The Effect of Mature Caragana Shelterbelts on Microclimate, Soil Moisture and Growth of Spring Wheat.

by

Mitchell I. Long

A thesis
presented to the University of Manitoba
in partial fulfillment of the
requirements for the degree of
Master of Science
in
Department of Plant Science

Winnipeg, Manitoba, 1984

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ABSTRACT

Long, Mitchell, I. M.Sc. The University of Manitoba

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Major Professor; Dr. L. J. LaCroix

A two year study of the shelter effect of mature caragana (*Caragana arborescens* Lam.) shelterbelts was carried out near Conquest, Saskatchewan. The parameters investigated were wind velocity, latent evaporation, minimum and maximum air temperature, total soil moisture and the growth of spring wheat.

Single-row caragana shelterbelts which were 6m tall and 800m in length were used in the study. The shelterbelts were oriented north-south and spaced 201m apart. The crop grown was *Triticum aestivum* L. cv. Neepawa. Sensor locations were set at 3H and 1H west and 1H, 5H, 10H and 20H east of the shelterbelts. In 1983 a sensor location was added 17H east of the shelterbelt.

A significant reduction in wind velocity and latent evaporation adjacent to the shelterbelt was observed. The wind velocities were reduced in a zone from 3H windward to 17H leeward. Latent evaporation was reduced in a pattern similar to that of wind velocity but to a lesser degree. Latent evaporation was reduced in a zone from 1H windward to 10H leeward. Minimum and maximum air temperatures did not show significant differences relative to distance from the shelterbelt.

The shelterbelts did not produce significant differences in total soil moisture at the sensor locations during essential periods in the crop's growth. Snow accumulation is the major means of increasing soil moisture on the Prairies. Snowfall was below normal both years of the study.

There were no significant differences in emergence attributable to the shelterbelts at the sensor locations. Soil moisture was the determining factor. Crop dry matter production patterns in 1982 indicated shelterbelt competition. This was not observed in 1983. Dry matter production generally peaked at 5H and diminished as distance from the shelterbelt increased. Grain yield results were similar to dry matter production. In 1982 grain yield peaked at 5H and diminished as distance from the shelterbelt increased. In 1983 a severe grasshopper infestation reduced yields on the west side of the shelterbelts. The 17H sensor location had a significantly low yield. The mean yield across the sheltered field in 1982 and 1983 was compared to the yield of a check area. In 1982 the mean yield across the sheltered field was less than the yield for the check area. The estimated yield for the check area may have been too large, therefore, the probable difference in yield was small. In 1983 the mean yield across the sheltered field was greater than that determined for the check area.

The water use efficiency of the crop was calculated for dry matter production and grain yield. The sensor locations adjacent to the shelterbelt and at 17H were generally least efficient. This indicated shelterbelt competition for both years of the study. The 17H location had the lowest combined effect of the two successive shelterbelts.

The major effect of the shelterbelt on the crop was the change in crop water use efficiency across the field. This was partly a result of reduced wind velocities and latent evaporation in the sheltered zone.

Based on the results of this study it is recommended that older caragana shelterbelts in the Conquest, Saskatchewan area be maintained and, if possible, rejuvenated. Removal or further neglect of the shelterbelts may lead to increased soil erosion.

ACKNOWLEDGEMENTS

The author wishes to gratefully acknowledge the following individuals and organizations for their assistance in the preparation of this thesis.

Dr. L.J. LaCroix, my advisor, for his guidance given during this study and the preparation of this thesis.

Dr. C. Shaykewich, Department of Soil Science, and Professor J.A. Menzies, Department of Plant Science, for reviewing this manuscript.

Dr. G.B. Neill, Dr. G. Howe and the staff of the PFRA Tree Nursery for their assistance in this study and their financial support.

Doug Sibbald and John Halliwell for their cooperation in this study.

Larry Sernyk for all his help with computer programs and Leesa Sereda for typing this manuscript.

My parents for their love and encouragement during these past years.

Special thanks to my wife, Lynda, for her patience, love and understanding.

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Chapter I

INTRODUCTION

In the 1930s drought and wind caused severe soil erosion on the Canadian prairies. There were many methods suggested to conserve soil moisture and to control soil erosion by the wind. One method that was proposed to mainly control soil drifting was the planting of field shelterbelts. These were to be established across fields at intervals of approximately 100 to 250 m and perpendicular to the prevailing wind.

In 1935, the federal government established test plantings at Conquest and Aneroid, Saskatchewan and Lyleton, Manitoba. These areas had suffered severe soil erosion. The soils are predominantly loams and fine sandy loams. The planting was directed by the PFRA Tree Nursery at Indian Head, Saskatchewan. The largest project was the Conquest planting which by 1958 had 1,120 km of hedges while those at Aneroid and Lyleton each had about 585 km of hedges (Pelton, 1976). Caragana (*Caragana arborescens* Lam.) was heavily used either as a pure single-row shelterbelt or in combination with maple, ash or elm.

It has been shown that shelterbelts do help control soil erosion by reducing wind velocity. Research has also shown that shelterbelts modify the microclimate that crops are grown in due to the effect wind has on temperature, humidity and evapotranspiration. Most of the work that is generally cited has been conducted in Europe, the United States or Russia. The shelterbelts in these areas, usually, are not of the same design or species as those used on the Canadian prairies. The United States has in the past recommended large trees planted in multi-row shelterbelts. The conclusions drawn from research on these shelterbelts do not necessarily apply to single-row caragana shelterbelts. Research has also been conducted in wind tunnels to predict what may happen under field conditions but actual field measurements do not always agree with the predictions from models.

During the 1950s, the Swift Current Research Station conducted investigations at the Conquest and Aneroid sites to determine the influence of previously established shelterbelts on wind velocity, soil moisture and crop yield (Staple and Lehane, 1955). There have been no recent investigations on these plantings. The shelterbelts are mature and are beginning to deteriorate due to age and lack of maintenance. New evidence is needed to emphasize the importance of shelterbelts. The continued neglect or removal of shelterbelts may once again open the land to the hazards of wind erosion.

The purpose of this study was to determine the influence a mature caragana shelterbelt has on the microclimate and soil moisture and how this affects the growth of spring wheat. Based on this study recommendations are to be made as to whether or not these older shelterbelts should be rejuvenated and maintained.

Chapter II

LITERATURE REVIEW

2.1 EFFECT OF SHELTERBELTS ON MICROCLIMATE

2.1.1 Wind Velocity

The primary purpose of a shelterbelt is to reduce wind velocity. The quality and extent of shelter depends on many factors including the height, permeability, length and orientation of the shelterbelt, ground surface roughness, thermal stability, the height above the ground at which the measurements are made and the topography (Marshall 1967; Read 1965; Siddoway 1970; van Eimern et al. 1964).

There is some disparity in the literature concerning the distance to which wind velocity reduction extends due to a shelterbelt. It is customary to express distances in the sheltered zone in multiples of shelterbelt height (H). Ross (1933) gave a value, for protective influence, of 15 m for every 30 cm of shelterbelt height. This would give a sheltered zone extending to 50 H leeward. The commonly accepted values are 30 H on the leeward side and 5 H on the windward side, but significant reductions, 20% or more, occur only upto 20 H leeward and 2 H to 5 H windward (Bates 1944; Peterson 1971; Read 1964; Staple 1961; van Eimern et al. 1964).

The extent of shelter is proportional to the height of the shelterbelt, though there is some question as to whether this holds true for very high belts (Kreutz 1957). Staple and Lehane (1955), working with

6.1 m tall shelterbelts at 200 m spacings, found that the mean wind velocity was reduced by more than 15 % across the whole field.. With 2.3 m tall belts comparable protection extended only 50.3 m. Lehane and Nielsen (1961) made similar observations. They found that with a 3.0 m tall hedge the point of 40% reduction occurred 13.0 m out, while with a 7.6 m tall hedge this point occurred 25.9 m out.

The permeability seems to have the greatest influence on the quality and extent of shelter. The degree of permeability is the ratio of the open area of the belt to the total vertical area of the belt. Permeability can be difficult to determine accurately. In most studies it has simply been estimated. Jensen (1954) tried to establish a density (inverse of permeability) scale for several types of shelterbelts with the aid of photographs.

Permeability directly effects the flow of wind. A dense shelterbelt will cause a strong displacement flow of air over it and also a zone of highly retarded flow directly behind it. The shear stress between these two is high, causing a quick recovery of the wind velocity and greater turbulence. A more permeable belt will let some air filter through it which reduces the shear stress and therefore the turbulence and rate of recovery of the wind velocity. The extent of the sheltered zone is increased though there is a decrease in the maximum reduction in wind speed. Read (1964) stated that a very dense shelterbelt reduces wind velocity most in the 0 H to 10 H zones, moderately dense belts reduce the velocity over a greater distance and very permeable belts reduce wind speed very little past 10 H. Skidmore and Hagen (1970) observed that a barrier of 0% permeability caused the greatest reduction in wind velocity immediately adjacent to it. For 40 and 60% permeable barriers the zone of greatest reduction occurred at 3.5 H and 5 H, respectively. The optimum permeability is considered to be 40 to 50% with small holes evenly distributed throughout the shelterbelt (Caborn 1957; Jensen 1954; Marshall 1967; Woodruff et al. 1963).

The length of a shelterbelt is an important factor effecting the extent of shelter. As air flows past the edges of a belt a shear stress develops with the calmer air behind the belt. This causes the air to move in toward the centre of the sheltered zone. Stoeckler (1962) stated that the area of barrier influence is within a transect forming a 60 degree angle with the barrier. Shelterbelt length is also important for maintaining a reasonable amount of shelter when the wind is not blowing perpendicular to the belt. Belts 11.5 and 20 H in length will provide adequate protection from winds at an angle of incidence of 60 and 45 degrees, respectively (Marshall 1967). Naegeli (1953) stated that the ratio of height to length must be at least 1:11.5 if the wind conditions of an infinitely long belt are to be achieved for a line perpendicular to its centre.

It is necessary that the shelterbelt be continuous along its length. Large gaps in the belt will cause a funneling of the wind which may reduce the amount of the field that is sheltered (van Eimern et al. 1964). A shelterbelt should be positioned so that it is perpendicular to the prevailing wind. This provides the greatest degree of protection. According to Lawrence (1955) the distance to which wind was reduced by 20 and 40%, compared with the reduction with winds blowing perpendicular to the belt, decreased at an angle of incidence of 75 degrees by about 5%, at 60 degrees by 5 - 15%, at 45 degrees by 40 - 50% and at 30 degrees by 65 - 70%. Rollen (1983) made similar observations. The commonly accepted extent of shelter of 20 H is believed to be a good average for crosswinds of angles up to 40 degrees (Staple and Lehane 1955). Even with a parallel wind there is a zone of reduced wind velocity near the belt (van Eimern et al. 1964).

There is some effect due to the wind itself, the thermal stability of the air and the topography. The absolute high wind velocity in itself has no immediate effect on the percent wind reduction, but it can influence the permeability of a shelterbelt. Generally, a deciduous belt acts more permeable in a strong wind and less permeable in a light wind. The reverse is observed with pines where strong winds force the needles together like venetian blinds, reducing the permeability (van Eimern et al. 1964).

Staple and Lehane (1955) noted that the effect of different degrees of thermal stability on wind reductions is probably one of the main causes of the diversity of data. According to van Eimern et al. (1964) with a stable vertical temperature gradient it takes more effort for the air to flow over an obstacle, therefore, there is an increase in the flow penetrating the obstacle which increases the distance shelter extends.

Topography can alter the extent of the sheltered zone. Ferrell (1957) showed that if on level land the distance to 50% reduction is 10.5 H, on a downslope it may be 12 H and on an upslope it may be 8 H. Freeman and Boyle (1973) stated that parallel windbreaks should be closely spaced on the upslope and widened out for downslope winds.

A single shelterbelt offers protection over a limited area. It is recommended that systems of parallel shelterbelt or parallel and crossing belts be planted. This will protect larger areas and, with crossing belts, protect from winds other than those of the prevailing direction. Kaiser (1959) considered that extensive systems of shelterbelts increase the roughness of the ground surface as a whole, thereby, causing a reduction of the surface windspeed at all places within the system. Staple and Lehane (1955) were not able to show a similar accumulative effect due to successive belts.

2.1.2 Evapotranspiration

The reduction of evaporation from soil and transpiration from plants is usually one of the most desirable effects of shelterbelts. Evaporation is influenced by wind velocity, turbulence, air temperature, relative humidity, distance from the shelterbelt, permeability of the belt, and size and shape of the protected zone (Peterson 1971).

Most measurements of evaporation are limited to potential evaporation or the capacity for evaporation of free water. The information is valuable but it is important to remember that this does not exactly represent field conditions. It represents conditions where soil moisture is not limiting. As soil dries the resistance to evaporation increases, also plants under moisture stress have reduced transpiration due to stomatal closure.

According to Rosenberg (1979) evaporation is a direct function of wind velocity. Skidmore and Hagen (1970), working with barriers of various permeability, found the curves for evaporation and wind velocity reductions to be nearly parallel. This suggests that evaporation and wind velocity are closely related regardless of turbulence, barrier permeability, or wind velocity reduction patterns. Naegeli (1953) determined evaporation from flat moist containers of soil to be proportional to the square root of wind velocity when temperature and relative humidity are constant.

Pelton (1967), using Black Bellani Plate atmometers, found evaporation in a sheltered field was reduced in a similar pattern, but to a lesser degree, than wind velocity. The maximum reduction in evaporation occurred at the site of maximum wind reduction.

In a Class A pan evaporation study, by Hanson and Rauzi (1977), data from 2 locations in the Great Plains indicated that evaporation from pans protected by shelterbelts was about 14% less than unprotected pans. Based on a study with atmometers Pelton (1967) found evaporation in a sheltered area to be 12 to 23% less than that from an open site.

Blundell (1974), using 3 water tanks, one in the open, one at 10 H and one at 20 H, showed shelter had no significant effect on evaporation in northern England. He found a low correlation with wind velocity and a large, significant, correlation with sunshine hours.

Walker (1946) reported evaporation studies leeward of a dense shelterbelt. He observed that at 2 H evaporation was 60% of that in the open and at 10 H it was 90% of that in the open. Staple and Lehane (1955) looked at free-water evaporation from a wheat field protected on the east and west by dense, 3-row shelterbelts. The belts were 5.4 m tall and 201 m apart. Tanks were placed at 4.6 H, 18.3 H and 32.1 H from the west belt. The reduction in evaporation losses over a 4 year period were 13, 5, and 11%, of that of the control, respectively.

Skidmore and Hagen (1970) observed that with less permeable barriers the minimum leeward evaporation occurred closer to the barrier and after reaching the minimum tended to increase more quickly. The minimum evaporation from 60, 40 and 0% permeable barriers occurred at 4.5 H, 3.5 H and immediately adjacent to the barrier, respectively. At 4 H leeward of a solid barrier evaporation recovered to 92% of the open. With 40 and 60% permeable barriers the values were 65 and 75%, respectively.

Shelterbelts tend to cause an increase in both air temperature and relative humidity in the sheltered zone. Higher air temperatures increase evaporative demand, while higher relative humidity decreases evaporative demand, therefore, the two factors generally offset each other (Skidmore and Hagen 1970).

The degree of reduction in evaporation will also depend on the importance of advection in the region concerned (Lomas and Schlesinger 1971). With non-advective conditions there may be no reduction in evaporation even though windspeed may be considerably reduced. Where advective energy is a relatively large component of the total energy available for evapotranspiration shelterbelts will have a greater affect. McNaughton (1983) substantiated, by theoretical and experimental evidence, that a windbreak can reduce the advective component of evapotranspiration by reducing turbulent transport, if the advective component used is the exchange flux rather than downward sensible heat flux.

Measurements of soil water depletion have been used to estimate long term integrated evapotranspiration rates. Such studies have generally shown decreases in evapotranspiration with shelter in dryland areas (van Eimern et al 1964). Rosenberg (1966b) observed an increase in soil water use by bean plants grown under irrigation in shelter. George (1971) concluded that barriers had no effect on reducing evapotranspiration from a crop growing in a lysimeter tank. However, the barrier did reduce evaporation of free-water from pans adjacent to the lysimeter.

