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Design and modification of windbreaks for better

winter protection of pheasants

by

John Frederick May

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INTRODUCTION

Winters characterized by deep snow, strong winds and low temperatures often cause severe hardship or death for individuals of many species of wildlife. Some species avoid such adverse conditions when they migrate to wintering areas with a relative abundance of food and more moderate climate. Most gallinaceous birds, including the ring-necked pheasant (*Phasianus colchicus*), do not migrate. One of the primary needs of pheasants is a winter food source or the stored energy of body fat to sustain them through the winter. In temperate and cold climates, winter is a time when no new food resources are being produced. While food items for certain predators may become more visible and concentrated due to reduction in cover or its obliteration by snowdrifts, the food sources for pheasants and other gallinaceous birds are often plowed under during the fall or drifted over by snow. While there have been reports of some normally sedentary gallinaceous species being prompted to migration by deep snow covering their food supply (Formozov 1946), starvation does not often threaten pheasant populations in the midwestern United States (Green and Beed 1936, Errington 1939, Trautman et al. 1939, Dahlgren 1967, Klonglan 1971, Farris et al. 1977). A greater problem may be the wide separation of feeding and cover areas, a point to be considered later.

Another winter mortality factor is predation. Pheasants in Iowa often have only isolated patches of protective cover surrounded by barren fall-plowed fields covered with snow. The birds may become highly visible targets for many predators which are able to concentrate their searching efforts on the relatively few areas of winter cover. However, predation does not seem to be the major factor limiting pheasant populations in Iowa (Green and Beed 1936, Farris et al. 1977).

In addition to predation and an unpredictable food supply, severe winter weather is another hazard for pheasants. Blizzards and severe snow or ice storms can often decimate local populations of pheasants (Scott and Baskett 1941, Klonglan 1971, George 1977). Heavy mortality most often occurs when pheasants are caught outside protective winter cover when the storm begins. Farris et al. (1977) state that any movement by pheasants out of their winter cover can be dangerous for them, and that the danger increases with the distance moved.

It has long been recognized that pheasants seek shelter in certain types of cover in the winter, depending on their activities and the weather. Different cover types are often selected for roosting, loafing, and protection from severe weather. The major determinant in the pheasants' selection of a certain type of cover for roosting or loafing is thought to be protection from predators. Low herbaceous cover without an overhead canopy used for night roosts permits the birds to fly up without hindrance if a mammalian predator approaches. Protection from avian predators in daytime is achieved by the pheasants' use of woody cover with canopy protection and little understory vegetation. Pheasants are also able to sun themselves in such cover (Green 1938, Lyon 1954, Gates and Hale 1974). Pheasants receive windbreak protection from severe weather by remaining in their roosting cover of low, dense herbaceous vegetation during stormy days, but conservation of body heat is thought to be only of secondary importance in the birds' selection of winter cover. Secure winter cover may be chosen instead of an abundant food supply. Pheasants often try to subsist on meager food resources near good cover rather than remain at good feeding sites with little protective cover (Lyon 1954, Gates and Hale 1974).

Although protection from weather may be a secondary consideration in choosing winter cover for some pheasant populations, it may mean the difference between life and death if a blizzard or severe storm strikes. The effects of blizzards on pheasants and other game birds have been well-documented (Errington 1936, Leopold 1937, Scott 1937, Errington 1939, Trautman et al. 1939, Scott and Baskett 1941). Low temperatures alone seem to be no problem for pheasants. Neither do deep snow nor high winds alone seem to adversely affect pheasants. A combination of low temperatures, high winds, and blowing snow is, however, dangerous (Klonglan 1971, Farris et al. 1977). Death is usually caused by exposure or suffocation when a pheasant is caught in the open during a storm. Wind-driven snow often blinds or disorients a bird, making it difficult for it to locate cover. Birds far from shelter usually turn their tails to the wind. When this happens, snow is blown into the feathers and either causes the bird to freeze to death or the snow may melt and run down the feathers and freeze, encasing the bird in ice. Melted snow may also run down into a bird's poorly vascularized bill and mouth and freeze there, eventually resulting in suffocation of the bird when a large enough ball of ice builds up (Klonglan 1971).

Pheasants are not always safe, even in good quality cover. If the windbreak or clump of vegetation is too small, it may fill up and either bury the birds remaining there, or cause them to seek other shelter. In storms with very high winds, pheasants are sometimes literally blown out of their cover. Klonglan (1971) reported that after one such storm, dead pheasants were found strewn haphazardly for hundreds of yards downwind of poor cover areas. There apparently is no escaping the effects of some blizzards, no matter what cover is available. However, blizzards don't usually occur over a state's whole pheasant range at one time. Some local populations may be severely decimated, but those in other locations may escape the blizzard's effects. If pheasants happen to be in secure winter cover when the storm begins, they will usually remain in their roosts and may be able to survive. The chief danger occurs when pheasants are in the open, exposed to the full effects of the storm. When a pheasant's food supply and winter cover are widely separated, the bird has a greater risk of exposure as it travels to and from the feeding area.

Winter habitat is the key to overwinter survival of a pheasant population to the breeding season. The proximity of good winter habitat to a food supply is also important. In recent years, however, good winter cover has become scarce, and interspersion of cover types has decreased dramatically. Mohlis (1974) reported a 33 per cent drop in pheasant winter cover from 1939 to 1972. Farris et al. (1977) have provided a series of maps of a north-central Iowa area which graphically show the increase in field size, consolidation of crop types, and the shift to a preponderance of row crops in recent years. Nomsen (1969) reported a 25 percent decrease in the number of farmsteads and their associated winter cover, due to the trend toward larger farms. Along with increased field size, fall plowing has eliminated much food and cover, resulting in a high probability of widely separated food and cover resources. With the reduction in winter cover, remaining windbreaks and cover areas become much more valuable to pheasants. Some habitat just does not provide pheasants with adequate protection from the severe weather often encountered in Iowa, and losses of pheasants due to winter storms can be great. Habitat improvement is the key to winter survival of pheasants. Although secure nesting habitat is probably the main limiting factor for pheasant populations, the best nesting habitat is useless without pheasants to nest there. Thus winter cover is also an important component of pheasant habitat, and with the present scarcity of cover, there is a need for well-designed windbreaks that provide protection from severe winter weather in Iowa.

In studying this problem, I have pursued three main objectives: (1) Identify windbreak characteristics associated with certain patterns of snow drifting and wind reduction, (2) evaluate the influence of these characteristics on winter survival of pheasants, and (3) test several windbreak designs that provide pheasants with protection from severe winter weather.

REVIEW OF LITERATURE

To more closely define and study protection of pheasants from the effects of severe winter weather, I have reviewed the literature concerning the several topics outlined below.

Effects of Blizzards on Pheasants

A knowledge of the actual effects of blizzards and other severe winter weather on pheasants is essential for the study of windbreak protection for these birds.

Physical stress on individuals

The actual physical stress on individual pheasants imposed by the weather may be of several types. These stresses may result in death or a diminished physical condition of the bird, making it more susceptible to other mortality factors.

Starvation   Seldom has starvation been severe for pheasant populations in Iowa and other midwestern states. Green and Beed (1936) reported an over-winter loss of 250 out of 400 pheasants on their Winnebago County, Iowa, study area, but only 1 death could be attributed to starvation. Green (1938) also reported a small loss due to starvation -- 1 out of 238 deaths -- in northern Iowa. Errington (1939) said that he could find little evidence of pheasant starvation in cultivated farmland, but suggested that it might be more of a problem in areas where cultivated fields were scarce. Frank and Woehler (1969) found that food stress on pheasants was evident in four of the seven winters during their study. They said that winter losses were proportional to depth of snow and the time it remained, but cited no figures for deaths due to starvation. Trautman, et al. (1939) could find no published record of pheasant starvation in Ohio. Robertson (1958) attributed lack of starvation of Illinois pheasants to the rarity of deep snow and availability of waste grain, especially corn (Zea mays). Kimball et al. (1956) stated that starvation might sometimes result in localized mortality, but was generally unimportant in the plains and prairie states. Nelson and Janson (1949) reported starvation of pheasants in South Dakota after an unusually heavy snowfall which made food inaccessible. Mortality due to starvation was only about 5 per cent. A March thaw prevented heavier losses by uncovering the birds' food supply.

When covered by deep snow or thick ice, waste grain may become unavailable to pheasants and other game birds, but pheasants are usually able to scratch and peck through the snow and ice to get to the food (Robertson 1958, Errington 1939). When corn and other waste grain cannot be reached, pheasants are able to rely on less nutritious foods to sustain them until their staple foods again become available (Errington 1937). Errington (1939) showed that while bobwhite quail (Colinus virginianus) could not subsist on emergency foods, pheasants were able to retard starvation during food crises by feeding on buds and other foods less nutritious than corn. He found that pheasants could withstand a 50 per cent loss of body weight and still recover over 60 per cent of their lost weight within 3 weeks on full feed. Nelson and Janson (1949) reported that some pheasants had maintained good body condition by feeding on carrion when normal food sources were unavailable.

There have been accounts of large-scale starvation of pheasants in certain instances, however. Beed (1938) reported a loss of 80 per cent of the pheasants on the Waubay Migratory Waterfowl Refuge in South Dakota. McClure (1948) also reported the loss of many pheasants due to starvation on the Valentine National Wildlife Refuge in Nebraska. In both cases, cash-grain crops were not produced on the areas and pheasants subsisted on weed seeds and herbaceous food items. When these food sources were buried by snow and ice, and the weather became bitterly cold, many pheasants died of starvation.

Predation One might suspect that as pheasants become weakened by lack of food, they could be taken more easily by predators. Errington (1936) said that heavy predation on wintering bobwhite quail depended on their physical weakness or their overpopulation relative to available habitat. Beed (1938), however, could not find any evidence of predation by native furbearers, even though a large percentage of birds had died of starvation. Beed thought that perhaps rabbits (*Lepus townsendii*, *Sylvilagus floridanus*) and mice (*Microtus pennsylvanicus*, *Reithrodontomys megalotis*, *Peromyscus leucopus*) acted as buffer species between pheasants and the predators of that area. Scott and Baskett (1941) could find no evidence of predation although they viewed storm-killed pheasants as a food-windfall for various flesh-eaters such as red foxes (*Vulpes vulpes*), minks (*Mustela vison*), and crows (*Corvus brachyrynchos*). Green (1938) and

Green and Beed (1936) both estimated the proportion of the total observed mortality due to predation to be less than 1 percent. Errington (1936) talked about the vulnerability of wintering bobwhite quail to predation, and said that if the individual birds were weak, they were vulnerable regardless of the types, numbers, and skill of the predators present. During the course of his field work in southern Illinois, Roseberry (1964) found 16 bobwhite quail carcasses, 6 of which (37.5 percent) had been killed by predators. He thought that the bobwhite quail's susceptibility to predation was increased by food shortage and increased visibility to predators while the birds were feeding against a snow background. Scott (1937) found evidence that a bobwhite quail had been killed by a mink during a blizzard in central Iowa. Wagner et al. (1965) said that pheasants may become more susceptible to heavy predation loss if their cover becomes filled with snow. They estimated the loss of pheasants to predators during the winter to be from 3 to 26 percent of the population on the areas they studied.

Burial by snowdrifts While drifting snow may fill in cover, making it useless to pheasants, it may also bury birds that have already sought shelter there, and the effect is often fatal. Scott (1937) described the effects on quail buried by 1.2 m (4 feet) of crusted snow while on their night roost. The birds probably died from a combination of starvation and suffocation because body and stomach content weights were low. At least one pheasant was able to break out through the snowbank at a place where the crust could support a man's weight. Scott and Baskett (1941) found evidence of a similar occurrence near Estherville, Iowa.

In spite of evidence that pheasants are in some instances physically able to escape moderately deep drifts, there is still the apprehension that certain winter cover attractive to pheasants may become a death trap when it fills up with snow during a blizzard. Thirty-eight of 203 dead pheasants found by Green (1938) had been buried by deep snow, although the cause of death in those instances could not be determined. Klonglan (1971) mentioned that some pheasants were buried by 3- to 6- m (10- to 20- foot) drifts in farm windbreaks and other "safe" winter cover areas. He implied that pheasant mortality would result from some blizzards, even if the birds used the best quality winter cover.

Exposure and suffocation Exposure and suffocation are usually the most significant causes of mortality associated with blizzards. Physical characteristics of blizzard-killed pheasants were described by Green and Beed (1936). They found that pheasants caught in the open during a storm invariably turned their tails to the wind. Snow was then blown into the feathers, was melted by body heat, and then combined with new snow and froze again. The bird was thereby encased in a ball of ice and died of exposure. Ice accumulated in the nostrils and bills of many birds and resulted in suffocation. Over half of the observed winter mortality of 250 pheasants was due to choking or freezing of the birds during blizzard conditions. Green and Beed noted that over three-fourths of the birds found dead during severe weather had ice covering their eyes. This condition perhaps led to high mortality because the birds were blinded and unable to find shelter. Pheasants blinded by ice covering their eyes and heavily weighted down with snow and ice were also reported by Scott and

Baskett (1941). They found that pheasants with ice-clogged bills and nostrils were common among the storm casualties. Bue (1949) observed the behavior of 14 pheasants caught in the open during severe drifting. The birds did not attempt to reach secure cover only 200 m (1/8 mile) away or move even 46 m (50 yards) to escape the zone of most serious drifting. Their heads became covered with ice, but they recovered when the storm subsided. Klonglan (1971) also felt that freezing and suffocation of pheasants because of their exposure to strong winds with blowing snow were the primary causes of death in all severe Iowa winters. In almost every account it was noted that the pheasants killed during the storm were in otherwise good physical condition and had not been weakened prior to their deaths.

Population declines due to storms

The physical stresses of severe weather on individual pheasants may at times cause heavy population losses. Losses of pheasants in a storm on 11 November 1940 (due to the 1940 Armistice Day storm) were estimated to be 50 to 90 percent of the populations in northwestern Iowa counties (Scott and Baskett 1941). Mohler (1959) reported similar rates of loss for pheasants in certain Nebraska counties in 1949. A 1949 blizzard killed 80 per cent of the pheasants in northeastern Colorado (Lyon 1959). Green and Beed (1936) reported a 62.5 percent loss of pheasants wintering on their northern Iowa study area. Severe weather caused most of those losses. The blizzard of January 1975 caused 80 percent losses in northwestern Iowa (George 1977). Although spectacular winter storm losses may often be found in local areas, seldom is a state's entire pheasant population reduced to such a great extent. Wagner et al. (1965) said that North Dakota seemed to be the only state in which severe winters caused a general population change over a period of years. Dahlgren (1963) showed that fall to spring was the least important period for pheasant mortality in South Dakota. Although losses are often local, or at least not statewide, a large loss of wintering pheasants would reduce the number of breeders the following spring and could affect total production that year. Heavy winter losses in 1 of 6 years in South Dakota resulted in a winter cover development program as an "insurance policy," according to Kimball (1948).

Reasons for pheasant losses

Several reasons have been cited for the heavy losses of pheasants due to the effects of blizzards and severe winter weather.

Food covered by snow and ice   As mentioned earlier, there have been reports of large-scale mortality due to starvation when the pheasants' food supply was covered by snow and ice (Beed 1938, McClure 1948). Dalke (1943) suggested that the ice covering food items was not serious for pheasants unless the coating was 2.5 cm (an inch) or more thick.
He also mentioned the use of emergency food items when waste grain was not available. Errington (1939) reported that the effects of starvation could be retarded by pheasants' use of less nutritive emergency foods for short periods.

Poor quality cover Another problem in many parts of the pheasants' range is poor quality cover. Green (1938) gave an example of a clump of willows (*Salix* spp.) that gave excellent protection to pheasants during mild weather, but drifted in quickly and became useless during severe storms. Green and Beed (1936) also found that willow clumps, slough vegetation, and weed patches became filled with drifting snow and were then useless as winter cover. According to Mohler (1959), pheasant mortality during a blizzard occurred in road ditches, shelterbelts, tree claims, weed patches, fencerows, cornfields, and wheat (*Triticum aestivum*) stubble. Normally secure cover was not adequate during blizzard conditions in the Nebraska panhandle in 1949.

Scarcity of winter cover One reason that good quality cover may become useless during severe storms is its scarcity. A small island of good quality cover encompassed by barren fall-plowed fields may soon drift full of snow swept in from the surrounding area. George (1977) reported pheasant mortality in the immediate vicinity of good quality winter cover areas after the January 1975 blizzard in northwestern Iowa. Small farmstead windbreaks were also found to be inadequate cover during the storm. Increased field size on Iowa farms resulted in more blowing snow and this was seen by Nomsen (1969) to decrease the effectiveness of available winter cover.

Wide separation of cover and feeding areas The chances of heavy pheasant mortality due to sudden severe winter storms increases when feeding areas and secure winter cover are widely separated. Green (1938) found that survival of pheasants was highest for flocks that roosted in dense cover adjacent to their feeding area. Survival was less for flocks roosting in good cover but traveling long distances for food. The blizzard on 11 November 1940 arrived suddenly when pheasants were feeding away from secure winter cover (Scott and Baskett 1941); the resulting losses were great. Heavy mortality occurred during the 1940 Armistice Day storm and the St. Patrick's Day blizzard on 17 and 18 March 1965 because the birds were feeding in the open too far from protective winter cover (Klonglan 1971). Farris et al. (1977) said that the greater the distance moved by pheasants out of winter cover, the greater the danger. The stationary nature of central Iowa pheasant flocks studied by Egbert (1968) was attributed to isolation by large surrounding acreages of fall-plowed land and lack of travel-lane cover.

Pheasant Winter-Cover Preferences

In designing windbreaks or cover areas to protect pheasants from severe winter weather, one should look at preferences the birds have for certain types of cover. Several researchers have listed certain factors which they feel influence selection of winter cover by pheasants.

Factors in cover selection

Gates and Hale (1974) studied movement and winter habitat use by pheasants in east-central Wisconsin and described a number of factors that influenced the birds' choice of winter cover. They found that hen pheasants tended to remain near their birthplaces unless forced to move by severe weather and unavailability of nearby cover. Movement of hens, led by returning adults, was then to traditional wintering areas. Cocks dispersed more randomly. The three major needs of wintering pheasants were emergency cover (used when heavy drifting made preferred cover unavailable), roosting cover for use at night, and loafing cover for use between daytime feeding periods. Woody and brushy loafing cover was found to be the most critical habitat requirement. Both loafing and roosting cover were selected primarily for protection against predators. Pheasants roosted at night in low ground cover without an overhead canopy so that their flight to escape mammalian predators would not be hindered. Avian predators were a greater threat during the daytime and pheasant loafing cover consisted of woody vegetation with an overhead canopy but without ground vegetation. Body heat conservation was thought to have played a subsidiary role in the birds' cover selection. Robertson (1958) in Illinois also found that pheasants loafed in woody cover but roosted at night exclusively in low herbaceous vegetation such as hay or stubble fields. In Colorado, the combination of low temperatures, deep snow, and high winds caused pheasants to move from cover normally used to patches of heavy weeds (Lyon 1954). Position of grain fields with respect to good cover did not seem to affect pheasant preferences. Lyon also concluded that pheasant cover could be judged for its value as roosting cover on the basis of height alone, the most-preferred cover being at least 38 cm (15 inches) high and open overhead. Through an evaluation of woody cover plantings in Colorado, Lyon (1959) found that width, composition, and understory did not influence use of these plantings by pheasants. The two most important factors in determining pheasant use were the proximity of low herbaceous vegetation for roosting and the tendency of certain plantings to accumulate snowdrifts 1.2 m (4 feet) deep or more causing pheasants to abandon use of them. Lyon found that deciduous plantings were deserted during periods of high wind and heavy snow, perhaps due to this drifting factor. Bue (1949) observed that pheasants in South Dakota selected loafing sites of woody cover close to a food source and avoided sites where feeding areas were 400 m (1/4 mile) or more away. The birds roosted in whatever low herbaceous cover was available, but seemed to prefer sparse weed patches less than 1 m (40 inches) tall.

Examples of winter cover use

Although the ring-necked pheasant is an upland game bird, wetlands supply important winter cover for these birds. Gates and Hale (1974) found that 29 of 32 winter cover areas used by pheasants contained some type of wetland cover. With heavy snowfall, the most important wetland cover type was shrub-carr, which is defined by Curtis (1959) as "... a wet-ground plant community dominated by tall shrubs other than alder (*Alnus* spp.) with an understory intermediate between meadow and forest in composition." Shrub-carr was used for loafing and for roosting when other roost sites were filled with snow. Canary grass (*Phalaris* spp.) and sedge-meadow (*Carex* spp.) cover types were used as roost sites when the weather was not severe. Evergreen shelterbelts were used for loafing and roosting during severe weather, but only when a food supply was nearby.

They also were more attractive to pheasants when nearby alternative roosting cover was available. Wight (1933) in Michigan and Lyon (1954) in Colorado also mentioned the significance of wetlands vegetation as cover for wintering pheasants. Lyon found that heavy weeds and cattails (*Typha* spp.) were highly preferred for roosting. Marsh vegetation was found to be the most important winter cover for Illinois pheasants (Robertson 1958), and annual movements of pheasants to these wintering areas was noted. Illinois pheasants followed the pattern mentioned by Gates and Hale (1974) of using open woody cover such as farmstead orchards and osage orange (*Maclura pomifera*) hedges for loafing and dense herbaceous cover such as hay or stubble fields for night roosts. Weston (1950) found that pheasants in northwestern Iowa used cattails and bulrushes (*Scirpus* spp.) for roosting and loafing. Giant ragweed (*Ambrosia trifida*) also provided excellent winter cover for roosting and loafing and for a refuge from strong winds and blowing snow. Stands of jack pine (*Pinus banksiana*), willows, cottonwood (*Populus deltoides*), and green ash (*Fraxinus pennsylvanica*) were used as protection from severe weather. Canary grass, which was easily matted down by snow, and grain stubble were judged to be poor winter cover and were seldom used by pheasants. Klonglan (1962) listed, in order of importance, waterways containing tall brush and weeds, farm windbreaks, road ditches, waste areas, fencerows, and fields as winter cover areas for pheasants on his southwestern Iowa study area. He also mentioned that in Winnebago County in northern Iowa, sloughs received heavy use during mild winters, but drifted full of snow during severe winters. While weather was still mild, Green (1938) observed pheasants in small grain stubble, pasture land, hayfields, fencerows, ditch banks, sweet clover, (Melilotus spp.) and sloughs, but the birds abandoned those areas when they became filled with snow in early winter. Pheasants remained in one slough a bit longer because it was bordered on the west by a row of willows which kept snow from drifting in so quickly. There was no pheasant use of several evergreen groves even during severe weather, perhaps because there were no nearby feeding areas. Deciduous groves received only occasional use by pheasants. During severe weather, pheasants roosted in willows, groves, sloughs, unmown sweet clover, and hand-picked sweet corn fields. Pheasants preferred cover with an adjacent food supply. Deep snowdrifts formed by fencerows sheltered pheasants from strong winds as they moved from roosting cover to feeding areas. Grondahl (1952) recorded pheasant roosting sites in stubble, weedy fence-rows, slough areas, and picked cornfields during mild weather. However, when temperatures dropped below -7 C (20 F), when winds were above 4.5 m/sec (10 mph) and when snow cover exceeded 15.2 cm (6 inches), pheasants sought shelter in farm shelterbelts comprised of various deciduous and evergreen vegetation. Pheasants also moved to these shelterbelts when other cover such as slough vegetation became filled with snow.

Windbreak Uses and Construction

Windbreaks, as discussed here, are man-made structures or vegetation which alter windflow and hence snowdrifting patterns in a particular area. Windbreaks have been established for a variety of reasons and although multiple benefits may be gained from a particular windbreak, the basic form depends primarily on the original reason for its establishment. Some of the most prominent uses of windbreaks and corresponding windbreak configuration that have been described in the literature are outlined here.

Protection from wind and snow

One of the most common reasons for establishing a windbreak or barrier has been to get protection from the effects of cold winds and deep snow.

Farmsteads In many parts of Iowa the only visible trees are the windbreaks planted near farmsteads to protect buildings and livestock from severe winter weather. Particularly common are linear and L-shaped windbreaks comprised of evergreens, deciduous vegetation, or a combination of the two. These windbreaks were designed to be relatively dense so that wind velocities would be greatly reduced and snow deposited within or shortly behind the windbreak. Upfield and Grafton (1972) and Campbell and Grau (1948) give directions for tree selection, location, planting, and maintenance to establish a protective windbreak near a farmstead. Evergreens were recommended because of their high density at all times of the year. Some penetrability is desirable to prevent intense turbulence behind the windbreak, but low-level density is needed to prevent wind from funneling through the barrier at high speed. At least three rows of trees were recommended to prevent gaps if a few of the trees were lost. Bates (1945) thought that to achieve maximum resistance to wind a windbreak should rise abruptly from the ground rather than being tapered with lower vegetation windward and leeward of the main rows. Williams (1949) said that windbreaks at least seven rows wide trapped all the drifting snow in or near the plantings. Artificial windbreaks have also been used to protect crops and livestock from wind. A windbreak made of plastic mesh with a porosity of 45 percent is described by Freeman and Boyle (1973).

Roads Roadways are usually kept free from deep drifts whether by elevation of the roadbed or placement of snow fences. The purpose of snow fences is to store windblown snow. Researchers from the Rock Island Railway found that the storage capacity of a particular slat-type snow-fence could be increased if it were raised after storage capacity was reached at the lower level (Railway Engineering and Maintenance Journal, 1950).

Pugh and Price (1954) have described many types of snowfence and their characteristics. They gave many examples of snowfence placement to protect roads and railways, and the main objective was to deposit blowing snow before it reached the protected area. The greatest snow accumulation occurred behind fences with a porosity of 50 to 60 per cent.

Soil erosion control In areas where soil erosion is a serious problem, shelterbelts have been planted to reduce wind speeds and lessen soil erosion. Single rows of trees spaced at regular intervals are useful for this purpose. According to Stoeckeler (1938), single or double-row belts can be just as effective as windbreaks with 10 to 15 rows. Chepil (1949) reported the use of single-row shelterbelts for erosion control in China. Leaverton (*ca.* 1955) recommended single-row belts of trees and shrubs spaced at intervals of 100 to 200 m for control of soil erosion in Iowa.

Overgrown fencerows and cross-slope fences may also help prevent soil erosion (Edminster 1938).

Moisture control In many western states windbreaks are used to store snow on fields for moisture. Windbreaks that reduce wind velocities for a great distance leeward are needed. George et al. (1963) compared wind velocities behind a number of windbreaks and found that as the barrier becomes more open in the lower part the greatest reduction in wind speed moves further leeward. They said that since the ability of winds above the threshold velocity (velocity at which soil or snow particles begin to move) to move snow increases with the cube of the velocity, only small wind reductions are needed to decrease drifting or erosion. Relatively open single-row shelterbelts or slat-fence barriers performed better than dense multiple-row plantings which produced short, deep drifts. Bates (1948) also recommended narrow, porous windbreaks for moisture conservation. Some cropping patterns are designed to trap snow to provide moisture for the plants. Parallel rows of sorghum (Sorghum vulgare) are used to hold snow in winter-wheat fields (Greb and Black 1961a). Black and Siddoway (1971) found that perennial tall wheatgrass (Agropyron elongatum) seeded in 91-cm (36-inch) rows 15.3 m (50 feet) apart would provide desirable snow deposition and protection from soil erosion. Slat-fence barriers are used to store water (in the form of deep snow drifts) where even distribution over a field is not important. Deep drifts are sometimes desired to provide runoff for a longer period than shallow, even snow cover which may melt quickly (Lull and Orr 1950).

