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CULTURAL PRACTICES FOR GROWING SHELTERBELT TREES ON THE NORTHERN GREAT
GEORGE, E.J. 1 OF 1

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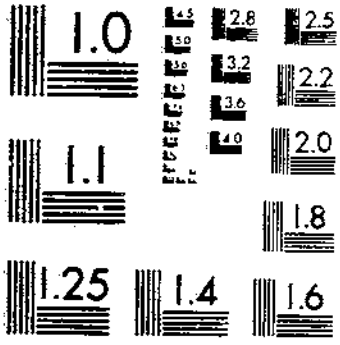

MICROCOPY RESOLUTION TEST CHART
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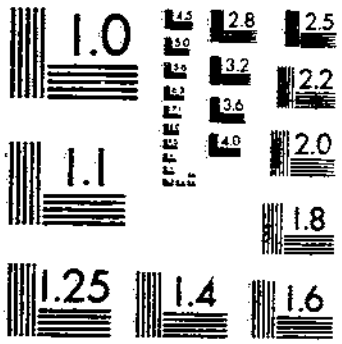

MICROCOPY RESOLUTION TEST CHART
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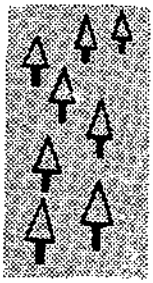
Cultural Practices for GROWING SHELTERBELT TREES on the Northern Great Plains[1]



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INTRODUCTION

Growing trees that will give protection to farm buildings, livestock, and feed lots against cold winter winds and drifting snow, and also against hot, drying winds that damage field, orchard, and garden crops is accepted as a necessity by many of the farmers and ranchers of the northern Great Plains. Tree growing in that area is frequently difficult owing to the low average rainfall, periodic severe droughts, extremes of temperature in both winter and summer, the high rate of evaporation during the growing season, and the fairly constant, strong, drying winds. Success depends on the planter's knowledge of suitable species and methods.

Since 1914 the United States Northern Great Plains Field Station at Mandan, N. Dak., has conducted investigations on the growing of trees and other farm crops. In 1918 tests were started with windbreak trees and shrubs to obtain information on spacing distances, various types of pruning, and methods of cultivation. This publication summarizes what was learned from these investigations.

The tests at Mandan were duplicated at the United States Dry Land Field Station, Ardmore, S. Dak., and at the Judith Basin Branch Station, Moccasin, Mont. Mathews and Clark (*6*) reported, in part, the results obtained during the first 15 years at the Ardmore station, and Jensen and Harrington (*5*) reported the results of the first 11 years at the Moccasin station.

CLIMATIC DATA

The monthly, growing-season (April–September), and annual precipitation at the Mandan station for the years 1918–53 are given in table 1. Precipitation during the growing season ranged from 2.96 to 16.86 inches, with a mean of 12.08 inches for the 36-year period. This mean is about 77 percent of the average annual precipitation of

[1] Submitted for publication July 6, 1955.

[2] U. S. Northern Great Plains Field Station, Mandan, N. Dak.

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15.77 inches, which ranged from 6.43 inches to 21.76 inches during the 36-year period. The years 1934, 1936, and, to a less extent, 1952 were severe drought years. Precipitation in 1952, while exceeding that of 1934 and 1936, was the third lowest annual, and fourth lowest seasonal precipitation for the years 1914–1953, the time during which records have been kept at the Mandan station.

The mean monthly, and the maximum and minimum daily temperatures; the mean, high, and low monthly evaporation from a free water surface during the growing season; and the mean monthly wind velocity for the years 1918–1953 at the Mandan station are given in table 2. Yearly temperatures show a range of 161° from −46° F. to 115° F. The average evaporation during the growing season was nearly three times the average precipitation that fell during the same period.

TABLE 1. *Monthly, growing-season, and annual precipitation at the Northern Great Plains Field Station, Mandan, N. Dak., 1918–53*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Apr.–Sept.[1]	Annual
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1918	0.20	0.11	0.45	2.61	2.45	0.68	2.17	2.63	0.63	0.27	0.45	1.02	10.87	13.37
1919	.08	.80	.83	1.72	3.05	1.12	.85	1.22	.49	.98	1.19	.25	9.35	13.48
1920	.52	.20	1.25	.58	1.72	1.85	2.68	1.81	1.29	.25	.37	.21	9.93	12.60
1921	.18	.09	.79	2.50	3.05	.82	3.38	.25	1.58	1.39	.87	.24	11.67	15.23
1922	.28	1.55	.52	.66	2.05	3.43	3.17	.32	2.31	.64	1.60	.82	11.94	17.35
1923	.36	.38	.16	1.85	1.18	1.91	4.12	1.15	2.31	.54	.28	.14	12.55	14.41
1924	.03	.25	.28	1.68	.41	5.56	2.07	2.35	1.31	1.04	.06	.28	13.41	16.25
1925	.28	.03	.44	.04	1.18	7.31	.33	1.31	.10	.69	.15	.38	12.00	14.08
1926	.71	.22	.04	.13	2.41	1.20	2.10	1.31	2.38	.18	.30	.44	9.62	11.51
1927	.18	.14	1.17	1.37	6.65	2.00	2.37	3.16	.49	.44	1.56	.77	16.04	20.30
1928	.20	.07	.23	.09	.57	6.32	4.94	2.24	.89	.19	.06	.17	15.93	16.85
1929	.80	.31	1.47	1.75	2.68	.99	1.20	.81	1.56	1.81	.14	.70	8.99	14.22
1930	.10	1.68	(2)	1.71	2.23	1.59	2.40	2.09	2.56	1.85	1.13	.13	12.40	17.38
1931	.05	.44	1.02	.43	2.14	1.65	5.32	1.01	3.11	1.46	.47	.74	12.65	17.41
1932	.44	.19	1.09	1.99	3.48	3.33	1.90	.70	.24	2.12	.10	.18	11.64	15.76
1933	1.23	.34	1.02	.86	1.83	2.18	1.80	.41	.27	.55	.09	.52	7.35	11.01
1934	.06	.05	.58	.03	.17	3.78	1.10	.25	.47	.73	.17	.14	6.40	8.13
1935	.13	.36	1.13	3.09	2.63	2.85	4.71	1.34	.22	(2)	.06	.88	14.84	18.30
1936	.61	.72	1.12	.48	.01	.43	0	.55	1.46	.17	.61	.24	2.06	6.43
1937	.86	.49	.48	1.38	1.29	5.65	1.83	1.34	1.37	.43	.34	.63	12.86	16.09
1938	.54	1.06	.64	.97	2.42	3.11	2.90	.72	1.25	.21	1.04	.18	11.37	15.04
1939	.07	.62	.44	.74	1.93	4.65	1.69	2.10	.17	.54	(2)	.31	11.37	13.95
1940	.03	.45	.03	4.24	1.20	1.95	2.73	.25	1.28	1.09	.08	.41	11.65	16.14
1941	.31	.22	1.09	1.37	1.95	5.72	1.10	2.36	4.16	.09	.27	.16	16.86	19.72
1942	(2)	.47	.79	3.15	2.30	2.44	3.10	1.30	2.33	.69	.04	.46	14.62	17.07
1943	1.17	.55	1.67	.87	1.95	7.67	1.56	3.20	.16	1.56	.69	.19	15.41	21.15
1944	.26	.49	.27	1.22	3.13	5.54	.67	3.19	1.17	.07	3.64	.01	14.02	19.46
1945	.60	.25	1.01	1.02	1.54	1.78	1.04	3.48	1.85	.04	.53	.01	11.61	14.65
1946	.04	.63	1.36	1.28	1.81	3.14	1.25	1.28	2.36	2.56	.24	.82	11.12	16.77
1947	.52	.15	.32	1.90	.73	7.72	3.21	1.17	1.77	2.15	1.08	.39	16.50	21.11
1948	.47	.95	.41	3.21	.80	2.32	2.28	1.08	.01	1.34	.53	.31	9.79	13.71
1949	.75	.41	.33	2.54	1.03	1.62	6.53	1.22	.69	2.04	.14	.18	12.44	16.29
1950	.75	.46	2.82	2.03	3.13	2.67	1.42	2.35	1.65	.58	.36	1.14	13.25	19.30
1951	.87	1.25	.14	.51	1.72	3.28	4.12	6.16	.86	.50	.13	.77	16.65	20.31
1952	.80	1.11	.39	(2)	.40	4.38	1.84	.66	.18	.09	.17	.13	7.46	10.25
1953	.47	.34	2.01	2.38	3.21	6.58	1.08	2.05	.36	1.69	.89	.30	16.56	21.76
Average	.44	.49	.81	1.53	2.00	3.31	2.31	1.64	1.28	.92	.60	.40	12.08	15.77

[1] Growing season.
[2] Trace.

The average frost-free period for the years 1918–53 was 138 days. The longest period was 172 days, and the shortest, 115 days. Dates of the last killing frost in the spring ranged from April 19 to May 29. Dates of the first killing frost in the fall ranged from September 9 to October 8.

TABLE 2.—*Mean monthly, and maximum and minimum daily temperatures; mean, high, and low monthly evaporation from a free water surface during the growing season; and mean monthly wind velocity at the Northern Great Plains Field Station, Mandan, N. Dak., 1918–53*

TEMPERATURE

[Degrees Fahrenheit]

Classification	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual or seasonal
Mean	9	13	26	43	55	64	71	69	58	45	28	15	41
Maximum	57	65	81	91	102	108	115	109	104	91	71	66	115
Minimum	−37	−36	−26	0	17	32	38	32	16	−14	−19	−36	−46

EVAPORATION

[Inches]

Mean				3.6	5.3	6.0	7.3	6.5	4.4				33.0
High				4.9	8.4	9.2	12.6	8.5	5.8				49.4
Low				2.0	3.1	4.1	5.4	5.1	3.1				22.8

WIND VELOCITY

[Miles per hour]

Mean	5.4	5.7	6.4	7.1	6.7	5.5	4.5	4.6	5.0	5.3	5.5	5.1	5.6

METHODS OF TESTING

A series of 12 identically arranged, 10-row blocks of trees and shrubs were planted in 1918 (fig. 1). Seedling or rooted nursery stock 1 or 2 years of age, grown in the station nursery, was planted on land that had been summer-fallowed the previous year. The arrangement of species in each block, from east to west, was as follows:

Row 1—Silver buffaloberry (*Shepherdia argentea* Nutt.)
Row 2—Brittle willow (*Salix fragilis L.*)
Row 3—Boxelder (*Acer negundo L.*)
Row 4—Green ash (*Fraxinus pennsylvanica* var. *lanceolata* (Borkh.) Sarg.)
Row 5—Boxelder
Row 6—Northwest poplar (*Populus* sp.)
Row 7—Green ash
Row 8—Boxelder
Row 9—Daphne willow (*Salix daphnoides* Vill.)
Row 10—Amur maple (*Acer ginnala* Maxim)

The tests were designed to compare growth and survival of trees and shrubs (1) that were grown under identical conditions except for spacing distance; (2) that were unpruned, moderately pruned, and severely pruned; and (3) that were grown under a system of clean cultivation, hay or straw mulch in lieu of cultivation, and neglect, where no attempt was made to control weed growth.

Data on height, survival, and winter injury were taken in the fall of each year. Crown-spread data were taken periodically for all species. Diameter-at-breast-height data were taken periodically for

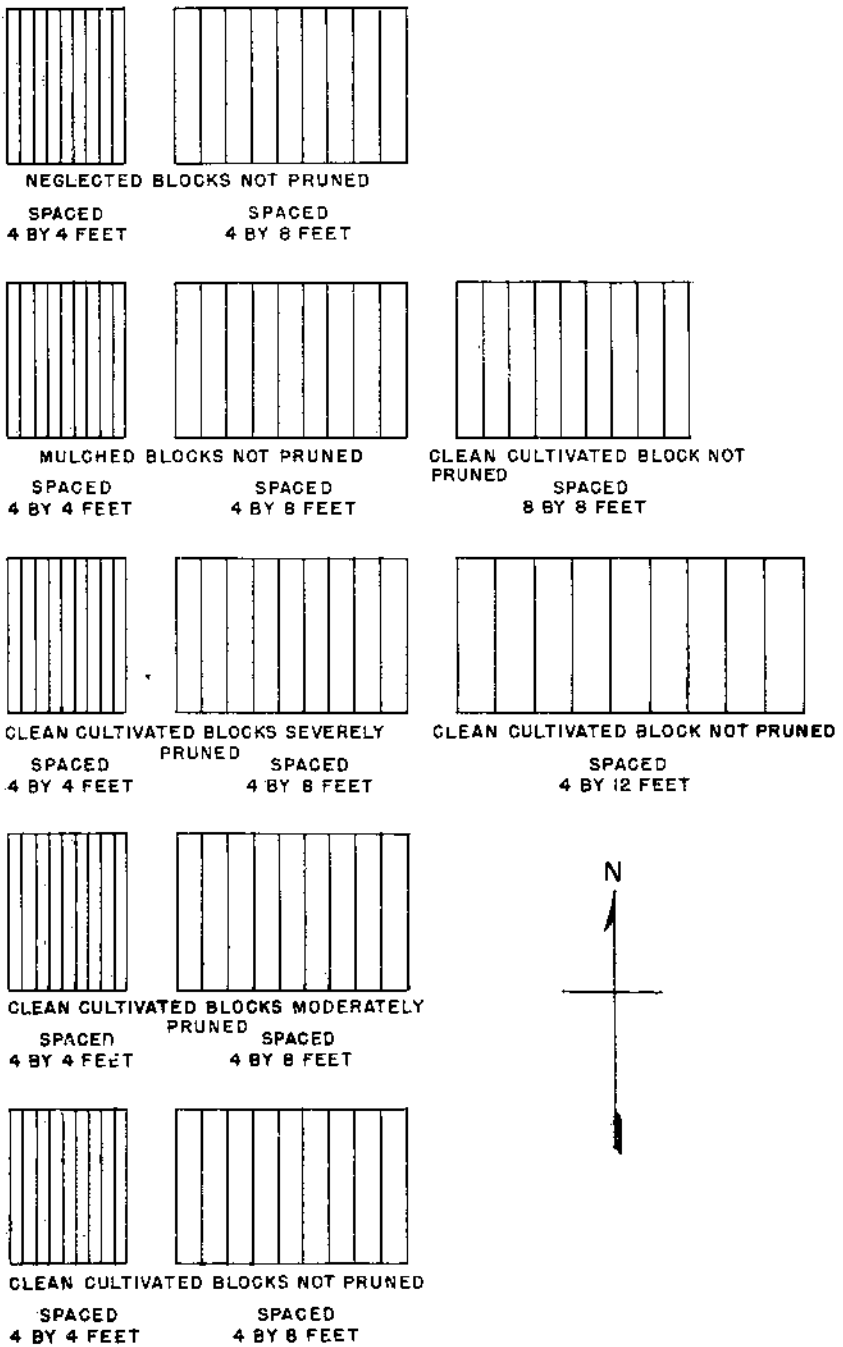

FIGURE 1. Plan of the pruning, spacing, and cultivation experiments with deciduous shelterbelt trees and shrubs at the Northern Great Plains Field Station, Mandan, N. Dak.

green ash only. Certain other data dealing with crown position and form have been taken annually since 1943.