"The variation in results indicate the difficulty in associating potential or latent evaporation with actual evapotranspiration. Actual evapotranspiration will always be equal to or less than potential evaporation, but even though the potential evaporation is lower behind shelter, the actual evapotranspiration behind shelter may be greater than the actual evapotranspiration in the open. Once plants have produced a good canopy most of the water loss from a field is through transpiration. Plants in the open are, generally, under a greater water stress than in shelter so stomatal closure results in some decrease in transpiration. Plants in shelter are not under the same stress so they transpire more freely" (George 1971).

2.1.3 Air Temperature

The effect shelterbelts have on air temperature is due mostly to the change in wind velocity. There is both a seasonal and daily change in temperature patterns. Seasonally, a 5.5 to 9 C temperature increase, in the protected zone, occurs in spring and a 1 to 3 C decrease occurs in summer (FAO 1969). Read (1964) also found mean summer temperatures were lower and winter temperatures higher in the protected zone.

The daily air temperature fluctuation in the leeward zone may be considerable. The decrease in wind velocity and change in wind profile of the sheltered zone causes a reduction of vertical diffusion and mixing of the air. This usually results in higher daytime temperatures and lower night time temperatures (Marshall 1967; Rosenberg 1976; Rosenberg 1979; van Eimern 1964).

Woodruff et al. (1959) found both warmer and cooler daytime temperatures in shelter. Hagen and Skidmore (1971) also observed lower daytime temperatures in the lee of shelterbelts than in the open. This may occur if the soil in the sheltered zone is more moist than in the open. The greater evapotranspiration in the sheltered area would result in a lower sensible heat flux and, therefore, a lower air temperature (Rosenberg 1979).

The leeward daytime air temperature patterns are closely related to the eddy zone produced by the shelterbelt. The warm zone is located near the ground and the barrier where the eddy currents are rising. During the day this warm zone extended 5 H to 10 H leeward and the air temperature beyond this was lower than in the open (Woodruff et al. 1959; Hagen and Skidmore 1971). Bates (1911) found a 4 to 6% increase in air temperature as far as 10 H leeward of shelterbelts. Woodruff et al. (1959) observed increases of 2 to 4 C close to shelterbelts. At distances greater than 6 H they found decreases relative to the air temperature in the open.

Bates (1911) and Rosenberg et al. (1963) both found that cloudiness has an effect on the magnitude of the temperature difference. Rosenberg also noticed that windiness will effect the magnitude. An increase in cloud or wind minimizes the magnitude of the temperature difference between a sheltered area and the open.

Shelterbelt permeability also effects the magnitude of the temperature difference. Skidmore et al. (1972) experimented with barriers of different permeabilities. They concluded that temperature differences leeward of solid barriers were not as large as differences leeward of more permeable barriers.

The change in night time temperatures, with shelter, is usually slightly positive or negative (Marshall 1967). A decrease in night time temperatures would be due to an inversion being less disrupted by turbulence (Rosenberg 1976). An increase in night time temperature may be due to the shelterbelt or the crop canopy trapping warm air during the day and reradiating it at night (van Eimern 1964).

Woodruff et al. (1959) found night time temperatures, in a thin stratum of air extending to 26 H and 60 to 91.5 cm deep, was the same or slightly warmer than in the open. Overall, greater than 90% of the leeward area was cooler than the open with about 73% cooler by 1 C or more. Rosenberg et al. (1963) observed night time temperatures that were generally warmer in sheltered plots but the difference was 1 C or less.

2.1.4 Radiation

Shelterbelts influence the radiation balance of the ground surface or crops by shading them from short-wave solar radiation as well as by reducing the effective long-wave ground radiation. The shading and reduction are limited to an area very close to the shelterbelt (Marshall 1967; Rosenberg 1976; Rosenberg 1979; van Eimern et al. 1964). In very sunny climates, this shading can be advantageous but generally it is detrimental due to slower drying of the soil, in spring, and windrows, at harvest.

Dirmhirn (1953) calculated the relative daily amounts of solar radiation at different distances from shelterbelts, at 48 degrees north latitude, and found a greater reduction for north-south shelterbelts. Rosenberg (1979) observed the opposite effect. Shading was not of major importance for north-south shelterbelts as only small areas were shaded for short periods. On a full day basis the difference may be negligible since the area shaded in the morning will receive additional reflected energy off the shelterbelt in the late afternoon. East-west belts had a greater effect because the areas to the north are shaded for longer periods and areas to the south are subject to the reflection of solar radiation, from the belt, throughout the day.

Rosenberg et al. (1963) found a significant change in net radiation on fields sheltered on all four sides. They determined that net radiation was positive for a slightly shorter time on sheltered fields. This was due to a reduction in incoming short wave radiation on sheltered fields, by shading as the sun set, which occurred when the out going long-wave radiation was at its daily peak. The shading, along with the greater mean daily intensity of out going long-wave radiation due to higher temperatures of air, soil and plant surfaces, combine to reduce the net radiation of the sheltered area to 7% less than the open. The seasonal net radiation balance in the sheltered field was 12% less than the open field.

On cloudy days the predominance of diffuse radiation minimizes or eliminates the effects of shading. A reduction in long-wave radiation emission from the ground surface or crop is possible close to the shelterbelt. The reported reduction is slight but may still be enough to provide some frost protection on the edges of orchards (van Eimern et al. 1964).

2.1.5 Humidity

The effect of shelterbelts on humidity is not always straight forward. Several factors, such as soil moisture, evapotranspiration, diffusion and air mixing, as well as temperature and radiation, affect humidity (van Eimern at al. 1964). Many of these factors vary appreciably during the day, therefore, the influence of shelterbelts will vary with the time of day.

In sheltered fields the water vapor pressure generally increases during the day, due to the reduction in wind. As a result, relative humidity is often slightly higher during the day despite the counteracting influence of higher temperatures on the saturation vapor pressure though the effect extends for only a short distance (Peterson 1971; Rosenberg 1979; Siddoway 1970; Stoeckler 1962).

Lehane and Nielson (1961) found the difference in relative humidity between sheltered and open fields too small to measure with a hygrothermograph. Rosenberg (1966a) determined that the vapor pressure of water in the air above sugarbeets sheltered by a snow fence and two rows of corn was not effected by the shelter. In another experiment with irrigated beans, Rosenberg (1966b) found the water vapor pressure in the sheltered field was 0.2 to 0.3 KPa greater.

Read (1964) observed 2 to 4% greater relative humidity in the sheltered zone which extended as far as 24 H leeward. Skidmore and Hagen (1970) found water vapor pressure was slightly higher 2 H leeward of a barrier. The increase was 0.15, 0.31 and 0.26 KPa for 60, 40 and 0% permeable barriers, respectively. At 12 H leeward the vapor pressure was reduced by 0.07, 0.20 and 0.25 KPa for the 60, 40 and 0% permeable barriers, respectively.

The increase in humidity due to sheltering may lead to a reduction in evapotranspiration and moisture stress, but it may also favor the development of fungal diseases.

2.1.6 Carbon Dioxide in the Atmosphere

Little research has been conducted on the effect of shelterbelts on carbon dioxide in the atmosphere. It was long believed that air near the soil, behind shelterbelts, contained more carbon dioxide due to less air mixing. Recent studies have shown that carbon dioxide concentration is barely affected by wind shelter (Rosenberg 1976). At low wind velocities and under conditions of low diffusion rates, such as in the lee of a shelterbelt, carbon dioxide in the crop canopy tends to increase above the atmospheric concentration during the night and decrease below it during the day (Skidmore 1976).

The decrease in carbon dioxide in the air surrounding the leaves during the day may cause a reduction in the photosynthetic rate (Lemon 1970). Ruesch (1955) measured carbon dioxide concentrations in open and sheltered alfalfa using chemical absorption techniques. He found a small decrease in the sheltered crop during the day, which he concluded may be due to more luxuriant plant growth. Brown and Rosenberg (1971) found that shelter diminished vertical transport resulting in a slight or negligible reduction in carbon dioxide concentration. In further studies, Brown and Rosenberg (1972) collected air samples in the open and at 3 H east of a north-south barrier. The samples were pumped through an infrared gas analyzer to determine carbon dioxide content. They found the mean daytime concentration was 1 ppm less in the sheltered plot.

2.1.7 Snow Distribution

The primary factors affecting snow distribution patterns are wind velocity, wind direction or shelterbelt orientation and permeability of the shelterbelt. Many researchers report that snowdrifts leeward of a shelterbelt will be deeper, narrower and closer to the belt as the wind velocity increases, the angle of wind direction decreases and the permeability decreases (Scholten 1981).

Increasing wind velocity makes eddying, on the leeward side, more vigorous. As the eddying becomes more vigorous it blows the snow back towards the shelterbelt leading to deeper, narrower drifts near the belt. As wind direction decreases from a 90 degree angle normal to the belt, wind protection is reduced leading to the same type of drifting (Scholten 1981). Scholten (1981) and George (1971) both noticed that, in north central U.S.A., snowdrifts are deeper, narrower and closer to the shelterbelt for north-south orientations. The east-west belts collected snowdrifts that were wider and shallower. This was due to the small angle between the shelterbelt and the wind direction.

Shelterbelts with a dense lower level cause snow to drift, deeply, near the belt. This can benefit the trees but may delay spring seeding operations. Also in areas where dryland salinity (saline seep) is a problem, dense shelterbelts that trap snow in excessive amounts, may contribute to the problem and should be removed (Sommerfeldt 1976). More permeable lower levels allow the snow to be spread more uniformly over the leeward side and this is more desirable (George et al. 1963; Peterson 1971; Read 1964; Stoeckeler 1962). Dense belts accumulate snow, in most cases, to only 2 H to 5 H leeward and immediately adjacent to the belt windward. More permeable belts form drifts extending to 15 H or 25 H leeward (van Eimern 1964).

In studies on the major shelterbelt planting sites in the prairies, it was determined that, essentially all the snow that fell within the projects was retained (Lehane and Nielsen 1961; Staple and Lehane 1955). Snow depths in drifts along the belts averaged 50 to 70 cm and the drifts were up to 25 m wide. Snow depths in the centre of sheltered fields was 13 to 15 cm on stubble fields and 8 to 10 cm on fallow fields, which was equivalent to open fields (Pelton 1976).

Properly designed shelterbelts will distribute snow evenly across fields and help retain the snow cover. This may prevent the deep freezing of soils which provides for better water infiltration in spring and, consequently, less moisture loss due to runoff. Kreutz (1957) determined that the protective effect of only 8 to 10 cm of snow is sufficient to protect soils from low temperature. In his study the air temperature was -13 C while in sand without snow cover the temperature was -7.3 C and in sand with snow cover it was -2.9 C. Also protected land may get 2.5 to 3 times as much moisture from snow as unprotected land (Stoeckeler 1962).

2.2 EFFECT OF SHELTERBELTS ON SOIL MOISTURE

In spring the soil moisture in the sheltered area can be appreciably higher due to snow accumulation and the reduction of potential evaporation (Marshall 1967; Pelton 1967; van Eimern et al. 1964). On the Canadian prairies and the northern United States the accumulation of snow has the most importance. Stoeckeler and Dortignac (1941) showed that where shelterbelts were of such design as to cause deep snowdrifts, the increase in soil moisture from fall to spring could be as much as 25 cm of water. Areas within 8 to 10 H of the belt showed an increase of 12.5 cm of water due to the lateral movement of moisture from melting snowdrifts.

Pelton (1976), in reviewing research conducted at the Aneroid, Saskatchewan planting site, stated that shelterbelts increased spring soil moisture in an area 1 to 6 H leeward, which corresponded with snowdrifts. Staple and Lehane (1955), in their studies at Aneroid and Conquest, Saskatchewan, found the spring soil moisture content near shelterbelts generally greater than in the centre of the field, which also corresponded to the area occupied by snowdrifts. The moisture available to the crop ranged from 14 cm near the belt to 8 cm at mid-field.

Soil moisture determinations conducted by Staple (1961), in fallow soil near caragana shelterbelts, showed soil moisture was extracted, by the roots of the belt, out to 1.5 to 2 H. The sapping of moisture by the shelterbelt is partially offset by snow accumulation but can be a serious problem in dry years.

Frank and Willis (1978) partitioned the summer effects of microclimate modification and the winter effects of snow trapping for soil water gain of non-competitive barriers. The results showed yield of spring wheat was determined more by winter effects than summer effects in normal years. In dry years, the summer effects also contributed to yield.

The direct evaporation of moisture from the soil is reduced behind shelterbelts which may provide an important advantage in maintaining better conditions for seed germination (Rosenberg 1966a). As crop cover on a field increases and the soil dries, the importance of direct evaporation from the soil decreases while transpiration becomes the major means of moisture loss. In time, assuming transpiration is a function of leaf area alone, water depletion will induce soil moisture stress in shelter. Jensen (1954) found the initial soil moisture increase in the sheltered zone was eventually dissipated due to the sheltered plants transpiring more than the unsheltered plants.

2.3 EFFECT OF SHELTERBELTS ON CROPS

The response of crops to shelter has been shown to vary with species and variety (Marshall 1967). There is also a variation in response from year to year due to seasonal differences in weather, geographical location and soil conditions.

2.3.1 Germination

The higher soil moisture and soil temperature found with shelter in spring should favor the rapid germination and emergence of crops. Rosenberg (1966b) found that the rapid germination of sheltered sugar beets, in Nebraska, was due more to an increase in soil moisture than soil temperature. In later work with beans, Rosenberg (1967) did not find significant differences in germination due to shelter. Marshall (1967) stated that germination usually occurs more rapidly at higher temperatures such as encountered in the surface soil layers in shelter and that this, coupled with more rapid hypocotyl elongation, at higher temperatures, can result in earlier emergence. Sturrock (1978) reported that soybeans sheltered by temporary windbreaks, in New Zealand, germinated and emerged more rapidly due to both favorable soil moisture and soil temperatures.

2.3.2 Plant Water Status

Leaf water potential is usually higher and stomatal diffusion resistance lower in shelter. Frank and Willis (1972) studied leaf water status in spring wheat under three shelter conditions; an open plot, a plot sheltered by a slat-fence barrier and a plot sheltered by a multiple row shelterbelt. They found leaf water potential in the shelterbelt plot to be, 405.2 to 506.5 KPa higher than the slat-fence barrier which was 202.6 to 303.9 KPa higher than the open plot. The stomatal diffusion resistance measurements were lower, as were leaf water potentials for open compared to sheltered plants. This was contrary to the expected results. The plants in the open seemed to have lost the potential for stomatal regulation. Grace (1974) reported similar observations of reduced stomatal diffusion resistance in wind treated grass leaves due to leaf surface abrasion.

Skidmore et al. (1974) found considerable differences, in leaf water potential and stomatal diffusion resistance, in cultivars of winter wheat. Generally stomatal diffusion resistance was lower in shelter and the increase in resistance across the field corresponded with the increase in evaporative demand. Leaf water potential at intermediate stress was significantly higher in the sheltered plants. At low stress levels neither leaf water potential nor stomatal diffusion resistance were affected by shelter. At high stress levels there was no significant difference in leaf water potential between sheltered and unsheltered plants.

Frank et al. (1976) monitored plant water relations of soybean and wheat plants with or without irrigation and with or without shelter. Under irrigation both crops had higher leaf water potentials in shelter.

Without irrigation, wheat had the same leaf water potential with or without shelter and soybeans had a lower mean leaf water potential with shelter. Stomatal diffusion resistance tended to be lower in the irrigated, sheltered plants than in the irrigated, unsheltered plants. The combination of shelter and irrigation resulted in more favorable plant water status and this beneficial effect prevailed throughout the daylight period for both wheat and soybeans.

Brown and Rosenberg (1970) observed a decrease in stomatal diffusion resistance with shelter. They found that when soil moisture was low and sugar beets were stressed, the difference in stomatal diffusion resistance between sheltered and unsheltered plants increased, indicating that shelter was effective in reducing stress. The mean stomatal diffusion resistance of the sheltered crop was 6% lower than that of plants grown in the open. Based on these results they suggested that the expected benefits of shelter may be greater in arid regions.

