Effect of Field Windbreak Design on Snow Distribution Patterns in Minnesota

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*Throughout this publication the terms Morris Station, Crookston Station or merely Morris and Crookston are used interchangeably and refer to the West Central Experiment Station, Morris and the Northwest Experiment Station, Crookston.

Effect of Field Windbreak Design on Snow Distribution Patterns in Minnesota

INTRODUCTION

Americans became aware of the seriousness of soil loss through wind erosion on May 12, 1934—date of the first great dust storm. It originated in western Kansas, Texas, Oklahoma, and eastern Colorado and swept across the United States in a north and east direction, extending hundreds of miles over the Atlantic. It carried an estimated 200 million tons of soil, reaching heights of almost 2 miles. Dust settled in Canada, blocked out the sun in Washington, D.C., and sifted through screens of houses and office buildings across the country. Some farms lost topsoil to plow depth. The blowing soil particles, sharp as knives, cut off crop plants at the soil line.

The catastrophic crop destruction and loss of productive farmland topsoil that occurred in that 1934 dust storm had a pronounced effect. Farmers who saw this destruction knew that something had to be done at once to build up their land and prevent any future topsoil loss. It was quickly realized that the farmers' crop loss was the public's food loss. Individuals and organizations banded together to protect the nation's topsoil. Thus began a widescale planting of trees, referred to as *shelterbelts* and/or *windbreaks*,[1] on the Great Plains.

As these young tree plantings or windbreaks became established and grew to useful heights, it was obvious that windbreaks did more than keep the topsoil in place. Windbreaks protected young, tender crops from wind damage and the sandblasting effect of blowing soil; reduced moisture loss from evaporation and transpiration; reduced lodging of maturing crops; served as travel lanes for wildlife; and affected the distribution of snow over cropland.[2]

Snow accumulation and distribution varied, depending on the density of the windbreaks. The ideal pattern was a uniform distribution of snow over the protected cropland resulting in a uniform distribution of soil moisture for the spring planting season—a most important advantage for the farmer. The search began for the most effective windbreak design and cultural practices that would hold the topsoil in place and permit a uniform distribution of snow.

While researchers were looking for the perfect windbreak, public interest shifted to other, more popular, causes. Some farmers, wanting expanded cropland areas to accommodate the ever increasing size of farm equipment, began to look at field windbreaks as obstacles to efficient use of large machinery. As the importance of the windbreak seemed to be forgotten, farmers often removed the very windbreaks that probably contributed to favorable crop years.

The mid-1970 drought years resulted in drastic reductions of crop yields and some crop failures. In these drought-stricken agricultural areas, storms sometimes occurred which were reminiscent of the dust bowl era. Farmers, again, needed to reconsider practices which would prevent future loss of fertile topsoil. Once again attention was focused on the windbreak method of conserving topsoil.

To help farmers design the best possible field windbreak, the author began a study during winter 1961-62, which extended through the January 1975 blizzard, to determine the effect of windbreak density on snow distribution patterns. Snow depth measurements and observations of existing, well-established windbreaks in east central, west central, and northwestern Minnesota were recorded periodically.

To understand the results of this study, the reader should first know the important characteristics of the ideal field windbreak species, and how snowdrifts are formed behind field windbreaks.

THE IDEAL FIELD WINDBREAK SPECIES

An ideal field windbreak species must (1) attain maximum heights, (2) provide minimum shading of adjacent crops and not shed twigs and branches which might interfere with farming equipment, and (3) provide minimum root competition with adjacent crops for soil water and nutrients. In selecting a species for field windbreaks, the following characteristics must be considered for each species adapted to the planting site: height growth, branching habits, and rooting habits. Once the species has been selected, consideration must be given to spacing and later thinning, and pruning from underneath.

Species Choice

HEIGHT GROWTH

Height is important in that protection of cropland to the leeward (the side protected from the wind) extends greater distances as tree heights increase. This means that the taller the trees, the fewer the number of windbreaks required to protect a given expanse of farmland. Fewer windbreaks also mean fewer obstacles for large modern farm machinery.

[1]In Minnesota a shelterbelt is a planting to protect farmstead buildings and feedlots and a windbreak is a planting in the field to reduce soil erosion and conserve soil moisture. In other states, however, the terms and definitions may be reversed or used interchangeably.

[2]For a comprehensive listing of benefits derived from field windbreaks as reported by worldwide investigators, see Read's (11) Appendix, pages 58-65.

BRANCHING HABITS

Tree species with wide-spreading branches are undesirable for field windbreaks because they shade out more of the adjacent crops and catch more snow than narrow-crowned species. Siberian elm (*Ulmus pumila*), the most widely used field windbreak species, has wide-spreading branches while green ash (*Fraxinus pennsylvanica*), the second most popular windbreak species, has a narrower crown because of more vertical branching habits. Siberian elm also has many more twigs and branches which increase the density of the windbreak and catch too much snow.

Some tree species produce strains with different branching characteristics. For example, figure 1 shows a strain of ponderosa pine (*Pinus ponderosa*) with right-angle, wide-spreading branches and a strain with vertical branching and a narrow crown. (Ponderosa pine is one of the few tall conifer species adapted to many soils of the prairie states and is often used in farmstead shelterbelts.) Siberian larch (*Larix siberica*) has the potential of being an ideal windbreak species because of its tendency to produce a fairly narrow crown. Unfortunately, most tree species do not develop a narrow crown and therefore would not function as ideal windbreak species.

Figure 1. Two forms of ponderosa pine: narrow crown with angled branching on the left and broad crown with spreading branches on the right.

Some of the poplar (*Populus*) species and varieties have quite narrow crowns making them ideal for use in field windbreaks. However, since poplar species are intolerant (unable to grow in shade), the lower branches eventually die when they become too shaded from the upper branches. These lower branches shed naturally soon after they die. When the lower trunks become clear (void of branches) to heights of roughly 6 feet or more, the windbreak becomes too open in the lower portion to slow down wind and drifting snow. Another disadvantage of the poplar species is that their branches and twigs are brittle. High winds may snap off branches and twigs and blow them onto adjacent cropland. This can be exasperating to the farmer; for example, when cultivating a row crop, a branch or twig caught in front of a cultivator shoe will root out young crop plants.

ROOTING HABITS

Ideally, a field windbreak species should have a deep but not wide-spreading root system, which deprives adjacent crops of soil water and nutrients. Depending on the species, root systems may extend 0.5 to 3 tree heights into the cropland (14). Since most of the root system is concentrated under the periphery of the crown, the narrower the crown, the more confined the root system.

Initial Spacing and Later Thinning

Spacing is determined by branching characteristics. Species having dense crowns and wide-spreading branches such as Siberian elm require a wider spacing than a narrow-crowned species such as green ash. The spacings used in the past—anywhere from 3 to 6 feet—were too close for Siberian elm and perhaps too close for green ash. Figures 2, 3, and 4 compare branching characteristics of Siberian elm and green ash at 5-, 10-, and 15-foot spacings.

Ideally, a fairly close spacing should be used at planting time with the intent of performing appropriate thinning operations later. George (5) reported that the removal of every other tree from part of a single-row Siberian elm windbreak where trees were spaced 4 feet apart resulted in 2-foot snowdrifts extending 150 feet to the leeward. Drifts behind the unthinned section were 4 feet deep and extended only 50 feet to the leeward. These results were obtained during a winter of below-normal snowfall.

Pruning Single-Row Siberian Elm from Underneath

Snowdrifts along both sides of a windbreak, especially along the leeward side, indicate that the windbreak is too dense—the denser the windbreak, the deeper the snowdrifts. An effective windbreak should not stop the wind but should slow it down so that blowing snow will filter through the windbreak and settle uniformly over the cropland. To make existing dense windbreaks such as Siberian elm windbreaks more efficient, the lower branches should be pruned. As stated by Frank (2): "The main purpose for pruning field windbreaks is to decrease their winter density so more wind will move through the canopy and thus spread

Figure 2. Green ash and Siberian elm on 5-foot spacing.

Figure 3. Green ash and Siberian elm on 10-foot spacing.

Figure 4. Green ash and Siberian elm on 15-foot spacing.

snow over a wider crop area." Pruning lower branches may encourage grass or weeds to grow in the tree row. This must be controlled for pruning to be effective.

The following researchers have reported the effectiveness of pruning lower limbs in dense Siberian elm windbreaks:

1. George (5): "As the barrier becomes more open in the lower part, the greatest velocity wind reduction, within certain limits, moves further away from the barrier."
2. Frank et al. (3) reported that pruning has the effect of reducing the depth of snowdrifts and "spreading the snow over a larger area."
3. Zaylskie (15) reported that even after the second blizzard of March 1966, pruned windbreaks held snow on the cropland up to 195 feet (approximately 15H[3]) to leeward, which was 75 percent further than snowdrifts behind unpruned windbreaks.

Figures 5 and 6 show summer 1969 and early spring 1970 scenes of alternate 200-foot sections of pruned and unpruned Siberian elm in a single-row, east-west windbreak at Crookston.

Figure 5. Single-row, east-west Siberian elm field windbreak showing 200-foot pruned section in center and ends of 200-foot unpruned sections on either side. Picture taken in 1969 after pruning. Crookston, Minnesota.

Figure 6. Same windbreak as in figure 5. Picture taken in early spring 1971 following a winter of below-normal snowfall. Snowdrifts on the windward (north) side occur opposite the 200-foot unpruned sections, while grass cover occurs opposite the 200-foot pruned sections. The same pattern can be seen on the plowed land behind (south) the windbreak. Crookston, Minnesota.

[3]H refers to average tree height.

Apparently the height of tree pruning from underneath is critical. As will be shown later, pruning Siberian elm to a height of approximately 3 feet is not enough to get uniform snow distribution. Zaylskie (15) reported that removal of lower branches to a height of 4.5 feet resulted in longer snowdrifts than when trees were pruned to a height of 2.5 feet. Frank (3) reported that pruning the lower branches in a dense Siberian elm windbreak to a height of 4.5 feet reduced the depth of snowdrifts and extended the distance of snow cover. George et al. (6) reported that pruning to a height of 5 feet gave wider and shallower snow distribution than pruning to a height of 4.5 feet.

During the fall of 1974, the windbreak at Crookston (figure 7) was pruned to a height of about 6 feet. The photograph (taken 2 days after the January 21, 1975, blizzard) shows that this pruning, which included the removal of large branches from lower forks, was much too drastic—it provided little barrier to wind and snow. The end tree in figure 7 shows a stub left after the removal of a large fork near the ground line. Large lower forks in the lower portion of Siberian elm are quite common. These forks should not be allowed to develop but should be cut off soon after planting.

Figure 7. Same windbreak as in figures 5 and 6 pruned to a height of 6 feet in the fall of 1974, and pictured 3 days after the second January 1975 blizzard. This windbreak failed to catch more than a few inches of snow. Crookston, Minnesota.

Thinning and pruning Siberian elm may not be a final solution—thinning may result in prolific stump sprouting, and pruning may result in prolific sprouting at the branch wounds on the trunk. Either form of sprouting, and especially a combination of both, will have the effect of eventually increasing density in the lower portion of the windbreak above what it would have been had the windbreak not been thinned and/or pruned. To quote Frank et al. (3,4): "Pruned Siberian elm will sprout at the base, and regrowth will be as dense as before." To quote George (5): "New regrowth in 3 years following the pruning indicated the trees might eventually develop a denser growth than if they had not been pruned" (figures 7 and 8).

Figure 8. Same windbreak as in figure 7 showing stump sprouts and sprouting from pruning wounds. Picture was taken in midsummer of 1976 during second growing season after pruning. Crookston, Minnesota.

HOW SNOWDRIFTS FORM BEHIND FIELD WINDBREAKS

The location of snowdrifts with respect to the windbreak tells something about wind turbulence and eddying (reverse in wind direction). As reported by Caborn (1), wind approaching the windbreak is forced upward by the tree barrier and a lower cushion of air that develops on the windward side. Wind velocity increases as air passes over the tree tops, but the relatively calm air behind (leeward) the windbreak causes a vacuum which literally sucks the air (and snow) coming over the trees, downward, resulting in wind turbulence and eddying. Gloyne (8) states that the denser the barrier, the more vigorous the eddying. Also, the area of turbulence will occur closer and be more restricted as windbreak density increases. Caborn (1) also reports that eddying behind a dense windbreak does not occur beyond 10H.