Average height and survival data are presented for trees and shrubs 4, 10, 16, 20, 25, 30, and 36 years of age; average diameter-at-breast-height data for green ash only at 15, 25, and 36 years of age; data on crown position and growth form at 36 years of age; and crown spread data for trees and shrubs in the spacing and pruning studies at 36 years of age.

The fourth year was selected as the starting point for comparative measurement data because it represented the last year in which losses in stand were replaced. The percentages of survival at 10 and later years are based on the stand which became established the fourth year, which in some cases numbered fewer trees than were actually planted. The sixteenth year was selected because it provided data for the year 1933, which immediately preceded the severe drought in 1934, and a more severe one in 1936. The twentieth-year data are for the year 1937, which was the first approximately normal-rainfall year after the two severe drought years. The data for trees and shrubs at 36 years of age were collected in the fall of 1953.

TOPOGRAPHY AND SOIL TYPE

The experimental blocks were located on land that had a very gentle slope to the north. Clean-cultivated blocks that were unpruned and moderately pruned had more runoff than the other blocks. The soil type was classed as Cheyenne fine sandy loam. Fine gravel encountered in the fourth to fifth foot graded into fine sand in the seventh to beyond the tenth foot. Water penetrated the soil readily, but the holding capacity was low from the fourth through at least the tenth foot. A high percentage of the water held was available to the trees and shrubs.

EXPERIMENTAL DATA

Spacing Distances

The spacing study consisted of 4 blocks of trees and shrubs, one of which was spaced 4 by 4, one 4 by 8, one 4 by 12, and one 8 by 8 feet.[3] Clean cultivation and hand hoeing to control weed growth were practiced when necessary in all blocks. No pruning was done except to remove dead or injured trees and branches.

HEIGHT AND SURVIVAL

The average height of all species at 4, 10, 16, 25, 30, and 36 years of age, and the average diameter at breast height of green ash at 15, 25, and 36 years of age are shown in table 3. The percentages of survival of the stands that became established the fourth season, at ages similar to those of the height data, are shown in table 4, and the percentages of the trees and shrubs which fell in various crown positions and densities, and had various growth forms, are shown in table 5.

[3] The first figure gives the distance between trees in the row, and the second figure the distance between rows.

TABLE 3.—*Effect of spacing distance on growth of deciduous trees and shrubs set out in 1918 in 10-row mixed plantings*

Species and row No.	Spacing distance	Height at age (years)—							Diameter breast high at age (years)—		
		4	10	16	20	25	30	36	15	25	36
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Inches*	*Inches*	*Inches*
Silver buffaloberry, 1	4 by 4	3.5	6.2	8.3	8.7	9.3	7.8	7.8	.....	.....	.....
	4 by 8	3.0	5.4	6.6	7.2	8.6	10.5	5.4	.....	.....	.....
	4 by 12	4.0	9.2	10.3	7.2	10.1	12.0	9.2	.....	.....	.....
	8 by 8	4.5	7.2	7.1	5.4	7.7	8.4	9.6	.....	.....	.....
Brittle willow, 2	4 by 4	6.0	13.9	20.6	0	0	0	0	.....	.....	.....
	4 by 8	7.5	19.3	21.7	14.2	16.1	20.2	25.9	.....	.....	.....
	4 by 12	7.0	19.6	22.2	0	0	0	0	.....	.....	.....
	8 by 8	7.5	18.8	25.1	16.2	22.2	27.6	29.2	.....	.....	.....
Boxelder, 3	4 by 4	8.0	14.9	17.9	12.8	17.7	20.9	20.2	.....	.....	.....
	4 by 8	7.5	16.9	19.7	12.1	18.9	22.4	23.4	.....	.....	.....
	4 by 12	9.0	16.1	18.9	10.9	17.6	23.1	25.8	.....	.....	.....
	8 by 8	7.5	15.8	20.7	8.2	15.9	19.9	23.0	.....	.....	.....
Green ash, 4	4 by 4	4.0	11.3	12.9	12.0	14.4	16.0	16.8	1.1	2.0	3.3
	4 by 8	3.5	12.6	14.7	15.6	17.7	20.5	21.2	1.5	2.8	3.5
	4 by 12	4.0	11.8	17.1	17.4	19.2	22.7	24.3	2.0	3.3	4.3
	8 by 8	4.5	12.3	17.2	17.1	18.5	23.2	25.7	2.0	3.6	4.7
Boxelder, 5	4 by 4	7.0	14.7	15.4	8.1	12.9	15.0	14.3	.....	.....	.....
	4 by 8	8.0	16.2	16.0	9.8	13.9	18.5	17.5	.....	.....	.....
	4 by 12	9.0	15.5	17.5	8.0	13.5	17.9	20.6	.....	.....	.....
	8 by 8	7.5	15.0	18.0	7.0	13.9	19.5	22.6	.....	.....	.....
Northwest poplar, 6	4 by 4	9.0	18.3	19.7	21.4	0	0	0	.....	.....	.....
	4 by 8	10.5	17.4	27.1	0	0	0	0	.....	.....	.....
	4 by 12	10.5	19.7	20.5	0	0	0	0	.....	.....	.....
	8 by 8	10.0	18.3	22.2	0	0	0	0	.....	.....	.....
Green ash, 7	4 by 4	4.0	10.6	11.9	11.7	12.8	13.5	7.3	1.0	1.7	3.0
	4 by 8	5.0	11.7	15.9	16.2	16.8	18.8	17.9	1.7	3.3	4.3
	4 by 12	4.5	12.1	17.4	18.0	18.7	21.3	20.8	2.2	3.6	4.3
	8 by 8	4.5	12.6	18.0	17.7	19.2	23.4	24.8	2.0	3.8	5.0
Boxelder, 8	4 by 4	7.0	15.0	18.1	15.6	17.8	18.6	16.4	.....	.....	.....
	4 by 8	6.5	15.1	19.4	15.0	16.5	21.6	22.0	.....	.....	.....
	4 by 12	8.6	16.2	17.4	11.3	17.1	19.6	18.8	.....	.....	.....
	8 by 8	7.5	14.7	19.2	12.9	16.8	20.8	22.3	.....	.....	.....
Daphne willow, 9	4 by 4	6.5	16.2	17.9	0	0	0	0	.....	.....	.....
	4 by 8	6.5	11.2	0	0	0	0	0	.....	.....	.....
	4 by 12	4.5	13.3	0	0	0	0	0	.....	.....	.....
	8 by 8	2.5	0	0	0	0	0	0	.....	.....	.....
Amur maple, 10	4 by 4	4.0	6.4	8.8	5.1	4.3	8.3	5.2	.....	.....	.....
	4 by 8	4.0	9.7	13.1	5.8	12.5	15.0	15.5	.....	.....	.....
	4 by 12	5.0	10.7	13.6	6.6	13.0	16.7	15.1	.....	.....	.....
	8 by 8	5.0	9.4	12.9	4.1	10.6	13.4	11.1	.....	.....	.....

Silver Buffaloberry

Growth and survival of silver buffaloberry were affected more by the wind breaking or uprooting the shrubs than by the factor of spacing distance. The wind-breakage resulted from the brittleness of the wood and from heart rot caused by *Fomes fraxinophilus* (Pk.) Sacc. forma *ellisianus* (F. W. Anders.) Baxter. It was severe during the last several years, and was responsible in all spacings, except that of 8 by 8 feet, for the reduction in average height at 36 years of age. The majority of these shrubs in all spacings, except that of 4 by 12 feet, were either overtopped or pushed outward by the brittle willow in row 2 or the boxelder in row 3 (table 5 and fig. 2). A certain amount of suppression within the row took place in the block spaced 4 by 12 feet. This spacing, however, resulted in much higher survivals and considerably greater growth throughout the period, except for the last 6 years when wind breakage of tops lowered the average height to slightly less than that of shrubs spaced 8 by 8 feet. Silver buffaloberry definitely should not be planted closer than 12 feet to faster growing species with spreading growth habits, such as brittle willow

TABLE 4.—*Effect of spacing distance on survival of deciduous trees and shrubs set out in 1918 in 10-row mixed plantings*

Species and row No.	Spacing distance	Survival at age (years)—						
		4 [1]	10	16	20	25	30	36
	Feet	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Silver buffaloberry, 1	4 by 4	73	90	84	68	68	68	32
	4 by 8	77	100	95	65	50	50	25
	4 by 12	96	100	100	88	84	84	80
	8 by 8	86	100	83	33	33	33	25
Brittle willow, 2	4 by 4	101	73	19	0	0	0	0
	4 by 8	100	92	88	50	42	35	27
	4 by 12	92	87	71	0	0	0	0
	8 by 8	100	100	86	64	57	57	57
Boxelder, 3	4 by 4	96	100	100	96	96	96	96
	4 by 8	100	96	96	96	96	96	96
	4 by 12	100	100	100	100	100	92	92
	8 by 8	100	100	100	100	100	100	100
Green ash, 4	4 by 4	92	100	100	100	98	88	71
	4 by 8	100	100	96	88	88	88	85
	4 by 12	96	100	100	100	100	100	100
	8 by 8	93	100	100	100	100	100	100
Boxelder, 5	4 by 4	100	96	89	54	50	50	50
	4 by 8	100	100	100	69	65	62	62
	4 by 12	100	100	100	92	85	81	81
	8 by 8	100	100	100	64	64	64	64
Northwest poplar, 6	4 by 4	96	60	24	12	0	0	0
	4 by 8	100	31	8	0	0	0	0
	4 by 12	100	58	12	0	0	0	0
	8 by 8	93	71	31	0	0	0	0
Green ash, 7	4 by 4	92	100	96	96	92	88	46
	4 by 8	100	100	100	100	100	96	92
	4 by 12	96	100	100	100	100	100	100
	8 by 8	93	100	92	92	92	92	92
Boxelder, 8	4 by 4	100	100	100	100	100	100	92
	4 by 8	100	100	92	81	81	81	77
	4 by 12	100	100	100	96	92	85	85
	8 by 8	100	100	100	100	100	93	93
Daphne willow, 9	4 by 4	61	56	56	0	0	0	0
	4 by 8	65	5	0	0	0	0	0
	4 by 12	96	8	0	0	0	0	0
	8 by 8	100	0	0	0	0	0	0
Amur maple, 10	4 by 4	92	100	87	21	21	8	8
	4 by 8	100	100	96	16	8	8	8
	4 by 12	69	100	100	83	67	67	67
	8 by 8	93	100	100	46	31	31	31

[1] No losses were replaced after the fourth year. Survival at 10 years and later are based on the stand which became established the fourth year.

and boxelder. The shrubs in the block spaced 4 by 12 feet were 24 feet away from the next row of trees for the last 18 years owing to the complete loss of brittle willow in row 2.

Brittle Willow

Brittle willow had suffered a very heavy loss in the block of trees spaced 4 by 4 feet, and a more moderate loss in the block spaced 4 by 12 feet, by the sixteenth year. All brittle willow trees spaced 4 by 4 feet were dead following the drought of 1934, and those spaced 4 by 12 feet following the drought of 1936. Heavy losses had taken place in the other two spacings at 20 years of age. Most of those losses followed the drought of 1936. Lack of hardiness to drought conditions prevented the species from yielding reliable information on spacing distances. The available data indicate that the distance of 8 by 8 feet gave greater height and survival, and more vigorous trees than the other spacings.

