# EFFECT OF AGRONOMIC TREATMENT ON YIELD, PATTERN OF SOIL WATER USE AND FOLIAR DISEASES IN WINTER WHEAT IN NORTHEAST SASKATCHEWAN

A Thesis
Submitted to the Faculty of Graduate Studies and Research
in Partial Fulfillment of the Requirements
for the Degree of
Doctor of Philosophy
in the
Department of Crop Science and Plant Ecology
University of Saskatchewan
Saskatoon, Saskatchewan

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December, 1989

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# ABSTRACT

Three separate experiments were conducted in the period 1986 to 1988 to examine the effect of various seed rate and row spacing combinations on: yield and yield components, grain protein, soil water use and foliar disease development in winter wheat. A fourth experiment was designed to determine the optimum time to spray fungicide to control powdery mildew and septoria and to maximize grain yield. A range of disease epidemics were created by spraying with different fungicides at various stages of crop growth.

The highest seed rate (140 kg $ha^{-1}$) and narrowest row spacing (9 cm) considered in this study produced the highest winter wheat grain yields. Increasing the seed rate and decreasing the row spacing together produced a 21% increase in grain yield over the more conventional combination of 70 kg $ha^{-1}$ seed rate and 18 cm row spacing.

A higher seed rate also produced slightly earlier crop maturity. Increased nitrogen fertility, high seed rate and narrow row spacing were associated with higher levels of grain protein.

Nitrogen rate, seed rate and row spacing all affected the pattern of soil moisture use. Increasing nitrogen promoted water use throughout the growing season. Increasing seed rate increased water use over the course of the growing season especially before anthesis. Narrow row spacing also increased water use over the course of the growing season. Highest grain yield and highest water use efficiency were associated with the combination of 140 kg/ha seed rate and 9 cm row spacing.

Powdery mildew and septoria development were both a greater problem on the semi-dwarf cultivar Norwin than the tall cultivar Norstar. However, it was not possible to determine whether this was due to shorter plant height, a more susceptible genotype, or a combination of both factors. Powdery mildew development was promoted by increased nitrogen fertility and increased seed rate. Wide row spacing also aided powdery mildew development, particularly in the dispersal phase of its infection cycle; the effect of wide row spacing was most evident in the early stages of the epidemic. Narrow row spacing may promote powdery mildew development after the pathogen is established on a leaf. Septoria development was promoted by increased seed rate while reduced nitrogen fertility promoted septoria development under some environmental conditions.

Higher wind speed within the crop canopy was associated with wide row spacing. This may be important in aiding the dispersal of powdery mildew spores and it may explain the higher levels of powdery mildew that were associated with wide row spacing in the early stages of an epidemic.

The highest minimum daily relative humidity was associated with increased seed rate and reduced row spacing which may explain the higher levels of powdery mildew at the higher seed rate.

Increased duration of leaf wetness was favoured by increased seed rate and to a lesser extent, by reduced row spacing. Increased duration of leaf wetness could be particularly important for septoria development, because spore germination requires the presence of water. This may account for the fact that higher levels of septoria were associated with increased seed rate.

The fungicide propiconazole applied at Feekes growth stage 8 provided better disease control and produced higher grain yield and kernel weight than single applications of tridimefon or mancozeb. Split applications of fungicide provided only marginally better results than the single application at growth stage 8.

# ACKNOWLEDGEMENTS

I would like to express my gratitude to my supervisor, Dr. Brian Fowler for his advice and assistance through this study. My research committee Dr. H. M. Austenson, Dr. J. Romo, Dr. L. Duczeck, and Professor R. A. A. Morrall also provided helpful suggestions. Figures 2.2 and 2.4 were adapted from a generalized disease infection cycle diagram developed by Professor Morrall. Thanks also for field and laboratory assistance provided by the Agriculture Canada Research Station at Melfort, particularly Frank Campbell and Craig Stevenson.

This project was funded by the Canada-Saskatchewan Economic Regional Development Agreement.

Thanks also to A. T. Wright for his: advice, and assistance, (and use of his fly swatter).

Special thanks to my wife and children whose support and understanding were invaluable during the writing of this thesis.

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# 1. INTRODUCTION

The practice of seeding winter wheat into standing stubble has extended winter wheat production into the Saskatchewan Parkbelt region. Production of winter wheat in the Parkbelt region offers some significant advantages to growers. These include: soil conservation, earlier maturation and harvest than spring wheat, better utilization of spring moisture, early crop competition with annual grasses such as wild oats, and typically higher grain yield. However, further information is needed on practices that would maximize winter wheat production in the area.

The Parkbelt region of Saskatchewan tends to have better moisture conditions than many other areas in the Saskatchewan grain growing region. Consequently, the use of higher seed rates and narrower row spacings may produce an increase in grain yield over conventional practices.

Changes in crop management produce changes in the microenvironment within the crop canopy that may result in increased problems with foliar pathogens. The foliar diseases powdery mildew (*Erysiphe graminis* DC f.sp. *tritici* E. Marchal) and septoria (*Septoria* spp.) are potential problems on winter wheat in much of the Parkbelt region. Spraying with fungicide to control these pathogens is of marginal benefit at current wheat prices.

This study was undertaken to examine the effects of seed rate and row spacing on grain yield and yield components. The pattern of soil moisture use and how it influences the various yield components were also examined. Changes in microclimate, produced within the crop canopy at the different seed rate and row spacing combinations, were evaluated together with the effect these changes have on the development of powdery mildew and septoria on the crop. Agronomic methods of reducing problems with these pathogens and optimizing the use of fungicides were also examined in this study.

# 2. LITERATURE REVIEW

## 2.1 Agronomic Responses to Variations in Seed Rate and Row Spacing

The Parkbelt area of Saskatchewan tends to have better moisture conditions than many other Saskatchewan grain growing regions. Winter wheat, in particular, may respond to higher seed rates as it is better able to make use of spring moisture. Unfortunately, while spring tends to be the time of the year when moisture is least limiting, this is also the time of the year when seedlings are small with the result that a large proportion of the incident solar radiation falls on bare ground. One way to partially alleviate this problem is to improve spatial distribution by increasing seed rate (SR), and decreasing row spacing (RS)(Table 2.1).

### 2.1.1 Seed Rate

Wheat yield is determined by the product of interactions among the three yield components; heads $m^{-2}$, number of kernels $head^{-1}$, and kernel weight. Most often compensation occurs among these yield components such that an increase in heads $m^{-2}$ results in a decrease in the number of kernels $head^{-1}$ and to a lesser extent kernel weight (Willey and Holliday, 1971). Generally there is a positive correlation between SR and heads $m^{-2}$. Some compensation for low SR occurs through increased tillering, especially under favourable environmental conditions (high moisture and long growing season). Yields usually decline sharply at very low SR due to the small number of heads $m^{-2}$ and

Table 2.1 Abbreviations used in this thesis.

| Term | Abbreviation Used |
|---|---|
| seed rate | SR |
| row spacing | RS |
| seed rate and row spacing | SRRS |
| water use | WU |
| water use efficiency | WUE |
| nitrogen | N |
| phosphorus | P |
| grain protein | GP |
| straw protein | SP |
| powdery mildew | PM |
| relative humidity | RH |
| growth stage | GS |
| 9 cm RS and 140 kg $ha^{-1}$ SR | 9-140 |
| 9 cm RS and 35 kg $ha^{-1}$ SR | 9-35 |
| 18 cm RS and 70 kg $ha^{-1}$ SR | 18-70 |
| 36 cm RS and 140 kg $ha^{-1}$ SR | 36-140 |
| 36 cm RS and 35 kg $ha^{-1}$ SR | 36-35 |

at very high SR due to a drastic reduction in the other yield components(Puckridge and Donald,1967). Between these two extremes, there is a large "plateau" area where yield changes slowly relative to SR (Briggs and Aytenfisu, 1979).

Optimum SR varies for different environments and for agronomic practices. For example, optimum SR has been reported to vary with soil moisture and nitrogen (N) levels (Fischer et al, 1975) as well as for cultivar (Anderson, 1986) and tillage practices (Read and Warder, 1982). During the early part of the growing season, much of the incident solar radiation falls on bare ground and does not contribute to crop growth. Consequently, higher SR achieves quicker ground cover with the result that more of the incoming radiation is intercepted. However, if the plant density is too high, water and nutrients may become limiting, and much of the early dry matter production will be lost (Puckridge and Donald, 1967). In this instance, dry matter production is maximized by a higher SR than is grain production (Fischer et al, 1975).

In southwestern Saskatchewan, where drier growing conditions usually prevail, lower SR has been shown to produce higher spring wheat grain yields, particularly in a dry year. Pelton (1969) examined SR ranging from 22 kg ha$^{-1}$ to 101 kg ha$^{-1}$ in spring wheat and found that low SR produced a higher grain yield. Read and Warder (1982) reported that SR as low as 20 kg ha$^{-1}$ for spring wheat seeded on stubble was optimum, whereas 60 kg ha$^{-1}$ was required for wheat seeded on fallow where moisture was less limiting.

In the Parkbelt region of the Prairies, moisture is generally less of a limiting factor. Briggs (1975), found that higher SR (up to 101 kg $ha^{-1}$) resulted in higher spring wheat grain yield in the Edmonton area. In the Peace River region, Guitard et al (1961) also found a rate of 101 kg $ha^{-1}$ was optimal for spring wheat grain yield. There were yield increases with SR as high as 202 kg $ha^{-1}$ at two of the three sites in the latter experiment. In the Melfort area of the Saskatchewan Parkbelt, Wright et al (1987) reported that a 124 kg $ha^{-1}$ SR produced the highest average grain yield for spring wheat. On both stubble and fallow, the highest yield was obtained with the combination of highest fertility and highest SR. Since winter wheat grows early in the season when moisture is less limiting, it might be expected to show an even greater response to increased SR in the Parkbelt than spring wheat.

Seed rate also affects the maturation time of the plant. The time required for the plant to reach maturity often decreases as SR increases. This is at least partly related to the reduced tillering that occurs with a higher SR (Darwinkel, 1980). In high rainfall years these differences could be important in the Parkbelt region of Saskatchewan where the growing season is short.

Optimum N fertility is important if maximum response from increased SR is to be achieved (Wright et al, 1987). As with increased SR, N fertilization results in greater soil water use (WU) due to increased dry matter production during the early part of the growing season (Entz and Fowler, 1988a). High winter wheat yields in Saskatchewan are associated with a high level of dry matter accumulation prior to anthesis (Entz and Fowler, 1988b).

When N is not limiting, protein concentration in the grain generally varies indirectly with yield, and is negatively correlated with root zone water at time of stem elongation (Entz and Fowler, 1988a). With an increase in SR the effects on grain protein of increased yield and decreased water in the root zone at the time of stem elongation may offset each other. Consequently, while grain protein levels may be influenced by SR, the response can vary widely depending on the environmental conditions (Gare-Mariam and Larder, 1979; Read and Warder, 1982).

### 2.1.2 Row Spacing

It may be necessary to alter RS of wheat to achieve maximum yields particularly in environments with high rainfall. In Virginia, Joseph (1985) reported an 8-10% yield increase with 10 cm RS over a 20 cm RS. In Pennsylvania, Frederick and Marshall (1985), reported an 8% yield increase when RS was decreased from 17.8 cm to 12.7 cm. Baldwin (1963) found that a 4" RS yielded 4% better than an 8" RS in England. These tests were all conducted on winter wheat. Further observations made by researchers from Europe (Holliday,1963) and the U.S. (Johnson et al, 1988) on winter wheat and from Australia (Burch and Perry, 1986; Doyle,1980) and Brazil (Felicio, 1982) on spring wheat support these results.

In Ontario, Finlay et al (1971) reported increased barley yield with narrow RS in a normal year, but no RS response when grain yields were below normal. In Europe, Bachthaler (1971, cited in Sheikh et al, 1985) reported a favourable response for winter wheat grown in narrow RS on loamy soil, but no response on sandy soil. In Texas, Winter and Welch (1987) found that narrow RS produced greater winter wheat yields, but that the pattern of soil WU differed among RS. Wide row systems were effective in economizing soil WU before the boot stage, with the result that more water was available during the later stages of growth. However, total water depletion during the growing season was not affected. In southern Saskatchewan, Leyshon et al (1981) found that 30 cm RS produced the highest forage crop yields at the start of long term rotations. However, by the fifth year a transition in yield had occurred so that the 60 cm RS and the 90 cm RS were favoured.

According to Auld et al (1983), the yield advantage derived from narrow RS is brought about by an improved ability to exploit available "space". Holliday (1963), suggested that better spatial arrangements allow for greater availability of light, water and nutrients on a unit area basis. For example, better spatial distribution reduces leaf overlap. Stoskopf (1967), reported that leaf morphology may also affect the response of plants grown in narrow rows. He found that all winter wheat cultivars responded to narrow RS, but cultivars with upright leaves showed a greater yield response to narrow RS.

The increase in yield with narrow RS has been shown to be primarily due to an increase in heads $m^{-2}$ (Frederick and Marshall, 1985). Kernels $head^{-1}$ may decrease with narrow RS, but this does not compensate for the increase in the number of heads $m^{-2}$ (Joseph et al,1985). Kernel weight may remain unchanged, or show a slight increase under some conditions due to reduced intra-row competition during grain filling (Frederick and Marshall, 1985).

Some researchers have reported an interaction between RS and N uptake, so that higher N responses are achieved with narrow RS (Widdowson et al, 1980; Baldwin, 1963). Reinertsen and co-workers

(1984) found that N uptake by the crop was increased with narrow RS. Problems with wild oats were reduced at the narrow RS. There was no difference in total plant N uptake if uptake by wild oats was included.

Row spacing may have an effect on grain protein concentration under some environmental conditions. Plants in wide RS use less soil water by anthesis than plants in narrow RS (Winter and Welch, 1987), and higher soil water at anthesis is associated with reduced protein concentration (Entz and Fowler, 1988b). However, the decreased yield resulting from the wider RS should offset the influence of low early season moisture use, and slightly higher grain protein concentrations have been reported with wider RS (Hagras, 1981; Siemans, 1962).

Selection of the correct combination of SR and RS is important in maximizing grain yield (Marshall and Ohm, 1987). Higher SR maximizes ground cover when used in conjunction with narrow RS. This results in better use of incident solar radiation in the early part of the growing season. For winter wheat grown in the Saskatchewan Parkbelt, this would maximize ground cover at a time when moisture is usually least limiting to plant growth.

### 2.1.3 Influence of Seed Rate and Row Spacing on Weed Competition

High SR and narrow RS can increase crop competition thereby reducing weed populations. In Nebraska, Van der Vorst et al (1983) reported reduced weed populations in winter wheat when high SR and narrow RS was used. Although there was no effect on early germinating broadleaf weeds, fewer late germinating broadleaf weeds were present with the narrow RS. Narrow RS also significantly reduced annual grass weeds and the population differences were still evident two years later. In Minnesota, Oelke et al (1973) reported similar reductions in broadleaf weed populations in spring wheat due to high SR and narrow RS. High SR was more important than narrow RS. The effect of high SR was particularly important for short cultivars.

## 2.2 Response of Powdery Mildew to Agronomic Management

### 2.2.1 Autecology of Powdery Mildew

The fungal pathogen powdery mildew (*Erysiphe graminis* f. sp. *tritici*) is an ascomycete that belongs to the subclass Pyrenomycetes. It has an ascocarp or fruiting body that is a cleistothecium (a completely enclosed ascocarp). It is an obligate parasite requiring green plant tissue to develop. The pathogen utilizes nutrients, reduces photosynthesis, and increases respiration and transpiration of the host. The fungus remains entirely superficial except for haustoria that penetrate host epidermal cells (Wiese, 1977). Powdery mildew (PM) does not usually cause serious grain yield losses in the agricultural regions of western Canada. However, yield losses have been reported in soft white spring wheat grown under irrigation and in winter wheat (Martens et al, 1984). The magnitude of yield loss is related to the severity and timing of infestation. Early infestations are the most damaging and mainly affect the number of fertile tillers, although other yield components may be affected. Later infestations cause a reduction in kernel weight (Carver and Griffiths, 1982).

In the field, PM is initially observed as small grayish-white patches of mycelium on the lower leaves. These whitish areas eventually become spotted with minute black dots that are the cleistothecia or sexual fruiting bodies (Martens et al, 1984). The cleistothecia provide the overwintering form of the fungus, although in milder climates, the fungus can also overwinter as mycelium and conidia. In the spring, windborne ascospores produced by the cleistothecium act as primary inoculum (Fig. 2.1). The ascospores germinate and produce germ tubes that penetrate epidermal cells directly, establish haustoria in the penetrated cells and then produce superficial sporulating colonies. The conidia produced in this manner are wind-dispersed and give rise to secondary infections. When the conidia germinate, they also penetrate the epidermal cell directly in the same manner as the ascospores. Powdery mildew is heterothallic and hybridization between genetically dissimilar strains produces new physiological races (Wiese, 1977).

Powdery mildew conidia do not need water to germinate. In fact, liquid water inhibits germination of the conidia. Consequently, long periods of rain impede development of a PM epidemic (Obst, 1980). While the conidia can germinate in dry air (Martens et al, 1984), high relative humidity promotes germination and subsequent infection (Obst, 1980). Optimum development occurs over the temperature range of 15° to 20° C with extremes of 5° and 29° C. The effect of environmental conditions, particularly adequate moisture, may be more important in promoting rapid plant growth than in directly affecting the pathogen itself (Tapke, 1951).

As an obligate parasite, PM can only attack green plant tissue. Consequently, high stress conditions that cause premature senescence of

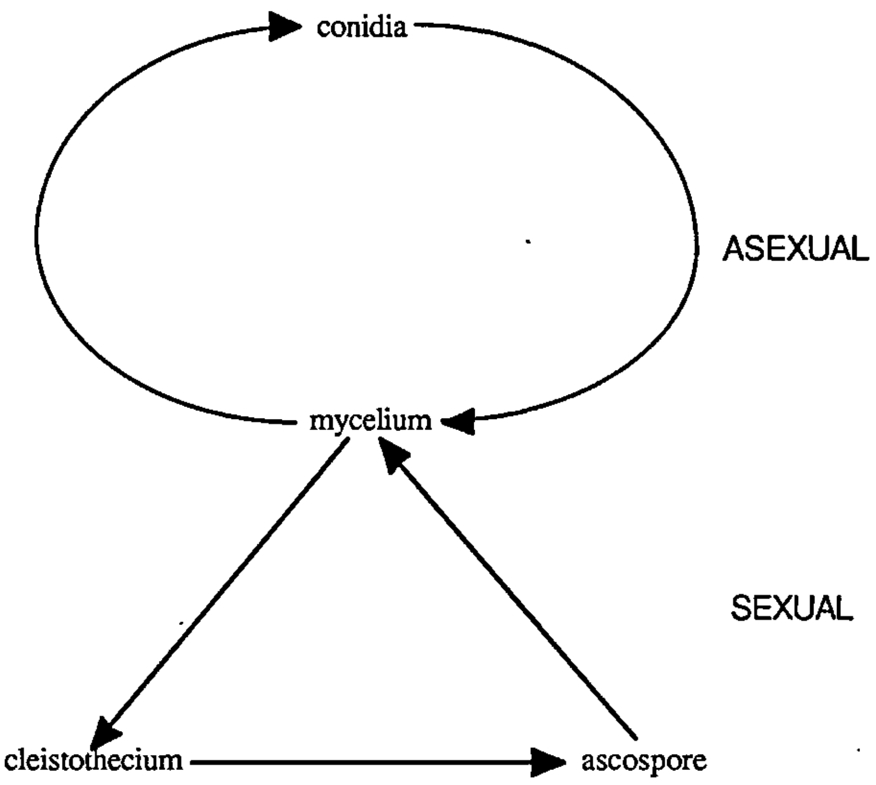

Figure 2.1 Life cycle of *Erysiphe graminis* f. sp.*tritici*

plant leaves are usually detrimental to the development of PM. On the other hand, conditions that promote rapid plant growth also predispose the plant to attack by the pathogen. This could be a function of cuticle thickness as the pathogen gains entry to the host by direct penetration of the cuticle and epidermis (Tapke, 1951).

Germination, infection and secondary sporulation of PM can be completed within 7 to 10 days under favourable field environments, (Wiese, 1977). Infection can be initiated by either conidia or ascospores, although conidia are more important epidemiologically. Spore germination occurs on the surface of the host leaf. Germination is promoted by darkness, high relative humidity and optimum temperature. Germination is inhibited by the presence of water (Fig. 2.2). Penetration of the host includes a number of morphologically identifiable stages: formation and maturation of appressoria, formation of a penetration peg that penetrates the host cuticle and epidermal cell wall, formation of a haustorium in the epidermal cell of the host, and formation of secondary hyphae (Ellingboe, 1972). Penetration occurs in the light and is favoured by rapidly growing plant tissue, thin cuticle (Tapke, 1951), and a susceptible genotype (Shaner and Finney, 1977). Conidial production occurs in the presence of light and is promoted by temperatures in the 15° to 20° C range. Conidial production declines as the colonies age. Conidia are wind dispersed and induce secondary infections (Wiese, 1977).

In summary, PM development on a susceptible host is favoured by high RH, cool temperature, and other factors (including high fertility and adequate moisture) that promote rapid plant growth. Prolonged rainy periods can hinder development.

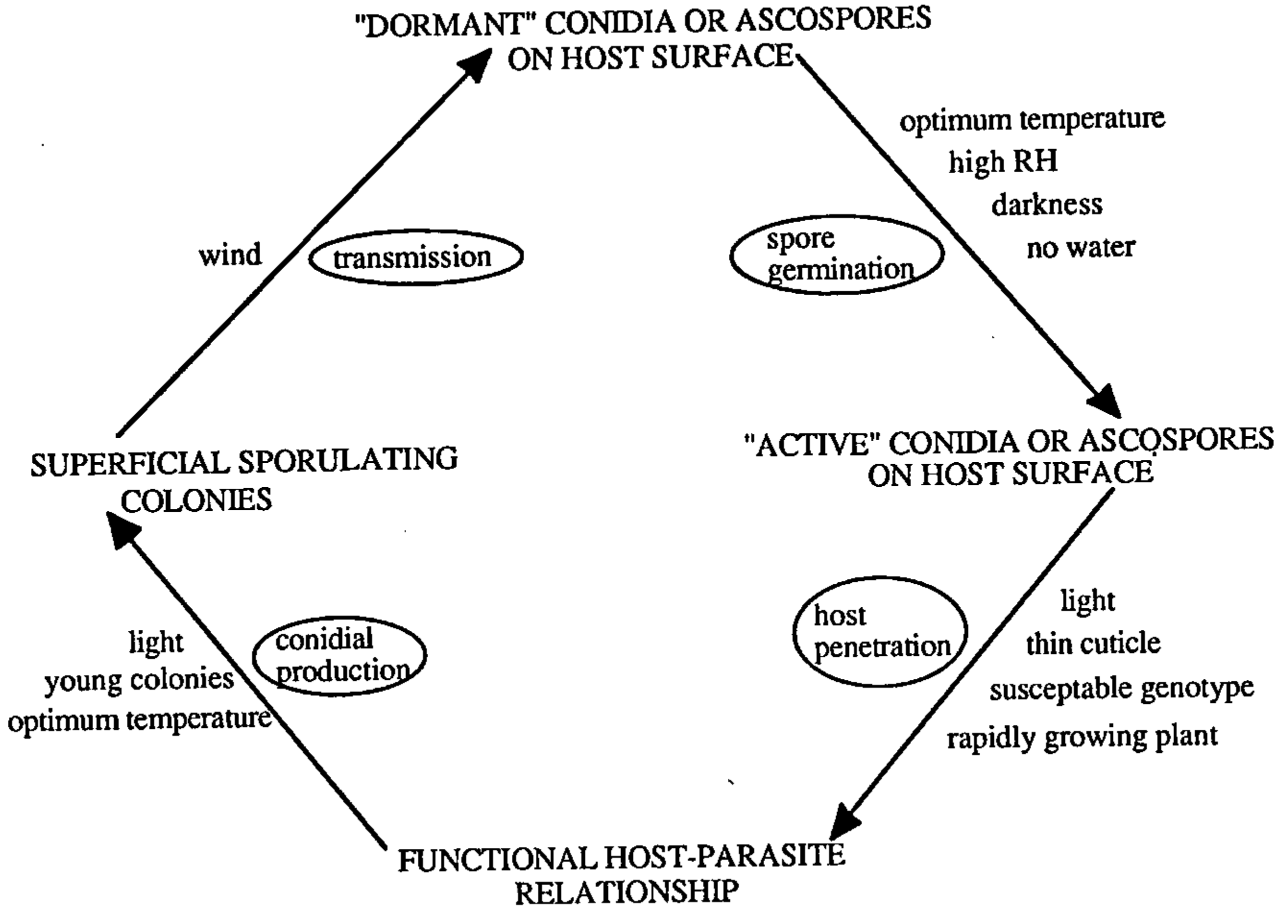

Figure 2.2 Environmental factors promoting processes in infection cycle of *Erysiphe graminis* f. sp. *tritici*.

### 2.2.2 Influence of Agronomic Practices on Powdery Mildew Development

#### 2.2.2.1 Effect of Fertility

Nitrogen fertility can have a direct influence on PM development. Last (1954) found that mature leaves of N deficient winter wheat plants, which had resisted mildew infection, became susceptible after N fertilization. Boquet and Johnson (1987) reported that increasing the rate of applied N on winter wheat resulted in an increased level of PM infection. In years when the level of endemic infection was low, increasing the N rate had little effect on the level of infection. However, in years when the level of endemic infection was high, increasing the N rate greatly increased the rate of infection. The increase in PM induced by N fertilization was reduced by adding phosphorus (P). Therefore, increased N fertility can result in increased levels of PM, particularly when there is an imbalance between N and P.

