering of trees by tall, overtopping herbaceous growth.

The importance of controlling herbaceous vegetation generally increases from the humid East to the dry West. Results of experiments in South Dakota showed that clean-cultivated trees after four seasons, averaged over 3 feet taller, 1 inch larger in diameter, and had more lower branches than trees cultivated only once during a season. The faster tree growth thus favored by clean cultivation made it possible to stop cultivation 1 year earlier, because the trees crowns closed and shaded out herbaceous vegetation.

Although the need for complete cultivation to conserve moisture may be less in years of surplus moisture, the need will remain to control weeds and grass likely to overtop the trees. It is true that during exceptionally windy weather, a moderate amount of herbaceous vegetation between the tree rows is desirable to reduce the bad effects

of hot, drying winds on young trees. The area immediately surrounding each tree, however, should always be kept free of grass and weed growth.

If a tree planting becomes thickly infested with tall weeds and grass during the season, complete removal of this vegetation surrounding the trees during hot, dry weather is not recommended. The sudden change of environment is usually too great a shock for young trees. Therefore, in such a situation, only the part of weeds overtopping the trees should be removed. This can be done either by high mowing or cutting by hand. Normally, the mechanical control of weeds and grass is best done while in the very young seedling stage. This is much easier than trying to control large, coarse weed growth, and it also conserves soil moisture.

Methods of Control

There are three ways to control unwanted vegetation in tree plantings. Chemicals sprayed or applied dry at the proper time either inhibit seed germination or kill the small seedlings of weed species without damaging the trees. Mechanical methods of cultivation cut the roots or tops of weeds and grass, and kill them or reduce their growth by either burying or throwing them on top of the soil. Mulching with dead or processed materials smothers weeds and grasses, stopping growth.

Chemicals.—Recent tests using various chemicals in tree plantings have given excellent control of weeds and grasses, without injury to the trees (fig. 37). Some tree species, however, are more sensitive than others to herbicides. Chemicals can damage trees and therefore should be used strictly as recommended. Soil type also influences the chemical effect and the rates recommended. Some injury to trees by chemicals may be acceptable if no other control of herbaceous vegetation is possible.

What to apply.—The chemicals simazine and diuron have been tested for several years and are effective through spraying treatment. Wettable powders are better than dry or granular chemicals. Weed growth stops when roots of newly germ-



F-503716

Figure 37.—Scots pine plantation in midsummer in eastern Nebraska after chemical treatment in early spring. Tree rows remain free of weeds and grasses.

inated seedlings absorb the chemical. Some control is also effected by preventing the germination of seeds. Once sprayed, the treated area should not be disturbed, since success of treatment depends on keeping the chemical in the surface 2 inches of soil. Most of the tree roots are below this depth.

How much to apply.—Recommendations for use of simazine and diuron vary according to soil texture. For medium to heavy-textured soils, use 5 pounds of 80 percent wettable simazine powder or 4 pounds of wettable diuron per acre of area to be covered. *Sandy soils* require a *weaker dosage* because chemicals permeate them more rapidly. For lighter textured sandy soils, use 2½ pounds of 80 percent wettable simazine, or 2 pounds of 80 percent wettable diuron per acre.

When to apply.—Chemicals should be applied in the spring *before* weed seeds germinate. Application before a rain appears to be most effective. If a week or two of dry weather follows applica-

tion, the treatment loses much of its effectiveness, because weeds begin growth before the chemical reaches their root zone. If the weather is windy, spraying should be postponed.

How to apply.—A high-pressure sprayer giving a constant pressure of 30 to 50 pounds and with a "Teejet" No. 8002-E nozzle¹ is suitable. A backpack or a 2-gallon hand-operated sprayer with a pressure gage can be used for small plantings (fig. 38). However, a power sprayer operating from a pump on the tractor power takeoff and a container of 50 gallons capacity is recommended for plantings of an acre or more. Agitation of the solution is necessary since wettable powders tend to settle. A bypass discharge into the bottom

¹ Trademark, Spraying Systems Co., Bellwood, Ill. The identification and description of commercial products in this publication are solely for information purposes. Endorsement of any commercial product is not intended and must not be inferred.



F-503717

Figure 38.—Backpack sprayer equipment for applying chemical to control weeds.

of the chemical tank will provide agitation. All screens should be 50-mesh or coarser.

The nozzle height should be adjusted to spray an 18- to 20-inch swath on each side of the tree row. The sprayer may be calibrated by determining the amount of water sprayed per acre at a given rate of travel at constant pressure.

Cultivation.—Cultivation of tree plantings by common farm equipment is best accomplished by never allowing herbaceous vegetation to grow large. Several cultivations will be needed during each of the first two growing seasons. Fewer cultivations will be required as control of germinating weeds and grasses is accomplished. Equipment should be used in such a way as to keep the soil fairly level, yet leave the surface in cloddy condition for maximum wind erosion control and absorption of moisture.

Rows of trees should not be ridged up as in corn cultivation, because some trees, especially conifers, are sensitive to depth of soil around the stem. Ridging often covers lower branches and increases

likelihood of mechanical damage to the tree stem. It also increases moisture runoff away from trees.

During the first year or two, tree rows may be straddled by cultivation equipment. When the trees are so tall that equipment whips the tree crowns, it is best to cultivate on each side of tree rows, destroying weeds as close to trees as possible without hitting them.

Cultivation should be just deep enough to kill weeds and grass. Cultivation deeper than 5 or 6 inches will interfere with tree root development.

If the planting has been cultivated in early season and growth of herbaceous vegetation is well under control, any new growth of weeds or grass after mid-August should be left standing. Late cultivation of the trees has a tendency to sustain growth into the fall, making some species more susceptible to winter injury. As previously mentioned, the presence of some herbaceous vegetation will furnish protection to trees and soil during winter.

With moderate (10- to 14-foot) tree-row spac-

ing, cultivation after 8 to 10 years will no longer be feasible or necessary. The tree crowns will close together between rows; shading and accumulation of leaf litter will reduce weed growth until little herbaceous vegetation remains. Crown closure between rows will take longer when wider spacings of 16 feet or more between rows are used. The wider the row spacing, the more years cultivation will be required. Clean cultivation of a strip of land on all sides of each tree planting is recommended for all times as a protection against wildfire.

A single-row cultivator is recommended by the South Dakota extension forester as the best all-around implement for maintaining tree plantings. Finger-type weeders for "over-the-row" cultivation while trees are small, are favored in the Dakotas. Two-row cultivators, spring-tooth harrows, duckfoot cultivators, sweeps, and disk harrows are recommended and useful under various conditions (fig. 39, A). Sweeps and disk harrows are required to clear thick stands of large weeds in tree plantings. A single-disk is not recommended, however, because it ridges the soil toward the tree rows. Spring-tooth harrows are useful only for small seedlings of weeds and grasses.

Cultivation between trees in the rows, where ordinary farm implements cannot work, requires special care. Cultivation is not necessary if the vegetation is chemically treated or frequently hoed or mowed. However, special cultivators can be purchased or constructed for this purpose. A grape-hoe implement that is pulled by or swings in and out from the side of the tractor works well for controlling vegetation between trees in the rows (fig. 39, B). For the extra touch that gives trees the best opportunity to grow and develop, there is no substitute for hoeing around each tree with a hand hoe.

Mowing.—In normal to wetter seasons and especially in the eastern Plains, mowing instead of cultivation between the rows may have some advantages. Mowing tends to favor establishment of grass while reducing weed populations. A grass cover of summer annuals, controlled by mowing between tree rows, will reduce damage from water erosion on sloping land. This is a good practice when combined with chemical control of vegetation in the tree rows.

Mowing can be a substitute for cultivation only under especially favorable conditions. As the trees reach 3 to 4 feet or more in height, the danger of overtopping by weeds is less. At this point mowing between tree rows can take the place of cultivation as long as sufficient moisture is available in the soil. However, if soils become extremely dry owing to presence of deep-rooted perennial grasses, cultivation rather than mowing should be practiced, even in older plantations.

Mulching.—Mulching is not generally recommended for control of coarse weeds in tree plant-

ings. To be effective in controlling weeds, the mulch must normally be 6 to 10 inches deep, and thus a source of mulching materials from other than the tree planting area is required. However, the mowing and mulching of coarse grasses has often been used successfully to retard growth of vegetation. Vegetation mowed and allowed to remain in place can make an effective mulch.

There are some disadvantages to mulching for vegetation control. In the northern Plains, thick mulches encourage large populations of small rodents which girdle trees during winter. Heavy mulches tie up soil nitrogen as they decompose. The organisms that break down the cellulose of mulch materials require large quantities of nitrogen and therefore leave less available for the trees.

WHY PROTECTION IS IMPORTANT

Trees established in the Plains by planting or natural means are normally subjected to greater stresses in moisture, temperature, and wind than trees in naturally forested areas. These extremes of environment often damage trees. Furthermore, damaging agencies such as livestock, rodents, fire, insects, disease, and chemical weed sprays may put additional restrictions on tree growth unless the trees are given protection against these agencies.

Tree establishment in the Plains is much too difficult and costly to allow animals or plant pests to nullify early successes. As previously mentioned, tree planting is a long-term investment. Positive protective action against damage can be a major item in the protection of that investment.

METHODS OF PROTECTION

Methods of protection vary according to the damaging agency. Protection from grazing, browsing, or trampling by livestock is effected simply by fencing the tree plantation to keep livestock out of it. Protection from insects or diseases, on the other hand, is often difficult and costly, since chemicals, sprayers, saws, axes, and other equipment may be required. Treatments must frequently be repeated to be fully effective. Protection from volatile chemicals used to control weeds in agricultural crops is a problem that can be solved only on a community basis. Application of herbicides by field sprayers or aircraft should not be done during windy weather, when the chemical is likely to drift across tree plantings.

Livestock Damage.—When tree plantations or windbreaks are open to use by livestock or are fenced for use by livestock, damage to soil, tree growth, and windbreak effectiveness is the result (fig. 40). Cattle and horses browse the foliage from lower limbs, break off small trees, trample young seedlings, and compact the soil.



SCS-1549, 1781

Figure 39.—Well-maintained farmstead windbreaks in central Nebraska: A, Cultivation by disk harrow. B, Cultivation close to trees by grape and berry hoe plow.



F-485794

Figure 40.—Windbreak plantings damaged by livestock browsing. The lower level foliage has been destroyed. The soil has been compacted and is almost impermeable to water.

Soil porosity and water infiltration are reduced and runoff increased. Wind velocity through the windbreak is increased near the ground and efficiency of protection on the leeward side is reduced. Shrubby species less than 4 feet tall are usually hedged back to the ground.

Damage by livestock may be temporary. A moderately browsed tree plantation can be expected to recover in 10 years if livestock are kept out. However, if extremely heavy browsing has killed all shrubs, the lower level of the windbreak will usually remain inadequate in foliage density for many years.

Rodent Damage.—Damage by rabbits, mice, ground squirrels, and gophers is usually most severe when trees are young. Occasionally a new planting is so hard hit by rodents that complete replanting is necessary.

In some winters, mice will girdle the bases of larger trees beneath the snow. Rabbits often girdle or debark the limbs of some species up to whatever height the snow surface reaches. Rabbits and ground squirrels frequently chew off the tops of 1-year-old conifers.

Control of rodents should be started the winter before tree planting and continue through the first season, if the rodent population is known to be high. Although shooting, trapping, and chemical repellents all help to reduce damage, the most satisfactory control method is use of poison baits containing strychnine or arsenic. Recommended

formulations of poison compounds and techniques of baiting can be obtained from the county agents and local Soil Conservation Service personnel. Strychnine alkaloid mixed with a starchy paste or with alfalfa meal has been particularly effective. Care should be taken to place these baits where domestic animals cannot reach them. Dead rodents should be gathered up and buried so that dogs and other tame animals cannot reach them.

Insect Damage.—Insect populations can often build up to damaging proportions before the landowner is aware of the problem. Frequent inspections and alertness in recognizing insect damage in early stages are the main items in an effective protection program.

Insects must first be identified, then a careful check made to determine the extent of the infestation. Assistance should be sought from county agents, extension entomologists, and forest entomologists for identification and recommended controls.

Insect damage to trees and shrubs may be grouped into the following categories, depending on plant parts usually affected and the feeding habits of the insects: (1) Leaves eaten, mined, or galled; (2) buds, shoots, twigs, or flowers damaged; (3) main stem or large branches girdled, weeviled, or bored; (4) sucking of sap from leaves, twigs, branches, or bark.

The leaf eaters are the most common insects attacking trees in the Plains region. Many of

them are general feeders, likely to occur on any tree and shrub species. For example, the spring and fall cankerworms, hornworms, tent caterpillars, webworms, bagworms, leaf beetles, and grasshoppers may attack and damage many kinds of trees and shrubs under epidemic conditions (fig. 41). Normally most trees and shrubs can withstand a single defoliation; they will soon recover if weather conditions are favorable.

Damage to buds, shoots, and twigs is usually more serious in its effect than defoliation, because recovery is slower and trees are often deformed. For example, the pine tip moth, a terminal shoot borer, causes extensive damage to ponderosa pines by killing new shoot growth and retarding height and crown development.

Insects attacking the main stems or large branches of trees are even more damaging. Cottonwood borers, roundheaded and flatheaded borers, and carpenter worms frequently kill outright some broadleaf tree species. Pines and red-cedars are not often attacked by borers or bark beetles except during extremely dry periods. Other serious pests which girdle the main stems of smaller trees include the cutworms and armyworms.