TABLE 5.—*Effect of spacing distance on classification in 1953 of deciduous trees and shrubs set out in 1918 in 10-row mixed plantings*

Species and row No.	Spacing distance	Crown position			Crown density			Form	
		Above general canopy	In general class	Suppressed	Well-developed	Medium	Poor	Straight, upright growth	Pushed outward or leaning
	Feet	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Silver buffaloberry, 1	4 by 4	0	0	100	0	100	0	0	100
	4 by 8	0	60	40	100	0	0	60	40
	4 by 12	0	70	30	60	30	10	75	25
	8 by 8	0	33	67	100	0	0	0	100
Brittle willow, 2	4 by 4								
	4 by 8	0	67	33	67	17	16	50	50
	4 by 12								
	8 by 8	0	100	0	75	25	0	63	37
Boxelder, 3	4 by 4	0	75	25	68	24	8	54	46
	4 by 8	0	56	44	48	40	12	56	44
	4 by 12	0	91	9	79	17	4	46	54
	8 by 8	0	86	14	57	36	7	79	21
Green ash, 4	4 by 4	0	59	41	47	23	30	65	35
	4 by 8	0	59	41	55	36	9	68	32
	4 by 12	0	80	20	60	36	4	72	28
	8 by 8	0	100	0	92	8	0	92	8
Boxelder, 5	4 by 4	0	31	69	23	77	0	46	54
	4 by 8	0	62	28	44	37	19	62	28
	4 by 12	0	90	10	62	38	0	81	19
	8 by 8	0	100	0	78	22	0	89	11
Northwest poplar, 6	4 by 4								
	4 by 8								
	4 by 12								
	8 by 8								
Green ash, 7	4 by 4	0	16	52	9	18	73	82	18
	4 by 8	0	54	46	50	21	29	75	25
	4 by 12	0	76	24	60	28	12	80	20
	8 by 8	0	75	25	75	25	0	83	17
Boxelder, 8	4 by 4	0	54	46	42	37	21	75	25
	4 by 8	0	80	20	75	10	15	75	25
	4 by 12	0	68	32	55	27	18	59	41
	8 by 8	0	77	23	69	31	0	69	31
Daphne willow, 9	4 by 4								
	4 by 8								
	4 by 12								
	8 by 8								
Amur maple, 10	4 by 4	0	50	50	0	50	50	100	0
	4 by 8	0	100	0	100	0	0	100	0
	4 by 12	0	83	17	75	25	0	75	25
	8 by 8	0	100	0	100	0	0	100	0

Boxelder

Boxelder was planted in rows 3, 5, and 8. The species was killed back severely in all rows during the drought years 1934 and 1936. Injury was much more severe in plantings spaced 4 by 12 and 8 by 8 feet than in those spaced 4 by 4 and 4 by 8 feet. Recovery in height growth to equal or exceed that at 16 years—the year prior to the first drought—was not accomplished until the trees were 30 years of age. Further killing back took place in the 4- by 4- and 4- by 8-foot plantings when the trees were between 30 and 36 years of age. Average heights at 36 years were 22.6, 21.7, 21.0, and 17.0 feet in the spacing distances 8 by 8, 4 by 12, 4 by 8, and 4 by 4 feet, respectively.

Boxelder survivals remained high throughout the period in all spacings except in row 5. This row suffered a heavy loss in all blocks, except the one spaced 4 by 12 feet, during the severe droughts of 1934 and 1936. No reason can be advanced for the heaviest loss taking place in that row. Green ash, having very similar survivals, was the adjacent species on one side of all boxelder rows. The adjacent species on the other side differed. Survivals of trees adjacent to rows 5 and 8 were much lower at 16 years of age than those adjacent to row 3. Survivals in all rows at 36 years of age averaged 86 percent

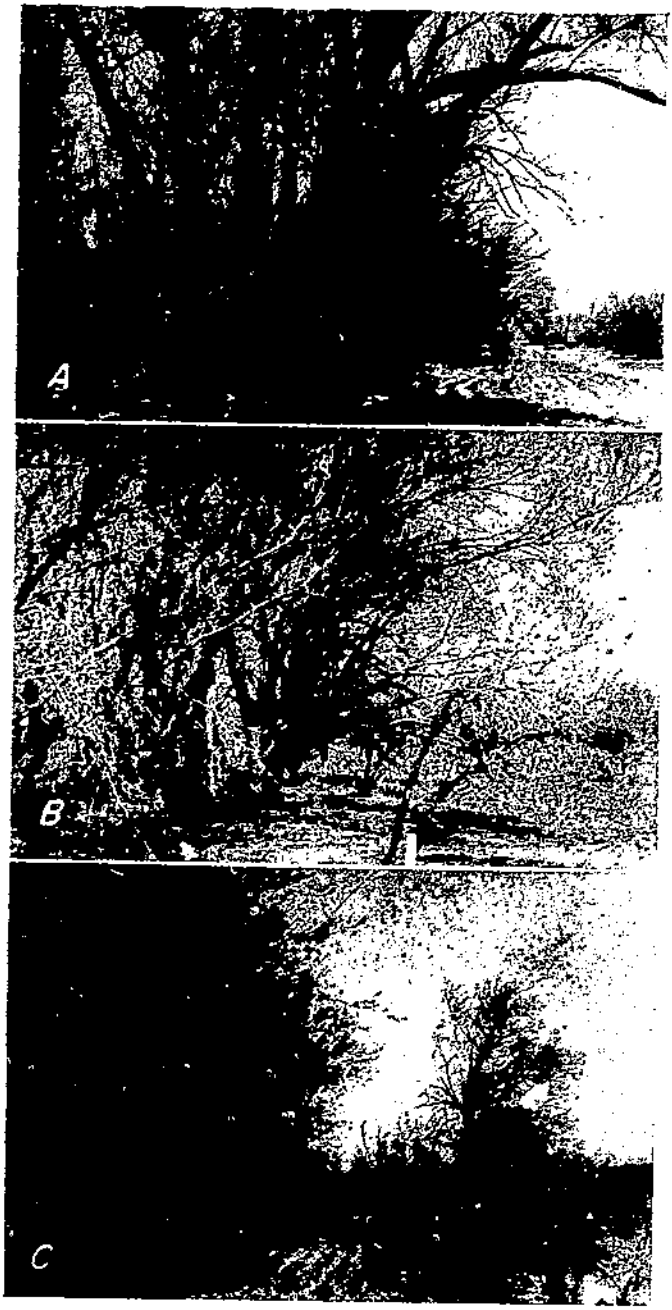

FIGURE 2.—Silver buffaloberry in row 1 (right) has either been overtopped or pushed outward in *A* and *B* by both brittle willow in row 2 and boxelder in row 3, which were 8 and 16 feet away, respectively. No overtopping or pushing outward has taken place in *C* because the brittle willow in row 2 has been dead for the past 18 years, and the boxelder in row 3 was 24 feet away.

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in the blocks spaced 4 by 12 and 8 by 8 feet, 79 percent in the block spaced 4 by 4 feet, and 78 percent in the block spaced 4 by 8 feet.

Suppression of boxelder within the row, as well as between rows, took place in all blocks having 4 feet between trees in the row. Rows spaced 4 by 12 and 8 by 8 feet had the lowest percentage of suppressed trees. Rows spaced 8 by 8 feet had the highest percentage of well-developed trees of upright growth (table 5).

Green Ash

Green ash was planted in rows 4 and 7. Survivals of trees in rows adjacent to row 4 were good. The Northwest poplar, adjacent on one side of row 7, became a complete loss at 17 years of age in all spacings except that of 4 by 4 feet, where some survival was maintained through the 24th year. Survivals were good on the other side of row 7, which consistently made a poorer showing in height growth than row 4. The average heights of trees in all rows at 36 years of age were 25.2, 22.6, 19.6, and 12.0 feet in the spacings 8 by 8, 4 by 12, 4 by 8, and 4 by 4 feet, respectively.

Winterkilling during the drought years of 1934 and 1936 was not severe. The average height at 20 years was approximately the same as that at 16 years.

Diameter growth showed a trend very similar to that of height growth, the greatest taking place in trees spaced 8 by 8 feet, and the least in trees spaced 4 by 4 feet. The average diameter growth at 36 years varied from 4.8 to 3.1 inches.

Survivals remained at a high level until the thirty-sixth year, when heavy losses took place in the rows spaced 4 by 4 feet. Survivals for all green ash were 100, 96, 89, and 58 percent for the trees spaced 4 by 12, 8 by 8, 4 by 8, and 4 by 4 feet, respectively. The percentage of suppressed trees and those having poorly developed crowns decreased as the spacing distance increased. Suppression occurred within the row in all spacing distances of 4 feet.

The data indicate that the best all-round growth of green ash will be obtained when it is spaced at least 8 by 8 feet. Trees spaced 4 by 12 feet were superior to those spaced 4 by 8 and 4 by 4 feet.

Northwest Poplar

Northwest poplar planted in row 6 suffered a complete loss at 17 years of age in all spacings except that of 4 by 4 feet, where some survival was maintained through the 23rd year. The results were due more to a lack of hardiness of the species to drought conditions than to the factor of spacing. Northwest poplar is not suitable for dryland planting.

Daphne Willow

Daphne willow planted in row 9 became a complete loss at 8 years of age in the block spaced 8 by 8 feet; at 11 years of age in the block spaced 4 by 8 feet; at 12 years of age in the block spaced 4 by 12 feet; and at 17 years of age in the block spaced 4 by 4 feet. Like Northwest poplar, Daphne willow losses were the result of a lack of hardiness to drought conditions rather than the factor of spacing. The species is not suitable for dryland planting.

Amur Maple

Amur maple was killed back severely during the drought years, the average height at 20 years in all spacings, except that of 4 by 4 feet where damage was not so severe, being less than half that at 16 years. Many of the shrubs were suppressed by boxelder in row 8 until such time that either the boxelders or the Amur maples died out. The greatest average height growth was made in the block spaced 4 by 8 feet, and the least in the block spaced 4 by 4 feet. The Daphne willow planted in the adjacent row had been dead in all spacings for many years.

Survivals of Amur maple remained high through 16 years, but dropped rapidly at 20 years as a result of the severe droughts of 1934 and 1936. Survivals were much higher at 36 years of age in the block spaced 4 by 12 feet because the shrubs were not suppressed by adjacent species, the nearest having been located 24 feet away for the previous 24 years.

Amur maple can be classed as only semihardy when planted under dryland conditions. It should not be planted on dry upland sites unless supplemental water is available. The data indicate that it should be planted at least 16 feet away from species of spreading growth habit such as boxelder.

CROWN SPREAD

The average crown spread of the various species in each of the spacing distances is shown in figure 3.

Silver buffaloberry, row 1, was overtopped by boxelder, row 3, in the block having 4 feet between rows; and by brittle willow, row 2, in the blocks having 8 feet between rows. Green ash, row 7, and Amur maple, row 10, were suppressed and pushed outward by boxelder, row 8, in the block having 4 feet between rows. Interlocking of crowns across rows took place in all blocks except the one having 12 feet between rows. That distance was the most desirable for preventing overtopping or suppression by species in adjacent rows.

The difference in growth of boxelder in row 5 and green ash in row 7, in the blocks spaced 4 by 8, 4 by 12, and 8 by 8 feet, is shown in figure 4.

CONCLUSIONS ON SPACING DISTANCES

This series of shelterbelt studies at the end of 36 years indicated that 48 square feet per tree or shrub is the minimum necessary for successful growth and survival of those species that are sufficiently drought-hardy for planting on the northern Great Plains. The data show that 64 square feet per tree or shrub will usually give better results than 48 square feet. There are indications, however, that a rectangular system of planting, having the greater distance between rows, will give better results than a square system. The rectangular system prevents a high degree of suppression of shrubs and trees by faster or taller growing species in an adjacent row.

Jensen and Harrington (*5*) drew similar conclusions from a similar spacing study at the Moccasin station. They reported, "* * * the 8 by 8 and 4 by 12 plantings are superior to the close plantings in general thrift and vigor, and this difference is becoming more marked every

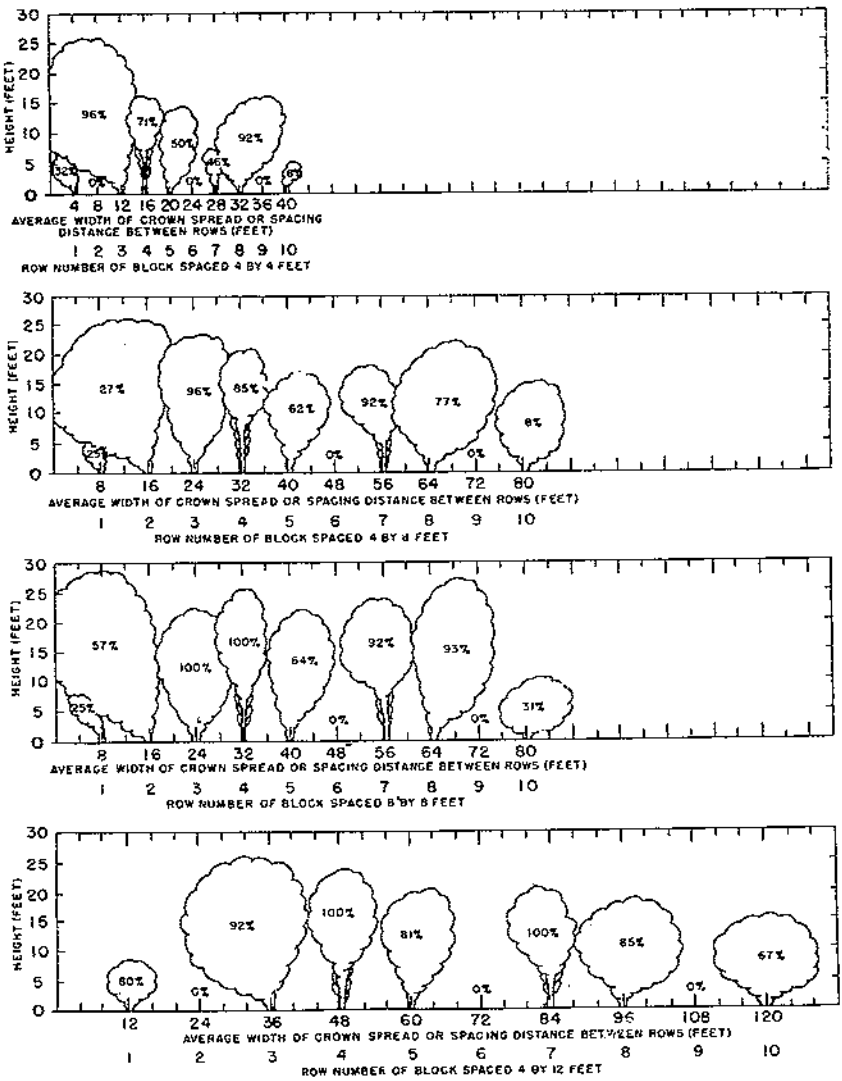

FIGURE 3.—Comparison of the average crown spread of each tree and shrub species used in the series of tests spaced 4 by 4, 4 by 8, 8 by 8, and 4 by 12 feet to study the effect of spacing distance on growth and survival. Circled figures indicate the percentage of survivals in each row. All data are for trees and shrubs 36 years of age.

year." These investigators recommended a distance of 10 or 12 feet between rows, and thought a distance of 4 to 6 feet in the row would be satisfactory.