2.3.3 Water Use

As crop cover increases and soil dries, the relative importance of direct evaporation from the soil decreases. Transpiration becomes the major mechanism of water loss. The more luxuriant plant growth and lower stomatal diffusion resistance found with shelter may lead to greater transpiration, and therefore greater water use (Rosenberg 1966b). Studies on soybeans by Ogbuehi and Brandle (1981) and Radke and Burrows (1970) did not show significant differences in plant water use between sheltered and open plants. Radke and Burrows suggested this was due to the system not having a closed bottom and the possibility of horizontal water movement. Rosenberg et al. (1963) found no difference in water use by sheltered and unsheltered snap beans in a season of ample water supply. In a study on irrigated soybeans by Miller et al. (1973) lysimeters were used to measure water use. They found that shelter reduced water use by about 20% from July 14 to July 24. The greatest water saving effect was on days of strong sensible heat advection. Under non-advective conditions the differences between sheltered and open plants may be small and if the stomatal diffusion resistance is lower in shelter, it is possible that water use in shelter may exceed that found in the open.

Frank et al. (1977b) found that with spring wheat under dryland conditions the plant water relations were not favorably influenced by the presence of shelter. The microclimatic data indicated a higher evaporative demand for both the irrigated open and dryland sheltered areas as compared with the irrigated sheltered and the dryland open sites.

Water use efficiency (dry matter produced per unit of water evapotranspired) is either unaffected or increased in shelter (Rosenberg 1974). Radke and Burrows (1970) observed an increase in yield of soybeans in shelter but no statistical difference in water use between sheltered and open soybeans indicating an increase in water use efficiency with shelter. Aase and Siddoway (1974) observed significant increases in water use efficiency of winter wheat grown in shelter during one year but no difference in the following year. The first year was considered dry and the second year wet which indicates that shelter may be more beneficial in dry years. Frank et al. (1977a) found that sheltered, irrigated spring wheat had greater water use efficiency than open, irrigated plants and open, dryland plants had greater water use efficiency than sheltered, dryland plants. Plants under irrigation had better water use efficiency than those on dryland. Sturrock (1978) stated that, in dry climates improved water use by plants is the chief factor in improving the growth of sheltered plants.

2.3.4 Photosynthesis

The few studies in which photosynthesis of plants under shelter was compared to that of plants grown in the open indicate an increase in photosynthesis with shelter. Skidmore et al. (1974) reported differences in photosynthesis in winter wheat in sheltered and open sites. They found considerable differences between cultivars but the photosynthetic rate was always higher in shelter even though the crop in the open contained up to 24% more chlorophyll. Grace (1977) stated that unpublished data by Grace and Russell showed no difference in photosynthetic rates between sheltered and open plots of grasses. Brown and Rosenberg (1970), studying sugar beets, determined that a 6% increase in photosynthesis with shelter was due to a decrease in stomatal diffusion resistance. Miller et al. (1973), using the carbon dioxide flux gradient method, found no difference in photosynthetic rates between sheltered and open irrigated soybeans.

Any increase in photosynthesis may be due to a longer daily duration of photosynthesis or lower nocturnal respiration and/or photorespiration (Rosenberg 1974; Miller et al. 1973).

2.3.5 Dry Matter Production

The increase in photosynthesis in shelter leads to an increase in dry matter production. Aase and Siddoway (1974) found greater dry matter production for winter wheat grown in shelter. The shelter enhanced the leaf area development, height and the number of heads per meter row length. Production peaked at about 1 to 3 H from the barriers. Leaf area showed the greatest difference, a four-fold increase with shelter, early in the season when plant protection was needed most and the difference decreased until at maximum leaf area the sheltered plant had 1.6 times the leaf area of the open plants.

Frank et al. (1976) reported no difference in dry matter production for soybeans with or without irrigation and with or without shelter. The leaf area was greater for the sheltered dryland plants than the open dryland plants but the leaf density of the sheltered dryland plants was lower. This indicates that larger, thinner leaves developed with shelter. Irrigated, sheltered spring wheat produced more dry matter at heading, a higher leaf area index, lower leaf density, more tillers per plant and taller plants. Under dryland conditions, with spring wheat, shelter stimulated height but reduced tillering. Frank and Willis (1972) stated that in 1971 their sheltered spring wheat plants were 107 cm tall and the plants in the open were 80 cm tall. Skidmore et al. (1974) showed that sheltered winter wheat plants were taller and larger leaved. Tod et al. (1972) found tiller production greater in shelter.

Radke and Burrows (1970) observed that soybeans sheltered by temporary corn windbreaks grew taller, had a larger leaf area index and produced more dry matter and higher yields. Ogbuehi and Brandle (1981) found the same results and attributed them to a better plant water status, lower stomatal diffusion resistance and lower leaf temperature.

Rosenberg et al. (1963) installed barriers on plots of irrigated beans after they had emerged. Within two weeks the sheltered plants were taller. The sheltered plants had a greater leaf area index, greater leaf number, greater pod set and, even though maturity was delayed, better quality beans.

2.3.6 Crop Yield

Yield response to shelter is greater in dry years than in wet years (Lehane and Nielsen 1961; Staple and Lehane 1955; van Eimern et al. 1964). When actual yields are given, the increase due to shelter in dry years results from a decrease in yield in unprotected areas. Staple and Lehane (1955) stated that in the dry years of 1936 to 1938, crops were harvested, on the Canadian prairies, in strips along shelterbelts when those in open areas were a failure. Percentage yield increase due to shelter may be greater on less fertile soils and there is a more beneficial yield effect on highly erodible sandy soils than on relatively more stable soils (Stoeckeler 1962).

Crops can be classified into three groups according to their yield response to shelter. Low response crops are drought hardy cereals, moderate response crops are forage crops, coarse grains and corn, and high response crops are vegetable and horticultural crops. Low response crops show increases in yield, behind shelter, during dry years only, whereas, moderate and high response crops generally show an increase in yield with shelter regardless of rainfall (Peterson 1971).

According to Bates (1944) shelterbelts compete with crops for moisture, soil nutrients and sunlight. This causes a reduction in crop growth and yield adjacent to the shelterbelt. Yields may be substantially reduced at 1 to 2 H depending on the species of tree or shrub used (Frank et al. 1976; Staple and Lehane 1955). Studies at Aneroid, Saskatchewan by Staple and Lehane (1955) showed that wheat yields were greatest at 2 to 3 H and tapered off toward the centre of the field. This was similar to the moisture pattern. The mean increase in yield over the field, including the land occupied by the shelterbelts, was 47 kg/ha. Frank et al. (1976) investigated the effect of single row Siberian elm shelterbelts on spring wheat yields. A noticeable reduction in yield was observed at 1 and 2 H, while maximum yield occurred at 5 H. The mean yield from 1 to 13 H was 2.6 tonnes/ha which was the same as the check area between 15 and 20 H. Taking the land occupied by the trees into account reduces the mean yield for 1 to 13 H to 2.4 tonnes/ha. Wheat responded to the combination of irrigation and shelter by yielding 21.8% more than the open crop. Under dryland conditions the shelter reduced spring wheat yield by 19.4%. The results indicate that if soil water is adequate shelter will substantially increase yields.

Stoeckeler (1962), in summarizing the effects of shelterbelts on crops in the Great Plains, concluded that in Nebraska and Kansas only the fields on the east, of north-south oriented belts, and south, of east-west oriented belts, showed substantial benefits. In the Dakotas he found the mean annual increase in wheat yields was about 67 kg/ha and benefits showed on both sides of the shelterbelts. The difference was probably due to differences in snow accumulation and over-winter soil water gain.

Frank and Willis (1978) partitioned the winter effect, snow trapping, and summer effect, microclimate modification, of non-competitive barriers. Average wheat yields were the same for all treatments during three wet years. For the dry years, the winter only and winter and summer barrier treatments increased yields by 2.1 and 3.2 quintals/ha respectively over the treatment with no barrier. The summer only treatment had no effect on wheat yield. The results indicate that grain yield increases were mostly due to increased over-winter soil water accretion resulting from snow trapping and not microclimate modification.

Pelton (1967) eliminated the effect of snow accumulation on grain yield of spring wheat. A snow fence barrier was erected after seeding. The yields obtained in the sheltered area ranged from 24 to 43% above the check yields. The area of maximum grain production corresponded to the area of maximum wind and evaporation reduction. The yields were extremely variable during individual years and from year-to-year, suggesting that other environmental factors were also affecting it.

Brown and Rosenberg (1971) hypothesized that the greater water vapor pressure in the sheltered area results in the stomatal aperture remaining open greater thus offsetting any possible influence of carbon dioxide concentration on the photosynthetic rate. This may, in areas where water stress is frequent, result in a significantly greater photosynthetic rate for sheltered plants which in turn can result in increased yield.

Chapter III

MATERIALS AND METHODS

This research was conducted in 1982 and 1983 at Conquest, Saskatchewan. The site was located on the Doug Sibbald farm (legal description: 30-9-16 NW) which was sheltered by single-row caragana shelterbelts. The shelterbelts were planted in the early 1940's at a spacing of 201 m and oriented north-south. They were 6 m tall and 800 m in length. The soil was a well drained, very fine, sandy loam within the Bradwell association.

The crop grown was Triticum aestivum L. cv. Neepawa. The previous cropping sequence of the fields was a two year rotation of wheat-summer fallow. The experiment was set up as shown in Figure 1 and replicated twice on adjacent sheltered fields. The replicates were 50 m by 170 m.

In 1982 the sensor locations were set at 3 H and 1 H west of the shelterbelts and 1 H, 5 H, 10 H and 20 H east of the shelterbelts. In 1983, a sensor location was also established at 17 H east of the shelterbelt which corresponded to the midpoint between adjacent shelterbelts. The data recorded were daily wind run, daily latent evaporation, daily minimum and maximum air temperatures, weekly volumetric soil moisture to 135 cm, crop emergence, dry matter production and grain yield.

The replicate locations were the same for both years of the study. In 1982 the crop was planted into summerfallow over the entire field containing each replicate. In 1983 only the test area was seeded in the previous year's stubble with the rest of the field left fallow. Ferti-

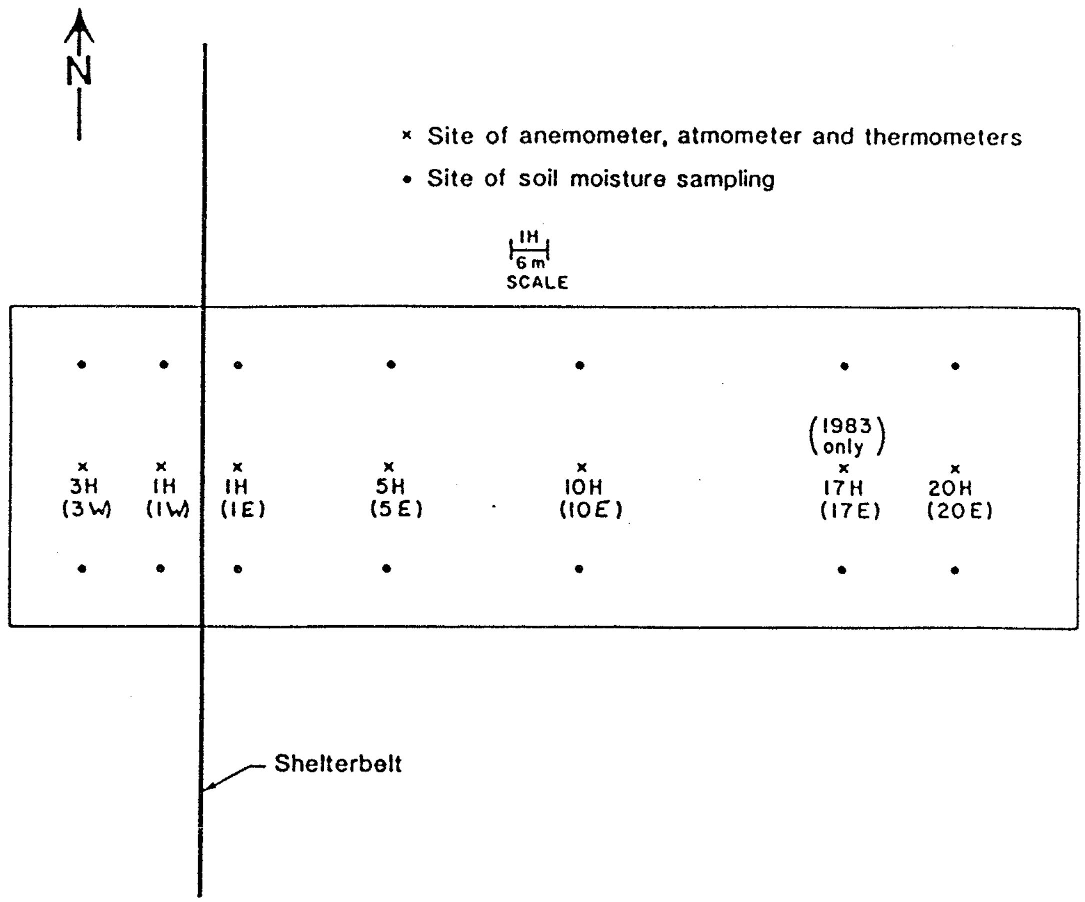

Figure 1: Field Diagram 1982-83.

lizing rates along with herbicide and insecticide practices are shown in the appendix (Table 18 and 19).

3.1 MICROCLIMATE

3.1.1 Wind Velocity

Three-cup anemometers were used to monitor the daily wind run at each sensor location. The anemometers were set at one meter above the soil surface as shown in Figure 2. In both years an anemometer which recorded both wind run and direction was located at 20 H leeward of the shelterbelt. The other anemometers recorded wind run only. Due to a shortage of equipment the anemometers were set up in the area occupied by one replicate for one week then rotated to the next for the following week. The anemometers were calibrated each year and the wind run values were adjusted accordingly. It was also necessary to convert some values to kilometers as some anemometers recorded in statute miles, some in nautical miles and some in kilometers. The values determined for west winds consist of northwest, west and southwest winds and those for east winds consist of northeast, east and southeast winds. The wind velocity for each sensor location was expressed as the percentage of that found at 20 H leeward of the shelterbelt.

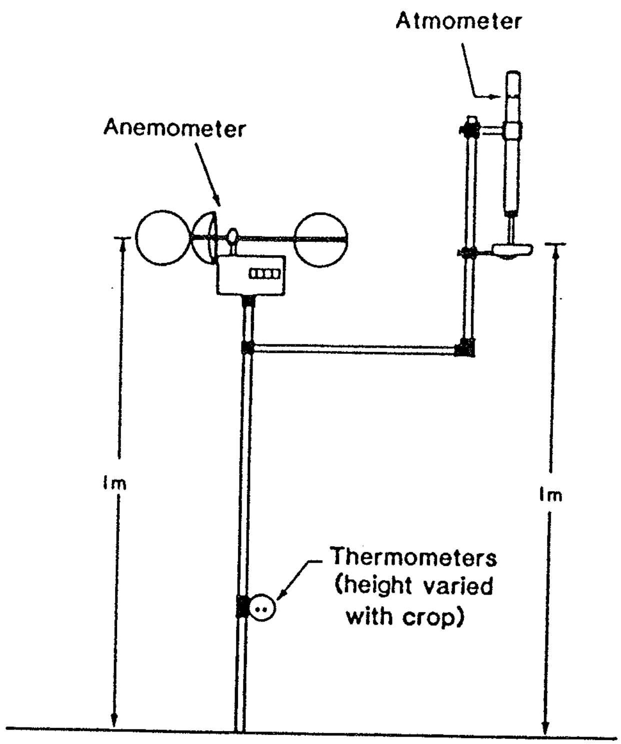

Figure 2: Arrangement of equipment at each sensor location across field (except 20 H where the anemometer was erected separately from the atmometer).

3.1.2 Latent Evaporation

Black Bellani Plate atmometers, which were cleaned weekly, were used to determine latent evaporation. The evaporating surface was set at one meter above the ground as shown in Figure 2. The volume of water evaporated was recorded daily at which time the reservoirs were refilled.

Due to a shortage of equipment, atmometers were placed at 3 H and 1 H on the west side of the belt and at 1 H, 5 H and 10 H on the east side of the belt in 1982. In 1983 the atmometers were placed at the same sensor locations as in 1982 for the first two week period then placed at 1 H, 5 H, 10 H, 17 H and 20 H east of the belt for the next two week period. In both years the atmometers were rotated weekly between the two replicates. The atmometers were calibrated against each other both years and the values corrected. Latent evaporation is expressed as percentage of that found at 10 H leeward of the belt.