Sap-feeding insects such as scales, mealybugs, aphids, and red spider mites are nearly always present in the Plains area. They feed on most of the trees and shrubs used in windbreaks. Normally the damage they cause is not serious, but occasionally they get out of control with favorable weather conditions for their increase and a lack of predators. Their effects are usually seen only for 1 or 2 years, after which natural enemies bring about control. In addition to the four categories listed above, there are root-feeding insects, chiefly the white grubs, which curtail root development of established trees.

The following tabulation lists the common and scientific names of the more important insects causing damage to tree and shrub species used in windbreaks in the central Great Plains. The numbers 1, 2, 3, and 4 denote the category of insect damage as given above.

Cottonwood, poplar, and willow

1	Cottonwood leaf beetle-----	<i>Chrysomela scripta</i>
1	Spring cankerworm-----	<i>Paleacrita vernata</i>
1	Fall cankerworm-----	<i>Alsophila pometaria</i>
1	Willow leaf beetle-----	<i>Chrysomela interrupta</i>
1	Cottonwood dagger moth---	<i>Acronicta lepusculina</i>
1	Eastern tent caterpillar----	<i>Malacosoma americanum</i>



Figure 41.—Defoliation of caragana shrubs by grasshoppers.

Cottonwood, poplar, and willow—Continued

1	Fall webworm	<i>Hyphantria cunea</i>
2	Twig girdler	<i>Oncideres cingulata</i>
3	Flatheaded apple tree borer.	<i>Chrysobothris femorata</i>
3	Cottonwood borer	<i>Plectrodera scalator</i>
3	Poplar borer	<i>Saperda calcarata</i>
4	Poplar stem gall aphid	<i>Pemphigus populicaulis</i>
4	Poplar petiole gall aphid	<i>Pemphigus populitransversus</i>
4	Poplar vagabond aphid	<i>Mordwilkoja vagabunda</i>

American elm

1	Elm sawfly	<i>Cimbex americana</i>
1	Mourning-cloak butterfly	<i>Nymphalis antiopa</i>
1	Spring cankerworm	<i>Paleacrita vernata</i>
1	Fall cankerworm	<i>Alsophila pometaria</i>
1	Elm leaf beetle	<i>Galerucella luteola</i>
2	Twig pruner	<i>Hypermallus villosus</i>
3	Smaller European elm bark beetle.	<i>Scolytus multistriatus</i>
3	Elm borer	<i>Saperda tridentata</i>
3	Flatheaded apple tree borer.	<i>Chrysobothris femorata</i>
4	Elm cockscomb gall	<i>Colopha ulmicola</i>
4	Woolly elm aphid	<i>Eriosoma americanum</i>
4	Scurfy scale	<i>Chionaspis furfura</i>
4	European elm scale	<i>Gossyparia spuria</i>
4	Elm scurfy scale	<i>Chionaspis americana</i>
4	Oystershell scale	<i>Lepidosaphes ulmi</i>

Siberian elm

1	Fall webworm	<i>Hyphantria cunea</i>
---	--------------	-------------------------

Bur oak

1	Green-striped mapleworm	<i>Anisota rubicunda</i>
2	Oak twig pruner	<i>Hypermallus villosus</i>
2	Twig girdler	<i>Oncideres cingulata</i>
3	Flatheaded apple tree borer.	<i>Chrysobothris femorata</i>
4	Oystershell scale	<i>Lepidosaphes ulmi</i>

Green ash

1	Great ash sphinx	<i>Sphinx chersis</i>
1	White-lined sphinx	<i>Celerio lineata</i>
3	Ash and privet borer	<i>Tylonotus bimaculatus</i>
3	Eastern ash bark beetle	<i>Leperisinus aculeatus</i>
3	Carpenterworm	<i>Prionoxystus robiniae</i>
3	Ash borer	<i>Podosesia syringae frazieri</i>
4	Oystershell scale	<i>Lepidosaphes ulmi</i>

Hackberry

1	Blackberry nipple gall	<i>Pachypsylla celtidis mam-</i> <i>ma</i>
1	Mourning-cloak butterfly	<i>Nymphalis antiopa</i>
2	Twig pruner	<i>Hypermallus villosus</i>
3	Flatheaded apple tree borer.	<i>Chrysobothris femorata</i>
4	Oystershell scale	<i>Lepidosaphes ulmi</i>

Honeylocust

1	Blister beetle	<i>Epicauta</i> spp.
2	Twig girdler	<i>Oncideres cingulata</i>
3	Honeylocust borer	<i>Agrilus diffcilis</i>

Black walnut

1	Walnut caterpillar	<i>Datana integerrima</i>
2	Twig pruner	<i>Hypermallus villosus</i>
3	Flatheaded apple tree borer.	<i>Chrysobothris femorata</i>
4	Scurfy scale	<i>Chionaspis furfura</i>

Boxelder

1	Boxelder bug	<i>Leptocoris trivittatus</i>
1	Fall webworm	<i>Hyphantria cunea</i>
1	Cecropia moth	<i>Hyalophora cecropia</i>
1	Green-striped mapleworm	<i>Anisota rubicunda</i>
2	Boxelder twig borer	<i>Proteoteras willingana</i>
3	Flatheaded apple tree borer	<i>Chrysobothris femorata</i>
4	Boxelder aphid	<i>Periphyllus negundinis</i>
4	Oystershell scale	<i>Lepidosaphes ulmi</i>

Caragana

1	Grasshopper	<i>Melanoplus</i> spp.
1	Caragana blister beetle	<i>Epicauta subglabra</i>
1	Nuttall blister beetle	<i>Lytta nuttallii</i>
1	Alfalfa caterpillar	<i>Colias eurythema</i>

American plum

1	Variable oak leaf caterpillar.	<i>Heterocampa mantee</i>
1	Eastern tent caterpillar	<i>Malacosoma americanum</i>

Chokecherry

1	Prairie tent caterpillar	<i>Malacosoma lutescens</i>
1	Leaf webber	<i>Archips</i> spp.
1	Fall cankerworm	<i>Alsophila pometaria</i>
1	Eastern tent caterpillar	<i>Malacosoma americanum</i>
1	Fall webworm	<i>Hyphantria cunea</i>

Lilac

3	Lilac borer	<i>Podosesia syringae</i> <i>syringae</i>
4	Oystershell scale	<i>Lepidosaphes ulmi</i>

Eastern redcedar and Rocky Mountain juniper

1	Bagworm	<i>Thyridopteryx ephemerae-</i> <i>formis</i>
3	Eastern juniper bark beetle.	<i>Phloeosinus dentatus</i>
4	Red spider mites	<i>Tetranychus</i> spp.

Ponderosa pine

1	Red-headed pine sawfly	<i>Neodiprion lecontei</i>
2	Nantucket pine tip moth	<i>Rhyacionia frustana</i> <i>bushnelli</i>
2	Pine tip moth	<i>Rhyacionia neomexicana</i>
3	Red turpentine beetle	<i>Dendroctonus valens</i>
3	Ponderosa twig moth	<i>Dioryctria ponderosae</i>
4	Pine needle scale	<i>Phenacaspis pinifoliae</i>

Austrian pine

3	Ponderosa twig moth	<i>Dioryctria ponderosae</i>
4	Pine needle scale	<i>Phenacaspis pinifoliae</i>

Scots pine

2	Nantucket pine tip moth	<i>Rhyacionia frustana</i> <i>bushnelli</i>
3	Ponderosa twig moth	<i>Dioryctria ponderosae</i>
4	Pine needle scale	<i>Phenacaspis pinifoliae</i>
4	Pine tortoise scale	<i>Toumeyella numismaticum</i>

Jack pine

2	Nantucket pine tip moth	<i>Rhyacionia frustana</i> <i>bushnelli</i>
3	Ponderosa twig moth	<i>Dioryctria ponderosae</i>
4	Pine tortoise scale	<i>Toumeyella numismaticum</i>

Shortleaf pine

2	Nantucket pine moth	<i>Rhyacionia frustana</i>
3	Red turpentine beetle	<i>Dendroctonus valens</i>

Disease Damage.—Trees infected by disease-causing organisms are more likely to be killed when weakened by extreme drouth than if maintained in vigorous condition by irrigation and cultivation. However, disease-causing organisms can attack and kill perfectly healthy trees. As with insect damage, prevention is better than the cure; and early detection is of paramount importance. Frequent examination of tree stands should be followed up, if diseases are suspected, by a request for aid from the county agent, Extension plant pathologist, or from a plant pathologist at one of the Forest Service Experiment Station offices at Lincoln, Nebr., and Bottineau, N. Dak.

Diseases are generally of three types, affecting: (1) Foliage, (2) stems and branches, or (3) roots.

Organisms causing foliage diseases may become established on many of the tree and shrub species used in windbreaks. These organisms may reduce the area capable of photosynthesis by penetrating and ultimately killing the leaf tissues. They can also enter the leaf petioles and move into the vascular system, thus killing the entire leaf. Cedar blight fungus enters through the leaves, then works into the small twigs, girdling them.

Leaf rust fungi, which often depend on an alternate host to maintain their life cycle, are fairly common on many tree species in the Plains region. Cottonwood leaf rust, green ash rust, and cedar-apple rust are examples of diseases caused by these fungi. Cottonwood leaf rust can also persist in the absence of an alternate host.

Other foliage diseases such as needle cast and the needle and twig blights frequently build up to epidemic conditions on ponderosa, Austrian, Scots, and other pines during warm, humid weather. Several consecutive years of heavy infection by these diseases can seriously weaken trees.

Stem and branch diseases are generally more severe than foliage diseases in their effect on tree growth. They frequently affect the vascular (conducting) system and consequently cut off the movement of water from roots to leaves. When this happens the entire tree or large portions of it wilts and dies. Dutch elm disease, phloem necrosis, and *Dothiorella* wilt are examples of stem and branch diseases on elms. *Diplodia* on Russian-olive causes wilting and death of stems and branches.

Wood-rotting fungi frequently enter trees through wounds on the main stem and through dead branch stubs. Although these fungi usually do not cause death, they do weaken trees and subject them to easy breakage during wind and snow storms.

Bacterial infection on the elms and some other species causes wetwood (known also as slime-flux), which brings about gradual deterioration of stems and branches and sometimes death. *Cytospora* canker, generally assumed to attack only weakened trees, may be very severe on cottonwoods and willows.

Root diseases, including those caused by nematodes, are often more difficult to diagnose than diseases of above-ground tree parts. Root disease fungi such as *Fomes annosus* and *Phytophthora* species may occur in plantations of windbreak trees, although little is known of the present distribution of these diseases. The cotton root rot fungus *Phymatotrichum omnivorum* is present in certain soils in Oklahoma and Texas and will kill many species of trees planted on those areas. A few tree species are somewhat resistant to this rot.

The following tabulation lists the common and scientific names and the symptoms of the most common diseases that occur on the tree and shrub species used in windbreaks in the central Great Plains.

TREE AND SHRUB DISEASES

Cottonwood, poplar, and willow

Poplar and willow leaf rusts. *Melampsora* spp. SYMPTOMS: Yellow or orange powdery pustules on undersurface of leaves in summer. In late summer or fall, small slightly raised orange-yellow areas appear, later turning dark brown to black. Early defoliation if severe infection.

Leaf spot. *Septoria* spp. SYMPTOMS: Small, angular brown spots, often with a pale outer halo. Also causes bark cankers by infection in lenticels.

Leaf spot. *Marssonina* spp. SYMPTOMS: Leaf spot and shoot blight. Spots usually most conspicuous on upper leaf surface; small, circular, reddish brown with dark margin at first. Spots may coalesce until entire leaf is affected.

Willow scab. *Fusicladium saliciperduum*. SYMPTOMS: Olive-brown, velvety pustules along main veins of lower leaf surfaces on willows. Young growing twigs often killed back to previous season's growth.

Cytospora canker. *Cytospora chrysosperma*. SYMPTOMS: Cankers are slightly sunken, round to irregular areas on smooth bark of branches and stem. Cankers often enlarge until stems are girdled. Diseased bark becomes brown and sunken. Yellow to red spore tendrils appear on dead bark during moist weather. Small branches and twigs often die back without forming cankers.

Poplar canker. *Dothichiza populea*. SYMPTOMS: Canker on branches and young stems, which soon girdles and kills them.

Siberian elm

Slime flux (wetwood). *Erwinia nimipressuralis*. SYMPTOMS: Excessive sap flow from crotches or wounds; bark turns grayish; wood is water soaked. Dark brown streaks of discoloration appear in annual rings. Leaves may curl, wilt, and drop if toxic sap is carried into branches.

Elm root rot. *Chalaropsis thielavioides*.

SYMPTOMS: Grayish-white moldlike growth on injured areas of roots. Outer tissues become dark brown to black, and break down to a slimy mass.

American elm

Dutch elm disease. *Ceratocystis ulmi*. **SYMPTOMS:** Leaves wilt, curl, turn yellow, and fall prematurely. In some trees only a few branches wilt; in others entire tree wilts and dies in a few weeks. Sapwood of wilted branches brown streaked, appearing in cross section as dots in the annual ring. Evidence of elm bark beetles in crotches of tree.

Phloem necrosis. Virus. **SYMPTOMS:** Leaves curl, droop, turn yellow or brown, and fall prematurely in June or July. On trees killed quickly in 2 to 3 weeks, leaves merely wilt, turn brown, and remain on tree. Inner bark, especially at base of tree, turns butterscotch color and often smells like wintergreen.

Elm wilt. *Dothiorella ulmi*. **SYMPTOMS:** Leaves wilt and young twigs die back. Wilt spreads gradually downward through tree, sometimes killing it.