Mathews and Clark (*6*) did not mention specifically the results of a similar spacing study at the Ardmore station. They did report, however, that spacing of other plantings had little effect on survival. The qualities inherent in the species, rather than planting distance, determined their ability to survive adverse conditions.

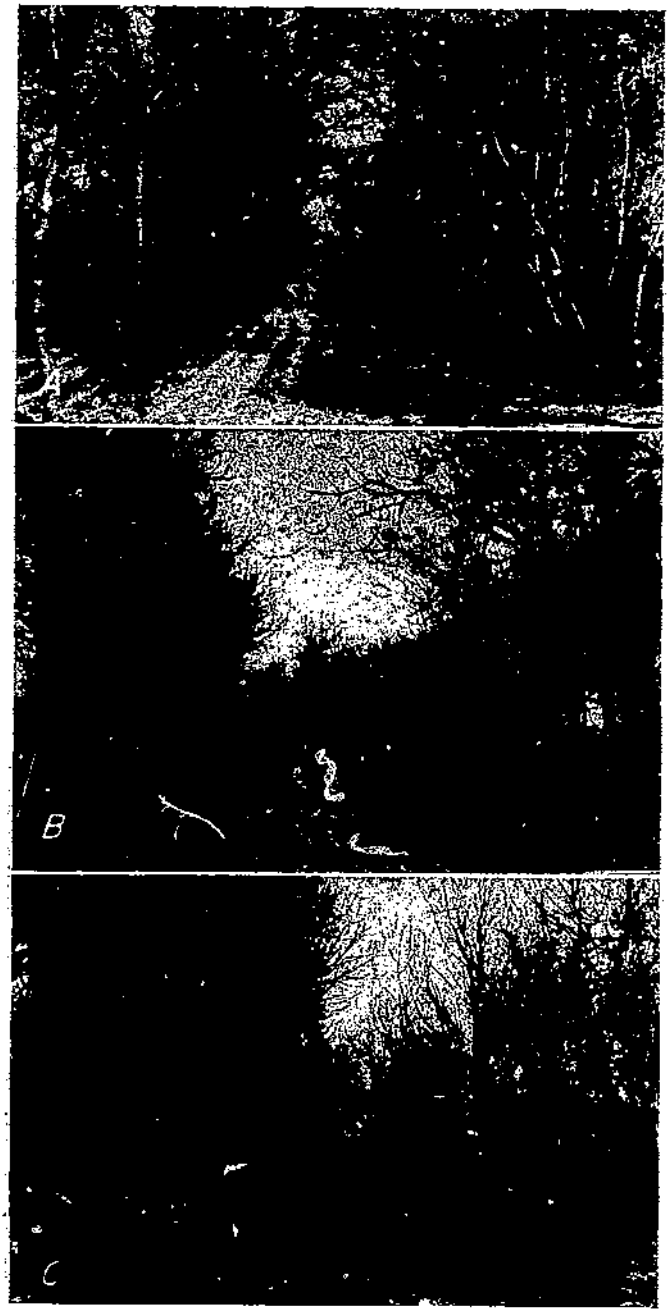

FIGURE 4.—Comparison of the growth of boxelder, row 5 (right), and green ash, row 7 (left), in the blocks spaced (*A*) 4 by 8 feet, (*B*) 4 by 12 feet, and (*C*) 8 by 8 feet. An area of 64 square feet per tree or shrub usually gave better results than a smaller one. The open area in the center was formerly occupied by Northwest poplar, row 6.

The author, in previously summarizing observations on spacing distances (George *1, 3*), reported that green ash, in a series of tests spaced 4 by 4, 4 by 8, 4 by 12, and 8 by 8 feet, made the greatest overall growth when spaced 8 by 8 feet. In a series of farm shelterbelt tests it was found that a spacing of 13 to 15 feet between rows and 6 to 8 feet between trees in the row gave very satisfactory results.

While the trees and shrubs in this series of tests were planted primarily to study the effect of spacing distance on growth and survival, they also yielded information on hardiness and suitability of species for northern Great Plains conditions. Silver buffaloberry, boxelder, and green ash were the only species found to be sufficiently hardy to warrant their use in dryland shelterbelts. The silver buffaloberry was very subject to heart rot and to breakage and uprooting by wind. Brittle and Daphne willows, Northwest poplar, and Amur maple were found unsatisfactory for dryland planting. These conclusions are very similar to those of Jensen and Harrington (*5*) who reported, "Willows and Tatarian maple have in no way indicated any value for continued use in dryland shelterbelts."

A list of tree and shrub species worthy of trial on the northern Great Plains was prepared (George *2*) on the basis of results of the 38-year program of species testing, and can be used as a guide for future plantings.

Pruning Methods

The pruning study consisted of 6 blocks of trees and shrubs, 2 each of which received one of the following treatments:

1. No pruning. The trees and shrubs were allowed to grow naturally.
2. Moderate pruning. All trees were pruned to one central stem from which all branches were removed to a height of about 2.5 to 3 feet. Silver buffaloberry and Amur maple shrubs were allowed to remain with multiple stems from which the lower side branches were removed to a height of about 2 feet.
3. Severe pruning. All trees were pruned to one central stem from which all branches were removed to a height of 5 to 6 feet. Silver buffaloberry and Amur maple were allowed to remain with multiple stems, as in moderate pruning, but side branches were removed to a height of about 3 feet.

One block of each treatment was spaced 4 by 4 feet, and the other 4 by 8 feet. Clean cultivation and hand hoeing were practiced in all blocks when it was necessary to control weed growth.

HEIGHT AND SURVIVAL

The average height of all species at 4, 10, 16, 20, 25, 30, and 36 years of age and the average diameter at breast height of green ash at 15, 25, and 36 years of age are shown in table 6. Percentages of survival of the stand that became established the fourth season, at ages similar to those for which height data are given, are shown in table 7.

TABLE 6.—*Effect of pruning method on growth of deciduous trees and shrubs set out in 1918 in 10-row mixed plantings*

Species and Row No.	Pruning treatment	Spacing distance	Height at ages—							Diameter breast high at ages—		
			4 years	10 years	16 years	20 years	25 years	30 years	36 years	15 years	25 years	36 years
		Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Inches*	*Inches*	*Inches*
Silver buffaloberry, 1	None	4 by 4	3.5	6.2	8.3	8.7	9.3	7.8	7.8	----	----	----
	Moderate	do	4.0	7.2	9.4	6.6	9.4	8.5	7.6	----	----	----
	Severe	do	4.5	7.3	9.8	5.2	7.5	10.6	9.6	----	----	----
	None	4 by 8	3.0	6.4	6.6	7.2	8.6	10.5	5.4	----	----	----
	Moderate	do	4.5	7.1	8.1	6.3	8.6	14.1	8.8	----	----	----
	Severe	do	4.5	7.8	10.0	4.6	10.0	12.2	10.8	----	----	----
Brittle willow, 2	None	4 by 4	6.0	13.9	20.6	0	0	0	0	----	----	----
	Moderate	do	6.5	15.7	8.1	0	0	0	0	----	----	----
	Severe	do	5.5	13.5	0	0	0	0	0	----	----	----
	None	4 by 8	7.5	19.3	21.7	14.2	16.1	20.2	25.9	----	----	----
	Moderate	do	8.5	21.1	23.8	13.3	20.7	25.8	27.7	----	----	----
	Severe	do	5.0	15.8	11.5	0	0	0	0	----	----	----
Boxelder, 3	None	4 by 4	8.0	14.9	17.9	12.8	17.7	20.9	20.2	----	----	----
	Moderate	do	7.5	15.7	19.8	6.4	16.1	21.3	21.1	----	----	----
	Severe	do	8.0	14.3	17.7	3.5	12.0	16.8	18.2	----	----	----
	None	4 by 8	7.5	16.9	19.7	12.1	18.9	22.4	23.4	----	----	----
	Moderate	do	8.0	16.2	18.5	8.3	16.6	21.7	23.8	----	----	----
	Severe	do	9.0	14.5	18.4	8.2	15.5	21.1	23.3	----	----	----
Green ash, 4	None	4 by 4	4.0	11.3	12.9	12.0	14.4	16.0	16.8	1.1	2.0	3.3
	Moderate	do	3.5	9.8	9.6	9.7	14.8	18.5	15.5	.7	2.2	2.0
	Severe	do	3.5	9.0	9.8	10.6	14.6	17.8	18.4	.8	2.4	3.7
	None	4 by 8	3.5	12.6	14.7	15.6	17.7	20.5	21.2	1.5	2.8	3.5
	Moderate	do	4.0	12.4	15.4	14.4	17.3	21.4	23.4	1.4	2.9	3.7
	Severe	do	4.5	10.9	15.0	14.4	16.4	20.0	21.4	1.4	2.9	4.1
Boxelder, 5	None	4 by 4	7.0	14.7	15.4	8.1	12.9	15.0	14.3	----	----	----
	Moderate	do	8.0	15.3	16.9	5.6	11.1	15.9	16.4	----	----	----
	Severe	do	8.5	14.0	16.7	3.6	10.6	13.6	15.4	----	----	----
	None	4 by 8	8.0	16.2	18.0	9.8	13.9	18.5	17.5	----	----	----
	Moderate	do	7.0	14.9	16.9	5.8	13.1	18.0	20.5	----	----	----
	Severe	do	8.5	14.3	17.1	2.8	0	0	0	----	----	----
Northwest poplar, 6	None	4 by 4	9.0	18.3	19.7	21.4	0	0	0	----	----	----
	Moderate	do	10.5	17.7	23.7	0	0	0	0	----	----	----
	Severe	do	8.5	15.1	0	0	0	0	0	----	----	----
	None	4 by 8	10.5	17.4	27.1	0	0	0	0	----	----	----
	Moderate	do	10.5	17.5	26.7	0	0	0	0	----	----	----
	Severe	do	9.0	16.4	23.1	0	0	0	0	----	----	----
Green ash, 7	None	4 by 4	4.0	10.6	11.9	11.7	12.8	13.5	7.3	1.0	1.7	3.0
	Moderate	do	4.0	10.5	13.2	12.9	16.2	18.1	15.1	1.1	2.4	3.2
	Severe	do	3.5	8.9	11.9	12.4	14.9	18.3	18.8	1.1	2.8	3.8
	None	4 by 8	5.0	11.7	15.9	16.2	16.8	18.8	17.9	1.7	3.3	4.3
	Moderate	do	4.5	11.9	16.2	14.3	17.6	21.5	22.8	1.8	3.3	4.4
	Severe	do	5.0	11.6	16.5	16.4	19.3	23.7	24.3	2.0	3.7	4.9
Boxelder, 8	None	4 by 4	7.0	15.0	18.1	15.6	17.8	18.6	16.4	----	----	----
	Moderate	do	5.5	14.5	19.1	8.5	13.6	17.3	17.8	----	----	----
	Severe	do	8.5	13.1	16.9	1.9	0.2	13.9	18.1	----	----	----
	None	4 by 8	6.5	15.1	19.4	15.0	18.5	21.6	22.0	----	----	----
	Moderate	do	7.0	15.1	18.9	8.5	14.5	18.3	21.3	----	----	----
	Severe	do	8.5	14.5	18.1	4.5	11.5	17.6	17.0	----	----	----
Daphne willow, 9	None	4 by 4	6.5	16.2	17.9	0	0	0	0	----	----	----
	Moderate	do	7.5	9	9	0	0	0	0	----	----	----
	Severe	do	5.0	0	9	0	0	0	0	----	----	----
	None	4 by 8	6.5	11.2	0	0	0	0	0	----	----	----
	Moderate	do	7.5	15.2	0	0	0	0	0	----	----	----
	Severe	do	5.0	0	0	0	0	0	0	----	----	----
Amur maple, 10	None	4 by 4	4.0	6.4	8.8	5.1	4.3	8.3	5.2	----	----	----
	Moderate	do	4.0	8.2	11.6	0	0	0	0	----	----	----
	Severe	do	3.5	7.2	10.2	5.0	9.6	12.1	10.7	----	----	----
	None	4 by 8	4.0	9.7	13.1	5.8	12.5	15.0	15.5	----	----	----
	Moderate	do	5.0	10.3	13.3	8.8	10.6	11.4	16.0	----	----	----
	Severe	do	4.0	8.7	10.4	3.7	9.8	11.1	12.8	----	----	----