3.1.3 Air Temperature

Minimum and maximum air temperatures were recorded daily at each sensor location. The measurements were made with thermometers which were shielded from direct solar radiation (Figure 3). The thermometers were set at the top of the crop canopy, as shown in Figure 2, and were moved up as the crop grew. Thermometers were positioned at all sensor locations in both replicates. The thermometers were calibrated each year and the values corrected. The temperatures were recorded in degrees Fahrenheit and converted to Celsius.

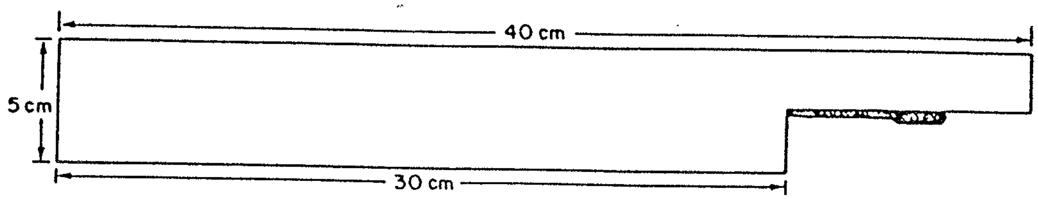

Figure 3: Shield for thermometers. Plastic central vacuum tube covered with reflective duct tape.

3.2 SOIL MOISTURE

Volumetric soil moisture content to a depth of 135 cm was measured weekly to determine the difference in plant water use across a sheltered field.

Soil cores of a known volume (17.36 cc) were used to determine the volumetric soil moisture in the top 20 cm. Samples were taken at two points at each sensor location at depths of 5 and 15 cm. The wet weight of each sample was recorded then the samples were dried in a convection oven at 110 C for 48 hours and the oven-dry weight was recorded. The moisture content (W), bulk density (Bd) and volumetric water content were then calculated using the following formulas.

$$W = \{(\text{Wet wt} - \text{Dry wt})/\text{Dry wt}\} \times 100$$

$$Bd = \text{Dry wt}/\text{Soil volume}$$

$$\text{Volumetric water content} = W \times Bd$$

Volumetric soil moisture from 20 to 135 cm was determined with a neutron moisture meter. At each sensor location two aluminum access tubes (51 mm O.D.) were placed to a depth of 150 cm. Rubber stoppers were placed in both ends to prevent water from entering the tubes. Measurements were made at 30, 60, 90 and 120 cm. Volumetric moisture content was calculated through the use of a linear regression equation determined by on site calibration of the neutron probe.

3.3 CROP GROWTH

3.3.1 Emergence

Plant counts were taken to determine differences in emergence patterns of the wheat across the sheltered field. In 1982 counts were made on four one meter rows at each sensor location. In 1983 counts were made on five one meter rows per sensor location. Plant counts were started one week after seeding and were taken every second or third day for the next three weeks.

3.3.2 Dry Matter Production

Dry matter samples were taken during the growing season to determine differences in plant growth across a sheltered field. The top growth of plants was cut off at ground level and dried in a convection oven at 80 C to a constant dry weight and the weight was recorded. In 1982 four 0.25 m^2 samples were taken at each sensor location at the boot stage and at anthesis and four 1 m^2 samples were taken at maturity. The 1 m^2 samples were air dried to approximately 8% moisture then computed to an oven dry weight. In 1983 four 0.25 m^2 samples were taken at anthesis and maturity.

3.3.3 Grain Yield

The grain yield was determined by taking four 1 m^2 samples at each sensor location. The plants were cut at ground level and placed in bags. The samples were air dried then threshed in a stationary threshing machine. In 1982 the grain did not thresh completely so it was also put through a set of corrugated rollers and hand sieved before weighing.

Grain was harvested on August 23 in both years. The yields were determined in kg/ha.

3.4 STATISTICAL METHODS

Analysis of the data was carried out under the Statistical Analysis System (SAS) package using the University of Manitoba Amdahl computer. The microclimatic data were not replicated, therefore, regression analysis was used to determine if the shelter effect changed significantly as distance from the shelterbelt increased. The wind velocity data were transformed, using a square root function, prior to regression analysis. Analyses of variance were used with the remaining data to determine the distance effect and replicate effect. A square root + 0.5 transformation was applied to the emergence data prior to analysis. When variation due to treatment was significant Duncan's Multiple Range Test was used to identify the means which differed significantly ($P<0.05$).

Chapter IV

RESULTS AND DISCUSSION

4.1 CLIMATE DURING THE 1982 AND 1983 GROWING SEASONS

The weather patterns experienced in the two years of the study were distinct. Air temperature, Class "A" pan evaporation, mean wind speed, prevailing wind direction and precipitation for the 1982 and 1983 growing seasons are shown in Tables 1, 2, 3, and 4 and Figure 4.

The mean temperature for July 1982 was higher than normal while the mean temperatures for May and August were lower than normal. The mean temperature for June was near normal. The 1983 readings show the mean temperature to be higher than normal for August, near normal for June and July, and below normal for May. A comparison of the temperatures for both growing seasons indicates the months of May to July were similar while August 1983 was hotter than August 1982.

The Class "A" pan evaporation measurements suggest that the evaporative demand of the atmosphere was greater in 1983. This is related to the higher temperatures observed during the 1983 growing season.

The wind data presented indicate the great variation in wind speeds and directions which occurred during the growing season in both years of the study.

The precipitation records show that more rainfall was received during the 1983 growing season. The distribution of precipitation within the two growing seasons was dissimilar. In 1982 precipitation occurred in small amounts throughout the summer, whereas, in 1983 most of the precipitation was received in July, a critical period for the crop.

Table 1: Maximum, minimum and mean air temperature and Class 'A' pan evaporation during the 1982 growing season.[1]

Date	May Temperature °C Max.	Min.	Mean	May Evap mm	June Temperature °C Max.	Min.	Mean	June Evap mm	July Temperature °C Max.	Min.	Mean	July Evap mm	August Temperature °C Max.	Min.	Mean	August Evap mm
1	25.5	1.0	13.3	9.0	20.0	8.5	14.3	6.6	27.0	14.5	20.8	7.2	30.5	14.0	22.3	10.8
2	24.5	6.0	15.3	10.4	20.5	6.5	13.5	7.8	25.5	17.0	21.3	7.6	21.0	16.5	18.8	5.2
3	22.5	10.0	16.3	12.4	23.0	9.0	16.0	10.4	25.5	15.0	20.3	9.0	22.5	11.0	16.8	4.6
4	10.5	3.0	6.8	5.0	25.5	8.5	17.0	7.8	24.5	13.0	18.8	12.4	26.0	9.0	17.5	7.2
5	5.5	-1.5	2.0	1.7	22.5	12.0	17.3	8.9	21.5	10.5	16.0	6.8	28.0	11.0	19.5	6.8
6	3.5	-5.5	-1.0	1.7	11.5	7.0	9.3	3.6	21.5	12.5	17.0	7.0	30.5	14.0	22.3	11.5
7	7.0	-3.5	1.8	1.7	14.5	5.0	9.8	4.4	23.0	7.5	15.3	8.8	23.0	12.0	17.5	8.0
8	6.5	-1.0	2.8	1.6	20.0	4.0	12.0	8.2	18.0	11.0	14.5	4.0	23.0	8.5	15.8	7.4
9	10.0	-2.0	4.0	1.6	19.0	7.5	13.3	6.2	24.0	8.0	16.0	4.4	23.5	9.0	16.3	9.2
10	14.0	2.0	8.0	1.6	22.0	6.5	14.3	7.6	27.0	13.0	20.0	7.4	25.0	10.0	17.5	10.0
11	18.0	-2.0	8.0	7.8	22.0	5.5	13.8	7.0	29.5	13.0	21.3	11.8	32.0	16.0	24.0	8.2
12	17.0	2.0	9.5	4.2	25.5	8.5	17.0	6.4	27.0	15.0	21.0	5.2	21.5	14.5	18.0	4.8
13	21.5	2.5	12.0	5.8	28.0	13.0	20.5	10.4	28.5	13.5	21.0	7.0	27.5	9.5	18.5	6.7
14	23.5	4.0	13.8	10.2	26.5	12.0	19.3	6.0	22.0	15.5	18.8	8.4	27.0	10.5	18.8	8.6
15	21.0	9.0	15.0	9.5	27.0	14.0	20.5	8.4	21.5	11.0	16.3	4.4	22.5	8.0	15.3	7.0
16	10.0	6.5	8.3	0.6	22.0	12.0	17.0	5.8	18.0	11.0	14.5	3.0	28.0	14.0	21.0	6.4
17	13.5	8.0	10.8	1.8	18.0	9.0	13.5	4.8	22.0	10.0	16.0	6.4	32.0	14.5	23.3	7.6
18	16.0	7.0	11.5	2.4	25.0	7.5	16.3	7.6	25.5	10.5	18.0	7.2	27.0	13.5	20.3	8.0
19	16.0	7.5	11.8	2.8	24.5	11.0	17.8	9.4	28.0	13.0	20.5	9.0	27.5	10.5	19.0	8.2
20	14.0	9.5	11.8	1.2	25.0	7.0	16.0	6.6	19.5	13.0	16.3	5.2	27.5	9.5	18.5	7.2
21	18.5	10.5	14.5	1.8	30.5	12.0	21.3	11.6	25.5	9.0	17.3	8.2	26.0	14.5	20.3	9.0
22	23.0	7.0	15.0	0.0	31.0	14.5	22.8	11.0	25.0	17.0	21.0	8.4	18.5	12.0	15.3	2.8
23	13.0	9.0	11.0	5.0	20.0	13.0	16.5	6.6	25.0	10.0	17.5	8.0	22.5	8.0	15.3	5.2
24	23.5	8.5	16.0	7.4	21.0	6.5	13.8	7.4	25.0	11.5	18.3	7.2	23.0	7.0	15.0	5.2
25	27.5	7.5	17.5	12.4	17.5	11.5	14.5	2.1	26.5	12.0	19.3	7.8	13.5	6.5	10.0	2.2
26	17.5	8.0	12.8	5.2	25.0	9.0	17.0	6.0	20.5	14.0	17.3	4.2	14.0	6.5	10.3	4.6
27	9.0	6.5	7.8	0.0	18.5	13.0	15.8	4.4	26.0	11.0	18.5	5.2	12.5	2.0	7.3	5.0
28	4.0	0.0	2.0	3.6	20.5	11.5	16.0	5.4	24.0	14.0	19.0	7.2	19.5	6.5	13.0	5.8
29	1.5	-0.5	0.5	3.6	21.0	10.0	15.5	7.2	28.0	10.0	19.0	9.0	18.0	4.5	11.3	3.8
30	11.5	0.0	5.8	3.6	25.5	12.0	18.8	10.2	31.5	15.0	23.3	12.0	22.5	9.0	15.8	4.0
31	22.0	4.5	13.3	3.6					29.5	16.5	23.0	7.4	21.0	5.5	13.3	3.2
	15.2	4.0	9.6	139.2	22.4	9.6	16.0	215.8	24.7	12.5	18.6	226.8	23.8	10.2	17.0	204.2

[1]From PFRA, Outlook, Saskatchewan

Table 2: Maximum, minimum and mean air temperature and Class 'A' pan evaporation during the 1983 growing season.[1]

Date	May Temperature °C Max.	May Temperature °C Min.	May Temperature °C Mean	May Evap mm	June Temperature °C Max.	June Temperature °C Min.	June Temperature °C Mean	June Evap mm	July Temperature °C Max.	July Temperature °C Min.	July Temperature °C Mean	July Evap mm	August Temperature °C Max.	August Temperature °C Min.	August Temperature °C Mean	August Evap mm
1	11.0	2.0	6.5		21.5	10.5	16.0	6.2	25.0	10.5	17.8	10.4	24.5	15.0	19.8	4.2
2	15.5	-0.5	7.5		18.0	6.0	12.0	8.2	18.0	15.5	16.8	4.6	34.0	14.5	24.3	6.0
3	10.5	-2.5	4.0		12.0	4.0	8.0	3.0	18.0	13.5	15.8	3.6	35.5	16.5	26.0	13.0
4	19.0	1.0	10.0		15.5	0.0	7.8	4.8	17.5	11.0	14.3	3.0	32.0	19.5	25.8	10.0
5	18.5	1.0	9.8		20.5	1.5	11.0	7.4	28.5	9.5	19.0	7.0	32.5	16.0	24.3	5.8
6	18.0	1.0	9.5		25.0	3.0	14.0	9.8	31.5	16.0	23.8	11.0	37.0	19.0	28.0	5.8
7	21.0	5.5	13.3		22.0	10.5	16.3	7.0	29.5	17.5	23.5	12.2	28.0	15.0	21.5	9.2
8	20.0	8.0	14.0		25.5	6.0	15.8	10.0	29.0	18.0	23.5	12.0	21.5	10.0	15.8	4.8
9	14.0	5.0	9.5		31.0	12.5	21.8	10.0	25.5	18.0	21.8	6.6	30.5	16.0	23.3	6.4
10	-2.0	-3.0	-2.5		29.5	13.0	21.3	13.8	17.0	12.0	14.5	4.0	30.0	13.5	21.8	10.4
11	2.0	-8.0	-3.0		21.0	13.0	17.0	4.0	25.0	12.0	18.5	8.0	35.5	14.0	24.8	12.8
12	4.5	-5.0	-0.3		19.0	12.5	15.8	5.6	29.5	15.0	22.3	10.2	23.5	17.5	20.5	6.2
13	13.0	-2.0	5.5		22.0	7.0	14.5	8.0	26.0	14.0	20.0	5.4	29.0	11.0	20.0	8.8
14	8.0	1.5	4.8		21.5	11.0	16.3	6.8	27.5	18.5	23.0	9.8	31.5	15.5	23.5	13.0
15	8.5	-2.5	3.0		22.5	7.0	14.8	9.0	22.0	10.5	16.3	0.0	26.0	11.5	18.8	10.0
16	18.0	0.5	9.3	7.0	26.5	7.0	16.8	11.0	20.5	9.5	15.0	0.8	28.5	13.5	21.0	6.4
17	19.5	4.5	12.0	9.1	28.5	11.0	19.8	13.0	23.0	9.5	16.3	9.6	27.0	14.5	20.8	7.8
18	18.5	8.5	13.5	6.8	22.5	14.0	18.3	10.8	26.0	9.5	17.8	2.6	23.5	12.5	18.0	8.2
19	17.5	1.5	9.5	6.4	23.5	12.0	17.8	10.4	29.0	14.5	21.8	11.8	20.0	6.0	13.0	5.8
20	18.5	6.0	12.3	7.4	21.5	9.5	15.5	8.8	26.0	16.0	21.0	7.6	25.5	12.5	19.0	7.0
21	13.0	5.5	9.3	3.0	22.5	9.0	15.8	7.4	25.0	14.0	19.5	8.2	24.0	10.0	17.0	7.2
22	17.5	6.0	11.8	1.8	23.0	12.0	17.5	10.6	26.0	13.0	19.5	6.8	24.5	7.5	16.0	7.0
23	12.5	7.0	9.8	4.7	29.5	9.0	19.3	11.2	25.5	11.0	18.3	7.6	23.5	9.0	16.3	5.0
24	16.5	3.0	9.8	4.7	31.0	18.0	24.5	11.2	26.5	13.5	20.0	8.2	29.0	11.0	20.0	6.4
25	28.0	7.0	17.5	8.4	21.0	14.0	17.5	13.4	29.5	17.5	23.5	5.8	26.5	12.5	19.5	5.2
26	27.0	13.0	20.0	10.2	15.0	11.0	13.0	3.8	26.0	17.5	21.8	11.6	30.0	11.5	20.8	8.6
27	22.5	12.0	17.3	9.5	24.0	7.0	15.5	8.6	25.0	10.5	17.8	9.2	29.0	11.0	20.0	8.4
28	21.0	6.0	13.5	9.8	28.0	13.0	20.5	8.8	24.5	11.0	17.8	8.0	30.5	11.0	20.8	9.0
29	22.0	4.0	13.0	6.4	27.0	14.0	20.5	9.0	23.0	12.0	17.5	1.4	30.0	10.5	20.3	8.4
30	15.0	3.0	9.0	7.6	24.0	14.0	19.0	3.6	26.0	14.0	20.0	8.6	34.5	9.5	22.0	9.6
31	19.5	3.0	11.3	6.0					28.0	10.5	19.3	0.0	36.0	13.0	24.5	12.0
	15.7	3.0	9.4	108.8	23.1	9.7	16.4	255.2	25.1	13.4	19.3	215.6	28.8	12.9	20.9	248.4

