BULLETIN 492 MARCH 1946

37 Years of WINDBREAK PLANTING at Akron, Colorado

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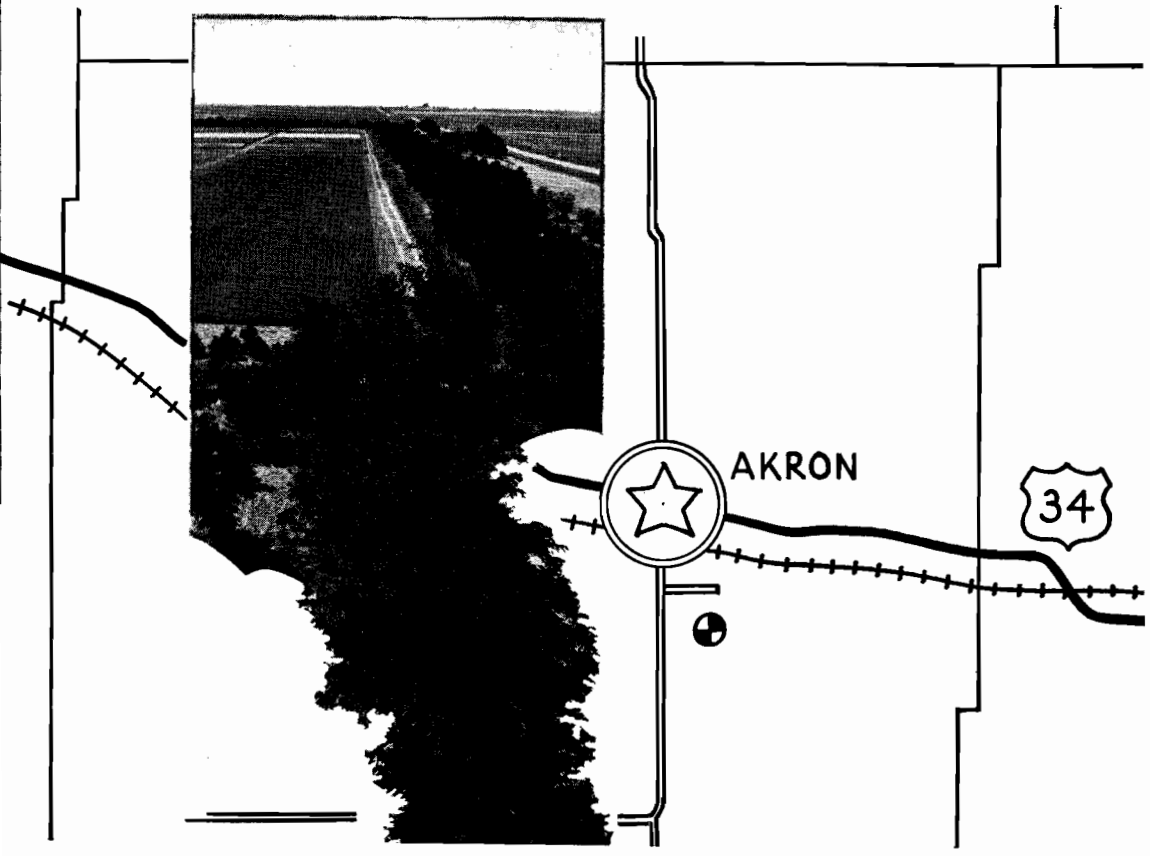

COLORADO AGRICULTURAL EXPERIMENT STATION
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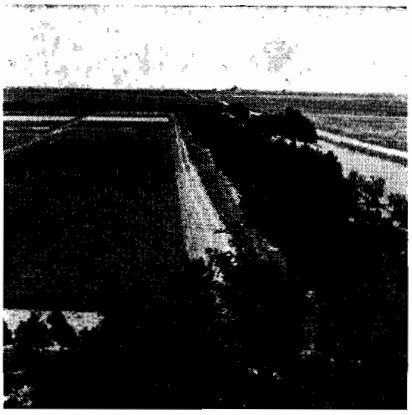
Synopsis . . . .

TWENTY-NINE species of trees in six experiments were planted in the Great Plains region of eastern Colorado during the years 1909, 1910, 1912, 1935, and 1936. Success of these plantings definitely establishes the practicability of windbreaks, provided that correct species and planting methods and proper care are used. Recommendations as to species adapted to these dry-land conditions, based on the results of these experiments, should prove of value, both because of the time since their establishment and because of the severe drought cycle which occurred in this period.

In spite of the broad scope of these experiments not all variables concerned with windbreak species were covered in these plantings. Certain woody species growing successfully in eastern Colorado were not included in this study. It is recognized that other species which were not adapted to the "hardlands" of these plantings might prove successful on light soils in other parts of eastern Colorado. The species which have shown up well at Akron can be expected to do reasonably well in other plains sections of the State.



Cover Picture

General view of the windbreak plantings at the U. S. Dry Land Field Station at Akron, Colo.

At extreme right, Experiment 1 about 1934 after removal of the bulk of the trees. The solid windbreak at the right is Evergreen Experiments 4 and 5.

Experiment 2 can be seen in the distant background.

37 Years of Windbreak Planting at Akron, Colorado

RICHARD J. PRESTON, JR. [1]
and
J. F. BRANDON

ONE OF the early attempts to study the practicability of tree planting on the Great Plains was the experiment established at Akron, Colo. By act of Congress March 2, 1907, 160 acres of dry land approximately 4 miles east of Akron was granted to the Colorado A & M College for forestry experimental purposes. The following year an agreement was reached between the United States Forest Service, the Bureau of Plant Industry, and the Colorado Agricultural Experiment Station for conducting the studies to be known as the "Akron Forest Experiments." The maintenance of these experiments composes a portion of the activities of the United States Dry Land Field Station at Akron. [2]

Experimental plantings were made in the years 1909, 1910, 1912, 1935, and 1936. It is the purpose of this paper to picture the present condition of these plantings, as well as to describe their survival and development during this extended period of growth. Recommendations as to species adapted to these dry-land conditions, based on the results of these plantings, should be of considerable value, both because of the time since the plantings were established, and because of the severe drought cycle which occurred in this period.

SITE

The Akron Forest Experiments are located in northeastern Colorado, a section included in the upland portion of the Central Great Plains. This area is naturally treeless, except along the scattered water courses. The native vegetation is typical of the short-grass belt, characteristically consisting of a mixture of the low-stature blue grama and buffalo grasses. Sage and other dry-land shrubs occur with the grasses on the lighter soils.