Silver Buffaloberry

Silver buffaloberry planted in row 1 of blocks receiving the moderate- and severe-pruning treatments was killed back severely following the 1934 and 1936 droughts. The average heights of shrubs at 20 years of age were considerably below those at 16 years, particularly in the severely pruned blocks. Average growth of unpruned shrubs at 20 years was only slightly greater than at 16 years. Wind

TABLE 7.—*Effect of pruning method on survival of deciduous trees and shrubs set out in 1918 in 10-row mixed plantings*

Species and row No.	Pruning treatment	Spacing distance	Survival at ages—						
			4[1] years	10 years	16 years	20 years	25 years	30 years	36 years
		Feet	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Silver buffaloberry, 1	None	4 by 4	73	90	84	68	68	68	32
	Moderate	do	69	100	100	56	44	33	22
	Severe	do	73	95	90	32	21	21	21
	None	4 by 8	77	100	95	65	50	50	25
	Moderate	do	77	100	95	25	20	10	10
	Severe	do	69	94	78	50	44	44	28
Brittle willow, 2	None	4 by 4	100	73	19	0	0	0	0
	Moderate	do	100	73	16	0	0	0	0
	Severe	do	100	8	0	0	0	0	0
	None	4 by 8	100	92	88	50	42	35	27
	Moderate	do	100	96	88	46	46	42	38
	Severe	do	100	85	65	0	0	0	0
Boxelder, 3	None	4 by 4	96	100	100	96	96	96	96
	Moderate	do	88	100	100	100	91	91	91
	Severe	do	96	96	96	20	16	16	16
	None	4 by 8	100	96	96	96	96	96	96
	Moderate	do	100	100	100	81	81	81	81
	Severe	do	96	96	96	88	88	88	88
Green ash, 4	None	4 by 4	92	100	100	100	96	88	71
	Moderate	do	96	92	88	88	88	88	88
	Severe	do	96	100	100	96	96	96	96
	None	4 by 8	100	100	96	88	88	88	85
	Moderate	do	96	100	100	100	100	96	96
	Severe	do	100	100	100	100	100	96	92
Boxelder, 5	None	4 by 4	100	96	89	54	50	50	50
	Moderate	do	96	100	84	32	28	24	24
	Severe	do	96	96	92	16	16	16	16
	None	4 by 8	100	100	100	69	65	62	62
	Moderate	do	100	100	96	46	38	38	38
	Severe	do	96	100	92	4	0	0	0
Northwest poplar, 6	None	4 by 4	96	60	24	12	0	0	0
	Moderate	do	100	42	4	0	0	0	0
	Severe	do	100	38	0	0	0	0	0
	None	4 by 8	100	31	5	0	0	0	0
	Moderate	do	100	35	4	0	0	0	0
	Severe	do	50	16	4	0	0	0	0
Green ash, 7	None	4 by 4	92	100	96	96	92	83	46
	Moderate	do	100	100	100	100	100	96	77
	Severe	do	100	100	100	92	92	88	88
	None	4 by 8	100	100	100	100	100	96	92
	Moderate	do	100	100	100	100	96	96	96
	Severe	do	100	100	100	92	92	92	92
Boxelder, 8	None	4 by 4	100	100	100	100	100	100	92
	Moderate	do	100	100	96	85	81	77	73
	Severe	do	100	96	92	29	29	29	29
	None	4 by 8	100	100	92	81	81	81	77
	Moderate	do	100	100	96	58	58	58	58
	Severe	do	92	100	100	27	23	23	19
Daphne willow, 9	None	4 by 4	61	56	56	0	0	0	0
	Moderate	do	81	0	0	0	0	0	0
	Severe	do	85	0	0	0	0	0	0
	None	4 by 8	65	5	0	0	0	0	0
	Moderate	do	96	20	0	0	0	0	0
	Severe	do	69	0	0	0	0	0	0
Amur maple, 10	None	4 by 4	92	100	87	21	21	8	8
	Moderate	do	96	88	80	0	0	0	0
	Severe	do	92	83	75	12	12	12	12
	None	4 by 8	100	100	96	16	8	8	8
	Moderate	do	100	100	100	8	8	8	4
	Severe	do	96	96	84	24	24	24	20

[1] No losses were replaced after the fourth year. Survivals at 10 years and later are based on the stand which became established the fourth year.

breakage was responsible for further reductions in average height in all experiments. Suppression of the silver buffaloberry by brittle willow in row 2 and boxelder in row 3, was common in all experimental blocks with spacings of 4 by 4 feet, and to a less extent in the wider spacings (fig. 5).

There was a rapid drop in survivals between the sixteenth and twentieth years as a result of the droughts in 1934 and 1936. Losses

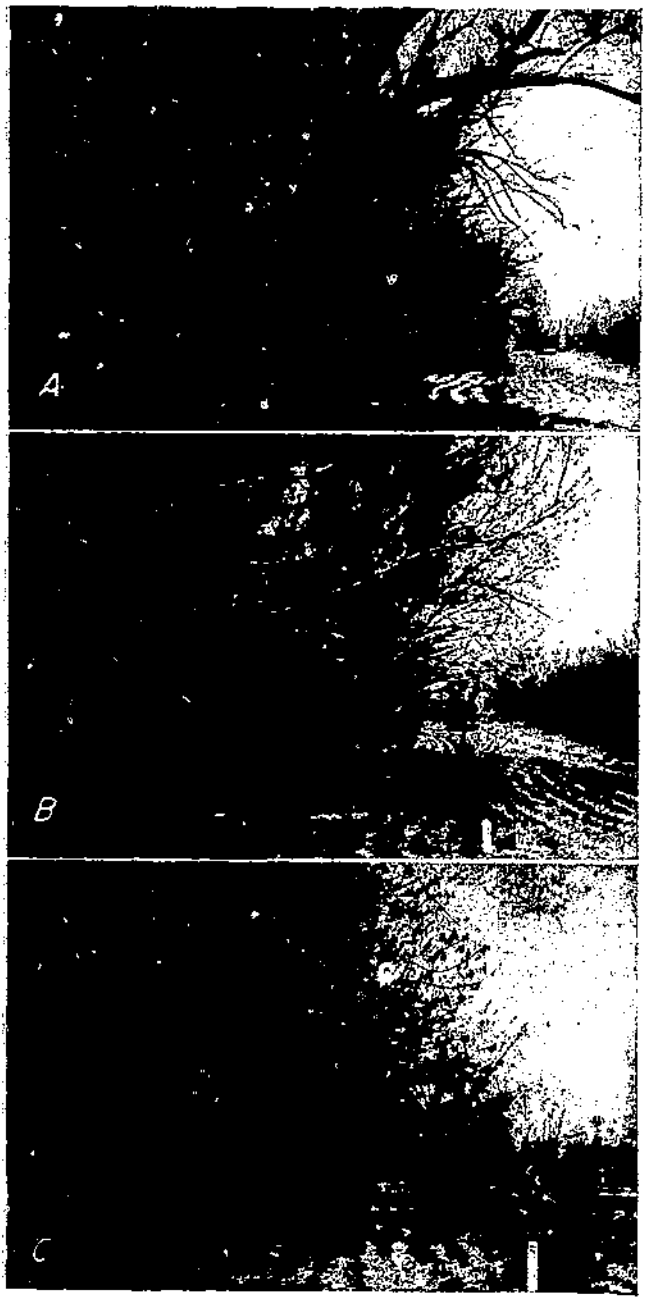

FIGURE 5.—Silver buffaloberry in row 1 (right) has been overtopped or pushed outward by brittle willow, row 2, or boxelder, row 3, in (*A*) the unpruned block and (*B*) the moderately pruned block. It was overtopped by boxelder, row 3, in (*C*) the severely pruned block. All blocks were spaced 4 by 8 feet.

since that time can be attributed more to uprooting by wind than to pruning methods. Survivals were low at 36 years of age in all pruning experiments.

Lower branches should not be removed from shrubs in an outside row because wind and snow can then pass to the interior, or through the belt of trees.

Brittle Willow

Brittle willow planted in row 2 was a complete loss at 12 years of age in the severely pruned block spaced 4 by 4 feet, and at 17 years of age in the unpruned and moderately pruned blocks spaced 4 by 4 feet; also in the severely pruned block spaced 4 by 8 feet. Considerable dying-back took place following the droughts of 1934 and 1936. It was not affected severely after that time, but survivals continued slowly to decline. The results show that lack of hardiness to drought conditions was a more important factor than method of pruning.

Boxelder

Boxelder was planted in rows 3, 5, and 8. Severe dying-back was apparent in the twentieth year as a result of the droughts of 1934 and 1936. The heaviest damage occurred in the severely pruned blocks, and the least in the unpruned blocks. At 36 years of age, height growth averaged 21.9, 21.0, and 20.1 feet in the moderately pruned, unpruned, and severely pruned blocks, respectively, spaced 4 by 8 feet. It ran in the order of moderately pruned, severely pruned, and unpruned trees in the blocks spaced 4 by 4 feet.

Losses in survival were heavy only in the severely pruned blocks during the drought years. At 36 years of age losses averaged 71, 63, and 20 percent for the unpruned, moderately pruned, and severely pruned blocks, respectively, spaced 4 by 4 feet; and 78, 59, and 36 percent for the same order of treatments spaced 4 by 8 feet.

While moderate pruning of trees gave a small increase in average height over unpruned trees, the practice cannot be recommended. Unpruned trees maintained higher survivals and were much more satisfactory for holding wind and drifting snow. Pruning should be limited to developing single-trunk trees in those cases where multiple stems are present. Side branches should not be removed from the trunk that is allowed to remain.

The heavier losses of both moderately and severely pruned trees can be attributed to a reduction in branch and leaf coverage that left both the stem and the soil exposed to severe drying during drought periods.

Green Ash

Green ash was planted in rows 4 and 7. The trees were not killed back severely during the drought years of 1934 and 1936, but effects of the drought extended through the next 3 years. Average heights at 22 years of age were approximately the same as those at 20 years. Good recovery had been made in all pruning experiments by the 25th year.

Average heights of green ash at 36 years of age were 18.6, 15.3, and 12.0 feet in the severely pruned, moderately pruned, and unpruned blocks, respectively, spaced 4 by 4 feet; and 23.1, 22.8, and 19.6 feet in the moderately pruned, severely pruned, and unpruned blocks, respectively, spaced 4 by 8 feet. It is possible that the heavy losses

of boxelder in rows 5 and 8 at 20 years of age in the moderately and severely pruned blocks had more to do with height growth of green ash than the pruning systems. The average height of green ash in row 7 of the unpruned block was 17.9 feet; and 22.8 and 24.3 feet in the moderately and severely pruned blocks, respectively. The increasing order of growth followed the decreasing order of survival of species in competitive adjacent rows.

Green ash survivals in blocks spaced 4 by 8 feet were high in all pruning experiments. They averaged 96, 92, and 88 percent for the moderately pruned, severely pruned, and unpruned blocks, respectively. Survivals in blocks spaced 4 by 4 feet averaged 92, 82, and 58 percent in the severely pruned, moderately pruned, and unpruned tests, respectively.

Diameter growth at 36 years of age was 4.5, 4.0, and 3.9 inches for the severely pruned, moderately pruned, and unpruned trees, respectively, spaced 4 by 8 feet; and 3.9, 3.2, and 3.0 inches for the severely pruned, unpruned, and moderately pruned trees, respectively, spaced 4 by 4 feet. It was apparent at 25 years of age that the greatest diameter growth was made by trees that were severely pruned.

Severely pruned green ash trees have no value for shelterbelt purposes, and moderately pruned trees are not as satisfactory as unpruned trees for breaking the force of the wind and stopping drifting snow. The average survivals and heights of trees under the different pruning systems at the end of 36 years of growth were not sufficiently different to warrant the use of a pruning system that gives somewhat greater height growth and survival, but which is decidedly less satisfactory for serving the protective purpose for which the trees were planted.

Northwest Poplar

The Northwest poplar in row 6 died out at 16 and 17 years of age in all blocks except the clean-cultivated block spaced 4 by 4 feet. There were some survivals in the latter through the twenty-second year. Growth and survival were affected more by lack of hardiness to drought conditions than by pruning. The species cannot be recommended for dryland planting.

Daphne Willow

The Daphne willow in row 9 died out at 8 years of age in the two severely pruned blocks, and in the moderately pruned block spaced 4 by 4 feet; at 11 years of age in the unpruned block spaced 4 by 8 feet; at 15 years of age in the moderately pruned block spaced 4 by 8 feet; and at 17 years of age in the unpruned block spaced 4 by 4 feet. Growth and survival were affected more by lack of hardiness to drought conditions than by pruning. The species cannot be recommended for dryland planting.

Amur Maple

The Amur maple planted in row 10 had no species adjacent to it in any of the pruning experiments for many years. The shrubs were killed back severely following the droughts of 1934 and 1936, and periodically after that time. The average heights at 20 years were considerably less than they were at 16 years. At 36 years of age the best average growth had taken place in the moderately pruned block,

and the next best in the unpruned block. Survivals, however, had been so low since the shrubs were 20 years old, it was apparent that other factors, such as intolerance to drought and possibly increased spacing distance, had affected growth more than pruning treatments. The species is not hardy under dryland conditions, and cannot be recommended for dryland shelterbelt planting.