[1]From PFRA, Outlook, Saskatchewan

Table 3: Mean wind speed and prevailing direction during the 1982 growing season.[1]

Date	May		June		July		August	
	Mean spd	Prev dir	Mean spd	Prev dir	Mean spd	Prev dir	Mean spd	Prev dir
1	15.5	SE	7.8	NE	19.9	SE	10.0	SW
2	12.8	SW	11.8	SE	12.8	S	15.8	SW
3	20.8	SW	16.1	SW	25.3	SW	11.0	SW
4	27.4	NW	9.8	S	26.0	SW	8.2	SVL
5	30.4	SVL*	13.0	SW	20.9	SW	7.0	NE
6	27.7	NW	22.5	NW	21.1	NW	16.3	SE
7	10.8	NE	10.4	NW	5.6	NE	16.9	NW
8	12.9	E	11.0	SW	5.9	S	8.0	NE
9	11.0	NE	13.3	NW	7.7	SW	13.5	SE
10	8.0	N	15.8	NE	9.3	NW	24.2	SE
11	15.3	S	10.7	SE	7.5	NW	17.7	SE
12	15.7	SE	8.9	SE	7.8	NE	14.6	NW
13	8.6	NW	8.6	NE	10.6	SE	12.7	SW
14	11.9	NE	7.7	SVL	16.2	SE	16.9	SW
15	20.3	E	7.7	S	10.4	SW	11.6	SE
16	9.6	NE	11.0	N	14.3	W	12.6	SE
17	6.5	NE	5.5	E	12.4	NW	12.8	SE
18	11.2	E	12.6	W	13.7	SE	10.8	E
19	12.7	SE	12.4	NW	14.3	NW	8.5	NE
20	14.8	SE	4.5	NW	9.8	NW	10.9	NE
21	14.8	SE	12.9	SE	14.5	SE	11.0	NE
22	19.6	SE	8.8	SE	20.5	SE	10.8	NW
23	21.9	W	18.3	NW	8.6	SVL	12.1	SVL
24	14.2	NW	5.8	NE	12.9	NW	13.1	SW
25	20.7	SVL	13.6	E	5.4	S	7.9	SW
26	17.4	NW	6.4	NW	7.2	SVL	12.4	NW
27	18.9	N	10.9	E	7.3	SW	16.2	SE
28	25.4	NE	12.9	SE	14.0	NW	17.5	SE
29	28.5	NE	14.8	SE	8.0	S	6.9	NW
30	14.3	N	22.6	SE	12.6	NW	16.3	SE
31	15.2	SW			10.4	NE	11.0	NW
	16.6	SVL	11.6	NW	12.7	SW	12.8	SE

[1]From PFRA, Outlook, Saskatchewan

*SVL - Several

Table 4: Mean wind speed and prevailing direction during the 1983 growing season.[1]

	May		June		July		August	
Date	Mean spd	Prev dir	Mean spd	Prev dir	Mean spd	Prev dir	Mean spd	Prev dir
1	15.5	NW	14.6	NW	11.9	SE	11.5	SE
2	9.6	W	16.7	NW	11.8	E	7.6	S
3	15.7	NW	15.8	NW	14.3	NW	14.1	SW
4	11.7	NW	5.5	E	9.0	E	13.9	SVL
5	15.1	E	7.8	NW	9.7	SE	12.5	SE
6	14.4	SE	7.3	SW	13.2	SE	18.3	SW
7	28.0	SE	15.5	NW	10.0	NE	12.6	NW
8	16.8	SW	8.2	SE	28.5	E	8.8	SE
9	27.6	N	15.7	SW	13.7	N	10.3	NW
10	26.0	N	17.4	SW	17.3	NW	7.9	S
11	10.0	NE	13.6	NW	14.2	W	20.8	SE
12	17.6	NE	12.0	NW	16.5	SW	18.8	NW
13	7.8	NW	19.0	NW	10.5	SE	10.8	SW
14	15.4	N	18.4	NW	16.1	W	22.0	SVL
15	14.6	SE	11.7	SE	12.3	SW	10.3	SE
16	14.1	S	18.2	SE	18.6	SW	9.3	N
17	11.3	SW	24.6	SE	15.0	SW	9.3	NE
18	13.9	N	30.5	SE	7.5	E	17.8	NE
19	11.8	SE	25.1	SW	10.0	E	11.7	NW
20	13.1	SW	19.8	SW	16.7	SE	13.9	SE
21	17.9	NW	14.0	SW	20.6	SW	6.5	NW
22	11.4	SW	11.5	NW	16.3	NW	11.5	SE
23	11.3	NE	14.9	SE	6.4	SE	9.3	SE
24	8.0	NW	22.3	SE	15.4	SE	10.1	SE
25	22.3	SE	33.5	SW	12.8	S	8.1	SW
26	13.2	NE	12.3	NE	23.3	SW	7.9	SW
27	15.4	N	13.9	E	10.5	SW	12.2	SW
28	11.0	NE	14.7	SE	11.8	NW	13.5	SE
29	12.4	S	9.3	SE	7.5	E	11.0	NW
30	9.0	NE	8.2	SE	13.1	NW	11.6	SE
31	10.2	SVL *			6.8	W	13.2	NW
	14.6	NW	15.8	SE	13.5	SW	12.2	SE

[1]From PFRA, Outlook, Saskatchewan

*SVL - Several

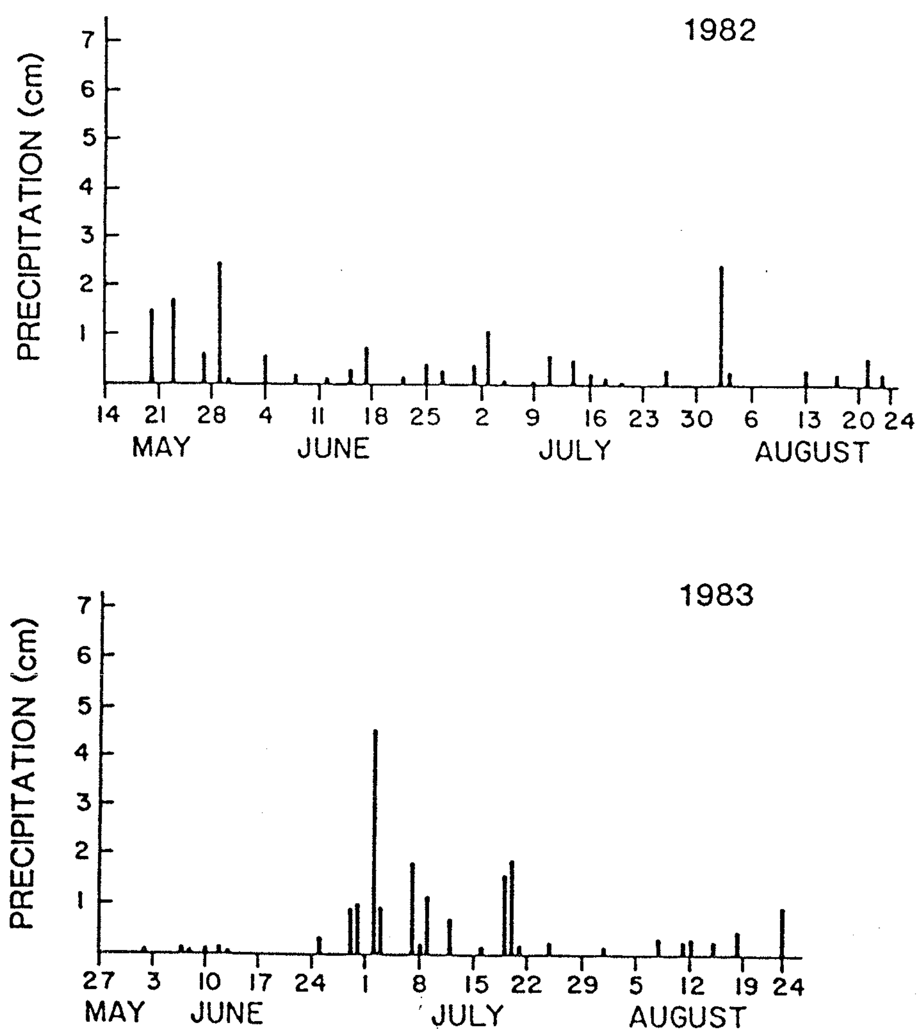

Figure 4: Precipitation received during the 1982 and 1983 growing seasons.

4.2 MICROCLIMATE

4.2.1 Wind Velocity

Daily wind run measurements 1m above the soil surface were recorded throughout the growing season in both years of the study to determine the shelterbelt effect. The wind data for each sensor location were converted to a percentage of that observed 20H leeward of the shelterbelt with a west or an east wind. The value for 20H leeward for an east wind was interpolated from the data.

Shelterbelt effects on both windward and leeward sides were observed in 1982 (Figure 5). East winds at locations 1E to 20E and west winds at locations 1W to 3W illustrate the windward effect. As the wind approached the shelterbelt there was no significant change in velocity until a reduction at 3H windward. The greatest windward velocity reduction occurred adjacent to the shelterbelt at 1H where it was 67% of that observed 20H leeward. The results for west winds at locations 1E to 20E and east winds at locations 1W to 3W illustrate the leeward shelter effect. The greatest reduction in wind velocity occurred 1H leeward where it was 13% of 20H leeward. There was a steady increase in wind velocity as the distance leeward of the shelterbelt increased to 20H. The velocities at 5 and 10H were 39% and 80% of 20H, respectively.

In 1983, the effects were similar although the degree of wind velocity reduction adjacent to the shelterbelt was not as great (Figure 6). On the windward side of the shelterbelt the velocity reduction became noticeable at approximately 2H. The greatest windward velocity reduction was again at 1H where it was 84% of 20H leeward. The greatest red-

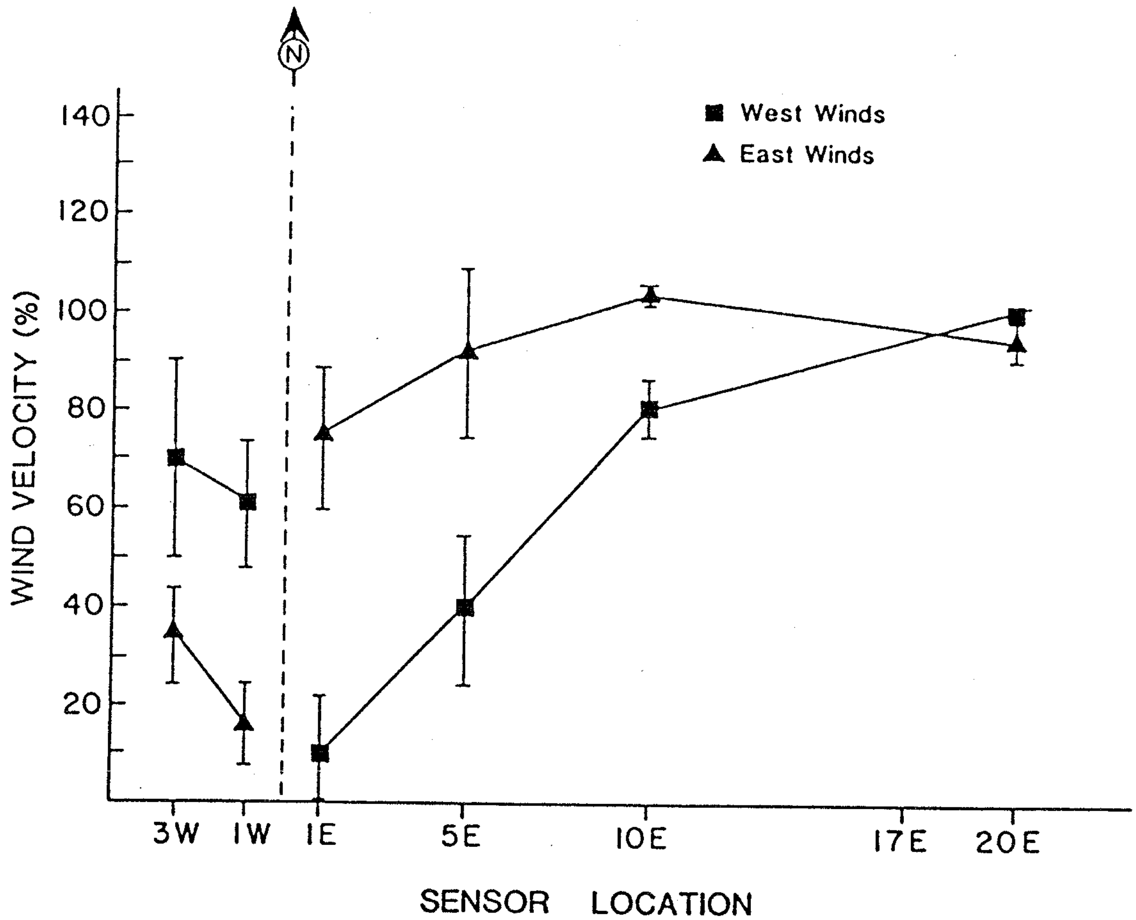

Figure 5: Wind velocity relative to 20H leeward for east and west winds during the period of June 11 to August 8, 1982.

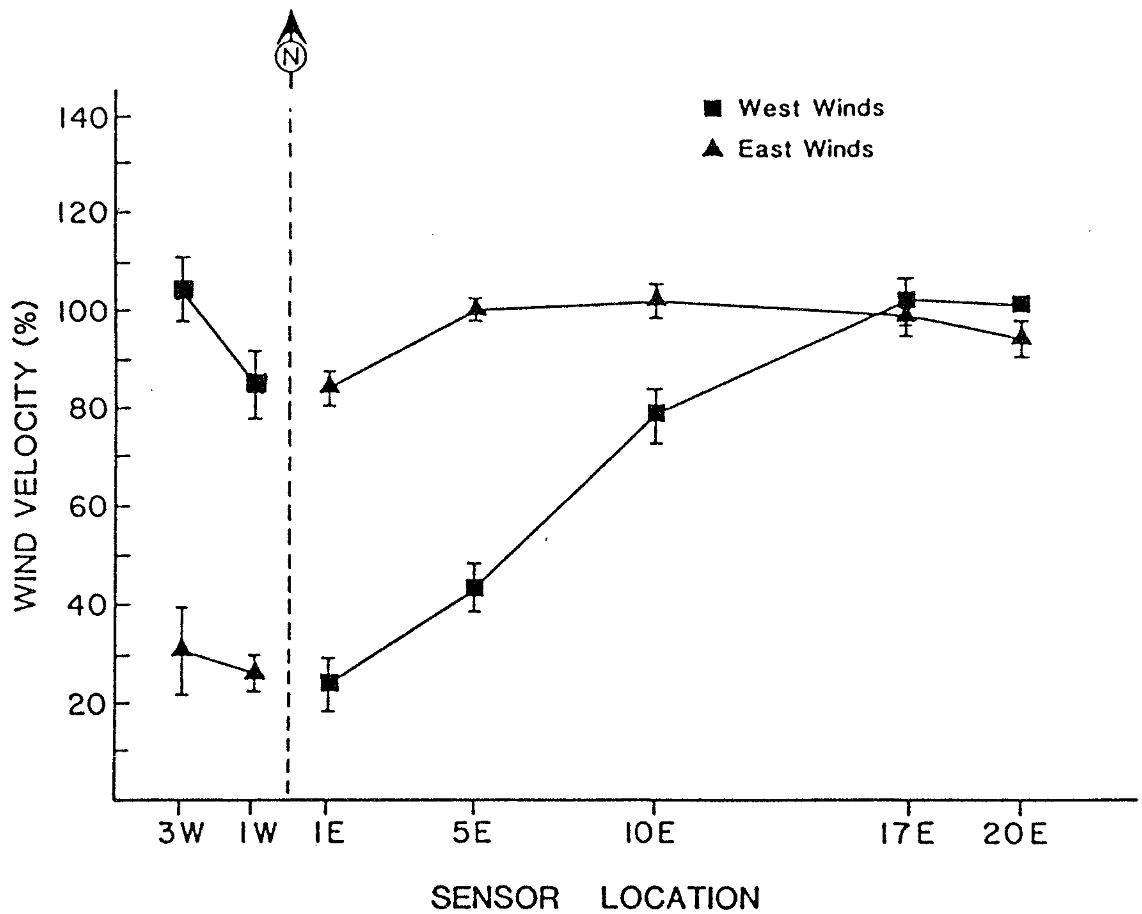

Figure 6: Wind velocity relative to 20H leeward for east and west winds during the period of June 6 to August 24, 1983.

uction in wind occurred 1H leeward where the velocity was 25% of 20H leeward. There was a steady increase in wind velocity with distance leeward to 17H. The wind velocities at 5 and 10H were 43% and 78% of 20H leeward, respectively.