Verticillium wilt. *Verticillium albo-atrum*. **SYMPTOMS:** Leaves wilt suddenly and fall prematurely. Branches die back and contain brownish streaks, or broken rings of discoloration in cross section.

Leaf spot (anthracnose). *Gloeosporium ulmicolum*. **SYMPTOMS:** Elongated, raised leaf spots along leaf veins.

Elm black spot. *Gnomonia ulmea*. **SYMPTOMS:** Lesions appear on leaves, which usually fall prematurely. Most serious during very moist seasons.

Slime flux (wetwood). *Erwinia nimipressuralis*. **SYMPTOMS:** See Siberian elm.

Sycamore

Anthracnose. *Gnomonia veneta*. **SYMPTOMS:** Leaves turn brown as they expand in spring; leaves fall prematurely.

Honeylocust

Thyronectria canker. *Thyronectria austro-america*. **SYMPTOMS:** Slightly depressed bark cankers ranging from pinhead size to 1/2 inch diameter, eventually enlarging or coalescing to girdle the branch. Gummy exudate occurs on many cankers.

Northern catalpa

Basal canker. Unknown disease. **SYMPTOMS:** Large basal canker.

Green ash

Leaf spot (anthracnose). *Gloeosporium aridum*. **SYMPTOMS:** Large irregular brown spots usually along leaf edge; leaves fall prematurely.

Ash rust. *Puccinia peridermiospora*. **SYMPTOMS:** Leaves deformed and twigs and petioles swollen. Fruiting bodies (aecia) on leaves, petioles, and twigs soon after swelling.

Hackberry

Witches'-broom. *Sphaerotheca phytophila*. **SYMPTOMS:** Broomlike growths on twigs and branches. Buds swell and open wider than normal, with bud scales distorted or enlarged. Shoots from affected buds dwarfed and clustered, and leader or long shoot fails to develop.

Bur oak

Oakleaf blister. *Taphrina caerulescens*. **SYMPTOMS:** Circular, raised, wrinkled, yellowish-white areas up to 1/2 inch in diameter on upper leaf surface.

Oak wilt. *Ceratocystis fagacearum*. **SYMPTOMS:** Leaves wilt and turn bronze in upper crown; spreading from upper crown downward and inward. Leaves color at apex and lobes first, spreading to midrib and base. Single branches most usually affected, with additional branches each subsequent year.

Leaf spot (anthracnose). *Gnomonia veneta*. **SYMPTOMS:** Brown dead areas appear that follow veins to leaf edges. Some affected leaves are curled. Leaves fall prematurely.

Boxelder

"Blight." 2, 4-D herbicides. **SYMPTOMS:** Leaves on new shoots chlorotic and deformed.

Verticillium wilt. *Verticillium* sp. **SYMPTOMS:** Leaves of single branches or one side of crown wilt suddenly. Dark streaks appear in one or more annual rings.

Russian-olive

Canker. *Diplodia* sp. **SYMPTOMS:** Leaves wilt and turn light tan; branches die, and gum frequently exudes from branches and stem. Roots are killed.

Russian mulberry

Slime flux (wetwood). *Erwinia nimipressuralis*. **SYMPTOMS:** See Siberian elm.

Bacterial spot. *Pseudomonas mori*. **SYMPTOMS:** Black lesions on leaf petioles and small twigs.

Chokecherry

Western-x. Virus. **SYMPTOMS:** Leaves dull to brilliant red in late July, early August. Following years' leaves are smaller and occur in rosettes, and plants frequently die in third or fourth year after infection.

Leaf spot, shot hole. *Coccomyces lutescens*. **SYMPTOMS:** Chlorotic lesions on leaves; become necrotic and often fall out. Severe infections produce general blighting and leaves fall prematurely.

Black knot. *Dibotryon morbosum*. SYMPTOMS: Hard dark swellings on branches; affected branches usually killed.

Honeysuckle

Leaf blight. *Herpobasidium deformans*. SYMPTOMS: Leaves brown and usually rolled or twisted.

American plum

Necrotic ring spot. Virus. SYMPTOMS: Leaves contain very fine and pale circles and lines, or may have yellow blotches, circles, or spots and be tattered. New leaves show most symptoms; young shoots often die back.

Brown rot. *Sclerotinia fructicola*. SYMPTOMS: Blighted shoots. Cankers on branches. Mummified fruit clinging to branches.

Plum pockets. *Taphrina communis*. SYMPTOMS: Fruits peculiarly enlarged and hollow, containing a thin shell with no seed. Shoot tips and leaves enlarge and are often twisted or curled.

Bacterial canker. SYMPTOMS: Cankers on stems, often exuding gum.

Caragana

Leaf spot. *Phyllosticta gallarum* or *Septoria* spp. SYMPTOMS: Small spots appear on leaves; leaves fall prematurely.

Skunkbush sumac

Leaf spot. *Septoria* spp. SYMPTOMS: Small spots appear on leaves; leaves fall prematurely.

Lilac

Powdery mildew. *Microsphaera alni*. SYMPTOMS: White, powdery appearance on leaf surfaces. Leaves become crinkled and distorted.

Bacterial blight. *Pseudomonas syringae*. SYMPTOMS: Dark, black stripes appear on young shoots in early spring; spots may occur on leaves; immature leaves turn black and die; flower buds turn black.

Nanking cherry

Leaf spot. *Coccomyces hiemalis*. SYMPTOMS: See Chokecherry.

Necrotic ring spot. Virus. SYMPTOMS: See American plum.

Bacterial canker. SYMPTOMS: See American plum.

Ponderosa pine

Hard pine needle blight. *Dothistroma pini*. SYMPTOMS: Slightly swollen dark spots or

bands appear in late summer on 1-year-old needles. Distal ends of needles turn brown and die. Fruiting bodies protrude from leaf surface by May and needles fall prematurely.

Pine twig blight. *Diplodia pinea*. SYMPTOMS: Newly elongating shoots are infected before needles are half grown. Needles cease growth, turn brown, and die. Fruiting pustules appear at needle base and on sheaths.

Western gall rust. *Peridermium harknessii*. SYMPTOMS: Globose to pear-shaped galls on branches. Large confluent aecia form on the galls and witches'-brooms frequently form just above the galls.

Austrian pine

Hard pine needle blight. *Dothistroma pini*. SYMPTOMS: See Ponderosa pine.

Pine twig blight. *Diplodia pinea*. SYMPTOMS: See Ponderosa pine.

Scots pine

Western gall rust. *Peridermium harknessii*. SYMPTOMS: See Ponderosa pine.

Hard pine needle blight. *Dothistroma pini*. SYMPTOMS: See Ponderosa pine.

Pine twig blight. *Diplodia pinea*. SYMPTOMS: See Ponderosa pine.

Jack pine

Needle rust. *Coleosporium solidaginis*. SYMPTOMS: Conspicuous white fruiting bodies (aecia) appear on needles in spring and summer.

Eastern redcedar and Rocky Mountain Juniper

Cedar blight. *Phomopsis juniperovora*. SYMPTOMS: Foliage on branch tips becomes light, then brown, and finally gray. Lesions form on invaded stem tissue; small stems are girdled. Fruiting bodies (pycnidia) appear on leaves and stems.

Cedar-apple rust. *Gymnosporangium juniperi-virginianae*. SYMPTOMS: Brown globoid galls appear on branches. During moist weather in spring, jellylike orange spore masses develop from galls.

Many trees and shrubs

(In certain areas of Oklahoma and Texas)

Cotton root rot. *Phymatotrichum omnivorum*. SYMPTOMS: Areas in which root rot affects plants are typically circular in shape. Seedlings die suddenly; older trees show gradual reduction in growth and vigor, with leaves off color. Roots badly rotted, with shrunken and shriveled epidermis.

How To Manage Windbreaks

Management of windbreaks is the final step in the series of practices beginning with land preparation for trees and culminating in a system of windbarriers that provide longtime effective protection for farmlands.

Good management of windbreaks has two general objectives: (1) To maintain and improve the vigor and growth of individual trees and shrubs for best foliage density and longevity, and (2) to maintain and improve the structure of the windbreak in its entirety so that it functions as an effective barrier in reducing wind velocity.

Management should begin as soon as trees have become well established and before any crowding takes place. The time cannot be stated as a specific number of years after planting, because this will vary according to rate of growth and spacing between trees and rows. Under average conditions, however, the need for starting management practices will probably arise between the 5th and 10th years after planting.

After 5 to 10 years of growth the faster growing trees, such as cottonwood and Siberian elm, will be 20 to 30 feet tall and crowding each other if planted 8 to 10 feet apart. The faster growing shrubs will be 8 to 10 feet tall and tending to lose their lower foliage.

As trees grow, the relationships among them change. The density and position of tree crowns change in relation to height above ground and neighboring trees. Some changes are also brought about rather abruptly when extreme drouth, cold, insects, diseases, or fire offset tree stands. These changes affect the structure of windbreaks, and consequently modify their influence in reducing wind velocities.

Good management attempts to anticipate these changes by installing treatments to maintain and constantly improve tree growth and windbreak structure. For example, with severe crowding the stress of competition for moisture and light can cause rapid loss of vigor or death of trees. One aim of management is to forestall such losses by treating windbreaks before they lose vigor.

Some specific objectives of windbreak management are described in the following section. These include the most common problems encountered in older windbreaks. Keeping the objectives in mind, the manager should first examine the windbreaks carefully to assess their present condition. If the vigor and growth of trees and shrubs appears to be declining, a thinning or release treatment may be needed. If foliage density of the lower level is sparse, a cut and coppice treatment or perhaps an interplanting is indicated. If the windbreak is wider than necessary, treatments to remove ineffective rows and to increase lower level foliage density should be considered.

The "Methods of Management" described later (p. 54) can be used to improve the growing conditions and structure of most windbreaks. These methods will often provide a means for correcting mistakes in composition, arrangement, or width.

OBJECTIVES OF MANAGEMENT

Relieve Crowding

Since windbreak trees are normally planted rather closely together (6 to 10 feet) to form a barrier as soon as possible, it follows that they will begin to crowd one another after 15 to 20 years of age. This crowding should be relieved to keep the trees most healthy and vigorous.

Some species such as eastern redcedar can tolerate shaded and crowded situations. Others such as cottonwood and pines require more space and sunlight. Some species on being shaded and crowded grow very slowly and finally die. Others remain alive though suppressed, until the stand is opened up by diseases, insects, or drought, at which time they resume growth.

Certain signs of deterioration are evident in trees suffering from shading, crowding, moisture stress, etc. Some of these signs are loss of color, loss of foliage particularly from the oldest branches, thinning of the upper crowns, presence of diseases and insects, and greatly reduced annual diameter growth of the stem. The incidence of diseases and insects generally increases as conditions such as crowding and lack of moisture become more severe.

In many 20-year-old windbreaks the interior tree rows, especially hackberry, honeylocust, and Siberian elm, show extreme effects of crowding. The signs are narrow crowns of low vigor and the presence of diseases and much dead wood. Under crowded conditions Siberian elm appears to be a rather short-lived species, insofar as maintenance of good vigor is concerned. Thinning of interior broadleaf rows will stimulate growth and increase vigor of the remaining trees. It should result in increased foliage density in the middle and upper levels of windbreaks.

Release Conifers

The suppression of pine and redcedar rows by fast-growing broadleaf species, such as Russian olive, green ash, and boxelder, is a common problem in many field windbreaks in the central Great Plains.

Since conifers are one of the most important components of windbreaks in providing longevity and effectiveness the year round, they should be given special consideration in management.

Release to provide growing space and to eliminate overtopping by adjacent rows of trees will stimulate growth and increase the vigor of conifers. Redcedars apparently respond more quickly to release than the pines. Release should be done before crowding becomes severe, so that lower branches of conifers are retained. Once suppression has killed lower branches of pines, they will no longer produce lower foliage density. Redcedars, on the other hand, can remain suppressed for quite a time and still respond in growth of lower branches.

Add Conifers

In many windbreaks having ineffective or no conifer components, one of the major objectives of management should be to add redcedars and pines. These trees will enhance the effectiveness of windbarriers during winter and early spring, and will add longevity to all broadleaf plantings. While most broadleaf trees and shrubs will probably be adequate for snow control, they make poor barriers for reduction of wind movement during winter and spring when they are not in leaf.

The addition of several rows of conifers will also help to offset any desired reduction in windbreak width. Because the foliage of conifers is dense, windbreaks containing them need not be so wide to be fully effective.

Modify Low-Level Density

As short trees and shrubs grow they tend to lose their lower branches, especially if crowded. Since the function of shrubs is to form a dense barrier close to the ground, it is important that such plants not be allowed to grow tall and spindly. They should be cut back to the ground every 4 or 5 years, so they will sprout anew and provide dense foliage close to the ground.

In windbreaks lacking low-level foliage because of ineffective shrub rows or damage by grazing animals, the density may be increased by several methods. Several broadleaf tree or shrub rows can be cut to the ground and allowed to sprout. As an alternative, new rows of shrubs or eastern redcedar can be planted within or on the outside of the present planting.

When it is necessary to reduce low-level foliage density to increase snow spreading effects, some tree and shrub rows should be cut and stumps treated to prevent sprouting. Pruning the lower branches of trees will also reduce low-level density.

Reduce Width

The desire to reduce windbreak width often comes from the observation that a strip of land adjoining the windbreak is not producing crops because of shading and competition from trees.

In many cases windbreaks containing 10 or more rows of trees and shrubs may be reduced in width by cutting out certain rows that contribute little or nothing to density and effectiveness of the barrier. When this can be done without changing the windbreak structure appreciably, it is good practice.