Wind action in the region of eddying can be explained simply as follows: the wind reverses direction behind the windbreak, blowing snow in a rolling or circular fashion toward the windbreak—much like a huge ball rolling toward the windbreak with a reverse spin (rolling toward the windbreak but spinning in a direction away from the windbreak). The more vigorous the blowing, rolling snow, the deeper the snowdrift and the closer the drift behind a dense windbreak.

SNOW DISTRIBUTION PATTERNS: VARIOUS WINDBREAK DESIGNS

To determine the effect of windbreak design on snow distribution patterns, snow depth measurements were taken within the tree row and at snowdrift peaks, dropoffs, rises, and swells on both the leeward and windward sides of several existing windbreaks. In selecting transects for measuring, the windbreak sections with missing trees were avoided. For ease of understanding, this research is organized as follows:

1. Multiple-row effect on snow distribution of north-south windbreaks.
   a. Three-row red pine (*Pinus resinosa*) windbreak (winter 1961-62; southwest of Newport, Minnesota).
   b. Two-row green ash—wild plum (*Prunus americana*) windbreak (winter 1961-62; southeast of Hastings, Minnesota).
   c. Three-row green ash windbreak (winter 1961-62; south of Hastings, Minnesota).
2. Pruning and spacing effect on snow distribution of single-row, east-west windbreaks.
   a. Siberian elm windbreak (winter 1970-71; Northwest Agricultural Experiment Station, Crookston).
   b. Siberian elm windbreak (winter 1974-75; Northwest Agricultural Experiment Station, Crookston).
   c. Siberian elm windbreak (winter 1974-75; West Central Agricultural Experiment Station, Morris).
   d. Green ash windbreak (winter 1974-75; West Central Agricultural Experiment Station, Morris).
3. North-south orientation effect on snow distribution of single-row Siberian elm windbreak (winter 1974-75; Warren, Minnesota).
4. Observations of snow distribution patterns of a series of unpruned and pruned single-row Siberian elm windbreaks (winter 1974-75; Warren, Minnesota).

Multiple-Row Effect on Snow Distribution of North-South Windbreaks (12)

Snow distribution studies of three multiple-row windbreaks were conducted after two moderate snowfalls during the winter of 1961-62. All three windbreaks, located less than 50 miles southeast of St. Paul, Minnesota, are on gently rolling sites of sandy loam soils. Each windbreak has a different composition—three rows of red pine, two rows of green ash bordered on each side by a row of wild plum, and three rows of green ash. These were north-south oriented windbreaks.

THREE-ROW RED PINE WINDBREAK (WINTER 1961-62; SOUTHWEST OF NEWPORT, MINNESOTA)

This three-row red pine windbreak, located near Newport, Minnesota, was planted on an 8- by 10-foot spacing, and trees averaged 20 feet tall. Ground cover on both sides of the windbreak consisted of soybean stubble.

Figure 9 shows the snow distribution pattern following a moderate snowfall. There was a heavy accumulation of snow adjacent to the trees on both sides. Maximum snow depth to the windward was almost 3 feet at approximately 1H, then dropped off to 1.5 feet at

2H. Peak snow depth to the leeward was 4 feet at 0.5H. There was a sharp drop-off to almost a 3-foot depth at 1H, after which there was a gradual tapering off to approximately 2 feet at 4H.

Normal snow depth in open fields averaged 16 inches. This depth occurred in the center of the windbreak and beyond 4H to the windward and beyond 12H to the leeward.

Conclusions

It is obvious that a three-row red pine windbreak is much too dense because it tends to stop the wind and causes snow to accumulate next to the outside tree rows. This conserves considerable moisture for the trees, but not for the cropland beyond 4H to the leeward. Also, spring farming operations near the windbreak will be delayed considerably until all the snow has melted and the soil has dried enough to work.

TWO-ROW GREEN ASH—WILD PLUM WINDBREAK (WINTER 1961-62; SOUTHEAST OF HASTINGS, MINNESOTA)

This green ash–wild plum windbreak was located several miles southeast of Hastings, Minnesota. It was a

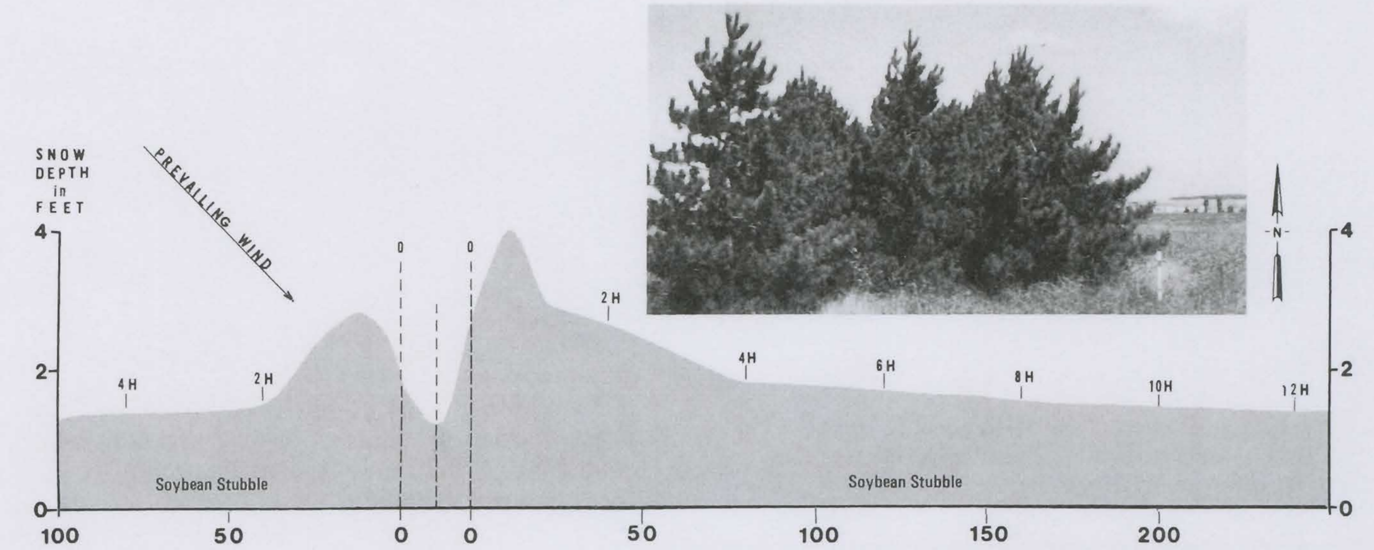


Figure 9. Snow distribution pattern of three-row, north-south red pine field windbreak. Average height—20 feet. Spacing—8 by 10 feet. Photograph shows a south-end view of this windbreak. Newport, Minnesota, 1961-62.

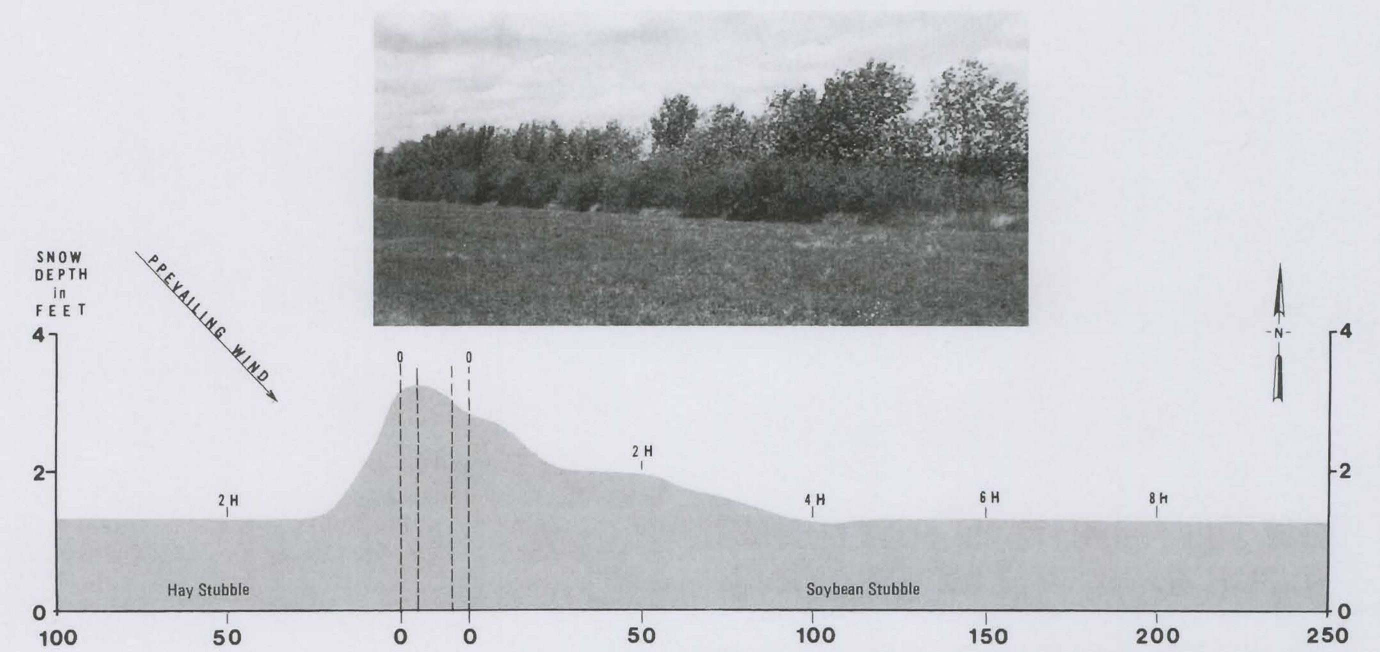


Figure 10. Snow distribution pattern of two-row, north-south green ash, bordered on both sides with wild plum, field windbreak. Average height—25 feet. Spacing—6 by 10 feet. Photograph shows a west-side view of this windbreak. Hastings, Minnesota, 1961-62.

25-foot-tall, two-row green ash windbreak spaced 10 feet apart between rows and 6 feet apart in the rows and bordered on each side (about 6 feet from the ash) with a row of wild plum that averaged 10 feet tall. Ground cover consisted of hay stubble on the windward side and soybean stubble on the leeward side.

Figure 10 shows the snow distribution pattern following a moderate snowfall during the winter of 1961-62. The snow distribution pattern is generally similar to the pattern caused by the three-row red pine windbreak (figure 9) except that maximum snow accumulation occurs within the windbreak near the windward side where the depth was a little over 3 feet. There was a sharp dropoff from a 3-foot depth at 0H to a depth of 16 inches (normal depth in the open) at 1H to the windward. Normal snow depth occurred at 4H to the leeward.

Conclusions

Two rows of green ash would not have stopped this much snow. The shrub row on the windward side caught the "brunt" of the snow resulting in a deep drift on both sides and within the windbreak. The shrub row on the leeward side helped hold the snow, preventing much of it from spreading over the cropland.

This windbreak has essentially the same moisture-conserving benefits as the three-row red pine windbreak. Cropland beyond 4H to the leeward does not receive any added moisture.

THREE-ROW GREEN ASH WINDBREAK (WINTER 1961-62; SOUTH OF HASTINGS, MINNESOTA)

Located just south of Hastings, Minnesota, the trees in this three-row green ash windbreak averaged 35 feet tall and were on a 4- by 6-foot spacing. The ground cover on both sides consisted of corn stubble.

Figure 11 shows the snow distribution pattern following a moderate snowfall during the winter of 1961-62 (spacing between rows not to scale). Normal snow depth in open fields averaged about 2 feet. This depth occurred in the center of the windbreak, beyond 6H to the windward and beyond 10H to the leeward. Maximum snow depth to the windward was only about 2.5 feet at 4H. Snow depth to the leeward was a little over 2 feet from 0H to 2H, after which it increased to 3.5 feet at 4H and then gradually tapered off to the normal 2-foot depth at 10H.