The results are due to the shelterbelt displacing the approaching flow of air. As the air flow is pushed upward over the shelterbelt a zone of retarded flow occurs beneath it on the windward side. The shear stress between these two leads to turbulence. On the leeward side of the shelterbelt there is a zone of highly retarded flow. The shear stress between this zone and the displacement flow is very high, which causes turbulence and a quick recovery of the wind velocity near the ground. At 1 and 5H leeward the flow is displaced high enough above the sheltered area that turbulence does not affect the velocity reduction near the ground as it does at 1H windward.

Linear regression analysis was also applied to the results. Values were calculated for the windward and leeward relationships between wind velocity and distance from the shelterbelt out to 20H. A square root transformation was used with the data from Figures 5 and 6. Details of the analysis are in Table 5. The r^2 values indicate that in 1982 the leeward relationship was significant at the P=0.05 level and in 1983 it was significant at the P=0.01 level. The windward relationship was insignificant in both years. The values can be used to determine approximate wind velocities relative to 20H leeward for distances not directly measured in this study.

The patterns of wind velocity reduction follow the trends expected for a dense shelterbelt such as caragana. The results agree with Read's

TABLE 5

Linear regression values for wind velocity at all sites of measurement relative to 20H leeward(%). A square root transformation was applied to the wind velocity data before regression.

	Direction	Intercept	Slope	R^2	C.V.
1982	Leeward	4.2813	0.3252	0.8333*	18.7116
	Windward	8.5748	0.00795	0.4708	8.0398
1983	Leeward	4.9573	0.2846	0.9320**	8.7625
	Windward	9.7848	0.0061	0.0160	4.2197

* Significant at the P=0.05 level
** Significant at the P=0.01 level

(1964) statement that very dense shelterbelts reduce wind velocity most in the 0 to 10H zone and Skidmore and Hagen's (1970) observation that the greatest reduction occurs adjacent to the shelterbelt. The extent of the sheltered zone, in both years, was similar to commonly accepted values. Peterson (1971) said an efficient shelterbelt reduced wind velocity significantly within a zone 2H windward and 20H leeward.

There was a difference in the degree of wind velocity reduction for 1982 and 1983. In 1982 the velocity was reduced a greater amount within the 1H to 5H zone. This difference was probably due to damage to the caragana foliage by the fruittree leafroller (<u>Archips</u> <u>argyrospilus</u>). This insect was a problem in both years but caused greater damage in 1983 and, therefore, less wind reduction adjacent to the shelterbelt.

Greater variation in the 1982 results was observed due to a limited number of days of data which could be used in the calculations. Equipment malfunctions and the observed wind direction frequencies (Table 6)

TABLE 6

Wind direction frequencies during the growing season 1982-83 (%).

		N	NE	E	SE	S	SW	W	NW
June	1982	8.8	18.1	12.9	25.7	8.2	6.2	8.7	11.3
	1983	4.8	7.0	3.8	34.9	3.8	21.9	2.1	21.5
July	1982	13.2	7.0	12.0	17.0	5.8	10.4	9.6	25.1
	1983	17.6	4.4	4.6	19.2	5.4	34.6	7.1	7.1
August	1982	21.7	7.2	14.3	3.8	0.8	16.2	14.3	21.7
	1983	14.9	7.8	8.3	32.8	3.7	19.3	6.1	7.2
Average for Season	1982	12.7	11.0	12.6	18.4	6.0	9.6	9.8	19.7
	1983	11.7	6.7	5.6	30.2	4.2	24.2	4.8	12.7

were the limiting factors. The 1982 growing season showed a greater frequency of wind from the north and south.

4.2.2 Latent Evaporation

Black Bellani Plate atmometers were positioned across a sheltered field to determine the effect of a shelterbelt on the evaporating potential of the atmosphere. The latent evaporation recorded 1m above the soil surface at each sensor location was converted to a percentage of the value 10H leeward to accomodate variability in the data. The mean seasonal value for each sensor location was calculated for east and west winds, for both 1982 and 1983.

The values recorded for east winds at locations 1E, 5E, and 10E and west winds at 1W and 3W illustrate the windward effect. The leeward effect is shown by the values recorded for west winds at locations 1E, 5E and 10E and for east winds at 1W and 3W.

In 1982 an increase in latent evaporation was observed 5H windward of the shelterbelt while a slight reduction occurred at 1H (Figure 7). Values of 110% and 89%, of 10H leeward, were determined for 5 and 1H windward, respectively. On the leeward side latent evaporation was reduced at 1H to 61%, at 3H to 72% and at 5H to 89% of that observed 10H leeward.

The results for 1983 were similar to the previous year (Figure 8). There was an increase in latent evaporation windward which occurred at 10H and continued to 3H and a slight, though insignificant, reduction at 1H. The values observed were 108, 113, 116 and 94%, of 10H leeward, for 10, 5, 3 and 1H windward, respectively. On the leeward side latent evaporation was reduced at 1H to 60%, at 3H to 73% and at 5H to 78% of 10H. Data were recorded for locations 17E and 20E but the limited amount which was usable led to extreme variation, therefore, it is not shown. The minimal data obtained did not indicate a change in latent evaporation past 10H.

Regression analysis was applied to the data to determine if there was a significant relationship between latent evaporation and distance from the shelterbelt. Components of the regression equations are shown in Table 7. The r^2 values indicate a significant linear relationship on the leeward side of the shelterbelt. In 1982 the relationship was significant at the P=0.10 level while in 1983 it was significant at the P=0.05 level. The windward relationship was not significant in either year.

The results agree with the observations of Pelton (1967) in that latent evaporation was reduced in a pattern similar to wind velocity but

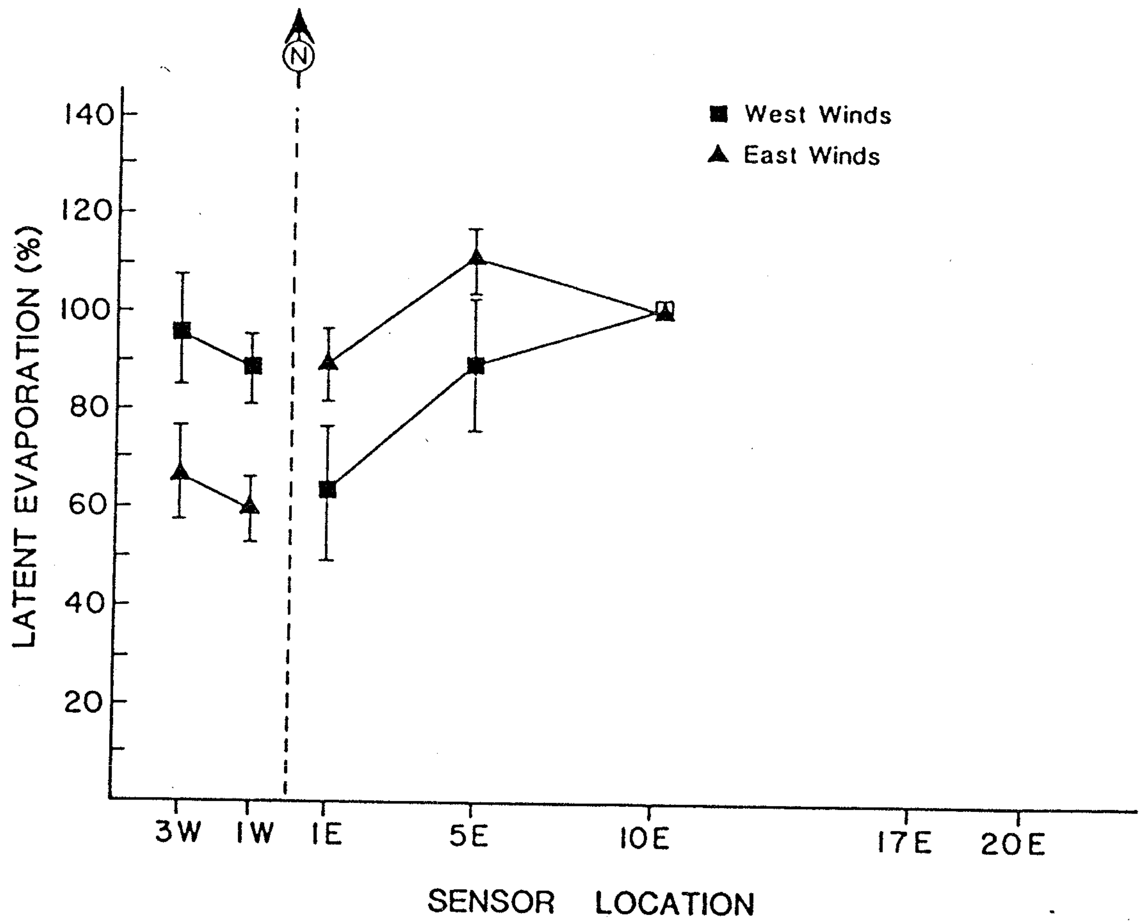

Figure 7: Latent evaporation relative to 10H leeward for east and west winds during the period of June 11 to August 8, 1982.

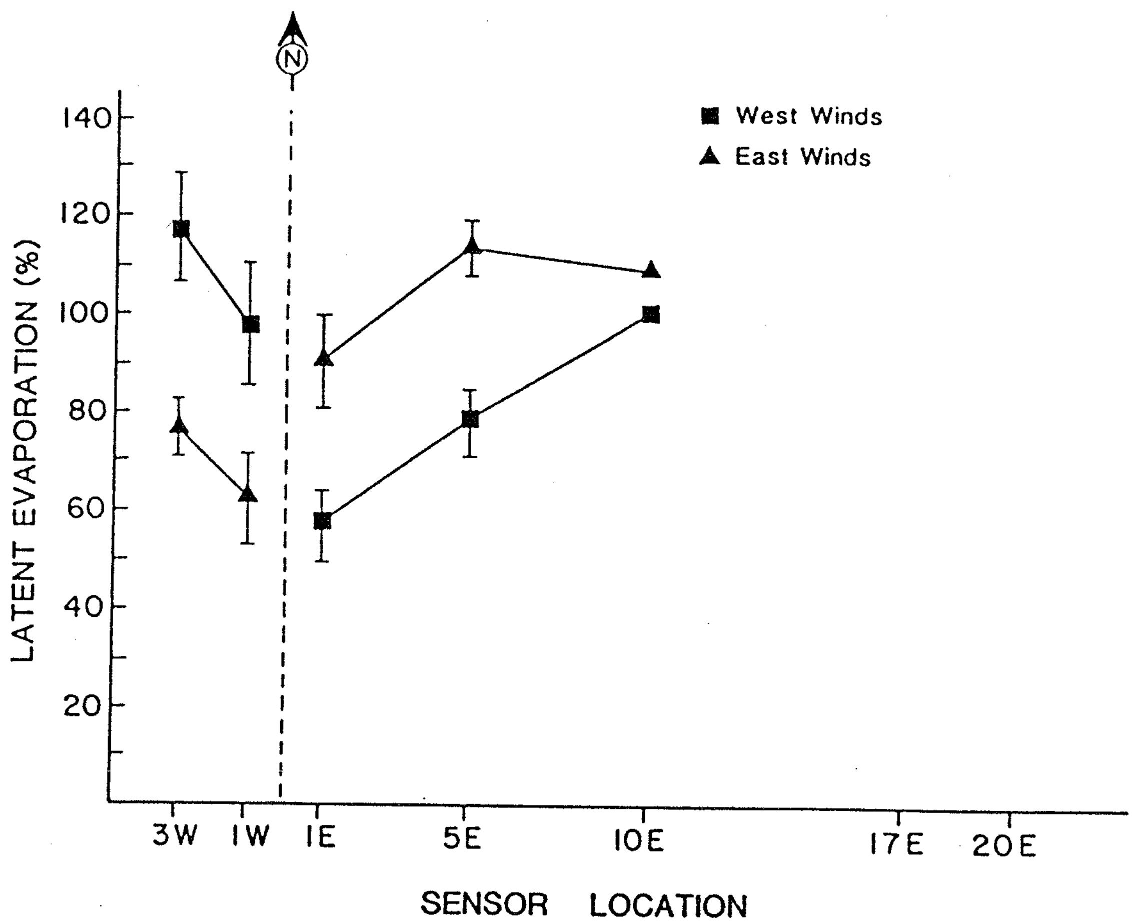

Figure 8: Latent evaporation relative to 10H leeward for east and west winds during the period of June 6 to August 24, 1983.

TABLE 7

Linear regression values for latent evaporation at all sites of measurement relative to 10H leeward(%).

	Direction	Intercept	Slope	R^2	C.V.
1982	Leeward	56.0609	4.7040	0.8786*	10.5472
	Windward	92.7208	1.1835	0.2795	9.1404
1983	Leeward	57.1561	4.2830	0.9240**	7.4959
	Windward	104.3803	0.9471	0.1170	11.3055

* Significant at the P=0.10 level
** Significant at the P=0.05 level

to a lesser degree. The greatest reduction in latent evaporation occurred at the site of maximum wind velocity reduction. Skidmore and Hagen (1970) found evaporation and wind reduction curves to be nearly parallel which is evident here. They also stated that minimum evaporation for 40 and 0% permeable barriers occurred at 3.5H and immediately adjacent to the barrier, respectively. At 4H evaporation had recovered to 65 and 92% of the open for the 40 and 0% permeable barriers, respectively. Based on their observations the permeability of the caragana shelterbelts in this study may have been between 40 and 0%. The results found in this study are in line with those of Skidmore and Hagen.

An increase in latent evaporation from 1982 to 1983 was observed during the study. The 1983 growing season was hotter and there were fewer small rain showers, therefore, the atmosphere had a greater evaporating potential. The increase in latent evaporation windward of the shelterbelt was due to increased air turbulence mentioned previously, produced by the upward displacement of the approaching air flow. Turbulent transfer increases evaporation rates in this area.

Extensive variability was observed in the data. This is expected for measurements of this type as they are dependent on many climatic factors such as wind velocity, turbulence, air temperature and relative humidity.

4.2.3 Air Temperature

Maximum and minimum air temperatures at the top of the crop canopy were recorded daily for each sensor location in both years of the study. The mean seasonal temperatures were calculated to determine the shelter effect (Table 8). The mean seasonal maximum air temperatures were greater in 1983. This was a general weather trend and can not be attributed to the shelterbelt. The mean seasonal minimum air temperatures did not differ significantly over the two years.

In 1982 there was no significant change in air temperature with distance from the shelterbelt. The minimum air temperatures tended to be lower adjacent to the shelterbelt and increased with distance. Maximum air temperatures were greatest leeward immediately adjacent to the shelterbelt and were lowest immediately adjacent windward. When the air temperatures were compared to that observed at 20H leeward no trends were visible.

The 1983 values did not differ significantly across the sheltered field. The greatest maximum temperatures occurred leeward of the shelterbelt and the increase extended further out from the belt than in 1982. The minimum air temperatures responded similarly as the lowest temperatures occurred leeward of the belt and the effect extended further. This supports the claim that the shelterbelt density varied from

TABLE 8

Mean seasonal air temperatures (C).