The effect of N fertilization on PM level in winter wheat has been reported to be independent of the effect of SR, RS, seeding depth (Broscious et al, 1983) and cultivar (Teich et al, 1987).

#### 2.2.2.2 Effect of Seed Rate and Row Spacing

Broscious and co-workers (1986) reported that wider RS promoted increased PM severity on winter wheat. This effect was attributed to changes within the crop canopy microclimate. Low SR also seemed to promote increased PM severity for SR ranging from 101 kg $ha^{-1}$ to 235 kg ha$^{-1}$. It was suggested that the decrease in plant population density, due to reduced SR, may have decreased interplant competition for light, water, and nutrients. Consequently, plants may have grown more vigorously and incurred higher levels of powdery mildew in a response similar to that which develops with high N fertility. In contrast, Smith and Blair (1950) found higher levels of PM associated with narrow RS.

## 2.3 Response of Leaf Spot Diseases to Agronomic Management

### 2.3.1 Diseases of the Leaf Spot Complex

There are a number of leaf spot diseases that are similar in their symptoms and are very difficult to distinguish in the field. The most important of these in Saskatchewan are caused by two species of septoria: Septoria nodorum Berk. and Septoria tritici Rob. ex Desm. Both of these pathogens are Ascomycetes that belong to the subclass Loculoascomycetes (fruiting body is a pseudothecium). Their names in the perfect state are: Leptosphaeria nodorum Muller and Mycosphaerella graminicola (Fuckel) Sand. However, the imperfect states of these fungi are the most important epidemiologically, especially in western Canada. Consequently, they are typically grouped within the Deuteromycetes among the Sphaeropsidales (conidia produced within a semi-closed body called a pycnidium). Tan spot is also an Ascomycete that belongs to the subclass Loculoascomycetes. Tan spot will be referred to by the sexual state Pyrenophora tritici-repentis (Died.) Drechs. The asexual state is called Drechslera tritici-repentis. Tan spot is a disease of relatively minor importance in western Canada (Martens et al, 1984). In a particularly wet year it can increase in severity.

Septoria avenae blotch (Septoria avenae Frank f.sp. triticea Johns.) also contributes to the leaf spot complex in some areas. However it is generally of minor importance in north east Saskatchewan, and will not be dealt with in detail in this review.

In this thesis, unless referring to a specific disease, the leaf spot diseases will be referred to as "septoria". This term will include Pyrenophora tritici-repentis, Septoria nodorum and S. tritici.

### 2.3.2 Autecology of Leaf Spot Diseases

#### 2.3.2.1 Septoria nodorum and Septoria tritici

Septoria nodorum and S. tritici are necrotrophic pathogens; they kill the host tissue and feed on the dead cells. The pathogens advance within the dead tissue, but necrosis can extend well beyond the colonized cells, presumably due to diffusible toxins (Wiese,1977).

These organisms can overwinter in the Canadian prairies on straw and standing stubble (Samborski and Tekauz, 1986). The primary source of inoculum in the spring is diseased standing stubble and crop residue (Eyal, 1981), although seed and alternative hosts such as wheatgrasses (Agropyron spp.) are potential sources of inoculum (Krupinsky, 1983). Asexual spores, called conidia, are produced within the pycnidia. The conidia initiate growth on the wheat plants (Fig. 2.3). After penetration of the host tissue, mycelial growth occurs within the host

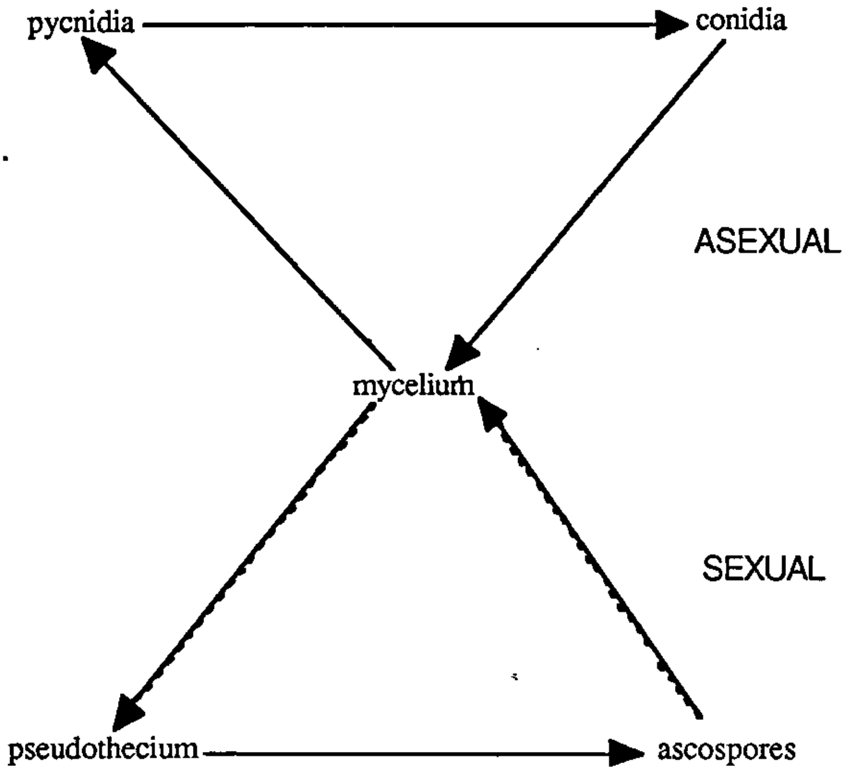

Figure 2.3 Life cycle of *Septoria nodorum* and *Septoria tritici*

tissue eventually producing pycnidia with enclosed conidia that are responsible for secondary infections (Martens et al, 1984). Undisturbed stubble can support conidial production for up to 3 years (Wiese,1977).

A sexual phase of the septoria life cycle may also occur in parts of the world where the climate is moderate and crop residues are rapidly broken down. In these areas, a pseudothecium produces ascospores that may act as a primary inoculum source. Conidia are important and effective for short-term dispersal, such as within the crop. Ascospores are more effective as a long range dispersal mechanism (Jenkyn and King, 1977; Sanderson et al, 1983). Planting wheat on wheat stubble may greatly increase the incidence of septoria in areas where the conidia act as the primary source of inoculum (Eyal, 1981). However, crop rotation is of less importance in determining the incidence of septoria in areas where ascospores act as a primary inoculum source (Sanderson et al, 1983). In western Canada, the importance of ascospores as a source of inoculum has not been established and the sexual state of _S. tritici_ has not even been reported (Martens et al, 1984). Consequently, the asexual phase of the life cycle and the conidia are more important epidemiologically. Parasexual mechanisms like hyphal anastomosis are also known to occur (Wiese, 1977).

Wet windy weather with temperatures ranging from 15° to 27° favour septoria development. Hot dry weather can slow or stop its development (Martens et al, 1984). Compared to _Septoria nodorum_, _Septoria tritici_ prefers slightly cooler temperatures and requires a longer period of post inoculation leaf wetness (or high RH) in order for infection to take place (Holmes and Colhoun, 1974). Consequently, Septoria tritici is more active early, while Septoria nodorum becomes more dominant later in the growing season (Wiese, 1977).

Moisture is an important environmental factor for each of the processes in the septoria infection cycle (Fig. 2.4). Conidia, present on the surface of a leaf, are forcibly dispersed to another host by rainsplash (Sanderson et al, 1983). Infection of the new host by the conidia includes the processes of germination of the conidia and penetration of the stomata by the germ tube (Wiese, 1977). These processes require adequate moisture and warm temperature. Moisture occurs as leaf wetness due to: rain, heavy dew, or RH greater than 90%. Post penetration septoria development involves several interactions between host and pathogen. These include killing of host tissue by cell wall degrading enzymes and diffusible toxins. These processes are also optimized by conditions of prolonged leaf wetness or high humidity (Eyal et al, 1977). Host genotype is important in determining susceptibility to the pathogen. The growth stage of the host has also been reported to be a factor, with Septoria tritici being aggressive at an earlier growth stage than Septoria nodorum (Williams and Jones, 1972). This observation may be merely a reflection of prevailing environmental conditions at different times of the season. Host vigour would also have to be considered a factor in the interaction between host and pathogen. Environmental stresses such as nutrient imbalances (Cunfer et al, 1980) may result in plants with increased susceptibility. Moisture stress will detrimentally affect both host and pathogen.

Reduced light intensity may be a factor favouring inoculum

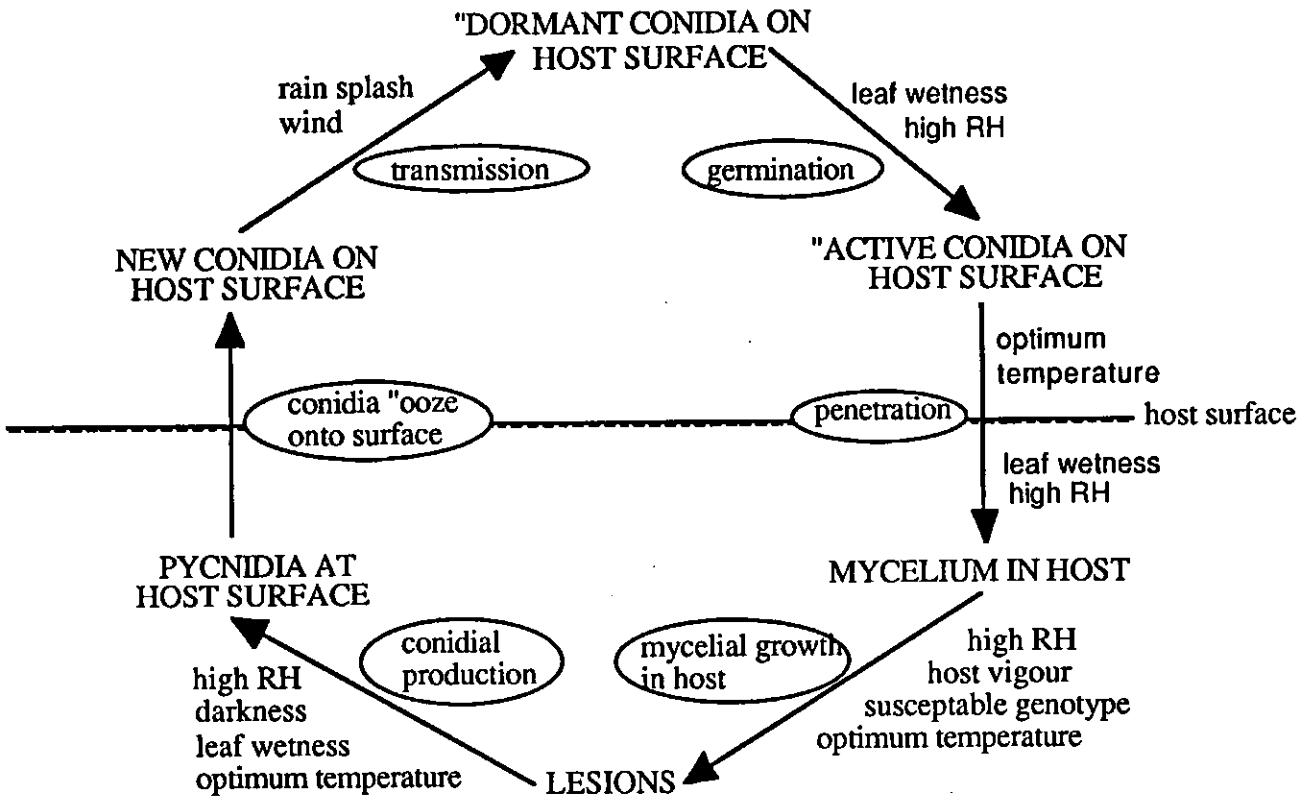

Figure 2.4 Environmental factors promoting processes in infection cycle of *Septoria nodorum* and *Septoria tritici*

production, at least in Septoria tritici (Benedict, 1971). Under sub-optimal conditions there may be both a reduced number of lesions (Eyal et al, 1977) and a reduced number of pycnidia in each lesion (Shaner et al, 1975). Environmental conditions influence not only the amount of inoculum produced, but also the time required to produce inoculum. Shearer and Zadoks (1974) reported that the length of the latent period (time from inoculation to production of inoculum) was shorter under conditions of favourable temperature and moisture. Under favourable conditions, secondary spores can be produced within 10 days (Wiese, 1977).

Liberated septoria conidia "ooze" from the pycnidia onto the leaf surface in a slime that protects them from radiation and desiccation. This slime may also help stimulate germination (Wiese, 1977). The spores may be transmitted by rain splash to another plant or leaf initiating secondary infections.

In areas where ascospores are an important method of septoria dispersal, the ascospores are released in the presence of water and are dispersed by wind. Ascospores can also function as long range dispersal agents of septoria (Sanderson et al, 1983).

In summary, conditions that favour septoria outbreaks include prolonged periods of rain, high humidity and temperatures in a range of 12° to 27°C (Eyal,1981). Shaner and Finney (1976) suggested a high probability of having a septoria epidemic in the U.S. Midwest when there were 34 days with rain or high humidity and no more than 2 days with minimum temperatures of 7° C or below in a 40 day period. Heavy dews are also important as the hours of leaf wetness are more critical than the frequency of rainy days. Disease progress can be stopped at any stage by the onset of warm, dry weather (Eyal et al,1977).

Some authors have suggested that Septoria nodorum is more likely to cause severe yield losses than Septoria tritici. Presumably it is more successful at attacking the upper leaves of the plant due to the shorter post-inoculation wet period requirements (Cooke and Jones, 1971; Holmes and Colhoun,1974).

Work on Septoria tritici suggests that disease development prior to flowering is at least as important as that during grain filling. Gaunt (1983) has reported that early infestation caused a reduced number of kernels head$^{-1}$ (with some compensation by an increase in kernel weight), while a late infestation caused a reduced kernel size. Some wheat lines demonstrated a tolerance to high levels of disease without incurring significant yield loss. Typically, these lines had high kernel weights when the disease was not present (Ziv et al, 1981). In contrast, Septoria nodorum can cause yield losses as a result of later developing epidemics. The yield component most affected by Septoria nodorum was kernel size.

### 2.3.2.2 Pyrenophora tritici-repentis

The life cycle of Pyrenophophora tritici-repentis is similar to that of Septoria spp. (Fig. 2.3) except that the sexual stage is more important. Tan spot overwinters on standing stubble and crop residues. In the spring, ascospores provide the major source of primary infection, although the conidia contribute to a lesser extent (Hosford, 1972). During the post inoculation period, conidial germination and germ tube production occur. Unlike septoria, a tan spot spore forms an appressorium and penetration peg and penetrates the host epidermal cell. Penetration occurs within 6 to 12 hours, so this represents a minimum leaf wetness requirement for optimum infection. Inside the host cell, the fungus develops a vesicle and then secondary hyphae invade the mesophyll intercellularly (Laerz et al, 1986). Light is required for the production of conidiophores (conidium bearing structures) and dark is required for the production of conidia (Khan, 1971). When other factors are favourable for sporulation, the fungus produces one "crop" of conidia per day. These conidia mature in the dark and are released in the morning when the wind increases (Morrall and Howard, 1975). Therefore, windspeed is a factor in tan spot dispersal.

Tan spot typically does not cause serious yield losses (Martens et al, 1984) but may cause losses in years when environmental conditions include prolonged wet periods with cool temperatures (Hosford and Busch, 1974). Highest yield losses occur when infection takes place at stem elongation and is followed by a prolonged wet period (Rees and Platz, 1983). A high level of tan spot inoculum in the spring (Rees et al, 1982) and a susceptible host genotype (Raymond et al, 1985) also favour severe infestation. Grain yield losses due to tan spot result from a reduced kernel weight and a reduced number of kernels head$^{-1}$ (Shabeer and Bokus, 1988).

### 2.3.3 Influence of Agronomic Practices on Septoria Development

#### 2.3.3.1 Effect of Fertility

Reports on the effect of N fertility on septoria development on winter wheat are conflicting. Gheorghies (1974) reported an increase in *Septoria tritici* with the use of high rates of N and Pirsen (1960, cited by Cunfer *et al*, 1980) reported an increase in *Septoria nodorum* with application of N fertilizer. Increased N fertility increases the plant density which in turn increases the leaf wetness period thereby promoting germination of septoria spores on the leaf. Alternatively, Naylor and Su (1988) and Johnston et al (1979) found that *Septoria nodorum* decreased as N rates were increased. Under minimum tillage (with reduced N availability) Cunfer *et al* (1980) found that levels of *Septoria nodorum* increased with increased use of P fertilizer. Septoria is a necrotrophic pathogen that advances within the host by feeding on dead tissue. A less vigorous plant, such as would occur under conditions of nutrient imbalance or deficiency, may promote the advance of the pathogen within the host tissue. This would result in an increased rate of lesion development. Therefore, increased N fertility may increase spore germination, but decrease the rate of lesion development, so the overall effect on septoria development may vary with different environmental conditions.

Tan spot has been reported to decrease as the rate of N application was increased on winter wheat (Huber *et al*, 1987). There were similar numbers of infection loci, but the rate of lesion development decreased as N rate increased.

### 2.3.3.2 Effect of Seed Rate and Row Spacing

The relationship between SRRS combination and septoria severity has not been clearly established. However, there are two separate processes to consider in this relationship. The first is the effect that the differing planting arrangements have on transmission of the disease and the second is the effect that changed microenvironmental conditions have on disease buildup.

Eyal (1981) made a general observation from work in Israel that the horizontal spread of septoria from foci in a spring wheat field occurred at a faster rate in thin stands. Supposedly the thin stand increased the raindrop splashing effect. Alternatively, Broscius et al (1985) reported increased severity of septoria on winter wheat as SR was increased.

The effect of RS on septoria severity is also unclear. Broscious et al (1985) reported no significant relationship between winter wheat RS and septoria severity. Mmbaga et al, (1979), studying Septoria glycines in soybeans reported an increase in severity with narrower rows.

While a relationship between SRRS and septoria severity has not been clearly established, it would be expected that changes to the microenvironment within the crop canopy would affect septoria levels. Conditions that favour prolonged periods of leaf wetness and higher RH within the crop canopy should favour the development of septoria.

### 2.3.3.3 Effect of Plant Height

Generally, there seems to be a relationship between shorter spring wheat plants and increased severity of septoria (Travella, 1978). It is possible that these are simply genotypic differences. For example, the genetic information controlling short plant height and increased susceptibility to septoria may be closely linked. However, the response may also be due to the decreased height.

Eyal (1981), suggested that vertical progress of the disease is affected by the distance between consecutive leaves. Like climbing a ladder, it takes less time to get to the top of a short ladder than to the top of a long ladder. In shorter cultivars, close leaf proximity facilitates contact of newly emerging leaves with splashing conidia or with infected lower leaves. According to Eyal and Ziv (1974) the shorter internodes with short cultivars increases the probability of greater septoria severity on the upper leaves even under moderate disease conditions. Ziv and co-workers (1981) suggested that the association between increased septoria severity and dwarfness may simply be the result of a longer pathogen stress on the photosynthetic tissue of short cultivars from an earlier stage of the growing season.

Scott et al (1985) reported that relative to plots on level ground, less septoria developed on winter wheat in plots raised on mounds and more septoria developed in plots sunk in trenches. Furthermore, measurements of photosynthetic area per unit volume of space occupied by canopies showed that taller cultivars had lower canopy densities than shorter cultivars. Leaf surface wetness lasted for a shorter period of time on two taller cultivars than on a shorter cultivar.

## 2.4 Interactions Between Powdery Mildew and Leaf Spot Diseases

Powdery mildew and septoria can be found on the same leaf. These pathogens interact with each other and with other pathogens (Frank, 1983). Mathis (1986) reported that PM allows *Fusarium culmorum* to infect wheat leaves. Chester (1944) found that infection by *Septoria tritici* reduced infection by leaf rust. Brokenshire (1974) reported that on a cultivar resistant to septoria, infection by PM predisposed the leaf to infection by septoria. Broscious et al (1982) found that on plants treated with triadimefon to control PM, there was an increase in the severity of septoria. Frank (1983) suggested that septoria and PM are competitors for leaf area and that tissue previously colonized by septoria was not readily colonized by PM. As *Erysiphe graminis* f.sp. *tritici* is an obligate parasite, necrotic regions on the plant surface resulting from septoria infection would restrict PM development.

# 3. MATERIALS AND METHODS

Three separate experiments were conducted in the period 1986 to 1988 to examine the effect of various SR and RS combinations on: yield and yield components, grain protein, soil water use, and foliar disease development in winter wheat. These SRRS studies have been designated: 1) experiment A, 2) experiment B and 3) experiment C. A fourth experiment was designed to determine the optimum time to spray fungicide to control PM and septoria, and to maximize grain yield. A range of disease epidemics were created by spraying with different fungicides at various stages of crop growth.

## 3.1 Studies of Seed Rate and Row Spacing - General

Field plots were seeded with a no-till offset double disk press drill, custom built to allow different SRRS combinations. Plot size was 1.4 m by 7 m. All trials were seeded in late August or early September.

In the fall after seeding, soil from each trial was sampled at depths of 0-15, 15-30 and 30-60 cm. Samples were bulked, air dried and ground to pass through a 2 mm sieve. In 1986 and 1987, samples were analyzed at the Melfort Research Station for available N at each of the depths and for available P at the 0-15 cm depth. The samples were extracted with 1 N $K_2SO_4$ and available nitrate was analyzed with an -29-

autoanalyzer (Kamphake et al, 1967; Clare and Stevenson, 1964). Phosphorus was extracted with 0.5 N $NaHCO_3$ and the concentration was determined using the molybdophosphoric blue method (Zandstra, 1968).

In 1988 the samples were submitted to the Saskatchewan Soil Testing Laboratory for analysis of nitrate-N and sulphate-S at each depth. Phosphorus and potassium were analyzed for the 0-15 cm depth. Nitrate N was extracted with 0.001 M $CaCl_2$. Nitrate level was determined by autoanalyzer using the cadmium reduction method. Phosphorus and potassium samples were extracted in 0.5 N $NaHCO_3$. Phophorus concentration was determined by autoanalyzer using the molybdophosphoric blue method (Zandstra, 1986) and potassium level was determined using flame emission spectrometry. Sulphate-S was extracted with 0.001 M $CaCl_2$ and concentration was determined by autoanalyzer using the methylthymol blue method.

Information on soil type and test results for each location, and each year are summarized in Table 3.1.

Seventy-five kg $ha^{-1}$ $P_2O_5$ from monoammonium phosphate fertilizer was broadcast on each trial after soil tests were taken in the fall. In early May, all plots received 100 kg N $ha^{-1}$ as broadcast ammonium nitrate fertilizer. Plots at Carrot River in 1987 were also broadcast fertilized with 20 kg $SO_4$ $ha^{-1}$ applied as ammonium sulfate and 80 kg $K_2O$ $ha^{-1}$ applied as potash.

Data from the weather station at the Melfort Research Station were used for weather information at the Melfort area trials since trials were located within 6 km. For the trials at Aylsham and Carrot River, weather stations were set up at the plot sites during the growing season. The weather station at the Nipawin airport was used for weather data from other times of the year since the Aylsham and Carrot River trials were within 35 km.

At three trials, irrigation water was added to supplement rainfall. At trial 6 38mm water was added by flood irrigation. Trials 7 and 10 were sprinkler irrigated with 50mm and 125mm of water respectively.

Experimental data were subjected to an analysis of variance. Single degree of freedom contrasts were used to examine biologically relevant factors such as the nature of the response to SRRS (Little and Hills, 1978). Mean separation for trial and cultivar were carried out using Fischer's protected least significant difference (Carmer and Walker, 1982; Chew, 1976). Regression curves were derived for SR and RS responses (Little, 1981). All analyses were run on SAS Version 5.16 (SAS, 1987).

Sub-samples of the harvested grain and straw were used for determination of protein and P content. Air dried samples were ground to a fine powder. Micro-Kjeldahl digestion of 0.25 g of ground sample in 10 ml concentrated sulfuric acid preceeded analysis with an autoanalyzer (cadmium reduction method) to determine percent N (Technicon Instrument Corp.,Tarrytown, N.Y.). Percent protein was calculated by multiplying percent N by 5.7. Phosphorus levels were determined using the vanadomolybdophosphoric yellow colour method (Jackson, 1958).

### 3.1.1 Experiment A

The experimental design for experiment A was a split-plot with four replicates. The winter wheat cultivars, Norstar and Norwin, were main plots and subplots were a factorial of 35, 70, 105, and 140 kg $ha^{-1}$ SR and 9, 18, 27, and 36 cm RS. Five trials were established over the period 1986 to 1988: 1, 2, 3, 5, and 7 (Table 3.1).

Levels of PM and septoria on the flag leaf were evaluated in mid-July using the Horsfall-Barratt Scale (Horsfall and Barratt, 1945). This method is outlined in the experiment C section (Section 3.1.3.1).

All plots were harvested in the late summer with a Hege small plot combine after removing the outside rows of the plot.

Nitrogen and P levels in the grain were measured in trial 3 and trial 7. Date of maturity measurements were taken in trial 2.

### 3.1.2 Experiment B

The experimental design for experiment B was a split-plot with two replicates. Only the cultivar Norstar was used in this study. Nitrogen fertility treatments, 0 and 100 kg applied N $ha^{-1}$, were main plots. Subplots were a factorial of 35 and 140 kg $ha^{-1}$ SR and 9 and 36 cm RS, providing extreme treatments for Saskatchewan Parkbelt conditions. An extra plot was seeded between each treatment as a buffer.

Soil moisture measurements were taken in each plot in early spring, at anthesis and immediately prior to harvest. Soil moisture was measured to a depth of 1 m with a Troxler 3331 depth moisture gauge. Access tubes were placed in the soil in early spring and readings were taken at depths of 20, 40, 60, 80 and 100 cm below the surface. The depth moisture gauge was calibrated by comparing readings with volumetric moisture values measured from drying soil cores. The calibration equation had an $r^2$ value of 0.91.