CONCLUSIONS ON PRUNING

Trees and shrubs planted in shelterbelts for the protection of buildings, livestock, and crops against strong winds and drifting snow must be dense from the ground up if they are to serve that purpose effectively. Trees and shrubs that are pruned to heights of 5 to 6 feet do not have this density and are useless for protection against low wind and snow. Such pruning also permits wind and sun to dry out the soil, and encourages weed growth as a result of the additional light. Moderately pruned trees are much more effective for protection purposes than trees that have been severely pruned. However, moderately pruned trees permit much more wind and snow to pass through than nonpruned trees that have side branches and sometimes multiple stems from the ground up.

While better growth and survival were sometimes found in pruned trees and shrubs, they were not sufficiently better to warrant recommendation of pruning practices. It is very possible that the better growth was due to factors such as increased spacing distance rather than the system of pruning. A compromise might be worked out whereby all species ordinarily having a tree form of growth would be pruned to one central stem from which no branches would be removed. This system should give good results from the standpoint of growth and survival, and also protection afforded (figs. 6 and 7).

Jensen and Harrington (*5*) concluded that pruning to a single trunk with no removal of branches from that trunk gave the best type of tree. Mathews and Clark (*6*) found that the trees in the unpruned blocks were more vigorous than those in the pruned blocks and survival was better. They noted that the evil effects of pruning were apparent as soon as the trees had reached a height of 7 or 8 feet, and that the pruned trees were entirely unsatisfactory for catching snow or providing protection from the wind.

Cultivation Methods

The cultivation study consisted of 6 blocks of trees, 2 each of which received one of the following treatments:

1. Clean cultivation. Hand hoeing was done when necessary to control weeds missed by cultivation equipment.
2. Mulching. Clean cultivation was practiced the first season and a moderate amount of cultivation the second season, followed by the application of a heavy straw or hay mulch the third and succeeding seasons through the year 1932. No mulch was applied after that time. A heavy herbaceous cover became established in the block spaced 4 by 8 feet. This cover, principally grass, was mowed once each year and allowed to remain where it fell. It amounted to a light mulch in most years.
3. Neglect. Clean cultivation was practiced the first season, and

FIGURE 6.—Comparison of the growth of boxelder in row 5 (right) and green ash in row 7 (left) in (*A*) the unpruned block, and (*B*) the moderately pruned block; and of green ash in rows 4 and 7 in (*C*) the severely pruned block. All trees were spaced 4 by 8 feet. Severe pruning makes trees lose their ability to hold wind and snow.

a moderate amount the second season, followed by complete absence of any method to control weed growth afterwards. Grass and weeds were clipped once each year, as was done in the mulched blocks. The herbaceous ground cover did not become heavy at any time in the neglected blocks.

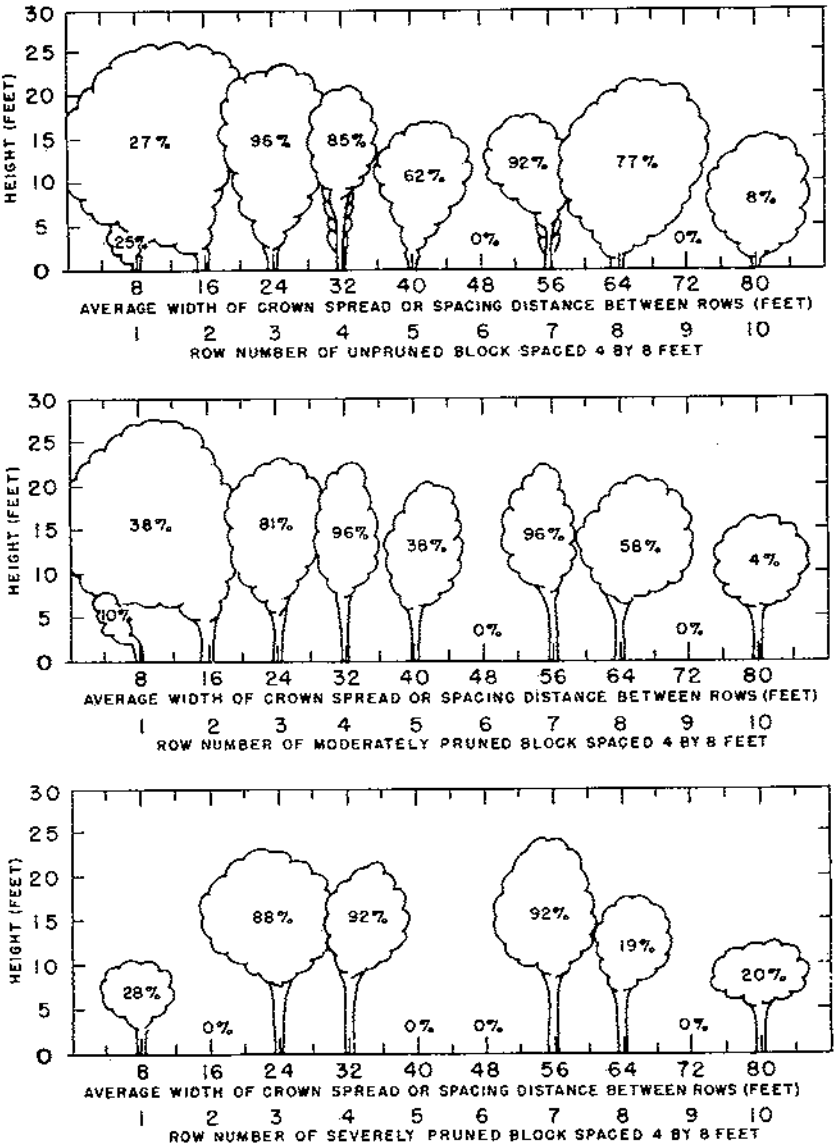

FIGURE 7.—Comparison of the ability of unpruned, moderately pruned, and severely pruned trees and shrubs to hold wind and snow. Unpruned trees and shrubs give the best protection owing to the density of branches from the ground up. Severely pruned trees and shrubs suffer more losses than those that are unpruned or moderately pruned, and have no lower branches to hold wind and snow. Circled figures indicate the percentage of survival in each row. All data are for trees and shrubs 36 years of age.

No pruning was done in any block except to remove dead or broken stems or branches. One block of each treatment was spaced 4 by 4 feet and the other 4 by 8 feet.

HEIGHT AND SURVIVAL

The average height of all species at 4, 10, 16, 20, 25, 30, and 36 years of age, and the average diameter at breast height of green ash at 15, 25, and 36 years of age are shown in table 8. Survival percentages of

TABLE 8.—*Effect of cultivation treatment on growth of deciduous trees and shrubs set out in 1918 in 10-row mixed plantings*

Species and row No.	Cultivation treatment	Spacing distance	Height at ages—							Diameter breast high at ages—		
			4 years	10 years	16 years	20 years	25 years	30 years	36 years	15 years	25 years	36 years
		Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Inches*	*Inches*	*Inches*
Silver buffaloberry, 1	Clean	4 by 4	3.5	6.2	8.3	8.7	9.3	7.8	7.8	----	----	----
	Mulch	do	3.5	5.8	7.4	4.6	6.9	8.3	6.7	----	----	----
	Neglect	do	4.0	6.0	8.3	5.3	8.3	10.2	10.2	----	----	----
	Clean	4 by 8	3.0	6.4	6.6	7.2	8.6	10.5	8.4	----	----	----
	Mulch	do	4.0	6.5	8.5	7.4	9.7	10.6	9.6	----	----	----
	Neglect	do	4.0	7.8	6.9	5.5	9.1	12.7	11.6	----	----	----
Brittle willow, 2	Clean	4 by 4	6.0	13.9	20.6	0	0	0	0	----	----	----
	Mulch	do	5.5	12.2	0	0	0	0	0	----	----	----
	Neglect	do	6.0	16.8	25.7	0	0	0	0	----	----	----
	Clean	4 by 8	7.5	19.3	21.7	14.2	16.1	20.2	25.9	----	----	----
	Mulch	do	8.0	17.5	17.6	0	0	0	0	----	----	----
	Neglect	do	7.5	19.8	20.2	13.3	18.6	22.6	20.3	----	----	----
Boxelder, 3	Clean	4 by 4	8.0	14.9	17.9	12.8	17.7	20.9	20.2	----	----	----
	Mulch	do	8.0	16.9	17.9	8.4	14.4	20.2	21.8	----	----	----
	Neglect	do	7.9	15.5	17.9	7.5	15.8	21.5	23.0	----	----	----
	Clean	4 by 8	7.5	16.9	19.7	12.1	18.9	22.4	23.4	----	----	----
	Mulch	do	8.0	15.4	18.7	9.0	14.2	18.6	16.9	----	----	----
	Neglect	do	8.0	15.4	17.4	8.0	16.1	20.4	21.5	----	----	----
Green ash, 4	Clean	4 by 4	4.0	11.3	12.9	12.0	14.4	16.0	16.8	1.1	2.0	3.3
	Mulch	do	3.5	9.3	9.3	9.1	11.2	14.1	18.2	.7	1.9	2.6
	Neglect	do	3.0	10.8	11.4	10.3	12.7	16.2	15.6	1.0	1.7	2.6
	Clean	4 by 8	3.5	12.6	14.7	15.6	17.7	20.5	21.2	1.5	2.8	3.5
	Mulch	do	4.0	12.4	16.3	14.0	14.1	15.5	16.3	1.6	2.6	3.4
	Neglect	do	4.0	12.1	16.3	13.5	15.1	17.7	17.6	1.7	2.7	3.6
Boxelder, 5	Clean	4 by 4	7.0	14.7	15.4	8.1	12.9	15.0	14.3	----	----	----
	Mulch	do	8.0	16.2	16.3	5.4	11.5	16.7	16.8	----	----	----
	Neglect	do	7.5	14.9	14.3	4.8	12.5	18.1	21.1	----	----	----
	Clean	4 by 8	8.0	16.2	16.0	9.8	13.9	18.5	17.5	----	----	----
	Mulch	do	8.0	15.5	11.4	3.4	7.1	12.6	10.1	----	----	----
	Neglect	do	7.5	13.7	14.3	5.1	9.9	15.5	19.0	----	----	----
Northwest poplar, 6	Clean	4 by 4	9.0	18.3	19.7	21.4	0	0	0	----	----	----
	Mulch	do	9.0	0	0	0	0	0	0	----	----	----
	Neglect	do	8.0	22.0	30.0	0	0	0	0	----	----	----
	Clean	4 by 8	10.5	17.4	27.1	0	0	0	0	----	----	----
	Mulch	do	8.5	0	0	0	0	0	0	----	----	----
	Neglect	do	9.0	15.6	25.5	0	0	0	0	----	----	----
Green ash, 7	Clean	4 by 4	4.0	10.6	11.9	11.7	12.8	13.5	7.3	1.0	1.7	3.0
	Mulch	do	3.5	9.4	9.5	9.2	11.3	14.8	15.1	.8	2.0	2.8
	Neglect	do	5.0	14.9	15.9	13.1	14.6	18.7	21.0	1.5	2.6	3.8
	Clean	4 by 8	5.0	14.7	15.9	10.2	10.8	18.8	17.9	1.7	3.3	4.3
	Mulch	do	4.0	12.5	10.0	14.2	13.3	16.1	17.4	1.9	2.8	3.8
	Neglect	do	4.0	10.3	15.8	15.7	15.8	18.9	19.3	1.5	3.0	4.1
Boxelder, 8	Clean	4 by 4	7.0	15.0	18.1	15.6	17.8	18.6	16.4	----	----	----
	Mulch	do	7.0	15.9	15.7	8.5	14.4	19.6	22.6	----	----	----
	Neglect	do	9.0	15.5	13.5	4.9	11.1	17.5	18.2	----	----	----
	Clean	4 by 8	6.5	15.1	19.1	15.0	18.6	21.6	22.0	----	----	----
	Mulch	do	8.5	10.3	17.7	6.7	9.1	15.1	17.6	----	----	----
	Neglect	do	7.5	14.8	17.2	5.8	10.9	15.7	18.4	----	----	----
Daphne willow, 9	Clean	4 by 4	6.5	10.2	17.9	0	0	0	0	----	----	----
	Mulch	do	6.5	16.0	0	0	0	0	0	----	----	----
	Neglect	do	7.5	0	0	0	0	0	0	----	----	----
	Clean	4 by 8	6.5	11.2	0	0	0	0	0	----	----	----
	Mulch	do	6.5	0	0	0	0	0	0	----	----	----
	Neglect	do	8.5	15.0	0	0	0	0	0	----	----	----
Amur maple, 10	Clean	4 by 4	4.0	6.4	8.8	5.1	4.3	8.3	5.2	----	----	----
	Mulch	do	3.5	6.5	6.1	0	0	0	0	----	----	----
	Neglect	do	3.0	8.8	11.2	0	0	0	0	----	----	----
	Clean	4 by 8	4.0	9.7	13.1	5.8	12.5	15.0	15.5	----	----	----
	Mulch	do	3.5	8.4	8.0	0	0	0	0	----	----	----
	Neglect	do	4.0	9.0	12.2	3.2	8.8	10.7	10.8	----	----	----

the stand that became established the fourth season, at ages similar to those for the height data, are shown in table 9.