1982 Sensor Location	West Winds Maximum	West Winds Minimum	East Winds Maximum	East Winds Minimum
3W	27.7 (30.4)	10.4 (5.3)	28.7 (39.0)	10.7 (3.6)
1W	27.7 (30.9)	8.7 (5.0)	30.0 (37.7)	8.5 (4.2)
1E	30.1 (32.0)	8.2 (5.5)	26.6 (38.3)	10.3 (6.0)
5E	29.4 (31.9)	8.8 (4.6)	27.2 (36.0)	10.0 (4.3)
10E	29.7 (31.8)	9.6 (4.6)	27.9 (36.4)	10.9 (4.8)
20E	28.5 (31.2)	9.2 (3.9)	27.1 (35.3)	10.0 (4.4)

1983 Sensor Location	West Winds Maximum	West Winds Minimum	East Winds Maximum	East Winds Minimum
3W	31.2 (39.4)	9.7 (2.2)	34.8 (40.0)	9.6 (2.8)
1W	30.8 (38.3)	9.8 (2.9)	34.2 (40.6)	9.9 (3.8)
1E	33.1 (42.5)	9.5 (3.2)	31.2 (39.3)	10.6 (5.1)
5E	32.0 (38.9)	9.1 (2.2)	31.4 (36.1)	10.1 (4.0)
10E	30.3 (38.2)	10.1 (2.6)	31.3 (37.1)	10.8 (3.7)
17E	30.0 (38.0)	9.6 (2.6)	31.4 (35.4)	11.1 (3.2)
20E	29.8 (37.6)	10.5 (2.6)	31.2 (36.3)	11.4 (4.0)

* values in brackets are the most extreme temperatures observed.

1982 to 1983 as previously mentioned. When the air temperatures were compared to the value observed at 20H leeward trends were apparent. The maximum air temperature values for each sensor location were greater than that at 20H leeward while the minimum air temperatures were lower.

Similar results were noted by others. Woodruff et al. (1959) observed warmer and cooler daytime temperatures with shelter. A lower maximum air temperature, such as that found in 1982 on the windward side may be due to greater evapotranspiration. The small difference in temperature between sensor locations agrees with observations of Skidmore and Hagen (1972), who found temperature differences leeward of solid barriers to be less than those of more permeable barriers.

Marshall (1967) stated that minimum temperatures are usually slightly greater or less within shelter. An increase would be due to the crop canopy trapping warm air and reradiating it at night. A decrease would be due to an inversion being less disrupted by turbulence (Rosenberg 1976; van Eimern et al. 1964).

4.3 SOIL MOISTURE

Soil moisture increases on sheltered fields are attributed to snow accumulation and a reduction in evapotranspiration. On the Prairies snow accumulation generally has the most importance. The initial analysis of the data collected showed significant differences in soil moisture with depth and also with distance from the shelterbelt. The interaction between depth and distance from the shelterbelt was not significant, therefore, the data were calculated for total soil moisture to 135 cm.

Equipment malfunctions in 1982 led to the loss of some data so representative dates were chosen to illustrate the trends (Figure 9). There were no significant differences in total soil moisture as distance from the shelterbelt increased, however, the decline in soil moisture from one date to the next was significant. As the season progressed the moisture levels steadily declined at all locations across the field though the rate of decline was lower at 5E. There was no apparent shelterbelt competition for soil moisture as moisture levels were never significantly lower adjacent to the shelterbelt.

The results for 1983 were dissimilar to the previous year's. There was a significant difference in soil moisture levels between the two sheltered fields used in the study. Adjacent fields were used so this was not anticipated. The discrepancy was most noticeable at the lowest two depths measured. This suggests that the fields may have been different in depth to the water table. The difference in total soil moisture between the dates shown was significant. No differences in soil moisture with distance from the shelterbelt were observed for the first three dates (Figure 10). Significant changes in soil moisture with distance occurred by August 24. There was little precipitation during the winter of 1982-83 so soil moisture levels at seeding were low. A heavy rainfall in early July resulted in an increase in total soil moisture for July 6 to a level above that at seeding. There was a steady decline in soil moisture from then until harvest. The rates of decline were slowest at 5E and 17E. The 17E location was in the lowest area of both fields so the results may be inflated by runoff water and lateral moisture movement. The competitive effect of the shelterbelt is apparent as

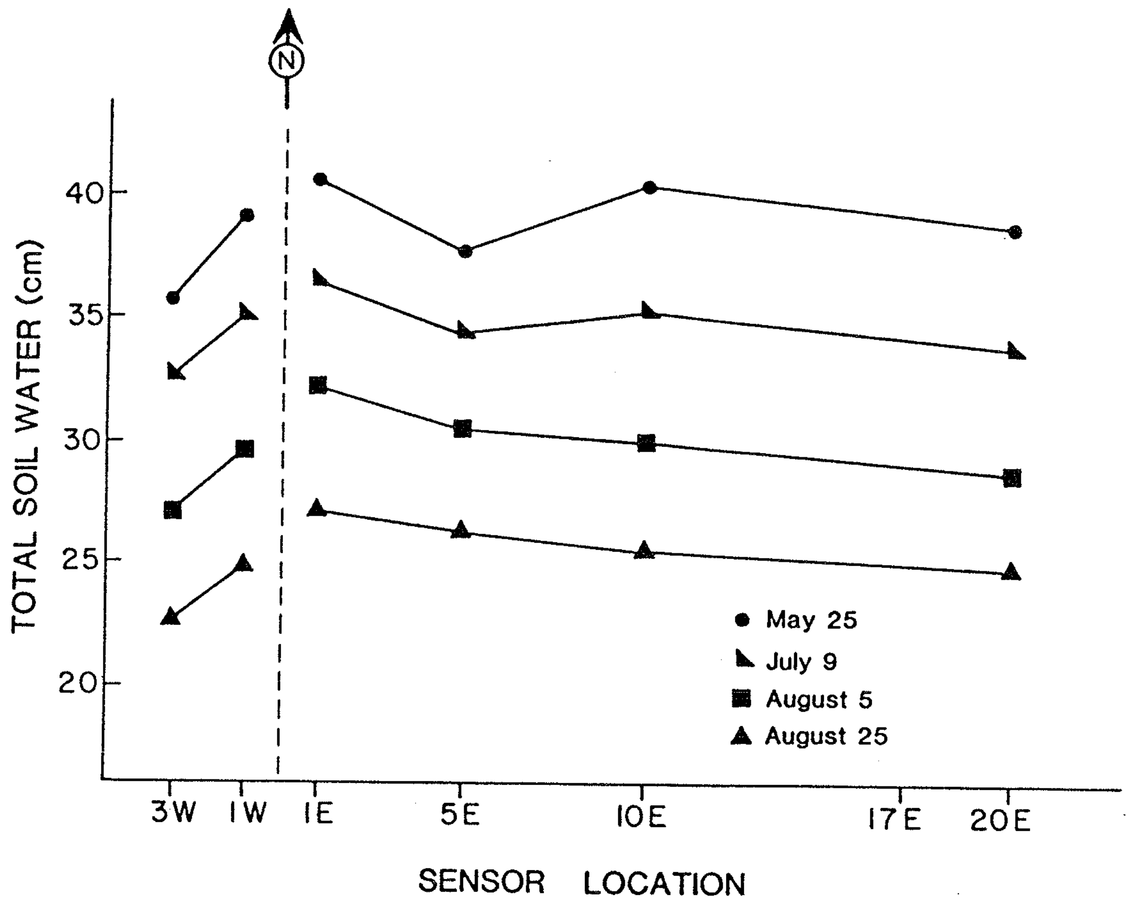

Figure 9: Total soil moisture in profile to 135 cm for 1982.

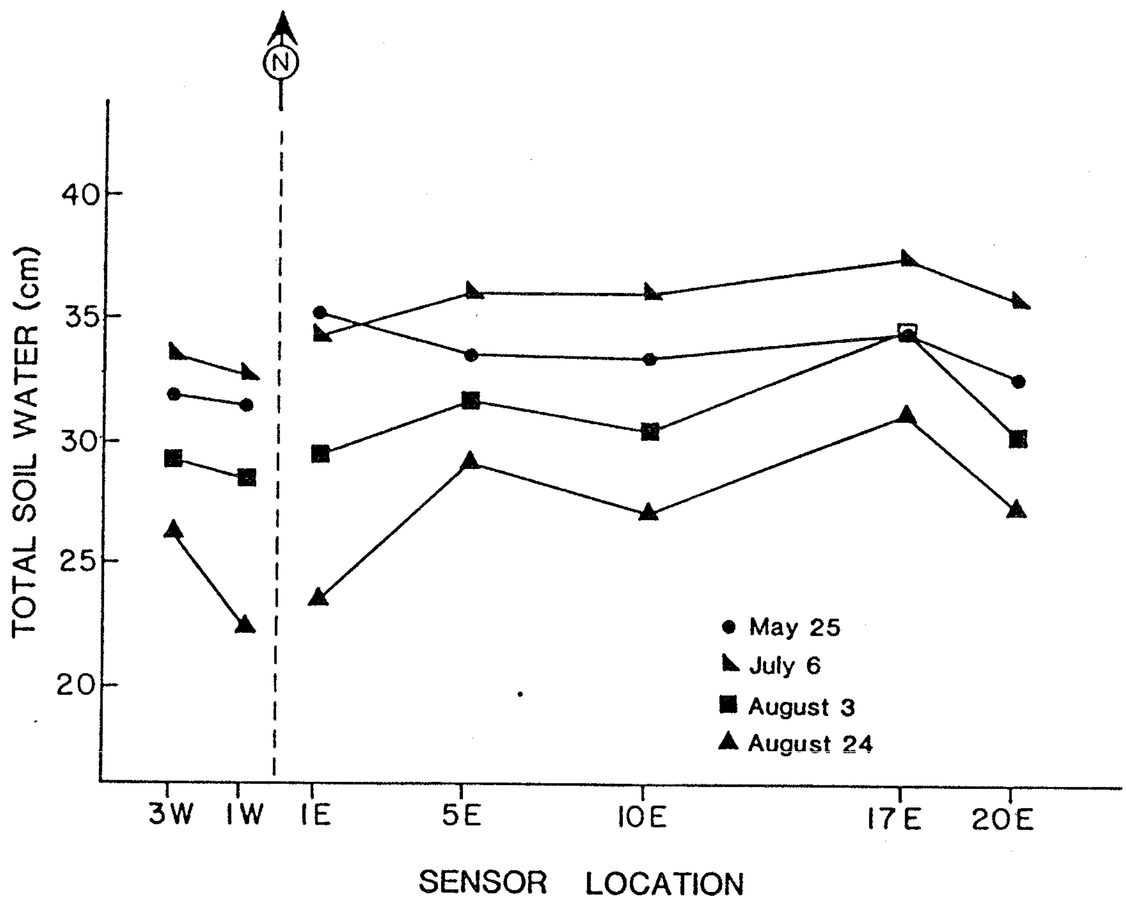

Figure 10: Total soil moisture in profile to 135 cm for 1983.

there was a significant decline in moisture levels adjacent to the shelterbelt.

The soil moisture patterns observed over the two years of the study do not parallel those in the literature. Snowfall during the time of the study was insufficient to cause significant soil moisture increases adjacent to the shelterbelts, in spring, such as observed by Pelton (1976) and Staple and Lehane (1955). Some of the difference between moisture levels at seeding for 1982 and 1983 are a result of the fields being fallow in 1981. Competition by the shelterbelt for soil moisture was only significant at the end of the 1983 growing season though more precipitation was received that year. Total rainfall for the 1982 and 1983 growing seasons was 178.4 and 192.7 mm, respectively. The greater moisture use by the shelterbelt in 1983 may be due to a reduction in water use efficiency of the shelterbelt caused by the fruittree leafroller infestation. The lower rate of soil moisture decline found at 5E corresponds to the area where latent evaporation was reduced and shelterbelt competition did not occur. This indicates a reduction in evapotranspiration 5H leeward of a shelterbelt. A reduction in evapotranspiration may occur at 1H both leeward and windward but shelterbelt competition for soil moisture conceals the effect.

4.4 CROP GROWTH

Field conditions were different for the 1982 and 1983 growing seasons. In 1982 seeding was carried out on May 14 and 15 while in 1983 it was delayed until May 27. The seeding rate for both years was 67.2 kg/ha at a depth of 5 to 7.5 cm. Fertilizer was added to the seed in 1982 but not in 1983. Grasshoppers were a problem in both years. Crop damage was severe in 1983 necessitating spraying insecticides twice a week over a four week period. Weed growth was controlled in both years as needed.

4.4.1 Emergence

Shelterbelts have been reported to modify emergence of crops due to the higher soil moisture and soil temperature often found in the sheltered area. No significant differences in emergence across sheltered fields, attributable to the shelterbelt, were determined for either 1982 or 1983.

In 1982 a check of the seed, two days after planting, showed it had begun to swell and sprout. Few plants had emerged at one week after seeding and the rate of emergence was low for the next week (Table 9). The first date of emergence counts suggested a shelter effect, as the greatest number of plants had emerged adjacent to the shelterbelt and the number decreased with distance. This was not noticeable on other dates. A surge in emergence was observed between May 26 and June 6 which corresponded to a snowfall that deposited 25.1 mm of moisture. Increases in plant stands were not detected beyond June 6.

Seeding was delayed in 1983, due to wet field conditions. The moisture conditions led to rapid emergence at all sensor locations and a shelter effect was not seen (Table 10). Grasshoppers began damaging the crop very soon after emergence. The number of plants at location 1E was significantly lower on June 13 for this reason. Increases in plant stand were not found beyond June 17 and the grasshopper damage had become consistent across the fields.

TABLE 9

Mean emergence counts[1] of wheat at each sensor location in 1982. Seeded May 14 and 15.

Sensor Location	May 21	May 24	May 26	June 6
3W	0.00	1.87	7.51	32.10
1W	0.27	1.19	7.85	32.91
1E	0.56	5.65	15.18	32.79
5E	0.20	2.32	17.73	32.91
10E	0.09	2.29	10.13	30.19
20E	0.00	2.26	11.13	29.20
C.V. (%)	31.2	54.4	31.2	5.7

[1] Number of plants emerged per meter row.

TABLE 10

Mean emergence counts[1] of wheat at each sensor location in 1983. Seeded May 27.

Sensor Location	June 6	June 8	June 11	June 13	June 17
3W	20.11	31.88	28.23	29.42 a*	28.23
1W	20.57	30.86	30.75	32.45 a	26.85
1E	21.03	30.45	22.44	22.92 b	23.71
5E	23.61	29.31	30.30	30.86 a	29.20
10E	24.60	28.12	27.20	29.20 a	28.55
17E	26.12	27.27	31.99	32.45 a	30.64
20E	25.71	26.23	27.20	30.86 a	26.44
C.V. (%)	14.1	11.5	12.6	10.7	11.4

[1] Number of plants emerged per meter row.

* Values, within columns, followed bythe same letter are not significantly different at P=0.05 (Duncan's Multiple Range Test).

The results are in contrast to the findings of authors who reported more rapid emergence in the sheltered zone. Marshall (1967) reported high soil temperatures led to more rapid emergence in the sheltered zone. Soil moisture was the most important factor in determining emergence of the crop in this study. In both 1982 and 1983 soil moisture did not differ significantly across the sheltered field at seeding time. The final stand counts were similar for both years.

4.4.2 Dry Matter Production

The microclimatic change induced by shelterbelts has been reported to modify crop growth patterns on sheltered fields. In both years of this study dry matter production was sampled during the growing season and at harvest to determine differences across the sheltered fields.

In 1982, shelter effects on dry matter production were already apparent by July 7 (Table 11). On this sample date crop dry matter production was lowest adjacent to the shelterbelt. It peaked at locations 5E and 3W then declined as distance from the shelterbelt increased. This shelter effect was still noticeable on the second sampling date. Significantly lower crop dry matter production at harvest was observed adjacent to the shelterbelt while yields from other samples did not differ significantly from unsheltered areas.

A shelter effect was not as readily apparent in the 1983 results (Table 12). Significantly greater crop dry matter production at location 5E was observed on the first sampling date. The other locations did not significantly differ from one another. The harvest samples showed a significantly lower production at 17E while dry matter production at the other locations did not differ. This sensor location was mid-way betwe-

TABLE 11

Dry matter production of wheat at each sensor location for 1982 (kg/ha).

Sensor Location	July 7	August 7	August 23 (Final)
3W	5085.2 a*	8987.2 a	7465.6 a
1W	3406.8 c	5039.2 d	4876.8 b
1E	2976.8 c	5906.4 cd	4907.6 b
5E	5216.0 a	9243.2 a	7964.4 a
10E	4378.0 ab	7932.8 ab	7710.0 a
20E	3867.2 bc	7193.6 bc	6676.0 a
C.V.(%)	20.7	18.4	18.2

* Values, within columns, followed by the same letter are not significantly different at P=0.05 (Duncan's Multiple Range Test).

TABLE 12

Dry matter production of wheat at each sensor location for 1983 (kg/ha).