Conclusions

Unlike the red pine and green ash–wild plum windbreaks, this windbreak did not conserve any added

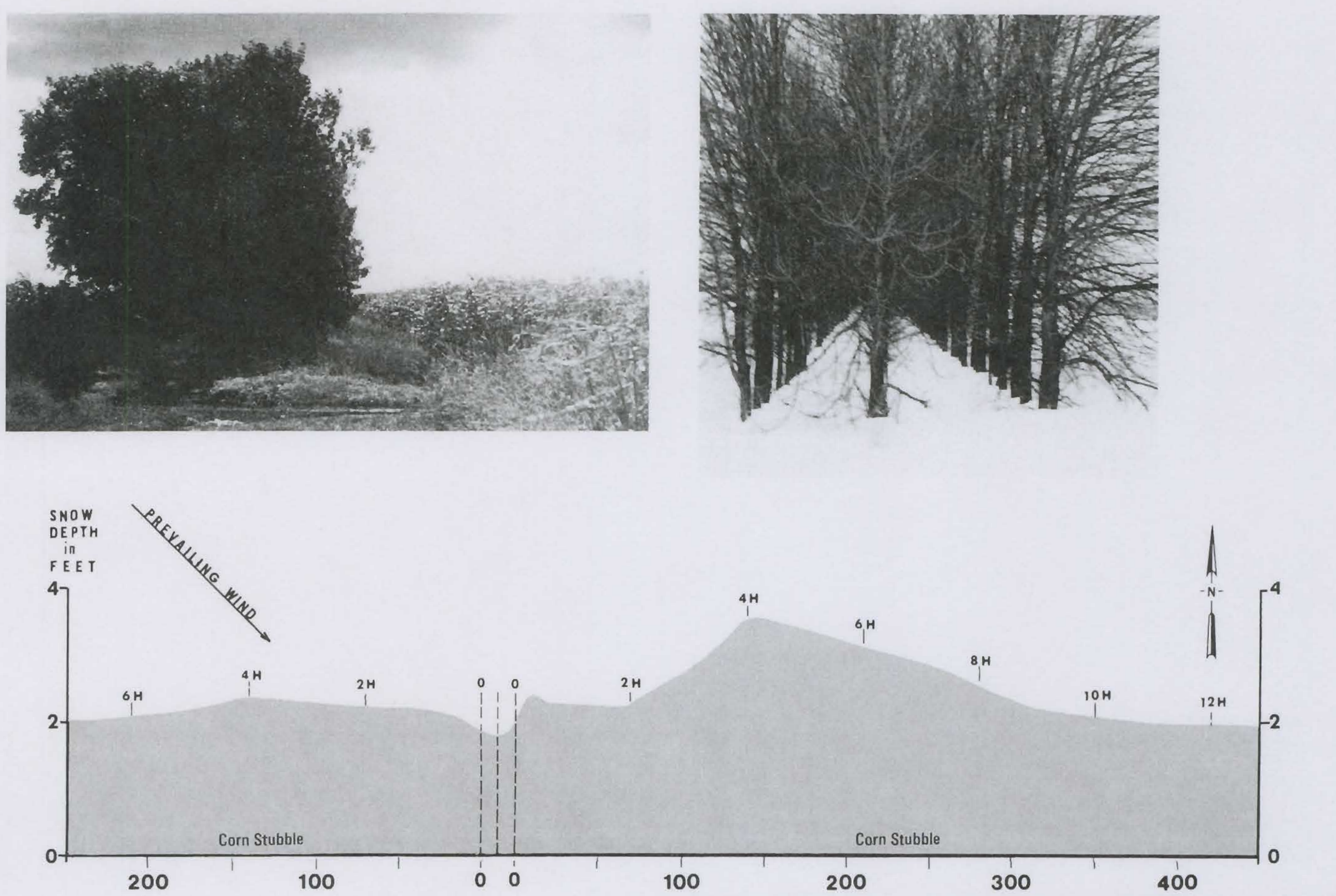


Figure 11. Snow distribution pattern of three-row, north-south green ash field windbreak. Average height—35 feet. Spacing—4 by 6 feet. Photographs show a fall and winter south-end view of this windbreak. Hastings, Minnesota, 1961-62.

moisture for the trees but did conserve additional moisture for the cropland from 2H to 10H on the leeward side.

Evidently the close spacing (4 by 6 feet) caused the lower branches to "shade out" and prune naturally a few feet from the ground line. This, plus the fact that green ash has sparse branching, caused the wind to slow down and filter through the lower portion of the trees, resulting in snow spreading out over a portion of the protected cropland. With proper spacing, a single row of green ash would have been more effective and would have taken less cropland out of production.

Pruning and Spacing Effect on Snow Distribution of Single-Row, East-West Windbreaks

During the winter of 1970-71 (a light snowfall winter), snow distribution measurements were taken of two single-row Siberian elm windbreaks—one pruned and the other unpruned—at the Northwest Agricultural Experiment Station, Crookston, in northwestern Minnesota. These windbreaks were planted in 1963, oriented east-west on level cropland.

Snow distribution measurements were again taken during the winter of 1974-75 at Crookston as well as the West Central Agricultural Experiment Station, Morris, in west central Minnesota. The same two windbreaks used in the 1970-71 Crookston study were used in the 1974-75 study. The windbreaks used at Morris were planted in 1966 and consisted of a single-row Siberian elm and a single-row green ash, both oriented east-west on rolling cropland. Both Morris windbreaks had three different spacings, and the elm windbreak had sections of pruned and unpruned trees. Cropland to the leeward and windward of all windbreaks at both experiment stations was fall plowed.

The 1975 measurements were taken after the second of two January blizzards (January 11 and January 21). Measurements at Morris were taken on January 22, and the Crookston measurements on January 23. Both storms, out of the northwest, began around noon with a drizzle, mild temperatures, and light winds. The drizzle changed to fairly heavy rains, while wind velocities increased, resulting in a driving rain. This soon changed to driving wet snow as the temperature steadily dropped. A full-scale blizzard developed as wind velocities increased and temperatures dropped—to approximately -20° F during the night.

Total snowfall as of January 22, 1975 (one day after the second blizzard), was approximately 1.5 feet at Crookston and 2.5 feet at Morris. There were 6 inches of snow on the ground on January 22 at Crookston and 18 inches at Morris. There were 62 mph maximum and 45 mph average winds during the January 21 blizzard at Crookston, while the maximum velocities at Morris were 75-80 mph.

Under normal winter storm conditions (storms not preceded by rain or wet snow), unprotected plowed fields would be swept clean—snow and topsoil would drift into roadside ditches or behind the first barrier in the path of the blowing snow. Immediately after the January 21 blizzard, unprotected plowed fields had several inches of snow cover with fairly uniformly distributed small mound-like drifts 12-18 inches deep interspersed with patches of bare land. On many fields these snowdrifts were covered with a layer of topsoil (figure 12); in fact, the fields were so black that from a distance they appeared as bare plowed land.

Figure 12. Valuable topsoil covering snowdrifts on open, plowed field in northwestern Minnesota following January 1975 blizzards.

Since unprotected plowed fields were more or less covered with snow, complete snow cover on plowed fields to the leeward of barriers could be expected. This was not true—fields were bare at distances of approximately 10H to 15H to the leeward of barriers. The width of the bare strip and the distance at which the bare area occurred to the leeward of the barrier depended on the height and density of the barrier. Such conditions were observed behind all types of barriers—field windbreaks, woodlands, farmsteads, roadways, and railroad beds. Maximum snow accumulation occurred near the barrier to the leeward—the denser the barrier, the deeper the snowdrifts and the closer the snowdrifts to the barrier.

Apparently the rain and wet snow preceding the January 11 and January 21 blizzards created a sticky base on plowed fields to catch blowing snow before the temperatures dropped well below freezing; consequently, the small snowdrifts on plowed fields increased in size as the snowdrifts extended farther to the leeward. If unprotected plowed fields were covered with snow, then why did the bare plowed fields occur beyond 10H to 15H to the leeward of barriers? Rain, snow, temperature, and soil surface conditions would be similar at 10H to 15H behind barriers (windbreaks) as they would be on open fields—only wind velocity, wind action, and wind chill would be different. Apparently winds of blizzard proportions created wind turbulence and eddies of sufficient force to prevent wet snow from sticking to the soil and swept it toward the windbreak, leaving bare soil beyond 10H to 15H.

SIBERIAN ELM WINDBREAK (WINTER 1970-71; NORTHWEST AGRICULTURAL EXPERIMENT STATION, CROOKSTON)

The north row and center row of a series of three windbreaks at the Crookston station were used in this study. The rows were approximately ½ mile long and were spaced about 50 rods (800 feet) apart. Trees in the row were spaced 5 feet apart.

The north row was unpruned, and the trees averaged about 20 feet tall in 1971. Cropland to the north was unprotected—there were no obstacles of any kind for at least a mile to the northwest. The center row, about 50 rods to the south, was pruned underneath to a height of about 3 feet, and the trees averaged 15 feet in height. Snow depth measurements were taken after a winter of light snowfall and no blizzard conditions.

Unpruned Windbreak

Since the unpruned windbreak was a dense windbreak, major snow accumulation occurred near the trees on both sides (figure 13). On the windward side, snow depth increased gradually from 1 foot at 0H to 2 feet at 2.5H, after which it gradually decreased to a depth of a few inches at 5H; bare land occurred at about 7H. On the leeward side, maximum snow depth occurred at 2H where it was 4 feet deep, after which it dropped off to a 6-inch depth at 6H; bare land occurred at about 8H and beyond.

McMartin et al. (10) reported maximum snow depths occurring at 1H on the leeward side of single-row Siberian elm windbreaks (14 windbreaks oriented both east-west and north-south) in North Dakota, and that there was a rapid drop-off from 2H to 5H beyond which "fields were free of snow." McMartin's study included the winters of 1970, 1971, and 1972. Recall that the maximum snow depth behind the Crookston windbreak occurred at 2H, then dropped off rapidly to 6H. This means that the snowdrift behind the North Dakota windbreak was 1 tree height (tree heights averaged from 21 to 25 feet) closer to the tree row than the snowdrift behind the Crookston windbreak—a difference of roughly 20 feet.

The difference in location of the snowdrift with respect to the windbreak must be attributed to differences in densities of the North Dakota and Crookston windbreaks. Stoeckeler (14), and many other workers, report that dense windbreaks tend to trap deep snowdrifts near the trees. Since trees in the North Dakota windbreaks were planted 2-3 feet apart compared to a 5-foot spacing in the Crookston windbreak, the North Dakota windbreaks are obviously denser and would be expected to trap snowdrifts nearer the trees.

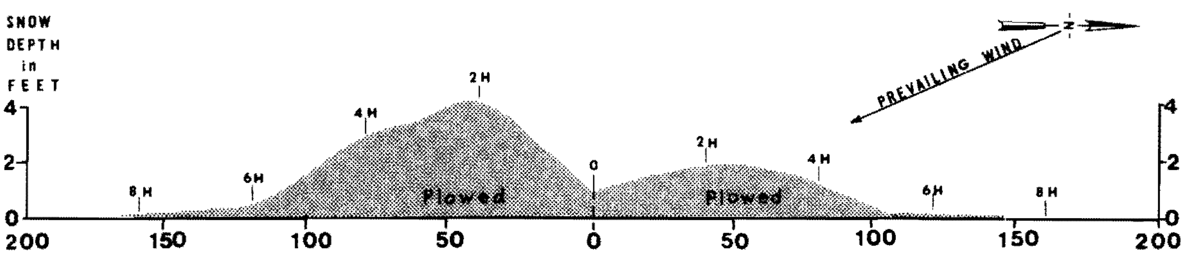
Pruned Windbreak

Figure 14 shows the snow distribution pattern of the pruned windbreak. Snow depth within this tree row was also about 1 foot. It reached a maximum of about 1.5 feet at 1.5H to the windward, after which the depth tapered down to bare land a little beyond 11H. On the leeward side, a 1-foot snow depth was maintained to a distance of 3H. A maximum depth of almost 3 feet occurred at 5H, after which it tapered off to 6 inches at 13H. This depth was maintained for several more tree heights.