Silver Buffaloberry

Silver buffaloberry planted in row 1 was killed back severely following the droughts of 1934 and 1936. Further reductions in height were caused by wind-breakage of tops. Many of the shrubs in the

TABLE 9.—*Effect of cultivation treatment on survival of deciduous trees and shrubs set out in 1918 in 10-row mixed plantings*

Species and row No.	Cultivation treatment	Spacing distance	Survival at ages—						
			4 years	10 years	16 years	20 years	25 years	30 years	36 years
		Feet	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Silver buffaloberry, 1	Clean	4 by 4	73	90	84	68	68	68	32
	Mulch	do	88	96	91	30	26	22	13
	Neglect	do	93	89	89	52	44	37	30
	Clean	4 by 8	77	100	95	65	50	50	25
	Mulch	do	100	96	92	77	69	69	54
	Neglect	do	79	100	83	61	61	44	30
Brittle willow, 2	Clean	4 by 4	100	73	19	0	0	0	0
	Mulch	do	100	46	0	0	0	0	0
	Neglect	do	100	41	10	0	0	0	0
	Clean	4 by 8	100	92	58	50	42	35	27
	Mulch	do	100	77	9	0	0	0	0
	Neglect	do	100	72	65	24	21	21	14
Boxelder, 3	Clean	4 by 4	96	100	100	96	96	96	96
	Mulch	do	92	100	100	87	83	79	79
	Neglect	do	100	100	100	76	72	69	69
	Clean	4 by 8	100	96	96	96	96	96	96
	Mulch	do	96	100	96	92	88	84	84
	Neglect	do	97	100	100	96	96	96	96
Green ash, 4	Clean	4 by 4	92	100	100	100	96	88	71
	Mulch	do	85	86	77	77	77	65	55
	Neglect	do	96	96	96	93	93	93	89
	Clean	4 by 8	100	100	96	88	88	88	85
	Mulch	do	100	100	96	96	96	85	77
	Neglect	do	100	100	100	100	100	100	96
Boxelder, 5	Clean	4 by 4	100	96	89	54	50	50	50
	Mulch	do	100	100	92	65	50	46	46
	Neglect	do	90	96	92	42	35	35	35
	Clean	4 by 8	100	100	100	69	65	62	62
	Mulch	do	100	100	96	23	15	15	15
	Neglect	do	100	100	100	48	45	41	41
Northwest poplar, 6	Clean	4 by 4	96	60	21	12	0	0	0
	Mulch	do	85	0	0	0	0	0	0
	Neglect	do	66	5	5	0	0	0	0
	Clean	4 by 8	100	31	8	0	0	0	0
	Mulch	do	100	0	0	0	0	0	0
	Neglect	do	100	31	3	0	0	0	0
Green ash, 7	Clean	4 by 4	92	100	96	96	92	83	46
	Mulch	do	88	91	91	91	91	83	74
	Neglect	do	97	100	100	96	96	96	93
	Clean	4 by 8	100	100	100	100	100	96	92
	Mulch	do	100	100	100	92	88	88	88
	Neglect	do	97	100	100	100	100	100	100
Boxelder, 8	Clean	4 by 4	100	100	100	100	100	100	92
	Mulch	do	100	100	92	85	73	69	65
	Neglect	do	97	100	100	39	20	25	25
	Clean	4 by 8	100	100	92	81	81	81	77
	Mulch	do	100	100	100	92	77	65	65
	Neglect	do	100	100	100	80	62	62	62
Daphne willow, 9	Clean	4 by 4	61	56	56	0	0	0	0
	Mulch	do	89	6	0	0	0	0	0
	Neglect	do	62	0	0	0	0	0	0
	Clean	4 by 8	65	5	0	0	0	0	0
	Mulch	do	98	0	0	0	0	0	0
	Neglect	do	93	4	0	0	0	0	0
Amur maple, 10	Clean	4 by 4	92	100	87	21	21	8	8
	Mulch	do	92	96	24	0	0	0	0
	Neglect	do	100	59	55	0	0	0	0
	Clean	4 by 8	100	100	96	16	8	8	8
	Mulch	do	100	100	69	0	0	0	0
	Neglect	do	96	100	100	4	4	4	4

[1] No losses were replaced after the fourth year. Survivals at 10 years and later are based on the stand which became established the fourth year.

blocks spaced 4 by 4 feet were badly suppressed by adjacent willow in row 2 or by boxelder in row 3. Wind-breakage and suppression affected the 36-year results more than the factor of cultivation (fig. 8). Height results at that time were best in blocks where no cultivating had been done.

Survival was best under a system of mulching for shrubs spaced 4 by 8 feet, and clean cultivation when they were spaced 4 by 4 feet. Losses were fairly heavy under all systems of cultivation following the 1934 and 1936 droughts. Since that time, uprooting by wind has accounted for most of the losses.

For the last several years there was a heavy growth of grass in the silver buffaloberry row of the mulched block spaced 4 by 8 feet. Very little grass and few weeds grew in the block spaced 4 by 4 feet, or in the neglected blocks spaced 4 by 4 and 4 by 8 feet. Survivals were highest in the mulched block spaced 4 by 8 feet, owing primarily to the fact that little uprooting by wind occurs where there is a heavy sod covering. The sod apparently acts as a binder for the roots. It has been noted that very little uprooting takes place in the native stands growing on the prairie.

Brittle Willow

The brittle willow planted in row 2 became a complete loss in the fourteenth year in the clean-cultivated block spaced 4 by 4 feet, and between the sixteenth and twentieth years in all other blocks except the clean-cultivated and neglected blocks spaced 4 by 8 feet. There were some survivals in those blocks at 36 years of age. Nonhardiness of the species to drought conditions had more to do with the results than cultivation treatments.

The area formerly occupied by the willow in the mulched block spaced 4 by 8 feet had been in heavy sod for many years. A few weeds had grown in the neglected blocks and in the mulched block spaced 4 by 4 feet.

Boxelder

Boxelder was planted in rows 3, 5, and 8. There were no survivals among adjacent species except in row 2 of the clean-cultivated and neglected blocks spaced 4 by 8 feet, where some brittle willow survived throughout the 36 years.

All boxelder trees, except those that were clean-cultivated, were killed back severely following the droughts of 1934 and 1936. Trees were killed back in later years, but only rarely was the damage of sufficient severity to cause a reduction in periodic height measurements.

The application of a hay or straw mulch was discontinued after the 1932 season. In the fall of that year average heights were 17.3, 17.1, and 16.5 feet in the mulched, clean-cultivated, and neglected blocks, respectively, spaced 4 by 4 feet; and 18.8, 18.0, and 16.4 feet in the clean-cultivated, mulched, and neglected blocks, respectively, spaced 4 by 8 feet. At 36 years of age they averaged 20.8, 20.4, and 17.0 feet in the neglected, mulched, and clean-cultivated blocks, respectively, spaced 4 by 4 feet; and 21.0, 19.6, and 14.9 feet for the clean-cultivated, neglected, and mulched blocks, respectively, spaced 4 by 8 feet. Trees in the mulched block spaced 4 by 8 feet averaged 3.1 feet shorter at 36 years of age than in 1932 at 15 years of age. During

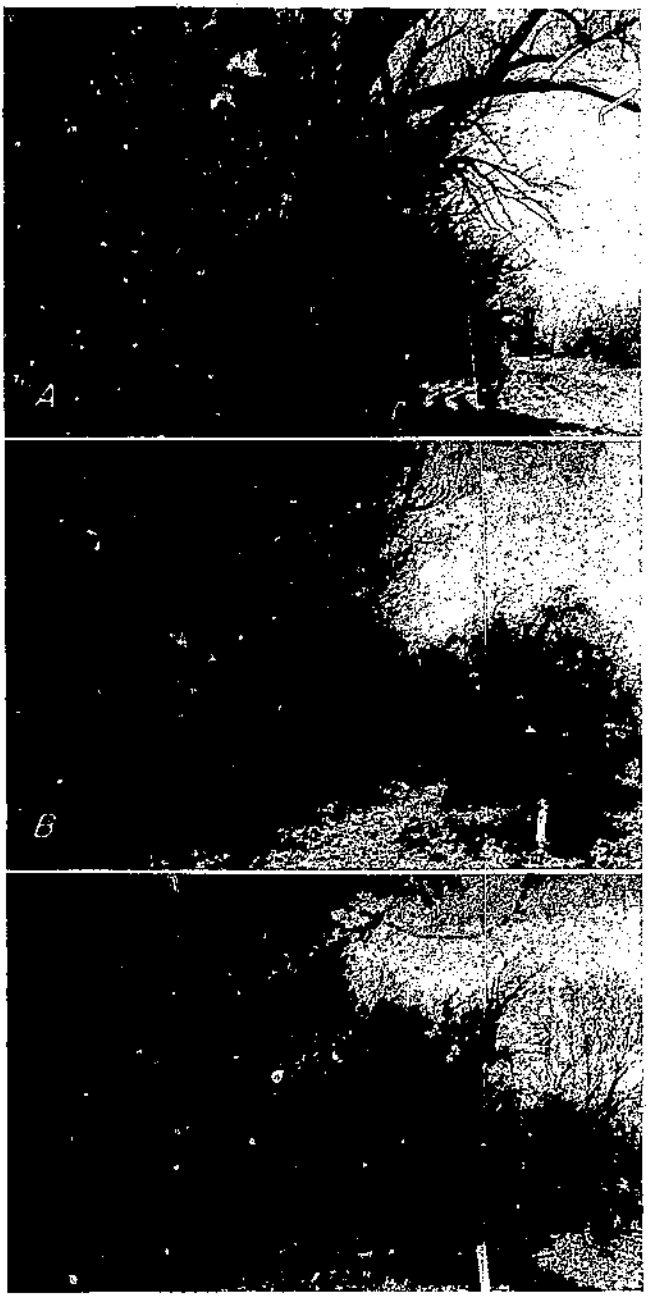

FIGURE 8.—Silver buffaloberry in row 1 (right) has been suppressed by adjacent brittle willow in row 2, and boxelder in row 3, in the clean-cultivated block (*A*) and the neglected block (*C*). In the mulched block (*B*) the adjacent willow has been dead for many years. Some pushing outward of tops was caused by boxelder in row 3. All trees were spaced 4 by 8 feet.

the same period trees under other types of cultivation showed average increases in growth up to 4.3 feet, with the exception of those in the clean-cultivated block spaced 4 by 4 feet, which showed a 0.1-foot decrease in height.

The heavy herbaceous growth that developed in the mulched block following discontinuance of mulching applications had a very unfavorable effect on the growth of boxelder.

In 1932, when mulching was discontinued, survivals of boxelder averaged 96 percent or above under all systems of cultivation except mulching in the block spaced 4 by 4 feet. Here, survivals averaged 81 percent. Survivals at 36 years of age were 79, 63, and 43 percent in the clean-cultivated, mulched, and neglected blocks, respectively, spaced 4 by 4 feet; and 78, 66, and 55 percent in the clean-cultivated, neglected, and mulched blocks, respectively, spaced 4 by 8 feet. Heavy losses in some rows of the mulched and neglected blocks followed the severe droughts of 1934 and 1936.

Clean cultivation gave the best all-round results, followed by the system of neglect. Mulching, as a substitute for cultivation, together with its after-effects, appeared to be very harmful to trees in the blocks spaced 4 by 8 feet. Mulched trees were markedly inferior to clean-cultivated trees in both vigor and appearance during the drought years. The differences were not so apparent when precipitation was more favorable. A heavy sod covering developed under the boxelder trees in the block spaced 4 by 8 feet following discontinuance of mulching applications. In most years grass and weeds grew rank in that block, and required mowing to prevent the spread of seeds. Very little grass and few weeds grew in the mulched block spaced 4 by 4 feet, and in the neglected blocks of both spacings.

Green Ash

Green ash was planted in rows 4 and 7. The trees were killed back in all blocks, except the clean-cultivated block spaced 4 by 8 feet, between the sixteenth and twentieth years as a result of the 1934 and 1936 droughts. Trees in the clean-cultivated block showed an increase in average height at 20 years over that at 16 years, while trees in the mulched and neglected blocks showed a decrease. The effects of the drought on height growth continued to be apparent through the next 5 years on trees in the mulched and neglected blocks spaced 4 by 8 feet. Average heights in those two blocks were less at 25 years of age than they were at 16 years, and in some cases less than they were at 20 years of age.

Mulching was discontinued after the 1932 season. In the fall of that year the average heights of green ash were 13.0, 11.7, and 9.0 feet in the neglected, clean-cultivated, and mulched blocks, respectively, spaced 4 by 4 feet; and 15.9, 15.0, and 15.0 feet in the mulched, clean, and neglected blocks, respectively, spaced 4 by 8 feet. At 36 years of age the average heights were 18.3, 16.7, and 12.0 feet in the neglected, mulched, and clean-cultivated blocks, respectively, spaced 4 by 4 feet; and 19.6, 18.4, and 16.8 feet in the clean-cultivated, neglected, and mulched blocks, respectively, spaced 4 by 8 feet. It will be noted that average heights in the mulched and neglected blocks were approximately the same in both spacing distances while

the average height in the clean-cultivated block spaced 4 by 8 feet was 7.6 feet greater than in the similarly treated block spaced 4 by 4 feet. The heavy herbaceous growth that developed following the discontinuance of mulching had a very unfavorable effect on the growth of green ash, as evidenced by the mulched trees in the block spaced 4 by 8 feet, which showed an increase of only 0.9 feet between 15 years of age in 1932 and 36 years of age in 1953. Clean-cultivated and neglected trees averaged 4.6 and 3.4 feet in growth increase, respectively, during the same period.