Wildlife cover The value of windbreaks to wildlife has been considered more as a fringe benefit than a goal, and most farm windbreaks have been constructed to provide something other than maximum protection for wildlife. Wildlife managers and researchers, however, have listed windbreak cover characteristics which they feel are needed to provide protection for pheasants and other wildlife. Wight (1933) recommended planting clumps of evergreens and food patches adjacent to them for Michigan pheasants. The evergreens would provide dense barriers against very cold winds and pheasants would not have to travel far for food. In Colorado, Lyon (1954) found that pheasants needed tall herbaceous cover for roosting. He suggested maintenance of heavy weed cover near woody cover, or planting clover, sudan grass (Sorghum sudanense), or other herbaceous vegetation which grew at least 38 cm (15 inches) tall. Frank and Woehler (1969) suggested that in Wisconsin, both food and winter cover could be provided by planting stands of forage sorghum (Sorghum vulgare), sorghum-sudan grass hybrids, or combinations of these plants with corn, soybeans (Gycine max), and grain sorghums. Although these are annual plantings, they could be used for short-term cover until woody vegetation was established, or in conjunction with normal winter cover. Utilization of minimum tillage, delay of plowing until spring, and leaving two or more rows of standing cornstalks in the field are ways of reducing downwind drifting of snow into pheasant cover, according to the Pheasant Task Force Committee in South Dakota (Aanderud et al. 1976). They also recommended increased use of junipers (_Juniperus_ spp.) in shelterbelts and field belts for protection of pheasants during blizzards. Bue (1949) said that a row or two of low shrubs on the windward side of shelterbelts would keep snow from passing through them and leave more leeward cover for game birds. He also thought that windbreaks should be at least 91 m (300 feet) wide to prevent total filling of the cover by snow during the most severe storms. Green (1948) planted field corners with evergreens and other woody vegetation to provide cover close to possible food sources for pheasants. Poor survival of evergreens due to lack of care by landowners prompted Green to recommend wild plum (_Prunus_ spp.), mulberry (_Morus rubra_), lilac (_Syringa_ spp.), elderberry (_Sambucus_ spp.), and hazelnut (_Corylus_ spp.), instead. Farris et al. (1977) stated that winter cover areas for northern Iowa pheasants should be large enough to catch snow on the north and west sides, while having some vegetation free of deep drifts. They recommended a combination of shrubs and conifers (plant species composition is unimportant as long as the cover provides security), with two or three rows of shrubs planted on the windward sides to catch the snow.

Windbreak Effects on Crop Yields

If windbreaks are constructed near commercial cropland, the effects of windbreak vegetation on adjacent crops should be considered. Many workers who have studied shelterbelt influence on crops report increased yields. The reason, in part, may be that many of the windbreaks studied were established to provide increased crop yields. Stoeckeler (1962) reviewed the literature on the shelterbelt effects on crop yields observed within and outside of North America and also reported on a Great Plains crop-yield study. He concluded that the effectiveness of a windbreak at increasing crop yields depended on the kind of crop, the amount of climatic stress on the plants, and the orientation of the tree plantings. Wind reduction was substantial up to 30 tree heights downwind, but effects on crops extended only half that distance. Windbreak vegetation was found to have a sapping effect on crop plants close to the windbreak, but this could be controlled by root pruning to a depth of 0.6 m (2 feet) or more. The primary reason for increased yields was snow retention that added to soil moisture. Net benefits increased with greater widths and densities of windbreaks up to 15.2 m (50 feet) wide. Bates (1911), who was a pioneer in the study of windbreak effects, described two zones of influence relative to a windbreak. The zone of competition is a narrow zone close to the windbreak which is unfavorable to crops because of shading, sapping, moisture, and soil fertility reduction due to the windbreak vegetation. The wider zone of windbreak protection results in increased crop yields due to decreased wind movement and evaporation, greater heat during the day with a concurrent increased moisture capacity of the air, and less extreme cold at night. Bates did not mention snow catchment effects on crop yields. A large increase in crop yield due to shelterbelt effects on microclimate is usually most evident in semi-arid regions where drying winds occur (Gloyne 1955). Windbreak effects are noticed in dry years when moisture stress occurs, but they are not as evident when winds are light with snow spread evenly on fields or when there is abundant moisture (Staple and Lehane 1955). Most of the benefit to crops in the Midwest and Great Plains Regions is due to increased moisture from snowmelt (George 1971, Staple and Lehane 1955, Stoeckeler 1962).

Windbreak vegetation can have an adverse effect on adjacent crop rows. Greb and Black (1961b) found that as climate became more arid, effects of windbreak competition with adjacent crops were more pronounced. Broadleaf trees were a bigger threat to adjacent crops than conifers, and shrubs had a very minor effect on crop yield. Dry conditions induce long shallow lateral roots and the ratio of root length to tree height in the instances studied was more than 2.5 to 1. Stoeckeler (1962) indicated that root pruning could alleviate this type of problem, but George (1971) found a great increase in root growth in response to cutting. The average distance of sapping for various windbreaks species was listed by Bates (1911) and he discussed a variety of remedies to reduce the effects of sapping.

Drifting and Wind Velocity Profile Patterns

The basic factors governing wind-velocity profiles and snowdrifting characteristics near natural or man-made barriers have been outlined by a number of researchers. Purposes of the studies differed, as did the measurement instruments. The particular type of anemometer used was not consistent. Cornish (1902) studied snowdrifting patterns in Canada and described a number of characteristics of snowdrifts and their formation near any obstruction. He found that the basic form of a completed drift formed around a stationary obstruction is that of an ichthyoid curve with the blunt end toward the wind, when viewed in longitudinal section. If the obstruction is not many times wider than tall, the same shape (plus its mirrored image) will be evident if viewed from above. A steep leeward cliff means that the drift is not yet complete. Cornish viewed the ichthyoid shape of drifts (blunt head with tapering tail) as a formation to minimize the aerodynamic drag effects of an obstruction. He also described the clearing away of snow at the edges of obstructions due to high speed vortices. Bates (1945) described the wind-velocity profile behind a slat-fence barrier as wedge shaped when viewed from the side, with the greatest wind speed reduction close to the barrier. The area of protection is widest near the windbreak and tapers to a point leeward. Also, the percentage reduction of wind velocity is greater with greater wind speeds and the field of wind reduction is lengthened. With a dense windbreak, Bates found that wind reduction to two heights windward may be four-fifths as great as the reduction to leeward. According to Caborn (1958), snow drifting near a barrier reflects local wind conditions, and its pattern depends on velocity and direction of wind, specific gravity of the snow, physical characteristics of the barrier, and the eddy area produced. He considered the permeability of the barrier to be the most important factor in the drifting pattern, but the amount of windblown snow and the roughness or ground cover of the windward terrain may at times be more influential. Low weed growth in front of a windbreak can cause snow that moves by surface creep to pile up to the windward side. Caborn also found that although wind reduction patterns behind two sections of a shelterbelt were the same, ground cover in the field to the windward side of one section prevented deep drifting in that belt, while the snow from a windward fallow field caused deep drifting in the second section of the windbreak. Caborn (1955) elucidated the effects of factors influencing wind profiles and snowdrifting near windbreaks, and stated that the most effective shelter allowed some wind to pass through the barrier and resume flow at a reduced speed on the leeward side. Severe leeward turbulence was thus avoided.

Examples of wind reduction and snowdrifting patterns near vegetation windbreaks can be found in articles by George et al. (1963), Gloyne (1955), DenUyl (1936), George (1971), and Stoeckeler (1962). Snowdrifting and wind-profile patterns behind man-made barriers have been reported by Gerdel (1960), Pugh and Price (1954), Berndt (1964), Geiger (1966), and Cornish (1902).

Wind-Tunnel Modeling of Snowdrifting Patterns

Field testing of the influences of windbreak structures on wind profiles and snowdrifting patterns is time consuming and dependent on weather conditions. Test duplication is almost impossible, due to variability of weather and other natural phenomena (Gerdel and Strom 1961). However, investigators can use scale-model windbreaks in a wind tunnel to test modifications of the windbreak while holding other variables constant. Gerdel and Strom (1961) discuss problems associated with wind-tunnel studies of atmospheric phenomena and list the factors that are significant in choosing a particle to model snow. These scale factors (which should be equal for both model and atmospheric counterparts) are: d/L, V_p^2/gd, V_p/V, V_f/V, and e, where:

L = linear reference dimension of rigid boundary objects such as buildings and snow fences,

d = diameter of snow particle,

V_p = velocity of snow particle,

V_f = free-fall velocity of snow particle,

V = ambient air velocity at the particle,

g = acceleration due to gravity, and

e = coefficient of restitution (ratio of velocity of rebound of a particle to its velocity of impact).

Gerdel and Strom found that commercial borax provided a satisfactory model for snow particles. Jensen (1954) said that to accurately simulate the atmospheric boundary layer (the layer of air in which wind speed is slowed by surface friction) the roughness parameter of the floor of the wind tunnel (z_{o_m}) should be scaled to the same atmospheric parameter (z_0) so that $z_{o_m}/z_0 = L_m/L$, where L is a linear measurement in nature (such as windbreak height) and L_m is the corresponding model measurement. Cermack (1971) views exact simulation of the boundary layer as impossible, but discusses technical criteria for good simulation. Iversen et al. (1973) studied wind-tunnel modeling of Martian eolian phenomena and discussed a long list of physical parameters and ratios important for proper modeling of particle drifting. They mention that while not all of the modeling parameters can be satisfied in the wind tunnel, the particle deposition patterns can provide some information about the atmospheric patterns of drifting. Woodruff and Zingg (1953) used cedar boughs to model shelterbelt trees and studied the effects on the wind velocity profile of varying widths (number of rows) and cross-sectional shape of natural windbreaks. Woodruff and Zingg (1952) also studied model windbreaks of various types in a wind tunnel and found that the wind flow pattern remains constant irrespective of wind velocity, that density and shape of the windbreak significantly affect flow patterns, and that windbreak effectiveness based on horizontal velocity measurements may be in error by 25 to 30 percent immediately leeward of the barrier.

DESCRIPTION OF WINDBREAKS STUDIED

Natural Windbreaks

Windbreaks which represented common cover types in Iowa were selected for study, and snowdrifting patterns and wind speeds present in the various cover types were compared. Windbreak types were selected on the basis of their potential use as pheasant cover or as potential supplements to better winter cover. Many of the windbreaks examined had actually been used by pheasants.

Two major types of natural windbreak were chosen. The type designated as "clump" is characterized by stands of vegetation in which individual stems are in a relatively compact group rather than strung out in a line. "Strip" type windbreaks are composed of one or more long and thin strips of vegetation, such as corn rows or a fencerow.

Natural windbreaks are here defined as those windbreaks comprised of resident vegetation and fence not specifically set up for testing in this study. Some natural windbreaks were modified by placement of snowfence near them, as explained in a later section. Legal descriptions for locations of natural, modified natural, and experimental field windbreaks are shown in Appendix I.

Ragweed stand

One of the two clump-type windbreaks studied in 1975 was a rectangular stand of giant ragweed in a plowed field west of Ames. Dimensions of the stand were 13 m by 26 m (44 ft by 86 ft), with the long axis in an E-W direction. The stand was 2.4 m (8 ft) tall, and the density of the ragweed was 46.0 stems/m^2 (38.5 stems/yd^2). Only a single pheasant was seen at the windbreak during the study.

Willow stand

The other clump windbreak was a willow stand in the northwest corner of Dunbar Slough near Scranton, Iowa. The dimensions of this windbreak were about 90 m (300 ft) by 60 m (200 ft), and its height varied from 1.2 m (4 ft) near the windward edge to 4.6 m (15 ft) in the middle, tapering down to 1.2-1.5 m (4-5 ft) at the leeward edge of the windbreak. Samples of the density of windbreak vegetation were made and stems were grouped into size classes of greater or less than 2.5 cm (1 in) in diameter. Stem density in leeward, middle, and windward thirds of the windbreak as well as along the windward edge was recorded (Table 1). The windbreak was bordered on three sides by grasses, sedges, cattails, and other vegetation, and on the windward side by a picked cornfield. Abundant rabbit and pheasant sign were found in and around the willow stand.

Weed strip

In addition to the two clump-type windbreaks, a number of strip-type natural windbreaks were also studied. One of these was a weed strip in a picked cornfield southwest of Ames. The 46 m (150 ft) strip was 0.6-1.2 m (2-4 ft) wide and the vegetation consisted mainly of foxtail

(Setaria spp.), lambsquarters (Chenopodium album), and smartweed (Polygonum, sp.). Measurements of the density of vegetation in the strip, which was not part of a fencerow, were made at two locations. At the first location, the vegetation consisted mostly of grass and the average density was 807 stems/m^2 (75 stems/ft^2). At the second location most of the stems were the larger smartweed and lambsquarters and the average density was 339 stems/m^2 (31.5 stems/ft^2). No signs of pheasant activity were found along the strip, although pheasants had been seen in adjacent fields.

Table 1. Stem density shown or stems/m^2 for two stem-size classes in various sections of a willow windbreak at Dunbar Slough, Green County, Iowa, in January 1975.

Section of windbreak	Stem size: Diameter 1 inch +	Stem size: Diameter under 1 inch
Leeward	0.9	7.2
Middle	1.2	12.3
Windward	3.3	4.8
Windward edge	0	14.7

Standing cornfield

Another strip-type windbreak studied was a standing cornfield south of Ames. The north-south rows of corn were planted 0.9 m (3 ft) apart, and there was a picked cornfield to the west. Pheasant tracks were seen in the standing corn, but no birds were flushed.

Honeysuckle windbreak

A strip of mature bush honeysuckle (Lonicerca sp.) planted along a north-south woven-wire fence south of Scranton, Iowa was studied in January, 1975. The "strip" of vegetation was an average of 6.7 m (22 ft) thick and 4.3 m (14 ft) high at the three points crossed by sampling transects. It extended about 92 m (100 yd) back from the road along the east side of the fence, just to the west of a farmer's driveway. There was an open field to the west, and no pheasant sign was found in the windbreak.

Honeysuckle-spruce windbreak

In January 1975, a honeysuckle-spruce windbreak north of Boone was studied. The windbreak was L-shaped, with the point of the L facing northwest and a barn and other buildings within 30 m (100 ft) to the southeast. Honeysuckle bushes 2.1 - 2.4 m (7 - 8 ft) tall were growing behind a woven-wire fence. The bushes had been planted a meter or so apart and there were gaps in the vegetation at the bases of the plants. Directly behind the honeysuckle were a number of 4.6 m (15 ft) spruce (Picea sp.) trees. Just to the west of the windbreak was a hard-surfaced road, and across the road was a picked soybean field. No pheasant sign was found in the windbreak, but rabbits made heavy use of the low spruce branches as cover.

Shrub row plantings

Iowa State University has a small plot of ground south of Ames on State Street on which are planted rows of various types of shrubs and trees for experimental growth tests. The plantings created a variety of windbreak situations that were investigated in 1975. Four basic groupings of shrubs were studied, and will here be called groups A, B, C, and D.

Shrub group A. The first of the groups consisted of three north-south rows of 1.8-m (6 foot) privet hedge (*Ligustrum* sp.), with rows 1.8-m (6 feet) wide and 1.8 - 2.1 m (6 - 7 feet) apart. A series of randomly located samples of stem density were made at a height of 0.9 m (3 feet) above ground level. All stems were less than 2.5 cm (1 inch) in diameter and the average of nine measurements was 155.0 stems/m^2 (14.4 stems/ft^2).

Shrub group B The second shrub group consisted of the same three rows of privet hedge as group A, with an additional row of very dense northern white cedar (*Thuja occidentalis*). The cedar hedge was 1.1 m (3.5 feet) tall and 1.5 m (5 feet) wide, and was located directly leeward of the second row of privet. The white cedar was too thick to obtain a measure of density, but the average density of the privet in shrub group B was 138.9 stems/m^2 (12.9 stems/ft^2).

Shrub group C Shrub groups C and D were located to the southwest of groups A and B. Group C. consisted of two rows of privet followed by a single row of rose bushes (Rosa sp.). The first row of privet was 1.7 m (5.5 feet) tall and 2.1 m (7 feet) wide, the second row 2.3 m (7.5 feet) tall and 4 m (13 feet) wide, and the rose bush row was 1.8 m (6 feet) tall and 1.5 m (5 feet) wide. There was a 4-m (13-foot) space between the two privet rows and a 0.9-m (3-foot) space between the rows of privet and rose. The average density of the privet was 123.8 stems/m^2 (11.5 stems/ft^2), while the average density of the rose bushes was 107.6 stems/m^2 (10 stems/ft^2) at a height of 0.9 m (3 feet) above ground level.

Shrub group D Shrub group D was located just to the north of group C. The vegetation consisted of the same two privet rows of group C, but there was no rose hedge. There was instead a row of dogwood (Cornus sp.) 1.1 m (3.5 feet) tall and 0.0 m (2 feet) in front of the first row of privet. In group D, the average density of dogwood was 72.1 stems/m^2 (6.7 stems/ft^2), while the average density of privet was 107.6 stems/m^2 (10 stems/ft^2).

No pheasant sign was seen near any of these rows of shrubs, and no pheasants were seen in nearby fields.

Modified Natural Windbreaks

Many natural cover areas do not provide pheasants with adequate protection from strong winds or drifting snow. An attempt was made to modify two existing natural cover areas by the use of vertical-slat snowfence which was 1.2 m (4 feet) tall.

Douglas-fir windbreak

At the Julius Black farm south of Ames, 30.5 m (100 feet) of snowfence was erected in a line parallel and 10.3 m (33.9 feet) windward of a windbreak of 10.7-m-tall (35-foot-tall) Douglas fir (Pseudotsuga menziesii) trees (Figure 1). Pheasant activity in this windbreak was observed both before and after placement of the snowfence.

Mulberry fencerow

About 30 to 40 pheasants used a small unmowed pasture and adjacent fencerow cover on the Verne Kingsbury farm for roosting, feeding, and loafing in January 1974 (Figure 2). A 30.5-meter (100-foot) line of snowfence extending diagonally across the fencerow from southwest to northeast was set up just to the north of mulberry (Morus rubra) loafing cover (Figure 3). Pheasant activity in the fencerow both before and after placement of the snowfence was noted.

For legal descriptions of natural and modified-natural windbreak locations, see Appendix I.

Experimental Windbreaks

In addition to studies of snow drifting and wind speeds near natural vegetation, tests of artificial windbreaks of certain designs were desired. Experimental designs were tested both in the field with full-sized models, and in a wind tunnel with scale model windbreaks.

Figure 1. Vertical-slat snowfence was placed parallel to and windward of a Douglas fir windbreak. The sheltering effects of the snowfence on the windbreak were compared to conditions of unsheltered areas along the same windbreak and fencerow.

Figure 2. A group of 30 to 40 pheasants used 3- to 4-m (10- to 12-foot) mulberry trees and an adjacent pasture as winter cover in January, 1974.

Figure 3. The mulberry cover was modifed by placing snowfence diagonally across the fencerow just north of pheasant loafing sites.

Field windbreak models

Windbreaks of several designs were constructed on barren University farmland and consisted mainly of 1.5- to 2.1-m (5- to 7-foot) Scotch pine (Pinus sylvestris) Christmas trees staked in various configurations with steel fenceposts. Lower sections of the trunks were trimmed so that the lower branches were near the ground. Vertical-slat snowfence was used in one of the designs as described below.

Double-horseshoe design In January 1973 an experimental windbreak constructed on a field of soybean stubble south of Ames consisted of a 15-m (50-foot) length of snowfence set up in the shape of a semicircle 5.6m (18.5 feet) to the northwest of a semicircular grouping of Christmas trees (Figure 4). It was hoped that the snowfence would shelter the trees to some extent from the strong northwest winter winds common in central Iowa.

Fencerow-intersection design In January 1974 two windbreaks of a fencerow-intersection design (Figure 5) were constructed on a plowed field south of Ames. North-south and east-west rows of Christmas trees, each row about 10.7 m (35 feet) long, were set up to simulate windbreak cover planted in farm fencerows. Two field models of the same materials, design, and locations as those of the 1974 windbreaks were constructed in January 1975.

Right-angle design Two experimental windbreaks of the right-angle design, common around Iowa farmsteads, were constructed in a plowed field south of Ames in January 1974. The Christmas trees used in these windbreaks were white pine (Pinus strobus) and their branches were much more sparse than the Scotch pine used for the other windbreaks (Figure 6).

Figure 4. The experimental double horseshoe windbreak studied in 1973 consisted of a semicircle of snowfence windward of a semicircle of evergreens.

Figure 5. Fencerow-intersection experimental windbreaks made of discarded Christmas trees were constructed and tested in 1974 and 1975. These models simulated possible windbreak plantings at the intersection of north-south and east-west fencerows.

Figure 6. The right-angle experimental windbreaks tested in 1974 were made of white pine trees whose branches were more sparse than those of the Scotch pine trees used in other models.

Scale-model windbreaks

Difficulties encountered in construction of experimental windbreaks and in gathering wind-speed and snowdrifting data during the winter of 1972-73 made clear the necessity of limiting the number of field-tested experimental windbreaks. It was thought that sheltering characteristics of a greater number of designs could be examined by testing scale models under controlled conditions than by testing full-sized windbreaks under natural conditions. The most promising designs could then be tested in the field. Due to the interest and cooperation of Dr. James D. Iversen of the Aerospace Engineering Department at Iowa State University, an opportunity for testing scale model windbreaks in a wind tunnel was provided.

Materials for modeling The material chosen to model snow particles was glass shot (small round glass beads) with an average diameter of 91 microns. This material was being used in other tests conducted at the Aerospace Engineering Lab and had good drifting properties for tests with model windbreaks. The models were made of 15-cm (6-inch) and 8-cm (3-inch) plastic shrubs purchased at a local store, and the scale of the model was 3/40 that of the prototype field windbreak. Plastic vegetation was used because of its durability and ease of clean-up after a test run.

Model windbreak designs Model windbreak designs tested in 1973 were fencerow-intersection designs with and without snowfence, a doughnut-shaped windbreak, and a more streamlined teardrop design. In 1975, tests were repeated for the same fencerow-intersection and doughnut designs, and a fencerow intersection adjusted for north wind was also tested. Wind-tunnel modeling techniques, technical modeling parameters, and testing procedures are further discussed in the METHODS section.

METHODS

Snow-depth Measurement

Snow-depth measurements were made with a wooden yardstick to the nearest 2.5 mm (0.1 inch). The yardstick was pushed down through the snow until either solid ground or an icy crust was felt. The latter represented the starting point of snow depth before the storm. Prior snow cover was always either absent or shallow and nearly level so that drifting snow was not significantly influenced by prior drift obstruction. Snow depths were always measured before the snow started to melt with either straight-line or grid-sampling arrangements, as discussed below.

Straight-line samples

At all nonexperimental windbreaks in the field, measurements were made at regular intervals in a straight line from windward to leeward through windbreak cover. These lines of measurement parallel to wind flow will be called "transects" in this report. For further clarification, the location of various measurements along the transects will be discussed in relation to a "line of reference" perpendicular to the wind direction at the time of drifting and tangent to the windward edge of the windbreak. A drift-depth profile could thus be obtained for natural and modified natural windbreaks.

Starting sites along the line of reference were selected at random for natural windbreaks and subsequent measurements were made along the transects at exact intervals by using a 3.7-m (12-foot) bamboo pole marked in feet and inches. The directions of the transects were determined before measurement started by using a compass to place wooden stake markers. The wind direction during drifting was determined by weather reports and by the general direction of drifts behind stems at the study site. Snow deposition amounts and accompanying wind speeds were obtained from weather reports given by WOI-TV in Ames or by the weather station nearest the site at which measurements were made.

Snow-depth measurements at two strip-type windbreaks (honeysuckle-spruce and shrub-row planting, group B) and at two clump-type windbreaks (ragweed and willow) were compared by an analysis of variance (Steel and Torrie 1960). The design was a randomized complete block with the different windbreaks as four treatments and the distance leeward (in 4-foot intervals from 0 to 40 feet) from the line of reference as 11 blocks. Each block-treatment cell had three replications.

At the Douglas fir windbreak modified by snowfence, snow depths were measured along transects which crossed the snowfence and also at the same points along other transects away from the snowfence for comparison (Figure 7). Measurements at levels 0.7, 2.0, and 3.4 m (2.3, 6.7, and 11.1 feet) south of the fencerow were selected for statistical analysis because they were in areas frequented most by pheasants in this windbreak. A T-test (Steel and Torrie 1960) was used to compare the mean for the 12 measurements leeward of the snowfence to the mean for the 12 measurements away from the snowfence. No snowdrift measurements were made at the mulberry fencerow windbreak because some melting had occurred by the time the windbreak was studied. General patterns of drifting there were noted, however.

Grid samples

Snow depth and pattern at experimental windbreaks were measured using a grid pattern sampling arrangement. Experimental windbreaks were of two types: (1) field, and (2) scale models placed in a wind tunnel, as described previously. The sampling grids were positioned so that snow depths were measured at the same reference points for both the field windbreak and the scale model. The grid-sampling points in the field were 133.3 cm (4.4 feet) apart and corresponded to 10-cm sampling intervals in the wind tunnel. A compass was used to orient grid boundaries on the field windbreaks and these were marked by semi-permanent stakes. A long bamboo pole calibrated in 133.3-cm intervals was used to determine sampling sites. Sampling points in the wind tunnel were determined from a grid constructed by use of a calibrated string oriented to marks made on the sides of the tunnel.

Drift-depth measurements at the double-horseshoe field windbreak were made in a grid pattern leeward of the semicircle of Christmas trees (Figure 8). The grid pattern at the right-angle field models had snow-depth measurement points windward, leeward, and beneath the trees (Figure 9). The mean snow depth beneath the trees (14 sample sites) was compared to the mean depth leeward (16 sample sites) with a T-test for each of the two right-angle windbreaks. Locations of sampling sites selected for these tests is shown in Figure 10.

Figure 7. Sampling sites for snow depth (+) and wind speeds(o) at the Julius Black farm windbreak in February 1974. Snow-depth samples at three levels just south of the fencerow were used to test the effect of snowfence on snow accumulation in areas of the windbreak used most by pheasants. Snow-depth sampling sites were 4.4 feet apart from north to south.

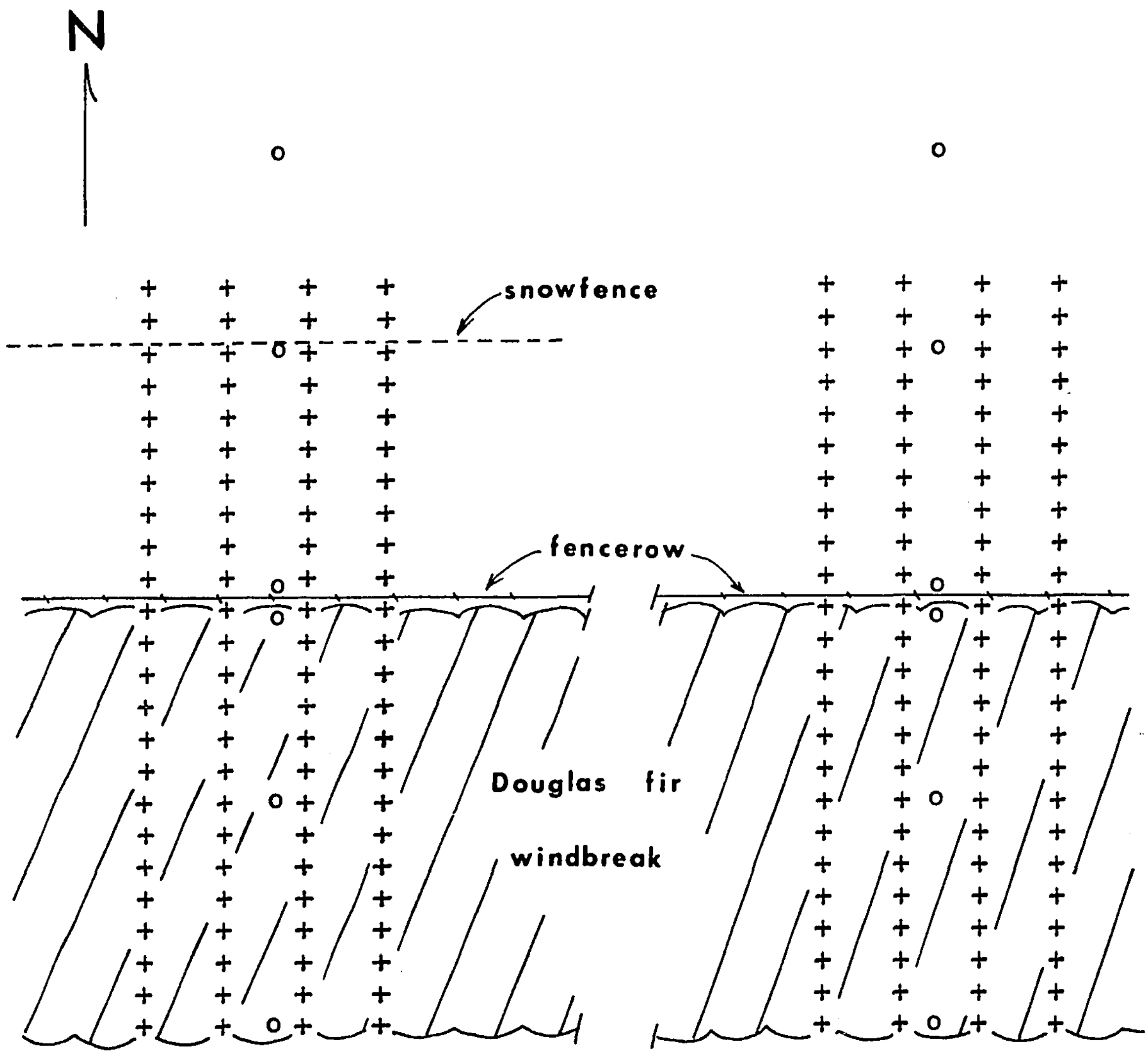

N
snowfence
fencerow
Douglas fir
windbreak

Figure 8. Sampling sites (+) for snow-depth measurements made behind the double-horseshoe windbreak tree barrier in January and February 1973.