The two snow distribution patterns in figures 13 and 14 show that the pruned windbreak (figure 14) distributes snow to a considerably greater distance over the cropland on the leeward side. A pruned Siberian elm windbreak, therefore, is of greater benefit in conserving soil moisture over a larger area of cropland. Since bare land occurred a little beyond 11H (165 feet) to the windward of the south windbreak (figure 14) and a little beyond 8H (160 feet) to the leeward of the north windbreak (figure 13), there was a 475-foot-wide strip of bare land in the center between the two belts.

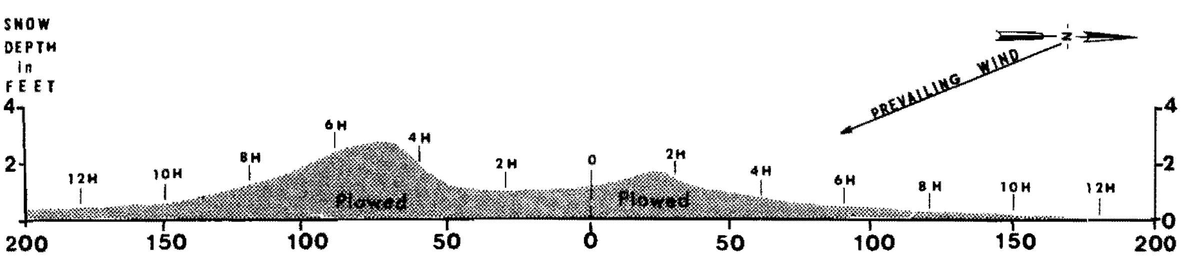
SIBERIAN ELM WINDBREAK (WINTER 1974-75; NORTHWEST AGRICULTURAL EXPERIMENT STATION, CROOKSTON)

Snow distribution patterns of the two Crookston windbreaks studied during the winter of 1970-71 were



Horizontal distance: Upper scale in tree heights—lower scale in feet

Figure 13. Snow distribution pattern of single-row, east-west unpruned Siberian elm field windbreak. Average height—20 feet. Spacing—5 feet. Crookston, Minnesota, 1970-71.



Horizontal distance: Upper scale in tree heights—lower scale in feet

Figure 14. Snow distribution pattern of single-row, east-west pruned Siberian elm field windbreak. Average height—15 feet. Spacing—5 feet. Crookston, Minnesota, 1970-71.

again studied during the winter of 1974-75. In 1975 the trees averaged 25 feet tall in the unpruned windbreak and 20 feet tall in the pruned windbreak. Because of four additional years of growth, both windbreaks were denser than in 1971.

Unpruned Windbreak

Figure 15 shows the snow distribution pattern of the unpruned windbreak. Snow depth was about 3.5 feet within the tree row. To the windward there was a sharp decrease in depth to 2 feet at 0.5H, a sharp increase to 3 feet at 0.75H, another sharp decrease to 2 feet at 1H, a gradual increase to 2.5 feet at 2H, followed by a gradual decrease to a depth of a few inches at about 7H.

On the leeward side there was a very sharp increase from a depth of 3.5 feet in the tree row to a 9-foot depth at about 1.5H. This was followed by a long, fairly steep decline to exposed plowed land at a little beyond 9H—a decrease in snow depth at the rate of approximately 1 foot for every tree height from the windbreak. This corresponds with George's (5) finding that snowdrifts to the leeward of dense windbreaks seldom extend beyond 10H.

Two factors were responsible for the snowdrift occurring so close to the windbreak (a maximum depth of 9 feet slightly beyond 1H): windbreak density and wind velocity. It was mentioned earlier that the denser the windbreak, the closer the snowdrift to the windbreak. In reporting on a study of the effect of various snow fences on snowdrifting with reference to a solid fence, Caborn (1) stated, "The greater the wind velocity, the closer is the drift to the fence" (figure 15).

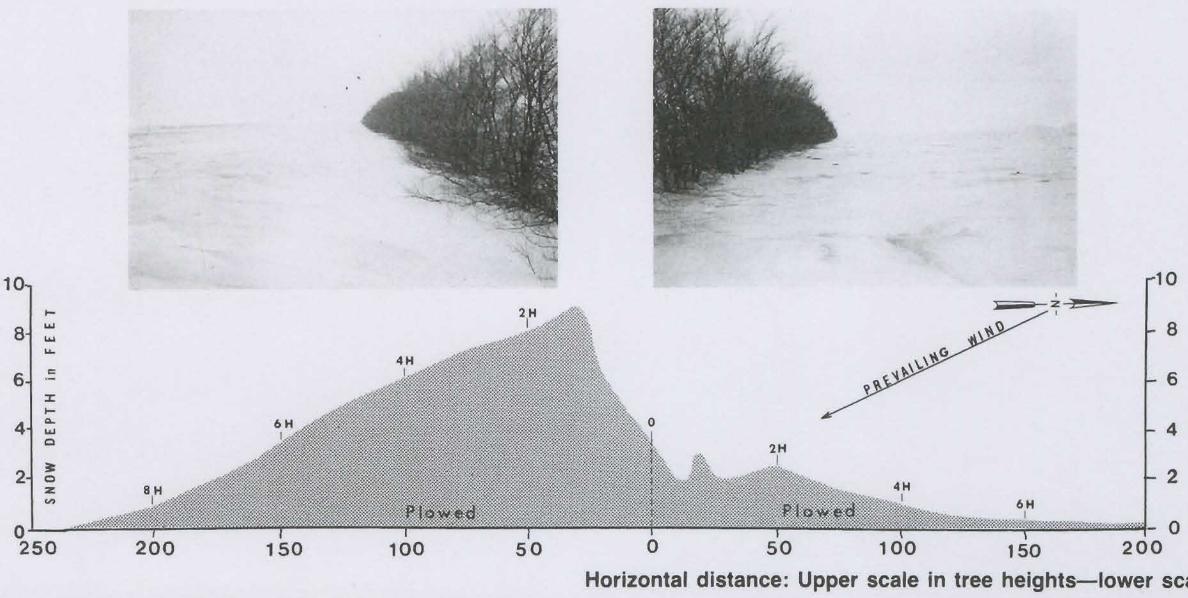


Figure 15. Snow distribution pattern of single-row, east-west unpruned Siberian elm field windbreak. Average height—25 feet. Spacing—5 feet. (Same windbreak as in figure 13.) Paired photographs show snowdrifts on south and north sides, respectively. Crookston, Minnesota, 1974-75.

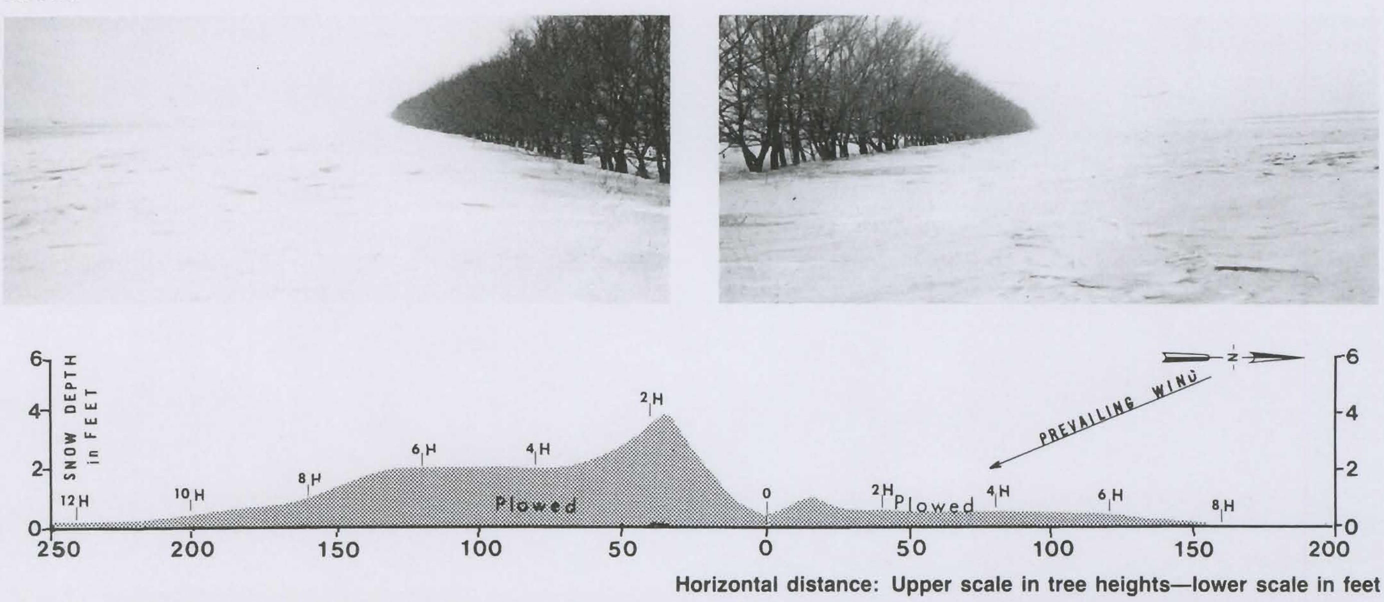


Figure 16. Snow distribution pattern of single-row, east-west pruned Siberian elm field windbreak. Average height—20 feet. Spacing—5 feet. (Same windbreak as in figure 14.) Paired photographs show snowdrifts on south and north sides, respectively. Crookston, Minnesota, 1974-75.

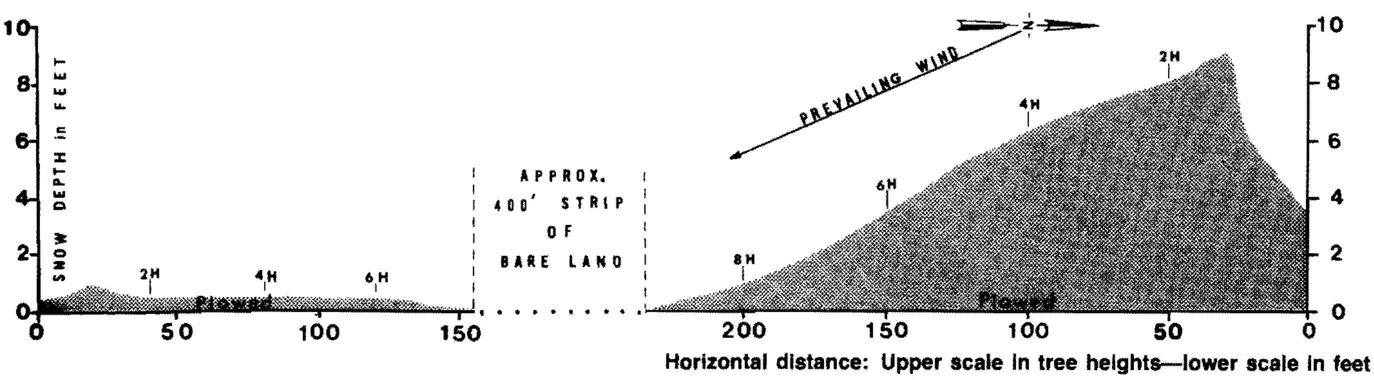


Figure 17. Snow distribution patterns between windbreaks shown in figures 15 and 16. Unpruned windbreak on the right; pruned windbreak on the left. Crookston, Minnesota, 1974-75.

Pruned Windbreak

Figure 16 shows the snow distribution pattern of a 20-foot-tall windbreak that was pruned from below to a height of approximately 3 feet. This windbreak was located about 50 rods south of the unpruned windbreak shown in figure 15. Snow depth within the row was about 6 inches. Maximum snow depth of 4 feet occurred at about 1.5H behind the windbreak. Bare land occurred slightly beyond 12H. The snow distribution pattern behind the unpruned windbreak indicated a large area of vigorous eddying between 9H and 1.5H. Behind the pruned windbreak there were two areas of less vigorous eddying—between 3H and 1.5H and between 10H and 7H.