In windbreaks containing effective rows of conifers, usually the side opposite from the conifers can be sacrificed to reduce width. However, rows of trees which alone provide the height needed for an effective barrier should not be cut. Examples of resulting windbreak profiles when rows are cut to reduce width are shown in figure 42.

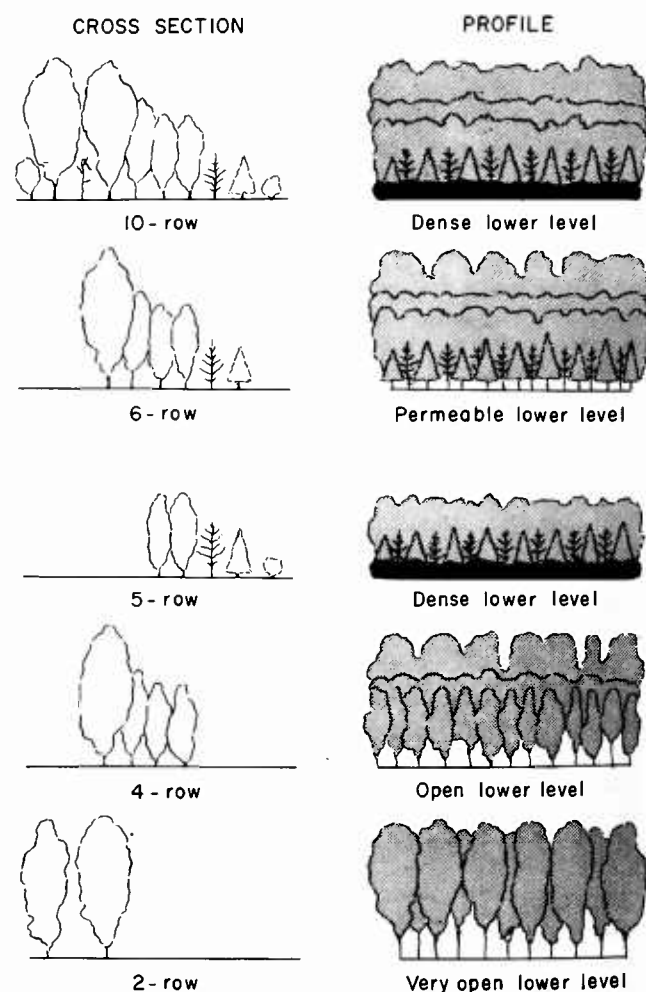


Figure 42.—Examples of windbreak profiles resulting when different tree rows are removed to reduce width.

METHODS OF MANAGEMENT

Thinning and Release Cutting

Thinning and release cutting designed to alleviate crowding and to improve individual tree growth and vigor may take different forms. One

method is the removal of single trees from around individual trees to be favored with more space. Another method is the removal of an entire row of trees which is crowding a more desirable row of trees (fig. 43, A).

It is not possible to recommend either one of these methods of thinning over the other, since no experimental work has been done using the former. However, the latter method, which is termed row thinning, may be the easiest and most economical of the two, since tree felling can begin at one end, and proceed along each row with little difficulty in the felling work. In removing single trees the space for felling is more limited, and the chance for damaging or hanging up trees greater.

To relieve crowding in windbreaks having two or more rows of Siberian elm at close spacing, such as 6 to 8 feet between trees, in rows 10 to 20 feet wide, alternate rows should be removed (fig. 44).

In contrast to the thinning of interior rows of broadleaf species, the release cutting of outer rows to free conifers from overtopping is fairly simple.

If survival of conifers has been good despite crowding, the overtopping tree rows should be cut. If few conifers remain, no treatment is called for.

When rows of pine are released, the stumps of cut trees should be allowed to sprout to provide a renewal of low-level density. Sprouts should then be cut back every 4 or 5 years to prevent repeated crowding. In releasing redcedar from overtopping trees, the stumps of cut trees may be treated with chemical to prevent sprouting. In this instance, the redcedar crowns will thicken up to provide low-level density, and there will be no need to retain the broadleaf sprouts.

In any thinning or release treatment, removal of enough trees to reduce crowding may drastically change the structure of the windbreak. This is especially true in older plantings that have grown for 20 years or more with no previous management. In a crowded windbreak the lower foliage of inner tree rows will have diminished to nothing, and when trees are removed the result will be an extremely porous windbreak of greatly reduced



F-503718, 719

Figure 43.—A, A release cutting within a windbreak to free eastern redcedar from crowding by green ash. B, Stump sprouts of green ash several feet tall, only 3 months after cutting the trees.



F-503720

Figure 44.—A row of Siberian elm within a windbreak cut to release other Siberian elm rows for increased growth and vigor.

effectiveness for slowing wind. This situation calls for one of the following special measures.

One way is to improve the lower level density of the windbreak before thinning it. Outside rows of shrubs or trees should be cut back to the ground in the spring of the year. Thinning within the windbreak can then follow 6 to 12 months later, at which time the sprouts of cut trees or shrubs will be dense enough to provide an effective lower level. Another way is to add shrub or tree rows to one or both sides of the windbreak several years prior to thinning. Thus by putting management practices into effect one step at a time, rather than all at once, the density and continuity of a windbreak can be maintained. It can continue to function effectively throughout the period of silvicultural work.

Coppicing

The cutting of trees and shrubs and management of their coppice sprouts appears to be a very effective method for controlling growth of large shrubby trees that overtop conifers, and at the same time improving the lower level density of windbreaks.

Nearly all broadleaf tree and shrub species used in windbreaks in the central Great Plains will produce vigorous sprout growth when cut back to the ground. Species such as Siberian elm, honeylocust, hackberry, mulberry, and green ash of 20 years age will grow sprouts 4 to 6 feet tall in one growing season after cutting (fig. 43, B).

The regrowth of cut shrubs is generally much thicker near the ground level than the previous uncut plants, because many more stems are produced from the stump and from roots near the surface. American plum, lilac, chokecherry, honeysuckle, caragana, and tamarisk may all be improved in density as shrub rows by this practice.

Trees originally planted to function as shrubs, but which have grown to tree size, such as Russianolive, boxelder, mulberry, and osage-orange, may also be improved if they are cut back to the ground. With these species, however, cutting back must be repeated every 4 or 5 years to maintain low foliage density.

Interplanting

Where maximum wind reduction is desired, several rows of conifers should be added to broadleaf windbreaks to strengthen the barrier density. Eastern redcedar can be planted almost anywhere within or on either side of well-established windbreaks, because this species can tolerate less light and more crowding than other conifers. Pines should be planted in a position of full sunlight to make best growth.

Many field windbreaks with conifers only on the south side are too open on the north side. Snow blows through the barrier and forms drifts across road rights-of-way leeward of the conifers. These windbreaks need to be strengthened for better snowdrift control by planting additional conifer rows on the north side. In some cases, the conifers can simply be planted as additional rows north of the existing windbreaks. In other cases, it is better to remove several rows of broadleaf species on the north side before planting conifers.

All rows of newly established trees should be maintained by the recommended cultivation methods for several years. When new tree rows are planted within windbreaks, enough space should be allowed for cultivation equipment. When this is not possible, chemicals should be used to control herbaceous vegetation.

Use of Natural Reproduction

In most well-established windbreaks that have been protected from livestock use and fire, there is an abundance of natural seedlings of various tree and shrub species. Elms, ash, hackberry, lilac, chokecherry, plum, boxelder, mulberry, honeylocust, black locust, and eastern redcedar ranging from 1 to 10 years old are usually present. Seedlings have become established beneath the older

trees throughout many windbreaks, and especially in the openings created by deteriorating, short-lived trees. This natural establishment of tree seedlings in the understory of windbreaks will help to maintain dense foliage in the lower level. The undergrowth will also catch and hold more snow for replenishment of soil moisture.

No research has been done to determine how this natural growth should be managed. However, several possibilities are suggested until such time as experimental results are available.

In windbreaks consisting of vigorous, moderate to fast-growing established trees, the understory reproduction need not be treated at all. It will usually slow down in growth and remain in the understory, to be utilized later on. On the other hand, if the older trees are beginning to deteriorate, it may be desirable to stimulate growth of the understory to take the place of the dying trees. This can be done in two ways:

(1) Manage the understory trees in row-wise fashion by cutting out all saplings except those in a row between the existing rows.

(2) Manage the understory trees as forest reproduction by selecting and favoring the best trees and cutting all the remaining understory.

Either of these alternatives or modifications of them will be necessary in windbreaks to be developed from a naturally established understory. Lacking any treatment, the natural reproduction is likely to grow very slowly, lose its lower foliage, and develop into spindly, sparse-crowned trees of little value for windbreaks.

Pruning

Many windbreak owners have pruned the lower branches of trees, especially conifers, with the idea

of improving their appearance. Pruning may improve the appearance of individual trees, but it reduces the wind-breaking effectiveness of plantings. In a windbreak, trimming trees from below very often defeats the purpose for which the windbreak was established.

Since the primary purpose of windbreaks is to provide control of wind movement through density and height of foliage, the removal of limbs and tree parts by pruning should not generally be done. Pruning is recommended only to accomplish certain objectives, for example, as a special sanitary measure to reduce incidence of diseases. Such a practice should be adopted only on advice from tree disease specialists.

Another possible reason for pruning, however, is to create an open lower level to obtain better snow distribution. This practice is applicable only where the main objective is to produce barriers for snow distribution rather than maximum wind control. However, even in the northern Plains where better snow distribution on adjacent fields is an important function of windbreaks, tree barriers are planted primarily for maximum reduction of soil blowing and protection of crops during the growing season. Pruning therefore should be done only in special cases where advised by windbreak technicians.

If pruning is needed, the branches should be cut with a saw close to the trunk. Pruning is best done in spring just before growth starts. This will favor rapid callusing and wood growth over the wound. Prune Siberian elm in summer, however, to reduce occurrence of wetwood. Protect large wounds (more than 2 inches diameter) by covering with an asphalt paint.

Appendix

EXAMPLES OF EFFECTS OF WIND-BREAKS ON FIELD ENVIRONMENT

Air and Soil Temperatures

1. Daytime air temperatures 1 foot above ground with a strong south wind were up to 6° F. warmer in the 0 to 4 H leeward zone and up to 5° F. cooler in the 4 to 25 H leeward zone compared to open field temperatures.

Nighttime air temperatures were up to 3° F. warmer in the 0 to 25 H leeward zone than in the open.

Type: Moderately dense, 10-row field windbreak 120 feet wide and 25 feet tall with south sloping cross section.

Season and year: July and August, 1956.

Place: Central Kansas, U.S.A.

Reference: Woodruff, Read, and Chepil, 1959.²

2. Air temperatures near the ground averaged 2° to 3° F. cooler on oat fields between windbreaks than on oat fields in the open on hot days.

Air temperatures were up to 4° F. warmer in protected oat fields than on oat fields in the open on cool days and during the night.

Air temperatures on fallow fields between windbreaks were not significantly different than on fallow fields on the open steppe.

Type: Series of parallel field windbreaks.

Season and year: 4-year study in summer, 1950's.

Place: Kamennaya Steppe, Russia.

Reference: Molchanov, 1956.

3. Daytime air temperatures averaged 5° to 6° F. warmer 4 inches above ground, and 1° to 2° warmer 4 feet above ground 0 to 10 H leeward than on open fields.

Type: Series of narrow oak coppice windbreaks, 15 feet to 45 feet wide at 160-foot intervals.

Year: 1940's.

Place: Holland.

Reference: Linde and Woudenberg, 1951.

4. Summer air temperatures averaged lower, and winter temperatures averaged higher between windbreaks than on open, unsheltered fields.

² See Literature Cited, p. 65. Additional references on the various subjects covered under examples of effects can be found in a "Bibliography of Great Plains Forestry," published in May 1961 as Station Paper 58 by the Rocky Mountain Forest and Range Experiment Station of the Forest Service, U.S. Department of Agriculture. Requests for this bibliography should be addressed to the Director of that Station at Ft. Collins, Colo.

Type: Series of parallel windbreaks.

Season and Year: Summer, 1930's.

Place: Germany.

Reference: Nageli, 1941.

5. Air temperatures on cool, windy mornings and afternoons were 3° to 7° F. warmer between strips than on the open field.

Type: Series of 2- to 5-foot-wide strips of corn, winter rye, and sunflowers at 15- to 25-foot intervals.

Season and Year: Summer, 1950's.

Place: Russia.

Reference: Gotovcev, 1957.

6. Soil temperatures on cool, windy mornings and afternoons were 3° to 5° F. warmer at 4-inch depth, and 2° to 3° warmer at 8-inch depth between strips, than on the open field.

Type: Series of 2- to 5-foot-wide strips of corn, winter rye, and sunflowers at 15- to 25-foot intervals.

Season and Year: Summer, 1950's.

Place: Russia.

Reference: Gotovcev, 1957.

7. Soil temperatures at 20-inch depth were 3° F. cooler at 0.5 H leeward and about 1° warmer at 2 H leeward than in open during spring and summer. They were 3° to 5° cooler at the same locations during fall and winter.

Type: Dense, cottonwood windbreak, 50 feet tall.

Year: Early 1900's.

Place: Nebraska, U.S.A.

Reference: Bates, 1911.

Atmospheric Humidity

8. Average monthly relative humidity was 2 to 3 percent higher during the day on oat fields between windbreaks than on oat fields of the open steppe.

Relative humidity was 4 to 5 percent higher on protected fields of oats than on open steppe oats on hot summer days.