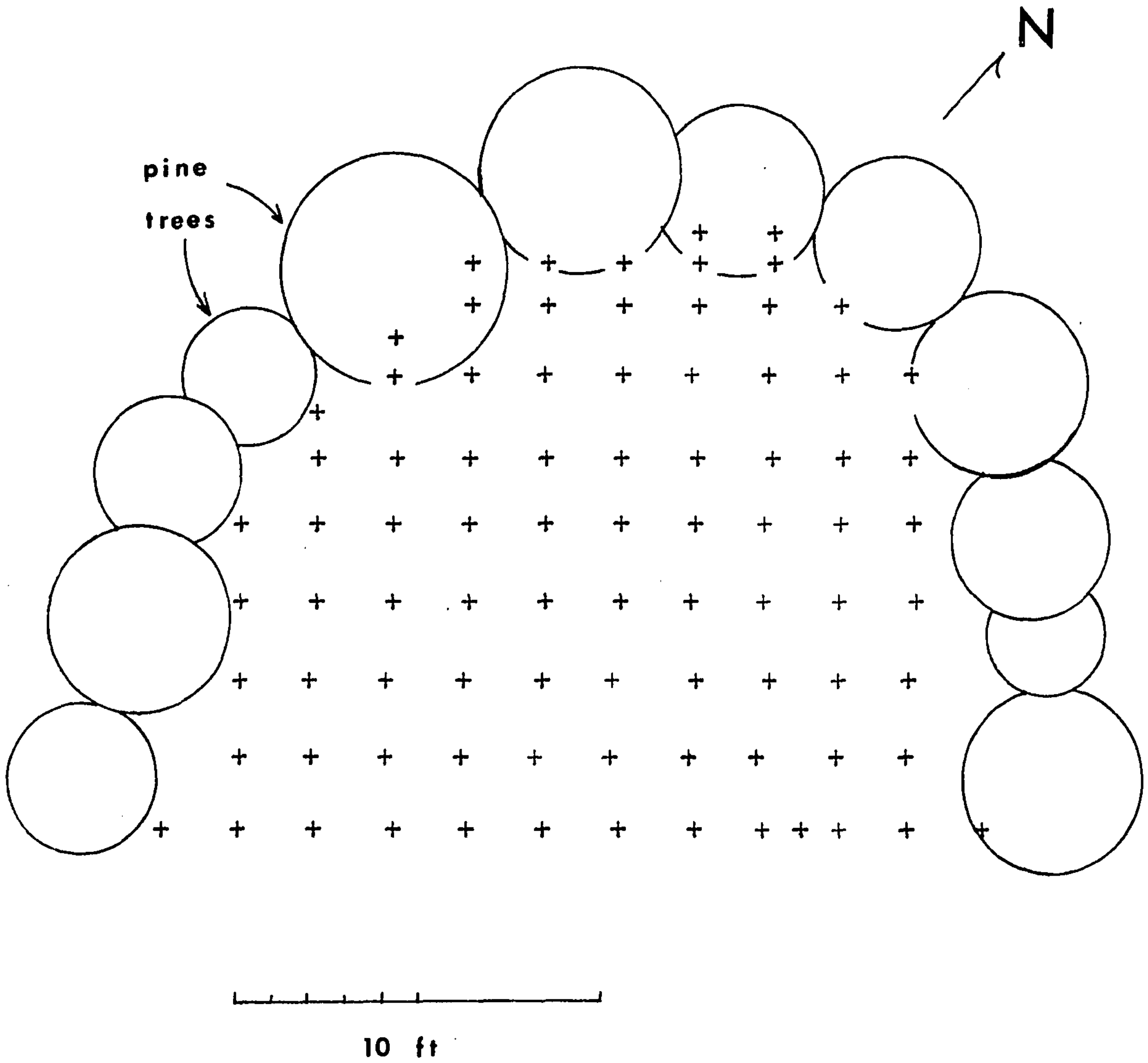

N
pine
trees
10 ft

Figure 9. Sampling sites for wind speeds (o) and snow depths (+) in relation to boundaries of the right-angle design windbreaks tested in January and February 1974. The single site at which open-field wind speeds were measured is not shown.

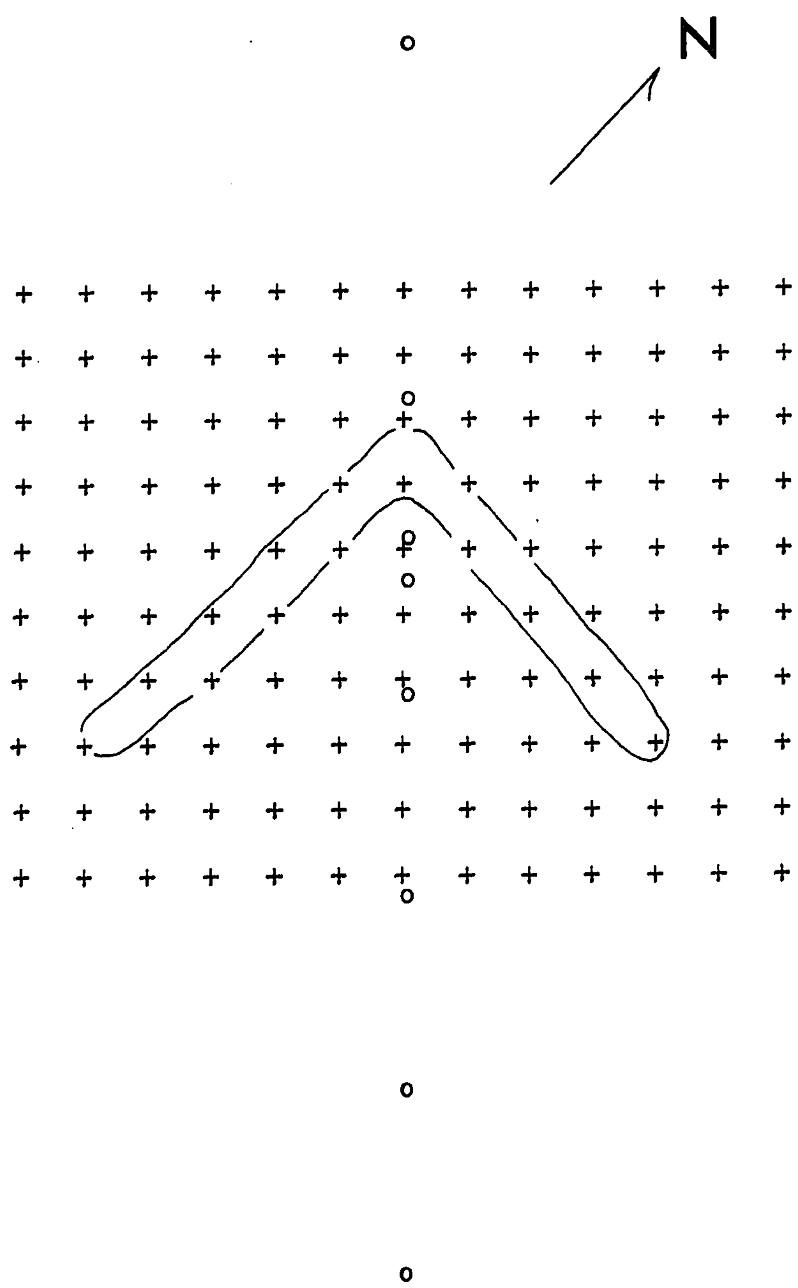
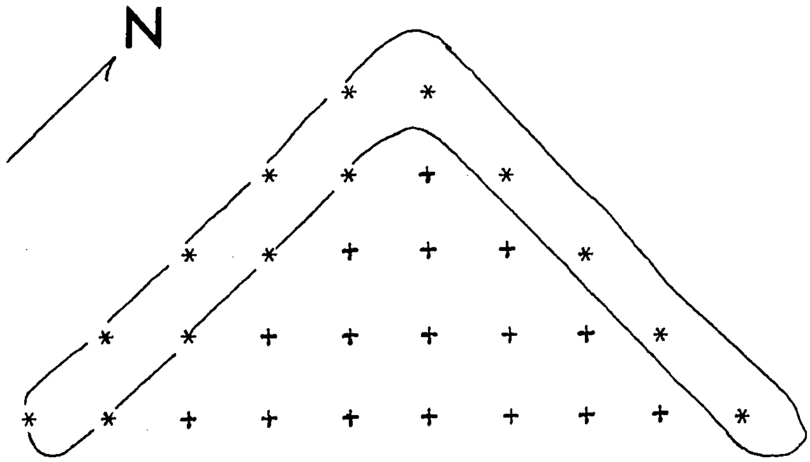

N

Figure 10. Selected snow-depth sampling sites at the two right-angle experimental windbreaks on 24 and 25 February 1974. Differences between the mean for 14 samples beneath the trees (*) versus the mean for 16 samples leeward of the trees (+) were tested for each windbreak.


N

Placement of the sampling grid in relation to the fencerow-intersection windbreaks in the field is represented in Figure 11. On 14 and 15 January 1974, measurements were made at the fencerow-intersection windbreak in snow which had drifted from the northwest. The mean of 11 samples beneath windbreak trees was compared to the mean of 24 samples outside and leeward of the vegetation (Figure 12) for both windbreaks by means of a t-test. An analysis of variance, with each of the three groups of eight samples outside the trees on the three sides as treatments, was made to see if a difference in snow depth due to the side on which the measurement was made could be found. In late February 1974, snow had drifted through the same experimental windbreaks from the north, and different sampling sites were chosen for comparison (Figure 13). The mean snow depth beneath the trees was again compared to the mean outside and leeward of the vegetation by means of a t-test for both windbreaks.

Drift depths at scale-model windbreaks in a wind tunnel were also sampled using grid patterns (Figures 14, 15, 16, and 17). In 1973 the particles used to model snow were spread over the wind tunnel floor and drifted past the models, but in the 1975 tests, the particles were dumped into the airstream from above. Drift-depth samples for the two years' runs were compared by tests of correlation (Steel and Torrie 1960) to see if the drifting patterns were similar or different. Tests of correlation between drifting patterns at the scale versus the field fencerow-intersection models were also made. Data from wind-tunnel tests in 1973 and 1975 were compared to field data for January 1974 at the fencerow-intersection model. A test of correlation between data collected

Figure 11. Grid pattern for sampling snow depths near the fencerow-intersection design experimental windbreaks in 1974. Sampling sites (+) are shown in relation to windbreak boundaries.

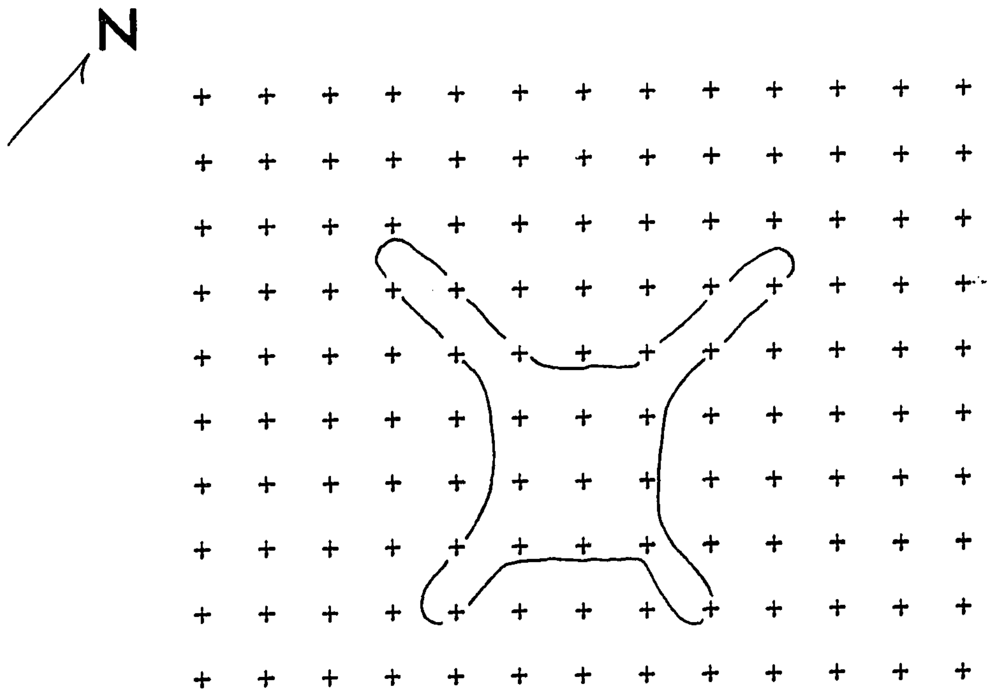

N

Figure 12. Selected snow-depth sampling sites at the two fencerow-intersection experimental windbreaks on 14 and 15 January 1974. Those sites beneath trees (*) and outside the windbreak (+) are shown in relation to the windbreak outline, and were used for several t-tests described in the text.

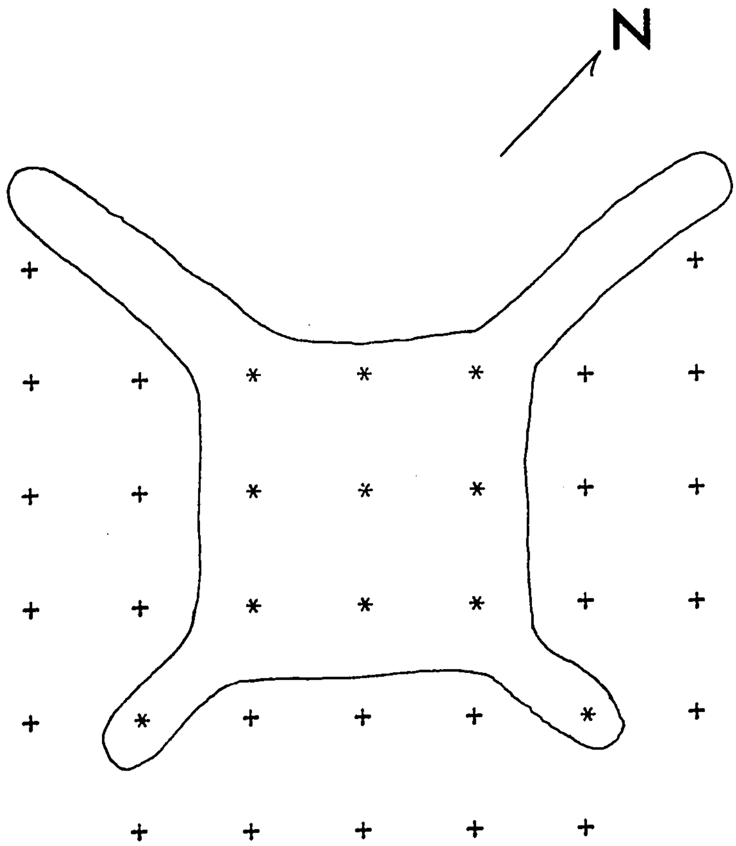

N

Figure 13. Selected snow-depth sampling sites at the two fencerow-intersection experimental windbreaks on 26 February 1974. Differences between means for 11 samples beneath trees and north of the north-south row (*) versus 15 sites outside (+) the windbreak were tested.

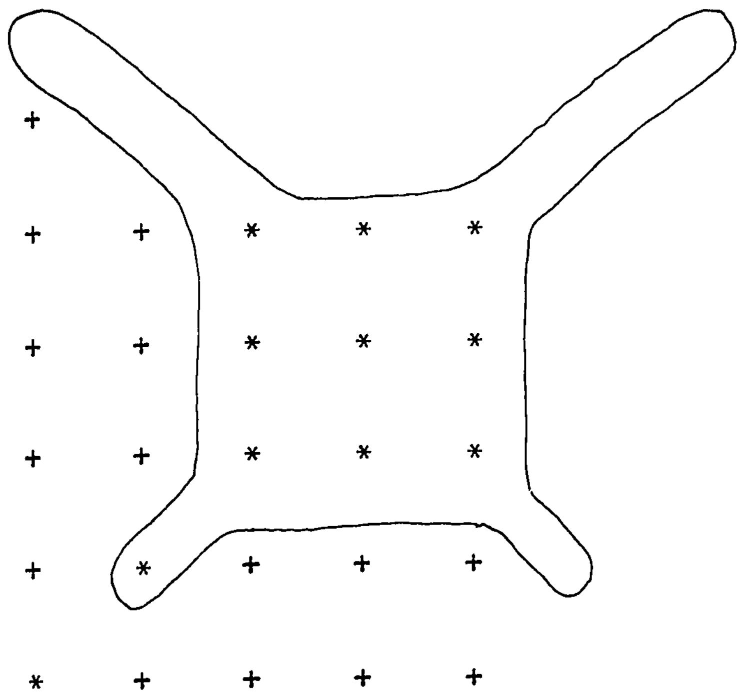
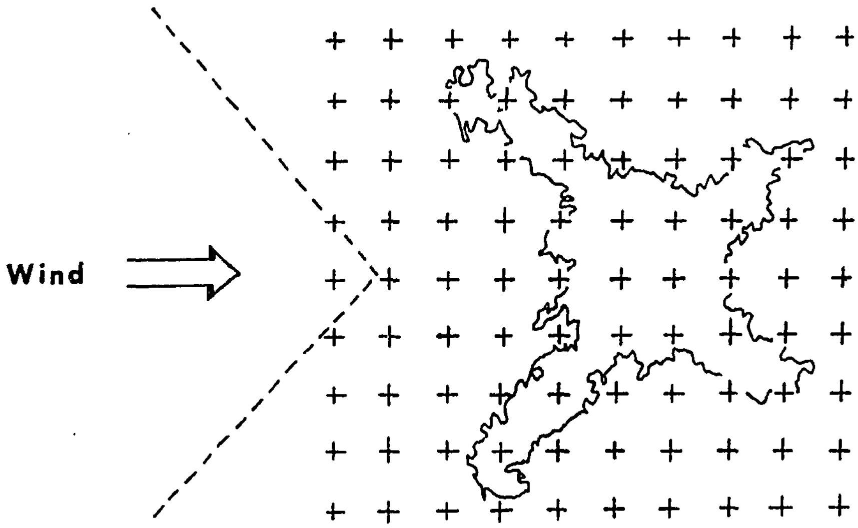


Figure 14. Wind-tunnel model of fencerow-intersection design, with removable snowfence. Plastic windbreak vegetation is outlined and crosses (+) represent drift-sampling sites. Dashed line represents model snowfence.

Figure 15. Wind-tunnel model of doughnut design. Vegetation is outlined and crosses (+) represent drift sampling sites.


Wind

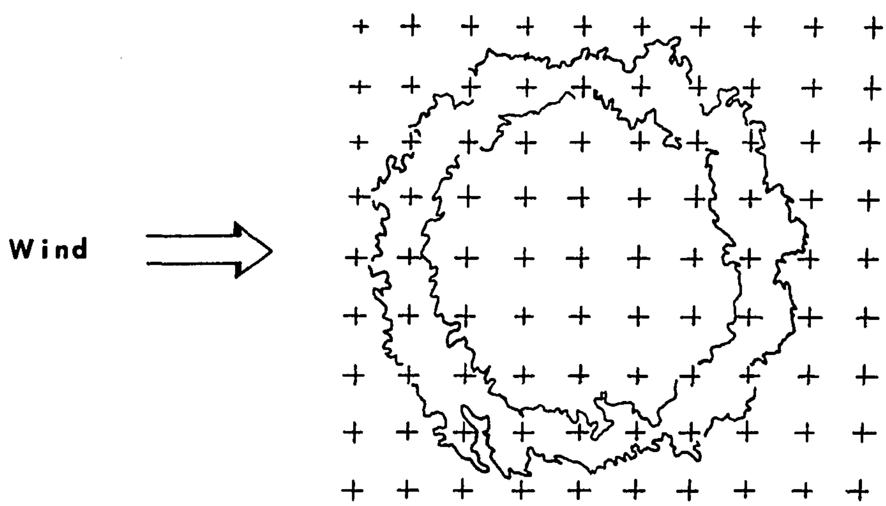
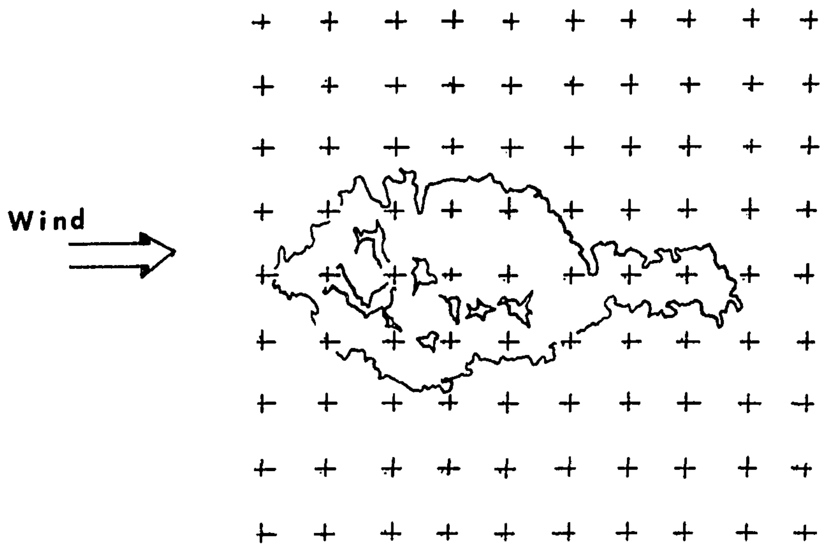
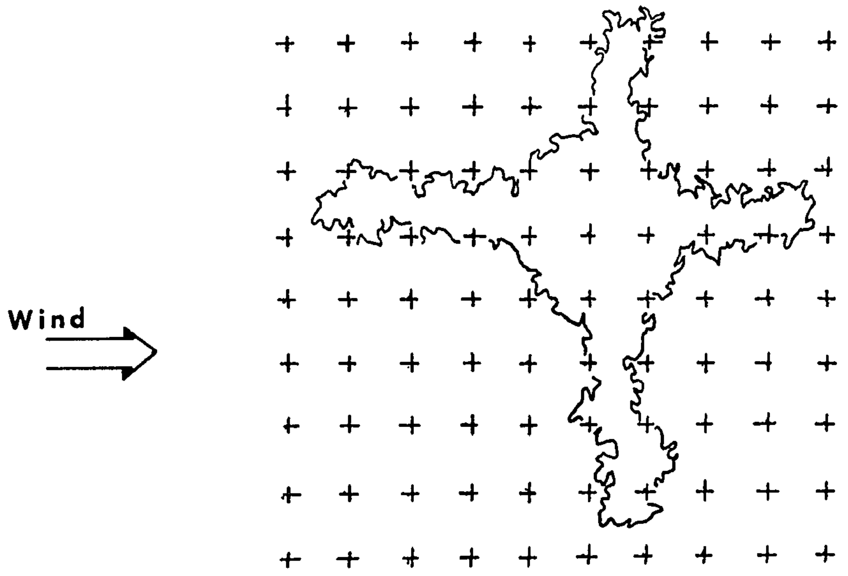

Wind

Figure 16. Teardrop-design windbreak tested in the wind tunnel. Windbreak vegetation is outlined and the drift depth sampling grid is represented by crosses (+).

Figure 17. Fencerow-intersection design rotated to simulate north rather than northwest wind. Cross grid represents drift-depth sampling sites, and vegetation is outlined.


Wind


Wind

at the scale model adjusted for north wind (Figure 17) and the February 1974 data from the fencerow-intersection field model was also made.

Wind-Speed Measurement

Wind-speed measurements were made at most of the windbreaks studied. Snow deposition patterns corresponded to airflow characteristics around windbreaks, and protection for pheasants from high winds with blowing snow is an important feature of good winter cover. Taylor and Weather Measure air meters were used to measure wind speeds at various points in and near the windbreaks. The air meter is an instrument with aluminum vanes which move as air passes through the meter and it records meters or feet of air passing the vanes while the meter is on. The very light vanes attain little momentum and can change speed suddenly with changes in airflow. The meters can detect as little as 0.2 m/sec (0.5 mph) air movement.

The amount of air passing the meter in 2 minutes was recorded and an average wind speed for that period was thus obtained. Measurements were made in two ways:

1) At the beginning of the study only a single Taylor air meter was available. Measurements for 2 min at various points in the windbreak were thus made one at a time. A set of consecutive measurements at a single location in the open field was also made to determine variability of wind velocities at the time measurements were made.

2) Three additional air meters were purchased later and measurements of windspeed in feet and meters per 2 min were obtained from four locations simultaneously. Each meter was turned on and off manually, thus, a 15-sec lag occurred between the time periods during which meters no. 1 and no. 4 were recording the wind movement.

The meters were secured to ring stands and placed 15-30 cm (6-12 inches) above the ground or snow surface. To protect the sensitive and expensive instruments from damage due to snow and ice accumulation, no measurements were made during snowstorms.

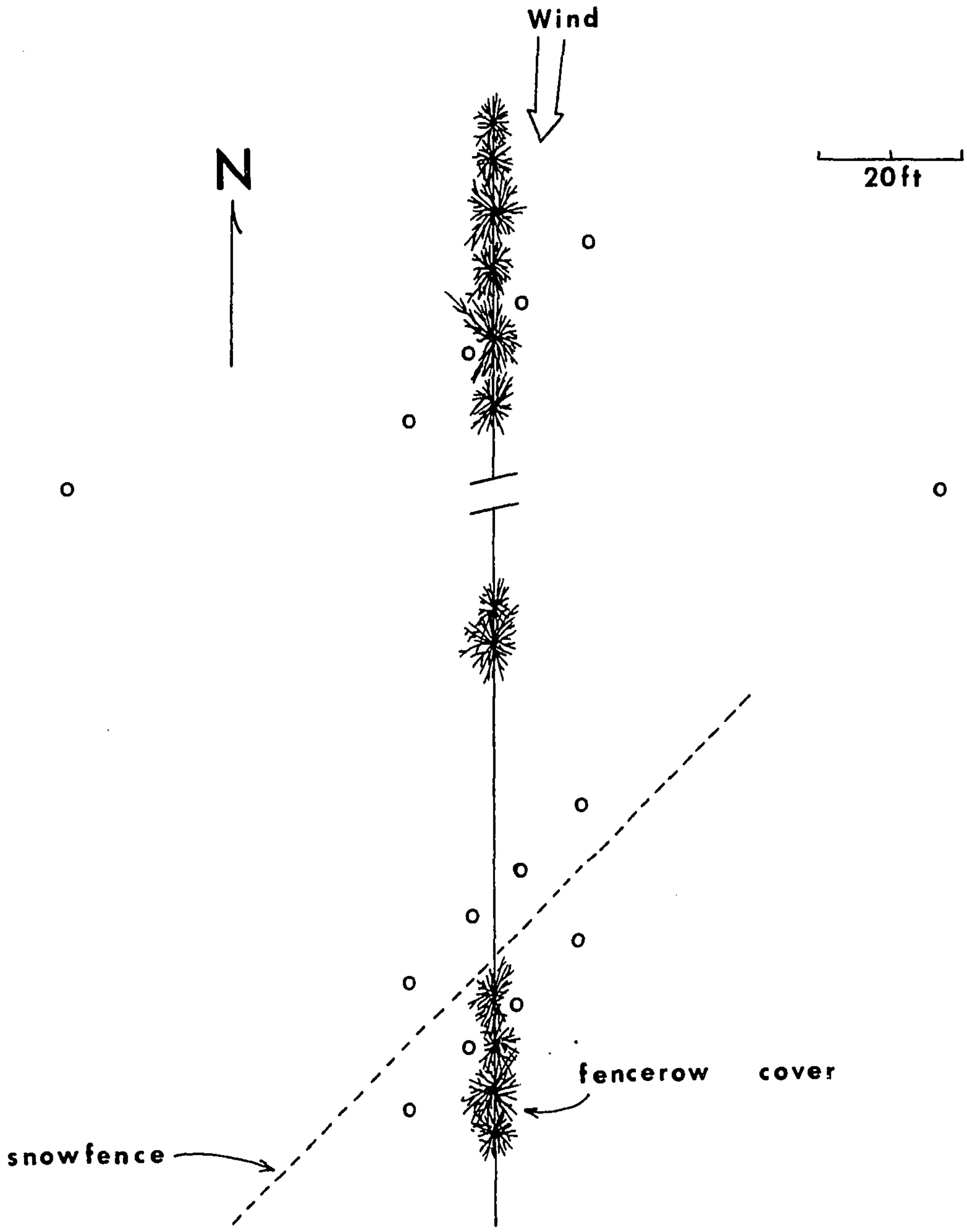
Wind speeds were measured at four natural windbreaks: the ragweed stand, the willow stand, the weed strip, and the field of standing corn. Two or more transects were established at each windbreak and four sampling points were located at the same distances from the line of reference along each transect. An analysis of variance was then made for each windbreak, with the distances from the line of reference as treatments and the transects as blocks. If there was a significant difference in treatments, a further analysis of treatment means was made using Duncan's multiple range test (Steel and Torrie 1960). A linear regression analysis (Sokal and Rohlf 1973) was used to establish regression lines for the decrease in wind speed with distance leeward from the line of reference for the ragweed and willow clumps. *F*-tests (Sokal and Rohlf 1973) were used to compare slopes of the regression lines for the two windbreaks to see if one was more effective than the other in reducing wind speeds.