Figure 17 shows the snow distribution pattern between the two windbreaks of figures 15 and 16. The pruned windbreak is on the left (south) and shows the snow pattern on the windward side, while the unpruned windbreak is on the right (north) and shows the snow pattern on the leeward side—note the strip of bare land about halfway between the two windbreaks.

Although the snowdrift behind the pruned windbreak (figure 16) is too deep and too close to the trees, it is obvious that this drift is shallower and extends farther to the leeward than the snowdrift behind the unpruned windbreak (figure 15).

Whether or not the unpruned windbreak had an effect on the pruned windbreak located 32H to the leeward is difficult to answer. Researchers do not agree as to the distance of windbreak effectiveness. Distance of effectiveness would vary with the nature of the snowstorm such as wind direction and velocity, amount of snowfall, and temperature. Most reports indicate maximum distance of protection is somewhere between 20H and 30H. Caborn (1), in reporting on Nageli's (1946) studies in Switzerland, stated that protection "extended to leeward for an average of 30H, seldom more than 35H, never more than 40H or less than 20H." He also stated that protection extended up to 9H to the windward. George et al. (6) reported that a series of single-row windbreaks spaced 400 feet apart of various species ranging from 10 to 14 feet tall and ranging in density from 30 to 70 percent had no cumulative effect in reducing wind velocities and in catching snow.

SIBERIAN ELM WINDBREAK (WINTER 1974-75; WEST CENTRAL AGRICULTURAL EXPERIMENT STATION, MORRIS)

The single-row Siberian elm windbreak at Morris was divided into three 900-foot sections. Each 900-foot section, in turn, was divided into six 150-foot sections. The 150-foot sections were randomly selected for three different spacings—5 feet, 10 feet, and 15 feet. One half of the 150-foot sections was randomly selected from each of the three spacings for pruning. These were pruned from below to approximately 3 feet.

Snow distribution patterns for both pruned and unpruned sections at the 5-foot, 10-foot, and 15-foot spacings are shown in figures 18, 19, and 20, respectively. Light-shaded areas in all three figures represent snow distribution patterns for the unpruned sections, and the dark-shaded areas represent patterns for the pruned sections. The average tree height was 20 feet.

Five-Foot Spacing

The snow distribution patterns (figure 18) were essentially the same for both pruned and unpruned sections at the 5-foot spacings, except that snow depths were consistently deeper where the trees were unpruned. Average snow depth within the row of the unpruned section was 5.5 feet compared with 2.5 feet within the pruned section. The maximum depths of 11 feet behind the unpruned section and 9 feet behind the pruned section were both located at 1.5H. Between 1.5H and 5.5H, behind both unpruned and pruned sections, there was approximately a 2-foot decrease in snow depth for every 1H increase in distance.

Figure 18 demonstrates that Siberian elm on a 5-foot spacing is much too dense, even when pruned to a height of 3 feet, to do an adequate job of distributing snow over the cropland.

It might be well to compare the leeward snow distribution patterns of the 5-foot-spaced unpruned sections in the Morris windbreak (figure 18) with the unpruned Crookston windbreak (figure 17). Snow depth within the tree row was 3.5 feet at Crookston compared to 5.5 feet at Morris; maximum depth on the leeward was 9 feet at Crookston compared to 11 feet at Morris; and maximum depth occurred at 1.5H at both locations. The

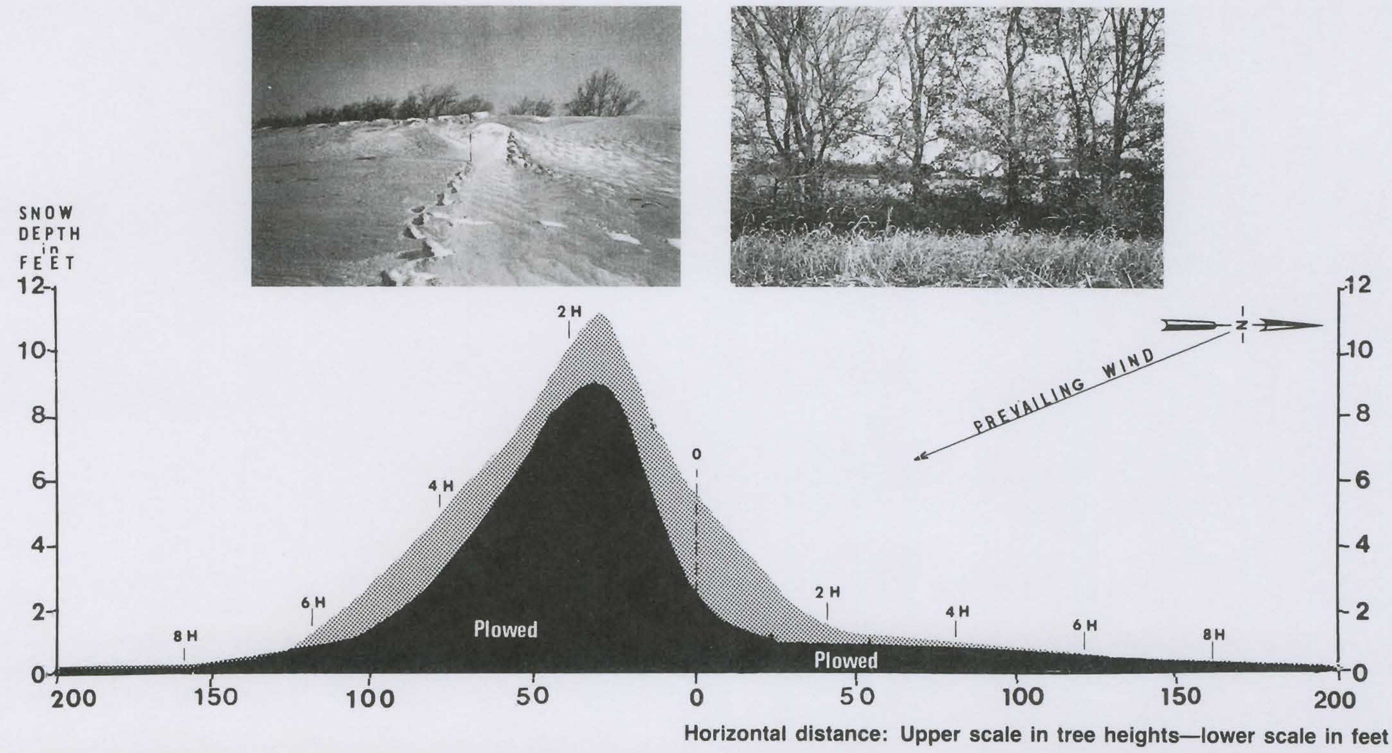


Figure 18. Snow distribution patterns of single-row, east-west pruned and unpruned Siberian elm field windbreak. Average height—20 feet. Spacing—5 feet. Light-shaded area represents the unpruned section, while dark-shaded area represents pruned section. Morris, Minnesota, 1974-75. Photograph on left shows an 11-foot snowdrift on the leeward side of unpruned section. Photograph on right shows 5-foot spacing (fall 1974).

south slope of the snowdrift behind the Morris windbreak dropped off at the rate of 2 feet per tree height compared to a drop-off of 1 foot per tree height at the Crookston windbreak; therefore, the snowdrift behind the Morris windbreak was narrower.

Since both windbreaks were about equal density, why was the snowdrift behind the Morris windbreak deeper and confined to a smaller area adjacent to the windbreak? There are two factors which contributed to this difference: Morris had received 12 inches more snow and maximum wind velocities during the January 21, 1975, blizzard were 15 mph greater at Morris (75-80 mph at Morris and 62 mph at Crookston). The higher wind velocity at Morris would create more vigorous eddying and cause eddying to occur in a more restricted area closer behind the windbreak.

The *pruned* windbreaks at both Crookston (figure 16) and Morris (figure 18, dark-shaded area) had maximum leeward snow depths occurring at 1.5H—beyond this point similarities cease. The snowdrift behind the Morris windbreak was more than twice as deep (9 feet versus 4 feet) and confined nearer to the windbreak—about 4 tree heights (4H) closer. Some of this difference was due to the greater amount of snowfall and higher wind velocities occurring at Morris; however, there may be another factor. There were no obstacles north of the Morris windbreak to influence wind velocity, but the Crookston windbreak is about 800 feet (32H) south of a dense 25-foot-tall unpruned windbreak (figure 15)—the results of most studies would indicate that this distance (32H) between windbreaks is too great for one windbreak to have an influence on the other.

Ten-Foot Spacing

At the 10-foot spacing (figure 19), a maximum snow depth of 10 feet occurred at about 1.5H behind the unpruned section, while a maximum snow depth of 5 feet occurred at 2.5H behind the pruned section. The difference in snow depth gradually narrowed until at a little over 8.5H the depths were the same where it was about 6 inches deep. Bare soil occurred just beyond 9H to the leeward of the unpruned section and somewhat beyond 10H to the leeward of the pruned section.

Unpruned Siberian elm on a 10-foot spacing is much too dense for uniform snow distribution. Although the snowdrift behind the pruned section occurred 1 tree height farther to the leeward than the drift behind the pruned section of the 5-foot spacing (figure 18), the drift is still too near the windbreak and too deep. So, under blizzard conditions, Siberian elm on a 10-foot spacing is too dense, even when pruned to a height of 3 feet.

Fifteen-Foot Spacing

Figure 20 shows snow distribution patterns for both unpruned and pruned sections of Siberian elm where trees are spaced 15 feet apart. The deepest part of the snowdrift behind the unpruned section was 1.5H wide, extending from 1.5H to 3H where the snow depth was 7.5 feet, compared to a maximum depth of 10 feet at 1H behind the 10-foot spacing. The maximum snow depth of 5 feet behind the pruned section was the same as behind the pruned section of the 10-foot spacing—the primary difference in drift pattern was that the maximum depth was located at 4H behind the 15-foot spacing compared to 2.5H behind the 10-foot spacing.

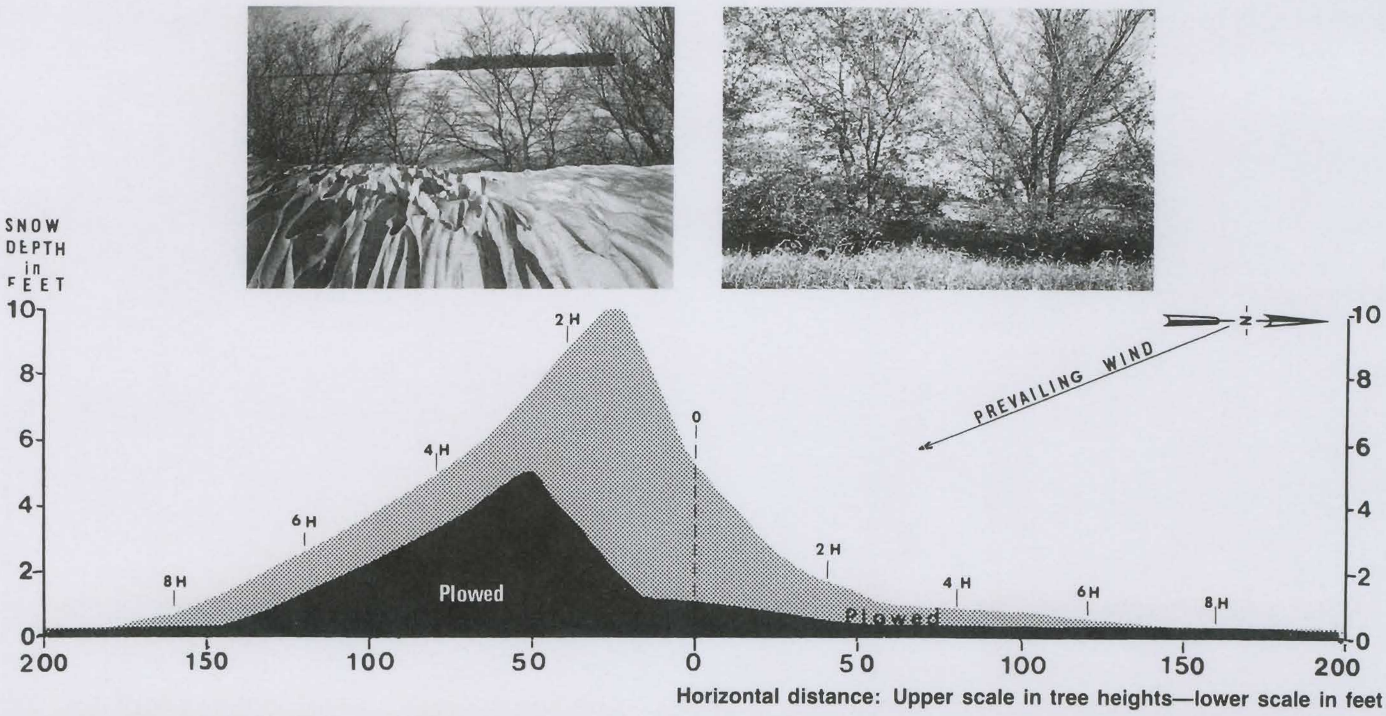


Figure 19. Snow distribution patterns of single-row, east-west pruned and unpruned Siberian elm field windbreak. Average height—20 feet. Spacing—10 feet. Light-shaded area represents unpruned section, while dark-shaded area represents pruned section. Morris, Minnesota 1974-75. All photographs taken from leeward side. Photograph on left shows a snowdrift facing a pruned section on the leeward side. Photograph on right shows 10-foot spacing (fall 1974).