Soil moisture near the surface was determined by sampling the top 10 cm with a hand probe and oven drying the sample to determine gravimetric moisture content. Gravimetric moisture content was converted to volumetric moisture by multiplying it by the bulk density. Soil moisture values for each depth were summed to provide a value for moisture present in the 1 m profile.

The difference between soil moisture measured in the spring and at anthesis, and measured rainfall during that time period was taken to be WU during the vegetative growth period of the crop. The difference between soil moisture measured at anthesis and at harvest plus measured rainfall during that time period was taken to be WU during the reproductive growth period of the crop. This does not, however, account for water losses due to evaporation and runoff.

At maturity two one square meter samples were harvested from each plot, excluding outside rows. These were used to determine dry matter yield, grain yield, harvest index and kernel weight. An earlier sampling at anthesis was used to determine dry matter at anthesis.

Data were collected from seven trials over the period 1987-1988: trials 4 to 10 (Table 3.1).

Nitrogen and P levels in the grain and the straw were measured in trials 5 to 10.

### 3.1.3 Experiment C

#### 3.1.3.1 Disease Development Test

The experimental design for experiment C was a split-split plot with two replicates. Nitrogen fertility treatments of 0 and 100 kg applied N $ha^{-1}$, were main plots. Cultivars Norstar and Norwin were subplots, and a factorial of 35 and 140 kg $ha^{-1}$ SR and 9 and 36 cm RS, were sub-subplots. An extra plot was seeded between each treatment as a buffer. Virtually no PM developed in the low fertility plots. Therefore, the low fertility treatment was dropped from the PM statistical analysis. Consequently, the design for PM was a split-plot with cultivars as the main plots and SR and RS as the sub-plots.

Disease ratings were made using the Horsfall-Barratt grading system (Horsfall and Barratt, 1945). This scale is based on the assumption that up to 50% infection the eye tends to judge the portion of the leaf that is diseased. Above 50%, it judges the healthy portion of the leaf. Furthermore, the ability to distinguish small differences in percent infection is best near 0 and 100% and poorest near 50%. The grade limits are set by progressively halving above and below 50% in

Table 3.1 Soil types, soil test results and preceeding crop for seed rate and row spacing studies for each trial location and year.

| Trial | Location | Crop Year | Soil Association | Soil Texture | Soil Test Results (kg ha$^{-1}$) |  |  |  | Preceeding Crop |
|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  | $NO_3$-N[1] | $P_2O_5$[2] | K[2] | $SO_4$-S[1] |  |
| 1 | Aylsham | 1986 | Tisdale | silty clay loam | * | * | - | - | fallow |
| 2 | Melfort | 1986 | Melfort | silty clay loam | 28 | 22 | - | - | canola |
| 3 | Carrot River | 1987 | Car. Riv. | sandy loam | 18 | 8 | - | - | barley |
| 4 | Melfort | 1987 | Melfort | silty clay loam | 54 | 15 | - | - | wheat |
| 5 | Aylsham | 1988 | Car. Riv. | sandy loam | 17 | 20 | 112 | 43 | canola |
| 6 | Carrot River 1 | 1988 | Car. Riv. | sandy loam | 26 | 14 | 56 | >100 | fallow |
| 7 | Carrot River 2 | 1988 | Car. Riv. | sandy loam | 34 | 17 | 51 | >49 | barley |
| 8 | Melfort 1 | 1988 | Melfort | silty clay loam | 78 | 55 | >500 | 47 | barley |
| 9 | Melfort 2 | 1988 | Melfort | silty clay loam | 25 | 18 | 298 | 3 | canola |
| 10 | Melfort 3 | 1988 | Melfort | silty clay loam | 153 | 29 | 303 | >75 | canola |

[1] 0-60 cm

[2] 0-15 cm

*trial not sampled but land had been summerfallowed for 2 years rounded figures (Table 3.2). These grade values can also be derived using a logistic transformation of the percentage of diseased leaf tissue. Consequently, this grading system is an example of a pre-transformed scale where the grade values represent logistically transformed values. When rating plots, several plants within each plot were assessed in order to determine a grade value that was representative of the disease severity in the plot. A separate value was assigned for the flag leaf and for the flag leaf-1. After statistical analysis, the scale values were transformed back to real values (Little and Hills, 1972).

Disease evaluations were made at weekly intervals starting when the disease had reached the flag leaf-1, and continuing until the flag leaf had senesced to the point that ratings were no longer possible.

When evaluating "septoria", no attempt was made to distinguish between the different diseases of the leaf spot complex as they are difficult to identify in the field. Consequently, "septoria" ratings could include tan spot lesions as well as lesions of at least two Septoria spp.

Measurements of PM development on the flag leaf and the flag leaf-1 were analyzed using an analysis of variance with a split plot in time design. Measurements of septoria development on the flag leaf and the flag leaf-1 were analyzed using an analysis of variance with a split-split-plot in time design (Steele and Torrie, 1980). Trials were analyzed separately and single degree of freedom contrasts were used to separate the effects of SR, RS and SR by RS interaction (Little and

Table 3.2 The Horsfall-Barratt grading system (Horsfall-Barratt, 1945).

| Grade | % Diseased | % Healthy | Grade Formula % |
|---|---|---|---|
| 0 | 0 | 100 | 1.17 |
| 1 | 0-3 | 97-100 | 2.34 |
| 2 | 3-6 | 94-97 | 4.68 |
| 3 | 6-12 | 88-94 | 9.37 |
| 4 | 12-25 | 75-88 | 18.75 |
| 5 | 25-50 | 50-75 | 37.50 |
| 6 | 50-75 | 25-50 | 62.50 |
| 7 | 75-88 | 12-25 | 81.25 |
| 8 | 88-94 | 6-12 | 90.63 |
| 9 | 94-97 | 3-6 | 95.31 |
| 10 | 97-100 | 0-3 | 97.66 |
| 11 | 100 | 0 | 98.82 |

Hills, 1978).

Plant counts were taken in early May and head counts were taken immediately prior to harvest. At maturity two one square meter samples were harvested from each plot and used to determine dry matter yield and grain yield. Kernel weight was measured and kernels head$^{-1}$ were derived arithmetically from the other yield component measurements. Nitrogen and P levels were determined on the grain and the straw.

Trials 3, 6, 7, and 10 were evaluated for both septoria and PM (Table 3.1).

### 3.1.3.2 Critical Point Evaluations

The mid-July disease ratings from the disease development test were combined with ratings on treatments in common from experiment A. As these ratings were taken only once they are referred to as critical point evaluations. These ratings were analyzed in a split-plot design with two to four replicates. Cultivars Norstar and Norwin were main plots, and SRRS combinations were subplots. These subplots were a factorial of 35 and 140 kg ha$^{-1}$ SR and 9 and 36 cm RS together with the combination of 70 kg ha$^{-1}$ SR and 18 cm RS. The latter treatment represents the conventional SRRS combination commonly used in the Parkbelt region. Six trials were evaluated for septoria: 1, 3a, 3b, 6, 7, and 10 (Table 3.1). Five trials were evaluated for PM: 1, 3a, 3b, 6, 7.

### 3.1.3.3 Measurements of Microclimate Differences Within the Crop Canopy

Campbell Scientific dataloggers (CR21 and 21X microloggers) together with appropriate sensors were installed at four trials: 3, 5, 7, and 10 (Table 3.1). Measurements of light intensity, wind speed, leaf wetness, temperature and relative humidity taken over the period from late May to the end of the growing season were stored at hourly intervals on the datalogger. The period from flag leaf emergence until leaf senescence was used for analysis. Measurements were taken in the Norstar plots.

Measurements of light intensity, wind speed, leaf wetness, temperature and relative humidity were analyzed using an analysis of variance in a RCBD with days as replications. Light intensity and leaf wetness were analyzed separately for each trial. Single degree of freedom contrasts were used to separate the effects of SR, RS and SR by RS interaction for temperature and relative humidity (Little and Hills, 1978).

#### 3.1.3.3.1 Light Intensity

Tube solarimeters were installed to compare light intensity at the base of the crop canopy. The solarimeters were constructed according to the procedure of Szeicz et al (1964). They measure visible and infra-red radiation for wavelengths of 0.35 to 2.5 μm. Tube size was 970 mm length with a diameter of 26 mm so they caused minimal disturbance to the crop. The tubes were calibrated in diffuse light to a sensitivity of 15 mV per kW $m^{-2}$.

Light intensity was measured for wide and narrow RS treatments used in conjunction with high SR in trial 5. The solarimeter tubes were placed in the middle of the plot parallel to the rows at the mid-point between rows. Therefore, the solarimeters measured light that was not intercepted by the leaf canopy.

Radiant flux density is the amount of radiant energy received per unit time per unit area and is measured in Watt $m^{-2}$ (Monteith, 1973). The radiant flux density for the two RS was compared for a 41 day period commencing after the flag leaf was fully emerged. Approximations of daily integrals were also calculated using the formula:

$$(2N/pi)S_{tm}$$

where N is the daylength measured in seconds and $S_{tm}$ is the irradiance at solar noon. Daily integral is measured in MJ $m^{-2}$. A reading at solar noon should be carried out under cloudless conditions to determine an absolute value for the daily integral that is meaningful. This did not always occur. However, a relative value was obtained that was useful for the purpose of comparing light interception under wide and narrow RS.

### 3.1.3.3.2 Wind Speed

Wind speed was measured using a model 03101-5 Young wind sentry anemometer. The anemometers were mounted in the centre of a plot midway between rows with the cups at a height of 30 cm above the ground. The cup rotating radius was 6 cm. Consequently, for the narrow RS, it was necessary to prune a few plants immediately around the anemometer to reduce interference. Measurements were taken for wide and narrow RS treatments at the high SR in trials 5, 7, and 10.

### 3.1.3.3.3 Leaf Wetness

Leaf wetness periods were measured using Campbell Scientific model 231 and 237 leaf wetness sensors. Sensors were calibrated by exposing them to a series of wetting and drying cycles and determining an appropriate cutoff point between wet and dry readings. The percentage of time the sensor was wet was recorded at hourly intervals.
The sensors were installed in the middle of the plot mid way between the rows. High and low SR at the narrow RS were compared in trials 5 and 10. Narrow and wide RS at the high SR were also compared in trials 7 and 10.

### 3.1.3.3.4 Temperature

Temperature was measured using Campbell Scientific model 101 and 107 thermistor probes. After calibration over a range of temperatures, the probes were placed in the middle of a plot mid-way between rows. The probes were covered to shelter them from direct sunlight and rain and were suspended 2.5 cm above ground. If unshielded, a probe would read higher than ambient air temperature in response to irradiance and would read lower than ambient air temperature when water was evaporating from the surface (Sutton et al, 1984). Temperatures with high and low SR and wide and narrow RS were measured in trials 3, 5, 7, and 10.

### 3.1.3.3.5 Relative Humidity

At a constant dew point, the relationship between saturation vapour pressure and temperature can be expressed in the following manner:

$$e_{sat} = 6.107 \text{ X } e^{(17.27t)/(t + 237.3)}$$

where $e_{sat}$ is the saturation vapour pressure at a particular air temperature and t is the temperature in degrees centigrade. The actual vapour pressure ($e_{act}$) can be calculated as follows:

$$e_{act} = \text{RH X } e_{sat}.$$

Therefore, assuming a constant dewpoint, if relative humidity (RH) and temperature at a trial are known, the actual vapour pressure for the area can be calculated. From this, relative humidity can be calculated for each of the treatments for which temperature was recorded (Sutton et al, 1984).

Relative humidity was measured using a Campbell Scientific model 201 thermistor and relative humidity probe calibrated to the other thermistor probes used in a trial. From the measured trial value for RH and the measured treatment values for temperature, RH values were derived for high and low SR and wide and narrow RS. Relative humidity was measured in trials 3, 5, and 7.

### 3.1.3.3.6 Rainfall

Rainfall was measured for trials 3, 5, 7, and 10 using a Campbell Scientific model TE525 tipping bucket rain gauge. The rain gauge was mounted in each trial in a pathway that was free from obstruction.

## 3.2 Fungicide Study

Field experiments were established using the cultivar Norstar in a four replicate split-plot design with fungicide treatments as main plots and times of fungicide application as subplots. Three foliar fungicides were used in this experiment: mancozeb (trade name Dithane M-45) applied at a rate of 1.8 kg a.i. $ha^{-1}$ for control of septoria, triadimefon (trade name Bayleton WP 50) applied a rate of 0.125 kg a.i. $ha^{-1}$ for control of PM, and propiconazole (trade name Tilt) applied at a rate of 0.125 kg a.i. $ha^{-1}$ for control of both septoria and PM. Times of application included Feekes growth stage (GS) 5, 8, 10 a split application at 5+10, and a check. Plot size was 4 m by 8 m. Two square meter samples were harvested from each plot and used to determine dry matter yield and grain yield. Kernel weights were also measured. Six trials were established over the period 1986-1988: trials 11 to 16 (Table 3.3).

Disease ratings were taken in early to mid July at each trial using the Horsfall-Barratt Scale. Critical point evaluations were made of septoria in trials 12 to 16. Critical point evaluations were made of PM in trials 12, 13, 15, and 16. Mean separation for type of fungicide and time of application was carried out using Fischer's protected least significant difference (Carmer and Walker, 1982).

Table 3.3 Soil types for each trial location and year for the fungicide study.

| Trial | Location | Year | Soil Association | Soil Texture |
|---|---|---|---|---|
| 11 | Melfort | 1986 | Melfort | silty clay loam |
| 12 | Carrot River | 1986 | Carrot River | sandy loam |
| 13 | Carrot River | 1986 | Tisdale | clay |
| 14 | Birch Hills | 1987 | Naicam | silty loam |
| 15 | Carrot River | 1987 | Carrot River | sandy loam |
| 16 | Carrot River | 1988 | Carrot River | sandy loam |

# 4. RESULTS AND DISCUSSION

There was below average precipitation in all three years of these studies (Table 4.1). The April 1 to June 30 period, in particular, was dry for all trials except those at Carrot River in 1987. In 1986, April 1 to June 30 precipitation was 73% of normal at Melfort and 85% of normal at Carrot River. In 1987, it was 55% of normal at Melfort and about normal at Carrot River. In 1988, early season precipitation was 26% of normal at Melfort and 74% of normal at Carrot River.

Above normal temperatures during this time period were reflected in higher growing degree days (Table 4.2). While there were increased growing degree days during the whole year, this increase was particularly evident during the early part of the growing season especially in 1987 and 1988. For example, the number of growing degree days between April 1 and June 30 at Melfort was 144% of normal in 1987 and 148% of normal in 1988.

The combination of relatively dry conditions and elevated temperatures during this early part of the growing season resulted in below average growing conditions particularly in the last two years of the study. These abnormal weather conditions were also not ideal for the development of the foliar diseases powdery mildew and septoria.

Table 4.1 Summary of precipitation (mm) data for 1986-1988.

| Trials | Location | Year | Total Year[1] | | Growing Season[2] | | Early Season[3] | |
|---|---|---|---|---|---|---|---|---|
| | | Sept 1-Aug 31 | Precip. | %Normal[4] | Precip. | %Normal[4] | Precip. | %Normal[4] |
| 1 | Aylsham | 1985-86 | 345 | 86 | 214 | 87 | 105 | 85 |
| 2, and 11 | Melfort | 1985-86 | 369 | 90 | 242 | 98 | 94 | 73 |
| 12, and 13 | Carrot River | 1985-86 | 345 | 86 | 214 | 87 | 105 | 85 |
| 3, and 15 | Carrot River | 1986-87 | 494 | 123 | 348 | 141 | 129 | 105 |
| 4, and 14 | Melfort | 1986-87 | 363 | 88 | 233 | 94 | 71 | 55 |
| 5 | Aylsham | 1987-88 | 300 | 74 | 154 | 63 | 28 | 23 |
| 8, and 9 | Melfort | 1987-88 | 301 | 73 | 147 | 59 | 33 | 26 |
| 16 | Carrot River | 1987-88 | 300 | 74 | 154 | 63 | 28 | 23 |
| 6[5] | Carrot River | 1987-88 | 338 | 83 | 192 | 79 | 66 | 54 |
| 7[5] | Carrot River | 1987-88 | 350 | 86 | 204 | 83 | 78 | 64 |
| 10[5] | Melfort | 1987-88 | 426 | 103 | 272 | 109 | 158 | 124 |

[1] September 1 to August 31

[2] April 1 to August 31

[3] April 1 to June 30

[4] based on 30 year average, 1951-1980.

[5] includes rainfall and irrigation water.

Table 4.2 Summary of growing degree days (°C) for 1986-1988.

| Trials | Location | Year | Growing Season[1] | | Early Season[2] | |
|---|---|---|---|---|---|---|
| | | | GDD | %Normal[3] | GDD | %Normal[3] |
| 1 | Aylsham | 1986 | 1250 | 95 | 551 | 104 |
| 2, and 11 | Melfort | 1986 | 1303 | 104 | 592 | 114 |
| 12, and 13 | Carrot River | 1986 | 1250 | 95 | 551 | 104 |
| 4, and 14 | Melfort | 1987 | 1389 | 111 | 742 | 144 |
| 3, and 15 | Carrot River | 1987 | 1304 | 99 | 672 | 127 |
| 5 | Aylsham | 1988 | 1529 | 116 | 743 | 140 |
| 8, 9, and 10 | Melfort | 1988 | 1565 | 126 | 766 | 148 |
| 6, 7, and 16 | Carrot River | 1988 | 1529 | 116 | 743 | 140 |

[1] April 1 to August 31

[2] April 1 to June 30

[3] based on 30 year average, 1951-1980.

## 4.1 Effect of Agronomic Treatment on Yield and Yield Components

### 4.1.1 Experiment A

Grain yield. Differences among trials were significant for grain yield (Table 4.3). Contrasts indicated that this effect was due to year rather than location. Yields were higher in 1986 than in either 1987 or 1988 when drier conditions prevailed.

The effects of cultivar and the interaction between site and cultivar on grain yield were also significant (Table 4.3). The tall cultivar Norstar outyielded the semi-dwarf Norwin by 15% on average, an increase of 330 kg ha$^{-1}$ (Table 4.4). However, differences between cultivars were significant only in trials 1 and 3. In trial 1 there was an infestation of PM. The disease was present at low levels on the top two leaves of the cultivar Norstar, but at much higher levels on the Norwin upper leaves. In trial 3, Norwin yields were much lower than those of Norstar. Dry growing conditions in the spring, together with high levels of septoria (particularly on Norwin) may account for the differences in yield in this trial.

Seed rate had a significant effect on grain yield (Table 4.3). Highest mean grain yield was produced with the 140 kg ha$^{-1}$ SR (Table 4.5). The overall relationship between SR and grain yield (Y) expressed in kg ha$^{-1}$ is described by the equation:

$$Y = 1603 + 13.7\ SR - 0.05\ SR^2 \quad (R^2=0.99).$$

Moisture differences among years was one factor that produced a significant interaction of site and SR: the yield increase associated with 140 kg ha$^{-1}$ as compared to 35 kg ha$^{-1}$ ranged from 290 kg ha$^{-1}$ in

Table 4.3 Analysis of variance for grain yield and kernel weight for experiment A in five trials, 1986 to 1988.

| | | Mean Square | |
|---|---|---|---|
| Sources of Variation | df | Grain Yield | Kernel Weight |
| Trials | 4 | 85968248** | 3064.66** |
| Rep in trials | 14 | 2254383 | 28.37 |
| Cultivars (CV) | 1 | 15091398** | 30.97 |
| Trial x CV | 4 | 6726905** | 174.20** |
| Rep x CV in trials | 14 | 350081 | 10.66 |
| Seed Rate (SR) | 3 | 8401980** | 6.62* |
| Row Spacing (RS) | 3 | 4473442** | 12.37** |
| SR x RS | 9 | 262343* | 2.10 |
| Trial x SR | 12 | 868793** | 2.26 |
| Trial x RS | 12 | 251972* | 3.21 |
| CV x SR | 3 | 414757* | 2.89 |
| CV x RS | 3 | 82984 | 1.46 |
| Trial x SR x RS | 36 | 162918 | 1.46 |
| CV x SR x RS | 9 | 51962 | 3.88 |
| Trial x CV x SR | 12 | 136166 | 2.07 |
| Trial x CV x RS | 12 | 201781 | 3.54 |
| Trial x CV x SR x RS | 36 | 155294 | 2.21 |
| Error | 416 | 120164 | 2.21 |

*,**Significant at p=0.05 and p=0.01, respectively.

Table 4.4 Effect of trial and cultivar on grain yield in experiment A, 1986 to 1988.

| | Grain Yield (kg ha$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | Trial | | | | | |
| Cultivar | 1 | 2 | 3 | 5 | 7 | Mean[1] |
| Norstar | 3550a | 3290a | 2160a | 1880a | 1730a | 2520a |
| Norwin | 2970b | 3400a | 1050b | 1750a | 1790a | 2190b |
| Mean | 3260 | 3350 | 1600 | 1810 | 1760 | |
| $S_{\bar{x}}$ | 79 | 74 | 87 | 74 | 74 | 35 |

[1] Within a column, means followed by the same letter are not significantly different at p=0.05 by LSD.

Table 4.5 Effect of trial and seed rate on grain yield in experiment A, 1986 to 1988.

| | Grain Yield (kg $ha^{-1}$)[1] | | | | | | |
|---|---|---|---|---|---|---|---|
| | Trial | | | | | | |
| Seed Rate (kg $ha^{-1}$) | 1 | 2 | 3 | 5 | 7 | Mean[2] | $S_{\bar{x}}$ |
| 35 | 2940 | 2600 | 1340 | 1640 | 1560 | 2020 | 29.1 |
| 70 | 3310 | 3390 | 1540 | 1800 | 1730 | 2350 | 28.7 |
| 105 | 3270 | 3630 | 1750 | 1870 | 1890 | 2480 | 29.0 |
| 140 | 3520 | 3770 | 1790 | 1930 | 1870 | 2580 | 29.9 |
| Mean[3] | 3260a | 3350a | 1600b | 1810b | 1760b | | |
| $S_{\bar{x}}$ | 146 | 133 | 160 | 133 | 133 | | |

[1] Trial by seed rate interaction was significant at p=0.05 (F-test).

[2] Seed rate differences significant at p=0.05 (F-test).

[3] Within a row, means followed by the same letter are not significantly different at p=0.05 (LSD).

trial 5 to 1160 kg $ha^{-1}$ in trial 2. The highest grain yield was attained with the highest SR in four of the five trials.

In Saskatchewan, optimum SR varies widely depending on environmental conditions, particularly moisture. Observations on spring wheat suggest that optimum SR can be increased in moving from the Brown to the Black soil zones, corresponding to a move from a drier to a moister environment. Pelton (1969) working in the Brown soil zone found a SR as low as 22 kg $ha^{-1}$ was optimum, particularly in a dry year. Clarke and DePauw (1988), also working in the Swift Current area, found a SR of 80 kg $ha^{-1}$ was optimum when seeding on fallow. In the Dark Brown soil zone, an 81 kg $ha^{-1}$ SR produced the highest yields (Dominion Experimental Station Progress Report, 1948-1953, Scott). In the Black soil zone, Wright et al (1987) found a SR of 124 kg $ha^{-1}$ produced the highest yield. Elsewhere in the Parkbelt region, Briggs (1975) in Edmonton and Guitard et al (1961) in the Peace River area reported that a SR of 101 kg $ha^{-1}$ was optimum. In the studies by Briggs (1975) and Wright et al (1987), the SR reported to produce highest yield was the highest SR used in the test, so optimum SR may have been even higher than that evaluated.

Winter wheat research in humid regions of the U.S.A. supports the use of high SR in those areas. Joseph et al (1985) found SR of 101 to 134 kg $ha^{-1}$ was optimal in Virginia. Roth et al (1984) reported a SR of 168 kg $ha^{-1}$ produced highest grain yields in Pennsylvania.

Results from this present study compare favourably with the above studies. Under the moister growing conditions prevailing in 1986, which are more normal for this area, a SR of 140 kg $ha^{-1}$ or greater was optimum. Ideally, a higher SR should have been included in this study to determine whether the 140 kg $ha^{-1}$ SR is optimum under these conditions. With the drier conditions experienced in 1987 and 1988, a SR of 105 kg $ha^{-1}$ produced the highest grain yield at two of the three sites and the high SR produced the highest yield at the other site. Winter wheat can make better use of the early spring moisture than spring wheat. Therefore, in a year with normal moisture patterns, grain yield should be optimized at a higher SR for winter wheat than for spring wheat.

Norstar exhibited a greater response to increased SR than Norwin, resulting in a significant cultivar by SR interaction (Figure 4.1). Contrasts identified the interaction was attributable to differences in the linear portion of the response curve. The linear coefficients were 16.2 for Norstar and 11.2 for Norwin ( Table 4.6).

Row spacing also affected grain yield (Table 4.7). The linear relationship between grain yield (Y) expressed in kg $ha^{-1}$ and RS is described by the equation:

$$Y = 2692 - 14.9\ RS\ (R^2=0.94).$$

The 4% or 110 kg $ha^{-1}$ mean yield increase achieved with 9 cm as compared to 18 cm RS was less than the 7-10% that has been reported for winter wheat at similar RS in more humid areas of the U.S.A. (Joseph et al, 1985; Roth et al, 1984; Frederick and Marshall, 1985). It is, however, higher than the inconclusive results obtained by Briggs (1975) on spring wheat in the Edmonton area. Year to year variation in moisture conditions may account for a significant site by RS interaction. The interaction between SR and RS had a significant effect on grain yield (Table 4.3). The highest yield was achieved with the combination of narrow RS and high SR (9-140) (Figure 4.2). This

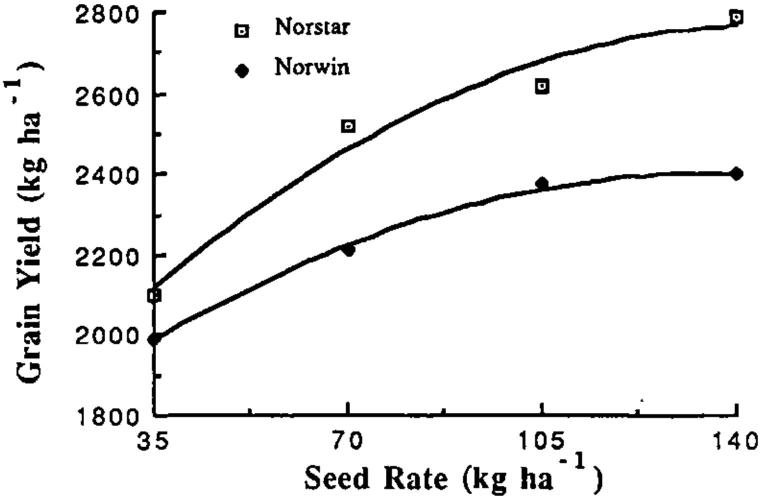

Figure 4.1 Effect of cultivar and seed rate on grain yield. Mean of four row spacings and five trials, 1986 to 1988 (SE = 41).