Precipitation is not only scanty but highly variable. Over the 37-year period of this study the average annual precipitation was 16.9 inches, considerably below what has been considered the minimum re-

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[2] The United States Dry Land Field Station, located in northeastern Colorado at an altitude of about 4,600 feet, is operated by the Division of Dry Land Agriculture, Bureau of Plant Industry, Soils, and Agricultural Engineering, United States Department of Agriculture, in full cooperation with the Colorado Agricultural Experiment Station. The forestry experiments were under the care of the superintendent of the field station. The superintendents of the field station since its establishment were: J. E. Payne, 1907-10; O. J. Grace, 1910-20; and J. F. Brandon, 1920 to date.

quired for natural tree establishment. During this period the annual precipitation ranged from a low of 9.93 inches in 1939 to a high of 25.00 inches in 1915. The minimum figure is most certainly critical, trees having to be able to adapt their water economy to such low levels in order to survive. It was not uncommon for much of the precipitation to occur during heavy storms, in which case a large amount of water was carried from the area as run-off. Approximately four-fifths of the annual precipitation falls during the half year April to September. This indicates that extreme drought exists during the dormant period.

Drifted snow is an important source of supplemental water for trees. Although the quantity varies greatly from year to year, it offsets to a large extent the scarcity of precipitation, and may be the factor that enables trees to survive. In winters having heavy precipitation the snow drifted among the trees to a depth of 5 feet or more (figure 1), and even in years of very scanty winter precipitation there was appreciable drifting. Normally most of the water from the melting snow seeped into the ground below the trees, although a combination of deep drifts and warm weather resulted in considerable run-off.

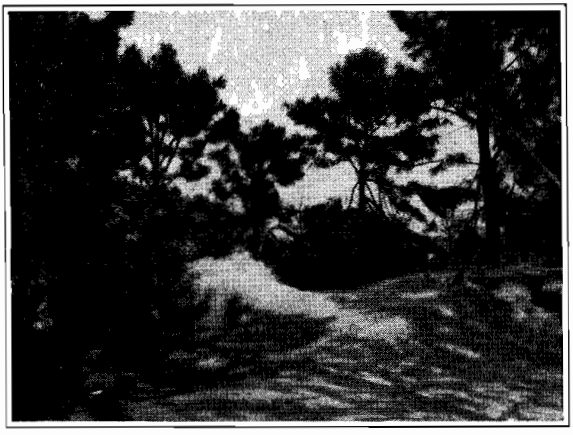

Figure 1. Unusually heavy snow drifting among the ponderosa pine in January of 1922.

The sudden severe storms and changes in temperature occurring throughout the year in this region are unpredictable factors which may have a decided influence upon the success of a windbreak planting. While such storms are to be expected several times during the life cycle of a windbreak, the amount of damage caused will vary with such factors as age of the windbreak and time of year in which the storm occurs. In at least 2 of the 37 years covered by this study, considerable damage was inflicted on the trees by exceptional weather conditions. Inspection reports [3] indicate that in

[3] **Comments on the condition of the plantings for the years 1910 to 1918, 1921, 1924, and 1927 are taken from the reports of inspections made during those years. These reports are in the Akron files. The inspections were made by Mr. Fred Johnson of the United States Forest Service, Professors B. O. Longyear and W. J. Morrill of Colorado Agricultural and Mechanical College, and Superintendent J. F. Brandon.**

August and September of 1910 severe hail storms destroyed much of the foliage and bruised the bark on every species, resulting in heavy mortality, while in 1915 late snow and frost, May 20-21, killed many of the leaves and practically all of the flower buds.

The soils on which the project is conducted are locally called "hardlands" and are characteristic for much of eastern Colorado. Three representative soil types, Rago silt loam, Rago very fine sandy loam, and Platner loam, occur in the area used for the tree plantings. Experiments 1, 4, 5, 6, and the eastern half of 2 are located on the Platner loam; the west half of Experiment 2 is on the Rago very fine sandy loam; Experiment 3 is on the Rago silt loam. There is no observable difference in tree growth or survival on these soil types.

DESCRIPTION OF THE EXPERIMENTS

The tree plantings at Akron were divided into several different experiments. The location and area of these experiments are indicated in figure 2. The cover picture shows the east side of the plantings (Experiments 1, 4, and 5) and a portion of the north side (Experiment 2). The trees in all experiments were planted in rows running the long way of the plot.

Arrangement

Experiment 1, planted in 1909, and Experiments 2 and 3, planted in 1910 (with 2 additional species added in 1912), tested the suitability of 13 species of broadleaf trees. The 10 species in Experiment 1 were planted in 10 rows with the species mixed in the rows without any definite planting plan. Experiment 2 consisted originally of eight rows of trees with a ninth row added in 1912. The arrangement of species by rows starting at the north side of the planting and progressing to the south side was:

Row 1.	Honey locust	Row 5.	Honey locust
Row 2.	American elm	Row 6.	Hackberry
Row 3.	Honey locust	Row 7.	Black locust
Row 4.	American elm	Row 8.	Black locust

Row 9. Black walnut and black locust

Experiment 3 consisted of seven rows of trees (the catalpa in row 3 being planted in 1912). The arrangement of species by rows working from west to east was:

Row 1.	Russian mulberry	Row 4.	Hackberry
Row 2.	Hackberry	Row 5.	Green ash
Row 3.	Black locust and catalpa	Row 6.	Russian mulberry
		Row 7.	American elm

ARRANGEMENT OF TREE PLANTING EXPERIMENTS
U. S. DRY LAND FIELD STATION, AKRON, COLO.