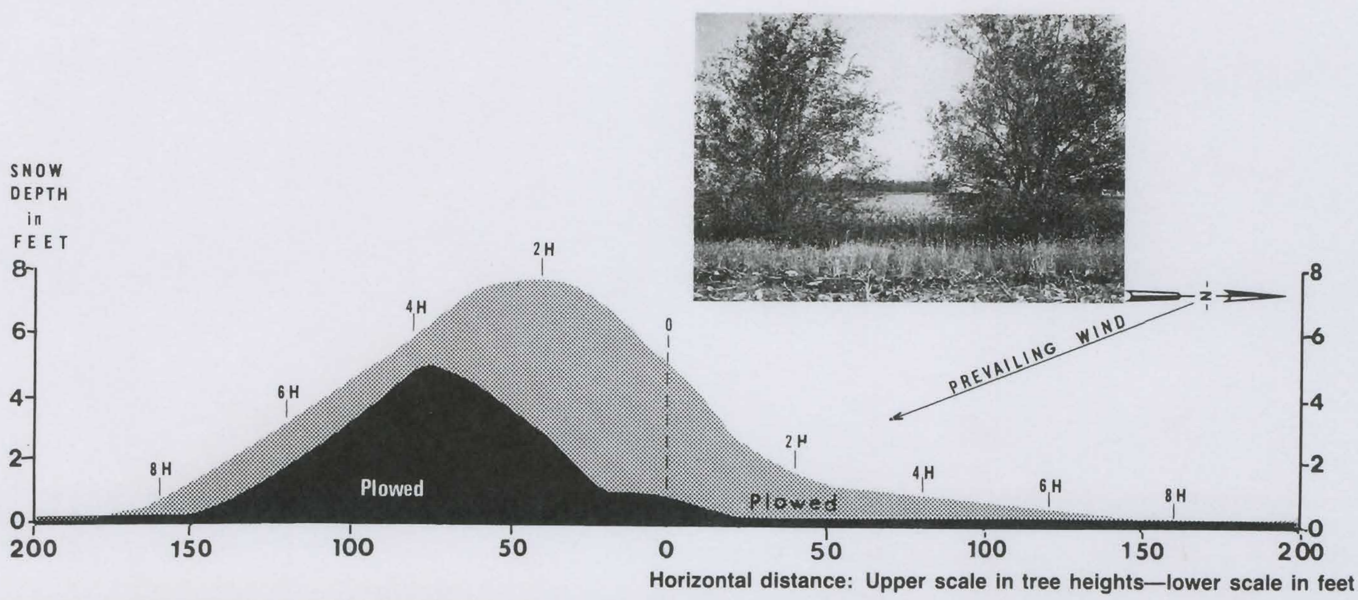


Figure 20. Snow distribution patterns of single-row, east-west pruned and unpruned Siberian elm field windbreak. Average height—20 feet. Spacing—15 feet. Light-shaded area represents unpruned section, while dark-shaded area represents pruned section. Morris, Minnesota, 1974-75. Photograph shows 10-foot spacing (fall 1974).

The conclusion is that increasing the spacing of Siberian elm to 15 feet results in a windbreak that is still too dense under blizzard conditions for uniform snow distribution even when trees are pruned to a height of 3 feet.

Comparison of Five-, Ten-, and Fifteen-Foot Spacings

Steepness of the leeward snowdrift slope (south slope) tends to decrease as trees are spaced farther apart. Behind the pruned sections there is a pronounced movement of the snowdrift away from the windbreak as tree spacing increases—peak is located at 1.5H behind 5-foot spacing, 2.5H behind 10-foot spacing, and 4H behind 15-foot spacing (table 1) (13). In comparison, peaks behind the unpruned sections are located at about 1.5H behind both 5-foot and 10-foot spacing, and the center of a wider peak located at 2H behind the 15-foot spacing. In no situation did eddying occur beyond 9H. Gloyne (8) reported that the denser the windbreak, the more vigorous the eddying, and that eddying is usually

Table 1. Comparison of snow depths within row and to the leeward of unpruned and pruned sections of a 20-foot-tall, single-row Siberian elm field windbreak at 5-, 10-, and 15-foot spacings: Morris, Minnesota, 1974-75

	5-foot spacing		10-foot spacing		15-foot spacing	
	Unpruned	Pruned	Unpruned	Pruned	Unpruned	Pruned
Snow depth within row	5.5 ft.	2.5 ft.	5.5 ft.	1.0 ft.	5.0 ft.	1.0 ft.
Maximum snow depth	11.0 ft.	9.0 ft.	10.0 ft.	5.0 ft.	7.5 ft.	5.0 ft.
Approximate distance to maximum snow depth	1.5H[1]	1.5H	1.5H	2.5H	1.5-3H[2]	4H
Approximate distance to bare land	7H	10H	9H	10H	9H	10H

[1]H = average tree height in the windbreak row.

[2]Maximum snow depth was a plateau extending from 1.5H to 3H.

evident within 10H or 15H on the leeward side of a dense windbreak.

GREEN ASH WINDBREAK (WINTER 1974-75; WEST CENTRAL AGRICULTURAL EXPERIMENT STATION, MORRIS)

The single-row green ash windbreak was designed in the same manner as the single-row Siberian elm except that no pruning was performed. This windbreak was located 660 feet south of the Siberian elm windbreak shown in figures 18, 19, and 20. The average tree height was 15 feet.

Five-Foot Spacing

The light-shaded area in figure 21 indicates the snow distribution pattern for the 5-foot spacing. Snow depth gradually increased from 1.5 feet within the row to the maximum depth of 4 feet at 3H on the leeward side, an increase of 6 inches in depth for every 1H increase in distance from the windbreak up to 3H. From the maximum depth of 4 feet at 3H, snow depth decreased to the leeward at the rate of approximately 3 inches per 1H until bare land occurred beyond 12H.

Although the total volume of snow is essentially the same as that behind the pruned Siberian elm spaced at 15 feet (figure 20), it is spread out over more cropland. The snowdrift behind the ash would disappear earlier in the spring, and the cropland would dry out sooner and would be ready for earlier seeding.

Ten- and Fifteen-Foot Spacing

Since there was no appreciable difference in snowdrift patterns behind the 10- and 15-foot spacings, the dark-shaded area of figure 21 shows the drift pattern for both spacings. There was a shallow snowdrift on the leeward side with a maximum depth of a little over 1 foot at about 2.5H; the major drift covered an area between 1H and 3.5H. There was about a 6-inch depth at 4H, after which the drift tapered off to a few inches which extended out over the cropland to a distance of approximately 15H. It is obvious that this snowdrift will not delay spring farming operations.

The snow distribution patterns in figure 21 indicate that green ash is too dense when trees are spaced 5 feet apart. Since there was no apparent difference when either a 10-foot or 15-foot spacing was used and there

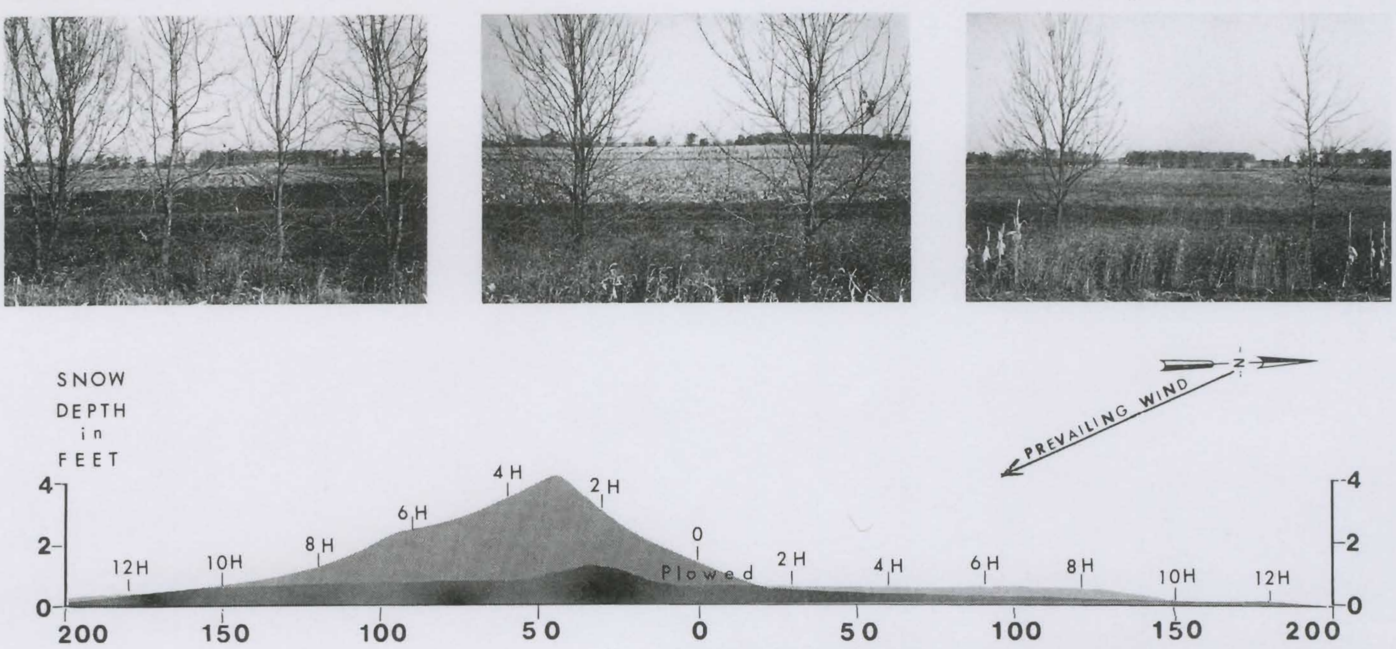


Figure 21. Snow distribution pattern of single-row, east-west green ash field windbreak. Average height—15 feet. Light-shaded area represents 5-foot spacing, while dark-shaded area represents both 10- and 15-foot spacings. Morris, Minnesota, 1974-75. Photograph shows 5-, 10-, and 15-foot spacings (fall 1974).

was fairly uniform snow distribution over the cropland at both spacings, the 10-foot spacing probably should be recommended because it would give better protection from soil erosion. Apparently snow distribution behind green ash can be controlled by regulating spacing, without the need for pruning.