Wind speeds at the Douglas fir windbreak were measured with a single wind meter at six points along each of two transects (Figure 7). The data were analyzed as a randomized complete block design with the two transects as treatments and the five levels leeward of the snowfence (and the corresponding levels along the transect away from the snowfence) as blocks. There were four sample replications per block per treatment. In addition to this analysis of variance, the mean of the four measurements at each level along one transect was compared to the mean at the corresponding level on the other transect by a t-test.

At the mulberry fencerow windbreak, wind speeds were measured with a single wind meter at various points along the fencerow and in the open field (Figure 18). The data were analyzed using an analysis of variance with a complete block design. The samples were divided into three treatments: 100 ft north of the snowfence (far north), 9 ft north of the snowfence (near north), 9 ft south of the snowfence (south). At each of these three levels (treatments), measurements were made at four locations (blocks): 10 ft west, 1 ft west, 1 ft east, and 10 ft east of the fencerow. The three treatment means were also compared to each other by using t-tests.

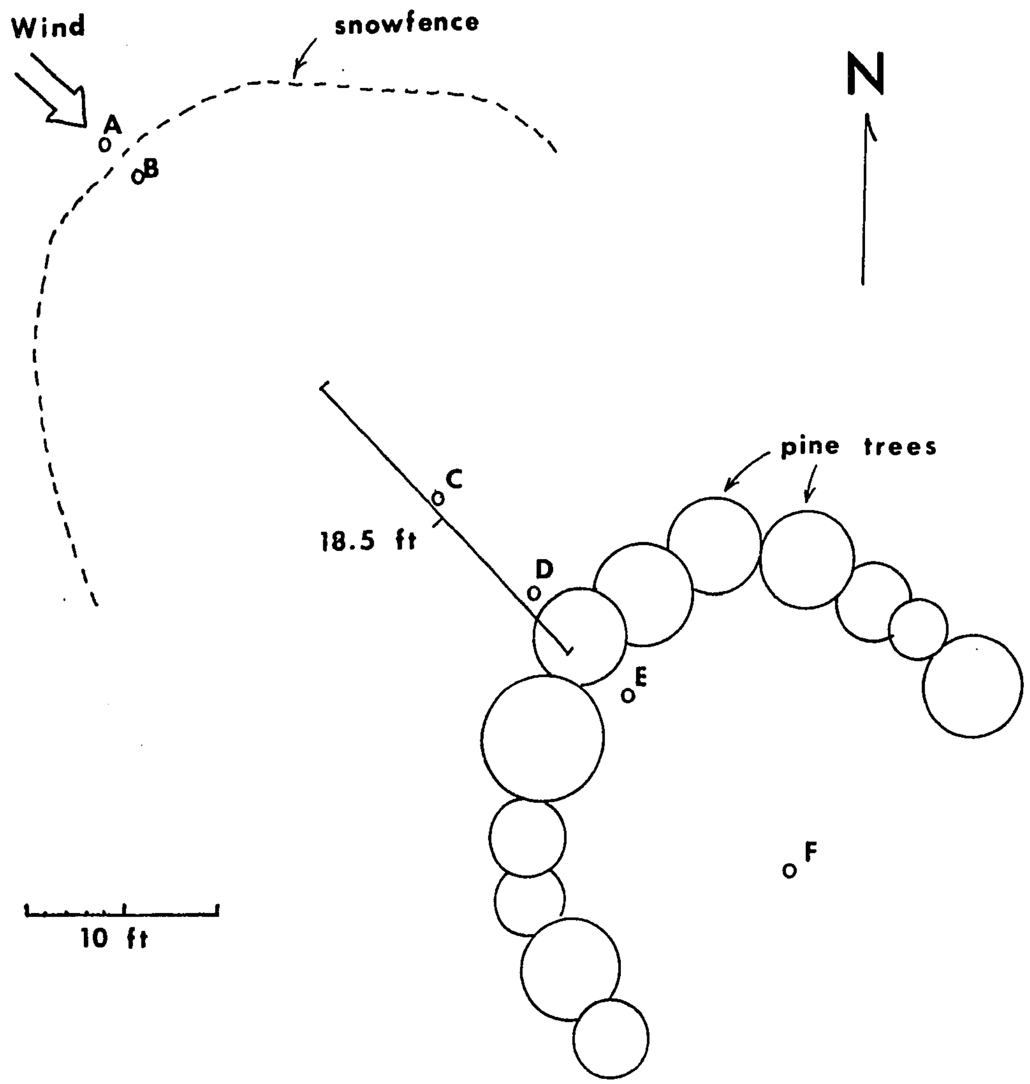
At the double-horseshoe experimental windbreak, windspeed measurements were made 30, 60, 90, and 120 cm (1, 2, 3, and 4 ft) above ground surface with a Taylor wind meter at the six positions near the windbreak (Figure 19). Wind speed and direction in the open field away from the windbreak were obtained by use of a Taylor windscope.

Figure 18. Wind-speed sampling sites (o) near mulberry fencerow cover which was modified by diagonally placed snowfence in February 1974.



Wind
N
20 ft
fencerow cover
snowfence

Figure 19. Double-horseshoe windbreak with points A through F at which wind-speed measurements were made in January 1973.


Wind
snowfence
N
A
B
C
18.5 ft
D
E
F
pine trees
10 ft

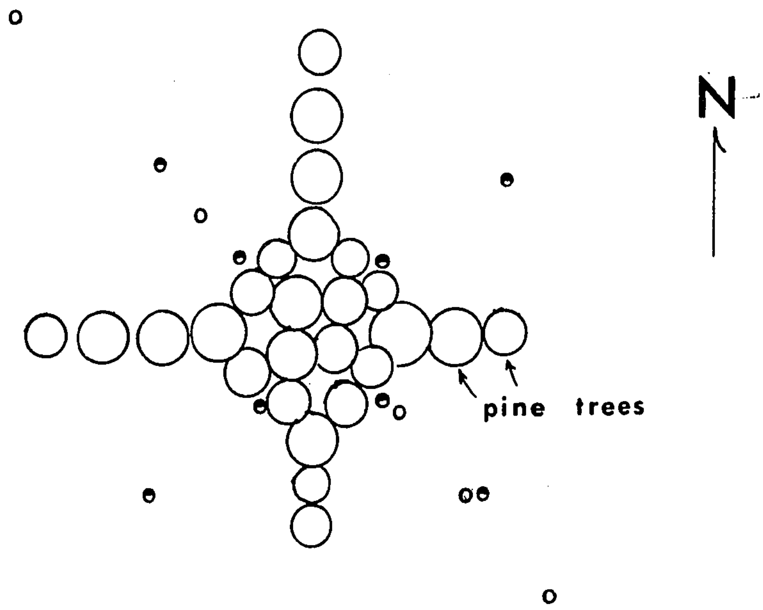
Wind-speed measurements were made at five points along a transect and at eight points in the "field corners" near the two experimental fencerow-intersection field models in 1974 (Figure 20). Control measurements of open-field wind speeds were made sequentially at a point away from the windbreaks. In 1975, wind-speed measurements were made at points 2.7 and 0.6 m (8.8 and 2.0 feet) windward and 0.6 and 5.4 m (2.0 and 17.6 feet) leeward of fencerow-intersection field models along a similar transect. Analysis of variance was used to determine whether or not there were differences in mean wind speeds at the various points on the transect or in the field corners. Sampling positions were treatments in the ANOVA and the two windbreaks were blocks. If the effect due to position was significant, a Duncan's multiple-range test was used to further analyze the differences.

Wind speeds at two right-angle field windbreaks were sampled at eight points along a transect for each windbreak (Figure 9). Open-field wind velocities were sampled sequentially at a ninth point away from the windbreaks. An analysis of variance, with sampling positions as treatments and windbreaks as blocks, was used to determine whether or not wind speeds differed significantly due to the point along the transect at which they were measured.

Wind-Tunnel Modeling

The scale-model windbreaks used in this study have already been generally described. Consideration of various technical parameters,

Figure 20. Fencerow-intersection windbreak design tested in the field in 1974 and 1975. Straight-line (o) and field corner (●) sampling sites for wind speeds are shown.


N
pine trees

techniques, and procedures was necessary for accurate modeling of a blowing-snow environment in a wind tunnel.

Technical parameters for accurate modeling

Accurately modeling a blowing-snow environment in a wind tunnel is very difficult. To simulate actual conditions as closely as possible, one must consider a number of technical parameters and expressions when constructing the models. Dimensionless similitude parameters are expressions used to compare the physical and aerodynamic properties of a scale model structure and environment to those of a prototype. Because the units of measure for terms in both numerator and denominator are the same, the parameters are dimensionless. According to Iversen (1973: J. Iversen, Department of Aerospace Engineering, Iowa State University, Ames, personal communication) the following dimensionless similitude parameters are helpful in designing accurate models of eolian phenomena:
l/L, δ/L, z_0/L, $\rho L/\rho_p D_p$, U^2/gL, U_f/U_{*_t}, U/U_t, and U_t/L where:

- L = reference length (some linear measure, such as windbreak height is chosen as a representative dimension of the prototype),
- l = other linear measurements compared to the reference length,
- δ = boundary layer reference height, the maximum height above the base that wind velocity is less than it would be under free-flow conditions,
- z_0 = roughness height, the height at which wind-velocity reduction due to the effects of surface drag becomes zero,
- ρ = density of air,

ρ_p = particle density,

D_p = particle diameter,

U = reference velocity measured at a certain reference height, h,

U_f = particle terminal fall speed, the maximum speed that can be attained by the particle in free fall,

g = acceleration due to gravity,

U_{*t} = particle threshold friction speed, the lowest friction speed at which the majority of exposed particles on the surface are set in motion, and

U_t = reference velocity at threshold, the wind velocity at heighth when surface particles begin moving.

For an exact model, each dimensionless parameter for the model should equal that for the prototype, but this is often impossible with the materials and apparatus that are available. Gerdel and Strom (1961) list D_p/L, U/U_f, U^2/gL and e (coefficient of restitution -- a measure of the elasticity of a particle) as important factors for modeling snow drifting. Iversen (1973: personal communication) said that the parameters U_f/U_{*t}, and U_{*t}/gL are important in finding a particle to model snow. Finding the values of these physical parameters and expressions helped us choose the available materials that would provide the most accurate model of snow drifting near windbreaks. A comparison of the modeling parameters for the model and prototype are shown in Table 2.

Modeling techniques

Although the tests themselves were of fairly short duration, preparation of the models and tunnel was time-consuming.

Wind-tunnel set-up   The wind tunnel (Figure 21) was 19.2 m (63 feet) long. The working area was 6.4 m (21 feet) long with a square cross section 1.2 m (4 feet) on a side. A controlled non-circulating airflow was produced by an engine located in one end of the tunnel and the windspeed in the tunnel was monitored by pressure tubes inside the test section. Drifting patterns of the model snow were observed from two sealable windows in the sides of the tunnel. An observation booth and window on top of the tunnel facilitated taking pictures during the tests.

Testing procedure   Prior to testing the model windbreaks, a plywood disc 88.9 cm (35 inches) in diameter was constructed to fit into an opening in the floor of the wind tunnel test section. Holes were drilled into this base so that the plastic bushes, with bases fashioned from 6.35-mm (1/4-inch outside diameter) Bakelite tubing, could be inserted to form a specific design (Figures 22 and 23). Surplus holes, to be used for other designs, were then covered with plastic tape. For the 1973 tests, the glass shot was spread over the floor of the tunnel windward of the model and smoothed with a special rake to a uniform depth of 1 cm. The engine was then started and wind speed in the tunnel increased to about 4.9 m/sec (11 mph), causing the model snow to drift past the windbreak. The material not deposited in drifts behind the windbreak structure was baffled into a trap for collection and re-use. Each test was continued

Figure 21. Diagrammatic view of wind tunnel used to test model windbreak designs in 1973 and 1975. Windbreak models were set into the floor of the tunnel under the window. Glass shot used to model snow was spread over the tunnel floor in front of the model.

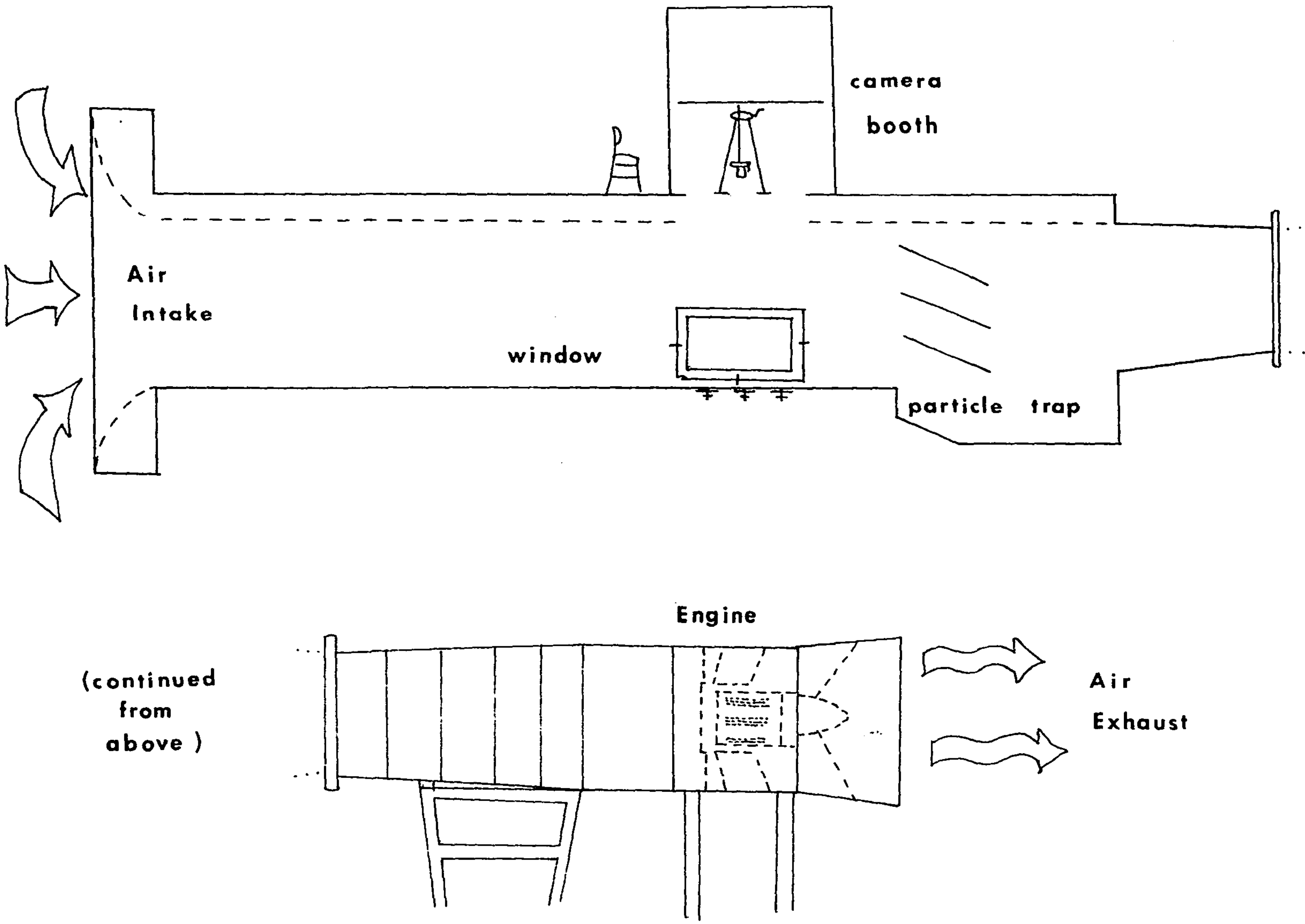
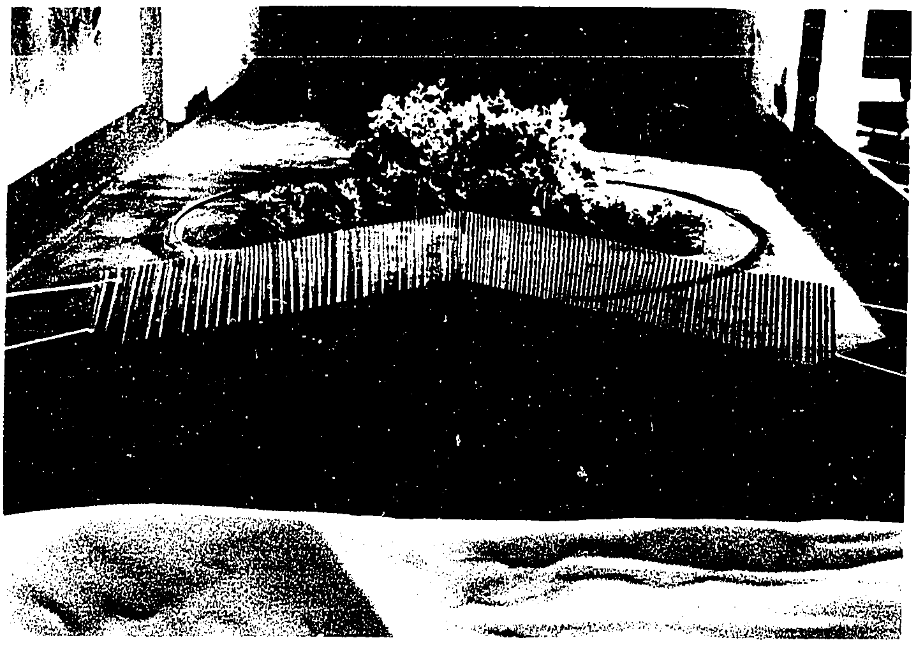

camera
booth
Air
Intake
window
particle trap
Engine
(continued
from
above)
Air
Exhaust

Figure 22. The teardrop-shaped windbreak and other scale models were made of 3-inch plastic bushes with their bases fitted into appropriate holes in a plywood base in the wind tunnel.

Figure 23. The fencerow-intersection design with removable snowfence was another of the scale models tested in the wind tunnel. The white material in the foreground is the glass shot used to simulate snow. In the 1973 tests, the model snow material was spread over the wind tunnel floor windward of the model and then allowed to drift past the model vegetation and snowfence.



until no more material was left in the forward section of the tunnel. For wind tunnel tests in 1975, the glass shot was placed in a shallow box and dumped into the airstream during the test instead of being spread over the test section floor. Drift-depth measurements were made in grid fashion with the use of a calibrated string marked at intervals of 10 cm stretched across the test section; this corresponded to the scale of the grid used for collecting snow-depth measurements at the experimental field windbreaks. Since the model snow had the consistency of fine sand and shifted quite readily when disturbed, a thin, lightly-oiled steel wire was inserted into the drifts at sampling sites. When the wire was removed, the small glass shot adhered to it and drifts could thus be measured to the nearest millimeter.

Table 2. Comparison of dimensionless similitude parameters for the wind tunnel model and its prototype (natural environment) for tests conducted in 1973 and 1975.

Parameter	Parameter values	
	Model	Prototype
D_p/L	0.6×10^{-3}	1.0×10^{-3}
U/U_f	8.1	1.4
U^2/gL	16.4	4.1
e	unknown	0.555
U_f/U_{*t}	3	14.5
U_{*t}^2/gL	1.4×10^{-3}	0.2×10^{-3}

RESULTS

Natural Windbreaks - Clumps

Two basic types of windbreaks -- clumps and strips of vegetation -- were studied to see if basic differences in snowdrifting patterns in the two types were evident. The two clump-type windbreaks studied were a ragweed stand in a plowed field west of Ames and a stand of willow at Dunbar Slough in Green County.

Ragweed stand

Snow depths at the ragweed windbreak were measured on 4 January 1975 after a 13-cm (5-inch) snowfall the previous day. A total of 49 snow-depth measurements were made in four north-south transects spaced 2.4 m (8 feet) apart through the rectangular windbreak (Figure 24). Peaks occurred about 2.4 to 4.0 m (8 to 13 feet) leeward from the line of reference, and the greatest depth recorded was 92.7 cm (36.5 inches) at 2.4 m (8 feet) leeward. The interval with the greatest mean snow depth (80.8 cm or 31.8 inches) was at 4.9 m (16 feet) leeward from the line of reference.

On 16 January 1975, measurements of snowdrifts caused by the January 11 blizzard were made at the same ragweed windbreak. A total of 80 measurements were made in three transects through the windbreak (Figure 25). Although only 5 cm (2 inches) of snow had fallen during the storm, drifts over 150 cm (60 inches) were found within the 2.4-m-tall (8-foot-tall) ragweed. The average length of transect within windbreak vegetation was 23.2 m (76 feet).

Figure 24. Snow depths in four windward-to-leeward rows at the ragweed stand on 4 January 1975. Most of the measurements were within the 45- to 50-foot-wide windbreak.

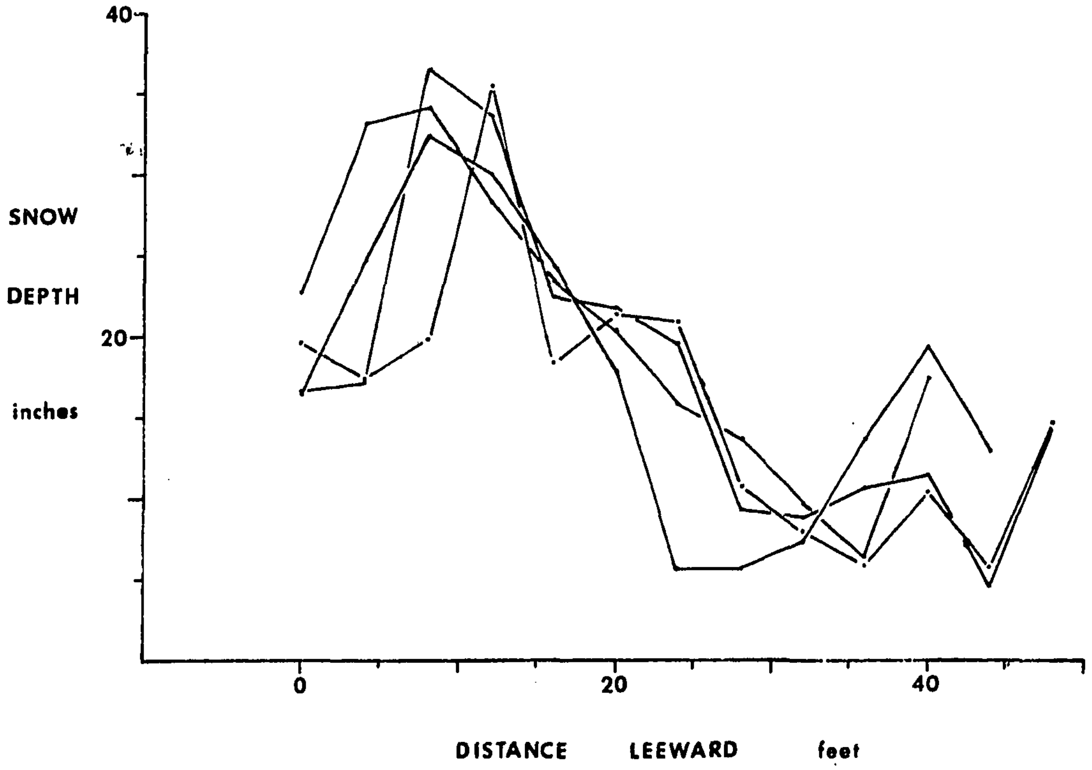
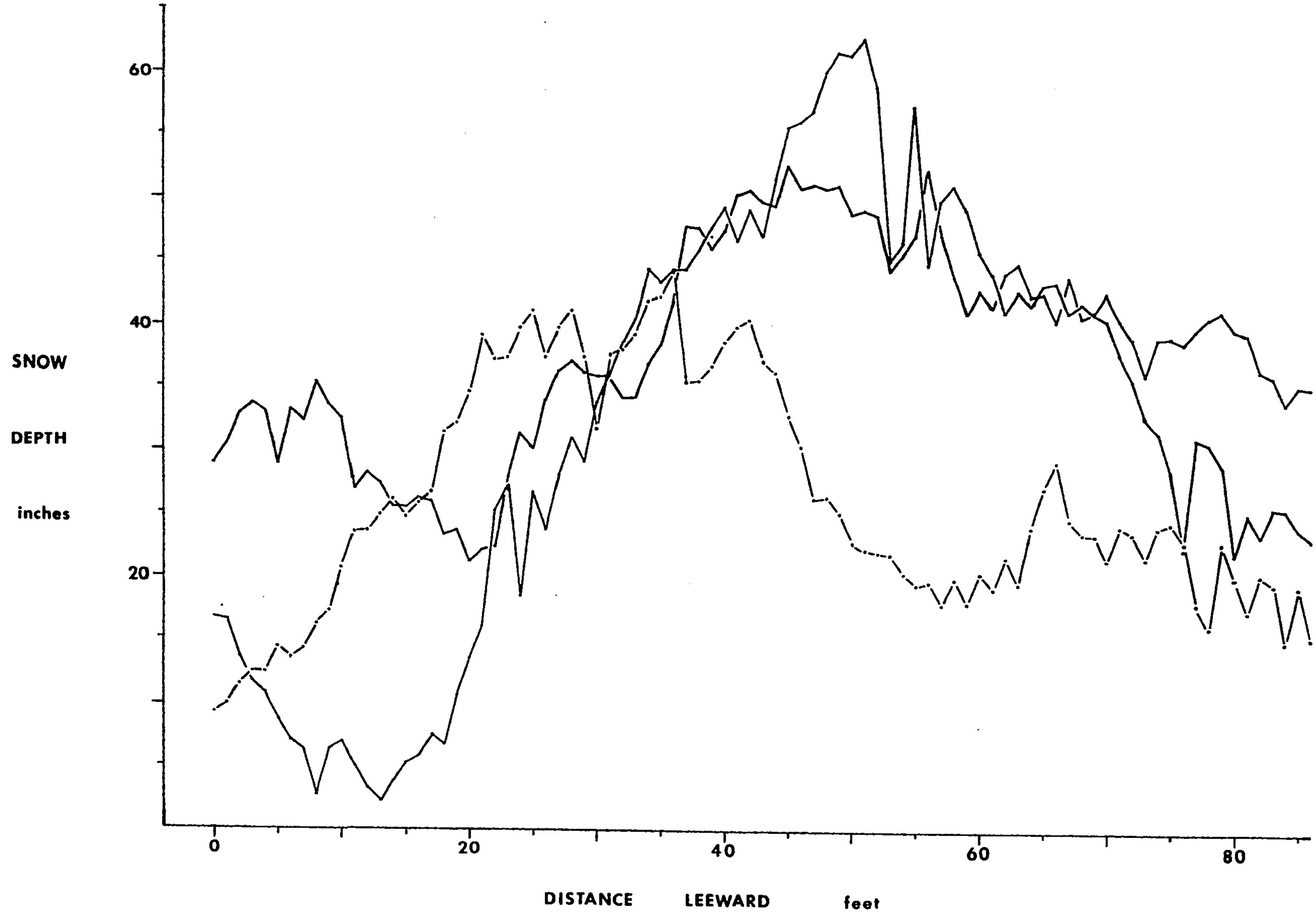

40
20
SNOW
DEPTH
inches
0
20
40
DISTANCE LEEWARD feet

Figure 25. Snow depths in three windward-to-leeward rows through the ragweed windbreak on 16 January 1975. Most of the measurements were within the 76-foot-deep ragweed stand.