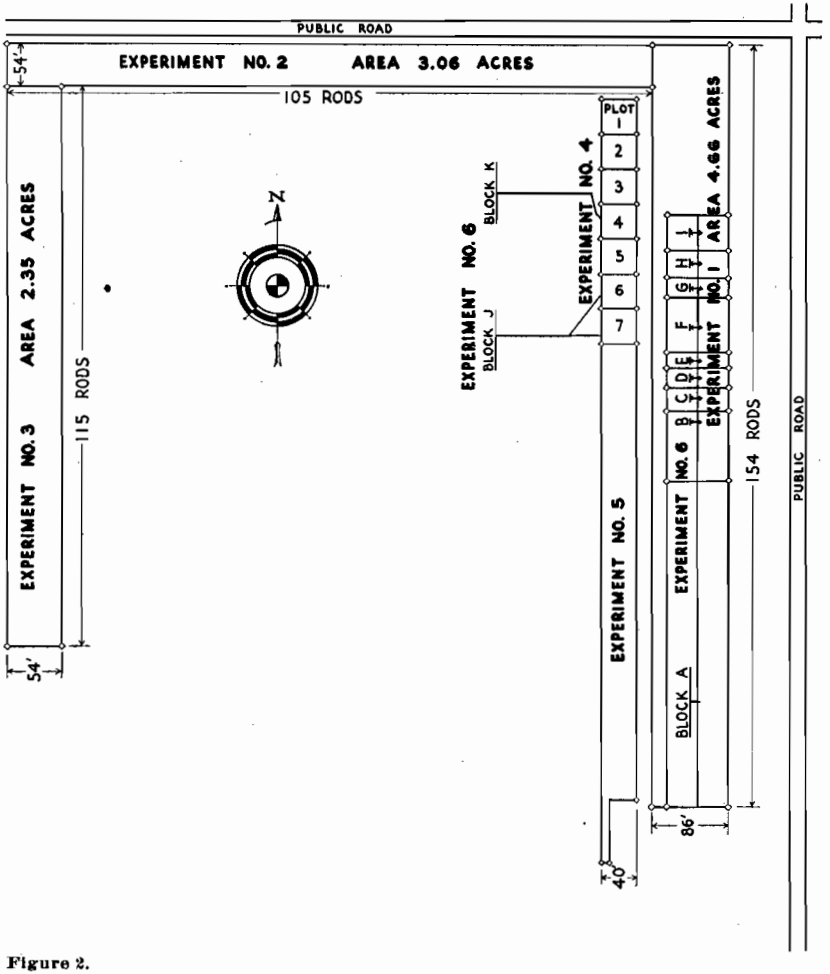

Figure 2.

Eight species of conifers were planted in Experiments 4 and 5. In the first of these, seven species were planted in 1910, each species occupying a plot 40 by 100 feet. The arrangement of species within these plots, progressing from north to south was:

Plot 1. European larch	Plot 4. Jack pine
Plot 2. Scotch pine	Plot 5. Ponderosa pine
Plot 3. Austrian pine	Plot 6. Douglas-fir
Plot 7. Black Hills spruce	

In 1912 a belt of conifers approximately 2,000 feet long and 40 feet wide was planted Four species were included in this fifth experiment, three being those that made the best early record in Experiment 4. This planting consists of nine rows, the first five, working from east to west, being ponderosa pine, the sixth and seventh Austrian pine, the eighth jack pine, and the ninth eastern redcedar.

By 1933 all the trees in Experiment 1 were dead except those in two low swales. During the fall of this year the dead trees were removed, leaving space for additional plantings. This area was fallowed through the season of 1934. In the springs of 1935 and 1936, five species of broadleaf trees and six species of conifers were planted in blocks in this area and in three plots in Experiment 4, where all the original trees were dead. The species planted and their location by blocks are given in figure 2 and tables 1 and 2 (see pages 22-25). These more recent plantings are designated Experiment 6.

Source of Planting Stock

The seedlings were obtained from government or private nurseries. An attempt was made to get stock from nurseries having a climate similar to that of Akron. Unfortunately no records of seed source are available.

Establishment

Poor initial survival in some of the early plantings indicated that proper preparation of the land was essential to the success of tree planting under dry-land conditions. Several methods of planting and land preparation were tried the first 2 years with varying degrees of success. For example, as shown in table 2, only 30 percent of the ponderosa pine and 41 percent of the Austrian pine planted in 1910 survived until autumn of the year planted; the same species, however, planted 2 years later according to the methods described in the following paragraph, showed survivals of 88 and 94 percent respectively in the autumn of the year planted. The successes of these methods have resulted in their widespread adoption.

In all areas planted after 1910 the land was allowed to lie fallow for at least 1 year in order to store adequate soil moisture. As early in the spring of the planting as weather conditions permitted the ground was cultivated. The seedlings were planted from the latter part of April to the middle of May. At the time of planting, lister furrows were plowed and the trees planted in the freshly turned furrows. The amount of moisture available to the trees was increased by leaving the planted trees in a slight depression below the level of the surrounding soil. Roots were kept moist at all times and were carefully compacted into moist soil when planted.

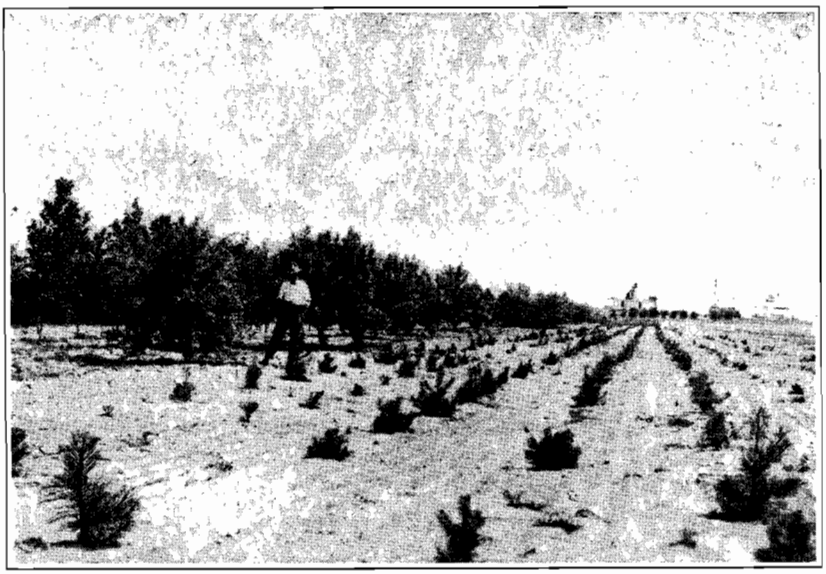

Figure 3. Austrian pine (two rows on right) and ponderosa pine (five rows in center) in Experiment 5 the second summer after planting. Five-year-old hardwoods in Experiment 1 are to the left.

Spacing

Trees planted in 1909 and 1910 (Experiments 1 to 4) were spaced 8 by 8 feet. In Experiment 5, planted in 1912, a spacing of 8 by 5 feet was used. In the 1935-1936 plantings (Experiment 6) the following spacings were used:

6 by 6 feet
- Chokecherry and Siberian pea-tree

6 by 10 feet
- Limber pine
- Lodgepole pine
- Pinyon pine
- Ponderosa pine
- Siberian elm
- Eastern redcedar
- Rocky Mountain Juniper

10 by 12 feet
- Black walnut
- Bur oak

From the standpoint of ease of cultivation, the wider spacings of from 10 to 12 feet between rows were found desirable. With closer spacings branch growth prevented horse or tractor cultivation at an early date. Stagnation of growth with evident loss of vigor in the center of block plantings of chokecherry and Siberian pea-tree, spaced 6 by 6 feet, was apparent by the eighth year, indicating that thinning within the rows and between the rows may soon become necessary where trees are planted close together. Windbreak effectiveness can be maintained by planting the trees close together within a row but

spacing the rows far enough apart to allow for cultivation and increased soil moisture.