North-South Orientation Effect on Snow Distribution of Single-Row Siberian Elm Windbreak (Winter 1974-75; Warren, Minnesota)

The previous discussion has been limited to snow distribution patterns of single-row windbreaks with an east-west orientation. For comparative purposes, snow depth measurements were also taken on both sides of a single-row *unpruned* Siberian elm windbreak with a north-south orientation (figure 22). This windbreak is located on a private farm south of Warren, Minnesota (about 25 miles north of Crookston), where there were many series of single-row Siberian elm windbreaks spaced about 40 rods apart and oriented both east-west and north-south. It was obvious that the snow distribution patterns behind north-south windbreaks were distinctly different from the patterns behind east-west windbreaks. The patterns behind all windbreaks having the same orientation were essentially the same.

Trees in the north-south windbreak shown in figure 22 were spaced 5 feet apart and averaged 15 feet tall. The snow distribution pattern shows three distinct peaks within 5H on the leeward side. The maximum depth was 6 feet just short of 5H, after which there was a near-vertical drop-off to a 1-foot depth at 5H. Also, the snowdrift immediately adjacent to the trees on the windward side dropped off sharply from a 3-foot depth to a 1.5-foot depth. These characteristics in the snow pattern (the three peaks and the two vertical dropoffs) were typical of north-south windbreaks and were not observed behind any of the east-west windbreaks. Usually, the snowdrift on the leeward of north-south oriented windbreaks was narrower and located closer to the trees.

CONCLUSIONS

Since the north-south windbreaks were of the same age, height, and density as the east-west windbreaks, the only remaining factor that could cause the difference in pattern of snow distribution is the angle at which the wind approached the windbreak. George (5), in his study of windbreaks near Mandan, North Dakota, reported that snowdrifts were wider and shallower behind east-west windbreaks than behind north-south windbreaks. He also reported that "winds seldom blow from due north, south, east or west," but rather from an angle of 45° or less, and that winds nearly parallel to the windbreak will cause narrower, deeper snowdrifts, while winds nearly perpendicular to a dense windbreak will cause wider, shallower snowdrifts. This would indicate that the snow distribution pattern of the north-south windbreak shown in figure 22 (as well as the east-west windbreaks) resulted from winds coming from an angle of less than 45° or somewhere between 315° (NW) and 360° (N). Lawrence (9) reported that winds nearly parallel to the windbreak resulted in frequent gusts toward the windbreak at distances of 3.6H to 6H on the leeward—in other words, eddying occurred within a 6H area. Figure 22 shows that violent eddying occurred between 5H and 6H. If these snowdrift patterns are consistent for north-south oriented windbreaks in a given area, such as western Minnesota, then east-west oriented windbreaks should be recommended for more uniform snow distribution over the protected cropland.

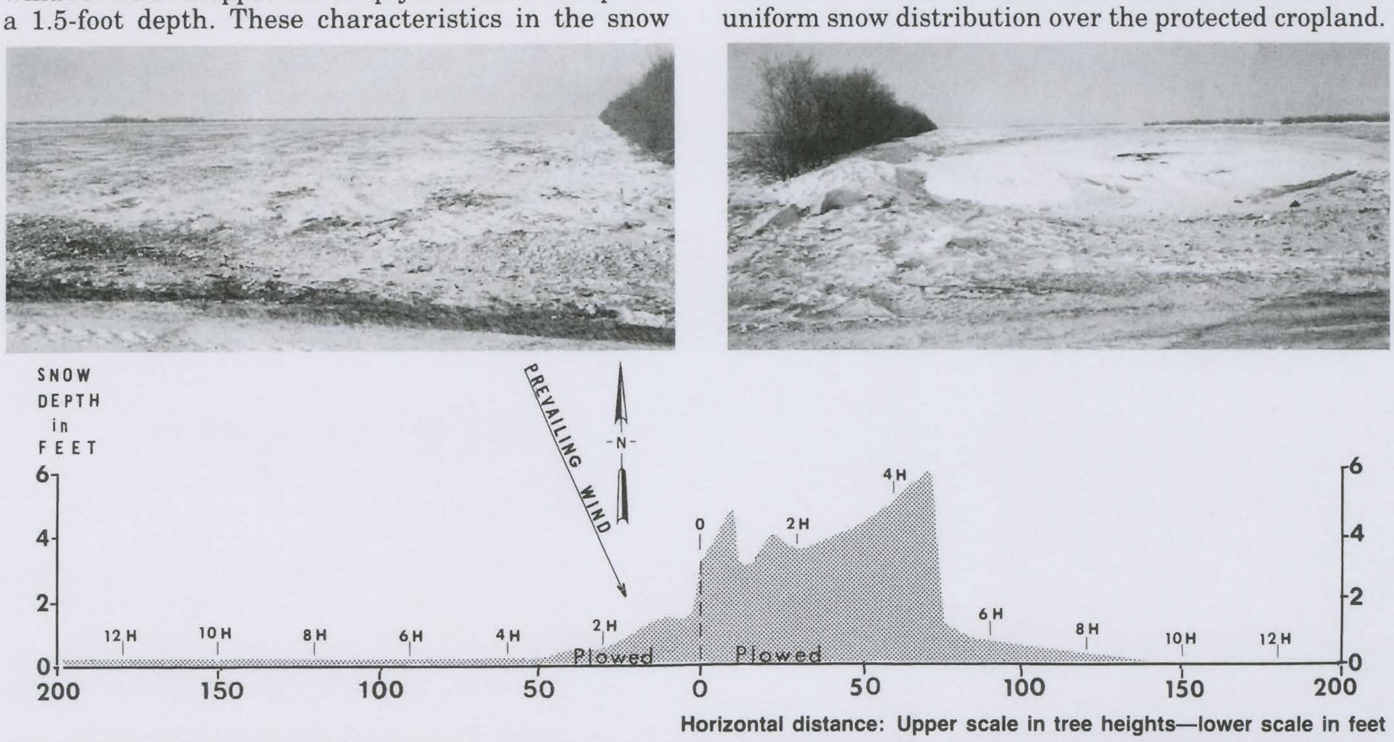


Figure 22. Snow distribution pattern of single-row, north-south unpruned field windbreak. Average height—15 feet. Spacing—5 feet. Note the difference in pattern compared with patterns of east-west elm windbreaks shown in other figures. Paired photograph shows snowdrifts on west and east (leeward) sides, respectively. Warren, Minnesota, 1974-75.

Observations of Snow Distribution Patterns of Unpruned and Pruned Single-Row Siberian Elm Windbreaks (Winter 1974-75; Warren, Minnesota)

While driving through the Warren area 2 days after the second of two January 1975 blizzards, a series of east-west oriented, single-row Siberian elm windbreaks was observed on both sides of the highway. The windbreaks on the east side of the highway were unpruned, while those on the west side were pruned from below to a height of about 3-4 feet. It was estimated that the trees were on a 5- or 6-foot spacing and averaged about 20 feet tall. The rows were spaced at intervals of about 660 feet. The photographs shown in figure 23 illustrate the difference in snow distribution patterns.

Figure 23 (left) was taken from the highway looking east halfway between two *unpruned* windbreaks. There was a heavy accumulation of snow next to the trees on the leeward side of the north (left) windbreak and a lighter accumulation on the windward side of the south (right) windbreak. There was approximately a 200-foot wide strip of exposed soil about halfway between the two windbreaks.

Figure 23 (right) was taken while facing west, halfway between two *pruned* windbreaks directly across the highway. The snowdrifts on the leeward side of the north (right) windbreak were not as deep as the drifts to the leeward of the unpruned windbreak, but the drifts extended farther across the cropland. There was very little exposed soil between these pruned windbreaks. These photographs show that light pruning allows some snow to filter through.

SUMMARY

The value of field windbreaks in preventing soil loss, conserving soil moisture, and thus increasing crop yields is as important today as it was immediately after the dust bowl of 1934. It may even be *more important* today. Since 1934, and particularly since World War II, the demands on farmers to produce more food increased as population increased. To increase production, farmers needed more land, improved seed varieties, chemicals for insect and weed control, and more fertilizer. All these needs required more and better equipment. Consequently, there was rapid improvement in technology which brought about vast changes in farming operations.

The horse and horse-drawn equipment were replaced by the tractor and tractor-drawn equipment; and over the years, tractors and equipment continued to increase in size. Such operations as plowing, seeding, cultivating, and harvesting that originally took days and even weeks can now be done in hours.

To accommodate large machinery, farmers bought each other out, so the total number of farms decreased while individual farm size increased. Farmers needed longer fields with as few "turnarounds" as possible. Consequently, abandoned farmstead buildings and fences were torn down, and some farm woodlands were cleared. Occasionally, some field windbreaks were also removed.

During this period of technological change, there was a shift from multiple-row to single-row field windbreaks. A few of these windbreaks consisted of trees alternated with a shrub species. It was soon discovered that shrubs catch too much snow; therefore, shrubs, for the most part, have been eliminated in more recent plantings, at least in North Dakota and Minnesota where snow is a problem.

Siberian elm was the most popular species planted in Minnesota because of its good initial survival, immediate rapid growth, and its ability to grow in the alkaline prairie soils. Green ash was the second most popular species. It has excellent survival and will grow in alkaline soils but is slower growing than Siberian elm. Quite a few poplar species and varieties were also planted, but some farmers complained about twigs and branches snapping off and blowing into the fields where they interfered with field equipment.

Trees were usually planted on 4-, 5-, or 6-foot spacings (some as close as 2 and 3 feet) regardless of species. The close spacing and rapid growth of Siberian elm, for example, along with its characteristic dense and wide-spreading branches, resulted in a dense, hedge-like

Figure 23. Left photograph: facing east halfway between two *unpruned*, single-row, 20-foot-tall field windbreaks spaced 40 rods apart. Note strip of bare land in center of picture. Right photograph: facing west (directly across highway from left photograph) halfway between two *pruned*, single-row, 20-foot-tall field windbreaks spaced 40 rods apart. Note that practically all of the cropland has a snow cover. Photographs taken south of Warren, Minnesota, 2 days after January 21, 1975, blizzard.

barrier in just a few years. This meant that at close spacings, Siberian elm trapped snow near the trees on the leeward side at an early age. With each succeeding year the trees became more crowded, the windbreak more dense, and the snowdrifts deeper and closer to the windbreak on the leeward side. According to George (5), dense windbreaks cause a wind turbulence to the leeward which results in a reverse of wind direction or eddying. Gloyne (8) reported that the denser the windbreak, the more vigorous the eddying, and that eddying is usually evident within 10H or 15H on the leeward side of a dense windbreak.

Although the single-row windbreaks in Minnesota served their primary purpose of slowing down the wind enough to prevent the fertile topsoil from blowing off the fields, they, like the earlier multiple-row windbreaks, were catching too much snow next to the trees on the leeward side. This was particularly true of Siberian elm windbreaks. These snowdrifts provided soil moisture for the windbreak trees in the spring; however, crops some distance to the leeward were deprived of additional soil moisture because much of the snow which made up the snowdrift next to the windbreak was swept off the cropland by turbulent winds and, through the process of eddying, blown toward the windbreak. Many farmers objected to these snowdrifts for three reasons: spring farming operations were delayed in the snowdrift area until the soil dried out enough to work; nutrients were leached out of the soil as the snowdrifts melted, requiring heavier applications of fertilizers in the snowdrift area along the entire length of the windbreak; and spring melt of large snowdrifts often caused soil erosion.

Researchers were now faced with the problem of treating (managing) established windbreaks and designing new windbreaks to slow down the wind enough to prevent soil erosion and yet allow blowing snow to filter through the trees and settle over the protected cropland. Established windbreaks could be treated by thinning and/or pruning out the lower branches. Designing new windbreaks, however, involves selecting the most desirable species adapted to the site and planting the trees at the correct spacing for that species.

Characteristics of the Ideal Windbreak Species

In selecting a tree species for field windbreaks, assuming it is adapted to the site, it is important to consider its branching, rooting, and sprouting characterics, as well as its resistance to chemical sprays. Preference should be given to species with the following characteristics:

1. Narrow crowns so that only a narrow strip of adjacent crops will be affected by shading from branches.
2. Porous (fairly open) crowns to allow wind and snow to filter through.
3. Nonbrittle twigs and branches to reduce the incidence of broken twigs and branches blowing into the field and interfering with farming equipment.
4. Nonspreading root system (usually associated with narrow crowns) to compete as little as possible with crops for soil water and nutrients.
5. A minimum tendency to sprout if windbreak is to be thinned and/or trees are to be pruned.
6. A high resistance to damage by chemicals used for controlling weeds in field crops.