Sensor Location	July 22	August 22 (Final)
3W	2911.0 b*	5612.4 a
1W	2803.4 b	5898.0 a
1E	3078.7 b	6158.4 a
5E	3645.6 a	5898.0 a
10E	3055.2 b	6012.4 a
17E	2710.0 b	4275.2 b
20E	2868.2 b	5527.2 a
C.V.(%)	16.4	17.6

* Values, within columns, followed by the same letter are not significantly different at P=0.05 (Duncan's Multiple Range Test).

en adjacent shelterbelts and the combined effect of the two shelterbelts would be smallest at this point.

The reduction in crop dry matter adjacent to the shelterbelt, in 1982, was a result of some type of competition. The soil moisture data presented previously did not indicate moisture competition, therefore, nutrient competition is suspected to have caused the decrease. In 1982 the fertilizer which was applied gave the crop a greater growth potential. The crop which was competing for nutrients with the shelterbelt was not able to grow to its potential resulting in significantly lower crop dry matter production as compared to locations not in competition with the shelterbelt. In 1983 a significant reduction in crop dry matter adjacent to the shelterbelt was not observed. The crop dry matter production at 1E and 1W was actually greater in 1983 than in 1982. As the crop was not fertilized in 1983 and the total soil moisture levels were similar to 1982 at critical times this result was not expected. An explanation for this occurrence can not be made with the limited data collected in this study. Reductions due to shading were not found in 1983 so shading probably did not contribute greatly to the reductions found in 1982. The final crop dry matter measurements for both years of the study do not indicate a significant shelter effect. Leaf area constituted a major portion of the difference in dry matter production. As senescence of the leaves occurred the differences in dry matter production became insignificant.

The results are similar to those observed by others in literature though when significant increases in crop dry matter were determined they occurred 3 to 5H from the shelterbelt. Aase and Siddoway (1974) reported production peaks 1 to 3H from a barrier. Visual observations, during this study, suggested the increases were due to greater height and leaf area index though measurements were not recorded. The differences between total crop dry matter production for 1982 and 1983 were a consequence of fertilization rates.

4.4.3 Grain Yield

Spring wheat is considered to exhibit a low yield response to shelter. Low response crops show yield increases in shelter during dry years only. Samples were taken to assess yield in 1982 and 1983 to determine the shelter effect (Table 13).

In 1982 mean yields were higher under shelter but differences were not significant. The crop yield at 1W and 1E was reduced significantly due to shelterbelt competition for nutrients, and possibly sunlight, as was discussed in the previous section. Yield peaked at 5E and declined as distance from the shelterbelt increased. The yield at 3W did not differ significantly from 5E.

Yield patterns in 1983 differed from those of the previous year. There was a significant difference in grain yield for sheltered fields used in the study. This led to a significant interaction between sheltered fields and distance. The differences occurred at locations 1E and 20E. On one of the fields 1E had a lower yield than locations farther from the shelterbelt on the west side while 20E had a significantly higher yield. On the other field the situation was reversed. Location 1E had a high yield and 20E had a low yield. The mean values indicate the crop yield peaked at 1E and was significantly greater than the yields at 17E and on the west side ofthe shelterbelt. The other locations on the east side of the shelterbelt did not differ from 1E.

TABLE 13

Mean grain yield of wheat at each sensor location for both years of study (kg/ha).

Sensor Location	1982 Yield	1983 Yield
3W	2926.6 ab*	1745.0 bc
1W	1887.5 c	1737.9 bc
1E	1726.7 c	2154.4 a
5E	3225.6 a	2019.7 ab
10E	3114.6 ab	2038.1 ab
17E	---	1468.7 c
20E	2713.6 ab	2012.5 ab
C.V.(%)	17.1	15.1

* Values, within columns, followed by the same letter are not significantly different at P=0.05 (Duncan's Multiple Range Test).

The crop yield results generally correspond to the crop dry matter production results. The reduction in crop yield adjacent to the shelterbelt found in 1982 may again be due to competition for nutrients. Soil moisture data, presented earlier, did not indicate moisture competition at critical periods in either year. The addition of fertilizer with the seed in 1982 added to yields away from the area of shelterbelt competition. The significant decrease in crop yield found at 17E in 1983 may be a result of this location being mid-way between successive shelterbelts. The high crop yield found at location 1E in 1983 was not expected. The limited data collected in this study do not provide a reason for this occurrence. The reduction in crop yield on the west side of the shelterbelt may be due to stress caused by the grasshopper infestation. The plot area was smaller on the west side, therefore, there was a higher concentration of grasshoppers.

The results for 1982 are similar to those reported in the literature. The crop did show a yield response to shelter in that year, whereas, in 1983 a shelter response was not noticeable. The yield reduction adjacent to the shelterbelt and the peak at 5E which occurred in 1982 is in agreement with the results of Frank et al. (1976). There was more precipitation in 1983 but soil moisture levels were not significantly different from 1982. The results do not correspond directly to low response crops as stated by Peterson (1971).

The mean crop yields across the sheltered fields, taking the land occupied by the shelterbelt into account, were calculated to be 2666.3 and 1767.1 kg/ha in 1982 and 1983, respectively. This indicates the effect the addition of fertilizer had on crop yield. In a study by Frank et al (1976) the area between 15 and 20 H was used as a check for crop yield. This check area was assumed to yield equal to an open field. In 1982 the crop yield at 20H was 2713.6 kg/ha. If this is assumed to equal an open field yield then it can be seen that the yield across the sheltered field was approximately 57.3 kg/ha lower. The loss in yield is due to land being taken out of production by the shelterbelt and the competition adjacent to the shelterbelt. The increased yield found at 5 to 10H did not compensate for the loss. The results for 1983 suggest that the yield at 20H may not be comparable to the open field yield. In that year the crop yield at 17H was lower than 20H and their mean may better approximate open field yields. The mean yield for the area 17 to 20H was 1740.6 kg/ha, therefore, the sheltered field had an average yield increase of 26.5 kg/ha. In 1983 the increased yield on the sheltered field would compensate for the land occupied by the shelterbelt. The yield loss which is apparent in 1982 when 20H is used to approximate the open field yield was small and may not have occurred if a mean value for the area 15 to 20H was used. The reduced soil losses due to the presence of a shelterbelt are well worth small reductions in yield over the total field.

4.4.4 Water Use Efficiency

Water use efficiency is a measure of crop dry matter or grain yield produced per unit of water consumed through evapotranspiration. As crop cover increases the relative importance of evaporation from the soil decreases and transpiration becomes the major mechanism of water loss.

Water use efficiencies were calculated for the 1982 and 1983 growing seasons. Significant differences in soil moisture levels across the sheltered fields were not observed therefore increases in crop dry matter or yield indicate an increase in water use efficiency.

The results for water use efficiency of dry matter production parallel those previously shown for crop dry matter productions in kg/ha. In 1982 the lowest water use efficiency was observed adjacent to the shelterbelt (Table 14). On the first two dates crop water use efficiency was greater at locations 5E and 3W, then decreased at greater distances from the shelterbelt. This was not apparent on August 24.

The first sampling date in 1983 showed significantly greater water use efficiency at location 5E (Table 15). The other locations were less efficient and did not differ significantly from one another. The results for August 22 were not significantly different.

TABLE 14

Average water use efficiency[1] of wheat based on dry matter production at each sensor location for 1982. ($x10^{-3}$)

Sensor Location	July 7	August 7	August 24 (Final)
3W	34.3 a*	35.5 a	22.7 a
1W	22.0 bc	19.3 c	14.4 b
1E	18.7 c	23.4 b	15.2 b
5E	25.7 a	38.7 a	26.8 a
10E	24.8 b	28.1 b	22.6 a
20E	23.0 bc	26.8 b	20.8 a
C.V. (%)	24.1	18.4	22.1

[1]Water use efficiency = $\frac{\text{Dry matter production (kg/ha)}}{\text{Evapotranspiration (kg/ha)}}$

* Values, within columns followed by the same letter are not significantly different at P=0.05 (Duncan's Multiple Range Test).

TABLE 15

Average water use efficiency[1] of wheat based on dry matter production at each sensor location in 1983. ($x10^{-3}$)

Sensor Location	July 22	August 22 (Final)
3W	16.1 b*	22.2 ab
1W	15.9 b	19.4 ab
1E	15.4 b	19.2 b
5E	20.6 a	24.1 a
10E	16.8 b	23.2 ab
17E	18.8 ab	18.7 b
20E	16.9 b	21.4 ab
C.V. (%)	16.6	19.0

[1]Water use efficiency = $\frac{\text{Dry matter production (kg/ha)}}{\text{Evapotranspiration (kg/ha)}}$

* Values, within columns, followed by the same letter are not significantly different at P=0.05 (Duncan's Multiple Range Test).

A difference in water use efficiency from 1982 to 1983 was observed. The crop was, generally, more efficient in the 1982 growing season. This was likely due to the greater soil fertility level in that year.

The pattern of water use efficiency for grain yield in 1982 was similar to those of dry matter production, shown previously (Table 14 and 15). The crop was significantly less efficient adjacent to the shelterbelt and most efficient at location 5E. In 1983 the pattern of water use efficiency for grain yield (Table 16) differed somewhat from that of dry matter (Table 15). The greatest efficiency was found at location 5E. The crop was least efficient adjacent to the shelterbelt and at location 17E. There was also a significant interaction between the shelterbelts and the sensor locations (Table 17). The differences occurred at locations 1E and 20E. On one of the fields 1E displayed low water use efficiency while the crop at 20E was the most efficient. The results were reversed on the other field where 1E was more efficient than 20E. This was identical to the interaction noted for soil moisture and grain yield in 1982 and was expected to carry on in these values.

The reduction in water use efficiency adjacent to the shelterbelt is an indication of the degree of competition between the shelterbelt and the crop for moisture and nutrients. The reductions in efficiency were much greater in 1982 which supports the earlier conclusion that the competition was greater in this year. The water use efficiency values for crop grain yield in both years of the study do suggest a shelter effect though the differences are not significant.

Based on the observed results, it appears that a shelterbelt influences water use efficiency of a crop which, in turn, results in changes

TABLE 16

Average water use efficiency[1] of wheat based on grain yield at each sensor location. ($x10^{-3}$)

Sensor Location	1982	1983
3W	8.8 a*	6.9 bc
1W	5.6 b	5.9 d
1E	5.3 b	6.7 bcd
5E	10.9 a	8.3 a
10E	9.4 a	7.8 ab
17E	---	6.4 cd
20E	8.4 a	7.6 ab
C.V.(%)	21.4	15.2

[1]Water use efficiency = $\frac{\text{Grain yield (kg/ha)}}{\text{Evapotranspiration (kg/ha)}}$

* Values, within columns, followed by the same letter are not significantly different at P=0.05 (Duncan's Multiple Range Test).

TABLE 17

Average water use efficiency[1] of wheat based on grain yield at sensor locations used in 1983. ($x10^{-3}$)

Sensor Location	SH 1**	SH 2
3W	6.8 bc*	7.1 abc
1W	6.8 bc	5.3 d
1E	5.9 c	7.7 ab
5E	8.2 ab	8.6 a
10E	7.9 ab	7.7 ab
17E	7.1 bc	5.9 cd
20E	9.5 a	6.3 bcd

[1]Water use efficiency = $\frac{\text{Grain yield (kg/ha)}}{\text{Evapotranspiration (kg/ha)}}$

* Values within columns followed by the same letter are not significantly different at the P=0.05 level (Duncan's Multiple Range Test).

** SH 1 and SH 2 refer to the two shelterbelts used in this study and the fields adjacent to them.

in crop dry matter production and grain yield. Water use efficiency would be altered due to the shelter effect on wind velocity and latent evaporation. The results correspond to the findings of others. Radke and Burrows (1970) and Aase and Siddoway (1974) found similar results with soybeans and winter wheat, respectively. Sturrock (1978) stated that, in dry climates, improved plant water use is the chief factor in growth increases of sheltered plants.

Chapter V

SUMMARY AND CONCLUSIONS

The shelterbelts used in this study were found to reduce wind velocity in a zone 3H windward to 17H leeward. The greatest reduction in wind velocity occurred leeward, adjacent to the shelterbelt. Latent evaporation was reduced in a pattern similar to wind velocity but to a lesser degree. A zone of diminished latent evaporation was found 1H windward to 10H leeward. The greatest reduction in latent evaporation also occurred leeward, adjacent to the shelterbelt. The mean seasonal air temperatures across the fields were not significantly affected by the shelterbelts. There was some concern as to the consequence of the extreme temperature range which may occur adjacent to the shelterbelt. In 1983 air temperature values as high as 42.5 C and as low as 2.2 C were recorded. Extreme temperatures such as these may be detrimental to the growth of sensitive crops.

Snowfall was below normal during the two years of the study. Snow accumulation on sheltered fields is generally the most important factor in soil moisture increases. The initial soil moisture level in 1982 was greater than that in 1983. This is attributed to the field being fallow in 1981. Soil moisture did not differ significantly across the fields at essential periods in the crop's growth in either year. Shelterbelt and crop competition for soil moisture could not be shown for either year.

Crop emergence was not significantly affected by the shelterbelt. Soil moisture was found to be the most important factor in determining emergence of the crop. Crop dry matter production patterns were found to vary between years. The 1982 results indicated competition between the shelterbelt and crop, most likely for nutrients. This was not observed in 1983 and the limited data collected in this study do not explain this occurrence. The greater total crop dry matter production for 1982 was a consequence of fertilization. Grain yield results were similar to the dry matter production results. The 1982 results again indicated competition between the shelterbelt and crop, most likely for nutrients. This was not observed in 1983 and no explanation is available from the data collected in this study. Grasshoppers were a severe problem in 1983 which may have altered the potential yields. The mean crop yield was greater in 1982, again, due to the addition of fertilizer. When the mean crop yield across the field was compared to a check area, as specified in the literature, a reduction in yield was found for the sheltered fields in 1982 and an increase in yield for the sheltered fields was found in 1983. The yield value used for the check area in 1982 may be too high, as a mean could not be taken for the total check area. Yield increases due to the shelter effect were found to compensate for the land taken out of production by the shelterbelt.

Water use efficiency followed similar trends both years of the study. The crop was least efficient adjacent to the shelterbelt and at the middle of the field. The water use efficiency reduction near the shelterbelt indicates soil moisture competition did occur while the middle of the field would correspond to the point receiving the least combined effect of the two successive shelterbelts. Water use efficiency was greatest approximately 5H from the shelterbelt and decreased at larger distances.

Based on the observed results, the major effect of the shelterbelt was the influence on water use efficiency of the crop. The reductions in wind velocity and latent evaporation found in the sheltered zone led to greater water use efficiency where shelterbelt competition was not present. An increase in water use efficiency resulted in improved crop dry matter production and grain yield.

As the shelterbelts were not found to have a detrimental effect on the parameters studied it is recommended that they be maintained and, if possible, rejuvenated. It could not be proven in this study that the shelterbelts caused a significant decrease in mean yield across a field and their proven benefits in reducing soil erosion make them too valuable to remove.

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Appendix A

APPENDIX

TABLE 18

Supplementary nutrients

Year	Nitrogen (kg/ha)	Phosphorous (kg/ha)	Potassium (kg/ha)
1982	5	20	0
1983	0	0	0

TABLE 19: Pesticide application

Year	Date	Treatment	Application method	Rate	Comments
1982	May 24	Treflan	Preplant incorporated	1.5 l/ha	
		Avadex (BW)	Preplant incorporated	13.4 kg/ha	Spot treatment
	June 18	Tordon 202C	Post - emergence	1.0 l/ha	
	June 22	Furadan	Post - emergence	275.0 ml/ha	Grasshopper control
1983	May 27	Treflan	Preplant incorporated	1.5 l/ha	
		Avadex (BW)	Preplant incorporated	13.4 kg/ha	Spot treatment
	June 8	Decis	Post - emergence	200.0 ml/ha	Grasshopper control in shelterbelt
		Furadan	Post - emergence	275.0 ml/ha	" in field
	June 15	Furadan	Post - emergence	275.0 ml/ha	" in field
	June 20	Decis	Post - emergence	200.0 ml/ha	" in shelterbelt
	June 29	Furadan	Post - emergence	275.0 ml/ha	" in field
	June 30	Decis	Post - emergence	200.0 ml/ha	" in shelterbelt
	July 7	Decis	Post - emergence	200.0 ml/ha	" in shelterbelt