Treatment

Windbreaks in the Central Great Plains need cultivation. Because of limited water supply it is essential that trees be protected from competing vegetation, especially during their early years. During the first 3 to 5 years of the experiments cultivation was carried on intensively, the areas being disked, cultivated with a corn cultivator, and hoed two or three times a season. After the third to fifth year, as the trees became larger and shaded out heavy herbaceous cover, the amount of cultivation needed became less and a single yearly disking proved sufficient. The single disking was continued for about 15 years under the broadleaf species and for about 5 years under the conifers, by which time the ground under the pines was so completely shaded and needle-covered that for several years there was an insignificant growth of grass and weeds, and cultivation was not necessary. In recent years downy chess (*Bromus tectorum* L.) has invaded the plantings, growing luxuriantly in open spaces and to some extent under closed canopies which can no longer be effectively cultivated because of interlacing branches. The effect this may have on continued growth and survival is not known, but it may prove a serious factor.

Replanting

Tables 1 and 2 indicate that initial survivals of from 70 to 100 percent can be obtained, provided that species adapted to the region are selected and proper precautions taken for their establishment. Experience at Akron indicates that replanting should be done within 1 or 2 years after the original planting. Seedlings planted at later periods were unable to compete with the established root systems of the trees in the original planting.

Thinning

The rapid growth of the broadleaf species planted in 1909 and 1910 made cultivation difficult as early as 1912. In 1914 several rows of the trees which appeared least able to survive were removed from Experiment 1, and other trees in Experiments 1, 2, and 3 were pruned, many severely, to make cultivation by horse possible. Additional pruning and removal of dead trees was recorded during the years 1916, 1922, and 1923.

In 1928 the surviving ponderosa and Austrian pines were thinned by removing every other tree in the rows. This removed approximately one-half the trees in Experiments 4 and 5. The trees had become so crowded by this time that growth and vigor in the interior

rows was visibly affected. Eighty percent of the trees removed had trunks long enough and large enough to make into fence posts with top diameters of 2 or 3 inches (material sufficient for 493 posts was obtained). A large amount of fire wood was also thus made available.

During the fall of 1933 a WPA project to recondition the forestry experiments was completed. Dead and nearly dead trees were grubbed out. Later this wood was hauled out for use by the local relief committee. Following this operation Experiment 1 was bare except for trees in two low swales, and a considerable percentage of the trees in Experiments 2 and 3 were removed. Experiments 4 and 5 had no appreciable number of dead trees to be removed.

Root Development

The general character of the root systems became evident when a large number of trees were grubbed out in 1933. In all species these were very shallow, within 1 to 3 feet of the surface, and extended horizontally for considerable distances. Species which normally develop deep tap-roots either had the tap-root early suppressed or, in several cases, turned at right angles and grown horizontally. Undoubtedly this shallow type of root development was in response to soil moisture conditions. There is no water table under the Akron Station soil, and moisture seldom penetrates to a depth of more than a few feet. There were almost no cases of trees being blown over, which indicates a surprising degree of wind-firmness considering the shallow type of root system and the very severe winds common to this region.

Grazing

The only grazing that took place on the experiments occurred in the early 1930's when sheep were allowed to graze for 1 year among the conifers in Experiment 5. The trees had attained considerable size by this time and there was no damage from trampling or breakage; however, the inspection reports state that almost all needles within reach were eaten, thus lowering the effectiveness of the windbreak.

PRESENT CONDITION OF THE EXPERIMENTS

Experiments 1, 2, and 3, planted to broadleaf species in 1909 and 1910, have not been very effective as windbreaks for several years. The survival and growth of the 13 species planted in these experiments are summarized in table 1. During the early years growth of nearly all species was good, and the windbreak was effective and made a striking appearance. By the tenth year, the less well adapted species had almost disappeared, but hardy species were vigorous and growing rapidly. The peak of height growth and effectiveness was attained by the best adapted species at about 15 to 20 years after planting, after which the trees went into a slow decline. Thirty-three

Figure 4. Ponderosa pine, 28 years old in Experiment 4. Sheep had grazed this plot and eaten the needles within reach, thus materially lowering its effectiveness as a windbreak.

years after planting, only a small number of the broadleaf trees were living and almost all these were dying back from the top. No differences were observed in survival or growth between trees planted in north-south rows (Experiments 1 and 3) and trees planted in east-west rows.

Experiment 1 became ineffective several years earlier than Experiments 2 and 3. As early as 1921 the poorer condition of the trees was noted in this experiment. This undoubtedly was a result of the plantings of conifers made just to the west of this experiment, which caught and held the drifting snows from the northwest. The extent of the effect which trees have on soil moisture in this region is further indicated by the fact that trees in Experiment 6 planted to the east of the belt of conifers did not attain their full vigor within a distance of at least 40 feet from the belt. Trees planted less than 40 feet from the belt were progressively shorter as the belt was approached.

Conifers planted in Experiments 4 and 5 which had proved adapted to this section were still growing vigorously in 1945 and made an effective windbreak of striking appearance (table 2). These trees were of good form and remarkably free from attack by insects or fungi. After 36 years there is no indication that these trees are approaching the end of their life cycle.

Six species of conifers and 5 species of broadleaf trees were planted in Experiment 6 in 1935 and 1936, (tables 1 and 2). All these species have done fairly well, and several have made excellent records to date. Records of the earlier plantings show that many species which are not

suited to dry-land conditions make good growth and survive well for a number of years, only to die out completely during unusually severe seasons. For this reason it is not safe to base recommendations on short-time observations.

SUITABILITY OF TREE SPECIES FOR WINDBREAKS

Conifers

Over a considerable period of time a windbreak of conifers proved to be more enduring than one of broadleaf species. Growth was slower during the early years, but this handicap could be alleviated by planting a fast-growing broadleaf species to the windward side of the windbreak. Life expectancy was longer than with broadleaf species, and the windbreak was effective and attractive for the entire year.

Twelve species of conifers were planted in the experiments at Akron. Two of these have been very successful over a 36-year period and can be highly recommended, four were not suitable, and six need further study.