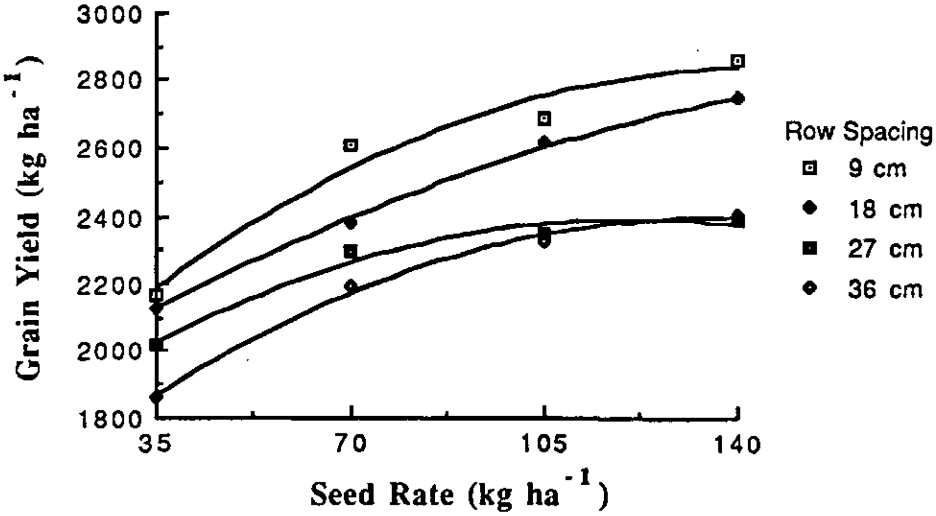

Figure 4.2 Effect of seed rate and row spacing on grain yield. Mean of two cultivars and five trials, 1986 to 1988 (SE = 57).

Table 4.6 Significant regression equations for grain yield in experiment A in five trials, 1986 to 1988.

| Regression | Level of Significance[1] | $R^2$ | Equation |
|---|---|---|---|
| Seed Rate (SR) | ** | 0.99 | $Y = 1603 + 13.7\ SR - 0.05\ SR^2$ |
| Row Spacing (RS) | ** | 0.94 | $Y = 2692 - 14.9\ RS$ |
| SR x RS | ** | 0.92 | $Y = 1940 + 13.8\ SR - 0.05\ SR^2 - 14.9\ RS$ |
| Cultivar x SR | | | |
| Norstar | ** | 0.93 | $Y = 1627 + 16.2\ SR - 0.06\ SR^2$ |
| Norwin | ** | 0.99 | $Y = 1581 + 11.2\ SR - 0.04\ SR^2$ |

[1] *,**,Significant at $p=0.05$ and $p=0.01$.

Table 4.7 Effect of row spacing on grain yield in experiment A in five trials, 1986 to 1988.

| | Grain Yield (kg ha$^{-1}$)[1] | | | | | | |
|---|---|---|---|---|---|---|---|
| | Trial | | | | | | |
| Row Spacing (cm) | 1 | 2 | 3 | 5 | 7 | Mean[2] | $S_{\bar{x}}$ |
| 9 | 3490 | 3680 | 1780 | 1970 | 1880 | 2560 | 29.9 |
| 18 | 3380 | 3510 | 1760 | 1820 | 1780 | 2450 | 29.4 |
| 27 | 3120 | 3130 | 1400 | 1750 | 1750 | 2230 | 28.6 |
| 36 | 3060 | 3070 | 1480 | 1700 | 1630 | 2190 | 28.7 |
| Mean[3] | 3260a | 3350a | 1600b | 1810b | 1760b | | |
| $S_{\bar{x}}$ | 146 | 133 | 160 | 133 | 133 | | |

[1] Trial by row spacing interaction was significant at p=0.05 (F-test).

[2] Row spacing differences significant at p=0.05 (F-test).

[3] Within a row, means followed by the same letter are not significantly different at p=0.05 (LSD).

combination produced a 1010 kg $ha^{-1}$ or 54% yield increase over the combination of wide RS and low SR (36-35). Producers in this region would more commonly use a RS and SR combination of 18 cm and 70 kg $ha^{-1}$ (18-70). Increasing the SR to 140 kg $ha^{-1}$ (18-140) increased yield by 320 kg $ha^{-1}$ or 13%. Reducing the RS to 9cm (9-70) increased yield by 240 kg $ha^{-1}$ or 10% over the 18-70 combination. The combined effect of increasing SR and decreasing RS (9-140) increased yield by 490 kg $ha^{-1}$ or 21% over the 18-70 treatment. Overall, the relationship among SR, RS, and grain yield (Y), expressed in kg $ha^{-1}$, was described by the equation:

$$Y = 1940 + 13.8\ SR - 0.05\ SR^2 - 14.9\ RS\ (R^2=0.92^{**}).$$

In two of the three years of the study, moisture levels were considerably below average. In a year with moisture levels approaching the long term average for the region, an even greater response to increased SR and narrow RS might be observed.

Kernel weight. Analysis of variance indicated that differences due to trial and the trial by cultivar interaction were significant for kernel weight (Table 4.3). The kernel weight of Norvin was higher than or equal to that of Norstar except for trials 1 and 3 (Table 4.8). The higher kernel weights for Norstar in these two trials may be due to the effect of higher levels of plant disease on Norwin.

Both reducing SR and RS significantly increased kernel weight (Table 4.9). Therefore higher kernel weight is associated with reduced

Table 4.8 Effect of trial and cultivar on kernel weight of winter wheat in experiment A, 1986 to 1988.

| | Kernel Weight (mg) | | | | | |
|---|---|---|---|---|---|---|
| | Trial | | | | | |
| Cultivar | 1 | 2 | 3 | 5 | 7 | Mean[1] |
| Norstar | 39.6a | 32.7b | 26.5a | 27.6a | 32.4b | 31.8a |
| Norwin | 37.3b | 34.7a | 22.6b | 27.6a | 34.1a | 31.3a |
| Mean | 38.4 | 33.7 | 24.5 | 27.6 | 33.3 | |
| $S_{\bar{x}}$ | 0.43 | 0.41 | 0.48 | 0.41 | 0.41 | 0.19 |

[1] Within a column, means followed by the same letter are not significantly different at p=0.05 by LSD.

Table 4.9 Effect of seed rate and row spacing on kernel weight in experiment A (average of two cultivars and five trials, 1986 to 1988).

| | Kernel Weight (mg) | | | | |
|---|---|---|---|---|---|
| | Row Spacing (cm) | | | | |
| Seed Rate ($kg\ ha^{-1}$) | 9 | 18 | 27 | 36 | Mean[1] |
| 35 | 31.9 | 31.9 | 31.6 | 31.0 | 31.6 |
| 70 | 32.2 | 32.2 | 31.6 | 31.2 | 31.8 |
| 105 | 31.4 | 31.4 | 31.2 | 31.4 | 31.3 |
| 140 | 31.6 | 31.4 | 31.4 | 31.0 | 31.3 |
| Mean[2] | 31.8 | 31.7 | 31.4 | 31.1 | |

[1] Seed rate differences significant at $p=0.05$ by F-test ($S_{\bar{x}}=0.12$).

[2] Row spacing differences significant at $p=0.05$ by F-test ($S_{\bar{x}}=0.12$).

numbers of plants per unit area and better spatial distribution of these plants. Both factors result in reduced plant competition. The relationship between SR, RS and kernel weight (Y) expressed in mg was described by the equation:

$$Y = 32.36 - 0.0034\ SR - 0.0239\ RS\ (R^2=0.53^*).$$

Kernel weight can be influenced by a number of factors, including stress during grain filling (Frederick and Marshall, 1985). Variable results have been reported concerning the effect of SR and RS on kernel weight (Briggs, 1975; Frederick and Marshall, 1985; Joseph et al, 1985). However, increased SR and wider RS promote greater intra-row competition for moisture and nutrients. Consequently, the slight decrease in kernel weight associated with increased SR or wider RS is not unexpected, particularly considering the relatively dry conditions during two of the three years of this study. This slight decrease in kernel weight is so small that it is not of practical concern.

### 4.1.2 Experiment B

Grain yield. Analysis of variance indicated that trial and N fertility both had a significant effect on grain yield (Table 4.10). Trials with better moisture conditions produced higher yields than the very dry trials, with average yields ranging from 430 kg $ha^{-1}$ to 2210 kg $ha^{-1}$ (Table 4.11). Nitrogen fertilization produced a 16% increase in average grain yield (Table 4.12).

Table 4.10 Analysis of variance for grain yield, dry matter yield, harvest index, and kernel weight in experiment B in seven trials, 1987 to 1988.

| Sources of Variation | df | Mean Square | | | | |
|---|---|---|---|---|---|---|
| | | Grain Yield | Dry Matter Yield | Harvest Index | Kernel Weight | Anthesis Dry Matter |
| Trial | 6 | 6728449** | 29419798** | .0636* | 107.32** | 6825342** |
| Rep in trial | 7 | 206554 | 1150247 | .0109 | 0.93 | 364027 |
| Fert | 1 | 2462410** | 8467735** | .0034 | 2.19 | 5225380* |
| Trial x fert | 6 | 501655* | 1541714 | .0049 | 3.92 | 249871 |
| Rep x fert in trials | 6 | 77234 | 473131 | .0013 | 3.38 | 344718 |
| SRRS | 3 | 199508** | 869774** | .0027 | 1.07 | 2163474** |
| RS | 1 | 357451** | 319522 | .0005 | 0.09 | 175238 |
| SR | 1 | 141386 | 2246397** | .0078 | 2.82 | 6101183** |
| SR x RS | 1 | 86786 | 8626 | .0000 | 0.24 | 202057 |
| Trial x SRRS | 18 | 45253 | 158148 | .0051 | 1.51 | 301746 |
| Fert x SRRS | 3 | 42063 | 116506 | .0034 | 4.08 | 100145 |
| Trial x Fert x SRRS | 18 | 83468* | 453866** | .0080 | 1.46 | 196651 |
| Error | 38 | 37747 | 151667 | .0044 | 1.51 | 164065 |

*,** Significant at p=0.05 and p=0.01, respectively.

Table 4.11 Effect of trial on water use, water use efficiency, grain yield, dry matter yield at anthesis and harvest, harvest index and kernel weight in experiment B.

| Variable | Trial |  |  |  |  |  |  | $S_{\bar{x}}$ |
|---|---|---|---|---|---|---|---|---|
|  | 4 | 5 | 6 | 7 | 8 | 9 | 10 |  |
| Water Use (cm) |  |  |  |  |  |  |  |  |
| Pre-anthesis | 5.2d | 9.4b | 8.2bc | 6.0d | 4.9d | 7.6c | 11.0a | 0.41 |
| Post-anthesis | 12.2a | 3.6de | 6.0c | 9.3b | 2.7e | 4.7cd | 8.7b | 0.45 |
| Growing Season | 17.4b | 13.0d | 14.3c | 15.3c | 7.5e | 12.4d | 19.8a | 0.36 |
| Efficiency(kg/cm) | 51b | 113a | 131a | 120a | 59b | 123a | 112a | 13.6 |
| Yield (kg $ha^{-1}$) |  |  |  |  |  |  |  |  |
| Grain | 890d | 1480c | 1970b | 1800bc | 430e | 1480c | 2210a | 117 |
| Dry Matter |  |  |  |  |  |  |  |  |
| Anthesis | - | 2260a | 2760a | 1240bc | 840c | 1530b | 2430c | 161 |
| Harvest | 2170c | 4450b | 4420b | 4280b | 1450c | 4350b | 4940a | 215 |
| Harvest Index | .41ab | .33bc | .45a | .42ab | .29c | .34bc | .45a | .016 |
| Kernel Wt. (mg) | 28.8c | 27.1d | 31.0b | 33.6a | 26.0e | 29.4c | 31.2b | 0.24 |

Within a row, means followed by the same letter are not significantly different at p=0.05 (LSD).

Table 4.12 Effect of nitrogen fertility on water use grain yield, dry matter yield, harvest index and kernel weight in experiment B (average of four seed rate and row spacing combinations and seven trials, 1987 to 1988).

| | Applied Nitrogen (kg N $ha^{-1}$) | | |
|---|---|---|---|
| Variable | 0 | 100 | $S_{\bar{x}}$ |
| Water Use (cm) | | | |
| Pre-anthesis | 7.3 | 7.8 | 0.19 |
| Post-anthesis | 6.6 | 6.8 | 0.29 |
| Growing Season | 13.9 | 14.6 | 0.15** |
| Efficiency | 99 | 105 | 3.7 |
| Yield (kg $ha^{-1}$) | | | |
| Grain | 1358 | 1572 | 38** |
| Dry Matter at Anthesis | 1672 | 2016 | 89* |
| Dry Matter at Harvest | 3505 | 3941 | 87* |
| Harvest Index | .38 | .40 | .005 |
| Kernel Weight (mg) | 29.7 | 29.5 | 0.25 |

*,** F-test significant at p=0.05 and p=0.01, respectively.

A significant trial by N fertilizer interaction for grain yield was due to the extremely dry growing conditions at trial 8. In this trial higher grain yield was associated with low N fertility. This is not of practical significance, as both fertilized and unfertilized yields were extremely low with little difference between them in absolute terms. The magnitude of response to increased N also differed between trials. Higher moisture trials exhibited a greater response to increased N fertilizer.

The SRRS combination had a significant effect on grain yield (Table 4.10). Contrasts indicated that RS was the factor that was most important, accounting for 60% of the variability due to SRRS. Highest grain yield was associated with the combination of high SR and narrow RS (Table 4.13). This is the same trend reported earlier in experiment A. The overall yields in this study were lower than in experiment A as this study contained a low fertility treatment and more drought-stressed trials. This may also account for the fact that RS seemed to have a greater effect on grain yield than SR.

There was a significant trial by N level by SRRS combination interaction in experiment B (Table 4.10). As noted previously, high N fertility generally resulted in increased grain yield except under very dry conditions (i.e. trial 8). In trial 7 growing conditions were very dry in the early and mid-part of the growing season. High N fertility reduced grain yield in the 36-140 treatment. Relatively dry conditions prevailed throughout the growing season at trial 9. Yields of the narrow RS treatments were reduced at high N fertility, especially at

Table 4.13 Effect of combinations of seed rate and row spacing on water use, grain yield and dry matter yield (average of two nitrogen levels and seven trials).

| | Seed Rate Row Spacing Combination | | | | |
|---|---|---|---|---|---|
| Variable | 9-35 | 36-35 | 9-140 | 36-140 | $S_{\bar{x}}$ |
| Water Use (cm) | | | | | |
| Pre-anthesis | 7.3 | 6.5 | 8.4 | 7.8 | 0.36** |
| Post-anthesis | 7.0 | 7.0 | 6.3 | 6.6 | 0.25* |
| Growing Season | 14.3 | 13.4 | 14.7 | 14.5 | 0.30 |
| Efficiency (kg/mm) | 101 | 103 | 106 | 96 | 3.5 |
| Yield (kg $ha^{-1}$) | | | | | |
| Grain | 1475 | 1391 | 1573 | 1420 | 38** |
| Dry Matter at Anthesis | 1460 | 1620 | 2190 | 2106 | 87** |
| Dry Matter at Harvest | 3640 | 3531 | 3921 | 3801 | 74** |
| Harvest Index | .40 | .39 | .38 | .37 | 0.01 |
| Kernel Wt. (mg) | 29.8 | 29.8 | 29.4 | 29.4 | 0.23 |

*,** F-test significant at p=0.05 and p=0.01, respectively.

the high SR in this trial. Yields of wide RS treatments at high SR and high fertility were also reduced. Consequently, this interaction may be viewed as a response to the varied moisture conditions that prevailed in these trials.

Dry matter yield. Analysis of variance indicated that trial and N fertility had a significant influence on dry matter yield (Table 4.10). Trials that received more moisture produced higher dry matter yields (Table 4.11). Increased N fertility also increased dry matter yield (Table 4.12).

The SRRS combination had a significant effect on dry matter yield. The 9-140 combination produced the highest dry matter yield (Table 4.10). Contrasts indicated that only the SR component had a significant influence on dry matter yield accounting for 86% of the variability due to SRRS. This was different from grain yield where RS accounted for more of the variability than SR.

There was also a significant trial by N fertility by SRRS interaction. The reasons for this interaction were similar to those outlined above for grain yield.

Harvest index. Trial was the only treatment variable that had a significant effect on harvest index (Table 4.10). Generally, the drier trials had a lower harvest index than the trials with more moisture (Table 4.11).

Kernel weight. Trial was the only treatment variable that had a significant effect on kernel weight (Table 4.10). Higher kernel weights were associated with the trials that had more moisture (Table 4.11).

Dry Matter at Anthesis. Trial and N fertility had significant effects on dry matter at anthesis (Table 4.10). Trials that received more moisture in the early part of the growing season produced more dry matter (Table 4.11). Increased N fertility also resulted in more dry matter production by anthesis (Table 4.12).

The SRRS combination had a significant effect on dry matter production by anthesis. Contrasts showed SR to be the important component accounting for 94% of the variability. High SR was associated with higher dry matter production by anthesis (Table 4.13). The increased dry matter at anthesis was also a reflection of higher WU by the high SR Treatments (Section 4.4).

### 4.1.3 Experiment C

Grain yield. Trial and N fertility had a significant effect on grain yield (Table 4.14). Trials with better moisture conditions produced higher yields than drier trials with average yields ranging from 360 to 2440 kg $ha^{-1}$ (Table 4.15). The high N treatment produced 21% higher grain yield than the low N treatment (Table 4.16). A poor yield response to N at two trials with severe early season moisture stress resulted in a significant trial by N fertility interaction.

Table 4.14 Analysis of variance for grain yield, kernel weight and heads $m^{-2}$ in experiment C (combined analysis for six trials, 1987 to 1988).

| | | Mean Square | | |
|---|---|---|---|---|
| Sources of Variation | df | Grain Yield | Kernel Weight | Heads $m^{-2}$ |
| Trial (T) | 5 | 11466209** | 342.55** | 77704** |
| Rep in T | 6 | 62666 | 3.50 | 6668 |
| Fertility (F) | 1 | 6035628** | 4.20 | 44764* |
| T x F | 5 | 1049838* | 2.29 | 14327* |
| Rep x F in T | 5 | 189670 | 1.48 | 2823 |
| Cultivar (CV) | 1 | 3491517** | 15.66* | 6040 |
| F x CV | 1 | 223457 | 0.96 | 6389 |
| T x CV | 5 | 346713 | 30.21** | 5410 |
| T x F x CV | 5 | 279023 | 1.82 | 10593* |
| Rep x CV in F and T | 9 | 175992 | 2.63 | 2861 |
| SRRS combination | 3 | 521299** | 11.93** | 200806** |
| RS | 1 | 1159098** | 0.00 | 528075** |
| SR | 1 | 14555 | 35.60** | 63278** |
| SR x RS | 1 | 390245* | 0.19 | 11063* |
| CV x SRRS | 3 | 106484 | 3.68 | 2040 |
| F x SRRS | 3 | 119887 | 2.08 | 3305 |
| T x SRRS | 15 | 153872** | 2.89 | 9994 |
| F x CV x SRRS | 3 | 47014 | 4.42 | 3021 |
| T x F x SRRS | 15 | 71646 | 2.22 | 3624 |
| T x CV x SRRS | 15 | 58275 | 1.95 | 5695* |
| T x F x CV x SRRS | 15 | 48950 | 1.93 | 3683 |
| Error | 60 | 62982 | 2.10 | 2676 |

*,**Significant at p=0.05 and p=0.01, respectively.

Table 4.15 Effect of trial on grain yield, kernel weight, heads $m^{-2}$, kernels $head^{-1}$, plants $m^{-2}$ and tillers $plant^{-1}$ in experiment C in six trials, 1987 to 1988.

| Trial | Grain Yield (kg $ha^{-1}$) | Kernel Weight (mg) | Heads $m^{-2}$ | Kernels $head^{-1}$ | Plants $m^{-2}$ | Tillers $plant^{-1}$ |
|---|---|---|---|---|---|---|
| 3 | 1250b[1] | 24.6a | 240b | 23.6c | 106a | 2.4c |
| 6 | 1860d | 31.3cd | 254b | 25.3cd | - | - |
| 7 | 1530c | 33.8e | 175a | 28.2de | 73d | 2.9bc |
| 8 | 360a | 27.2b | 152a | 10.0a | 78cd | 2.4c |
| 9 | 1310b | 30.5c | 286b | 17.4b | 84c | 4.0a |
| 10 | 2440e | 32.0d | 256b | 31.6e | 91b | 3.9ab |
| $S_{\bar{x}}$ | 47 | 0.4 | 15 | 1.2 | 1.7 | 0.3 |

[1] Within a column means followed by the same letter are not significantly different at p=0.05 (LSD).

Table 4.16 Effect of fertility and effect of cultivar on grain yield, kernel weight, heads $m^{-2}$, kernels $head^{-1}$, plants $m^{-2}$ and tillers $plant^{-1}$ in experiment C (mean of six trials, 1987 to 1988).

| Treatment | Grain Yield (kg $ha^{-1}$) | Kernel Weight (mg) | Heads $m^{-2}$ | Kernels $head^{-1}$ | Plants $m^{-2}$ | Tillers $plant^{-1}$ |
|---|---|---|---|---|---|---|
| Applied Nitrogen (kg N $ha^{-1}$) | | | | | | |
| 0 | 1320a[1] | 30.1a | 214a | 21.9a | 84a | 3.0a |
| 100 | 1600b | 29.7a | 241b | 23.4a | 89a | 3.3a |
| $S_{\bar{x}}$ | 46 | 0.13 | 5.7 | 0.8 | 2 | 0.2 |
| Cultivar | | | | | | |
| Norwin | 1320a[1] | 30.1a | 235a | 19.4a | 89a | 3.1a |
| Norstar | 1590b | 29.7b | 219a | 25.7b | 84a | 3.2a |
| $S_{\bar{x}}$ | 45 | 0.17 | 5.7 | 0.9 | 2 | 0.1 |
| Mean | 1460 | 29.9 | 228 | 22.7 | 87 | 3.2 |

[1] Within a column means followed by the same letter are not significantly different at $p=0.05$ (F-test).

Differences between cultivars were also significant for grain yield (Table 4.14). The tall cultivar Norstar outyielded the semi-dwarf cultivar Norwin by 20% under the relatively dry conditions that existed during this study (Table 4.16). It has been shown that Norwin produces high grain yields under high moisture conditions, but does not fare as well as Norstar under moisture stress (Entz and Fowler, 1989).

Seed rate and RS combination affected grain yield (Table 4.14). Contrasts indicated that the effect of RS was significant, accounting for 74% of the variability due to SRRS combination (Table 4.17). Contrasts also indicated a significant SR by RS interaction. Under the dry conditions experienced in this experiment, the 36-140 combination produced a lower yield than the 36-35 combination. This was particularly evident at trials 8, 9, and 10 resulting in a trial by SRRS interaction. This response can be explained by reduced moisture conditions for trials 8 and 9. This was not the case at trial 10 where good moisture conditions existed.

As was observed in experiment A, grain yield was promoted by increased SR and narrow RS. Unlike experiment A, the effect of RS on grain yield was more important than that of SR. This difference could have occurred because the soil moisture and foliar disease studies included more dry trials than experiment A. Clearly, SR produces the greatest grain yield response under conditions of favourable moisture. The response to RS may not be as moisture dependent, with a moderate yield increase occurring over a wide range of moisture conditions.

Yield components. Kernel weight, heads $m^{-2}$, (Table 4.14) kernels $head^{-1}$, plants $m^{-2}$ and tillers $plant^{-1}$ (Table 4.18) were all significantly influenced by trial. Better moisture conditions promoted higher kernel weight, increased heads $m^{-2}$, increased kernels $head^{-1}$, increased plants $m^{-2}$ and/or increased tillers $plant^{-1}$ (Table 4.15).

Heads $m^{-2}$, and kernels $head^{-1}$ were significantly influenced by fertility with high fertility promoting increased heads $m^{-2}$ and increased kernels $head^{-1}$ (Table 4.16).

Differences due to cultivar were significant for kernel weight, and kernels $head^{-1}$. Slightly higher kernel weight was associated with the cultivar Norwin while higher kernels $head^{-1}$ was associated with Norstar (Table 4.16). Therefore, the higher grain yield associated with Norstar was due to the increased number of kernels $head^{-1}$. This may have been a reflection on the inability of Norwin to perform well under the low moisture conditions present in this study.

A significant trial by cultivar interaction for kernel weight was probably due to a severe infestation of septoria at trial 3. The kernel weight of Norwin was reduced compared to that of Norstar at this trial.