Factors Influencing Snowdrift Patterns

The primary factors influencing snow distribution patterns (snowdrift depth, width, and proximity to the windbreak) on the leeward (and windward) side of a windbreak are wind velocity, wind direction or windbreak orientation, and windbreak density.

Many researchers have reported that snowdrifts behind (leeward) a windbreak will be *deeper, narrower,* and *closer to the windbreak* as wind velocities increase, the angle of wind direction decreases, and windbreak density increases.

WIND VELOCITY

As wind passes over the windbreak, wind velocity increases and eddying becomes more vigorous. The more vigorous the eddying, the deeper and narrower the snowdrifts and the closer the snowdrifts to the windbreak.

WIND DIRECTION OR WINDBREAK ORIENTATION

Another important factor in the formation of snowdrifts is wind direction and windbreak orientation. For example, snowdrifts behind east-west windbreaks will become deeper, narrower, and form closer to the trees as wind direction moves from north to west.

In northwestern Minnesota where a series of both east-west and north-south oriented windbreaks are located, the snowdrifts were deeper, narrower, and closer to the trees on the leeward side of north-south windbreaks. This would indicate that the January snowstorms blew in from a little north of northwest. If this is the prevalent pattern for snowstorms, then east-west oriented windbreaks should be recommended for more uniform snow distribution in northwestern Minnesota.

WINDBREAK DENSITY

Dense windbreaks reduce soil erosion, but do not give uniform snow distribution over protected cropland and increase chances of crop damage in the zone of eddying (7). (A windbreak of a deciduous species will be much denser during the growing season when it is in full leaf.) To reduce chances of crop damage and to get uniform snow distribution, it is necessary to design windbreaks that are porous in the lower crown area. This will allow wind and snow to filter through the windbreak which will have the effect of greatly reducing wind turbulence and the force of eddying. Windbreak density involves such factors as number of rows, spacing, thinning, and pruning.

1. Number of Rows

a. Multiple-row windbreaks, regardless of species, are too dense for uniform snow distribution and remove too much cropland from production.

b. Control of soil erosion and snow distribution can be attained with single-row field windbreaks if properly designed.

2. Spacing

a. Unpruned, single-row Siberian elm at the conventional 5-foot spacing is too dense for uniform snow distribution over protected cropland.

b. Increasing the spacing of single-row Siberian elm to 10 and 15 feet did not improve snow distribution patterns appreciably when left unpruned.

c. Green ash spaced at 5 feet is too dense for uniform snow distribution.

d. It appears that 10-foot spacing might be recommended for green ash; a spacing of 15 feet may be too open for good protection against soil erosion. The rather open branching characteristics of green ash allow wind and snow to filter through so that pruning lower limbs is not required. Snow distribution can be controlled by proper spacing.

3. Thinning

Studies on the effects of thinning dense field windbreaks were in reality spacing studies; however, later thinning to a given spacing does not have the same effect as beginning with the same spacing at the time of planting. Frank and George (3) report that the removal of every other tree in a single-row, 16-foot-tall Siberian elm windbreak, planted on a 5-foot spacing, resulted in approximately "the same total volume of snowpack" behind both thinned (10-foot spacing) and unthinned (5-foot spacing) sections, "but it was spread about 100 ft. further into the crop area." George (5) concluded: "Removal of every other tree in closely planted windbreak rows has given more promise of spreading snow over wider areas of cropland, reducing the water-erosion potential, and permitting earlier working of the land than has any other method. Improved planting practices now being used of spacing trees and shrubs farther apart in the row will solve many of the problems confronting farmers who have high-density windbreaks."

4. Pruning

a. Pruning single-row Siberian elm on either 5-, 10-, or 15-foot spacings to a height of 3 feet did not result in uniform snow distribution. (For comparison of snow distribution patterns to the leeward of unpruned and pruned single-row Siberian elm at 5-, 10-, and 15-foot spacings, see table 1.)

b. A Siberian elm windbreak at the Crookston Station, where pruning had been maintained at a height of 3 feet, was pruned to a height of about 6 feet in the fall of 1974. Two days after the second blizzard of January 1975, snow patterns were essentially the same as on unprotected fields, indicating a 6-foot pruning is too severe. When pruning Siberian elm to a height of 6 feet, it may be necessary to remove large branches. Main forks may occur below 6 feet, and each branch of a fork may be of approximately the same size. Removing large branches, especially one branch of a main fork, will open up the crown considerably—this was the result after pruning the Crookston windbreak.

c. Several researchers have studied the effects of various pruning heights. These studies have been performed primarily on dense, single-row Siberian elm field windbreaks; most of these windbreaks are dense because they were planted on a close spacing. Few, if any, Siberian elm have been planted on a wider spacing than 6 feet, unless the trees were alternated with shrubs; consequently, there have been few, if any, studies on pruning single-row Siberian elm windbreaks that were planted on spacings wider than 6 feet. Frank et al. (3, 4) report that pruning has the effect of reducing the depth of snowdrifts and "spreading the snow over a larger area." Zaylskie (15) reported that even after the second blizzard of March 1966, windbreaks pruned to a height of 4.5 feet held snow on the cropland up to 195 feet (approximately 15H) to leeward, which was 75 percent farther than snowdrifts behind unpruned windbreaks; and when trees were pruned to a height of 2.5 feet, the snowdrifts were narrower, deeper, and closer to the trees than behind the 4.5-foot pruning. George (5) reported that "a much wider snow distribution of less depth" occurred behind a dense windbreak pruned to a height of 5 feet than behind a windbreak pruned to a height of 4.5 feet—apparently an additional 6 inches of pruning is critical. Frank (2) states: "To maximize benefits to the crop from these dense windbreaks, landowners should consider pruning these trees by removing all branches to a height of about 5 ft. to decrease windbreak density."

The 6-foot pruning in Crookston resulted in prolific sprouting 2 and 3 years later, which made the windbreak denser than it was prior to pruning. George (5) reported similar observations on trees pruned to heights of 4.5 and 5 feet. Frank et al. (3, 4), in reporting on their snow management studies which included single-row Siberian elm windbreaks pruned to heights of 2.5 and 4.5 feet, also observed sprouting; however, they did not specify at which pruning height sprouting occurred. There was moderate sprouting in the Crookston windbreak and minimal sprouting in the Morris windbreak where trees were pruned to a height of 3 feet. These observations indicate that height of pruning may have an effect on degree of sprouting. Season of pruning may be a factor.

Need for More Research

In the mid-1970s, many farmers in the drought-stricken areas witnessed topsoil blowing off their plowed fields—fields unprotected by windbreaks. Consequently, some of these farmers, rather than subjecting their fields to further erosion, went from conventional fall plowing to chisel plowing or stubble mulching in the fall. Chisel plowing or stubble mulching leaves some crop residue protruding above the surface to hold the soil in place and to catch some snow.

According to some agricultural experts, chisel plowing or stubble mulching is not a permanent solution: cropland must be turned over, at least periodically, with the conventional plow. When chisel-plowed or stubble-mulched fields that are unprotected by field windbreaks are turned over with the conventional plow, they will be subjected to wind erosion. The best permanent protection from wind erosion is to plant single-row field windbreaks.

Although Siberian elm has been the most prevalent species used in Minnesota single-row field windbreaks, it has not been completely successful. The older established windbreaks are dying out (figure 24). Cankers caused by the fungus *Sphaeropsis ulmicola* are often found on dying trees. It is believed that this fungus attacked the trees because they had been under rather severe stress for several years as a result of (1) closely spaced trees competing for available soil moisture and (2) cumulative effects of annual crop spraying for weed control. Since Siberian elm is susceptible to chemical crop sprays and has dense branching and prolific sprouting habits, some specialists in Minnesota and other states no longer recommend Siberian elm for field windbreaks.

Figure 24. Typical scene of older Siberian elm field windbreak dying out as a result of what is believed to be the cumulative effects of annual spraying of crops for weed control.

The best tried and tested field windbreak species has been green ash, and it is rapidly gaining in popularity as the older Siberian elm windbreaks die out. Obviously it would be a serious mistake to rely only on green ash for field windbreak plantings. Research efforts must be expanded to other tree species and varieties in the following areas: species selection, field testing, spacing, pruning from underneath, and containerization.

SPECIES SELECTION

Species and varieties for field windbreaks should be selected which have growth characteristics that will best perform the functions of a windbreak—reduce soil erosion and allow wind and snow to filter through for uniform snow distribution. Once a potential species is selected, the next step is to either locate planting stock of a known quality seed source or collect seed from seed trees that meet the qualifications of a good windbreak tree.

FIELD TESTING

Potential windbreak species should be planted directly in the field or in test plots to determine their adaptability to various soil types, their resistance to chemicals used in crop spraying for weed control, and to study their growth characteristics—growth rate, form, and branching habits. Examples of species which should be considered for testing are as follows:

1. **Black ash**

   Although black ash grows naturally in bottomlands, it will grow on upland soils. Because it has growth characteristics favorable for windbreak use, it should be tested for adaptability to various field soils.

2. **Siberian larch**

   Siberian larch is a conifer that sheds its needles in the fall. It is a hardy species, will grow in alkaline soils, appears to be resistant to chemicals used in crop spraying, and has good growth characteristics for a windbreak species. Researchers in Minnesota, the Dakotas, and Canada believe Siberian larch has great potential for field windbreak use. However, it should be further tested.

3. **Conifers**

   Ponderosa pine, which will grow on alkaline soils, should receive serious consideration for use in field windbreaks. Only strains of conifer species having narrow crowns and resistance to winter injury should be tested. There are several advantages that conifer field windbreaks have over hardwood windbreaks:

   a. The density of a conifer windbreak does not change between summer and winter because conifers hold their foliage the entire year. This could be an important factor when considering the potential damage to crops as a result of wind turbulence and eddying on the leeward side of the windbreak. If conifers can be managed by proper spacing and pruning from underneath so that wind and snow will filter through to give uniform snow distribution, then wind will also filter through during the summer. This will prevent or greatly reduce wind turbulence and eddying on the leeward and prevent or reduce crop damage.

   b. Most conifers do not sprout so thinning and/or pruning would not increase the density in the lower portion of the windbreak.

   c. Conifers would provide better winter protection than hardwoods for wildlife.

   d. Conifers would add to the aesthetics of the landscape during the winter months—belts of green on a background of dark plowed fields or white snow.

SPACING

Since growth characteristics of tree species vary, proper spacing between trees in a field windbreak will vary. Therefore field studies should be conducted in an attempt to determine the most effective ultimate spacing for each species being tested. It could mean close spacing at planting time followed by later thinnings.

PRUNING FROM UNDERNEATH

For species requiring pruning from underneath, more research is needed to determine the most effective height to prune. This height may or may not vary with species.

CONTAINERIZATION

Bare-root seedlings have been used in the past in field windbreak plantings. The main disadvantage has been that the roots have to become reestablished in the field soil and during this process top growth is slowed down considerably, especially in conifers. It may take 4 years for conifer roots to become reestablished. In the meantime, tops may grow only a few inches per year and mortality is often high.

The only feasible solution for conifers, in this author's opinion, is to produce container stock in the greenhouse. The major advantage of container-grown stock is that the seedlings suffer little transplanting shock. There is little if any root disturbance when seedlings are lifted from the containers and planted in the fields. The result is better survival and immediate height growth (figure 25).

Figure 25. Ponderosa pine in 7-year-old farmstead shelterbelt. Row on left was planted as potted stock and tree heights average 10 feet. Row on right was planted as bare root transplants and tree heights average 3 feet. Note blanks in right row indicating poor early survival of bare root stock.

All too often lessons are not learned from history. During times of favorable weather conditions and adequate soil moisture, past crises are often forgotten. There will be more dry cycles with strong wind conditions and loss of topsoil as well as soil moisture. Now is the time to begin planting field windbreaks on farmlands exposed to the mercy of the winds.

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