Conifers Recommended for Planting

Ponderosa pine	*Pinus ponderosa* var. *scopulorum* Engelm.
Austrian pine	*Pinus nigra* Arnold

Conifers Needing Further Study

Rocky Mountain Juniper	*Juniperus scopulorum* Sarg.
Eastern redcedar	*Juniperus virginiana* L.
Limber pine	*Pinus flexilis* James
Lodgepole pine	*Pinus contorta* var. *latifolia* Engelm.
Pinyon pine	*Pinus edulis* Engelm.
Scotch pine	*Pinus sylvestris* L.

Figure 5. Ponderosa pine 10 years after planting. Average tree height 8½ feet.

Figure 6. Ponderosa pine (left) and Austrian pine (right) 12 years after planting. Average tree height 11 feet.

Conifers Not Suited to Eastern Colorado

Black Hills spruce	*Picea glauca* var. *albertiana* (S. Brown) Sarg.
Douglas-fir	*Pseudotsuga taxifolia* var. *glauca* (Mayr.) Sudw.
European larch	*Larix decidua* Mill.
Jack pine	*Pinus banksiana* Lamb.

Brief notes on these 12 evergreen species follow, pointing out characteristics of those surviving and causes of failure of those not adapted to eastern Colorado.

Ponderosa or Western Yellow Pine

This was by all odds the tree best adapted to windbreak planting. Care had to be taken with the seedlings at time of planting to assure a high survival. Growth during the first few years was slow, but over a period of 36 years this species made the outstanding record among the 29 species tested. The 1924 report stated that this tree was very thrifty and probably the most desirable tree for the windswept plains of eastern Colorado. This conclusion was substantiated by the surveys of 1942 and 1945, at which times the trees were outstandingly healthy and vigorous.

Austrian Pine

This species proved highly successful in the Akron plantings and appears well adapted to the section. As both the survival and rate of growth were slightly below those for ponderosa pine, coupled with the fact that the latter is more easily obtained from local nurseries, Austrian pine is less highly recomended.

Rocky Mountain Juniper

This species, like ponderosa pine, is native to portions of eastern Colorado and is well adapted to dry conditions. On the basis of 11 years' records at Akron, plus experience with older private plantings in the area, this species should prove valuable for the central Great Plains. Both survival and growth have been good, and the trees are healthy and make a fine appearance. Rocky Mountain juniper is a small, symmetrical, slow-growing tree that is well adapted for planting in marginal rows of windbreaks.

Eastern Redcedar

Results with this species vary in different experiments. However, it appears inferior in vigor, growth, and form to Rocky Mountain juniper, which it closely resembles. Because of poor stock and possibly careless early cultivation, only 6 out of 199 became established in the 1912 planting, but 3 of these are alive and vigorous today. In the 1936 planting 73 percent still survive.

Limber Pine

This species proved difficult to establish, repeated plantings in Experiment 6 still showing a low survival. Since this species grows naturally in eastern Colorado and western Nebraska it would appear to offer possibilties for windbreak planting. Studies should be made with differing ages of stock and varied transplanting methods to see if higher survivals cannot be obtained. Until better success is attained in establishing this species it cannot be recommended.

Lodgepole Pine

The 10-year record for this mountain tree has been surprisingly good, with a survival of 86 percent and an average height of 6½ feet. This tree must be observed over longer periods before recommendations can be made. It seems probable that, like the closely related jack pine, it may die out during periods of severe drought. At present the trees are vigorous and are already bearing a few cones.

Pinyon Pine

While making only slow growth and appearing to be less vigorous than lodgepole pine, this species showed a survival of 90 percent in 10 years of growth. Cones are now forming. If this tree will survive on the plains and form seed which will mature, it might result in a nut crop of some importance. Longer observation is necessary before conclusions can be reached.

Scotch Pine

On the records of one planting at Akron, Scotch pine was a failure in this region. Only 5 of 96 seedlings planted in 1910 lasted through the first season and by 1912 only 2 remained. In a farm lot planting in the vicinity of the Akron Station, well-established Scotch Pine went out at the end of about 22 years. This species deserves another trial.

Black Hills Spruce

This species was not adapted to conditions in northeastern Colorado. While a high percentage of the trees became established, growth was very slow, and none survived after about 10 years. Summer drought and winter-killing were given as the cause of failure.

Douglas-fir

The Akron records indicate that this species was not adapted to the central Great Plains. Only 4 percent of the trees planted became established, and these soon died. Plantings by the Colorado State Extension Forester also proved unsuccessful, definitely indicating that this tree should not be planted.

European Larch

This species was a definite failure in eastern Colorado. Only three individuals withstood the first summer drought, and none were living after 4 seasons.

Figure 7. Ponderosa pine 26 years after planting. Average tree height 17 feet.

Jack Pine

This species cannot be recommended. After making a fine start and surpassing all other conifers in growth for about 10 years, the trees, many 11 to 16 feet in height, began to die in 1923 and by 1928 were all dead. The experience with this species further emphasizes that sound recommendations cannot be made on short-time observations.

Broadleaf Species

While growth of the broadleaf species was generally very rapid during the first few years and a windbreak of considerable height may be early attained with them, the following considerations point out several disadvantages of broadleaf windbreaks:

1. They afford little effective protection against the wind during roughly one-half the year.
2. They have proved more susceptible than conifers to damage by hail, frost, and wind.
3. The life span of all species tested was greatly shortened over that of similar trees in native habitat; it was also much shorter than the span of recommended conifers.

Of the 17 species of broadleaf trees planted at Akron, only two can be given a general recommendation. Certain species are given qualified recommendations for special locations or purposes, and others are either not suitable or need further study.

Recommended broadleaf species

Hackberry	*Celtis occidentalis* L.
American or white elm	*Ulmus americana* L.

Broadleaf species in the Akron plantings adapted to restricted locations or for special purposes

Cottonwood	*Populus sargentii* Dode
Honey locust	*Gleditsia triacanthos* L.
Russian mulberry	*Morus alba* var. *tatarica* (L.) Ser.
Russian-olive	*Elaeagnus angustifolia* L.
Siberian elm	*Ulmus pumila* L.

Figure 8. Broadleaf species 20 years after planting in Experiment 2. The surviving trees consist almost entirely of American elm and hackberry and average about 15 feet in height.

Broadleaf species needing further study

Chokecherry	*Prunus virginiana* var. *melanocarpa* (A. Nels.) Sarg.
Bur oak	*Quercus macrocarpa* Mich.
Siberian pea-tree	*Caragana arborescens* Lam.
Black walnut	*Juglans nigra* L.