Relative humidity was 2 to 3 percent higher on protected fallow fields than on open steppe fields of fallow fields.

Type: Series of parallel field windbreaks.

Season and Year: 4-year study in summer, 1950's.

Place: Kamennaya Steppe, Russia.

Reference: Molchanov, 1956.

9. Average relative humidities during growing season:

	April	May	June	July
Protected fields-----	66.0	57.9	45.0	50.4
Open steppe-----	63.0	54.7	42.3	47.6

Type: Series of field windbreaks.
Season and Year: Summer, 1946-48.
Place: Astrakhan, Russia.
Reference: Kas'yanov, 1950.

10. Average relative humidity was 8 percent higher in fields between windbreaks than on open prairie.

Relative humidities averaged 11 percent higher between windbreaks than on open prairie in the morning hours.

Type: Series of field windbreaks.
Season and Year: Summer, 1933.
Place: Russia.
Reference: Sokolova, 1937.

11. Relative humidities were over 80 percent during half the growing season in the sheltered area. In contrast, they exceeded 80 percent for only one-third of the growing season in the open area. Midday humidity averaged 2 to 4 percent higher in shelter than in the open.

Type: Two 7-foot-tall slat (snow fence) barriers oriented east-west and 50 feet apart.
Season and year: May to August, 1959.
Place: Central Nebraska, U.S.A.
Reference: Bagley and Gowen, 1962.

12. Average relative humidity 1.5 feet above soil on days of greater than 50 percent humidity was 62 percent at 0 to 6 H leeward and 60 percent at 12 to 30 H leeward, compared to 57 percent on the open prairie.

Relative humidity was 45 percent at 0 to 6 H leeward and 40 percent at 12 to 30 H leeward, compared to 38 percent on the open prairie, on days of less than 50 percent humidity.

Type: Field windbreaks 30 feet wide and 50 feet tall.
Season and year: Summer, 1934.
Place: Rostashi, Russia.
Reference: Bodrov, 1935.

13. Dewfall was 200 percent greater on fields protected by windbreaks than on open fields. Heaviest dew was in the 2 to 3 H leeward zone.

Season and year: Summer, 1940's.
Place: Germany.
Reference: Steubing, 1952.

Evaporation

14. Windbreaks reduced evaporation and increased soil moisture in the 0 to 30 H sheltered zone as compared to open, unsheltered areas.

Type: Series of 30- to 40-foot-tall field windbreaks at 1,300- to 1,600-foot intervals.
Season and year: Summer, 1950.
Place: Russia.
Reference: Kalashnikov, 1955.

15. Nonproductive evaporation (from soil) was 27 percent less on sheltered fields than on the open steppe.

Productive evaporation (transpiration) was 22 percent greater on sheltered fields than on the open steppe.

Type: Series of 2-row, 50- to 60-foot-tall poplar windbreaks at 600-foot intervals.
Season and year: Summer, 1953.
Place: Trans-Volga, Russia.
Reference: Lvovich, 1954.

16. Evaporation during hot days was less on fields between windbreaks than on open fields.

Type: Series of parallel field windbreaks.
Season and Year: 4-year study in summer, 1950's.
Place: Kamennaya Steppe, Russia.
Reference: Molchanov, 1956.

17. Evaporation rates leeward of windbreak compared to open field were:

40 percent at 5 H
 60 percent at 10 H
 80 percent at 20 H
 Same as open at 25 H

Type: Windbreak of Japanese Black Pine, 5 feet tall and 20 feet wide.
Year: 1940's.
Place: Japan.
Reference: Iizuka and others, 1950.

18. Evaporation from water surface was 15 percent less at 4 H leeward and 9 percent less at 16 H leeward than in open.

Type: Series of parallel 3-row, 20-foot-tall windbreaks at 640-foot intervals.
Season and Year: May-September, 1951-54.
Place: Saskatchewan, Canada.
Reference: Staple and Lehane, 1955.

19. Evaporation rate at 2 to 10 H leeward of open-type windbreaks was 80 percent of open field evaporation.

Evaporation rate in the same zone leeward of dense-type windbreaks was only 40 to 65 percent of open field.

Type: 50-foot-tall cottonwood windbreaks of different densities.
Year: Early 1900's.
Place: Nebraska, U.S.A.
Reference: Bates, 1911.

20. Evaporation from the soil layer 0 to 8 feet deep was reduced by 2 to 2.5 percent in the 0 to 5 H leeward zone compared to open field with wind from the south.

Evaporation from the same soil layer was increased by 2 to 3 percent in the 0 to 2 H windward zone under the same south wind.

Type: Various types of field windbreaks.
Season and Year: Summer, 1936-38.
Place: Kansas and North Dakota, U.S.A.
Reference: Bates, 1948.

Snow Distribution

21. Average depths during 3 years of heavy snowfall were:

26 inches near barrier at 0 to 6 H
 7 inches on stubble at 25 H
 3 inches on summer fallow at 25 H

Average depths during 2 years of medium snowfall were:

- 15 inches near barrier at 0 to 3 H
 4 inches on stubble at 25 H
 3 inches on summer fallow at 25 H

Type: Series of parallel barriers consisting of 1-row caragana hedges 8 feet tall and 3-row field windbreaks 25 feet tall.

Season and Year: Winter 1950-52 (heavy) and winter 1953-54 (medium).

Place: Manitoba and Saskatchewan, Canada.

Reference: Staple and Lehane, 1955.

22. Snow depth was greater and freezing depth was less in sheltered area as compared to open fields. As a result, soil moisture was increased in the 0 to 20 H leeward zone, with maximum soil moisture adjacent to windbreak.

Type: 12- to 16-year-old field windbreaks, 16 to 20 feet tall.

Season and Year: Winter, 1949-50.

Place: Russia.

Reference: Dautov, 1953.

23. Distribution of snow was very uneven on leeward field with large drifts in zone nearest windbreak.

Snow was blown off the leeward field in the 240 to 600 feet zone, and in this zone freezing was deeper and moisture supply lower than where covered by snow.

Type: Multirow field windbreaks, 3 to 5 years old.

Place: Rostov, Russia.

Reference: Garjugin, 1955.

24. Water content of snow was 4.9 inches in sheltered fields compared to only 2.2 inches on open, unsheltered steppe.

Type: Series of 2-row poplar windbreaks, 50 to 60 feet tall, and at 600-foot intervals.

Season and year: Winter, 1953.

Place: Trans-Volga, Russia.

Reference: L'vovich, 1954.

25. Coefficient of snow blowoff (blowoff as percent of total fall) was 6 percent on fields surrounded by tree windbreaks compared to 68 percent on open land.

Type: Pattern of field windbreaks.

Season and year: Winter, 1930's.

Place: Kamennaya Steppe, Russia.

Reference: Panfilov, 1937.

Soil Moisture and Runoff

26. Moisture content of top 3 feet of soil was 25 to 30 percent higher in the 10 to 12 H leeward zone than on open, unsheltered fields.

Type: 5-row field windbreaks, 33 feet tall.

Season and Year: Early summer, 1930's.

Place: Vladimir, Russia.

Reference: Banasevich and Zakharov, 1940.

27. Moisture content of soil was high on fields in protection area of windbreaks compared to low moisture and drouth experienced on unprotected fields.

Type: Series of field windbreaks.

Year: 1946-47.

Place: Kamennaya Steppe, Russia.

Reference: Burnatski and Suchalkina, 1949.

28. Moisture content of top 3 feet of soil was 20 percent less in the 0 to 2 H sheltered area in vineyards than in the open. But it was 25 to 30 percent more in the 10 to 12 H zone than in the open, and was the same at 20 H.

Place: Russia.

Reference: Masinskaja, 1950.

29. Four to eight inches more water was stored in the soil profile beneath the trees in windbreaks than in the soil of the fields between windbreaks.

Type: Series of field windbreaks.

Place: Russia.

Reference: Karandina and others, 1956.

30. Soil moisture in the 0- to 6-inch surface layer was 13 percent greater on sheltered fields than on open, unsheltered fields. There was up to 23 percent more moisture in the profile of sheltered fields as compared to open fields.

Type: Black locust windbreaks.

Place: Rumania.

Reference: Catrina and Marcu, 1955.

31. Soil moisture was depleted to 4 feet deep by tree roots in the 0 to 2 H strip leeward of windbreaks. Moisture was 12 to 15 percent greater in the 0 to 2 H strip when isolated from tree roots by trenching.

Season: End of summer.

Place: Rumania.

Reference: Georgescu and others, 1954.

32. Soil moisture 0 to 2 feet deep was less under trees and at edges of windbreak than in the open field.

Type: Austrian pine windbreak, 20 feet tall and 98 feet wide, with no undergrowth.

Soil moisture 0 to 2 feet deep was greater in the 0 to 20 H sheltered zone than in open fields.

Type: Chestnut windbreak, 13 feet tall, with dense undergrowth.

Soil moisture 0 to 2 feet deep was greater in the sheltered zone of 700 feet between a windbreak and forest area than on open, unsheltered fields.

Type: Ash and alder windbreak 65 feet tall and 200 feet wide, with dense undergrowth.

Year: 1940's.

Place: Obristvi, Vinor, and Pisty, Bohemia.

Reference: Maran and others, 1950-51.

33. Moisture in surface 4 feet of soil was 31½ percent greater in the 0 to 5 H sheltered zone than in the 10 to 20 H zone.

Frost depth under 3 feet of snow was only 0 to 4 inches in the 0 to 5 H sheltered zone compared to 24 inches on open, unsheltered fields.

Type: Field windbreak 24 feet tall.

Year: Dry year of 1936.

Place: Great Plains, U.S.A.

Reference: Stoeckeler and Dortignac, 1941.

34. Runoff on an area with 6 percent of land in field windbreaks was reduced to 43 to 63 percent compared to runoff on open steppe. With 18 per-

cent of land in field windbreaks runoff was reduced to 25 percent.

Type: Field windbreaks at right angle to slope.

Year: 1930's.

Place: Kamennaya Steppe, Russia.

Reference: Basov, 1949.

Soil Properties

35. Soils of sheltered fields, compared to soils of the open steppe had:

- (a) higher humus content
- (b) 2 to 2½ times higher aggregate stability
- (c) lower horizon of effervescence (carbonate accumulation)
- (d) less water-soluble salts

Type: 18-year-old windbreak.

Place: Saratov, Russia.

Reference: Saralidze, 1955.

36. A clayey chernozem soil of moderate depth beneath the windbreak trees, compared to adjacent sheltered fields, had:

- (a) higher humus content
- (b) more nitrogen and phosphorus
- (c) higher aggregate stability

Cereal and grass field soils adjacent to windbreaks had a higher percentage of water-stable aggregates than fields on the open steppe.

Type: 50- to 60-year-old windbreak.

Place: Russia.

Reference: Bjalyi, 1950.

37. Soil structure was better in the 0- to 328-foot zone near windbreaks than on open, unsheltered fields.

Type: 15-year-old windbreaks.

Place: Trans-Volga, Russia.

Reference: Maljanov and Saralidze, 1957.

38. Water-holding capacity of soil was 4 to 5 times greater in windbreaks than on adjacent arable fields.

Type: Windbreak of old trees.

Place: Russia.

Reference: Molchanov, 1955.

39. A heavy loam chernozem under the trees in a windbreak had 30 times more water-stable aggregates larger than 1 mm. in size, than similar soil on open, plowed land. Soil porosity, infiltration, and resistance to erosion were all better in the 0 to 7 H sheltered zone than in the open, unsheltered zone.

Type: Oak-ash windbreak, 60 years old.

Place: Kuibyshev, Russia.

Reference: Mustafaev, 1957.

40. Porosity and infiltration capacity of a sandy loam soil was greater in the 0- to 32-foot

sheltered zone than in the open, unsheltered field. Soil in the sheltered area of 0 to 900 feet, compared to the open fields, had:

- (a) thicker A and B horizons
- (b) higher humus content
- (c) deeper carbonate accumulation
- (d) less sulfates

Type: 23-year-old shrub windbreak, 3 to 12 feet tall.

Place: Caspian lowland, Russia.

Reference: Birjukova, 1955.

41. With increasing distance from windbreaks, soils in less sheltered areas had:

- (a) less depth of humus
- (b) less depth of effervescence (carbonate accumulation)
- (c) less humus, nitrogen, and acidity
- (d) more nitrates and exchangeable bases
- (e) deteriorated structure

Place: Russia.

Reference: Baiko, 1955.

42. Soils beneath trees in windbreak compared to soils on open, unsheltered fields, had:

- (a) depth of A horizon increased by 5 to 8 inches.
- (b) increased porosity and permeability in A and B horizons
- (c) increased leaching of calcium sulfate
- (d) ground water raised by 16 to 27 inches

Type: 50-year-old irrigated windbreak of elm, maple, and caragana.

Place: Stalingrad, Russia.

Reference: Birjukova, 1958.

43. On arable land with 10 percent slope the soil in the 0- to 390-foot zone on downhill side of windbreaks as compared to open, unsheltered fields had:

- (a) less topsoil erosion
- (b) less calcium carbonate accumulation
- (c) greater humus content

Type: Single-row black locust windbreak, 26 feet tall and 13 feet wide.

Place: Hungary.

Reference: Lady, 1956.

44. Shifting sandy soils are stabilized by patterns of windbreaks at 50- to 60-foot intervals.

Type: Windbarriers of Scots pine, Austrian pine, locust, and poplar.

Place: Hungary.

Reference: Babos, 1949.

45. Soil blowing leeward of windbreaks was decreased to 50 percent at 30 H, 18 percent at 20 H, and to only 0.14 percent at 10 H, compared to open-field soil blowing.