SNOW
DEPTH
inches
60
40
20
0
20
40
60
80
DISTANCE LEEWARD feet

On 5 February 1975, wind-speed data were collected along a single transect through the ragweed windbreak (Figure 26). Original measurements were in units of meters per 2 minutes, but a mph scale is included as a more familiar reference. The four data points used for each line were obtained simultaneously with four wind meters. Four replications at each wind-meter position were made. At the time of data collection, winds were from the northwest at 6m/sec (14 mph) with gusts to 11m/sec (25 mph) and data were collected over snow cover. Wind speeds remained high even 1.8 m (6 feet) into the windbreak, but at 3.7 m (12 feet) leeward of the line of reference they decreased substantially (Figure 26). It was found by analysis of variance, however, that there were no significant differences (P 0.05) among wind-speed means for the four windward-to-leeward positions.

Willow stand

Snowdrifting patterns caused by the January 11 blizzard were studied at a willow stand in the northwest corner of Dunbar Slough on 13 January 1975. Three measurement transects from west to east were located 22.9 m (75 feet) north, 34.3 m (112.5 feet) north, and 45.7 m (150 feet) north of the south edge of the windbreak. The willow stand was large and measurements were therefore spaced at 1.2-m (4-foot) intervals within each row. The greatest snow accumulation occurred 12 to 18 m (40 to 60 feet) behind the windward edge of the windbreak, with the deepest drift (83.3 cm or 32.8 inches) located 14.6 m (48 feet) leeward (Figure 27). The greatest mean snow depth (70.9 cm or 27.9 inches) for the three transects occurred 17.1 m

Figure 26. Wind-speed measurements were made at the ragweed windbreak on 5 February 1975. Distances leeward of the samples from the windward edge of the windbreak are shown, and the four measurements along the transect were made simultaneously. The lines represent four replications along a single transect.

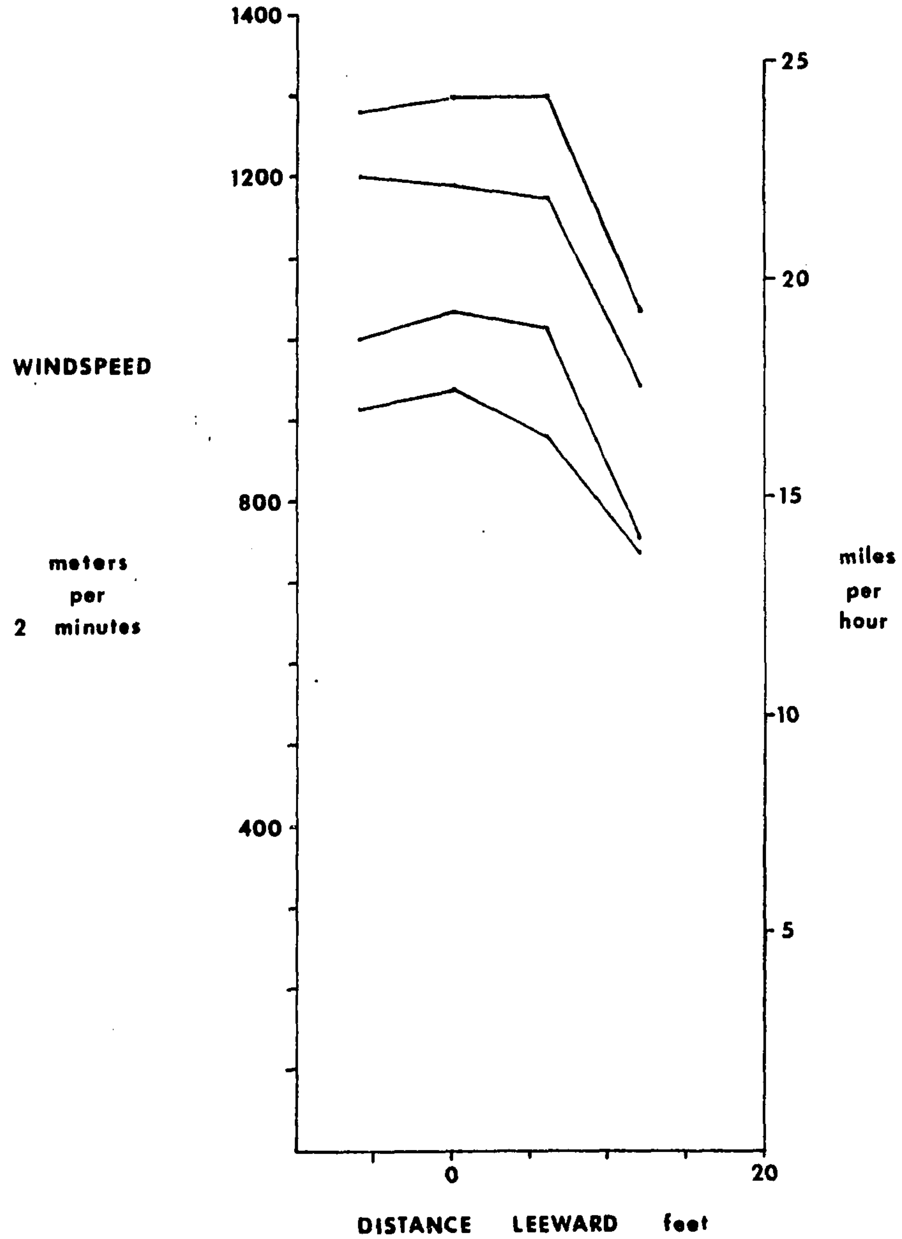
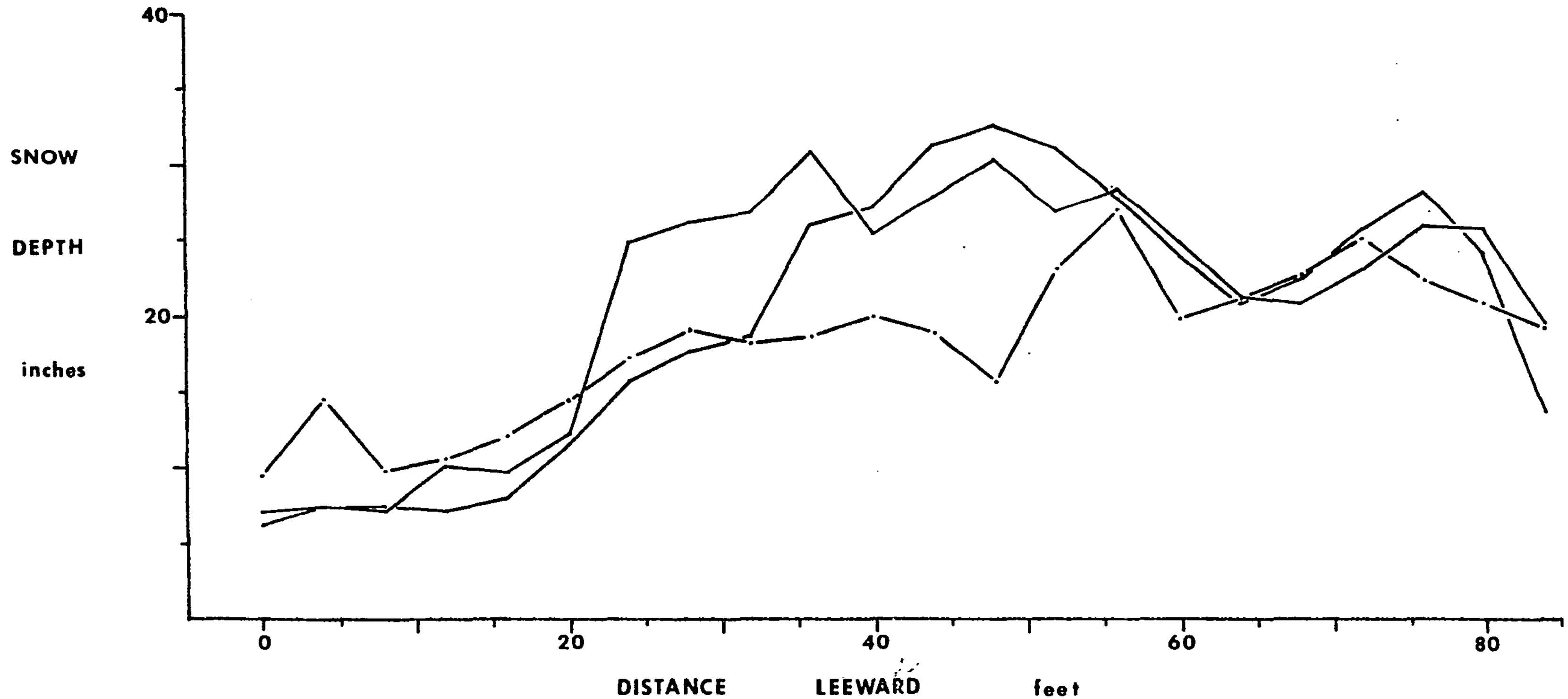

1400
1200
800
400
25
20
15
10
5
WINDSPEED
meters
per
2 minutes
miles
per
hour
0
20
DISTANCE LEEWARD feet

Figure 27. Three rows of snow-depth measurements made at various levels leeward of the windward edge of a willow stand on 13 January 1975. Sample sites were at 4-foot intervals in each row and all measurements were within the 200-foot-wide windbreak. Snow-depth values for sampling sites within only the first 85 feet of the windbreak are shown here.


40
20
SNOW
DEPTH
inches
0
20
40
60
80
DISTANCE LEEWARD feet

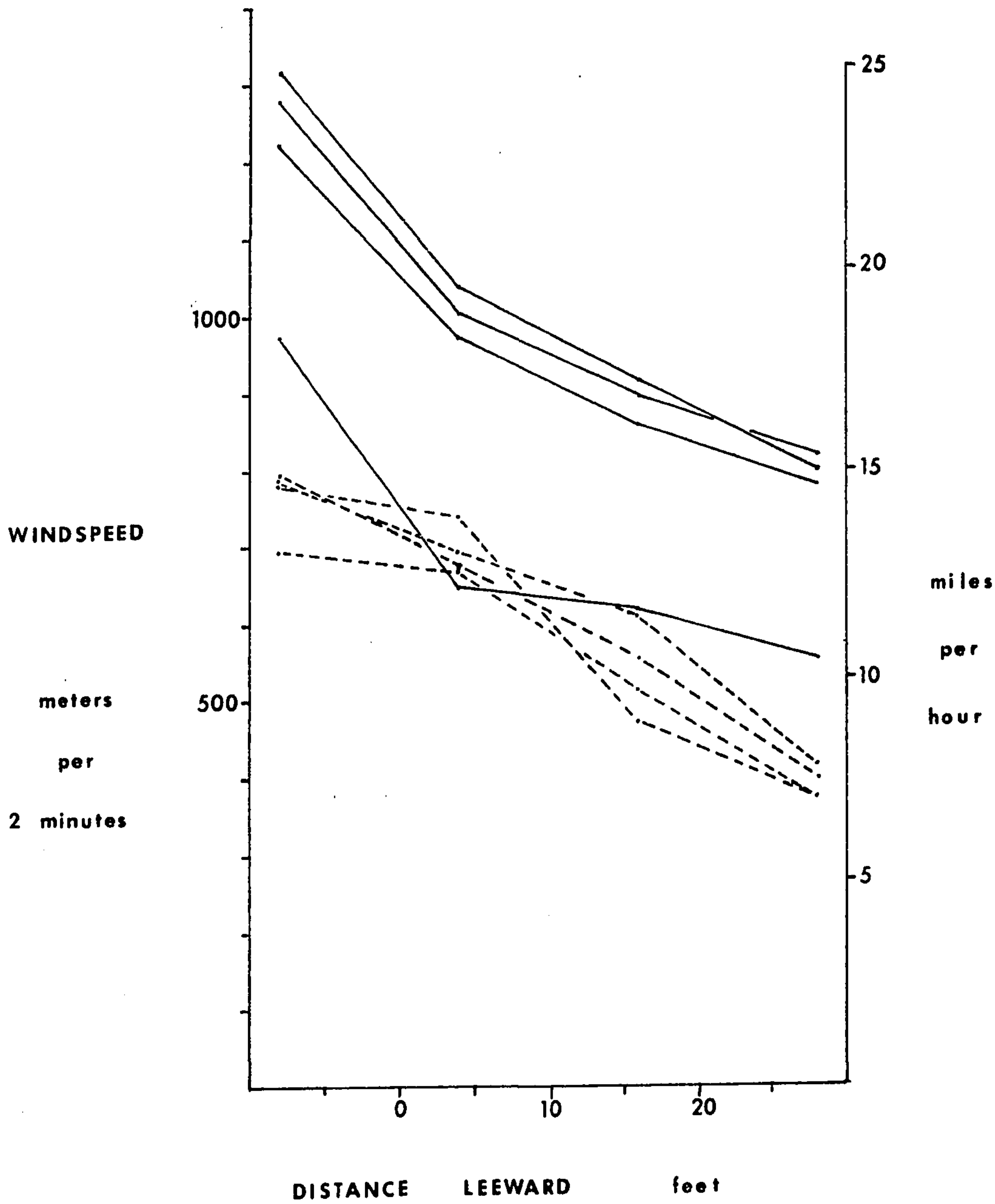
(56 feet) leeward of the line of reference, while the smallest mean snow depth (30.2 cm or 11.9 inches) occurred 39.0 m (128 feet) leeward.

With winds from the west, wind-speed measurements were made through the windbreak along two transects: (A) 23 m (75 feet), and (B) 46 m (150 feet) from the south edge of the willow stand. Readings were taken on a transect simultaneously at four points: 2.4 m (8 feet) windward, and 1.2, 4.9, and 8.5 m (4, 16, and 28 feet) leeward of the line of reference. Four replicate readings were taken at each of the four points on each transect (Figure 28). Average wind speeds were higher ($\underline{P} < 0.05$) at 2.4 m (8 feet) windward of the line of reference than at any of the three positions within the windbreak. Along transect A, mean wind speeds at the three points within the windbreak did not differ from each other ($\underline{P} > 0.05$). However, along transect B, these three points within the windbreak all differed from each other ($\underline{P} < 0.05$), with wind speeds decreasing as distance leeward increased.

Another set of wind-speed data were collected along transect A at four wider-spaced points: 2.4 m (8 feet) windward, and 4.9, 12.2, and 19.5 m (16, 40, and 64 feet) leeward of the line of reference. The three leeward positions were all within the windbreak. Mean wind speeds differed ($\underline{P} < 0.05$) at all four points on the transect, with wind speeds decreasing as distance leeward increased.

Wind speed data for the willow and ragweed windbreaks were analyzed further using linear regression. The independent variable was distance leeward from the line of reference, while the dependent variable was wind speed. The coefficients of regression (slopes) for the four sets of data

Figure 28. Eight rows of wind-speed measurements made at two locations at the willow stand on 29 January 1975. The four measurements per row were made simultaneously. Solid lines connect samples made 75 feet north and dashed lines connect samples at the location 150 feet north in the windbreak. Samples to the left of zero on the graph represent sites windward of the vegetation.



WINDSPEED
meters per 2 minutes
1000
500
25
20
15
10
5
miles per hour
0
10
20
DISTANCE LEEWARD feet

were -12.32, -10.66, and -10.21 for the willow stand and -12.06 for the ragweed data. No differences ($\underline{P} > 0.05$) were detected among regression coefficients for any of the four sets of data. Thus, wind velocities were reduced similarly in the ragweed and willow windbreaks even though the willow stand had fewer stems per unit area.

Natural Windbreaks - Strips

Five windbreaks which can be classified as strip-type cover were studied in 1974 and 1975. Snow-depth and wind-speed measurements were made along transects from windward to leeward through the cover strips. The line of reference was established at the windward edge of the most windward strip of cover.

Weed strip

On 2 December 1974, snow-depth measurements were made at an east-west weed strip in a picked cornfield southwest of Ames. The 0.6-meter-wide (2-foot-wide) strip was composed mainly of foxtail (Setaria, spp.), smartweed (Polygonum sp.), and orchard grass (Dactylis glomerata) with an average density of 807 stems/m^2 (75 stems/ft^2) at the measurement sites. Two days previously, 13 cm (5 inches) of snow fell and 9-m/sec (20-mph) winds from the north caused drifting at the weed strip. Four transects through the strip were established at 4.6 m (15-foot) intervals along the line of reference. Measurement points along each transect were at 2.8, 1.5, and 0.2 m (9.3, 4.9, and 0.5 feet) windward and 1.2, 2.5, 3.9, and

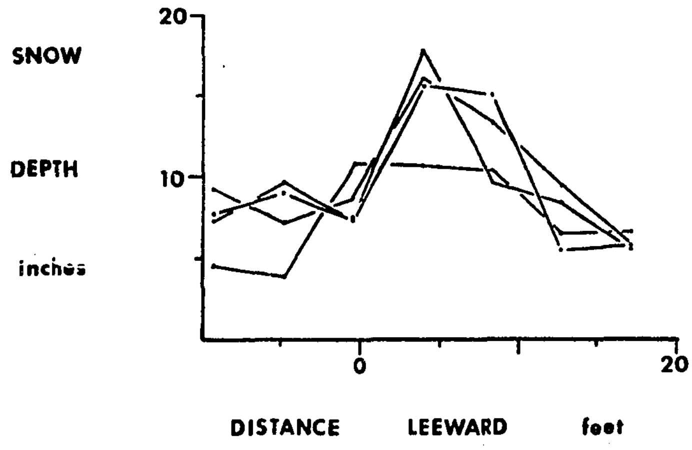
5.2 m (3.9, 8.3, 12.7, and 17.1 feet) leeward of the line of reference. The deepest drifts occurred just behind the vegetation, 1.2 to 2.4 m (4 to 8 feet) leeward of the line of reference (Figure 29), with the deepest drift (45.2 cm or 17.8 inches) located 1.2 m (3.9 feet) leeward. The greatest mean snow depth (38.1 cm or 15.0 inches) was also 1.2 m (3.9 feet) leeward.

Wind-speed data were collected over an 8-cm (3-inch) snow cover at the weed strip on 5 February 1975, with winds from the north at 6 to 11 m/sec (14 to 25 mph). Two transects through the strip were selected for measuring. Transect A was in a segment of the strip composed mostly of foxtail and orchardgrass, with an average density of 807 stems/m^2 (75 stems/ft^2). Simultaneous measurements of wind speeds were made at points 1.8 and 0.2 m (6 and 0.5 feet) windward and 0.8 and 2.4 m (2.5 and 8 feet) leeward of the line of reference. There were four replicate readings at each point. The readings at the sampling points along transect A are represented by the solid lines in Figure 30. Wind speeds at the point 0.8 m (2.5 feet) leeward were significantly lower than those at the other three points ($\underline{P} < 0.05$). This point of reduced wind speed was only 0.2 m (0.5 feet) leeward of the vegetation at the leeward edge of the weed strip. Means at the other three points were not different ($\underline{P} > 0.05$).

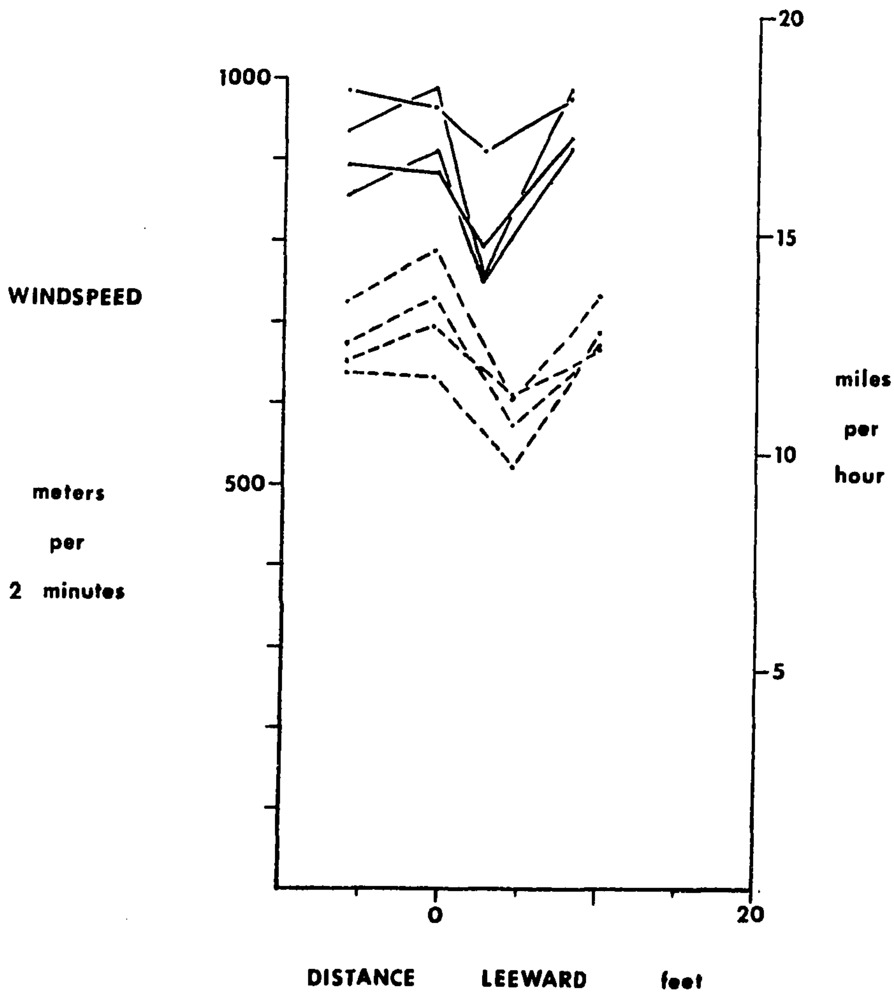
Transect B was through a segment of the weed strip which contained a greater proportion of smartweed and lambsquarters (<u>Chenopodium album</u>) than did transect A. The strip was 1.2 m (4 feet) wide at the sampling location and the average stem density was 339 stems/m^2 (31.5 stems/ft^2). Wind speeds were measured simultaneously at four points: 1.8 and 0.2 m

Figure 29. Four rows of snow-depth measurements made at 15-foot intervals windward-to-leeward through a weed strip on 2 December 1974.

Figure 30. Eight rows of wind-speed measurements made at two locations (indicated by solid and dashed lines) along the weed strip on 5 February 1975.



SNOW
DEPTH
inches
20
10
0
20
DISTANCE LEEWARD feet



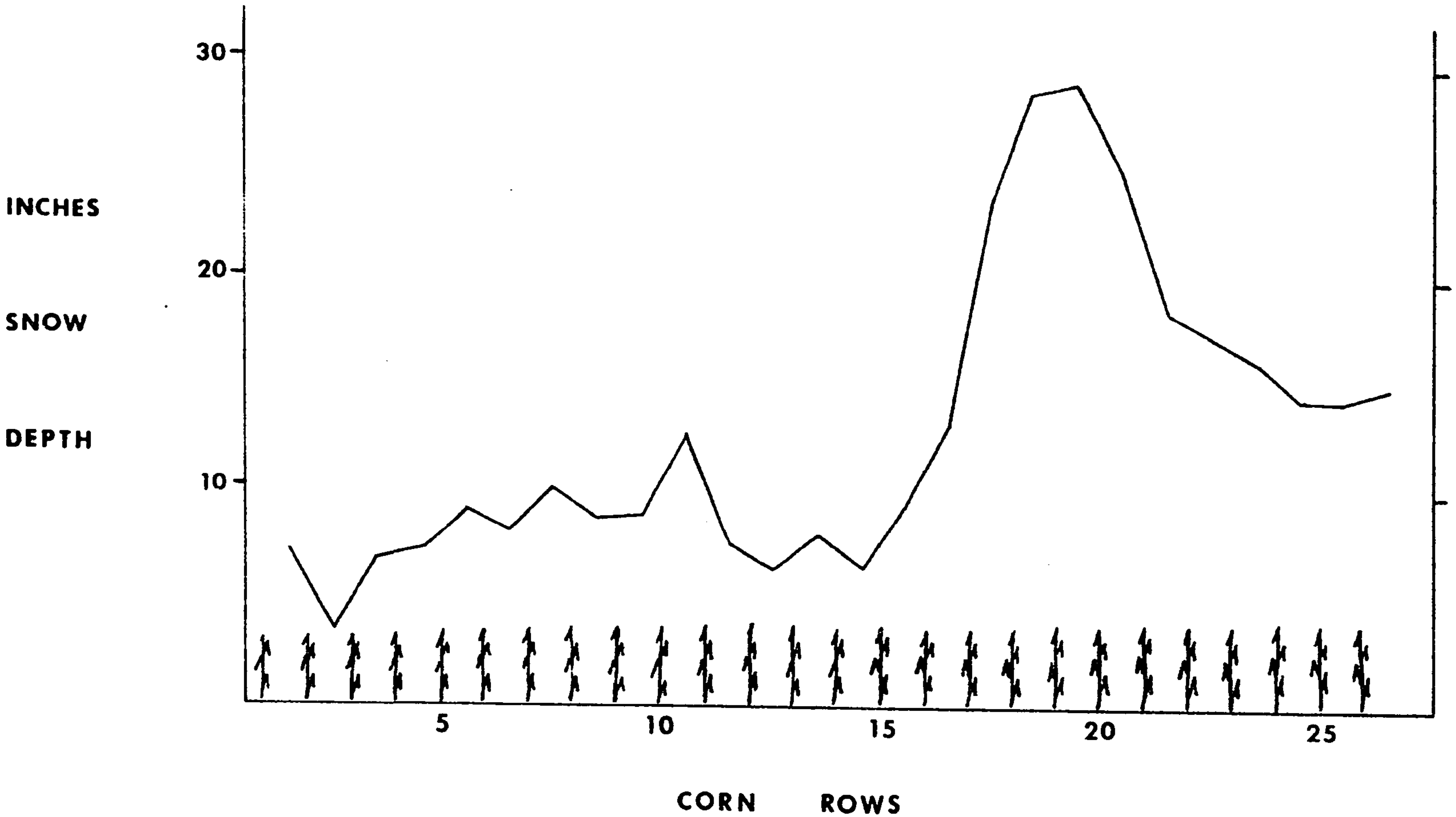
WINDSPEED
meters
per
2 minutes
1000
500
20
15
10
5
miles
per
hour
0
20
DISTANCE LEEWARD feet

(6 and 0.5 feet) north and 1.4 and 3.0 m (4.6 and 10 feet) south of the line of reference, with four replicate readings at each sampling point. Replication of transect-B samples are shown by dashed lines in Figure 30. Again, mean wind speed at the point 0.2 m (0.5 feet) leeward of the leeward edge of vegetation was lower ($\underline{P} < 0.05$) than the other three means, whose differences were not significant ($\underline{P} > 0.05$). Thus the pattern of wind-speed reduction for the two locations was quite similar, although wind speeds had diminished when readings along transect B were made.

Standing corn

On 12 January 1975, the day after a blizzard, snow depth was measured in standing corn in a partially picked field south of Ames. The selected windbreak consisted of standing corn in which the rows ran perpendicular to the direction of the prevailing wind. The windward-most row of standing corn served as the line of reference for measurements taken in the windbreak. Windward to the line of reference were eight rows of stubble, two rows of standing corn, and then about 100 rows of stubble. Snow depths were measured along three transects at points midway between corn rows (intervals of 0.9 m or 3 feet) beginning with the line of reference. The deepest drifts occurred 15 to 18 m (18 to 21 rows) leeward, with the greatest drift depth measurement of 84.6 cm (33.3 inches) found at 16.0 m (18 rows) leeward of the line of reference. The greatest mean snow depth (73.9 cm or 29.1 inches) was found 16.9 m (19 rows) leeward (Figure 31).

Figure 31. Average snow depths in a field of standing corn on 12 January 1975. Measurements were made windward to leeward (left to right in the diagram) between corn rows which were 3-feet apart. The graph represents an average of three rows of measurements.


INCHES
SNOW
DEPTH
30
20
10
5
10
15
20
25
CORN ROWS

Wind speed was measured also on 12 January along two transects about 37 m (120 feet) apart through the cornfield. Four sampling points were selected on each transect; points A and B were windward of the line of reference and C and D were leeward. Moreover, point A was windward and point B just leeward of the isolated two-row strip of standing corn (Figure 32) located windward of the windbreak. Wind speeds (Figure 33) differed at all four points ($\underline{P} < 0.05$) on each transect, but the order of decreasing windspeeds was A, C, B, D along one transect and A, B, C, D on the other. The difference in rank could have been produced by several corn stalks being more closely spaced just windward of the meter in one transect, thus providing an unnoticed sheltering effect on that meter. Differences in terrain, windward drifts, or gusting winds were not influential factors.