All of the yield components were affected by the SRRS combination. Kernel weight was primarily affected by SR with higher kernel weight associated with the lower SR (Table 4.17). This would relate to the pattern of water use elucidated in experiment B (Section 4.4). The low SR used less soil moisture prior to anthesis leaving more soil moisture for uptake during the post-anthesis period. Heads $m^{-2}$ were affected by

SR, RS and their interaction with high SR and narrow RS promoting increased number of heads $m^{-2}$. The difference between heads $m^{-2}$ at the high and low SR was greater at the narrow RS than at the wide RS. Increased intra-row competition at the high SR resulted in reduced tillering and fewer heads $m^{-2}$ for the wide RS. The number of kernels $head^{-1}$ was promoted by low SR and wide RS. Plants $m^{-2}$ were increased by high SR and narrow RS, while the number of tillers $plant^{-1}$ was greater for the low SR. Compensation occurs among the yield components, so a reduction in heads $m^{-2}$ would be expected to be compensated for by an increase in kernel weight or kernels $head^{-1}$.

Plants $m^{-2}$ were influenced by the interaction between trial and SRRS combination. At trial 10 the 36-140 combination had a higher plant population than the 9-140 combination.

Kernels $head^{-1}$ were influenced by the interaction between N rate and SRRS. All SRRS treatments had higher kernels $head^{-1}$ associated with higher N rate, with the exception of 9-35. As kernels $head^{-1}$ were derived from the other yield components, this exception may be due to variability in the measurement of the other yield components. An interaction between cultivar and SRRS for kernels $head^{-1}$ may have been due to the same cause.

A number of other significant interactions involving SRRS are due to the extremely dry conditions at trial 8 and, to a lesser extent, trial 9 (Tables 4.14 and 4.18). These interactions are simply a

Table 4.17 Effect of seed rate and row spacing combination on grain yield, kernel weight, heads $m^{-2}$, kernels $head^{-1}$, plants $m^{-2}$ and tillers $plant^{-1}$ in experiment C (mean of six trials, 1987 to 1988).

| Row Spacing-Seed Rate (cm) (kg $ha^{-1}$) | Grain Yield (kg $ha^{-1}$)[2] [3] | Kernel Weight (mg)[1] | Heads $m^{-2}$ [1] [2] [3] | Kernels $head^{-1}$ [1] [2] | Plants $m^{-2}$ [1] [2] | Tillers $plant^{-1}$ [1] [2] |
|---|---|---|---|---|---|---|
| 36-140 | 1340 | 29.5 | 184 | 24.2 | 108 | 1.7 |
| 36-35 | 1400 | 30.4 | 159 | 28.8 | 41 | 4.1 |
| 9-140 | 1590 | 29.4 | 311 | 17.4 | 130 | 2.4 |
| 9-35 | 1490 | 30.3 | 255 | 20.2 | 65 | 4.3 |
| Mean | 1460 | 29.9 | 227 | 22.7 | 86 | 3.1 |
| $S_{\bar{x}}$ | 38 | 0.2 | 7.8. | 1.0 | 3 | 0.2 |

[1] Within a column differences due to seed rate were significant at $p=0.05$ (F-test).

[2] Within a column differences due to row spacing were significant at $p=0.05$ (F-test).

[3] Within a column differences due to seed rate x row spacing interaction were significant at $p=0.05$ (F-test).

Table 4.18 Analysis of variance for kernels head$^{-1}$, plants m$^{-2}$ and tillers plant$^{-1}$ in experiment C, 1987 to 1988.

| | Mean Square | | | | |
|---|---|---|---|---|---|
| Sources of Variation | df | Kernels head$^{-1}$ | df | Plants m$^{-2}$ | Tillers plant$^{-1}$ |
| Trial (T) | 5 | 1538.7** | 4 | 5128.4** | 16.66* |
| Rep in T | 6 | 39.4 | 5 | 79.4 | 2.15 |
| Fertility (F) | 1 | 364.4 | 1 | 1342.1 | 2.14 |
| T x F | 5 | 43.6 | 4 | 486.3 | 1.31 |
| Rep x F in T | 5 | 61.0 | 4 | 317.3 | 1.72 |
| Cultivar (CV) | 1 | 2113.9** | 1 | 213.4 | 0.02 |
| F x CV | 1 | 34.4 | 1 | 49.1 | 0.04 |
| T x CV | 5 | 83.6 | 4 | 638.8 | 5.46** |
| T x F x CV | 5 | 65.0 | 4 | 1204.4 | 0.53 |
| Rep x CV in F and T | 9 | 64.4 | 7 | 363.1 | 0.32 |
| SRRS combination | 3 | 1042.5** | 3 | 53532.1** | 53.64** |
| RS | 1 | 2524.9** | 1 | 18557.4** | 9.66** |
| SR | 1 | 562.2** | 1 | 142038.1** | 149.69** |
| SR x RS | 1 | 40.3 | 1 | 0.8 | 1.56 |
| CV x SRRS | 3 | 175.3** | 3 | 425.9 | 0.91 |
| F x SRRS | 3 | 125.5* | 3 | 474.5 | 1.18 |
| T x SRRS | 15 | 74.2 | 12 | 2548.1** | 4.70** |
| F x CV x SRRS | 3 | 49.3 | 3 | 418.3 | 0.24 |
| T x F x SRRS | 15 | 11.8 | 12 | 548.7 | 2.37* |
| T x CV x SRRS | 15 | 30.5 | 12 | 1199.1** | 2.56* |
| T x F x CV x SRRS | 15 | 37.3 | 12 | 466.3 | 0.92 |
| Error | 60 | 41.2 | 48 | 315.6 | 1.09 |

*,**Significant at p=0.05 and p=0.01, respectively.

response to extreme moisture stress and need not be discussed further here.

The results of this study demonstrate the compensation that can occur among the yield components. An increase in heads $m^{-2}$ is the yield component that was most responsible for the increase in grain yield associated with increased SR and narrow RS. Kernel weight and kernels $head^{-1}$ partially compensated for this increase in heads $m^{-2}$, particularly at the high SR. Plants sown at low SR also partially compensated for the decreased plant population by increased tillering. However, increased tillering was not great enough to fully compensate for the reduced plant populations at low SR.

Dry Matter Yield. Dry matter yield was influenced by trial, N rate and the interaction between trial and N rate (Table 4.19). Trial differences can be related to moisture differences among trials (Table 4.20). Dry matter yield was higher under conditions of high N fertility (Table 4.21). The trial by N rate interaction was primarily due to trial 7 where the dry matter yield of the 0 N treatment was slightly higher than the 100 N treatment. This pattern of N response was probably due to severe early season water stress.

The difference between cultivars was significant for dry matter yield. Norstar produced 17% higher dry matter yield than Norwin (Table 4.21). This was similar to the 20% difference between the two cultivars for grain yield, and provides another indication that Norwin was not as productive under the growing conditions experienced in these

Table 4.19 Analysis of variance for dry matter yield and harvest index for six foliar disease trials, 1987 to 1988.

| | | Mean Square | |
|---|---|---|---|
| Sources of Variation | df | Dry Matter Yield | Harvest Index |
| Trial (T) | 5 | 21912592** | 0.1174** |
| Rep in T | 6 | 212494 | 0.0113 |
| Fertility (F) | 1 | 9251628* | 0.0419* |
| T x F | 5 | 3540948* | 0.0073 |
| Rep x F in T | 5 | 589748 | 0.0043 |
| Cultivar (CV) | 1 | 4892228* | 0.0554 |
| F x CV | 1 | 2543959 | 0.0004 |
| T x CV | 5 | 1602556 | 0.0057 |
| T x F x CV | 4 | 1319938 | 0.0008 |
| Rep x CV in T and F | 9 | 649724 | 0.0113 |
| SRRS combination | 3 | 2175596** | 0.0160** |
| CV x SRRS | 3 | 79177 | 0.0078* |
| F x SRRS | 3 | 819370 | 0.0017 |
| T x SRRS | 15 | 382941 | 0.0070** |
| F x CV x SRRS | 3 | 350180 | 0.0053 |
| T x F x SRRS | 13 | 272933 | 0.0028 |
| T x CV x SRRS | 14 | 243627 | 0.0028 |
| T x F x CV SRRS | 12 | 338388 | 0.0034 |
| Error | 55 | 342284 | 0.0023 |

*,**Significant differences at p=0.05 and p=0.01, respectively.

Table 4.20 Effect of trial on dry matter yield, harvest index and grain protein in experiment C, 1987 to 1988.

| Trial | Dry Matter Yield ($kg\ ha^{-1}$) | Harvest Index | Grain Protein (%) |
|---|---|---|---|
| 3 | 3130b[1] | 0.39b | 11.9a |
| 6 | 4170d | 0.44b | 12.9ab |
| 7 | 3730c | 0.41b | 13.7bc |
| 8 | 1440a | 0.28a | 16.8d |
| 9 | 4260d | 0.30a | 15.2cd |
| 10 | 5310e | 0.46b | 13.8bc |
| $S_{\bar{x}}$ | 93 | 0.02 | 0.5 |

[1] Within a column means followed by the same letter are not significantly different at p=0.05 (LSD).

Table 4.21 Effect of fertility and effect of cultivar on dry matter yield, harvest index and grain protein in experiment C in six trials, 1987 to 1988.

| Treatment | Dry Matter Yield (kg $ha^{-1}$) | Harvest Index | Grain Protein (%) |
|---|---|---|---|
| Applied Nitrogen (kg N $ha^{-1}$) | | | |
| 0 | 3370a[1] | 0.37a | 13.4a |
| 100 | 3980b | 0.39a | 14.8b |
| $S_{\bar{x}}$ | 85 | 0.01 | 0.3 |
| Cultivar | | | |
| Norwin | 3380a[1] | 0.37a | 14.3a |
| Norstar | 3970b | 0.39a | 13.9b |
| $S_{\bar{x}}$ | 89 | 0.01 | 0.1 |
| Mean | 3670 | 0.38 | 14.1 |

[1] Within a column means followed by the same letter are not significantly different at $p=0.05$ (F-test).

trials.

Seed rate and row spacing combination had a significant effect on dry matter yield with the 9-140 combination producing the highest dry matter yield and 36-35 producing the lowest dry matter yield (Table 4.22). This is in agreement with the results obtained in experiment B (Section 4.1.2).

Seed rate had a greater effect on dry matter yield while RS had a greater effect on grain yield. The efficiency with which the dry matter yield was translated into grain yield was lower in the trials grown under the dry conditions, both in this study and in experiment B. These observations can be related to the pattern of water uptake throughout the growing season by the various treatments, and is discussed in more detail in Section 4.3.1.

Harvest index. Harvest index was also influenced by both trial and N rate (Table 4.19) with a lower harvest index in the drier trials (Table 4.20) and under conditions of lower N fertility (Table 4.21).

Seed rate and row spacing combination affected harvest index with a higher harvest index associated with low SR. The highest harvest index was observed for the 36-35 combination (Table 4.22). A significant trial by SRRS interaction was due to the fact that at the very dry trial 8, much of the early season dry matter production was not translated into grain yield at the high SR.

Table 4.22 Effect of seed rate and row spacing combination on dry matter yield, harvest index, and grain protein in experiment C in six trials, 1987 to 1988.

| Row Spacing-Seed Rate (cm) (kg ha$^{-1}$) | Dry Matter Yield (kg ha$^{-1}$)[1] | Harvest Index [1] | Grain Protein (%)[2] |
|---|---|---|---|
| 36-140 | 3640 | 0.36 | 14.3 |
| 36-35 | 3390 | 0.41 | 14.0 |
| 9-140 | 4010 | 0.36 | 14.4 |
| 9-35 | 3660 | 0.39 | 13.6 |
| Mean | 3670 | 0.38 | 14.1 |
| $S_{\bar{x}}$ | 91 | 0.01 | 0.1 |

[1] Differences among treatments were significant at p=0.01 (F-test).

[2] Within a column differences due to seed rate were significant at p=0.05 (F-test).

## 4.2 Effect of Agronomic Treatment on Crop Maturity

### 4.2.1 Experiment A

Seed rate and row spacing both affected date of maturity at trial 2 (Table 4.23). High SR and wide RS produced increased intra-row competition resulting in earlier maturity, with higher SR having a greater effect (Table 4.24). Winter wheat grown at the 9-140 combination matured two days earlier than winter wheat grown at the 18-70 combination. Therefore, particularly in a wet year, the use of high SR may confer a slight advantage in earlier maturity over a lower SR. The relationship between SR, RS and maturity (Y) at trial 2 was described by the equation:

$$Y = 238.38 - 0.07\ SR - 0.05\ RS\ (R^2{=}0.89^{**}).$$

In a year with differing moisture conditions, the y-intercept and the magnitude of the SR and RS contribution could vary widely. Maturity dates were not taken at the other trials, but the period of time over which the treatments matured was abbreviated at the drier trials.

Cultivar also affected maturity. Norwin matured in an average of 233 days, three days earlier than Norstar.

Table 4.23 Analysis of variance for maturity in experiment A at trial 2.

| Sources of Variation | df | Mean Square Maturity |
|---|---|---|
| Rep | 3 | 52.22 |
| Cultivar (CV) | 1 | 270.28* |
| Rep x CV | 3 | 16.34 |
| Seed Rate (SR) | 3 | 292.09** |
| Row Spacing (RS) | 3 | 17.80* |
| SR x RS | 9 | 6.42 |
| CV x SR | 3 | 0.72 |
| CV x RS | 3 | 0.68 |
| CV x SR x RS | 9 | 5.56 |
| Error | 90 | 4.95 |

*,**Significant at p=0.05 and p=0.01, respectively.

Table 4.24 Effect of seed rate and row spacing on crop maturity (day of the year) in experiment A (average of two cultivars at trial 2).

| Seed Rate | Maturity (day of year) | | | | |
|---|---|---|---|---|---|
| | Row Spacing (cm) | | | | |
| (kg ha$^{-1}$) | 9 | 18 | 27 | 36 | Mean[1] |
| 35 | 236 | 235 | 235 | 235 | 235 |
| 70 | 232 | 232 | 234 | 232 | 232 |
| 105 | 231 | 230 | 230 | 228 | 229 |
| 140 | 230 | 229 | 227 | 228 | 228 |
| Mean[2] | 232 | 231 | 231 | 230 | |

[1] Seed rate differences significant at p=0.05 by F-test ($S_{\bar{x}}$=0.4).

[2] Row spacing differences significant at p=0.05 by F-test ($S_{\bar{x}}$=0.4).

## 4.3 Effect of Agronomic Treatment Soil Moisture Use

### 4.3.1 Experiment B

Water use. Trial had a significant effect on pre-anthesis, post-anthesis and total growing season water use (WU)(Table 4.25). These differences were largely a reflection of differences in available water in the various trials (Table 4.11). In trial 4, there was a relatively high level of post-anthesis WU. Much of this was a heavy late season rainfall that was too late to affect crop yield, and some may have been lost to runoff.

Nitrogen rate had a significant effect on total growing season WU. More water was used under conditions of higher N fertility (Table 4.12). While N fertility did not have a significant effect on pre-anthesis and post-anthesis WU, the trend was the same as for the total growing season WU. Higher N fertility resulted in greater WU than conditions of low N fertility. This increase in WU as a result of increased N fertility has been well documented and includes extraction of water from deeper in the soil profile (Brown, 1971).

More water was used under conditions of low N fertility in trials 7 and 8. This resulted in a significant trial by N rate interaction for the growing season WU. Trial 8 experienced severe drought stress. Trial 7 was also subject to severe early and mid season water stress. These conditions resulted in premature senescense of many plant leaves, especially under conditions of higher N fertility where more early

Table 4.25 Analysis of variance for water use and water use efficiency in experiment B in seven trials, 1987 to 1988.

| | | Mean Square - Water Use | | | |
|---|---|---|---|---|---|
| Sources of Variation | df | Pre-anthesis | Post-anthesis | Growing Season | Efficiency |
| Trials | 6 | 79.27** | 182.15** | 242.10** | 16261.49* |
| Rep in trials | 7 | 2.60 | 3.15 | 2.00 | 2707.01 |
| Fertility (fert) | 1 | 4.09 | 3.08 | 15.12** | 2486.81 |
| Trial x fert | 6 | 5.25 | 4.16 | 10.87** | 1480.02 |
| Rep x fert in trials | 7 | 2.03 | 4.46 | 1.14 | 693.26 |
| SRRS combination | 3 | 15.74** | 4.68* | 6.53 | 542.49 |
| RS | 1 | 10.44 | 0.03 | 8.60 | 0.32 |
| SR | 1 | 36.76** | 11.71** | 7.22 | 6.52 |
| SR x RS | 1 | 0.18 | 2.49 | 3.86 | 1603.01* |
| Trial x SRRS | 18 | 4.29 | 1.17 | 3.53 | 465.57 |
| Fert x SRRS | 3 | 2.98 | 0.67 | 1.03 | 53.41 |
| Trial x fert x SRRS | 18 | 2.03 | 1.06 | 1.10 | 546.98 |
| Error | 38 | 3.46 | 1.68 | 2.39 | 314.62 |

*,** Significant at p=0.05 and p=0.01, respectively.

season plant growth occurred. Consequently, at these two trials, lower N fertility resulted in more sustainable plant growth and increased WU over the course of the growing season.

Seed rate and row spacing combination had a significant effect on both pre-anthesis and post-anthesis WU (Table 4.11). Contrasts indicated that for both growth periods, the effect of SR on WU was highly significant. Seed rate accounted for 78% of the variability in WU due to SRRS combination in the pre-anthesis growth period and 83% of the variability in the post-anthesis growth period. In the pre-anthesis growth period, increased WU was associated with higher SR. In the post-anthesis growth period, increased WU was associated with low SR (Table 4.13). Winter wheat grown in narrow RS also used more soil water during the pre-anthesis growth period than those in wide RS (significant at p=0.09).

Contrasts indicated that for the growing season, the plants grown at high SR used more water than those grown at low SR (significant at p=0.09) and plants grown at narrow RS used more water than those grown at wide RS (significant at p=0.07). Row spacing accounted for 44% of the variability in WU during the growing season and SR accounted for 37% of the variability in WU.

The relationship between dry matter production, grain production and the pattern of water uptake for the different SR treatments is of interest. The amount of dry matter at anthesis and harvest both exhibited a much greater response to high SR than did grain yield (Table 4.13). This relates to the pattern of WU in the pre-anthesis and post-anthesis period. Prior to anthesis, more water was taken up by the high SR. Under the dry conditions present in this study, more water was taken up by the low SR in the period after anthesis, because there was more water still available. Consequently, much of the early season advantage of the high SR was not sustained. These results support the observation of Fischer and co-workers (1975) that dry matter production is maximized at a higher SR than is grain production. The higher post-anthesis WU did result in slightly higher kernel weights ($p \approx .18$)(Table 4.11).

Narrow RS also resulted in greater WU over the course of the growing season. This was due to increased WU during the pre-anthesis growth period of the plant. The effect of narrow RS on pre-anthesis WU was not as dramatic as the effect of high SR. Consequently, the reduced availability of water during the post-anthesis period was not as pronounced. Winter and Welch (1987) have reported similar results in Texas. Wide-row systems were effective in economizing soil WU before the boot stage. This would leave more water in the later growth stages, particularly at low seed rates. Steiner (1986), working with sorghum, suggested that narrow rows increase the proportion of water removed from the soil by transpiration as opposed to evaporation. It is possible that the better ground cover associated with narrow RS results in more efficient conversion of solar energy into dry matter, particularly early in the season.

Water use efficiency. Trial had a significant effect on water use efficiency (WUE)(Table 4.11). Dry conditions at trials 4 and 8 resulted in a lower WUE than at the other trials. At trial 4, summer rains were too late to affect grain yield resulting in a reduced WUE. At trial 8, severe drought conditions resulted in very low WUE as much of the early dry matter production did not result in grain yield.

The interaction between SR and RS also had a significant effect on WUE (Table 4.25). The treatment 36-140 had a reduced WUE compared to the other treatments (Table 4.13). Plants grown in the wide RS treatments used less soil water than plants grown in the narrow RS treatments, but also had reduced grain yield. At the higher SR the intra-row competition imposed by the combination of high SR and wide RS, together with the dry conditions that prevailed at most of the trials, resulted in a lower harvest index. Much of the increased dry matter production was not translated into increased grain yield. Highest WUE was associated with the 9-140 combination. Crops grown with the combination of high SR and narrow RS may demonstrate an even higher WUE compared to the other treatments during a year with normal moisture conditions for the Parkbelt area.

While the early season plant population was primarily determined by SR, RS had a greater effect on the number of heads $m^{-2}$ at harvest than did SR (Table 4.17). This could be partly due to increased intra-row competition for moisture and nutrients by plants in wide RS. However, the improved spatial distribution associated with narrow RS also improves the interception of incident solar radiation providing an advantage for plants grown in narrow RS. Plants grown in the 36-35 treatment had a higher WUE, but lower grain yield than plants grown in the 9-35 treatment. While plants grown in the 36-35 treatment used less water than in the 9-35 treatment, especially in the pre-anthesis growth period, grain yield was reduced even further. Generally, however, any practice that reduces limitations to growth imposed by factors other than water should improve WUE (Begg and Turner, 1976).

Fischer and Turner (1978) suggested that increasing the amount of water lost to transpiration rather than evaporation would improve WUE. This could be accomplished through increased soil water extraction, improved plant cover or increased harvest index, which can be aided by the use of narrower RS.

Higher WUE was associated with higher N fertility (p=.11). This is in agreement with results reported by Stepphun and Zentner (1986) for spring wheat.

## 4.4 Effect of Agronomic Treatment on Plant Protein and Phosphorus

### 4.4.1 Experiment A

Grain protein. There were significant differences in grain protein concentration (GP) among the trials in this study (Table 4.26). Higher GP was associated with the drier growing seasons. There were a number of interactions involving trial that were statistically significant, but not practically relevant. Consequently, these interactions will not be discussed.

Table 4.26 Analysis of variance for grain protein and phosphorus in experiment A in two trials, 1987 to 1988.

| | | Mean Square | |
|---|---|---|---|
| Sources of Variation | df | Grain Protein | Grain Phosphorous |
| Trial | 1 | 264.95** | 0.0250* |
| Rep in trials | 3 | 0.15 | 0.0009 |
| Cultivar (CV) | 1 | 0.17 | 0.0021 |
| Trial x CV | 1 | 22.34* | 0.0026 |
| Rep x CV in trials | 3 | 1.12 | 0.0056 |
| Seed rate (SR) | 3 | 1.96** | 0.0001 |
| Row spacing (RS) | 3 | 1.29** | 0.0001 |
| SR x RS | 9 | 1.25** | 0.0022 |
| Trial x SR | 3 | 1.19* | 0.0012 |
| Trial x RS | 3 | 0.98* | 0.0020 |
| CV x SR | 3 | 0.31 | 0.0008 |
| CV x RS | 3 | 0.30 | 0.0001 |
| Trial x SR x RS | 9 | 0.88** | 0.0006 |
| CV x SR x RS | 9 | 0.27 | 0.0014 |
| Trial x CV x SR | 3 | 0.75 | 0.0013 |
| Trial x CV x RS | 3 | 0.95* | 0.0014 |
| Trial x CV x SR x RS | 9 | 0.45 | 0.0016 |
| Error | 85 | 0.32 | 0.0012 |

*,**Significant at p=0.05 and p=0.01, respectively.

Seed rate, RS and the SR by RS interaction all had highly significant effects on GP. Grain protein concentration tended to increase as SR increased and as RS decreased (Table 4.27). The relationship between SR, RS and GP was described by the equation:

$$GP = 13.81 + 0.0044\ SR - 0.0144\ RS\ (R^2=0.30^*).$$

The low $R^2$ for this equation reflects the fact that SR and RS only account for a small amount of the variability in GP.

Grain phosphorous concentration. Grain phosphorous concentration (P) was significantly affected only by trial location (Table 4.26). There were higher levels of grain P in trial 3. Differences in P were related to kernel size suggesting that the differences in P for the two trials were due to a dilution effect. Kernel size was much smaller in trial 3 than in trial 7 (Table 4.8). This could be due to a severe septoria epidemic, or to moisture stress in the 1987 trial. There is a dilution effect when comparing grain P from the two trials.

### 4.4.2 Experiment B

Grain protein. Trial location and N rate both affected GP (Table 4.28). Higher GP levels were associated with the drier trials (Table 4.29) and with higher N rate (Table 4.30). In spring wheat high protein concentration in the grain is typically associated with moisture stress (Campbell et al, 1977). Very high protein levels occur when grain yield is restricted (Henry et al, 1986) such as at trial 8.

Table 4.27 Effect of seed rate and row spacing on grain protein in experiment A (average of two trials and two cultivars, 1987 to 1988).

| Seed Rate | Grain Protein (%)[1] Row Spacing (cm) | | | | |
|---|---|---|---|---|---|
| (kg $ha^{-1}$) | 9 | 18 | 27 | 36 | Mean[2] |
| 35 | 13.5 | 14.1 | 13.5 | 13.1 | 13.5 |
| 70 | 14.5 | 13.7 | 13.9 | 13.7 | 13.9 |
| 105 | 14.0 | 14.2 | 13.6 | 13.9 | 13.9 |
| 140 | 13.8 | 14.5 | 14.2 | 13.8 | 14.1 |
| Mean[3] | 14.0 | 14.1 | 13.8 | 13.6 | |

[1] Differences due seed rate by row spacing interaction significant at p=0.05 (F-test).

[2] Differences due to seed rate significant at p=0.05 by F-test ($S_{\bar{x}}$=0.09).

[3] Differences due to row spacing significant at p=0.05 by F-test ($S_{\bar{x}}$=0.09).