Broadleaf species not successful in the Akron plantings

Green ash	*Fraxinus pennsylvanica* var. *lanceolata* (Borkh.) Sarg.
White ash	*Fraxinus americana* L.
Catalpa	*Catalpa speciosa* Warder
Black cherry	*Prunus serotina* Ehrh.
Black locust	*Robinia pseudoacacia* L.
Osage-orange	*Maclura pomifera* (Raf.) Schneid.

Species recommended for general planting or for special purposes on the basis of the Akron plantings are briefly discussed in following paragraphs. Available information is summarized for the species which are not suited or need further study.

Hackberry

Over a period of 33 years hackberry made the best record among the broadleaf species tested. It has the highest percentage of survival, suffers little from drought, wind, or winter-killing, and makes a well-formed tree. After 33 years about 45 percent of the original number planted were living, but these were not in a vigorous condition and appeared to be nearing the end of their cycle. Tops were dead on 85 percent of the living trees, and the foliage on many was quite yellow. The average tree height of 13 feet is 1 foot less than in 1924, and the present effectiveness as a windbreak is not great. The peak period of usefulness of the windbreak provided by this species was reached by about the fifteenth year.

American or White Elm

This is the only other broadleaf species tested at Akron that can be given a general recommendation. While growing faster than hackberry, this tree was somewhat less drought resistant and of poorer form. Only 15 percent of the original number were living after 33 years, but these appeared to be more vigorous than surviving trees of other broadleaf species. The usefulness of the windbreak provided by this species also deteriorated after about the fifteenth year.

Cottonwood

In 1945 only one of the 85 cottonwoods planted in 1909 was alive. This tree, growing in a low swale where soil moisture accumulated, appeared vigorous and was the largest tree in the six experiments, being 40 feet high and 18 inches in diameter. In 1917 the 32 surviving trees were in very poor condition and by 1927 only the one

remained. Where the water table is not too deep these trees would probably do well, since they grow naturally along the water courses of the arid lands. Their fast rate of growth and good form makes them a desirable tree.

Honey Locust

Honey locust is recommended for planting in marginal windbreak rows or on protected sites. Apparently this species cannot withstand either competition or severe exposure as well as hackberry or American elm. Honey locust trees planted along the margins of Experiments 1 and 2 did rather well, while those planted in interior rows were not successful. During its early years, honey locust suffered rather severe winter-killing, and heavy breakage and splitting was reported, but it appears quite free from other forms of injury. This species has remarkable ability to sprout from the roots if killed back.

Russian Mulberry

This species is recommended for planting only in the locations indicated for honey locust. While survival held up fairly well for about 20 years, the tree winter-killed badly and was usually covered with quantities of dead wood. It is attractive to birds because of its fruit and in sheltered locations forms a low, bushy, symmetrical tree.

Figure 9. Broadleaf species in Experiment 1 the fifth year after planting. The trees in the nearest row are honey locust, and the tall trees in the background are cottonwoods.

Russian-olive

On not too exposed sites and where competition is not severe, this species forms a wide-spreading tree of rapid growth. While somewhat subject to tip-killing during the winters, it has been remarkably free from insect and other forms of injury. It can be given a qualified recommendation similar to that given honey locust.

Siberian Elm.

Siberian elm (often incorrectly called Chinese elm) has been planted extensively in recent years. While very fast growing (averaging 16 feet in height in 7 years at Akron), this tree is not satisfactory for general planting. The wood is very brittle and subject to wind and snow breakage. In recent years a canker fungus (*Cytospora*) has caused considerable damage to this species. It is not yet known whether this fungus attacks healthy trees or is restricted to trees weakened by severe freezes, hail, or other agencies. Although this species may prove to be short-lived under semi-arid conditions, it can be recommended where protection is desired in the shortest possible time. This tree could often be profitably planted as a "nurse" tree along the windward side of a windbreak, with slower-growing species of known long life planted to leeward. Such a planting would give effective protection and maintain interest in the windbreak during the early years of its development. There is some evidence that such nurse tree plantings should be not less than 40 feet away from the main planting because of their effect on the limited amount of soil moisture.

Chokecherry

This shrub or small tree has made an excellent record over an 11-year period, forming a rounded crown and making good growth. Until observations have extended over a longer period of time and the life cycle determined, this species cannot be given a definite recommendation for windbreak planting.

Bur Oak

This tree was very difficult to establish, and growth during the first few years was slow. Because the records cover only a 10-year period no conclusions as to merit are yet possible. The species grows naturally in northeastern Wyoming, so it is not unreasonable to expect fair success in Colorado.

Siberian Pea-Tree or Caragana

On the basis of 11 years' observation, this species holds promise for windbreak planting in the region. This shrub or small tree grew rapidly and formed a rounded, bushy crown. Insects were strongly attracted to this species and this may prove a serious handicap. Further observations are necessary before recommendations can be made.

Black Walnut

Fifty walnuts were planted in Experiment 2 and 30 more in Experiment 6. On the basis of this sketchy evidence it appears that this species is very difficult to get established and that it can survive only in sheltered locations.

Green Ash

This species was not suitable for the "hardland" regions in eastern Colorado. The records indicate that this tree persisted satisfactorily at Akron for about 10 years and then died out. Growth was slow and the vigor of the tree was not good. On light soils in eastern Colorado, this species has been reported as satisfactory for windbreak planting.

White Ash

This species appeared less well adapted to this area than green ash. It proved a definite failure in the Akron plantings.

Catalpa

Catalpa was not suitable for planting in eastern Colorado. Of the 178 trees planted in 1912 all were dead within 16 years. During this period they were repeatedly killed back, only to survive for a number of years by sprouting.

Black Cherry

Black cherry was not suitable for windbreak planting. The inspection reports indicate that winter-killing was the cause of failure of this species.

Black Locust

Because of the locust borer (*Cyllene robiniae*) this tree is not recommended. It may be several years before the borers appear (12 years in this experiment), but the large trees were killed soon thereafter. Sprouts continued to arise from the roots for many years, but these were in turn killed by the borers before attaining large size. This species grows well and in other respects was well adapted to planting under dry conditions.

Osage-orange

This species was a complete failure in northeastern Colorado because of winter-killing.

CONCLUSIONS AND SUMMARY

1. Success of the Akron experiments definitely establishes the practicability of planting trees for windbreaks in the Central Great Plains region, providing that correct species and planting methods and proper care are used.

2. Trees should be regularly cultivated in order to conserve vital

soil moisture. This is especially important during the early years and until the crowns have grown together to shade the ground and reduce weed competition.

3. Replanting should be done within 1 or 2 years after the original planting, since root competition becomes severe after this period.

4. A wide spacing of 10 to 12 feet between rows facilitates cultivation by horse or tractor and increases the amount of soil moisture available to each tree. Closer spacing within the marginal rows will reduce wind penetration.