Honeysuckle windbreak

On 13 January 1975 snow depth was measured at a honeysuckle windbreak on the E.E. Hensen farm south of Scranton, Iowa. The 4.3-m-high (14 foot-high) honeysuckle hedge was about 5.5 m (18 feet) wide and grew along a north-south fencerow. Deep drifts, caused by the January 11 blizzard, were present leeward of the windbreak. Windward of the windbreak were several plowed fields and barren fencerows which presented little resistance to the strong winds of the blizzard. Measurements were made at 0.3-m (1-foot) intervals along these windward-to-leeward transects (Figure 34). Two of the transects extended 8.2 m (27 feet) and one extended 11.3 m (37 feet) leeward from the line of reference. An

Figure 32. Positions of wind meters for simultaneous measurements of wind speeds in a cornfield on 12 January 1975. (The four positions are designated A, B, C, and D, respectively, from left to right.)

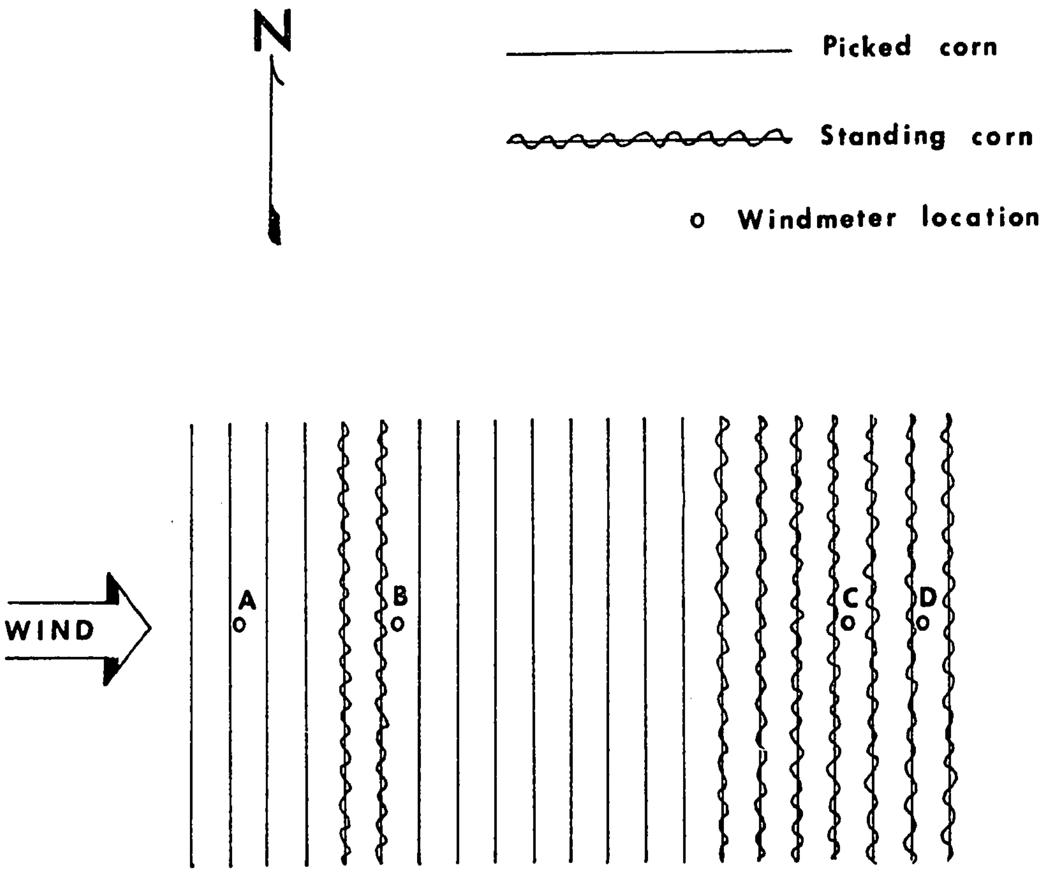
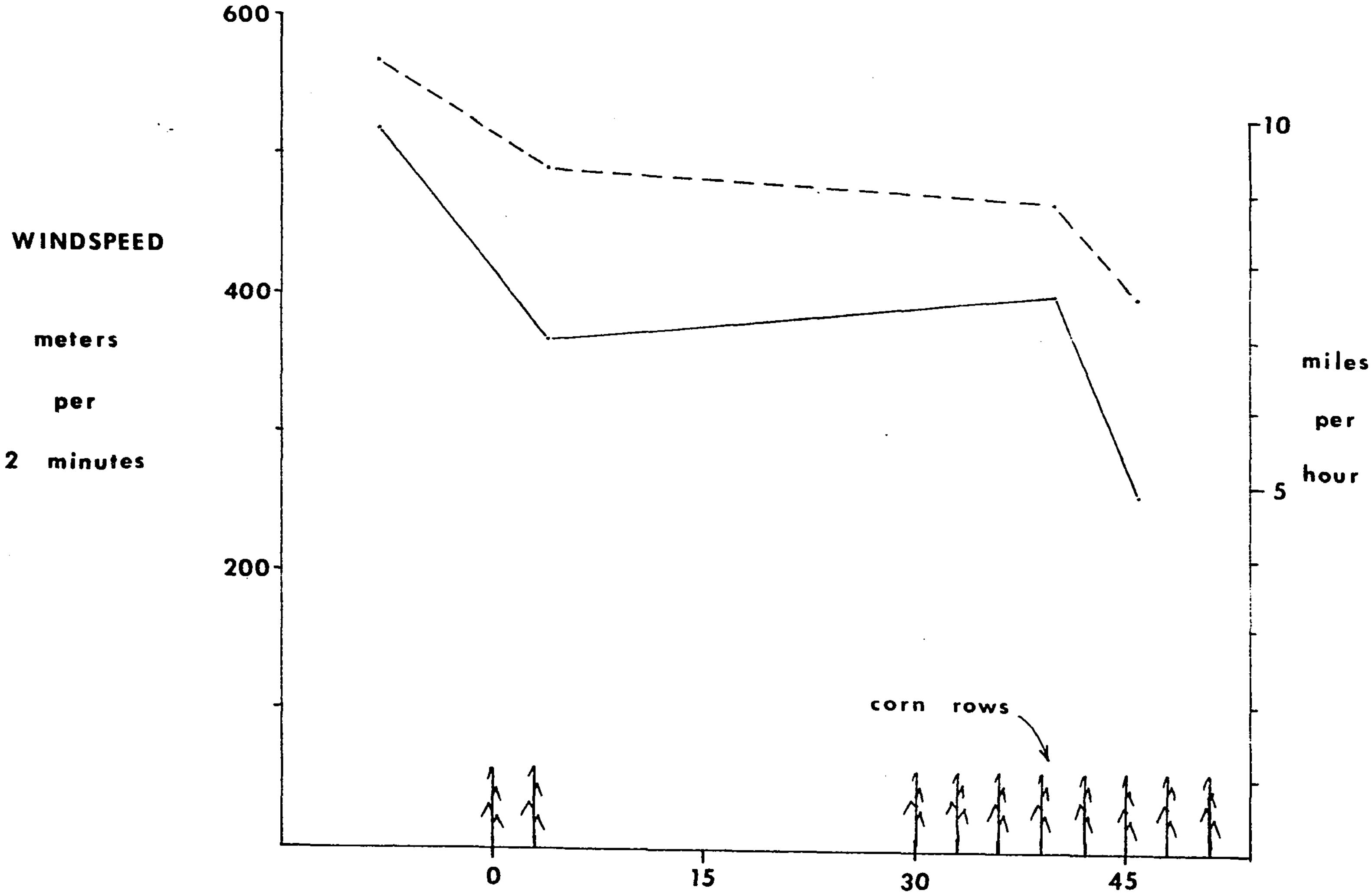
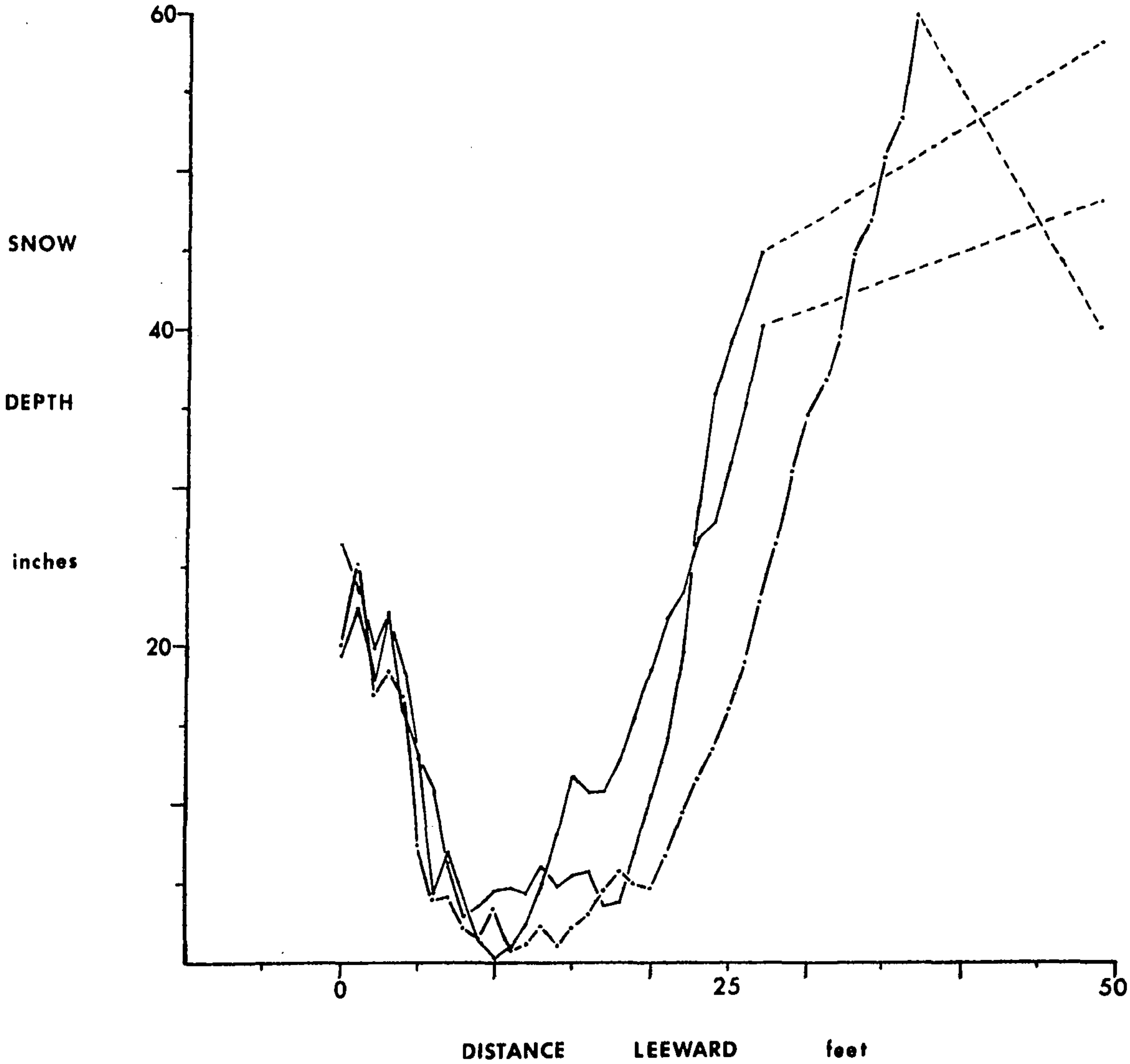

N
Picked corn
Standing corn
o Windmeter location
WIND
A
B
C
D

Figure 33. Mean wind speeds in a cornfield on 12 January 1975. Four rows of four simultaneous measurements were made in each of two locations, represented on the graph by solid and dashed lines. Corn rows are shown in relation to the sampling sites.



WINDSPEED
meters
per
2 minutes
600
400
200
10
5
miles
per
hour
corn rows
0
15
30
45

Figure 34. Three rows of snow-depth measurements through a honeysuckle windbreak on 13 January 1975. A majority of the samples were within the 18-foot-wide windbreak. There were no intervening measurements between points connected by the dashed lines.



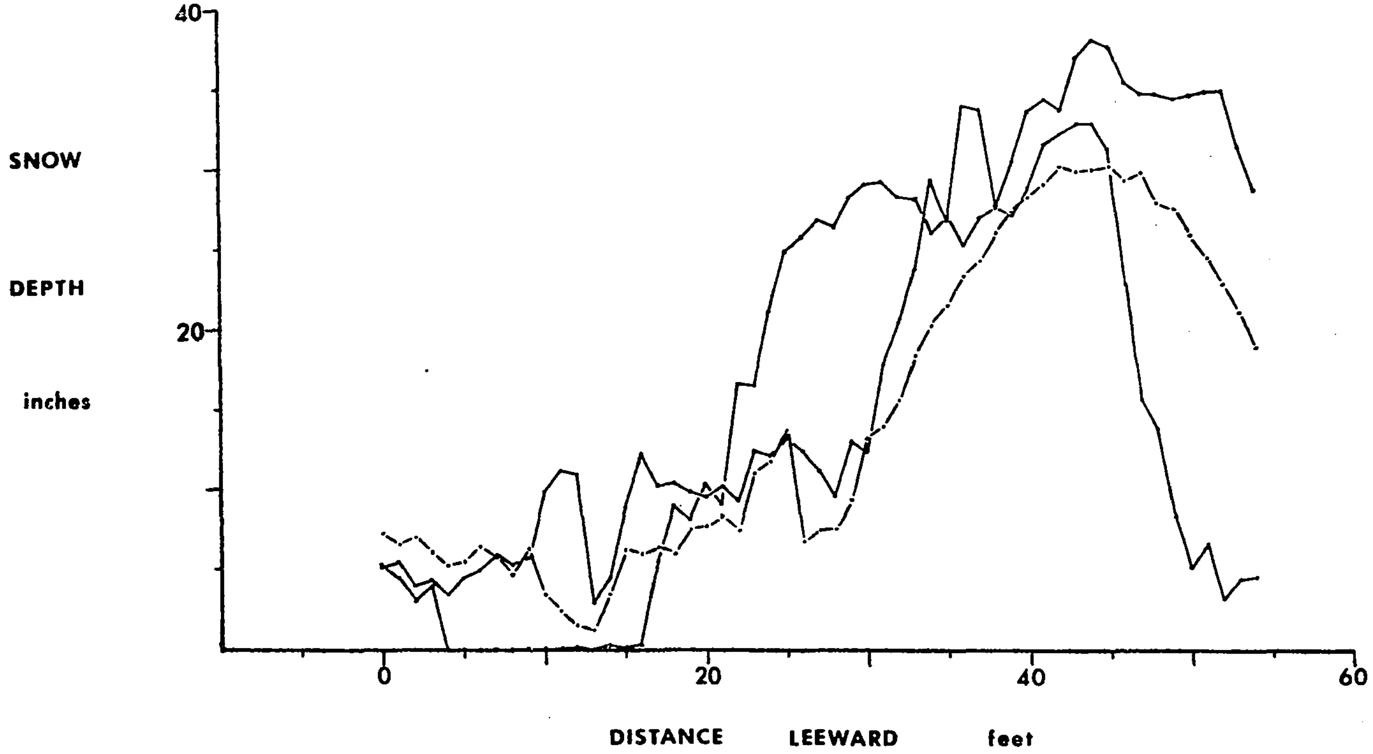
SNOW
DEPTH
inches
60
40
20
0
25
50
DISTANCE LEEWARD feet

isolated measurement on each transect was made 14.9 m (49 ft) leeward of the line of reference, a point where the drifts seemed to be deepest -- but the depth at this point was actually less than some previous measurements for one row (Figure 34). The deepest drift depth measured at this windbreak was 151.9 cm (59.8 in) and occurred 11.3 m (37 ft) leeward of the line of reference. The deepest mean snow depth (123.7 cm or 48.7 in) occurred 14.9 m (49 ft) leeward while the shallowest mean sample snow depths were found 2.7 and 3.4 m (9 and 11 ft) leeward of the line of reference.

Honeysuckle-spruce windbreak

On 15 January 1975, 4 days after a blizzard, snow-depth measurements were made at a honeysuckle-spruce windbreak 3 miles north of Boone, Iowa. The measurements were made at 0.3-meter (1-foot) intervals along three transects beginning at the line of reference (here, the woven-wire fence). The deepest snow (97.8 cm or 38.5 in) was 13.4 m (44 ft) leeward of the line of reference and deepest drifts for all three transects of measurements were found between 12 and 15 m (40 and 50 ft) leeward (Figure 35). The eight consecutive measurements of zero snow depth on one transect occurred beneath a large spruce tree with branches that touched the ground and kept out the snow. The greatest mean snow depth occurred 13.4 m (44 ft) leeward.

Figure 35. Three rows of snow-depth measurements were made through a honeysuckle-spruce windbreak on 15 January 1975. A 5-foot-wide honeysuckle hedge and a 13-foot-wide row of spruce trees were located just leeward of a woven-wire fence which was at point 0 on the graph's horizontal axis.


SNOW
DEPTH
inches
40
20
0
20
40
60
DISTANCE LEEWARD feet

Shrub row plantings

After the blizzard on 11 January 1975 had produced drifts behind strips of shrubs in experimental nursery plots south of Ames, four sets of snow-depth measurements were obtained there. Sample set A consists of two transects with measurements at 0.3-m (1-foot) intervals through three strips of 1.8-m-tall (6-foot-tall) privet hedge (Ligustrum, sp.). The deepest drift (73.7 cm or 29.0 inches) occurred at the point 11.0 m (36 feet) leeward of the line of reference (Figure 36). The deepest mean snow depth was 11.3 m (37 feet) leeward.

Sample set B consists of three transects with measurements at 0.3-m (1-foot) intervals through two rows of 1.8-m- tall (6-foot-tall) privet hedge, a 1.1-m-tall (3.5-foot-tall) row of dense northern white cedar (Thuja occidentalis), followed by another row of 1.8-m-tall (6-foot-tall) privet hedge. There were deep drifts just leeward of the evergreen row, and the deepest measurement was 115.1 cm (45.3 inches) at the point 8.2 m (27 feet) leeward of the line of reference (Figure 37). The greatest average snow depth was 91.4 cm (36.0 inches) at the point 8.2 m (27 feet) leeward.

The other sample sets were collected at another spot among the experimental rows of shrubs. A single transect (sample set C) was made through a 1.7-m-tall (5.5-foot-tall) row of privet hedge which was windward of two closely spaced 2.3-m-tall (7.5-foot-tall) rows of privet and a 1.8-m-tall (6-foot-tall) row of rose bushes (Rosa sp.). The deepest snow-depth measurements were 47.5 cm (18.7 inches) at a point

Figure 36. Average of two rows of snow-depth measurements made every foot windward to leeward through three rows of privet hedge. Vegetation height in drawing is scaled to units on the horizontal axis.

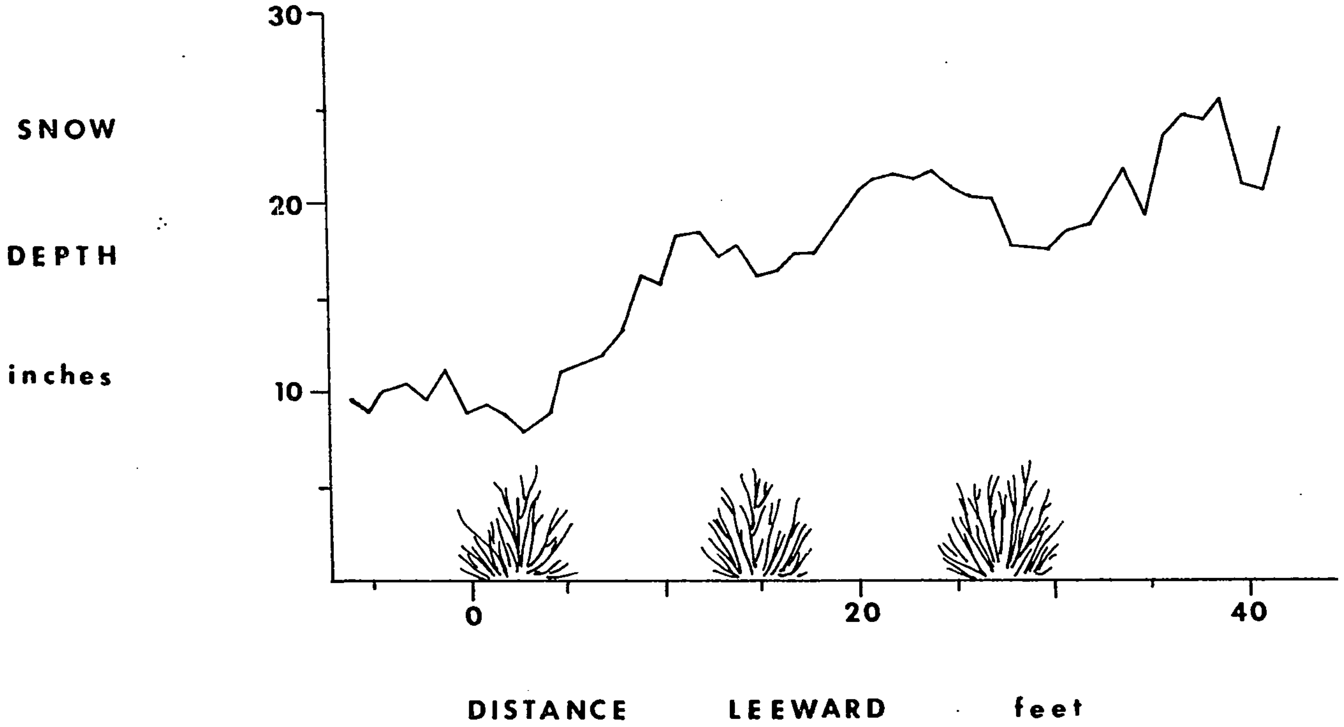
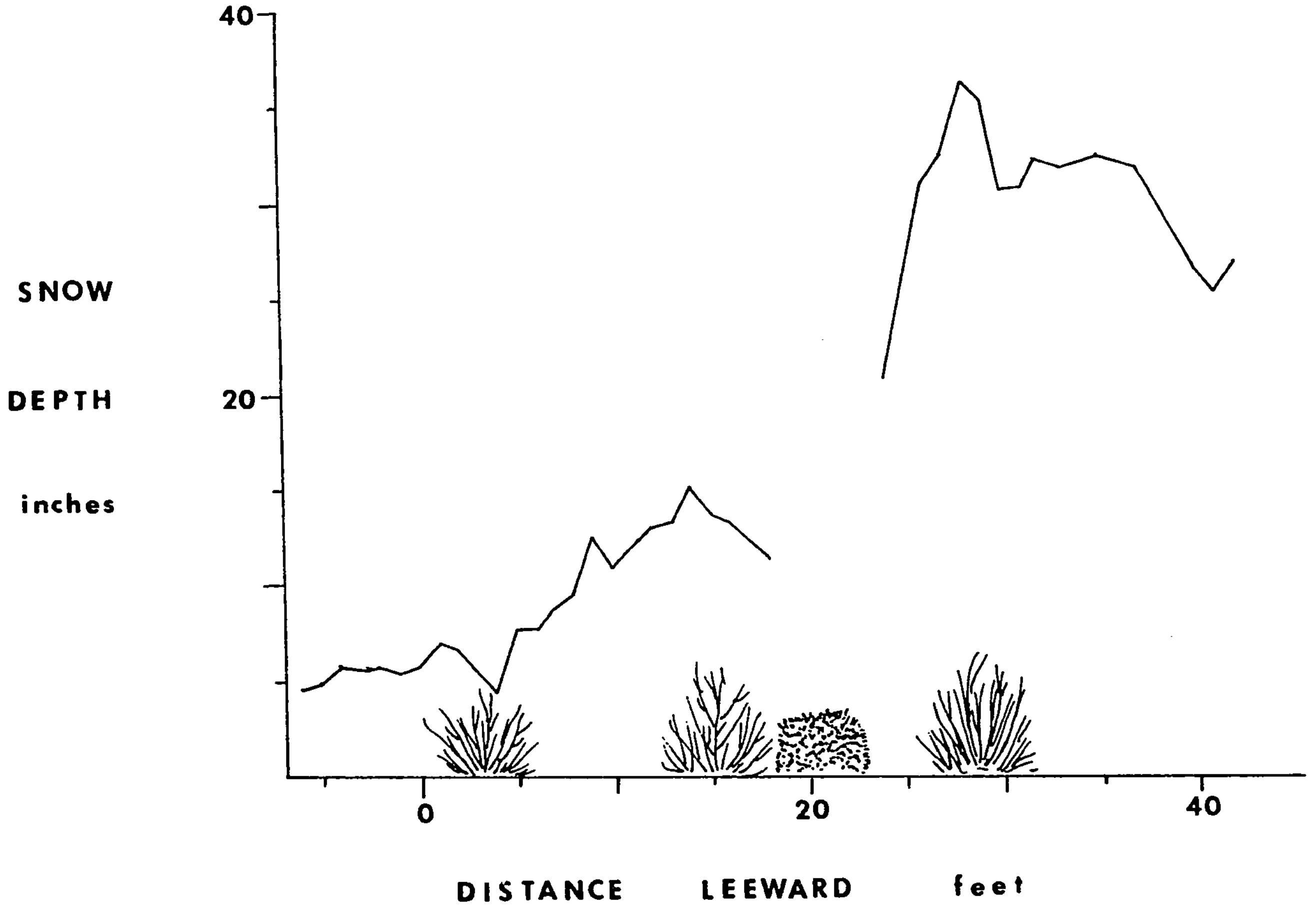

SNOW
DEPTH
inches
30
20
10
0
20
40
DISTANCE LEEWARD · feet

Figure 37. Average of three rows of snow-depth samples made every foot through three privet rows with a white cedar hedge between the two leeward rows. No measurements could be made within the cedar hedge. Vegetation height can be measured using the horizontal axis scale.


40
20
SNOW
DEPTH
inches
0
20
40
DISTANCE LEEWARD feet

4.0 m (13 feet) and 66.3 cm (26.1 inches) at a point 14.0 m (46 feet) leeward of the line of reference (Figure 38).

Sample set D consists of two transects through a 1-m-high (3- to 4-foot high) row of doogwood (Cornus sp.), a single row of privet that was 1.7 m (5.5 feet) tall, and three closely spaced rows of privet that were 2.3 m (7.5 feet) tall. The deepest measurement was 73.9 cm (29.1 inches) at a point 5.2 m (17 feet) leeward of the line of reference, and the deepest drifts for the two transects were found between 5 and 8 m (15 and 25 feet) leeward (Figure 39). The greatest average snow depth occurred 5.8 m (19 feet) leeward of the line of reference.

An analysis of variance was used to compare snowdrifting patterns among four windbreaks: the ragweed and willow clumps, the honeysuckle-spruce windbreak, and sample set B of the shrub row plantings. Effects of sampling position along the transects were significant ($P < 0.05$), as were the windbreak effects ($P < 0.05$). Compared to the sampling error (a measure of the variability of the three replications per sampling point per windbreak), experimental error was not significant ($P > 0.05$).

Snow depths of the two clump-type windbreaks were found to be different ($P < 0.05$). The ragweed had the greatest snow depth within the 12.2-m (40-foot_length tested. The effects the two strip-type windbreaks had on drifting were also different from each other ($P < 0.05$); average snow depth was greatest in the privet-spruce windbreak (sample set B).

The clump-type windbreaks apparently caught and held more drifting snow than did the strip-type windbreaks ($P < 0.05$), but upon inspection of

Figure 38. A single row of snow-depth measurements made every foot through three rows of privet and a row of rose bushes. Vegetation heights are proportional to horizontal axis scale.