Table 4.28 Analysis of variance for grain protein, grain phosphorus, straw protein and protein yield in experiment B in six trials, 1988.

| Sources of Variation | df | Mean Square | | | | |
|---|---|---|---|---|---|---|
| | | grain protein | grain phosphorus | straw protein | protein yield | phosphorus yield |
| Trials | 5 | 79.99** | 0.049** | 23.07** | 107535** | 98.43** |
| Rep in trials | 6 | 4.54 | 0.005 | 0.60 | 4947 | 2.52 |
| Fertility (fert) | 1 | 46.49* | 0.016* | 0.89 | 103794** | 14.98* |
| Trial x fert | 5 | 20.12 | 0.011* | 1.26 | 14585 | 7.88* |
| Rep x fert in trials | 5 | 4.38 | 0.002 | 1.10 | 3318 | 0.95 |
| SRRS combination | 3 | 9.53** | 0.010** | 0.38 | 2086* | 2.22** |
| RS | 1 | 0.61 | 0.002 | 0.01 | 1252 | 1.92* |
| SR | 1 | 25.30** | 0.029** | 1.10* | 2894* | 3.93** |
| SR x RS | 1 | 2.66 | 0.001 | 0.04 | 2113 | 0.81 |
| Trial x SRRS | 15 | 1.87 | 0.003** | 0.79** | 1856** | 1.03* |
| Fert x SRRS | 3 | 0.67 | 0.002 | 0.41 | 1174 | 0.66 |
| Trial x fert x SRRS | 15 | 1.69 | 0.002* | 0.53 | 1569* | 0.99* |
| Error | 33 | 1.30 | 0.001 | 0.23 | 663 | 0.42 |

*,** Significant at p=0.05 and p=0.01, respectively.

Table 4.29 Effect of trial on grain protein, grain phosphorus, straw protein, protein yield and phosphorus yield in experiment B (average of two nitrogen levels and four seed rate and row spacing combinations).

| Trial | Grain Protein (%protein) | Grain Phosphorus (%P) | Straw Protein (%protein) | Protein Yield (kg ha$^{-1}$) | Phosphorus Yield (kg ha$^{-1}$) |
|---|---|---|---|---|---|
| 5 | 10.2c | 0.23c | 1.5d | 154c | 3.35c |
| 6 | 12.8b | 0.32ab | 3.2bc | 252b | 6.51b |
| 7 | 13.2b | 0.35a | 3.7b | 242b | 6.29b |
| 8 | 18.0a | 0.37a | 5.7a | 57d | 1.07d |
| 9 | 14.2b | 0.27bc | 3.1bc | 207bc | 3.84c |
| 10 | 13.6b | 0.37a | 2.7c | 319a | 8.94a |
| $S_{\bar{x}}$ | 0.55 | 0.02 | 0.2 | 18.5 | 0.42 |

Within a column, means followed by the same letter are not significantly different at p=0.05 (LSD).

Table 4.30 Effect of nitrogen fertility on grain protein, grain phosphorus, protein yield phosphorus yield and straw protein in experiment B (average of four seed rate and row spacing combinations and six trials).

| | Applied Nitrogen (kg $ha^{-1}$) | | |
|---|---|---|---|
| Variable | 0 | 100 | $S_{\bar{x}}$ |
| Grain protein (% protein) | 13.0 | 14.4 | 0.3* |
| Grain phosphorus (% P) | 0.33 | 0.30 | .006* |
| Protein yield (kg $ha^{-1}$) | 179 | 231 | 8.7** |
| Phosphorus Yield (kg $ha^{-1}$) | 4.96 | 5.04 | 0.1 |
| Straw protein (%/protein) | 3.2 | 3.4 | .15 |

*,** F test significant at p=0.05 and p=0.01, respectively.

associated with an increased concentration of GP (Table 4.27). Darroch (1988) reported that 90% of the total plant N is accumulated by anthesis. Spiertz and Vos (1985) reported that 50% to 80% of the N used by the grain is derived from vegetative organs. Nitrogen assimilation is maximized in the pre-anthesis growth period, and carbohydrate assimilation is maximized in the post-anthesis growth period (Fowler et al, 1989). In this study, plants grown with high SR used more soil moisture in the pre-anthesis growth period, producing greater dry matter accumulation by anthesis. This would result in greater N uptake, possibly translating into higher GP as the N was partitioned. After anthesis, the period of maximum carbohydrate assimilation, there was less available soil water for the high SR treatments. This could result in slightly lower kernel weights (p=.18). More water was extracted by the high SR treatment than the by low SR treatment from the measured soil profile, resulting in a greater harvest of N (Table 4.13).

In experiment A, (Section 4.4.1) GP increased as RS decreased. There was a smaller GP response to reduced RS than increased SR. As for SR differences, the increase in GP associated with the narrow RS could be related to the patterns of soil moisture use and N uptake. Plants grown in narrower RS used more soil moisture before anthesis, during the period of maximum N assimilation.

The GP response to RS was nonsignificant in experiment B. However, the difference between pre-anthesis and post-anthesis moisture uptake and dry matter accumulation was much greater for SR

Table 4.31 Effect of seed rate and row spacing combination on grain protein, grain phosphorus, straw protein, protein yield and phosphorus yield in experiment B (average of two nitrogen levels and six trials, 1988).

| | Seed Rate and Row Spacing Combination | | | | |
|---|---|---|---|---|---|
| Variable | 9-35 | 36-35 | 9-140 | 36-140 | $S_{\bar{x}}$ |
| Grain Protein (%) | 12.9 | 13.4 | 14.3 | 14.1 | 0.24** |
| Grain Phosphorus (% P) | 0.30 | 0.30 | 0.34 | 0.32 | .007** |
| Protein Yield (kg $ha^{-1}$) | 199 | 200 | 219 | 203 | 5.5* |
| Phosphorus Yield (kg $ha^{-1}$) | 4.80 | 4.66 | 5.52 | 5.03 | 0.14 |
| Straw Protein (%) | 3.2 | 3.2 | 3.4 | 3.4 | 0.10 |

*,** F-test significant at p=0.05 and p=0.01, respectively.

than for RS. Consequently, the response of GP concentration to RS was not detectable in this study.

Grain phosphorus. Differences among trials were significant for grain P concentration (Table 4.29). These differences can be related to differences in available P at different trial locations and soil textures (Table 3.1).

Nitrogen fertility also had a significant effect on the concentration of grain P (Table 4.30). A higher concentration of P in the grain was associated with lower levels of N fertility. This was likely a dilution effect as grain P yield was higher with higher N fertility. A significant trial by N rate interaction was the result of a higher concentration of grain P together with the higher N response at trials 6 and 7.

The SRRS combination also had an effect on the concentration of P in the grain with SR accounting for 91% of the variability in grain P due to SRRS (Table 4.28). High SR resulted in higher grain P (Table 4.31). However, there was an interaction between trial and SRRS combination as SR had no effect on grain P in some trials.

Most P uptake occurs early in the plant's life cycle. Like GP, the relationship between increased P concentration and high SR can be related to the pattern of water uptake and crop growth. At high SR the plants extracted more soil water, at least to the depth which was measured. As P is a relatively immobile nutrient in the soil, this suggests more extensive root development with high SR. A more extensive root system resulting in the exploration of greater soil volume would promote P uptake (Raper and Barber, 1970).

Straw protein concentration. Differences among trials were significant for straw protein concentration (SP)(Table 4.29). Differences associated with N rate were also significant (Table 4.30). Slightly higher levels of SP were associated with the higher rates of applied N fertilizer.

High SR produced a slightly higher level of SP than did low SR (Table 4.31). There was a significant interaction between trial and SRRS combination. As for GP, these responses reflect the pattern of WU and N assimilation.

Grain protein yield. Protein yield was influenced by the same variables that affected grain yield and GP. Moisture and N rate, have a particularly strong effect on GP yield (Ramig and Rhoades, 1963). Trials that had very low grain yields due to moisture stress had a lower protein yield despite the higher GP (Table 4.29). Fowler and co-workers (1989), have reported similar trends for GP yield and GP of winter wheat and fall rye produced in Saskatchewan. Increased N rate also increased protein yield (Table 4.30). This increase in GP yield was expected as increased N fertility typically promotes both grain yield and GP.

High SR also promoted higher protein yield (Table 4.31) as the high SR treatment increased both grain yield and GP. In the very dry trial 8 there was a higher GP yield associated with the low SR resulting in a significant trial by SRRS combination interaction.

Grain phosphorus yield. Variation in grain P was influenced by the variables that affected grain yield as well as by the variables that affected grain P concentration. A significant trial effect (Table 4.29) was due to differences in grain yield at the different trials and to differences in P levels in the soil. A slightly higher P yield with the high N rate could be related to yield response (Table 4.30). Slightly higher P yield was also associated with the 9-140 SRRS combination (Table 4.31). This observation can be related to grain yield N response and increased P uptake by a more extensive root system at higher N rates.

## 4.5 Effect of Agronomic Treatment on Powdery Mildew

Uncharacteristically hot and dry weather, particularly in the springs of 1987 and 1988 (Table 4.1 and 4.2) meant that PM epidemics were late developing and for the most part remained at low levels.

### 4.5.1 Experiment A

Significant differences among cultivars were observed for PM severity on the flag leaf (Table 4.32). There was more PM present on the flag leaves of the semi-dwarf cultivar Norwin than the tall cultivar Norstar. This may have been due to differences in plant height or to genotypic differences in disease resistance.

Table 4.32 Analysis of variance for effect of winter wheat cultivar, seed rate and row spacing on powdery mildew level on flag leaves in experiment A at two trials, 1986 and 1987.

| | | Mean Square |
|---|---|---|
| Sources of Variation | df | Powdery Mildew on Flag Leaf |
| Trial | 1 | 0.59 |
| Rep in trials | 5 | 2.77 |
| Cultivar (CV) | 1 | 83.89** |
| Trial x CV | 1 | 0.15 |
| Rep x CV in trials | 5 | 1.73 |
| Seed Rate (SR) | 3 | 1.10* |
| Row Spacing (RS) | 3 | 0.38 |
| SR x RS | 9 | 0.35 |
| Trial x SR | 3 | 0.41 |
| Trial x RS | 3 | 1.00* |
| Trial x SR x RS | 9 | 0.08 |
| CV x SR | 3 | 0.54 |
| CV x RS | 3 | 0.96* |
| CV x SR x RS | 9 | 0.56 |
| Trial x CV x SR | 3 | 0.90* |
| Trial x CV x RS | 3 | 0.15 |
| Trial x CV x SR x RS | 9 | 0.43 |
| Error | 150 | 0.30 |

*,**Significant at p=0.05 and p=0.01, respectively.

Seed rate had a significant influence on PM severity on the flag leaf (Table 4.32). The level of PM increased as SR increased (Figure 4.3). Contrasts indicated that the relationship between PM and SR was linear. However, in trial 3 where PM levels were lower, the tall cultivar Norstar showed no PM response to increased SR. This lack of response by Norstar in trial 3 compared to the remaining trials was responsible for a significant trial by cultivar by SR interaction.

Unlike SR, RS did not have a consistent influence on PM severity (Table 4.32). Norwin had a higher severity of PM as RS was increased, but Norstar showed little response. There was also a significant trial by RS interaction. In trial 3, as RS increased PM increased, but there was no effect of RS on PM in trial 1.

### 4.5.2 Experiment C

#### 4.5.2.1 Critical Point Evaluations

Combined results of experiment A and experiment C. Cultivar and the trial by cultivar interaction had a significant effect on PM severity on the flag leaf and the flag leaf-1 (Table 4.33). Powdery mildew severity was greater on both the flag leaf (Table 4.34) and the flag leaf-1 (Table 4.35) of the semi-dwarf cultivar Norwin. At trial 7, early season moisture stress resulted in premature senescence of green leaf tissue, particularly on Norwin. This factor, together with the late developing epidemic of PM, meant that much of the green leaf

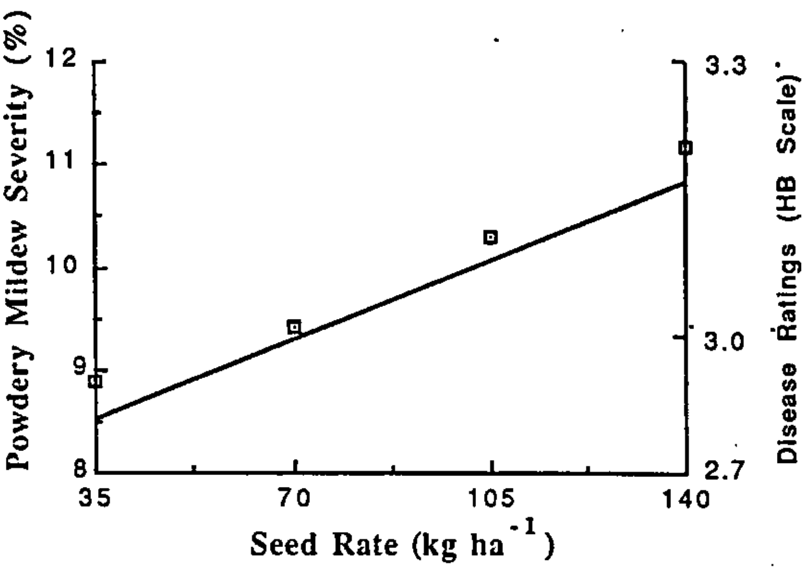

Figure 4.3 Effect of seed rate on powdery mildew severity on the flag leaf.. Mean of two cultivars and four row spacings grown in trials 1 and 3 (disease rating SE = 0.07).

Table 4.33 Analysis of variance for powdery mildew severity on the flag leaf and the flag leaf-1 in experiment C, 1986 to 1988.

| | Mean Square - Powdery Mildew Level | | | |
|---|---|---|---|---|
| Sources of Variation | df | Flag Leaf | df | Flag Leaf-1 |
| Trial | 4 | 4.29 | 3 | 15.11 |
| Rep in trials | 8 | 5.16 | 6 | 4.00 |
| Cultivar (CV) | 1 | 12.90** | 1 | 9.54* |
| Trial x CV | 4 | 10.16** | 3 | 9.09* |
| Rep x CV in trials | 8 | 1.61 | 5 | 1.06 |
| SRRS combination | 4 | 3.68** | 4 | 3.30** |
| RS | 1 | 6.93** | 1 | 0.23 |
| SR | 1 | 6.89** | 1 | 10.89** |
| SR x RS | 1 | 0.61 | 1 | 1.56* |
| Trial x SRRS | 16 | 0.74 | 12 | 0.90** |
| CV x SRRS | 4 | 0.10 | 4 | 0.62 |
| CV x RS | 1 | 0.01 | 1 | 1.56* |
| CV x SR | 1 | 0.00 | 1 | 0.39 |
| CV x SR x RS | 1 | 0.09 | 1 | 0.11 |
| Trial x CV x SRRS | 16 | 1.21** | 12 | 1.02** |
| Error | 64 | 0.44 | 43 | 0.32 |

*,**Significant at p=0.05 and p=0.01, respectively.

Table 4.34 Powdery mildew severity (%) on the flag leaf of two cultivars in experiment C (mean of five trials, 1986 to 1988).

| | Flag Leaf Powdery Mildew Severity (%)[1] | | | | |
|---|---|---|---|---|---|
| | Cultivar | | | | |
| Trial | Norstar | $S_{\bar{x}}$ | Norwin | $S_{\bar{x}}$ | Mean |
| 1 | 4a | 0.8 | 13b | 2.4 | 7 |
| 3a | 7a | 1.4 | 17b | 3.3 | 11 |
| 3b | 8a | 1.9 | 10a | 3.0 | 8 |
| 6 | 8a | 2.3 | 17a | 4.7 | 12 |
| 7 | 11a | 3.3 | 4b | 1.7 | 7 |
| Mean[2] | 7a | 1.0 | 11b | 1.9 | |

[1] Differences due to trial by cultivar interaction were significant at p=0.05 (F-test).

[2] Within a row means followed by the same letter are not significantly different at p=0.05 (LSD).

Table 4.35 Powdery mildew severity (%) on the flag leaf-1 of two cultivars in experiment C in four trials, 1986 to 1988.

| | Flag Leaf-1 Powdery Mildew Severity (%)[1] | | | | |
|---|---|---|---|---|---|
| | Cultivar | | | | |
| Trial | Norstar | $S_{\bar{x}}$ | Norwin | $S_{\bar{x}}$ | Mean |
| 1 | 8a | 0.9 | 28b | 3.8 | 14 |
| 3 | 8a | 1.5 | 7a | 1.4 | 8 |
| 6 | 19a | 4.2 | 50b | 6.5 | 34 |
| 7 | 21a | 4.7 | 3b | 0.8 | 11 |
| Mean[2] | 11a | 1.0 | 19b | 2.8 | |

[1] Differences due to trial by cultivar interaction were significant at p=0.05 (F-test).

[2] Within a row means followed by the same letter are not significantly different at p=0.05 (LSD).

tissue on the upper leaves of Norwin had senesced by the time the PM had advanced as far as the upper leaves. Powdery mildew is a biotrophic pathogen, requiring green leaf tissue to develop. Consequently, reduced development of PM on the upper leaves of Norwin in trial 7 produced a trial by cultivar interaction.

Seed rate/row spacing combination influenced PM severity on both flag leaf and flag leaf-1. Contrasts indicated that both SR and RS had a significant influence on PM severity on the flag leaf. However, only SR had a significant effect on PM severity on the flag leaf-1 (Table 4.33). Powdery mildew severity was promoted by wide RS and high SR with the combination of 36-140 producing the highest level of disease on the flag leaf (Table 4.36). On the flag leaf-1, high SR produced the greatest severity of PM (Table 4.37).

Powdery mildew spores are wind dispersed so movement of spores up the plant is aided by wind. Colony growth at a given leaf location is promoted by rapidly growing green leaf tissue, high relative humidity and optimum temperature. This suggests that wide RS aids PM dispersal up the plant, while the closed-in canopy associated with high SR, and to a lesser extent narrow RS, promotes PM development on a given leaf. If this is true, the early stages of an epidemic would be aided by wide RS, and later stages by high SR and perhaps narrow RS. Wide RS would be more important for dispersal to the flag leaf as opposed to the flag-1. It would also be more important for the tall cultivar Norstar than for the semi-dwarf cultivar Norwin because the spores have to be dispersed further to reach the flag leaf of a taller cultivar. Some support for this idea is provided by the significant trial by SRRS interaction for PM on the flag leaf-1. This interaction was due to a

Table 4.36 Powdery mildew severity (%) on the flag leaf of two cultivars at five seed rate and row spacing combinations in experiment C (average of five trials, 1986 to 1988).

| | Flag Leaf Powdery Mildew Severity (%) | | | |
|---|---|---|---|---|
| | Cultivar | | | |
| Row Spacing-Seed Rate (cm) (kg ha$^{-1}$) | Norstar | Norwin | Mean[1] | $S_{\bar{x}}$ |
| 36-140 | 9 | 17 | 12 | 1.0 |
| 36-35 | 7 | 13 | 9 | 0.5 |
| 18-70 | 6 | 11 | 8 | 0.5 |
| 9-140 | 7 | 12 | 9 | 0.5 |
| 9-35 | 5 | 7 | 6 | 0.5 |
| Mean[2] | 7a | 11b | | |
| $S_{\bar{x}}$ | 1.0 | 1.9 | | |

[1] Differences due to seed rate and row spacing combination significant at p=0.05 (F-test).

[2] Within a row means followed by the same letter are not significantly different at p=0.05 (F-test).

Table 4.37 Powdery mildew severity (%) on the flag leaf-1 of two cultivars at five seed rate and row spacing combinations in experiment C (average of four trials, 1986 to 1988).

| Row Spacing-Seed Rate (cm) (kg $ha^{-1}$) | Flag Leaf-1 Powdery Mildew Severity (%) | | | |
|---|---|---|---|---|
| | Cultivar | | | |
| | Norstar | Norwin | Mean[1] | $S_{\bar{x}}$ |
| 36-140 | 15 | 24 | 18 | 0.9 |
| 36-35 | 10 | 15 | 12 | 1.0 |
| 18-70 | 9 | 21 | 14 | 1.0 |
| 9-140 | 14 | 28 | 19 | 1.4 |
| 9-35 | 8 | 12 | 9 | 0.7 |
| Mean[2] | 11a | 19b | | |
| $S_{\bar{x}}$ | 1.0 | 2.8 | | |

[1] Differences due to seed rate and row spacing combination significant at p=0.05 (F-test).

[2] Within a row means followed by the same letter are not significantly different at p=0.05 (LSD).

high PM level on the 36-35 treatment compared to the other treatments in trial 7 (Table 4.38). The epidemic was later in developing in trial 7 so the epidemic could have still been in a dispersal phase at the time the disease ratings were taken. Contrasts also indicated a significant cultivar by RS interaction on the flag leaf-1 (Table 4.37). Higher levels of PM were associated with wide RS on the tall cultivar Norstar than on the semi-dwarf cultivar Norwin.

#### 4.5.2.2 Disease development

Seed rate influenced PM development on both the flag leaf and the flag leaf-1 in trial 3 (Table 4.39). High SR promoted PM development (Figure 4.5). A significant cultivar by SRRS interaction resulted from the fact that wide RS was relatively more important for promoting PM on the tall cultivar Norstar.

Powdery mildew development was significantly influenced by cultivar in trial 6 (Table 4.40). PM severity was greater on the semi-dwarf cultivar Norwin than on the tall cultivar Norstar (Figure 4.5). High SR promoted PM development on both upper leaves (Figures 4.6 and 4.7) while RS did not have a significant effect on PM development.

Seed rate and row spacing combination had a significant effect on PM severity in trial 10 (Table 4.41). Highest levels of PM were associated with the 36-140 combination (Figures 4.8 and 4.9).

Seed rate and row spacing combination had a significant effect on PM development in trial 7 (Table 4.42). High SR was most important in promoting increased levels of PM (Figures 4.10 and 4.11).

Table 4.38 Powdery mildew severity (%) on the flag leaf-1 at five seed rate and row spacing combinations in experiment C in four trials.

| | Flag Leaf-1 Powdery Mildew Severity (%)[1] | | | | | |
|---|---|---|---|---|---|---|
| | Row Spacing (cm)-Seed Rate (kg $ha^{-1}$)Combination | | | | | |
| Trial | 36-140 | 36-35 | 18-70 | 9-140 | 9-35 | Mean |
| 1 | 17 | 11 | 16 | 18 | 9 | 14 |
| 3 | 9 | 7 | 6 | 8 | 7 | 8 |
| 6 | 50 | 28 | 28 | 63 | 12 | 34 |
| 7 | 12 | 16 | 8 | 12 | 9 | 11 |
| Mean[2] | 18 | 12 | 14 | 19 | 9 | |
| $S_{\bar{x}}$ | 0.9 | 1.0 | 1.0 | 1.4 | 0.7 | |

[1] Differences due to interaction between trial and seed rate and row spacing combination significant at p=0.05 (F-test).

[2] Significant differences at p=0.05 (F-test).

Table 4.39 Analysis of variance for powdery mildew development on the flag leaf and the flag leaf-1 in trial 3.

| | Mean Square | | | |
|---|---|---|---|---|
| Sources of Variation | df | Flag Leaf | df | Flag Leaf-1 |
| Rep | 1 | 1.23 | 1 | 0.06 |
| Cultivar (CV) | 1 | 0.25 | 1 | 0.09 |
| Rep x CV | 1 | 1.60 | 1 | 7.29 |
| SRRS combination | 3 | 0.72 | 3 | 1.52* |
| RS | 1 | 0.14 | 1 | 0.00 |
| SR | 1 | 2.02* | 1 | 3.71** |
| SR x RS | 1 | 0.01 | 1 | 0.86 |
| CV x SRRS | 3 | 1.64* | 3 | 1.50* |
| Rep x SRRS in CV | 6 | 0.27 | 6 | 0.21 |
| Time | 4 | 39.89** | 3 | 8.51** |
| Rep x Time | 4 | 0.79 | 3 | 0.22 |
| CV x Time | 4 | 0.88 | 3 | 0.30 |
| CV x Early | 1 | 0.00 | 1 | 0.00 |
| CV x Mid | 1 | 2.19** | 1 | 0.49 |
| CV x Late | 1 | 1.35* | 1 | 0.70 |
| Rep x CV x Time | 4 | 0.09 | 3 | 0.32 |
| SRRS x Time | 12 | 0.40 | 9 | 0.31 |
| RS x Early | 1 | 0.09 | 1 | 0.14 |
| RS x Mid | 1 | 0.03 | 1 | 0.20 |
| RS x Late | 1 | 0.20 | 1 | 0.02 |
| SR x Early | 1 | 0.27 | 1 | 0.18 |
| SR x Mid | 1 | 1.09 | 1 | 0.03 |
| SR x Late | 1 | 1.89* | 1 | 0.05 |
| SR x RS x Early | 1 | 0.02 | 1 | 0.01 |
| SR x RS x Mid | 1 | 1.09 | 1 | 0.01 |
| SR x RS x Late | 1 | 1.02 | 1 | 0.00 |
| CV x SRRS x Time | 12 | 0.63 | 9 | 0.28 |
| Error | 24 | 0.32 | 18 | 0.25 |

*,**Significant at p=0.05 and p=0.01, respectively.

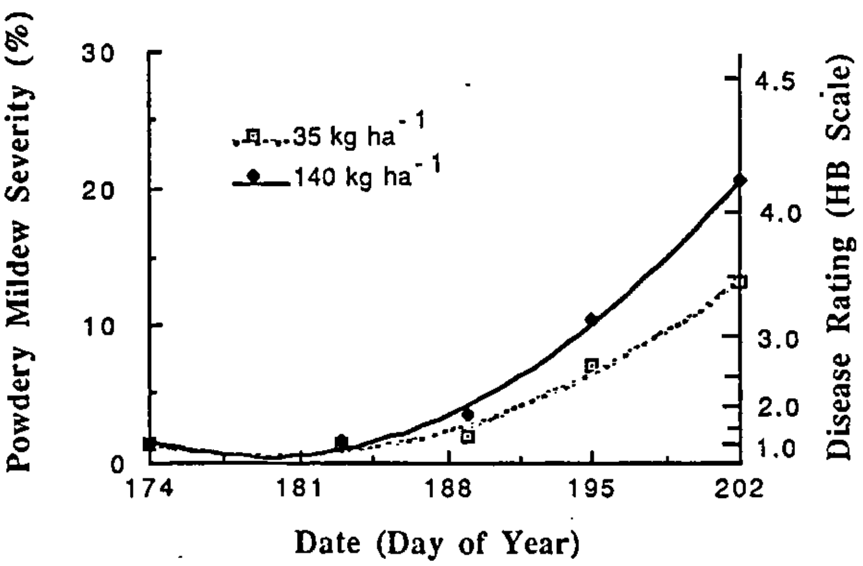

Figure 4.4 Effect of seed rate on powdery mildew development on the flag leaf at trial 3. Mean values of two cultivars and two row spacings (disease rating SE = 0.02).