Place: Japan.

Reference: Iizuka, 1950.

EXAMPLES OF EFFECTS OF WINDBREAKS ON CROPS, LIVESTOCK, AND FARMSTEADS

Field Crops

1. Average wheat yields during 3 years of heavy snow were:

- (a) 27 bu./A. at 0 to 15 H leeward.
- (b) 20 bu./A. at 15 to 25 H leeward.

Yields during 2 years of medium snow were:

- (a) 24 bu./A. at 0 to 15 H leeward.
- (b) 22 bu./A. at 15 to 25 H leeward.

Maximum wheat yields in years of heavy snow were:

- (a) 32 to 36 bu./A. at 0 to 6 H leeward.
- (b) 19 to 21 bu./A. at 25 H.

Type: Series of 1-row caragana field windbreaks 8 feet tall.

Year: 1950-54.

Place: Saskatchewan, Canada.

Reference: Staple and Lebane, 1955.

2. Wheat, rye, barley, and oat yields showed a 36-bushel total increase per one-half mile of windbreak in the 0 to 14 H leeward zone of high-yielding fields over the average of unprotected areas, in North Dakota and South Dakota.

The same crops showed a 74-bushel total increase per one-half mile of windbreaks in the 0 to 14 H leeward zone of low-yielding fields over the average of unprotected areas.

Corn yields averaged 19 percent greater in the 2 to 10 H leeward zone east of windbreaks than on unprotected fields in Nebraska.

Type: 40-year-old cottonwood and boxelder windbreaks of medium density, and averaging 40 feet tall.

Year: 1935-41.

Place: North Dakota, South Dakota, and Nebraska, U.S.A.

Reference: Stoeckeler, 1962.

3. Of 331 farmers interviewed, 83 percent estimated yield increases on protected compared to unprotected fields. Their estimates, averaged, were—

- (a) corn, oats, barley 81½ bu./A. increase
- (b) wheat and flax 3½ bu./A. increase
- (c) rye and soybeans 5½ bu./A. increase

Type: 10-row field windbreaks, 30 to 50 feet tall.

Year: 1952-54.

Place: South Dakota, U.S.A.

Reference: Ferber, Ford, and McCrory, 1955.

4. Corn yields between windbreaks compared to yields on open, unsheltered fields showed a net increase of 267 lb. per acre where windbreak interval was 1,100 feet; 222 lb. per acre at 1,950-foot interval, and 125 lb. per acre at 3,250-foot interval.

Type: Series of parallel field windbreaks at various intervals.

Place: Ukraine, Russia.

Reference: Kuz'micev, 1958.

5. Crop yields in shelter of windbreaks com-

pared to open, unsheltered fields showed these increases:

- (a) 20 percent, summer wheat.
- (b) 56 percent, winter wheat.
- (c) 26 percent, rye.
- (d) 48 percent, barley.

Type: System of field windbreaks.

Year: 1926-30.

Place: Kamennaya Steppe, Russia.

Reference: Gorshenin and others, 1934.

6. Barley, oats, and winter wheat in shelter of windbreaks compared to open, unsheltered fields gave yield increases of:

- (a) 100 to 400 percent in severe drouth years.
- (b) 50 to 60 percent in moderate drouth years.
- (c) 10 to 15 percent in years of no drouth.

Type: System of field windbreaks of various types.

Year: 1930's.

Place: Kuibyshev, Russia.

Reference: Karuzin, 1936 and 1947.

7. Wheat yields were increased by 48 percent on sheltered fields between windbreaks as compared to yields on open fields.

Type: Series of field windbreaks 15 feet tall and 12 feet wide, spaced 328 feet apart on contour.

Yields in 0 to 20 H leeward zone were increased 37 percent for rye, 25 percent for oats, and 39 percent for clover hay compared to open field yields.

Type: Oak-birch windbreaks, 13 to 25 feet tall.

Year: 1937-41.

Place: Central Forest Steppe, Russia.

Reference: Shaposhnikov, 1946.

8. Oat yields were 25 to 28 percent greater on sheltered than on open, unsheltered fields.

Type: 5-row field windbreak with open lower level.

Year: 1930's.

Place: Vladimir, Russia.

Reference: Kuckeryavkh, 1940.

9. Winter wheat, with equal amounts of moisture at start of growth, yielded twice as much in 18 H leeward zone as on open fields.

Type: Ash-locust windbreak, 18 feet tall and 50 feet wide.

Year: 1950.

Place: Russia.

Reference: Kalashnikov, 1955.

10. Crop yields on sheltered compared to open, unsheltered fields were:

- (a) wheat—27 bu./A. vs. 11 bu./A.
- (b) oats—65 bu./A. vs. 19 bu./A.
- (c) corn—45 bu./A. vs. 17 bu./A.
- (d) hay—5,240 lb./A. vs. 1,057 lb./A.

Type: Field windbreaks.

Year: 1952-53.

Place: Dobrudja, Rumania.

Reference: Lupe, 1954.

11. Wheat yielded 20 to 50 percent (6 bu./A.) more on sheltered than on open, unsheltered fields. Maximum yields were at 82 feet leeward of wind-

break. Oats yielded 18 percent more on sheltered fields.

Type: Field windbreaks at 800- to 1,000-foot intervals.

Year: 1952-53.

Place: Baragan, Rumania.

Reference: Lupe, Catrina, and Marcu, 1956.

12. Wheat yielded 18 percent more in the 2 to 10 H sheltered zone than on open, unsheltered fields. Maximum yield increases were in the 6 to 10 H leeward zone.

Type: Field windbreaks of pines 20 feet tall, and poplar and eucalyptus 33 feet tall.

Year: 1939-42.

Place: Italy and Sardinia.

Reference: Pavari and Gasparini, 1943.

13. Wheat and rye yields were greater on sheltered than on open, unsheltered fields.

Type: Earthwall hedges as windbreaks.

Place: Schleswig-Holstein, Germany.

Reference: Thran, 1952.

14. Winter wheat and rye had greater grain and straw weight in the 2 and 3 H sheltered zone than on open, unsheltered fields.

Weed population on fields adjacent to windbreaks was reduced because weed seeds were blown into and trapped in the windbreak where they do little harm.

Place: Germany.

Reference: Steubing, 1952.

15. Oats yielded 9 percent more on the west side at 0 to 30 H than on open, unsheltered field. Oat-barley straw yielded 10 percent more on east side at 0 to 15 H than on open, unsheltered field.

Type: Artificial barrier, 8 feet tall.

Year: 1950's.

Place: Germany.

Reference: Hanke and Kaiser, 1957.

16. Barley, oat, and spring wheat yields were greater in shelter of windbreak than on open, unsheltered fields.

Type: 15-year-old windbreak, 12 feet tall.

Year: 1940's.

Place: Iceland.

Reference: Kristjanson, 1955.

17. Cotton lint yield was 46 percent greater in the 3 H sheltered zone than on open, unsheltered fields. Average yield was 23 percent greater in the 1 to 22 H zone. Cotton seed yield was 27 percent greater in the 1 to 18 H zone.

Year: 1938-40.

Place: Oklahoma, U.S.A.

Reference: Stoeckeler, 1962.

18. Cotton stands in 5 to 10 H leeward zone, as compared to open field stands:

- (a) germinated 2 to 3 days earlier.
- (b) grew 2 to 8 inches taller.
- (c) flowered 4 to 5 days earlier.
- (d) fruited more heavily.
- (e) yielded 1.6 to 3.1 percent more fiber.

Year: 1950's.

Place: Kiangsu, China.

Reference: Anonymous, 1960.

19. Rice yields decreased 51 percent at $\frac{1}{2}$ H leeward, but were increased 3 percent at 1 H; 33 percent at 3 H; 49 percent at 6 H; 33 percent at 9 H; 28 percent at 12 H; and 8 percent at 15 H, compared to open, unprotected fields.

Type: Willow-ash windbreak 13 feet tall.

Year: 1950's.

Place: Japan.

Reference: Matsui and Yokoyama, 1955.

20. Tobacco yield (cured) was 10 percent greater in shelter of windbreak than on open field. Leaf quality was larger and brighter, and nicotine content was lower on sheltered field.

Place: Germany.

Reference: Kreutz, 1952.

Forage Crops

21. Alfalfa yielded 60 to 70 percent more in best part of protected field as compared to overall field average.

Year: 1935.

Place: North Dakota, U.S.A.

Reference: Bates, 1944.

22. Mixed alfalfa, timothy, and red clover hay yielded 37 percent more in the 1 to 7 H leeward zone than the normal field average.

Type: Conifer windbreak 17 feet tall.

Year: 1940's.

Place: Wisconsin, U.S.A.

Reference: Trenk, 1948.

23. Crested wheatgrass yield at 0 to 2 H leeward (south) was double the yield at 9 H leeward.

Five-year average yield was 1,209 lb. per acre in 0 to 2 H zone compared to 887 lb. at 9 H.

Type: Single-row windbreak, 18 feet tall.

Year: 1938.

Place: Wyoming, U.S.A.

Reference: Quayle, 1941.

24. Sweetclover and wheatgrass hay, 1 to 3 years old, yielded 2 to 4 times more in shelter of windbreaks than on the open steppe.

Place: Voronezh, Russia.

Reference: Ignatiev, 1940.

25. Pasture grass in sheltered area in a year with precipitation 46 percent above normal as compared to open fields had:

- (a) 68 percent more dry weight.
- (b) 108 percent more vitamin C.
- (c) 144 percent more protein.
- (d) 85 percent more starch.

Grass yields, in sheltered areas in a dry year were one-third of normal, compared to no yield on open, unsheltered areas.

Type: 65-foot-wide windbreak.

Place: Hungary.

Reference: Benkovits, 1955.

26. Hay crops were heavier on sheltered than on open, unsheltered fields.

Type: Poplar windbreaks.

Year: Years with late frost or spring drouth.

Place: Eberswalde, Germany.

Reference: Joachim, 1955.

27. Grass and clover hay yielded 22 percent more on sheltered than on open unsheltered fields.

Type: Series of parallel conifer windbreaks.

Year: 1909-25.

Place: Jutland, Denmark.

Reference: Soegaard, 1954.

Vegetables and Fruits

28. Tomatoes yielded 60 percent more at early harvest, 16 percent more at total harvest, and green snap beans 37 percent more on sheltered areas between barriers than on open, unsheltered plots. Tomato yields averaged 30 tons per acre in shelter and 26 tons per acre in open.

Type: Two 7-foot slat (snow fence) barriers oriented east-west and 50 feet apart.

Season and Year: May to August, 1959.

Place: Central Nebraska, U.S.A.

Reference: Bagley and Gowen, 1962.

29. Yields of 35 varieties of snap beans in sheltered area were:

(a) 5,080 lb./A. at 2 H.

(b) 4,758 lb./A. at 4 H.

(c) 4,526 lb./A. at 6 H.

(d) 3,859 lb./A. at 8 H.

Type: Single-row poplar windbreak, 20 feet tall.

Year: 1936.

Place: Wyoming, U.S.A.

Reference: Babb and others, 1941.

30. Virginia crab apples yielded 99 lb. per tree, per year in shelter compared to 21 lb. in open. Hibernial apples yielded 32 lb. in shelter and 3 lb. in open.

Year: 1928-49.

Place: North Dakota, U.S.A.

Reference: Duncan, 1950.

31. Citrus groves yielded a net advantage of \$77 per acre per year with full shelter protection as compared to partial shelter.

Type: Eucalyptus windbreaks, 60 feet tall.

Year: 1927-33.

Place: California, U.S.A.

Reference: Metcalf, 1936.

32. Potato yields were estimated 80 bushels per acre greater on sheltered than on open, unsheltered fields.

Type: 10-row, field windbreaks, 30 feet tall.

Year: 1952-54.

Place: South Dakota, U.S.A.

Reference: Ferber, Ford and McCrory, 1955.

33. Yield increases on windbreak-sheltered fields compared to open fields were:

(a) 138 percent for cucumbers.

(b) 240 percent for tomatoes.

(c) 228 percent for beets.

(d) 115 percent for carrots.

(e) 158 percent for potatoes.

Year: 1932.

Place: Saratov, Russia.

Reference: Suss, 1936.

34. Cucumbers, tomatoes, cabbages, sugar beets, and early potatoes yielded significantly more in sheltered than on open, unsheltered fields.

Type: Strips of rye, corn, and sunflower at 15- to 25-foot intervals.

Year: 1950's.

Place: Russia.

Reference: Gotovcev, 1957.

35. Cucumbers yielded more and earlier on sheltered than on open unsheltered fields.

Type: Strips of winter rye.

Place: Leningrad, Russia.

Reference: Byckova, 1958.

36. Strawberry yields were greater on sheltered than on unsheltered fields.

Type: Rows of sorghum or corn sown every 5 to 6 rows of berries.

Year: 1950's.

Place: Ukraine, Russia.

Reference: Berezhnoj, 1956.

37. Yields of potatoes increased 16 percent and sugar beets 23 percent under windbreak shelter as compared to open fields.

Year: 1909-25.

Place: Jutland, Denmark.

Reference: Soegaard, 1954.

38. Apple yields in bushels per acre in sheltered area of windbreak were:

(a) 175 at 1.5 H.

(b) 90 at 3 H.

(c) 39 at 5 H.

(d) 30 at 6 H.

(e) 26 at 8 H.

Type: 4-row deciduous tree windbreak, 20 feet tall.

Year: 1919-22.

Place: Jutland, Denmark.