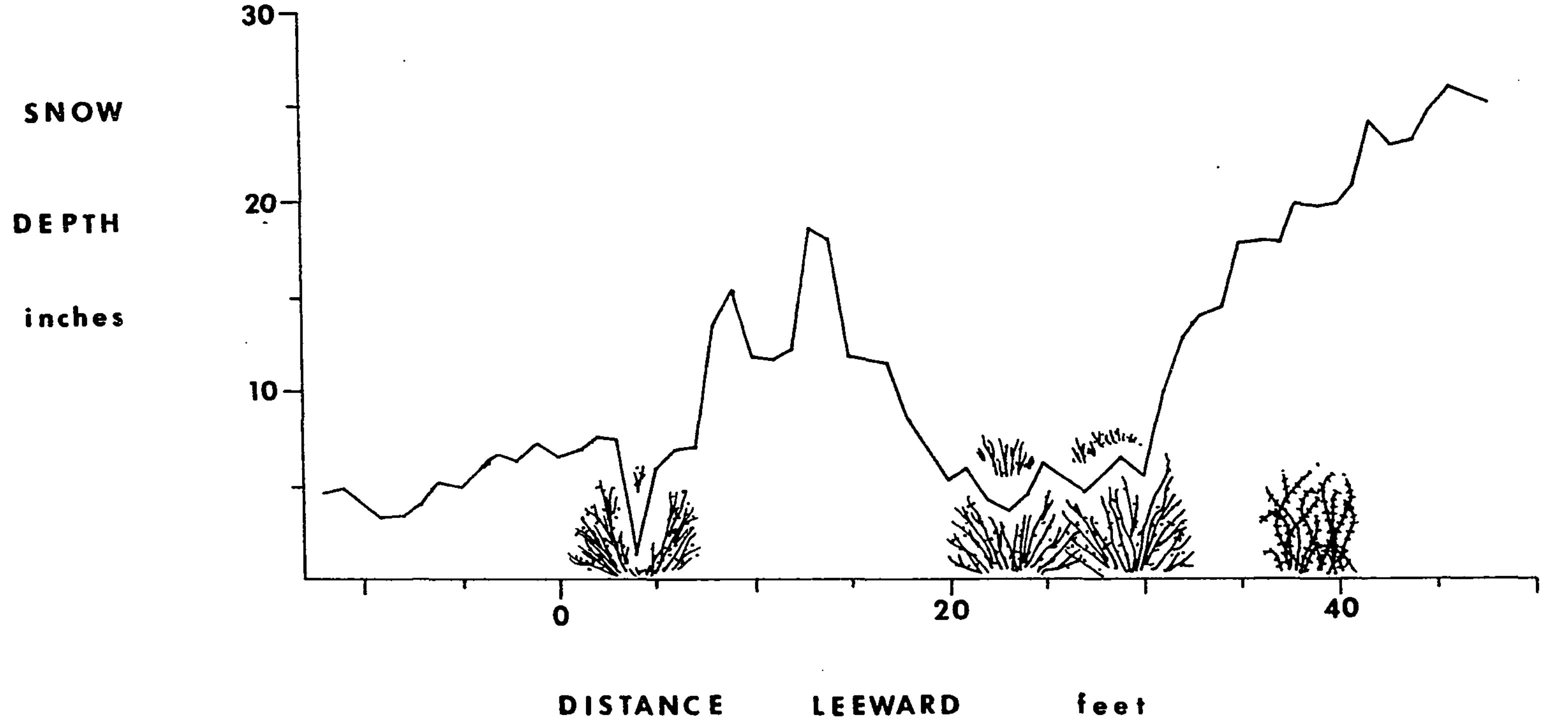
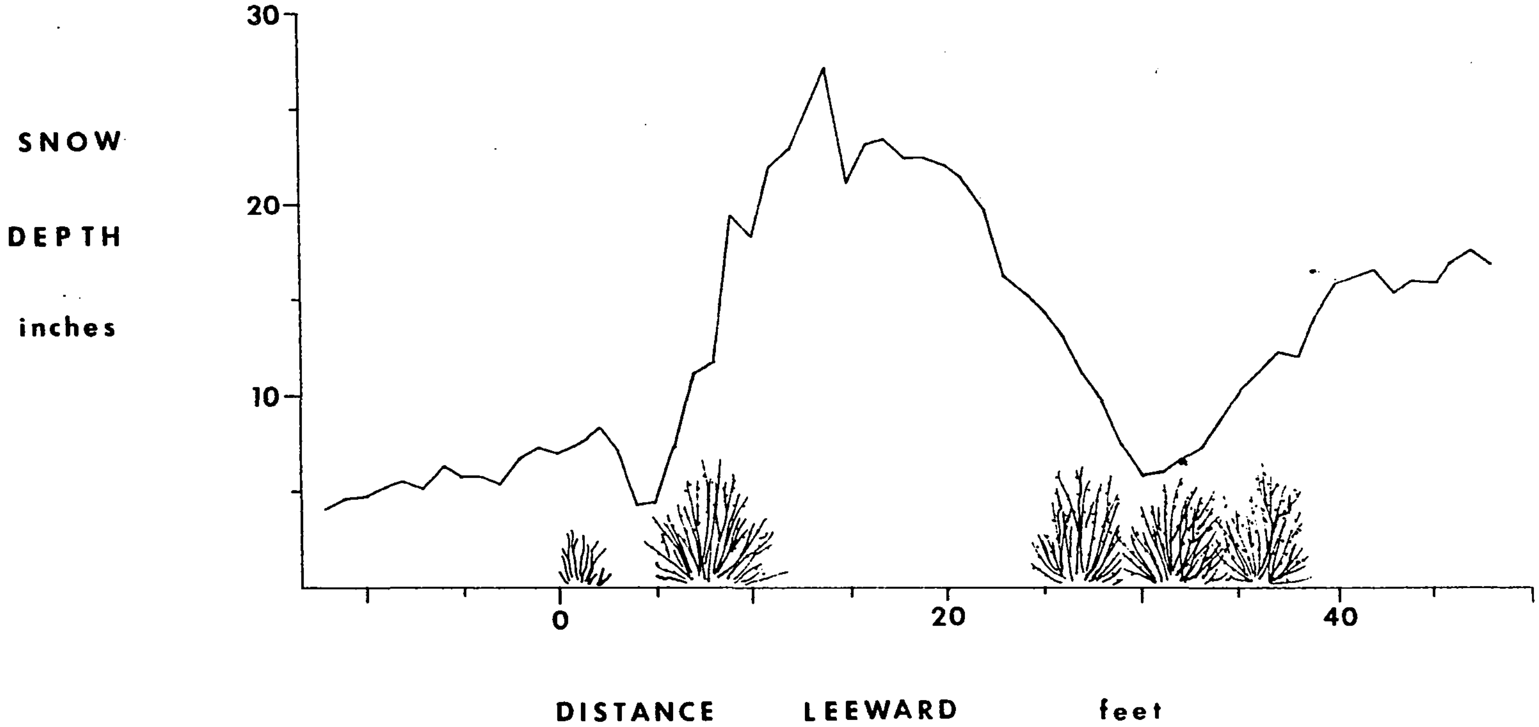

SNOW
DEPTH
inches
30
20
10
0
20
40
DISTANCE LEEWARD feet

Figure 39. Average of two rows of snow-depth measurements made every foot through a row of short dogwood bushes and four rows of privet hedge. Measure height of vegetation by horizontal axis scale.


SNOW
DEPTH
inches
30
20
10
0
20
40
DISTANCE LEEWARD feet

treatment (windbreak) totals of the measurements it seemed that the ragweed total was much greater than the totals for any of the other three windbreaks. A set of a posteriori statistical tests were then made in which a maximum number of degrees of freedom was used to establish a maximum critical value for the sum of squares, above which differences would be significant at the 0.05 level. It was found that the ragweed windbreak was different than the two-strip-type windbreaks, but the willow windbreak was not. Thus, the difference between snow depths in clumps versus strips was due mainly to the ragweed windbreak in which drifts were deeper in the first 12.2 m (40 feet) of the windbreak.

Modified Natural Windbreaks

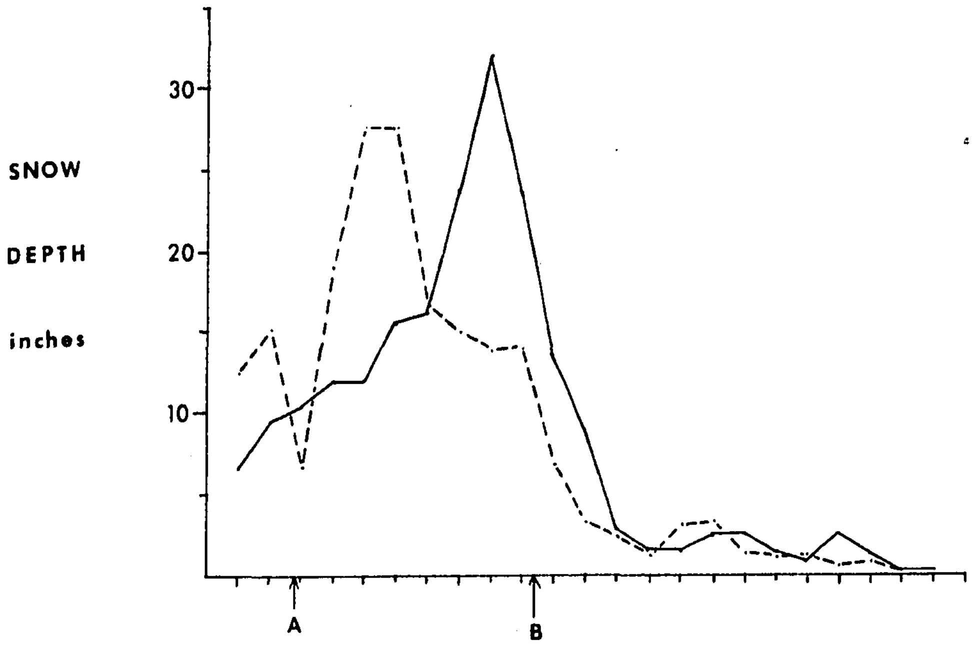
A Douglas fir windbreak on the Julius Black farm south of Ames and a mulberry fencerow on the Verne Kingsbury farm southwest of Ames were the two natural windbreaks modified by snowfence in 1974.

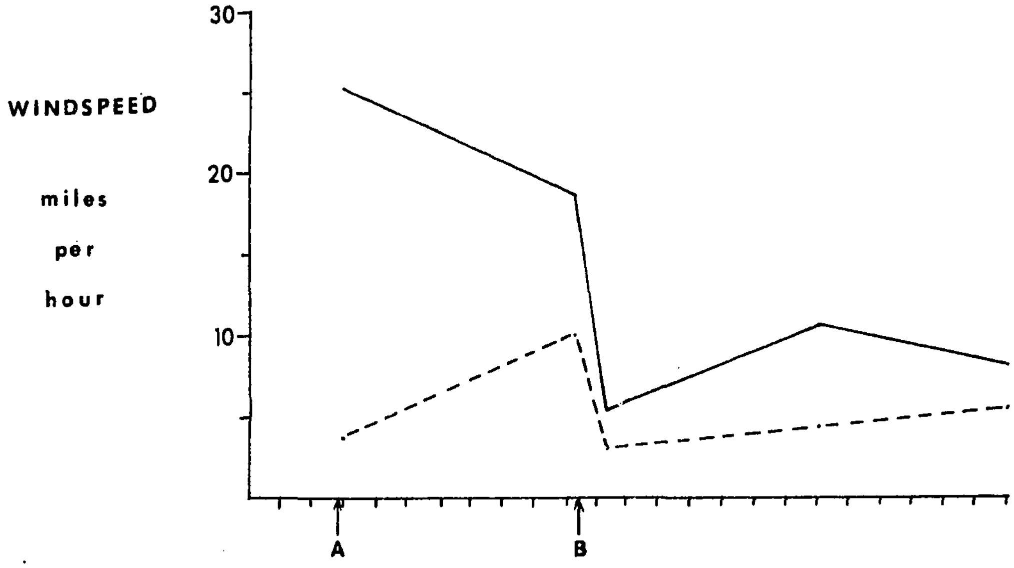
Douglas fir windbreak

Snow depths were measured along eight transects through the windbreak and snowfence on 26 February 1974 (Figure 7). Snow depth was at a maximum just windward of the fenceline not protected by snowfence, and at a low level within the windbreak (Figure 40). Where the fenceline was protected by snowfence, most of the snow was deposited a short distance leeward of this barrier, and there was a smaller average depth near the woven-wire fence and within the windbreak (Figure 40). The snow depths

Figure 40. Average snow depths at Douglas-fir windbreak locations modified by snowfence (dashed line) and at corresponding levels farther east (solid line) on 26 February 1974. Sampling sites every 4.4 feet are marked on the horizontal scale. Point A is the level at which snowfence was placed and point B is the level of the woven-wire fencerow. Points to the right of B represent sites within the windbreak vegetation.

Figure 41. Average wind speeds at Douglas fir windbreak locations modified by snowfence (dashed line) and at the same levels farther east (solid line) on 22 February 1974. Point A is the level at which snowfence was placed and B is the fencerow level. Measurements were made at five levels, but snow-depth sampling sites were marked on the horizontal axis for further reference.


SNOW
DEPTH
inches
30
20
10
A
B


WINDSPEED
miles
per
hour
30
20
10
A
B

in the windbreak leeward of the snowfence were less than those farther east which had no snowfence protection ($P < 0.05$). The mean for measurements at the three levels just leeward of the fenceline behind the snowfence was 10.2 ± 6.6 cm SD (4.0 ± 2.6 inches), while the mean for measurements farther east was 21.1 ± 14.5 cm (8.3 ± 5.7 inches).

On 22 February 1974, with winds from the northwest at 11 m/sec (25 mph), wind-speed measurements were made at six levels both near the snowfence and farther east (Figure 7). The averages of four replications for each level near the snowfence and farther east are shown in Figure 41. Wind speeds did not differ ($P > 0.05$) due to locations (behind snowfence or farther east) and neither did they differ due to measurement level relative to the fenceline ($P > 0.05$). When the two mean windspeeds at each level were analyzed by means of a t-test, however, wind velocities were found to be lower ($P < 0.05$) at all levels leeward of the snowfence than at the same level farther east, except at the leeward edge of the large natural windbreak (Table 3). Pheasants were most commonly found within 2 m (5 feet) of the fenceline, even though the windbreak was much wider, and may thus have benefited from the reduction of snow depth and wind speed caused by the snowfence.

Mulberry fencerow

Wind-speed data were gathered at the mulberry fencerow windbreak modified by a diagonal snowfence (Figure 18) on 6 February 1974, when winds were from the north-northeast at 4 m/sec (10 mph). It was found by analysis of variance of this complete block design that there was no difference in wind speed due to position relative to the fencerow (P > 0.05). There was a difference, however, due to position relative to the snowfence (P < 0.05). Average wind speeds (Table 4) at the level far north of the snowfence were not different from those at the near-north level (P > 0.05), but wind speeds south of the snowfence were lower than those to the near north and to the far north (P < 0.05).

Snow-depth measurements were not made at this windbreak because the drifts had begun to melt before the windbreak could be studied. Large drifts had accumulated just leeward of the snowfence (Figure 3). There

Table 3. Mean wind speeds in m/sec (mph in parentheses) on 22 February 1974 at the Douglas fir windbreak, with results of t-tests for the paired treatments expressed as probabilities of less than 0.05 (significant difference) or more than 0.05 (no significant difference).

Level	Treatment: Snowfence	Treatment: No snowfence	P
19.5 m (63.9 ft) N of fenceline or 9.2 m (30 ft) N of snowfence	5.2 (11.6)	5.5 (12.4)	>0.05
10.0 m (32.9 ft) N of fenceline or 0.3 m (1 ft) S of snowfence	0.6 (1.4)	5.7 (12.7)	<0.05
0.2 m (0.5 ft) N of fenceline	2.2 (4.9)	4.2 (9.5)	<0.05
1.2 m (4.0 ft) S of fenceline (front part of windbreak)	0.7 (1.5)	1.2 (2.7)	<0.05
8.8 m (28.7 ft) S of fenceline (middle of windbreak)	1.0 (2.2)	2.3 (5.2)	<0.05
16.8 m (55.1 ft) S of fenceline (back of windbreak)	1.2 (2.6)	1.8 (4.1)	>0.05

Table 4. Mean windspeeds in m/sec (mph in parentheses) at the mulberry fencerow windbreak on 6 February 1974.

Block	Treatment[a]		
	Far north	Near north	South
3.1 m (10 ft) W of fencerow	3.9 (8.7)	4.0 (9.0)	2.3 (5.2)
0.3 m (1 ft) W of fencerow	2.6 (5.9)	2.5 (5.6)	2.3 (5.1)
0.3 m (1 ft) E of fencerow	3.9 (8.8)	4.5 (10.1)	1.9 (4.2)
3.1 m (10 ft) E of fencerow	5.1 (11.4)	3.8 (8.5)	2.5 (5.6)
Combined (all blocks)	3.9 (8.7)	3.7 (8.3)	2.2 (5.0)

[a]Treatment = measurement level in relation to snowfence.

was an abundance of both new and old pheasant tracks around the fencerow cover just south of the snowfence and its large drifts, but very few tracks were seen at other spots along the fencerow. Before the snowfence was put up, heavy use of all the fencerow cover by pheasants was noted.

Experimental Windbreaks - Field Models

Experimental field windbreaks of three designs -- double horseshoe, fencerow intersection, and right angle -- were constructed on Iowa State University farmland and wind speeds and snow depths were measured near these artificial barriers.

Double-horseshoe windbreak

Winds were from the northwest at 7 to 9 m/sec (15 to 20 mph) on 22 January 1973 when wind-speed measurements were made at four elevations above ground level at six positions relative to the double-horseshoe windbreak (Figure 19). When the wind-speed readings for all four elevations at each position were averaged, the mean wind speed was greatest 0.3 m (1 foot) to the windward side of the snowfence, and least 0.3 m (1 foot) leeward of the tree-group apex (Table 5). Turbulence leeward of the snowfence and its drift caused wind direction and speed to be erratic at the 0.3-m (1-foot) level, both on the windward side of the tree group and at the next position windward (points C and D).

Several inches of snow had fallen the previous night and a 0.9-m-high (3-foot-high) drift had formed just leeward of the snowfence semicircle. The average of 81 snow-depth measurements leeward of the tree semicircle, however, was only 18.4 cm (7.25 inches). The deepest snow leeward of the trees was in drifts up to 36.8 cm (14.5 inches) deep at the inside edges of the tree barrier near the base of the formation, and the shallowest accumulation of snow (3 to 5 cm or 1 to 2 inches) was found on the leeward side of the apex of the tree group.

Fencerow-intersection windbreaks

Wind-speed and snow-depth measurements were made near two fencerow-intersection windbreaks in January and February 1974. With winds from the northwest on 31 January 1974, wind speeds were measured at six different positions: five from northwest to southeast through each

Table 5. Wind speeds in m/sec (mph in parentheses) at four levels of six positions (shown in Figure 19 methods) at the double horseshoe windbreak on 22 January 1973.

Height above ground level	Position A	B	C	D	E	F
1.2 m (4 ft)	7.2 (16.1)	7.4 (16.6)	5.8 (12.9)	4.3 (9.6)	1.1 (2.4)	3.8 (8.5)
0.9 m (3 ft)	7.8 (17.5)	5.4 (12.1)	4.8 (10.8)	2.9 (6.4)	1.2 (2.7)	4.1 (9.1)
0.6 m (2 ft)	6.1 (13.6)	5.6 (12.5)	1.7 (3.8)	1.8 (4.0)	1.4 (3.2)	2.6 (5.9)
0.3 m (1 ft)	4.6 (10.2)	3.8 (8.6)	-0.3 (-0.7)	-0.04(-0.1)	1.8 (4.0)	2.1 (4.8)
Average	6.4 (14.3)	5.5 (12.4)	3.0 (6.7)	2.2 (5.0)	1.4 (3.1)	3.1 (7.0)

windbreak (Figure 20) and one in the open field easy from the windbreaks. There was no difference in wind speeds due to windbreak ($\underline{P} > 0.05$), but there was a difference due to position relative to the windbreak ($\underline{P} < 0.05$). Wind speeds were lowest at points 0.6 and 2.7 m (2 and 9 ft) leeward of the windbreaks (Table 6).

On 1 February 1974, winds were from the east-northeast and wind-speed measurements were made at nine positions near each windbreak; eight in the four "field corners" (Figure 20) and one in the open field east from the windbreaks. There was no difference in wind-speed values due to windbreaks ($\underline{P} < 0.05$) but there were differences in means at the various measurement positions ($\underline{P} < 0.05$). The lowest average wind speeds were found at points 0.3 and 2.7 m (1 and 9 ft) leeward (southwest) of the windbreak and also 0.3 m (1 ft) to the northwest (Table 7).

In 1975, wind-speed measurements were made simultaneously at four positions from windward (southeast) to leeward (northwest) of the fencerow-intersection windbreaks on 9 January. The two windbreaks did not differ in their effects on wind speeds ($\underline{P} > 0.05$). Wind speeds did differ, however, due to position relative to the windbreak (Table 8).

Table 6. Mean wind speed in m/sec (mph in parentheses) at the fencerow intersection experimental windbreaks on 31 January 1974, with winds from the northwest. All means except those enclosed by brackets are significantly different, as tested by Duncan's multiple range test.

Position	Mean wind speed
6.7 m (22 ft) NW of windbreak	5.3 (11.8)
Open field	4.2 (9.4)
1.4 m (4.5 ft) NW of windbreak	3.3 (7.4) ┐
5.5 m (18 ft) SE of windbreak	2.9 (6.5) ┘
2.7 m (9 ft) SE of windbreak	1.3 (3.0) ┐
0.6 m (2 ft) SE of windbreak	1.0 (2.3) ┘

Table 7. Mean wind speeds in m/sec (mph in parentheses) at the fencerow intersection experimental windbreaks on 1 February 1974, with wind from the east-northeast. All means except those enclosed by brackets are significantly different.

Position	Mean wind speed
Open field	3.4 (7.5) ┐
2.7 m (9 ft) SE of windbreak	2.9 (6.5) ┘
2.7 m (9 ft) NE of windbreak	2.3 (5.2) ┐

Table 7 Continued.

Position	Mean wind speed
2.7 m (9 ft) NW of windbreak	2.3 (5.1)
0.3 m (1 ft) NE of windbreak	1.9 (4.2)
0.3 m (1 ft) SE of windbreak	1.7 (3.8)
0.3 m (1 ft) NW of windbreak	1.0 (2.2)
0.3 m (1 ft) SW of windbreak	0.9 (2.0)
2.7 m (9 ft) SW of windbreak	0.8 (1.9)

Table 8. Mean wind speeds in m/sec (mph in parentheses) for four positions at the two fencerow-intersection experimental windbreaks on 9 January 1975, with winds from the east-southeast. At each windbreak, the mean wind speed at one position differed from the mean at any other position ($P < 0.05$), as determined by Duncan's test.

Measurement position	Mean wind speed	
	Windbreak 1	Windbreak 2
5.4 m (17.6 ft) SE of windbreak	4.7 (10.6)	6.5 (14.5)
0.6 m (2.0 ft) SE of windbreak	3.1 (6.9)	5.1 (11.4)
0.6 m (2.0 ft) NW of windbreak	1.5 (3.4)	1.1 (2.5)
2.7 m (8.8 ft) NW of windbreak	1.2 (2.6)	0.5 (1.2)

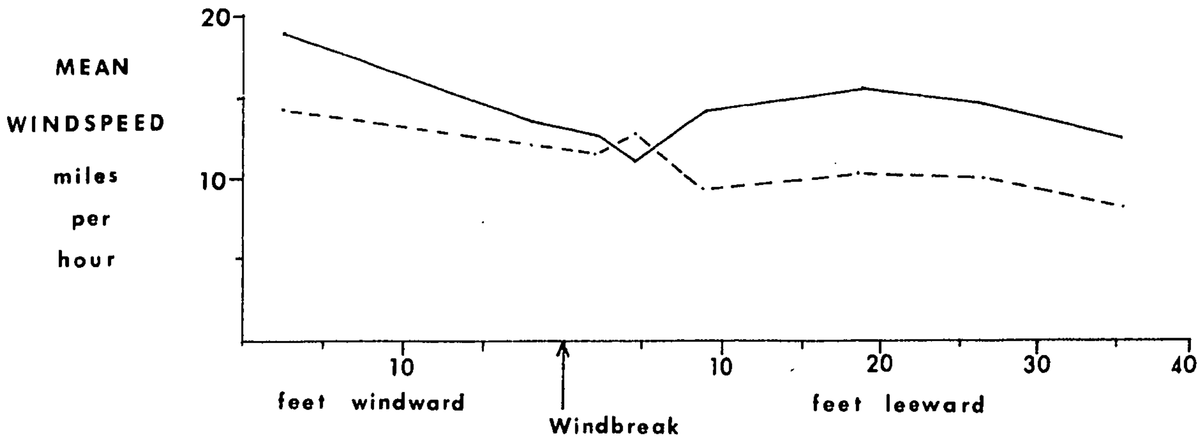
Snow depths were measured in grid fashion (Figure 11) at the fencerow-intersection windbreaks in January and February 1974. On 14 and 15 January, after a 5-cm (2-inch) snowfall with light winds from the northwest, shallow drifts had accumulated on all sides of the windbreak. An analysis of variance for snow depths near the windbreak in the southwest, southeast, and northeast corners (Figure 12) was made and snow depths on the three sides (treatments) did not differ ($P > 0.05$). Means for snow depths under the trees were smaller ($P < 0.05$) than means for measurements outside the windbreaks.

Snowdrifting patterns at the same two fencerow-intersection windbreaks were again studied on 26 February 1974 after a snowstorm with heavy drifting from the north. Upon casual observation of the drifts after the storm, it seemed that the only spots relatively free from deep drifts might have been either directly beneath the trees or just south of the north-south row. Data from 11 sample sites beneath the trees and south of the north-south row were compared to data from 15 sample sites on the leeward side of each windbreak (Figure 13) and there was no difference for either windbreak ($P > 0.05$). A blizzard on 11 January 1975 also produced sizeable drifts within and leeward of the fencerow-intersection field models, but no measurements could be made before significant melting had occurred.

Right-angle windbreaks

Wind-speed measurements were made at nine positions relative to each of the two right-angle experimental windbreaks on 27 and 28 February 1974 (Figure 9). Wind-speed values for the nine positions were different ($P < 0.05$), but there was also a difference between windbreaks ($P < 0.05$). Average wind speeds at each of eight sampling sites (open-field sampling site omitted) for each windbreak are shown in Figure 42. While the lowest

Figure 42. Mean wind speeds at experimental right-angle windbreaks #1 (solid line) and #2 (dashed line) on 27 and 28 February 1974.



20
10
MEAN
WINDSPEED
miles
per
hour
10
10
20
30
40
feet windward
Windbreak
feet leeward

average wind speed for windbreak #1 was found 1.4 m (4.5 feet) leeward, the lowest average wind speed for windbreak #2 was 11.0 m (36 feet) leeward. The wind-speed profiles shown in Figure 42 look similar except for the average wind speeds 1.3 m (4.4 feet) leeward of the windbreak vegetation. Different sheltering effects by snowdrifts at the two windbreaks may have caused the difference at that position.

Snow-depth measurements were made at the two right-angle windbreaks on 24 and 25 February 1974, and for each windbreak the mean of 14 samples beneath the trees was compared to the mean for measurements at 16 leeward sites (Figure 10). There was a difference between means for one windbreak but not for the other (Table 9). Large standard deviations for samples may have contributed to this discrepancy between windbreaks.

Table 9. Comparison of mean snow depths in centimeters (inches in parentheses) beneath windbreak trees versus those leeward of the trees for right-angle experimental windbreaks #1 and #2 on 24 and 25 February 1974. Probabilities (*P*) less than 0.05 indicate significant differences in means compared by using a *t*-test.

	Windbreak #1	Windbreak #2
Mean snow depth beneath trees (with 95 percent confidence interval)	26.4 ± 11.4	25.4 ± 8.4
	(10.4 ± 4.5)	(10.0 ± 3.3)
Mean snow depth outside windbreak	30.0 ± 8.6	39.6 ± 8.4
	(11.8 ± 3.4)	(15.6 ± 3.3)
Results of *t*-tests between means	$P > 0.05$	$P < 0.05$

See Appendix II for a description of the snowstorm studied.