5. The most effective and durable windbreak was composed of pines. Ponderosa pine after 36 years continues to make good growth and appears to retain its health and vigor; this pine has made the best record among the 29 species tested. Austrian pine is only slightly inferior to ponderosa pine. Jack pine and Scotch pine are not recommended. Lodgepole, limber, and pinyon pine show promise, although the latter two were difficult to establish; however, a longer period of observation is necessary before sound recommendations can be made on these species.

6. Rocky Mountain juniper made vigorous growth and is recommended for planting along the margins of windbreaks. Eastern redcedar appeared less vigorous, although when once established it maintained itself well.

7. European larch, Douglas-fir, and Black Hills spruce were not suitable for this region.

8. Hackberry and American elm are the broadleaf species most highly recommended. They were highly effective as a windbreak for about 15 to 20 years, but after this period survival was poor and nearly all the remaining trees died back from the top.

9. Cottonwood, honey locust, Russian mulberry, Russian-olive, and Siberian elm are given qualified recommendations. Under certain conditions or for special purposes they were of definite value.

10. Green ash, white ash, black cherry, catalpa, black locust, and Osage-orange were not adapted to the Akron region.

11. Siberian pea-tree and chokecherry made rapid early growth and appeared vigorous. Black walnut and bur oak were difficult to establish and grew more slowly. Observations over a longer period are necessary before recommendations concerning them can be made.

12. These experiments indicate that a good all-purpose windbreak for northeastern Colorado would consist of two to six interior rows of ponderosa pine with a marginal row on each side of Rocky Mountain juniper. Because these trees grow slowly during early years, a short-lived, fast-growing broadleaf species could be planted to the windward side of the windbreak for more immediate effect and then removed as the evergreens attained requisite size.

TABLE 1.—*Survival and Growth of Broadleaf Species.*

A—SURVIVAL OF BROADLEAF SPECIES

Species	No. planted	No. replanted [1]	Location	Survival											
				No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
BROADLEAF SPECIES PLANTED IN 1909 and 1910 (Experiments 1, 2, and 3)															
Years after planting				1st yr.		2nd yr.		5th yr.		8th-9th		18th-19th		33rd-34th	
Black cherry	145			60	41	58	40	59	41	17	12	0	0	0	0
Black locust	963			766	79	484	50	271	28	300	31	53	6	59	6
Cottonwood	85			46	54	46	54	44	52	32	38	1	1	1	1
Green ash	706			592	84	545	77	545	77	422	60	25	4	2	0
Hackberry	754			558	74	526	70	508	67	471	62	471	62	336	45
Honey locust	1,260			1,070	85	975	77	607	48	380	30	372	30	66	5
Osage-orange	330			129	39	38	12	37	11	0	0	0	0	0	0
Russian mulberry	982			912	93	772	79	746	76	688	70	404	41	12	1
Russian-olive	221			89	40	71	32	65	29	66	30	43	20	21	10
White ash	236			195	83	169	71	170	71	157	67	25	11	2	1
White elm	1,590			1,457	92	1,422	90	1,399	88	1,155	73	1,074	68	236	15
BROADLEAF SPECIES PLANTED IN 1912 (Experiments 2 and 3)															
Years after planting				1st yr.		2nd yr.		5th yr.		6th yr.		16th yr.		31st yr.	
Catalpa	178			147	83	110	62	100	56	100	56	0	0	0	0
Black walnut	55			46	84	.....	....	.....	....	24	44	11	20	2	4
BROADLEAF SPECIES PLANTED IN 1935 (Experiment 6)															
Years after planting				1st yr.		2nd yr.		8th yr.		11th yr.					
Chokecherry	78	47	Block K	31	40	73	58	67	53	67	53				
Siberian elm	126	7	Block B	119	94	124	93	122	92	122	92				
Siberian pea-tree	182	39	Block J	143	78	177	80	173	78	173	78				
BROADLEAF SPECIES PLANTED IN 1936 (Experiment 6)															
Years after planting				1st yr.		7th yr.		10th yr.							
Black walnut	21	9	Block G	12	57	11	37	10	33						
Bur oak	28	0	Block H	25	90	10	36	10	36						

[1] Replanting of dead seedlings took place in spring following original planting; subsequent survival figures include original planting and replanting.

B—GROWTH OF BROADLEAF SPECIES

Species	Height growth in feet													Diam. in inches 4½ feet above ground		
	Range	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Ave.	Ave.	Ave.
BROADLEAF SPECIES PLANTED IN 1909 and 1910 (Experiments 1, 2, and 3)																
	When planted	2nd yr.		3rd yr.		5th yr.		9th yr.		15th yr.		33rd yr.		9th yr.	15th yr.	33rd yr.
Black cherry	1.5-2	1.5-3		2 -5	3	-	6	6-8	-	0	0	0	0	..	0	0
Black locust	1 -1.5	3 -6		4 -9	6.5	10-14	13	10-18	15	-	..	3-16	9	3.4	Shrubs	..
Cottonwood	2 -3	7 -10		9 -13	11	17-23	19	-	-	30-40	..	40	40	6.0	..	18
Green ash	1 -2	1 -2.5		2 -5	3.5	6-10	7.5	6-12	8.5	-	13	8-18	12	2.0	..	..
Hackberry	-	1.5-3		3.5-5.5	4.5	6-11	7	9-15	12	-	14	4-30	13	2.5	2.8	5.4
Honey locust	1.5-2	1.5-4.5		2 -7	4.5	8-13	8.5	9-20	13	-	15	2-23	5	3.1	2.9	5.2
Osage-orange	1 -1.5	1.5-2.5		-	..	-	3.5	0	0	0	0	0	0	0	0	0
Russian mulberry	1 -4	1.5-3.5		3 -5	4	5-8	6.5	6-12	9	10-12	11	9-20	14	..	..	4.2
Russian-olive	1 -2	2 -3		2 -5	3.5	-	8	-	13	-	15.5	-	19	..	..	..
White ash	1 -2	1.5-2.5		2 -3.5	2.5	-	7.5	-	..	-	..	-	12	..	..	..
White elm	1.5-2	1.5-4.5		2 -7	4.5	7-12	7.5	6-15	12	-	16	2-33	13	3.1	3.7	6.8
BROADLEAF SPECIES PLANTED IN 1912 (Experiments 2 and 3)																
	When planted	2nd yr.		4th yr.		5th yr.		7th yr.		13th yr.		31st yr.				
Catalpa	-	-	1.5	4 -7	5	-	5	1.5-7	..	0	0	0	0			
Black walnut	-	.5-1	1	-	..	-	..	2 -6	..	5-10	..	-	8			
BROADLEAF SPECIES PLANTED IN 1935 (Experiment 6)																
	When planted	8th yr.		11th yr.										8th yr.		11th yr.
Chokecherry	-	4-8	6	4-11	7											
Siberian elm	-	10-21	16	11-27	19									2.0	..	3.1
Siberian pea-tree	-	4-8	6	4-10	6.5											
BROADLEAF SPECIES PLANTED IN 1936 (Experiment 6)																
	When planted	7th yr.		10th yr.												
Black walnut	.5-	3-8	5	4-10.5	8											
Bur oak	.5-	2-4	3	6-12	8.5											