Reference: Soegaard, 1954.

39. Yield increases due to protection by windbreaks were 160 percent for Cox variety apples; 32 percent for Golden Delicious apples.

Year: Recent.

Place: Zeeland, Western Netherlands.

Reference: Inst. Voor Toegepast, 1956.

40. French beans yielded more and higher quality on sheltered than on open, unsheltered fields.

Type: Strips of corn and grain at 15- to 20-foot intervals.

Year: 1950's.

Place: Netherlands.

Reference: Koomen, 1957.

41. Strawberries ripened earlier and yields increased in the 0 to 20 H sheltered zone compared to open, unsheltered fields.

Type: Poplar windbreak, 45 feet tall.

Year: 1952-54.

Place: Netherlands.

Reference: Linde, 1955.

42. Yields of apples increased 75 percent and pears 121 percent in the 6 to 12 H sheltered zone, as compared to yields in the open.

Year: 5-year average in 1950's.

Place: Netherlands.

Reference: Rhee, 1957.

43. Potatoes yielded 21 to 24 percent more on sheltered than on open, unsheltered fields.

Place: Germany.

Reference: Caborn, 1957.

44. Potato yields were greater on sheltered fields than on open fields.

Type: Earth wall hedge windbreaks.

Place: Schleswig-Holstein, Germany.

Reference: Thran, 1952.

45. Sugar beets yielded 6 percent greater weight and 8 percent higher sugar content in the 0 to 28 H sheltered zone than in the 32 to 60 H zone.

Type: Poplar, ash, locust windbreak, 26 feet tall, 22 feet wide.

Year: 1955.

Place: Germany.

Reference: Hanke and Kaiser, 1957.

46. Growth of peas and beans was greater in shelter than on open fields, and better on sloping than on level land.

Type: Tree windbreaks.

Year: 1950's.

Place: Japan.

Reference: Yamamoto, 1957.

Livestock

47. Cattle wintered in sheltered areas suffered fewer losses and required less feed for maintenance than cattle wintered on open range. Tree windbreaks provided better protection than constructed sheds.

Type: Tree and brush areas and sheds.

Year: 1920's.

Place: Montana, U.S.A.

Reference: Vinke and Dickson, 1933.

48. Ranches located in open, unprotected level areas required an average of 50 percent more winter feed for stock than those located in areas having natural protection of topography, trees, or brush.

Type: Tree and brush areas of rough topography.

Place: North Dakota, U.S.A.

Reference: Johnson, 1947.

49. Value of tree protection estimated by 44 livestock feeders averaged \$802 savings in feed and \$839 additional gain, or total of \$1,313 average annual saving (1929-35 prices) per farm with 100 cattle.

Type: Natural and planted tree stands.

Year: 1936.

Place: South Dakota, U.S.A.

Reference: Collins, 1952.

50. Sandhills ranchers maintain that winter losses from freezing, blizzard, snow, and inaccessible feed are greatly reduced if livestock have access to protective tree plantations.

Type: Conifer plantations.

Year: 1940's.

Place: Nebraska, U.S.A.

Reference: U.S. Forest Service.

51. High temperatures depress the yield of milk cows that normally are high-level producers. Very low temperature and high wind increases heat loss from dairy cows. (Moderating effects of trees and windbreaks on temperature and wind are therefore beneficial in obtaining highest milk production.)

Place: Netherlands.

Reference: Oosterlee, 1958.

52. Pigs require shelter from hot summer sun and from cold winter wind. Windbreaks provide cheap and profitable shelter, and prevent wind erosion around paddocks.

Type: Deciduous windbreaks.

Place: Queensland, Australia.

Reference: Abell, 1947.

Farmsteads

53. Savings in fuel costs for house heating were:

- (a) 25 percent (windbreak on north only).
- (b) 33 percent (windbreak on north and west).
- (c) 40 percent (windbreak on four sides).

Type: Tree windbreaks and artificial barriers.

Season and Year: Winter, 1936-37.

Place: South Dakota and Nebraska, U.S.A.

Reference: Bates, 1945.

54. Calculated savings in use of natural gas at Topeka, Kans., rates for homes with windbreaks was \$10 per season compared to those with none.

Type: Windbreak at 2 H windward of house.

Year: 1950's.

Place: Kansas, U.S.A.

Reference: Woodruff, 1954.

55. Average annual wind damage (for 10-year period) based upon 292 farms with various types of windbreaks, ranged from \$3.92 for those with the best-rated plantings to \$40.32 for those with poorest plantings.

Type: Excellent to poor windbreaks.

Season and Year: Winter, 1940's.

Place: South Dakota, U.S.A.

Reference: Collins, 1952.

LITERATURE CITED

Anonymous.

1960. [The efficiency of coastal shelterbelts in the north part of Kiangsu province (1958-59)] *For. Sci.*, Peking 1960(2) : 77-93. [Chin. russ.] [*Forestry Abs.* 21(4) : 589 (1960) No. 4408]

Abell, T.

1947. Shade trees and windbreaks on the pig farm (in

- Queensland). *Queensland Agr. Jour.* 65: 74-84. [Forestry Abs. 10: 340 (1949) No. 1824.]
- Babb, M. F., Kraus, James, Wade, B. L., and Zaumeyer, W. J.
1941. Drought tolerance in snap beans. *Jour. Agr. Res.* 62: 543-553, illus.
- Babos, I.
1949. [Problems of afforestation on sandy areas of the Great Plains.] *Erdesz. Lap.* 85(1): 2-5. [Hung.] [Forestry Abs. 11: 327 (1950) No. 1795.]
- Bagley, W. T., and Gowen, F. A.
1962. Growth and fruiting of tomatoes and snap beans in the shelter area of a windbreak. *Fifth World Forestry Congress Proc.* 1960: 1667-1670, illus.
- Baiko, A. S.
1955. [The effect of shelterbelts on the soil of the area between the shelter belts.] *Polezashch. Les.* 155-163. [Russ.] [Soils & Fert. Abs. 20(2): 74 (1957) No. 377.]
- Banasevich, N. N., and Zakharow, N. G.
1940. [The effect on soil moisture of shelterbelts of different wind permeability.] *Sovetsk. Agron.* 10: 63-65. [Russ.] [Forestry Abs. 4: 29 (1942).]
- Basov, G. F.
1941. [The influence of shelterbelts of the Kamennaya Steppe on the regulation of surface run-off.] *Lesnoe Khozyaystvo* 2: 8-18. [Russ.] [Forestry Abs. 6: 140 (1945).]
- Bates, Carlos G.
1911. Windbreaks: their influence and value. *U.S. Forest Service Bul.* 86, 100 pp., illus.
1944. The windbreak as a farm asset. *U.S. Dept. Agr. Farmers' Bul.* 1405 (rev.), 22 pp., illus.
1945. Shelterbelt influences. II. The value of shelterbelts in house-heating. *Jour. Forestry* 43: 176-196, illus.
1948. How shelterbelts benefit crops. *Jour. Forestry* 46: 767-768.
- and Stoeckeler, J. H.
1941. Snowdrift control on highways by planting of trees and shrubs. *U.S. Forest Serv. Lake States Forest Expt. Sta. Pub.*, 17 pp., illus.
- Benkovits, K.
1955. [The influence of tree planting on the microclimate and grass yield of pastures.] *Erdesz. Kutatas.* (Budapest) 3: 3-18. [Hung.] [Forestry Abs. 18(4): 497 (1957) No. 4087.]
- Bereznoj, P. S.
1956. [The effect of screens on the growth and yield of strawberries in the Donbas.] *Bjul. Naukovo-Tehn. Inform. po Sadivn.* 1: 12-14. [Ukrainian] [Hort. Abs. 28(2): 202 (1958) No. 1228.]
- Birjukova, A. P.
1955. [Soil changes under shelterbelts in the conditions of the Caspian lowland.] *Pocvoved.* 6: 60-65. [Russ.] [Forestry Abs. 17: 165 (1956) No. 1148.]
1958. [The influence of forest plantations in the desalinization of irrigated soils.] *Pocvoved.* 8: 29-33. [Russ.] [Forestry Abs. 20(2): 178 (1959) No. 1370.]
- Bjalyi, A. M.
1950. [Soil conditions under shelterbelts.] *Agrobiologiya* (4): 133-137. [Russ.] [Forestry Abs. 14: 53 (1953) No. 350.]
- Bodrov, V. A. (freq. Bodroff, B. A.)
1935. [Influence of shelterbelts on the micro-climate of the adjoining territory.] *Vsesoiuzny nauk. Lesokulturny i Agrolesomeliorativnyi, Inst.* [All-Union Sci. Res. Inst. on Silviculture and Improvement of Farmland by Forestation.] pp. 1-83. [Russ.] Transl. by C. P. de Blumenthal, U.S. Forest Serv., Div. Silvics No. 164, 53 pp., 1935.
- Burnatski, D. P., and Suchalkina, M. I.
1949. [The water regime of soils in the Kamennaya Steppe in drought years.] *Agrobiologiya* (1): 148-160. [Russ.] [Forestry Abs. 11: 65 (1949) No. 296.]
- Bychkova, Z. I.
1958. [Growing cucumbers between windbreaks and under polyamide film.] *Sad i Ogorod* 3: 23-25. [Russ.] [Hort. Abs. 28(3): 408 (1958) No. 2565.]
- Caborn, J. M.
1957. Shelterbelts and microclimate. *British Forestry Comm. Bul.* 29, 135 pp., illus.
- Catrina, I. and Marcu, G.
1955. [The influence of shelterbelts on the soil moisture of adjacent fields.] *Bul. Sti. Acad. Repub. rom. (Sect. Biol.)* 7(4): 1011-1026. [Rum.] [Forestry Abs. 17: 538 (1956) No. 3967.]
- Collins, Paul E.
1952. An evaluation of the economic and social benefits of windbreaks and shelterbelts in the Oahe Unit. *S. Dak. Agr. Expt. Sta. and U.S. Bur. Reclam.*, 19 pp.
- Dautov, R. K.
1953. [The effect of forest shelterbelts on the depth of snow cover and soil freezing.] *Dokl. Akad. Nauk SSSR* 89(3): 555-556. [Russ.] [Forestry Abs. 15: 49 (1954) No. 287.]
- Duncan, Donald P.
1950. Tree windbreaks for the orchard. *Minn. Hort.*, 2 pp., illus.
- Ferber, Arthur E., Ford, A. L., and McCrory, S. A.
1955. Good windbreaks help increase South Dakota crop yields. *S. Dak. Agr. Expt. Sta. Cir.* 118, 16 pp., illus.
- Garjugin, G. A.
1955. [The influence of shelterbelts on the snow regime of adjacent fields.] *Agrobiologiya* 3: 132-134. [Russ.] [Forestry Abs. 17: 384 (1956) No. 2811.]
- Georgescu, C. C., Lupe, I., Catrina, I., and Marcu, G.
1954. [The influence of shelterbelts on soil moisture in their immediate vicinity.] *Bul. Sti. Acad. Repub. rom. (Sect. Biol.)* 6(3): 777-790. [Rum.] [Forestry Abs. 17: 65 (1956) No. 434.]
- Gorshenin, N. M., Panfiloff, Y. D., Godounoff, N. T., and others.
1934. [Improvement of farmland in the irrigated region of the Zavoljje (East of the Volga).] *Extracts from Agrolesomelioratsia V. Oroshayemom Zavoljje [Experiments and Investigations of All-Union Research Institute for Silviculture and Improvement of Farmland by Afforestation, VNILAMI.]* (Moscow) No. 4: 5-143. [Russ.] Transl. by C. P. de Blumenthal, U.S. Forest Serv., Div. Silvics No. 64, 84 pp., 1934.
- Gotovcev, I. Ja.
1957. [Windbreaks for vegetables] *Sad i Ogorod* 3: 18-19. [Russ.] [Hort. Abs. 27: 384 (1957) No. 2391.]
- Hanke, E., and Kaiser, H.
1957. [The effect of windbreaks on yields of oats, and oat-barley mixture and sugar-beet in 1955.] *Z. Acker-u. Pflbau* 103(1): 90-110, illus. [Ger.] [Field Crop Abs. 10(4): 265 (1957) No. 1554.]
- Ignat'ev, S. N.
1940. [Shelterbelts and the productivity of perennial grasses.] *Dokl. vsesoyuz. Akad. s.-kh. Nauk.* 3: 9-13. [Russ.] [Forestry Abs. 3: 47 (1941).]
- Iizuka, H.
1950. [Wind erosion prevention by windbreaks.] *Meguro For. Expt. Sta. (Tokyo), Bul.* No. 45: 95-129. [Jap.] [Forestry Abs. 13: 504 (1951-52) No. 3853.]
- Tamate, S., Takakuwa, T., and Sato, T.
1950. [Experiment on model windbreak (2d report). Effect on evaporation.] *Meguro. For. Expt. Sta. (Tokyo), Bul.* 45: 17-26. [Jap.] [Forestry Abs. 15: 48 (1954) No. 286.]
- Instituut Voor Toegepast Biologisch Onderzoek in de Natuur.
1956. [Report for 1955.] *Meded. Inst. toegep. Biol.*