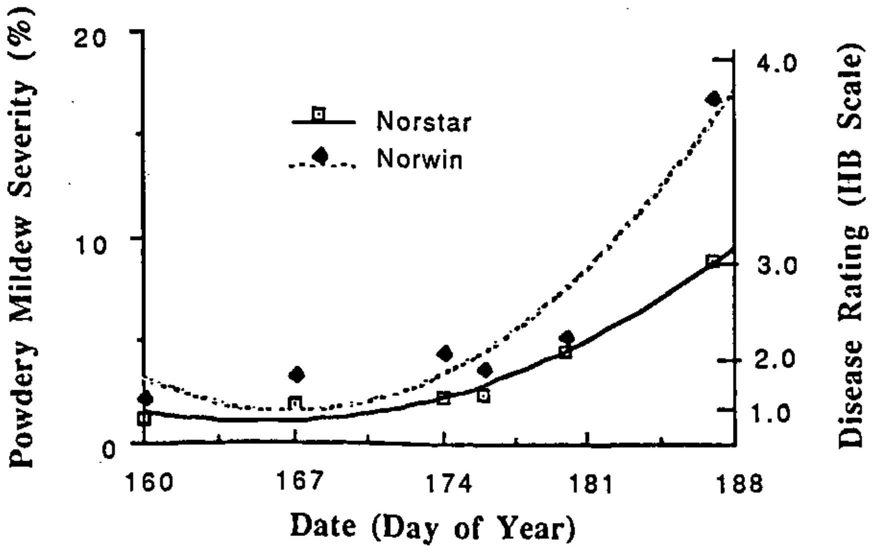

Figure 4.5 Effect of cultivar on powdery mildew severity. Mean of four seed rates and four row spacings in trial 6 (disease rating SE = 0.1).

Table 4.40 Analysis of variance for powdery mildew development on the flag leaf and the flag leaf-1 in trial 6.

| | Mean Square | | | |
|---|---|---|---|---|
| Sources of Variation | df | Flag Leaf | df | Flag Leaf-1 |
| Rep | 1 | 13.50 | 1 | 26.04 |
| Cultivar (CV) | 1 | 13.50* | 1 | 11.57* |
| Rep x CV | 1 | 0.04 | 1 | 0.04 |
| SRRS combination | 3 | 1.79 | 3 | 4.88* |
| RS | 1 | 0.17 | 1 | 0.32 |
| SR | 1 | 5.04 | 1 | 14.29** |
| SR x RS | 1 | 0.17 | 1 | 0.04 |
| CV x SRRS | 3 | 0.14 | 3 | 0.60 |
| Rep x SRRS in CV | 6 | 0.69 | 6 | 0.92 |
| Time | 5 | 16.03** | 6 | 22.93** |
| Rep x Time | 5 | 0.15 | 6 | 0.51 |
| CV x Time | 5 | 0.30 | 6 | 0.72 |
| CV x Early | 1 | 0.19 | 1 | 0.02 |
| CV x Mid | 1 | 0.05 | 1 | 0.02 |
| CV x Late | 1 | 0.42 | 1 | 0.08 |
| Rep x CV x Time | 5 | 0.14 | 6 | 0.64 |
| SRRS x Time | 15 | 0.88** | 18 | 0.71* |
| RS x Early | 1 | 0.08 | 1 | 0.19 |
| RS x Mid | 1 | 0.13 | 1 | 0.00 |
| RS x Late | 1 | 0.01 | 1 | 0.19 |
| SR x Early | 1 | 1.33* | 1 | 3.00** |
| SR x Mid | 1 | 1.88** | 1 | 0.75 |
| SR x Late | 1 | 6.38** | 1 | 6.75** |
| SR x RS x Early | 1 | 0.08 | 1 | 0.08 |
| SR x RS x Mid | 1 | 2.76** | 1 | 0.52 |
| SR x RS x Late | 1 | 1.88** | 1 | 1.02 |
| CV x SRRS x Time | 15 | 0.17 | 18 | 0.32 |
| Error | 30 | 0.20 | 36 | 0.38 |

*,**Significant at p=0.05 and p=0.01, respectively.

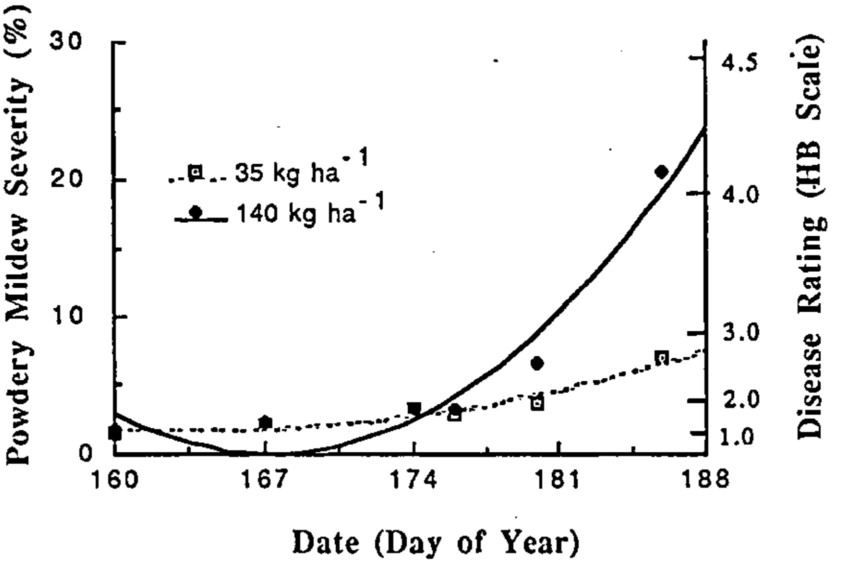

Figure 4.6 Effect of seed rate on powdery mildew development on the flag leaf at trial 6. Mean values of two cultivars and two row spacings (disease rating SE = 0.16).

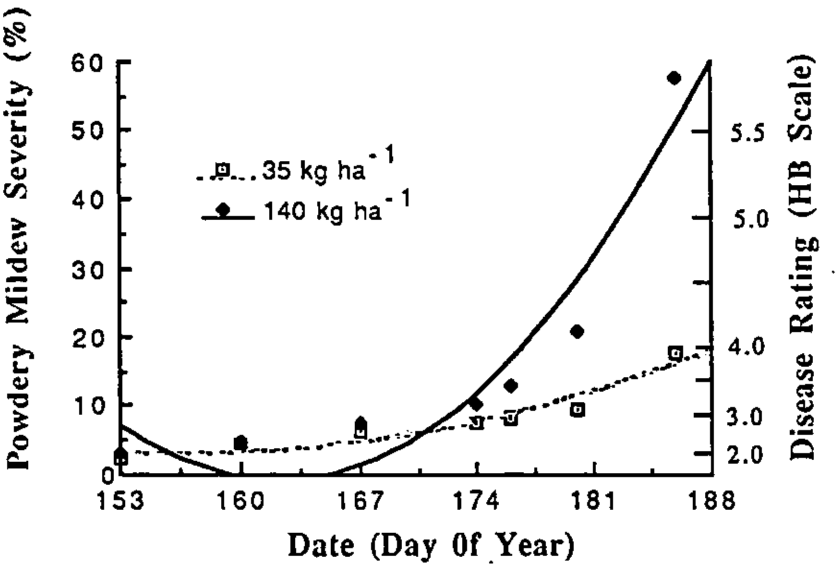

Figure 4.7 Effect of seed rate on powdery mildew development on the flag leaf-1 at trial 6. Mean values for two cultivars and two row spacings (disease rating SE = 0.22).

Table 4.41 Analysis of variance for powdery mildew development on the flag leaf and the flag leaf-1 of winter wheat cultivar Norstar in trial 10.

| | Mean Square | | | |
|---|---|---|---|---|
| Sources of Variation | df | Flag Leaf | df | Flag Leaf-1 |
| Rep | 1 | 1.56 | 1 | 0.56 |
| SRRS combination | 3 | 6.06* | 3 | 6.06* |
| RS | 1 | 10.56* | 1 | 7.56* |
| SR | 1 | 7.56* | 1 | 10.56* |
| SR x RS | 1 | 0.06 | 1 | 0.06 |
| Rep x SRRS | 3 | 0.56 | 3 | 0.56 |
| Time | 1 | 7.56* | 1 | 10.56* |
| Rep x Time | 1 | 0.56 | 1 | 0.06 |
| Seed x Time | 3 | 0.23 | 3 | 0.23 |
| Error | 3 | 0.23 | 3 | 0.73 |

*,**Significant at p=0.05 and p=0.01, respectively.

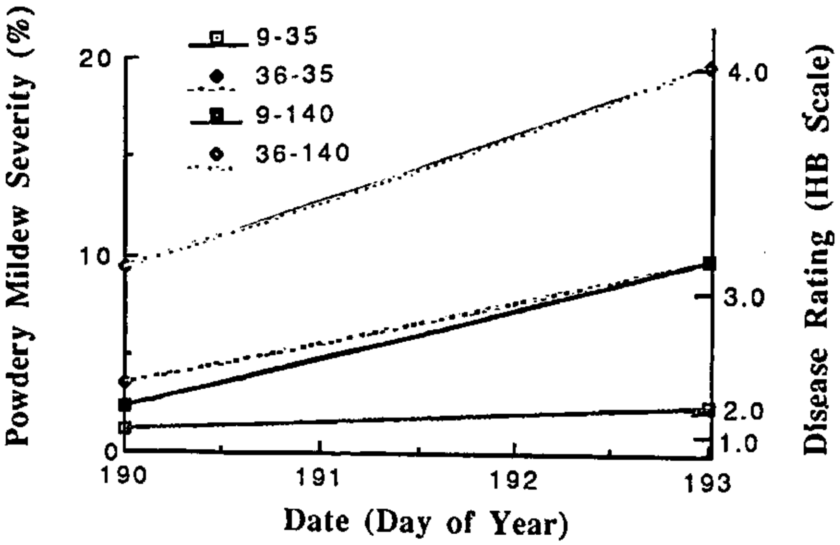

Figure 4.8 Effect of seed rate/row spacing combination on powdery mildew development on the flag leaf in trial 10 (disease rating SE = 0.34). Differences due to seed rate/row spacing combination were significant at p=0.05 (F-test).

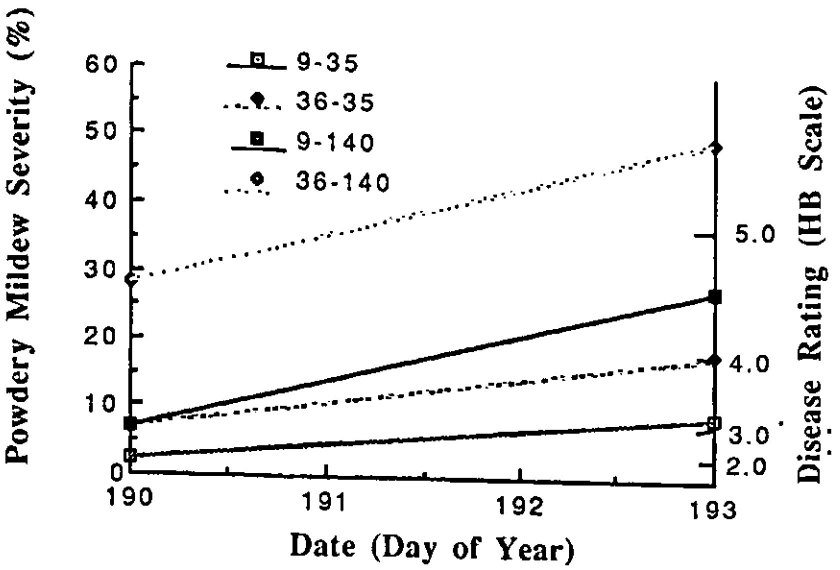

Figure 4.9 Effect of seed rate/row spacing combination on powdery mildew development on the flag leaf-1 in trial 10 (disease rating SE = 0.6). Differences due to seed rate/row spacing combination were significant at p=0.05 (F-test).

Table 4.42 Analysis of variance for powdery mildew development on the flag leaf and the flag leaf-1 of winter wheat cultivar Norstar in trial 7.

| | Mean Square | | | |
|---|---|---|---|---|
| Sources of Variation | df | Flag Leaf | df | Flag Leaf-1 |
| Rep | 1 | 57.04 | 1 | 140.17 |
| SRRS combination | 3 | 2.49 | 3 | 2.83 |
| RS | 1 | 0.38 | 1 | 0.17 |
| SR | 1 | 5.04 | 1 | 8.17* |
| SR x RS | 1 | 2.04 | 1 | 0.17 |
| Rep x SRRS | 3 | 2.04 | 3 | 0.61 |
| Time | 2 | 21.79 | 2 | 21.38 |
| Rep x Time | 2 | 7.29 | 2 | 6.54 |
| SRRS x Time | 6 | 1.24* | 6 | 0.38 |
| Error | 6 | 0.29 | 6 | 0.32 |

*Significant at p=0.05.

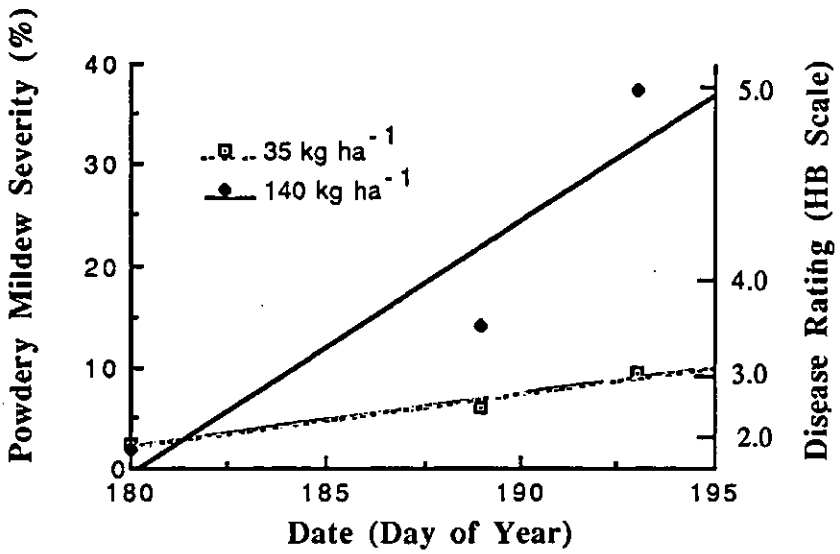

Figure 4.10 Effect of seed rate on powdery mildew development on the flag leaf in trial 7. Mean values of two cultivars and two row spacings (disease rating SE = 0.27).

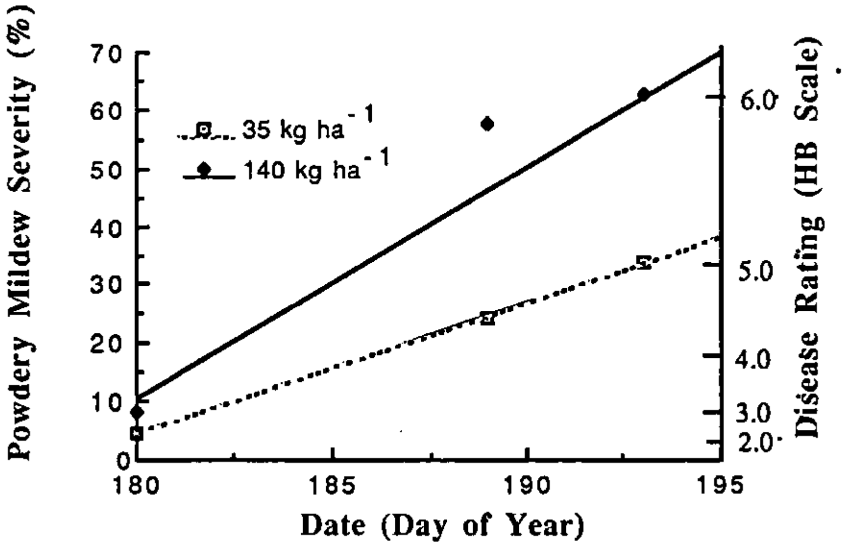

Figure 4.11 Effect of seed rate on powdery mildew development on the flag leaf-1 in trial 7. Mean values for two cultivars and two row spacings (disease rating SE = 0.3). Differences due to seed rate were significant at p=0.05 (F-test).

The observations made in these four trials demonstrated that high SR consistently promoted PM development on the upper leaves. The effect of RS was not as clear, although in many cases, wide RS promoted the development of PM. Wide RS appeared to be more important when the spores had further to travel to reach a leaf, such as the Norstar flag leaf. Wide RS appeared to be more important early in the epidemic and less important as the epidemic developed. For example, only trial 10 showed significant differences due to RS in the disease development test. In this trial, the epidemic developed late and PM was only present on the upper leaves for a short period of time before leaf senescence became a factor in arresting its development. Therefore, in this trial, the effect of wide RS on PM dispersal was a factor in determining PM levels on the upper leaves. When PM is present on the upper leaves for a longer period of time, it might be expected that the enhancement of PM dispersal by the wide RS would be of reduced importance in determining PM severity. Under these conditions factors promoting PM development, such as high SR, would be more important.

Under environmental conditions conducive to a more severe and prolonged epidemic, narrow RS and high SR would produce a more closed-in canopy that could promote PM development once the pathogen was present on a leaf. In trials 3 and 6 the PM epidemics developed on the upper leaves over a longer period of time than in trial 10. In both trials 3 and 6 the wide RS treatment had a higher level of PM early while narrow RS had more PM late in the epidemic. However, RS did not have a significant influence on PM development on the upper leaves and firm conclusions are not justified. However, the biology of the pathogen suggests that this trend might be expected.

A variable RS effect depending on the stage of the epidemic would explain the conflicting results reported by other workers. For example, Broscious and co-workers (1985) reported that PM severity was promoted by wide RS and low SR in Pennsylvania. Their results are in agreement with the RS observations made in this study. As the levels of PM reported were generally low, their observations could be due to differences in a dispersal phase of PM development. In contrast, Smith and Blair (1950) reported that higher levels of PM at narrower RS were associated with a denser canopy. Consequently, the differences between these two studies could have been due to differences in the dispersal and the developmental phase of the PM epidemics. The SR results reported for the Pennsylvania study (Broscious et al, 1985) disagree with the results of the present study. However, the Pennsylvania study used SR ranging from 101 kg $ha^{-1}$ to 235 kg $ha^{-1}$ compared to SR ranging from 35 kg $ha^{-1}$ to 140 kg $ha^{-1}$ in the present study. Therefore the high SR used in this study was only slightly higher than the low SR used in the Pennsylvania study. Also, there are some significant climatic differences between Saskatchewan and Pennsylvania, such as relative humidity.

## 4.6 Effect of Agronomic Treatment on Septoria

### 4.6.1 Experiment A

The level of septoria on the flag leaf was significantly higher in trial 3 than trials 1 or 7 (Table 4.43). Septoria severity was also

Table 4.43 Analysis of variance for effect of winter wheat cultivar, seed rate and row spacing on septoria level of flag leaves for three trials in experiment A, 1986 to 1988.

| | | Mean Square |
|---|---|---|
| Sources of Variation | df | Septoria on Flag Leaf |
| Trial | 2 | 60.9706* |
| Rep in trials | 8 | 7.3138 |
| Cultivar (CV) | 1 | 24.5752* |
| trial x CV | 2 | 0.6606 |
| Rep x CV in trials | 8 | 3.0359 |
| Seed Rate (SR) | 3 | 2.0524** |
| Row Spacing (RS) | 3 | 0.0493 |
| SR x RS | 9 | 0.4663 |
| Trial x SR | 6 | 0.8206 |
| Trial x RS | 6 | 0.2916 |
| CV x SR | 3 | 0.1870 |
| CV x RS | 3 | 0.1094 |
| Trial x CV x SR | 6 | 0.3590 |
| Trial x CV x RS | 6 | 0.2576 |
| CV x SR x RS | 9 | 0.4375 |
| Trial x CV x SR x RS | 36 | 0.4400 |
| Error | 239 | 0.4769 |

*,**Significant at p=0.05 and p=0.01, respectively.

significantly greater on the flag leaf of the semi-dwarf Norwin than on the taller cultivar Norstar (Table 4.44). This could have been due to the shorter plant height, or genotypic differences. There was a significant increase in septoria severity as SR increased (Figure 4.12). In contrast, RS did not have a measureable influence on septoria severity in this study.

### 4.6.2 Experiment C

#### 4.6.2.1 Critical Point Evaluations

Combined results of experiment A and experiment C. Trial and cultivar had a significant influence on septoria severity on the flag leaf and flag leaf-1 (Table 4.45). Highest levels of septoria were present in trial 3, and the lowest levels of septoria were present in trial 1 (Tables 4.56 and 4.57). The semi-dwarf cultivar Norwin had a larger percentage of the flag (Table 4.46) and flag leaf-1 (Table 4.47) area covered by septoria. A significant trial by cultivar interaction was also observed for septoria severity on the flag leaf-1. While there was consistently more septoria present on the cultivar Norwin, the magnitude of difference between the two cultivars differed among trials. In particular, trial 3 had a much higher level of septoria present on Norwin than on Norstar.

Seed rate had a significant and RS had a nonsignificant effect on septoria severity on the two upper leaves (Table 4.45). Higher levels of septoria coincided with high SR (Table 4.48). Septoria is a disease that is transmitted by rain splash. It requires a period of leaf

Table 4.44 Septoria severity (%) on the flag leaf on two cultivars at four seed rates. Means of three trials in experiment A, 1986 to 1988.

| Seed Rate (kg $ha^{-1}$) | Flag Leaf Septoria Severity (%) | | | |
|---|---|---|---|---|
| | Cultivar | | | |
| | Norstar | Norwin | Mean[1] | $S_{\bar{x}}$ |
| 35 | 3.7 | 5.2 | 4.5 | 0.2 |
| 70 | 4.2 | 6.1 | 5.2 | 0.4 |
| 105 | 4.2 | 6.1 | 5.2 | 0.4 |
| 140 | 4.5 | 7.0 | 5.6 | 0.4 |
| Mean[2] | 4.2a | 6.1b | | |
| $S_{\bar{x}}$ | 0.3 | 0.5 | | |

[1] Differences due to seed rate significant at p=0.05 (F-test).

[2] Within a row means followed by the same letter are not significantly different at p=0.05 (F-test).

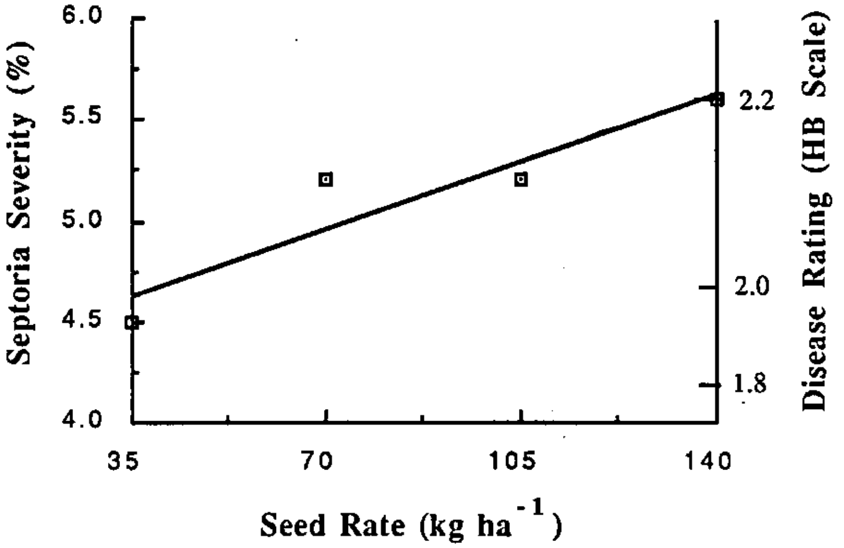

Figure 4.12 Effect of seed rate on septoria severity on the flag leaf. Mean of two cultivars and two row spacings grown in trials 1, 3 and 7 (disease rating SE = 0.07).

Table 4.45 Analysis of variance for effect of cultivar, and seed rate and row spacing combination on septoria severity (%) on the flag leaf and the flag leaf-1 in experiment C.

| | Mean Square - Septoria Level | | | |
|---|---|---|---|---|
| Sources of Variation | df | Flag Leaf | df | Flag Leaf-1 |
| Trial | 5 | 45.8310** | 4 | 51.1564** |
| Rep in trials | 16 | 3.2995 | 13 | 1.7082 |
| Cultivar (CV) | 1 | 32.8605** | 1 | 17.7410** |
| Trial x CV | 5 | 2.0102 | 4 | 3.1438* |
| Rep x CV in trial | 16 | 1.2745 | 11 | 0.9227 |
| SRRS combination | 4 | 3.5915** | 4 | 2.1379 |
| RS | 1 | 0.0278 | 1 | 0.2560 |
| SR | 1 | 13.2834** | 1 | 7.4720** |
| SR x RS | 1 | 0.6788 | 1 | 0.4311 |
| Trial x SRRS | 20 | 0.4797 | 16 | 0.8031 |
| CV x SRRS | 4 | 0.1703 | 4 | 3.4022 |
| CV x RS | 1 | 0.0840 | 1 | 2.0220 |
| CV x SR | 1 | 0.0071 | 1 | 1.8859 |
| CV x SR x RS | 1 | 0.0867 | 1 | 5.4201* |
| Trial x CV x SRRS | 20 | 0.2505 | 16 | 0.8071 |
| Error | 128 | 0.6901 | 102 | 1.0075 |

*,**Significant at p=0.05 and p=0.01, respectively.