Experimental Windbreaks - Scale Models

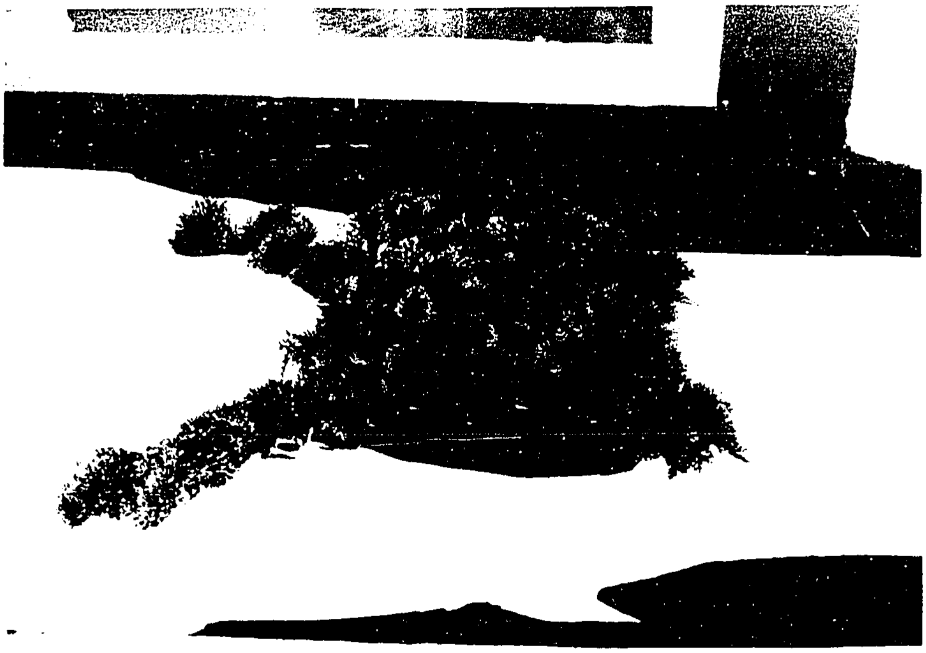
Several model windbreak designs were studied in a wind tunnel in 1973 and 1975 with hopes that models would simulate actual snowdrifting patterns at windbreaks in the field. No wind-speed profiles around model windbreaks in the tunnel were obtained because the appropriate apparatus for the tests was not available.

Fencerow-intersection model

The fencerow-intersection was the design chosen for comparison of drifting patterns of wind-tunnel models with those of experimental field windbreaks. In 1973, model-snow material was spread over the wind-tunnel floor in front of the model windbreak and drifted past it. The resulting drift pattern was characterized by relatively deep drifts on all four sides of the model, with no deposit within the vegetation (Figure 43). In 1975, however, the model-snow material was poured into the windstream from the top of the wind tunnel and allowed to drift past the fencerow intersection model. The resulting drifting pattern was characterized by shallow to moderate drifts in front and behind the windbreak, with moderate drifts within the vegetation (Figure 44). There was a negative correlation between 99 pairs of measurements for the two years' runs ($\underline{r}$ = 0.350, $\underline{P}$ < 0.05). A further test of the 2 years' measurements at 28 leeward sites (Figure 45) was made but no significant correlation was found ($\underline{r}$ = -0.007, $\underline{P}$ > 0.05). Two different drifting patterns near the fencerow-intersection model were produced by the two runs.

Figure 43. Scale model fencerow-intersection windbreak after surface-drifting particles had formed drifts around the model in a 1973 test. With wind from the left (simulating northwest), deep drifts accumulated on all four sides of the windbreak, but no material was deposited within the windbreak.

Figure 44. Scale model fencerow-intersection windbreak after a 1975 test in which model snow was released into the airstream from above. There were shallow drifts windward (left) and leeward, and moderate drifts within the windbreak.



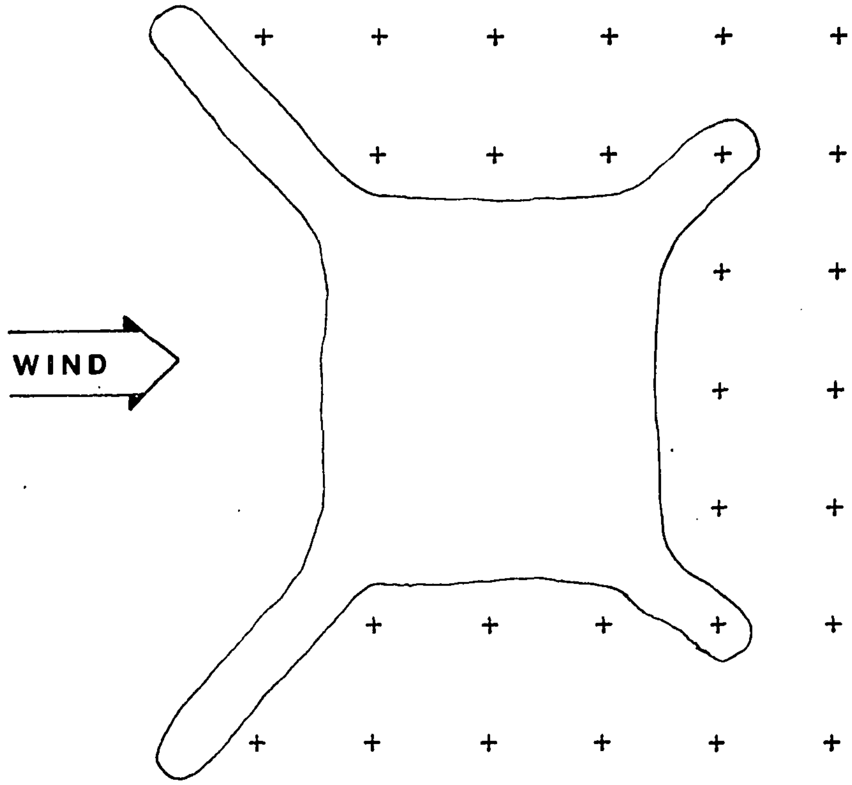
Since drift-depth measurements for the two wind-tunnel tests were negatively correlated, at least one of the sets of measurements will not reflect the drifting patterns seen at the experimental fencerow intersection windbreaks in the field. Measurements for the 1973 wind-tunnel test were compared to data collected on 14 and 15 January 1974 at the two experimental field windbreaks. Significant positive correlations were seen for the two 99-pair samples ($\underline{r}$ = 0.436, $\underline{P}$ < 0.001 and $\underline{r}$ = 0.348, $\underline{P}$ < 0.001), but not for comparisons of 28 leeward sites at the model and the two field windbreaks ($\underline{r}$ = 0.183, $\underline{P}$ > 0.10 and $\underline{r}$ = 0.085, $\underline{P}$ > 0.10). By comparison of the 1975 wind-tunnel results with field measurements at the same two windbreaks, significant negative correlations were found for 99 pairs of measurements ($\underline{r}$ = -0.222, $\underline{P}$ < 0.05 and $\underline{r}$ = -0.235, $\underline{P}$ < 0.05), but not for pairs of measurements at the 28 leeward sites ($\underline{r}$ = -0.305, $\underline{P}$ > 0.10 and $\underline{r}$ = -0.084, $\underline{P}$ > 0.10).

Fencerow-intersection model with north wind

In 1975, the fencerow intersection model was rotated 45 degrees so that drifting from the north rather than northwest could be simulated. Deep drifts occurred behind the "east-west" row of trees, with the shallowest areas of accumulation just south of the "north-south" row (Figure 46). This general pattern was seen in field studies, but by comparison of wind-tunnel data with corresponding field measurements made on 26 February 1974, it was found that no significant correlation existed ($\underline{r}$ = -0.086, $\underline{P}$ > 0.05 and $\underline{r}$ = -0.080, $\underline{P}$ > 0.05). Unfortunately, a wind-tunnel test of the fencerow intersection adjusted for north wind was not made with material spread over the floor, as in the 1973 tests.

Figure 45. A set of 28 leeward sampling sites was selected for one test of correlation between drifting patterns for the 1973 versus 1975 fencerow-intersection scale model windbreaks. No significant correlation was found.

Figure 46. The fencerow-intersection scale model was rotated 45 degrees counter-clockwise in 1975 to simulate north rather than northwest winds. Deep drifts accumulated leeward (to the right of the photo) of the "east-west" row.


WIND

Fencerow-intersection model with snowfence

The effect of snowfence modification of the fencerow intersection model was tested in both 1973 and 1975. Addition of snowfence caused accumulation of surface-drifted particles (1973 tests) in fairly deep drifts up to the windward edge of the vegetation, but little material was deposited in the main part of the windbreak or leeward of it (Figure 47). The same model without snowfence had moderate drifts on all four sides with no accumulation under the trees (due to high winds funneled beneath the trees, observed during the run). In contrast, the open areas in the design with snowfence seemed to be relatively calm during the run.

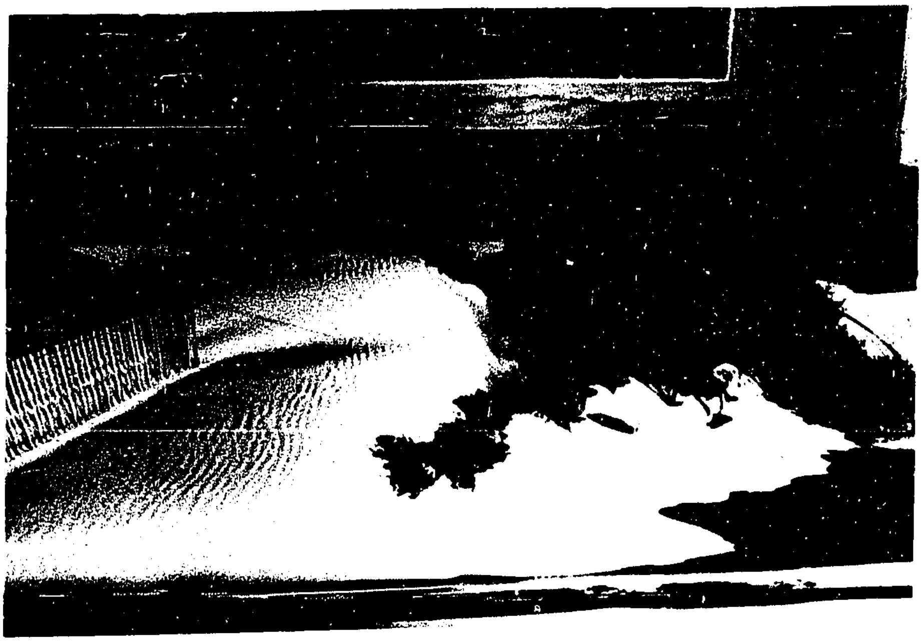
The fencerow-intersection model with snowfence was tested with windblown particles in 1975 and the deepest drifts were windward of the vegetation, with medium drifts on the sides and in the center of the windbreak. The shallowest drifts were leeward of vegetation (Figure 48). The greater accumulation of material in the main body of the windbreak in 1975 compared to 1973 may have been due to material drifting in from the airstream over the snowfence barrier. Without snowfence, deeper drifts accumulated within the windbreak vegetation in the 1975 tests.

Doughnut-shaped model

The drifting pattern of surface-drifted particles in 1973 near the doughnut-shaped model was characterized by medium drifts windward of the windbreak and on the sides, deep drifts in the middle, and very shallow drifts with some open spots near the leeward part of the windbreak (Figure 49). With windblown material in 1975, there were open areas along the

Figure 47. Fencerow-intersection scale model modified by windward snow fence for 1973 tests. Surface-drifting particles accumulated in deep drifts between snowfence and vegetation. Shallowest drifts occurred just leeward of the vegetation.

Figure 48. Scale-model fencerow intersection with windward snowfence tested in 1975. Windblown particles accumulated in deep drifts between snowfence and vegetation, as in 1973, but in the 1975 tests, more material was deposited within windbreak vegetation.



windward edge, deep drifts on the sides, medium drifts in the center and again, very shallow drifts on the leeward side of the model (Figure 50).

Teardrop-shaped model

In 1973, a teardrop design was tested and the drifting pattern around this model (Figure 51) was characterized by deep drifts in the windward half, with medium drifts on the edges of the windbreak near the back. A small area in the center of the windbreak toward the rear had very shallow drifts, and driftless areas outside the vegetation had been kept clear of material by relatively high windspeeds.

Figure 49. Deepest drifts at the doughnut-shaped scale model occurred in the open middle area in 1973 tests. The shallowest drifts occurred just leeward of the leeward edge of the windbreak (to the right in the photo).

Figure 50. In 1975 tests of the doughnut-shaped scale model, shallow drifts again occurred just leeward (right) of the windbreak, with deep drifts in the center. Open areas just leeward of the windward edge of the ring of vegetation were caused by high winds that funneled beneath the vegetation and prevented accumulation of particles there.

Figure 51. The drifting pattern (from above) near the teardrop-shaped scale model was characterized by deep drifts in the windward (left) half of vegetation, with medium drifts along the leeward edges and a small spot with shallow drifts in the center of the windbreak.

DISCUSSION

The ragweed and willow clumps represent common cover types in Iowa which are often used extensively by pheasants and other wildlife during the winter. It was found that moderate wind speeds (11 m/sec or 25 mph) were substantially reduced over a short distance (3.7 m or 12 feet) leeward of the line of reference by the ragweed stand, and deep snow was concentrated in the windward part of the windbreak. Much shallower drifts were found in the more leeward parts of the windbreak. With blizzard conditions, however, deep drifts formed throughout the windbreak and covered a great portion of it. Although wind speeds within the windbreak must have been reduced substantially during the storm, the tendency of the vegetation to become filled with snow was an undesirable characteristic of this windbreak. Perhaps if the stand had been much larger a leeward area with low wind speeds and shallow drifts could have been found.

The willow clump was a much larger windbreak than the ragweed stand, and the effects of the blizzard of 11 January were also studied there. The willow stand was more sparse than the ragweed clump in terms of stems per square meter, but the rates of wind reduction with distances leeward into the windbreak were similar for the two windbreaks. Although drifts in the willow clump were generally not as deep as those found in the ragweed, the pattern was similar in that the deepest drifts were not concentrated in the windward part of the windbreak but were instead found in more leeward sections. The fact that a blue jay (*Cyanocitta cristata*) was found frozen and huddled against a branch at the leeward edge of the willow stand is evidence that even a large windbreak may not be effective in protecting wildlife from the most severe winter storm conditions. A single hen pheasant which died of exposure during the storm was found within a short distance windward of the willow stand. There were many pheasant tracks within the windbreak, but pheasants may have remained in the cattail slough leeward of the willows until the storm subsided and later used the willow stand for loafing.

The deepest drifts in a field of standing corn after the blizzard on 11 January 1975 were about the same distance leeward from the line of reference as were the deepest drifts in the ragweed and willow stands. The large size of such windbreaks needed to provide protection from the most severe winter storm conditions seems to preclude their establishment or maintainance in most of the intensively farmed areas of the state. Such cover however, may be valuable in providing pheasants shelter from winter weather and storms of less than blizzard proportions. Six to eight rows of corn reduced wind speeds by a third to a half from 4.5-m/sec (10 mph) in the open field. A few corn rows left standing at the edge of a field could provide significant shelter for pheasants in nearby cover areas.

Another common drawback of many windbreaks regarding their suitability as winter shelter for pheasants can be seen by analysis of drifting patterns at the honeysuckle and honeysuckle-spruce natural windbreaks. As a result of the 11 January 1975 blizzard, very deep snowdrifts accumulated behind a mature honeysuckle windbreak on a farm near Scranton, Iowa. The deepest drifts were found almost 15 m (50 feet) leeward of the windward edge of the windbreak. Drifts within the windbreak were shallow and it looked as though the wind and drifting snow had been funneled at high speed through the more open portions of the windbreak near ground level. The same pattern was also noticed at a honeysuckle-spruce windbreak north of Boone. The honeysuckle bushes had been planted several feet apart to allow for good growth, but this resulted in gaps between the bushes close to ground level. Wind and snow were funneled at high speed through these gaps and the deepest drifts accumulated farther leeward in the windbreak. Thus a greater proportion of the windbreak was made undesirable to pheasants because of either high wind speeds or deep snow accumulation. At windbreaks with these characteristics, some type of low, dense vegetation is needed just windward of the primary windbreak cover to prevent this funneling effect.

One of the windbreak types studied in 1974 -- the weed strip -- was composed of low, dense vegetation in the form of grasses, smartweed, and lambsquarters. The small width and high density of the strip caused a large modification of wind and snow profiles within a very short distance, with the greatest snow depths and lowest wind speeds found just leeward of the vegetation. Similar weed strips along fencerows often become filled with snow and are then useless as pheasant cover. Such a weed strip located just windward of larger windbreak vegetation may become useful, however, by acting as a snow catch to break the wind near the ground and keep drifting snow from being funneled at high speed beneath larger woody vegetation.

Even a row of short, dense woody vegetation windward of the main rows of a windbreak may influence the drifting pattern. This happened with a 0.9-m-high (3-foot-high) row of dogwood to the windward side of several rows of privet. Without the dogwood row, the deepest drifts were leeward of the most leeward rows of privet, and more shallow drifts occurred just leeward of the first row. With the dogwood row windward, this pattern of buildup was reversed. A low, dense evergreen hedge was also found to be very effective in reducing surface winds and depositing snow over a short distance to its leeward side.

As mentioned at the beginning of this report, there are many uses made of windbreaks and the reasons for establishment of the majority of them have been for some purpose other than protection of wildlife. Many designs and advice on planting seem to emphasize the importance of maximizing the leeward zone of influence of the windbreak (e.g. for protection of fields against soil erosion, or for the deposition of snow for moisture over a wide area). The windbreak vegetation is thus fairly open so that the unidirectional windflow is maintained though wind speeds are reduced through the windbreak and to some distance leeward. If such a windbreak were established for protection of pheasants, much of the windward part of the planting would be characterized by relatively high wind speeds and an extensive area of snow accumulation, and would become undesirable for pheasants during times of heavy drifting or very high winds. The windbreak would have to be large in order to contain a leeward section of sheltered cover for pheasants, and large windbreaks do not seem to be very compatible with the intensive cropping patterns on much of Iowa's farm acreage. If pheasants are restricted to small cover areas, it is important that the cover itself be in a sheltered area, where it would not be subjected to high winds and heavy snow accumulation.

Vertical-slat snowfence was used to modify two natural windbreaks used by pheasants -- a Douglas-fir windbreak and mulberry fencerow cover. It was hoped that use of snowfence would provide additional protection near the pheasant cover by reducing wind speeds and acting as a snow catch windward of the vegetation. Snowfence placed parallel to a large Douglas fir windbreak did reduce wind velocities and snow depths in sections of the windbreak normally used by pheasants. However, snowstorms were not severe enough for me to judge whether or not the benefit to pheasants using the windbreak was substantial. No concentration of pheasants in areas of the windbreak protected by the snowfence was observed.

One drawback of using snowfence for protection of cover is that it requires a lot of work to take the snowfence out to the field and stake it up in the fall or early winter and then remove it in the spring before field work starts. Another design was tried -- diagonal placement of snow fence across a mulberry fencerow -- in which the snowfence could be rolled up and left along the fenceline when it was not in use. After crops had been harvested in the fall, the snowfence could be unrolled and staked into position. The significant sheltering effect produced by the snowfence and its associated large drift apparently influenced pheasants to concentrate their activities to the leeward mulberry loafing cover. The diagonal placement of snowfence enabled it to shelter the fencerow from winds out of the west, northwest, or north, and was thus more useful than if it had been placed perpendicular or parallel to the fencerow.

Several experimental windbreak designs were tested in the field and wind tunnel with the hope that a windbreak could be found which was small but still provided a sheltered area for pheasant cover. The double-horseshoe windbreak effectively reduced wind speeds and drifting in its leeward cover when the storms were from the northwest. However, the design was oriented to provide protection from storms from that direction and may not have been as effective against storms from the north or west. The right-angle windbreak design did not seem to be very effective at providing shelter from severe storms. With only a single row of vegetation, this design had extensive leeward drifts regardless of the direction of the storm. This design is seen most commonly near farm dwellings or feed lots, and to be effective cover for pheasants, this type of windbreak must contain more than a single row of vegetation.

The fencerow-intersection design represented a windbreak of dense vegetation planted where two fencerows cross. It was hoped that the "legs" of vegetation extending out along the fencerows to the north and west would shelter the other two legs to some extent. It became evident from field studies, however, that when the storm was directly from the west or north, large drifts were formed leeward of the row of vegetation perpendicular to the wind, and the windbreak became filled with snow when winds were strong and snowfall heavy. A scale model fencerow-intersection windbreak was tested in a wind tunnel in 1973, and drifts accumulated on all four sides of the windbreak -- the same pattern seen at the experimental field windbreaks. When model snowfence was placed windward of the windbreak model, surface-drifted particles accumulated between the snowfence and plastic vegetation, and a sheltered area with shallow drifts was found at the leeward edge of the model. Snowfences erected at field windbreaks might prevent snow from accumulating in the vegetation and burying pheasants. A 15-m (50-foot) length of snowfence could be stretched diagonally (northeast to southwest) between north-south and east-west fencelines to shelter the vegetation at their intersection and along both 11-meter (35-foot) sections of fenceline extending out to the snowfence. The snowfence could be rolled up and stored along the fenceline during the growing and harvest seasons and then easily unrolled and attached to the permanent end stakes the next winter.

Two other windbreak designs tested in the wind tunnel but not in the field were the teardrop-shaped windbreak and the doughnut-shaped model. The sheltered area in the teardrop design was rather small considering the windbreak size, and the design would not offer as much multi-directional protection as some of the other designs. The doughnut-shaped design, however, would offer perhaps the greatest range of protection due to its radial symmetry. The shelter effect of this design would be the same for any wind direction. The windward edge of the model acted as a snow catch and model snow was deposited in the center of the model. The leeward edge was left relatively free of snow and was the most sheltered part of the model. The model was made of a single ring of plastic vegetation, but perhaps two or more concentric rings of vegetation would provide even better protection for leeward parts of the windbreak.

The experimental field windbreak models studied were constructed of evergreens to provide a dense barrier. Establishment of windbreaks consisting of living evergreens, however requires much attention and care of seedlings and young trees in order to get a good stand established. Perhaps some of the dense perennial grasses such as switchgrass (Panicum virgatum) or reed grass (Phragmites communis) could be used along fencelines and at fencerow intersections instead of evergreens. They would not need as much care as evergreens, and would probably be cheaper to establish. Woody species (willows, dogwood, mulberry, and others) attract many wildlife species, however, and are often used by pheasants for loafing cover as well as for protection from wind and blowing snow. Perhaps some combination of woody and grassy vegetation would be best with grasses planted around the perimeter of the main woody vegetation to prevent wind and snow from funneling beneath it at high speed.

Tests of scale-model windbreaks in a wind tunnel seem to be a good way of predicting the gross patterns of snowdrifting for various designs. Tests with surface-drifted model snow showed the best correlation with field tests, perhaps because snowdrifts that accumulated near field windbreaks may have formed mainly from surface-drifting snow. More testing is needed to determine the optimum height, density, stem diameter, and size of natural windbreaks in the field for them to provide pheasants with adequate protection from severe winter weather while at the same time taking up minimum space. Perhaps a computer program could be developed which would relate snow depths and wind speeds to distance leeward from the windward edge for various values of the above-mentioned factors. One might then be able to predict the general level of protection (in terms of percent windspeed reduction and maximum snow depth) that would be given by the proposed windbreak planting. This information could be valuable to wildlife managers when planning cover plantings or crop distributions for a refuge or management area, or when advising landowners who wish to establish wildlife cover on their own land.

RECOMMENDATIONS

The following recommendations are based on winter observations of various windbreak types, on results of field studies of specific windbreak designs, and on a review of the literature pertaining to windbreaks and winter cover used by pheasants.

Bush honeysuckle is one of the most widely recommended shrubs for planting in windbreaks, either alone or in combination with evergreens. In many of the honeysuckle windbreaks observed during the study, individual plants were often spaced several feet apart for better growth. As the plants matured, the upper portions of the bushes had become dense and had formed a hedge-like effect, but there were openings between bushes near ground level. Wind and blowing snow often funneled through these openings at high speeds and drifts formed some distance leeward of the honeysuckle. Thus, vegetation on the leeward side of the windbreak became filled with snow and was useless as pheasant cover. The honeysuckle itself also became undesirable as cover because of the strong winds at ground level. A strip of low, dense vegetation (e.g. switchgrass, orchardgrass, foxtail) on the windward side of these windbreaks would prevent this funneling of wind and snow at high speeds beneath the vegetation. Other woody cover areas might similarly benefit from dense, weedy vegetation at ground level on the windward side of the windbreak.

In strip or row-type plantings, extra windbreak rows may help catch snow, leaving leeward rows more snow-free. A windward row of dense vegetation close to ground level would intercept snow moving by surface creep and cause most of the snow to be deposited in deep drifts for a short distance leeward. I observed that pheasants sought shelter from strong winds behind such deep drifts and used the sites for loafing or for protection when traveling to and from feeding areas.

Six or more rows of corn left standing on windward sides of fencerows or other cover may reduce windspeeds significantly in the leeward cover, as well as providing a source of food for wintering pheasants.

Unplowed corn or grain stubble in fields windward of cover areas reduces the amount of drifting within the cover. Alternatively, if large, barren fields occur on the windward sides of windbreaks, most of the snow on these fields will drift into the vegetation and reduce its effectiveness as wildlife cover.

Natural clump-type windbreaks should either cover a large area or be tall enough to prevent the vegetation from becoming filled with snow. A small, dense stand of ragweed studied in 1975 became almost filled with snow and was not used by pheasants. A larger and taller willow stand, however, contained deep drifts within the stand, but there was still enough woody cover to [illegible] attractive to pheasants as a loafing site.

Narrow row or strip-type windbreaks, such as vegetation in a fencerow, should be dense enough to provide shelter for pheasants from strong winds. Drifts near these windbreaks may be deep when snowfall and winds are great, but if the vegetation is tall enough, cover may still remain available.

Snowfence may be used to modify drifting and wind speeds in winter cover by causing snow to accumulate windward to rather than within the cover. For fencerow cover, snowfence placed diagonally to prevailing winds provides protection against most storms. A drawback of the use of snowfence in farmland is that it must be put up and taken down each year. By leaving the snowfence rolls and posts along the fencerow, set-up and removal time can be minimized.

It was found from field tests that dense fencerow-intersection windbreaks may become filled with snow during severe storms unless snowfence is used. Snowfence in a diagonal line intersecting both of the perpendicular fencerows and to the windward side of the fencerow intersection would help reduce drifting within the windbreak.

Field testing of the doughnut-shaped windbreak design is needed for determination of its effectiveness as shelter for pheasants. The diameter of the circle should be about 10 times the height of the windbreak vegetation. This design seems more suitable to non-agricultural areas in Iowa such as wildlife refuges or wetlands, where it would not take up crop land or interfere with farming practices.

Further studies should be made in an attempt to develop a computer program which would help predict the effectiveness of various windbreak types in providing pheasants with maximum shelter in the minimum space. Such information could be used by wildlife managers or private landowners when designing cover areas for wildlife.

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APPENDIX I. LOCATIONS OF NATURAL AND MODIFIED NATURAL WINDBREAKS STUDIED

Windbreak	Location
Ragweed stand	SW¼, Sec. 5, R-25W, T-83N, 5 P.M.
Willow stand	NE¼, NE¼, Sec. 18, R-32W, T-83N, 5 P.M.
Weed strip	NW¼, Sec. 13, R-25W, T-83N, 5 P.M.
Standing cornfield	S½, SE¼, Sec. 18, R-24W, T-83N, 5 P.M.
Honeysuckle windbreak	NE¼, Sec. 22, R-32W, T-83N, 5 P.M.
Honeysuckle-spruce windbreak	W½, Sec. 3, R-26W, T-84N, 5 P.M.
Shrub row plantings	N½, NE¼, NE¼, Sec. 17, R-24W, T-83N, 5 P.M.
Douglas fir windbreak	NW¼, NW¼, Sec. 27, R-24W, T-83N, 5 P.M.
Mulberry fencerow	SW¼, SE¼, Sec. 21, R-25W, T-83N, 5 P.M.

APPENDIX II. DESCRIPTION OF SNOWSTORMS STUDIED

Date	Description of weather conditions
21 January 1973	Snowfall of 8 cm (3 in) with winds from the NW at 7-9 m/sec (15-20 mph). Winds continued at same speed and direction on 22 January.
14 February 1973	Snowfall of 5-8 cm (2-3 in) with winds from the NW.
13 January 1974	Snowfall of 5 cm (2 in) with light winds from the NW.
21 February 1974	Snowfall of 7.6 cm (3 in) with winds from the N at 11 m/sec (25 mph). Winds switched to the NW on 22 February, but velocity remained at 11 m/sec (25 mph). Weather remained cold several days after the storm and no snow melting occurred during that time.
25 February 1974	Snowfall of 8 cm (3 in) with heavy drifting from the north.
30 November 1974	Snowfall of 13 cm (5 in) with winds from the N at 9 m/sec (20 mph).
2 January 1975	Snowfall of 13 cm (5 in) in central Iowa with winds from the northwest at 11 m/sec (25 mph) continuing on 3 January.
11 January 1975	Blizzard conditions across most of central Iowa. Snowfall was 5 cm (2 in), but winds reached 20 m/sec (45 mph) from the W and remained at that level all day. Temperatures remained well below freezing for several days after the storm and no snow melting occurred during that period.