TABLE 2.—*Survival and Growth of Conifers.*[1]

A—SURVIVAL OF CONIFERS

Species	Location	No. planted	No. replanted	Survival													
				No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
CONIFERS PLANTED IN 1910 (Experiment 4)																	
Years after planting				1st yr.		2nd yr.		5th yr.		8th yr.		18th yr.		33rd yr.		36th yr.	
European larch	Plot 1	96	0	3	3	1	1	0	0	0	0	0	0	0	0	0	0
Scotch pine [2]	Plot 2	96	0[2]	5	5	4	4	2	2	2	2	1	1	0	0	0	0
Austrian pine	Plot 3	96	50	39	41	25	26	23	24[3]	23	24[3]	59	40[4]	32	40[5]	32	40[5]
Jack pine	Plot 4	96	0	62	64	60	62	54	56	54	56	4	4	0	0	0	0
Ponderosa pine	Plot 5	96	40	29	30	5	5	46	34[4]	46	34[4]	53	39[4]	33	39[5]	33	39[5]
Douglas-fir [6]	Plot 6	96	0	4	4	2	2	1	1	0	0	0	0	0	0	0	0
Black Hills spruce	Plot 7	96	0	61	63	48	50	31	32	26	27	0	0	0	0	0	0
CONIFERS PLANTED IN 1912 (Experiment 5)																	
Years after planting				1st yr.		2nd yr.		4th yr.		6th yr.		17th yr.		31st yr.		34th yr.	
Ponderosa pine	Rows 1-5	905	175[7]	802	88[3]	830	77[4]	785	72	782	72	776	71	401	70[5]	392	70[5]
Austrian pine	Rows 6-7	426	73[7]	403	94[3]	374	75[4]	310	62	308	62	277	55	139	55[5]	130	54[5]
Jack pine	Row 8	181	78[7]	147	74[3]	127	49[4]	90	35	81	31	4	2	0	0	0	0
Eastern redcedar	Row 9	199	0	92	46	6	3	6	3	4	2	..	..	3	2	3	2
CONIFERS PLANTED IN 1935 (Experiment 6)																	
Years after planting				1st yr.		2nd yr.		8th yr.		11th yr.							
Ponderosa pine	Block A	872	170	760	87	814	83	840	80[4]	840	80						
Limber pine	Block C	210	161[8]	139	66	120	43	80	21[4]	80	21						
Rocky Mt. juniper	Block F	238	0	175	73	172	72	168	71	168	71						
CONIFERS PLANTED IN 1936 (Experiment 6)																	
Years after planting				1st yr.		7th yr.		10th yr.									
Lodgepole pine	Block D	28	0	28	100	24	86	24	86								
Pinyon pine	Block E	28	2	26	93	27	90	27	90[4]								
Eastern redcedar	Block I	91	25	66	73	85	73	85	73[4]								

[1] Replanting of dead seedlings of some species took place in the first or second spring following original planting.
[2] Replanted with ponderosa pine as 27 trees of this species were in this plot in 1945, averaging 22 feet in height and 8.8 inches in diameter.
[3] Based on number of trees originally planted.
[4] Based on number of trees originally planted plus replants.
[5] Based on total number planted, less those removed by thinning in 1928.
[6] This plot planted in spring of 1913.
[7] Replanted in 1913, but nearly all replants died before fall of 1913.
[8] Replanted in each of the first 4 years following establishment.

B—GROWTH OF CONIFERS

Species	Height growth in feet										Diam. in inches 4½ feet above ground			
	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Ave.	Ave.	Ave.	Ave.
CONIFERS PLANTED IN 1910 (Experiment 4)														
	3rd yr.		5th yr.		9th yr.		15th yr.		33rd yr.		36th yr.	15th yr.	33rd yr.	36th yr.
European larch		1	0	0	0	0	0	0	0	0	0	0	0	0
Scotch pine [2]		2.5	4.5- 6.5	5.5	2.5- 5.5	4	..	..	0	0	0	0	0	0
Austrian pine		1	2 - 5	3.5	4 -12.5	8.5	..	12	..	19.5	20	3.2	7.6	8.0
Jack pine		2	2 - 7	5	6 -12.5	9	..	15	0	0	0	3.4	0	0
Ponderosa pine		1	1 - 3	2.5	2.5- 8	5.5	..	11	..	17.5	18	2.7	6.9	7.3
Douglas-fir [6]		.5	2	2	0	0	0	0	0	0	0	0	0	0
Black Hills spruce		1	.5- 1.5	1	1 - 4	3	0	0	0	0	0	0	0	0
CONIFERS PLANTED IN 1912 (Experiment 5)														
	2nd yr.		3rd yr.		5th yr.		13th yr.		31st yr.		34th yr.	13th yr.	31st yr.	34th yr.
Ponderosa pine		.5	.5- 2	1.5	2.5- 5.5	4	..	11	7-26	19	20	2.5	6.8	6.9
Austrian pine		.5	.5- 1	1	2 - 3	2.5	..	9.5	6-26	18	19	2.1	6.3	6.6
Jack pine		.5	.5- 2	1.5	2.5- 5.5	4	..	..	0	0	0	..	0	0
Eastern redcedar		.5	..	..	..	..	..	..	17-18	17.5	18	..	4.3	4.3
CONIFERS PLANTED IN 1935 (Experiment 6)														
	8th yr.		11th yr.											
Ponderosa pine	2 -8	5	3 -13	8.5										
Limber pine	.5-3	2	1.5- 6.5	3.5										
Rocky Mt. juniper	4 -7	5	6 -11	8										
CONIFERS PLANTED IN 1936 (Experiment 6)														
	7th yr.		10th yr.											
Lodgepole pine	1 -5	3.5	2 - 9	6.5										
Pinyon pine	.5-3	2	1 - 5.5	3.5										
Eastern redcedar	2 -8	4	4 -12	7.5										

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