- Onderz. Natuur 25, 1956, pp. 28. [Hort. Abs. 27: 46 (1957) No. 261.]
- Joachim, H. F.
1955. [Examples of the successful use of poplars (to give shelter) in cultivated lands, and research on the effect of planting poplars on neighboring crops.] Holzzucht, Lignikultur 9(2): 9-10. [Ger.] [Forestry Abs. 17: 224 (1956) No. 1588.]
- Johnson, M. B.
1947. Range cattle production in western North Dakota. N. Dak. Agr. Expt. Sta. Bul. 347, 47 pp., illus.
- Kalashnikov, A. F.
1955. [The favourable influence of shelterbelts on the moisture of Cis-Caucasian chernozems during the warm season.] Pochvoved. 6: 74-82. [Russ.] [Forestry Abs. 17: 225 (1956) No. 1590.]
- Karandina, S. N., Kissis, T. Ya., and Olovyannikova, I. N.
1956. [A simultaneous study of root systems and water regime in soils of shelterbelts on southern chernozem.] Trudy Inst. Lesa Akad. Nauk 29: 146-193. [Russ.] [Soils & Fert. Abs. 20(1): 57 (1957) No. 357.]
- Karuzin, B. V.
1947. [Measures to obviate poor grain quality in the southeast.] Sovet. Agron. 2: 34-38. [Russ.] [Field Crop Abs. 1: 142 (1948) No. 743.]
- and Shestoporov, G. P.
1936. [A study of the narrow shelterbelts in the Timashev District of the Kuibyshev region.] Polezashchitnye Polosy [Shelterbelts: Experiments of All-Union Res. Inst. for Improvement of Farmland by Forestation.] 6: 117-169. [Russ.] Transl. by C. S. Beliaevsky, U.S. Dept. Agr. Library Transl. No. 7311, 38 pp., 1937.
- Kas'yanov.
1950. [The quantitative and qualitative significance of the role of shelterbelts.] Lesn. Khoz. 1: 38-45. [Russ.] [Forestry Abs. 12: 54 (1950) No. 323.]
- Koomen, J. P.
1957. [Experience with windbreaks in vegetable growing.] Meded. Proefst. Groent. Volle Grond, Alkmaar 6, 43 pp., illus. [Dutch. Eng. summary.] [Hort. Abs. 27: 547 (1957) No. 3415.]
- Kreutz, W.
1952. [The importance of wind protection for tobacco growing.] Dtsch. Tabakb. 32(11): 93-95. [Ger.] [Hort. Abs. 27: 94 (1957) No. 603.]
- Kristjansson, K. K.
1955. [Experiments with shelterbelts at Samsstodur in Fljotschlid.] Arsr. Skograektarf. Islands 1955: 38-44. [Icel.] [Forestry Abs. 17: 65 (1956) No. 433.]
- Kucheryavskiy, E. G.
1940. [The effect of shelterbelts of different structure on crop yields.] Sovetsk. Agron. 10: 18-22. [Russ.] [Forestry Abs. 4: 29 (1942).]
- Kuz'micev, V. P.
1958. [The influence of shelterbelts, with different distances between belts, on maize yields.] Lesn. Hoz. 11(6): 28-32. [Russ.] [Forestry Abs. 20(3): 394 (1959) No. 3193.]
- Lady, G.
1956. [Investigations on the soil protecting effect of a horizontal shelterbelt.] Erdesz. Kut. 3: 69-75. [Hung.] [Soils & Fert. Abs. 20(5): 301 (1957) No. 1920.]
- Linde, R. J. van der.
1955. [Research on shelter for fruit-growing.] Jversl. Proefstat. Fruit., Volle Grond, Wilhelminadorp, pp. 59-62. [Dutch.] [Hort. Abs. 26: 231 (1956) No. 1526.]
- and Woudenberg, J. P. M.
1951. On the microclimatic properties of sheltered areas: the oak-coppice sheltered area. Meded. Inst. Toegep. biol. Onderz. Nat. 10: pp. 151. [Eng.] [Forestry Abs. 13(2): 173 (1951) No. 1221.]
- Lupe, I.
1954. [The influence of forests and shelterbelts on climate and agricultural crops.] Rev. Padurilor 69(4): 170-175. [Rum.] [Forestry Abs. 16: 217 (1955) No. 1758.]
- Catrina, I., and Marcu, G.
1956. [The influence of shelterbelts on yields of wheat and oats in Baragan and the Dobrudja in 1952 and 1953.] Bul. Sti. Acad. Repub. Rom. (Sect. Biol.) 8(1): 199-208. [Rum.] [Forestry Abs. 18(2): 212 (1957) No. 1626.]
- L'vovich, M. I.
1954. [Regulating the water balance of irrigated fields by shelterbelts as a means of decreasing irrigation rates.] Izv. Akad. Nauk Ser. geogr. No. 2: 29-44. [Russ.] [Soils & Fert. Abs. 19(3): 278 (1956) No. 1333.]
- Maljanov, A. P., and Saralidze, T. V.
1957. [The influence of shelterbelts on the structure of the dark-chestnut soil of the Trans-Volga region.] Pochvoved. 3: 33-39. [Russ.] [Forestry Abs. 19(1): 14 (1958) No. 26.]
- Maran, B., Lhota, O., and Uhlir, P.
1950. [Influence of shelterbelts on soil moisture.] Sborn. cs. Akad. zemed. 23: 23-46. [Czech.] [Forestry Abs. 13(5): 503 (1952) No. 3849.]
- Lhota, O., and Uhlir, P.
1951. [Effect of shelterbelts on soil moisture at Vinor.] Sborn. cs. Akad. zemed. 24: 189-215. [Czech.] [Forestry Abs. 13(5): 503 (1952) No. 3851.]
- Masinskaja, L. P.
1950. [Establishing shelterbelts in vineyards.] Vinodelie i Vinogradarstvo SSSR, Moskva 10(6): 22-24. [Russ.] [Forestry Abs. 15: 181 (1954) No. 1377.]
- Matsui, Z., and Yokoyama, C.
1955. [On the efficiency of the wind-break hedge in protecting the rice crop in Horomui District.] Hokkaido Forest Expt. Sta. Spec. Rpt. No. 3, pp. 168-177. [Jap.] [Forestry Abs. 16: 515 (1955) No. 4103.]
- Metcalf, Woodbridge.
1936. The influence of windbreaks in protecting citrus orchards. Jour. Forestry 34: 571-580, illus.
- Molchanov, A. L.
1955. [Water-holding capacity in plowed, fallowed, and forested chernozem.] Trudy Kazakh. gidrometeorol. Inst. No. 5: 8-15. [Russ.] [Soils & Fert. Abs. 19(5): 414 (1956) No. 1941.]
- 1956. [Air-temperature, air-humidity and soil-temperature regimes in the fields between shelter belts.] Trudy Kazakh. gidrometeorol. Inst. 7: 57-65. [Russ.] [Soils & Fert. Abs. 20(2): 89 (1957) No. 485.]
- Mustafaev, Kh. M.
1957. [Changes in the properties of ordinary chernozems under shelterbelts of different ages [and] in the space between belts.] Pochvoved. 6: 102-107. [Russ.] [Forestry Abs. 19(2): 158 (1958) No. 1286.]
- Nageli, W.
1941. [On the significance of windbreaks to protection of cultivated agricultural land.] Schw. Zeitschrift f. Forstwesen 11: 265-280. [Ger.] [From Caborn, 1957, Shelterbelts and Microclimate.]
- Oosterlee, C. C.
1958. An investigation into the influence of climatic factors on the heat balance and milk yield of the cow, in relation to the question of building farms in the Netherlands. Koninklijke Drukkerij C. C. Callenbach N.V.-Nijkerk, 216 pp. illus. [Dutch. Eng. summary.]
- Panfilov, J. E.
1937. [Shelterbelts on the watershed plateau of the prairie zone of the Volga region.] Polezashchitnye Polosy [Shelterbelts: Report of All-Union Sci. Res. Inst. for Improvement of Farmland by Forestation.] 8: 3-64. [Russ.] Transl. by C. P. de Blumenthal, U.S. Dept. Agr. Library Transl. No. 7315, 66 pp., 1937.

- Pavari, A., and Gasparini, M.
1943. [The protective effect of windbreaks on cereal cultivation.] Mariano Ricci. Via S. Gallo 30 [Florence], pp. 34. [It.] [Forestry Abs. 9: 177 (1947) No. 869.]
- Quayle, W. L.
1941. Practical results from the state experiment farms. A shelterbelt increases hay yields. (p. 9) Wyo. Agr. Expt. Sta. Bul. 243, 43 pp., illus.
- Rhee, J. A. van.
1957. [Problems of orchard shelter in Zeeland.] Meded. Dir. van de Tuinbouw. 20(7): 416-426. [Dutch. Eng. summary.] [Hort. Abs. 28(1): 43 (1958) No. 230.]
- Saralidze, T. V.
1955. [The effect of shelter belts on dark chestnut soils of the Trans-Volga region.] Nauch. Ezhegod. 1954, Saratov. Univ. 332-333. [Russ.] [Soils & Fert. Abs. 20(2): 93 (1957) No. 518.]
- Shaposhnikov, A. P.
1946. [Growth and influence on crop yields of tree plantations for erosion control in the central forest steppe] Nauchny Ochet VNIALMI za 1941-42, Sel/Khozgiz (Moscow) pp. 82-90. [Russ.] [Forestry Abs. 9: 174(1947) No. 858.]
- Soegaard, B.
1954. Outline of shelterbelts and shelterbelt tests in Denmark. IUFGO 11th Cong. Proc. 1953 (Rome) Sec. 11, No. 3, pp. 246-269, illus. [Eng.] [Forestry Abs. 15: 314 (1954) No. 2523.]
- Sokolova, N. S.
1937. [Influence of shelterbelts on the yield of agricultural plants: grains, products of truck farming and oil-bearing plants.] Polezashtchitnye Polossy [Shelterbelts: Report of All-Union Sci. Research Inst. for Improvement of Farmland by Forestation.] 8: 120-158. [Russ.] Transl. by C. P. de Blumenthal, U.S. Dept. Agr. Library Transl. No. 7317, 68 pp., 1937.
- Staple, W. J., and Lehane, J. J.
1955. The influence of field shelterbelts on wind velocity, evaporation, soil moisture and crop yield. Canad. Jour. Agr. Sci. 35: 440-453, illus.
- Steubing, L.
1952. [Dew and the influence of windbreaks on it.] Biol. Zbl. 71(5/6): 282-313. [Ger.] [Forestry Abs. 14: 53 (1953) No. 349.]
1952. [The influence of shelterbelts on microclimate.] Dtsch. Landwirtsch. 3(10): 523-526 [Ger.] [Forestry Abs. 14: 170 (1953) No. 1219.]
- Stoeckeler, J. H.
1962. Shelterbelt influence on Great Plains field environment and crops. U.S. Dept. Agr. Prod. Res. Rpt. No. 62, 26 pp., illus.
- and Dortignac, E. J.
1941. Snowdrifts as a factor in growth and longevity of shelterbelts in the Great Plains. Ecology 22: 117-124, illus.
- Suss, N. I.
1936. [Achievements in the improvement of agricultural lands by forestation.] Selskoe Khoziaistvo SSSR. Ezhegodnik, 1935 (Moscow) pp. 172-183. [Russ.] Transl. by C. P. de Blumenthal, U.S. Forest Serv. Div. Silvics No. 286, 23 pp., 1936.
- Thran, P.
1952. [Increased yields obtained by shelter from wind afforded by hedges on earth-walls in Schleswig-Holstein.] Berichte des deutschen Wetterdienstes in der U.S. Zone, Bad Kissingen No. 32: 57-59. [Ger.] [Forestry Abs. 15(1): 49 (1954) No. 289.]
- Trenk, Fred B.
1948. Influence of planted tree belts in plainfield sand on erosion control and moisture conservation. Iowa State Col. Jour. Sci. 22(4): 449-461, illus.
- Vinke, Louis, and Dickson, W. F.
1933. Maintenance of beef cows for calf production. Mont. Agr. Expt. Sta. Bul. 275, 35 pp., illus.
- Woodruff, N. P.
1954. Shelterbelt and surface barrier effects on wind velocities, evaporation, house heating, and snow-drifting. Kans. Agr. Expt. Sta. Tech. Bul. 77, 27 pp., illus.
- Read, R. A., and Chepil, W. S.
1959. Influence of a field windbreak on summer wind movement and air temperature. Kans. Agr. Expt. Sta. Tech. Bul. 100, 24 pp., illus.
- Yamamoto, R.
1957. [Micro-meteorological conditions and growth of crop plants on a slope ground as influenced by windbreaks.] Jap. Crop Sci. Soc. Proc. 26(1): 27-29, illus. [Jap.] [Field Crop Abs. 11(2): 140 (1958) No. 844.]

ADDITIONAL REFERENCES

Consult the following publications for other tree and shrub recommendations for the Great Plains:

- Tree and shrub species for the northern Great Plains. U.S.D.A. Circular 912. 1953.
(Out of print; may be seen in libraries.)
- Windbreaks and shelterbelts. Montana State College, Extension Service Bulletin 318. 1962.
- Shelterbelts for South Dakota. South Dakota State College, Extension Service Circular 492. 1957.
- Trees for wind protection in northwest Oklahoma. Oklahoma Extension Service Circular E-721. 1961.
- The farmstead windbreak. Colorado State Forest Service, C.S.U. Ft. Collins. 1962.
- Trees for Colorado farms. Colorado Extension Service Bulletin 395-A. 1951.
- Windbreaks in conservation farming U.S.D.A. Misc. Pub. 759. 1958.
- Shelterbelts for the northern Great Plains. U.S.D.A. Farmers' Bul. 2109. 1957.
- The Great Plains shelterbelt in 1954. Nebr. Agr. Expt. Sta. Bul. 441. 1958.
- Shelterbelt influence on Great Plains field environment and crops. U.S.D.A. Prod. Res. Rpt. 62. 1962.