Survivals, when mulching was discontinued in 1932, averaged 98 percent or above in all cultivation experiments except in the mulched block spaced 4 by 4 feet, where they averaged 84 percent. Survivals remained high through the 30th year, after which time fairly heavy losses occurred in blocks spaced 4 by 4 feet. At 36 years of age survivals averaged 91, 64, and 58 percent in the neglected, mulched, and clean-cultivated blocks, respectively, spaced 4 by 4 feet; and 98, 89, and 82 percent in the neglected, clean-cultivated, and mulched blocks, respectively, spaced 4 by 8 feet. The order of survival in the blocks spaced 4 by 4 feet was the same as that of height growth.

Diameter growth of green ash at 36 years of age averaged 3.2, 3.2, and 2.7 inches in the clean-cultivated, neglected, and mulched blocks, respectively, spaced 4 by 4 feet; and 3.9, 3.8, and 3.6 inches in the clean-cultivated, neglected, and mulched blocks, respectively, spaced 4 by 8 feet. The application of a mulch and its after-effects had an unfavorable effect on diameter growth, as shown by comparison with trees grown under clean cultivation, and under a system where no cultivation or mulching had been practiced.

A heavy sod became established in the green ash rows of the mulched block spaced 4 by 8 feet, but only a few light weeds and a scattered light sod grew in the mulched block spaced 4 by 4 feet, and the neglected blocks of both spacings.

Northwest Poplar

The Northwest poplar in row 6 had suffered very heavy losses by the ninth year. The stand was entirely gone from the mulched blocks at 10 years of age, and from all the other blocks at 17 years of age except the clean-cultivated block spaced 4 by 4 feet. Some survivals remained in that block at 22 years, but the trees died before reaching 23 years of age.

Losses in this species took place as a result of lack of drought resistance rather than the factor of cultivation. It is not suitable for planting under dryland conditions.

Daphne Willow

The Daphne willow planted in row 9 died out at 9, 12, 15, and 17 years of age in the various cultivation experiments. It lived longest in the clean-cultivated block spaced 4 by 4 feet, and next longest in the mulched block of similar spacing. Survival in the latter block had been very low after the shrubs were 7 years of age. In the former block 56 percent were surviving at 16 years of age.

Losses were caused entirely by inability of the species to withstand drought conditions associated with dryland planting.

Amur Maple

The Amur maple planted in row 10 became a complete loss in the mulched and neglected blocks spaced 4 by 4 feet in the seventeenth and eighteenth years, respectively. Survivals in the other blocks were very low after the eighteenth year. Average heights at 36 years of age were based upon a small percentage of the original shrubs, and may have been influenced by factors other than cultivation. They are not, therefore, considered reliable for comparing cultivation treatments. Lack of hardiness to dryland conditions was one important factor influencing the results. Clean cultivation had some effect in prolonging the life of the shrubs.

CONCLUSIONS ON CULTIVATION METHODS

It has been concluded from this series of cultivation experiments that clean cultivation is the best method for growing shelterbelt or windbreak trees and shrubs on the northern Great Plains (fig. 9). If the trees can be cultivated for only the first 2 years, the data show that it is better to leave the weed growth uncontrolled than to apply a straw or a hay mulch. Application of a mulch resulted in a very heavy weed growth each season that was controlled by the application of more mulch the following season from the time of inception through the fifteenth year, when mulching was discontinued. A heavy sod cover became established in the mulched block spaced 4 by 8 feet following discontinuance of mulching. The resultant grass was mowed once each season for the last 20 years and was equivalent to a light mulch. Work in the mulched block spaced 4 by 4 feet, and in the two neglected blocks, was confined to the clipping of a very thin stand of seed heads to prevent spread of grass and weed seed to other cultivated areas. Those parts of the neglected blocks that had good tree and shrub survival remained free of any appreciative amount of competitive weed or grass growth.

Jensen and Harrington (*5*), reporting on a similar set of studies at the Judith Basin Branch Station, rated clean cultivation first, mulching second, and neglect third. Their observations covered only 11 years of growth as compared with 36 years for the Mandan study. Mathews and Clark (*6*) reported on a similar set of studies at 15 years of age made at the United States Dry Land Field Station, Ardmore, S. Dak. They found that the clean-cultivated trees gave the best growth and survival response. Trees in the neglected blocks had a slower growth rate than those in the mulched blocks. At 11 and 15 years of age, growth results at Mandan were similar to those reported by Jensen and Harrington, and by Mathews and Clark.

George (*3*) recommended, on the basis of a study of several thousand farm shelterbelts, that clean cultivation be practiced as long as it is possible to work between the trees, or until the tree crowns shade out competitive undergrowth.

No studies were made of the actual soil moisture present under the different cultivation methods, or their effect on soil nutrients. Such studies have been made by others.

Painter (*7*) studied the effect on soil moisture of a straw mulch applied around apple, peach, and sour cherry trees at the Goodwell, Okla., station. Soil samples were taken in June and December to

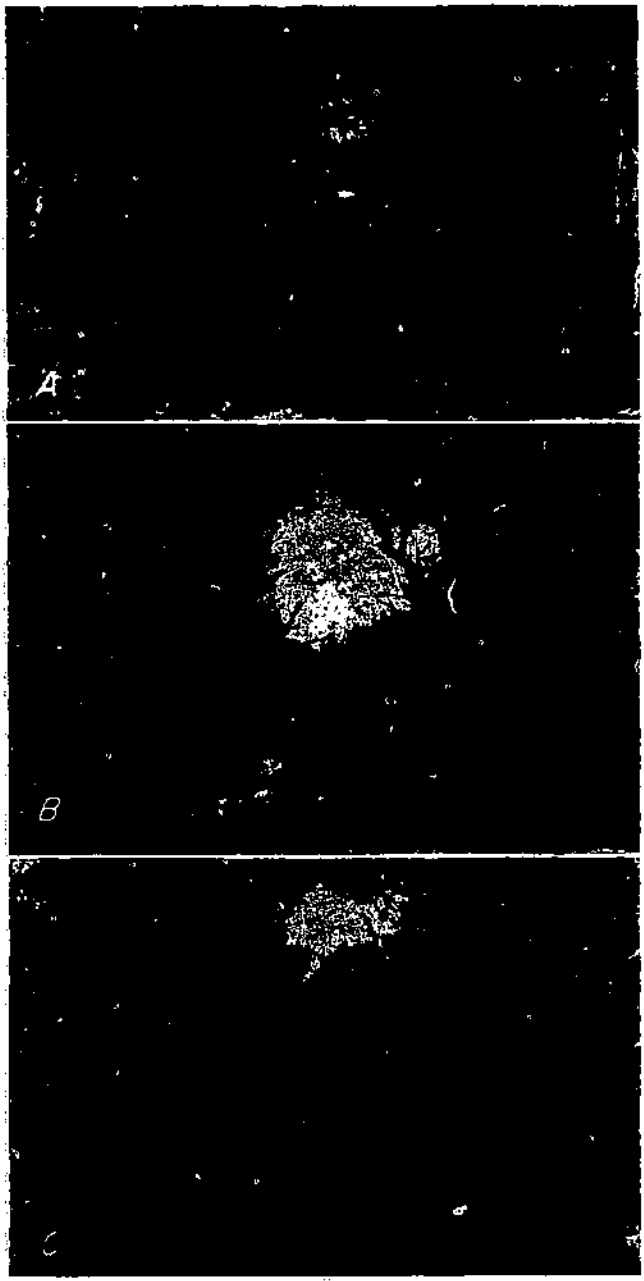

FIGURE 9.—Comparison of the growth of boxelder, row 5 (right), and green ash, row 7 (left), under (*A*) clean cultivation, (*B*) mulching with hay or straw from the 3d through the 15th year, followed by complete neglect, and (*C*) complete neglect with no effort made to control weed growth after the second season. Clean cultivation proved to be the best system, and mulching the poorest.

depths of 6 feet in the mulched and check plots. June samplings showed considerable gain in moisture in the fourth, fifth, and sixth foot of the mulched block over that of the unmulched block. December samplings showed similar gains in the first 4 feet of the mulched block. He concluded that the mulch permitted a greater percentage of water to enter the soil during the winter months, and reduced the loss through surface evaporation. He listed as disadvantages of mulches the difficulty of controlling weeds once they had become established, and the hazard of fire when mulches were applied to trees near farm buildings.

Gourley (*4*) reported the results of a study at the Ohio Agricultural Experiment Station, Wooster, where mulches were applied to supply nutrients to the soil as an aid in growing orchard crops. He found that the mulched trees always looked greener and more vigorous than the cultivated trees, and that the nutrients averaged higher. All elements investigated, excepting manganese and lead, were found to have been increased in the soil beneath a heavy mulch when compared with adjacent land that had been kept under cultivation. These increases appeared to be confined to the first 9 inches of surface soil. This author also reported an experiment in Massachusetts where from 4 to 6 times as many nitrates were found under mulch as under cultivation in some seasons.

Stephenson and Schuster (*8*) compared moisture conservation, nutrient supply, and soil structure on 5 treeless plots under the following treatments: Sod uncultivated, land scraped and kept bare of growth, tillage mulch, straw mulch, and a trash mulch with an adjacent orchard area in sod. They found that the straw mulch saved moisture equivalent to 2 to 3 inches of rainfall in dry weather, the saving being principally in the upper 2 feet of soil. Nitrates were as high under straw mulch after it had been established for 3 years as under clean cultivation. The straw mulch caused a marked increase in soluble potassium and an increase in the organic content of the top soil.

Turk and Partridge (*9*) used lysimeters to study the effect of mulches of hay, straw, and straw plus nitrogen on three orchard soils. Additional mulches of peat, shredded corn stover without nitrogen, sawdust, wood shavings, and gravel were used on one of the three soil types. Straw and alfalfa mulches were equally effective on all soil types in decreasing evaporation losses. Peat and sawdust were the least effective in decreasing moisture losses from the one soil type to which all mulches had been applied.

Observations made over a period of years on the northern Great Plains indicated that the use of a hay or straw mulch in shelterbelts had several disadvantages and few advantages. The more important disadvantages were:

1. Light rains were held in the mulch and did not enter the soil. A high percentage of the precipitation in the northern Great Plains falls in showers of small amounts.
2. Excavation of the roots of dead trees indicated that those in the mulched blocks were more shallow-rooted than those in the cultivated and neglected blocks.
3. The mulch harbored rodents that sometimes partially girdled the trees at the ground line under the mulch.
4. The mulch became a serious fire hazard at certain seasons of the year.

5. Each new application of mulch brought in a fresh crop of seeds of grass and weeds which, after germination, could be controlled only by hand methods or by the application of more mulch.

The main advantage in dry areas of a mulch is the prevention of soil erosion by wind and water, which is sometimes of considerable importance. Mulching may have other beneficial influences in areas where rain falls in greater amounts at any one period.

The trees and shrubs in the neglected blocks were able to shade out serious competitive weed growth. They were not able to shade out the heavy grass and weed stands established in the mulched blocks as a result of bringing in grass and weed seeds. Spacing rows more than 8 feet apart would permit excessive growth of weeds which, unless controlled, might seriously compete with the trees and shrubs for moisture.

CONCLUSIONS AND RECOMMENDATIONS

Shelterbelts and windbreaks are a necessity on the northern Great Plains for keeping farm yards and buildings free of drifting snow; for providing wind and snow protection to livestock and feeding areas; and for the protection of field, orchard, and garden crops against damaging strong and hot winds.

If the tree plantings are to be effective in reducing wind velocity and holding drifting snow, methods of spacing and caring for the trees must be followed that will assure maximum growth and the maintenance of high survivals over a long period of time. Hardy species must be used, and these should be capable of making the growth density necessary to reduce wind velocity and to trap blowing snow.

The results of this study warrant the following recommendations on methods of growing shelterbelt or windbreak trees:

1. Rows should be spaced a minimum of 12 feet apart, and the trees 6 to 8 feet apart in the row.
2. Species having spreading crowns, such as willow and boxelder, should not be planted next to a shrub species unless the distance between rows is such that there will be no danger of the shrub being overtopped.
3. Shrub species in outside rows should not be pruned. Trees in interior rows should be pruned to one stem, but no side branches should be removed from the stem that is left. Moderately pruned trees with lower branches removed are less satisfactory for holding wind and snow than trees allowed to grow unpruned. Severe pruning of trees and shrubs makes them useless for shelterbelt or windbreak purposes, and also results in higher mortality of the trees and shrubs than when they are left unpruned.
4. Competitive weed and grass growth should be controlled by cultivation. Mulching of the trees each year from the third season through the fifteenth year was not a satisfactory method of controlling weeds. Each mulch application brought in a new crop of weeds and grass, which could be controlled only by the application of another mulch or by handcutting.

5. Mulching prevented light rainfall from reaching the soil; it harbored rodents that sometimes partially girdled the trees; it constituted a fire hazard that would have been serious at times if the trees had been close to farm buildings; it tended to induce shallow-rooting of the trees and shrubs; and the method proved harmful to growth and survival.
6. Complete absence of any method of weed control after the second season gave better results than the application of a hay or straw mulch, but noncultivation was less satisfactory than clean cultivation. The weed problem never became serious under the system of neglect because the trees and shrubs developed sufficient crown shade to shut out most of the competitive growth. Wider spacing between rows might have resulted in a more serious weed problem, with consequent unfavorable effects on growth and survival.

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