Table 4.46 Septoria severity (%)on the flag leaf of Norwin and Norstar grown in experiment C (means of six trials, 1987 to 1988).

| | Flag Leaf Septoria Severity (%) | | | |
|---|---|---|---|---|
| | Cultivar | | | |
| Trial | Norstar | Norwin | Mean[1] | $S_{\bar{x}}$ |
| 1 | 3 | 4 | 4a | 0.7 |
| 3a | 8 | 11 | 9b | 2.1 |
| 3b | 28 | 40 | 34c | 6.0 |
| 6 | 8 | 15 | 10b | 2.4 |
| 7 | 7 | 19 | 11b | 2.6 |
| 9 | 7 | 10 | 8b | 1.7 |
| Mean[2] | 8a | 14b | | |
| $S_{\bar{x}}$ | 0.5 | 1.0 | | |

[1] Within a column means followed by the same letter are not significantly different at p=0.05 (LSD).

[2] Within a row means followed by the same letter are not significantly different at p=0.05 (F-test).

Table 4.47 Septoria severity (%) on the flag leaf-1 of Norwin and Norstar grown in experiment C (means of five trials, 1987 to 1988).

| | Flag Leaf-1 Septoria Severity (%)[1] | | | |
|---|---|---|---|---|
| | Cultivar | | | |
| Trial | Norstar | Norwin | Mean[2] | $S_{\bar{x}}$ |
| 1 | 8 | 12 | 9a | 1.4 |
| 3 | 19 | 55 | 36d | 4.1 |
| 6 | 26 | 36 | 30cd | 3.8 |
| 7 | 14 | 34 | 18c | 2.4 |
| 9 | 5 | 6 | 5a | 0.7 |
| Mean[3] | 12a | 19b | | |
| $S_{\bar{x}}$ | 1.0 | 1.4 | | |

[1] Trial by cultivar interaction significant at p=0.05 (F-test).

[2] Within a column means followed by the same letter are not significantly different at p=0.05 (LSD).

[3] Within a row means followed by the same letter are not significantly different at p=0.05 (F-test).

Table 4.48 Septoria severity on the flag leaf and the flag leaf-1 at five seed rate and row spacing combinations in experiment C (means of six trials, 1986 to 1988).

| Row Spacing-Seed Rate (cm) (kg ha$^{-1}$) | Septoria Severity (% leaf area) Flag Leaf[1] | $S_{\bar{x}}$ | Flag Leaf-1[1][2] | $S_{\bar{x}}$ |
|---|---|---|---|---|
| 9-140 | 14a | 1.0 | 18a | 2.4 |
| 36-140 | 12ab | 1.0 | 18a | 2.4 |
| 18-70 | 9bc | 0.7 | 14ab | 2.8 |
| 9-35 | 8c | 0.5 | 14ab | 2.8 |
| 36-35 | 9c | 0.5 | 11b | 1.9 |

[1] Within a column means followed by the same letter are not significantly different at p=0.05 (LSD).

[2] Flag leaf-1 values are the means of five trials.

wetness in order for the spore to germinate. Longer periods of leaf wetness may have been promoted by the more enclosed canopy associated with high SR.

At the high SR, higher levels of septoria on the flag leaf-1 were associated with narrow RS for Norstar, and wide RS for Norwin producing a significant cultivar by SR by RS interaction for this character (Table 4.49). However, the same trend was not evident on the flag leaf suggesting that this is not a consistent effect.

Experiment C. The results of this study were similar to those for the combined analysis of experiment A and experiment C. Trial, cultivar and SR all had a significant effect on septoria severity (Table 4.50). As in the combined analysis, the cultivar Norwin and high SR promoted septoria severity.

The effect of N rate has not yet been considered in the analyses of these studies. An analysis of variance indicated that N rate did not have a significant effect on septoria severity ($p=0.05$) (Table 4.50). However, N rate was the main plot in a split-split-plot design and it is possible that meaningful differences were not detectable because of the small number of degrees of freedom available to test the significance of its effect. There was a trend towards increased septoria severity on the low N rate treatments in three of the four trials with a large response in trial 3 (Table 4.51).

### 4.6.2.2 Disease development

Trial 3. Seed rate had a significant effect on septoria

Table 4.49 Septoria severity on the flag leaf-1 of two cultivars at five seed rate and row spacing combinations in experiment C (average of five trials, 1986 to 1988).

| Row Spacing-Seed Rate (cm)-(kg ha$^{-1}$) | Flag Leaf-1 Septoria Severity (%) Cultivar Norstar | Norwin | Mean[1] |
|---|---|---|---|
| 9-140 | 17 | 21 | 18a |
| 36-140 | 10 | 32 | 18a |
| 18-70 | 9 | 23 | 14ab |
| 9-35 | 10 | 13 | 11b |
| 36-35 | 14 | 14 | 14ab |
| Mean[2] | 12a | 19b | |

[1] Within a column means followed by the same letter are not significantly different at p=0.05 (LSD).

[2] Within a row means followed by the same letter are not significantly different at p=0.05 (F-test).

Table 4.50 Analysis of variance for effect of nitrogen fertility, cultivar and seed rate and row spacing combination on septoria severity on flag leaves in experiment C in four trials.

| | | Mean Square |
|---|---|---|
| Sources of Variation | df | Septoria Severity |
| Trial (T) | 3 | 31.0017* |
| Rep in T | 4 | 2.4415 |
| Fertility (F) | 1 | 6.9200 |
| T x F | 3 | 7.5067 |
| Rep x F in T | 3 | 2.2147 |
| Cultivar (CV) | 1 | 32.1446** |
| T x CV | 3 | 2.2193 |
| F x CV | 1 | 0.8061 |
| T x F x CV | 3 | 1.1649 |
| Rep x CV in F and T | 7 | 1.1651 |
| SRRS combination | 4 | 4.1268** |
| RS | 1 | 0.0017 |
| SR | 1 | 15.156** |
| SR x RS | 1 | 0.9506 |
| T x SRRS | 12 | 0.6408 |
| F x SRRS | 4 | 1.1673 |
| CV x SRRS | 4 | 0.1687 |
| T x CV x SRRS | 12 | 0.3635 |
| T x F x SRRS | 12 | 0.4129 |
| F x CV x SRRS | 4 | 0.1699 |
| T x F x CV x SRRS | 12 | 0.7847 |
| Error | 56 | 0.6104 |

*,**Significant at p=0.05 and p=0.01, respectively.

Table 4.51 Septoria severity on the flag leaf at two levels of applied nitrogen in four trials in experiment C, 1987 and 1988.

| | Flag Leaf Septoria Severity (%) | | | |
|---|---|---|---|---|
| | Applied Nitrogen (kg N ha$^{-1}$) | | | |
| Trial | 0 | 100 | Mean[1] | $S_{\bar{x}}$ |
| 3 | 48 | 24 | 34a | 3.7 |
| 6 | 14 | 8 | 10b | 1.9 |
| 7 | 8 | 15 | 11b | 1.7 |
| 9 | 9 | 8 | 8b | 1.7 |
| Mean[2] | 17a | 12a | | |
| $S_{\bar{x}}$ | 1.9 | 1.9 | | |

[1] Within a column means followed by the same letter are not significantly different at p=0.05 (LSD).

[2] Within a row means followed by the same letter are not significantly different at p=0.05 (F-test).

development on both the flag leaf and the flag leaf-1 in trial 3 (Table 4.52). High SR also promoted increased levels of septoria throughout the growing season (Figures 4.13 and 4.14).

The interaction between SRRS and cultivar had an influence on septoria development. High SR had a greater effect in promoting septoria development on the semi-dwarf cultivar Norwin than on the tall cultivar Norstar.

Low N fertility promoted septoria development on both the flag leaf (significant at p=0.06) (Figure 4.15) and the flag leaf-1 (significant at p=0.09) (Figure 4.16). Septoria nodorum and S. tritici have been reported both to increase (Broscious et al, 1985) (Gheorghies, 1974) and to decrease (Naylor and Su, 1988) (Johnston et al, 1979) in severity with increased N rate. Different stages in the infection cycle of septoria could have different limiting environmental factors. For example, spore germination is promoted by increased leaf wetness (Eyal et al, 1977). A thicker canopy resulting from increased N rate should therefore promote increased spore germination. However, lesion development may be promoted by conditions that produce a less vigorous plant such as reduced N rate. With different environmental conditions, either spore germination or lesion development could be of greater importance in limiting the rate of septoria development. Therefore N rate could have a variable effect on septoria development. In trial 3, the cool wet conditions in midsummer could have reduced the importance of spore germination relative to lesion development in limiting the rate of septoria development. Another disease of the leaf spot complex, Pyrenophora tritici-repentis has been reported to decrease in severity with increased N rate (Huber et al, 1987).

Table 4.52 Analysis of variance for septoria development on the flag leaf and the flag leaf-1 for experiment C at trial 3.

| | Mean Square | | | |
|---|---|---|---|---|
| Sources of Variation | df | Flag Leaf | df | Flag Leaf-1 |
| Rep | 1 | 4.2602 | 1 | 1.5602 |
| Fertility (F) | 1 | 46.6102 | 1 | 48.6203 |
| Rep x F | 1 | 0.3852 | 1 | 1.0563 |
| Cultivar (CV) | 1 | 47.8002 | 1 | 44.7323 |
| F x CV | 1 | 8.9269 | 1 | 1.3323 |
| Rep x CV in F | 1 | 0.8802 | 1 | 0.7563 |
| SRRS combination | 3 | 4.7523** | 3 | 3.7418 |
| RS | 1 | 0.2002 | 1 | 0.0160 |
| SR | 1 | 13.6533** | 1 | 10.9203** |
| SR x RS | 1 | 0.4033 | 1 | 0.2890 |
| F x SRRS | 3 | 0.3484 | 3 | 0.4044 |
| CV x SRRS | 3 | 1.2876* | 3 | 1.0247 |
| F x CV x SRRS | 3 | 0.6520 | 3 | 3.7888 |
| Rep x SRRS in F and CV | 12 | 0.3487 | 12 | 1.1111 |
| Time | 5 | 46.3853** | 4 | 33.5786** |
| Rep x Time | 5 | 1.0621 | 4 | 0.6101 |
| F x Time | 5 | 1.2656 | 4 | 1.5426 |
| Rep x F x Time | 5 | 1.0733 | 4 | 0.6355 |
| CV x Time | 5 | 1.3541 | 4 | 0.8602 |
| F x CV x Time | 5 | 0.4000 | 4 | 0.7796 |
| Rep x CV x Time in F | 10 | 0.7680 | 4 | 0.9548 |
| SRRS x Time | 15 | 0.7493* | 12 | 0.7895 |
| F x SRRS x Time | 15 | 0.3116 | 12 | 0.5063 |
| CV x SRRS x Time | 15 | 0.5043 | 12 | 0.6515 |
| F x CV x SRRS x Time | 15 | 0.2563 | 12 | 0.9648 |
| Error | 60 | 0.3676 | 48 | 0.8767 |

*,**Significant at p=0.05 and p=0.01, respectively.

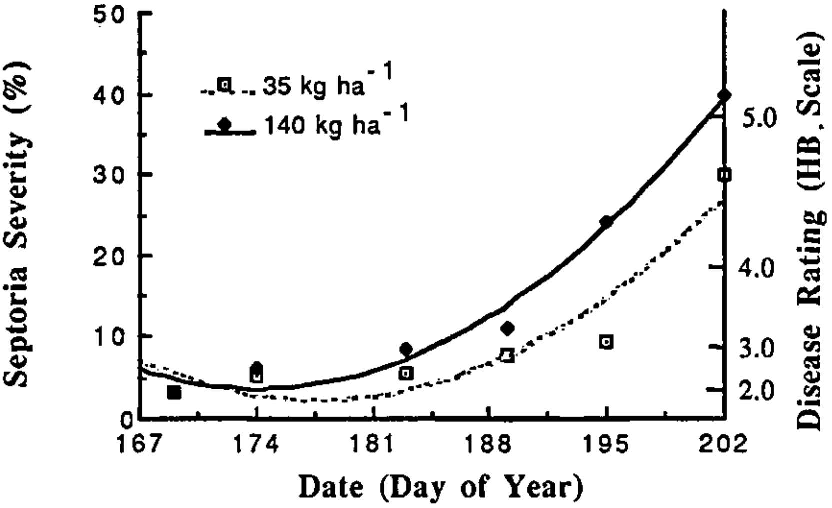

Figure 4.13 Effect of seed rate on septoria development on flag leaf. Mean of two nitrogen levels, two cultivars and two row spacings in trial 3 (disease rating SE = 0.15).

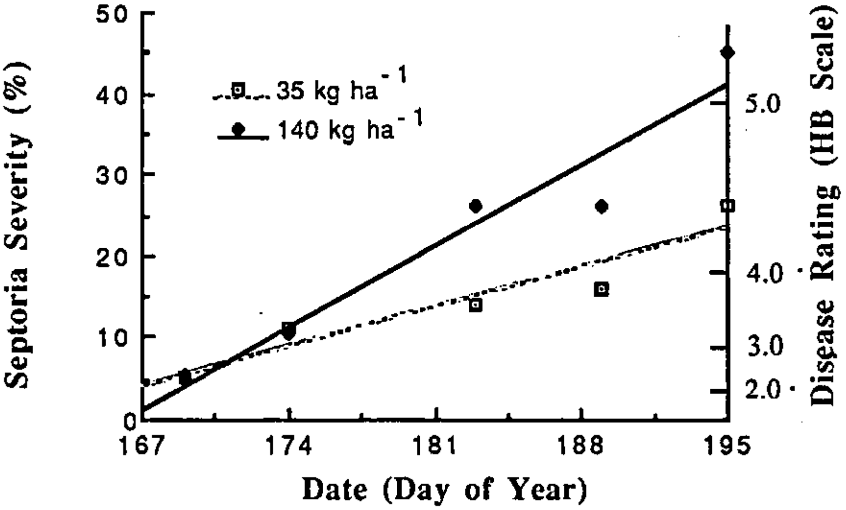

Figure 4.14 Effect of seed rate on septoria development on flag-1. Mean of two nitrogen levels, two cultivars and two row spacings grown in trial 3 (disease rating SE = 0.23).

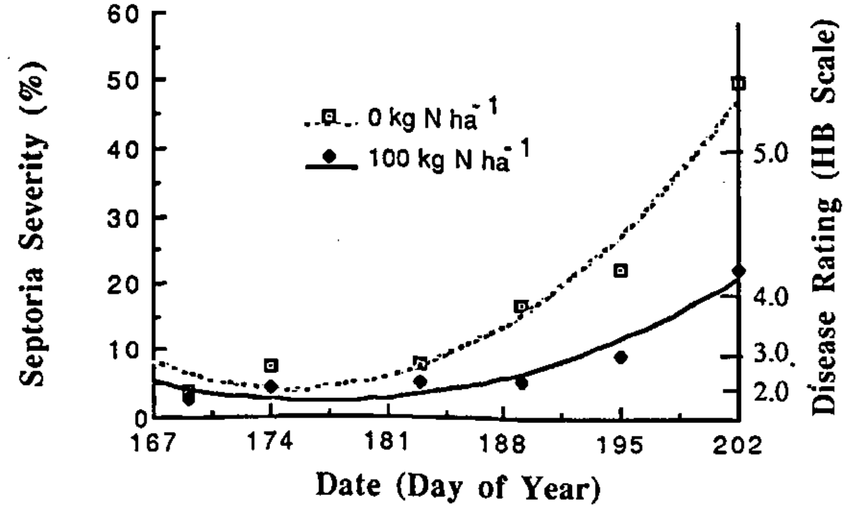

Figure 4.15 Effect of applied nitrogen on septoria development on flag leaf. Mean of two cultivars, two seed rates and two row spacings in trial 3 (disease rating SE = 0.26).

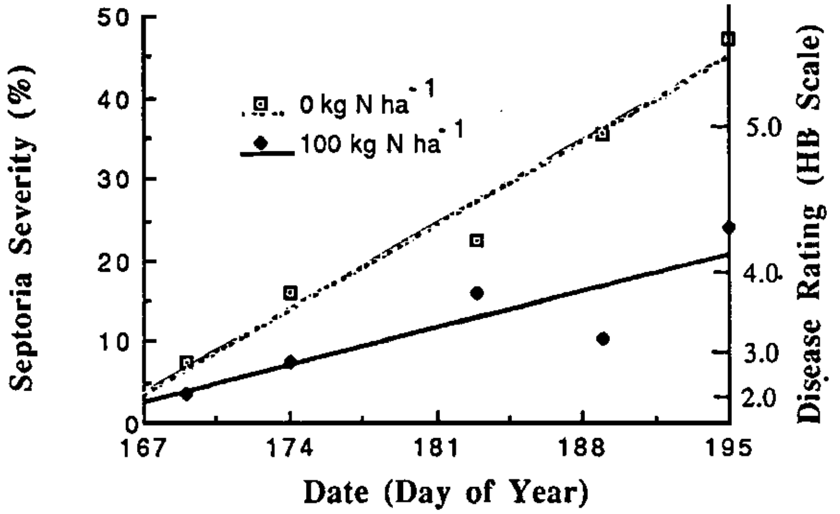

Figure 4.16 Effect of applied nitrogen on septoria development on the flag leaf-1. Mean of two cultivars, two seed rates and two row spacings in trial 3 (disease rating SE = 0.3).

Trial 6. High SR promoted significantly greater septoria development on the flag leaf in trial 6 (Table 4.53) (Figure 4.17). The effect of cultivar on septoria severity on the flag leaf was significant at p=0.10. Septoria severity was greater on the semi-dwarf cultivar Norwin (Figure 4.18). There was a trend towards earlier development of septoria on the Norwin flag leaf, although the cultivar by time interaction was not significant.

Trial 7. Increases in SR significantly increased septoria development on the flag leaf in trial 7 (Figure 4.19). The interaction between cultivar and time also had a significant effect on septoria development (Table 4.54). Septoria development began at an earlier stage for the Norwin suggesting that the shorter plant height was a factor in promoting septoria development (Figure 4.20).

Trial 10. Cultivar differences were only significant for septoria development on the flag leaf-1 in trial 10 (Table 4.55). Increased septoria was associated with Norwin (Figure 4.22). There was a trend towards earlier development of septoria on Norwin, although the cultivar by time interaction was not significant. High SR also promoted septoria development on the flag leaf (Figure 4.21).

High SR significantly increased and RS had a nonsignificant effect on septoria severity in all trials considered in this study. These observations are in agreement with results reported by Broscious and co-workers in Pennsylvania (1985). Septoria development was greater on the semi-dwarf cultivar Norwin than the tall cultivar Norstar. The

Table 4.53 Analysis of variance for septoria development on the flag leaf and the flag leaf-1 for experiment C in trial 6.

| | | Mean Square | |
|---|---|---|---|
| Sources of Variation | df | Flag Leaf | Flag Leaf-1 |
| Rep | 1 | 2.3616 | 5.4688 |
| Fertility (F) | 1 | 17.7188 | 25.1116 |
| Rep x F | 1 | 2.3616 | 1.2902 |
| Cultivar (CV) | 1 | 51.1116 | 29.2902 |
| F x CV | 1 | 1.6116 | 0.1116 |
| Rep x CV in F | 1 | 1.2902 | 4.2902 |
| SRRS combination | 3 | 1.3378 | 1.3259 |
| RS | 1 | 0.2188 | 1.0045 |
| SR | 1 | 2.7902* | 1.9688 |
| SR x RS | 1 | 1.0045 | 1.0045 |
| F x SRRS | 3 | 1.9211 | 2.9092* |
| CV x SRRS | 3 | 0.1473 | 0.4688 |
| F x CV x SRRS | 3 | 0.3616 | 1.9807 |
| Rep x SRRS in F and CV | 12 | 0.5788 | 0.7068 |
| Time | 6 | 18.4100** | 59.2396 |
| Rep x Time | 6 | 0.4554 | 0.5938 |
| F x Time | 6 | 0.5625 | 1.2574 |
| Rep x F x Time | 6 | 0.6012 | 0.7902 |
| CV x Time | 6 | 0.9137 | 2.2902 |
| F x CV x Time | 6 | 0.3929 | 0.9449 |
| Rep x CV x Time in F | 12 | 0.6890 | 1.4360 |
| SRRS x Time | 18 | 0.2718 | 0.6245 |
| F x SRRS x Time | 18 | 0.5149 | 0.3884 |
| CV x SRRS x Time | 18 | 0.1994 | 0.8299 |
| F x CV x SRRS x Time | 18 | 0.2540 | 0.3973 |
| Error | 72 | 0.3566 | 0.7346 |

*,**Significant at p=0.05 and p=0.01, respectively.

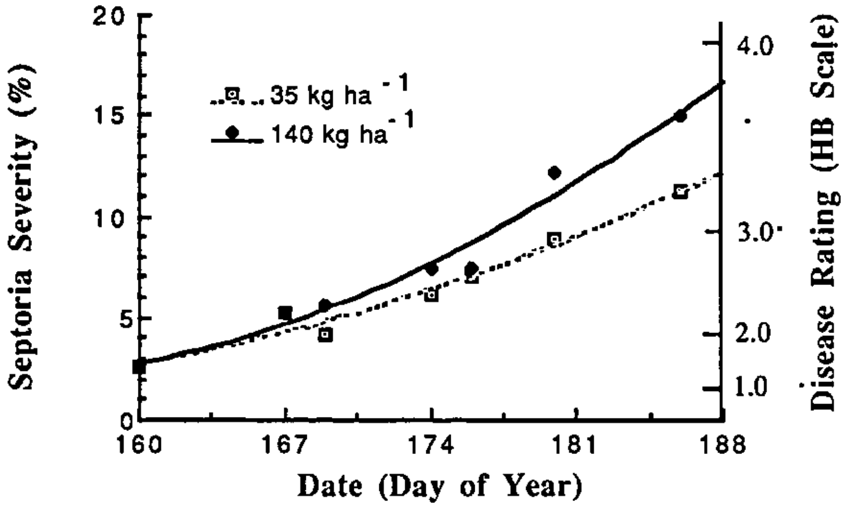

Figure 4.17 Effect of seed rate on septoria development on the flag leaf. Mean of two cultivars, two nitrogen levels and two row spacings in trial 6 (disease rating SE = 0.15).

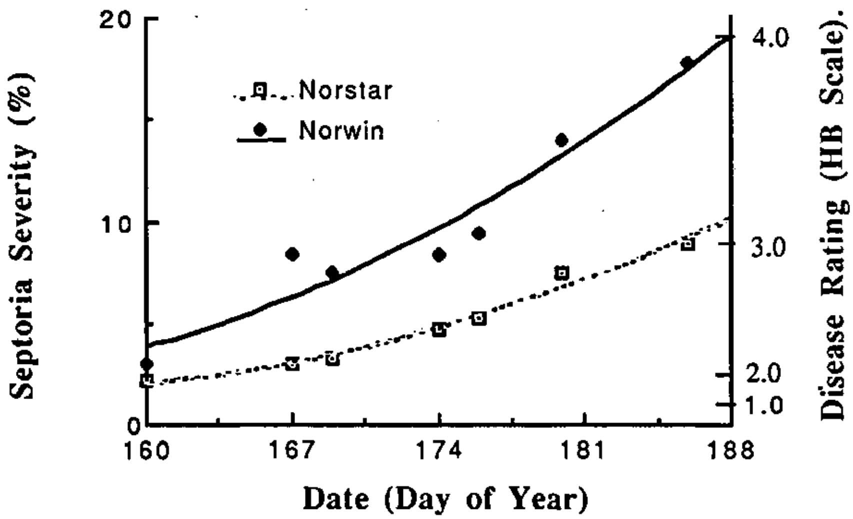

Figure 4.18 Effect of cultivar on septoria development on the flag leaf. Mean of two nitrogen levels, two seed rates and two row spacings in trial 6 (disease rating SE = 0.2). Differences due to cultivar significant at p=0.1 (F-test).

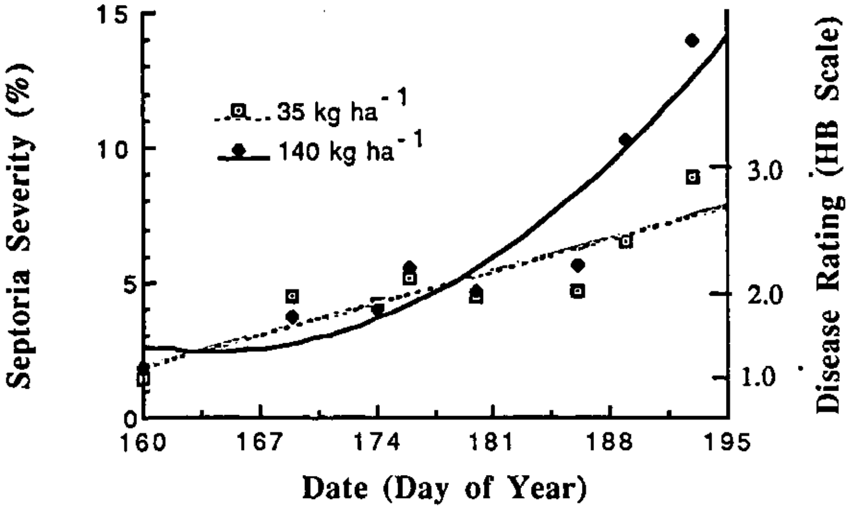

Figure 4.19 Effect of seed rate on septoria development on the flag leaf. Mean of two nitrogen levels, two cultivars and two row spacings in trial 7 (disease rating SE = 0.15).

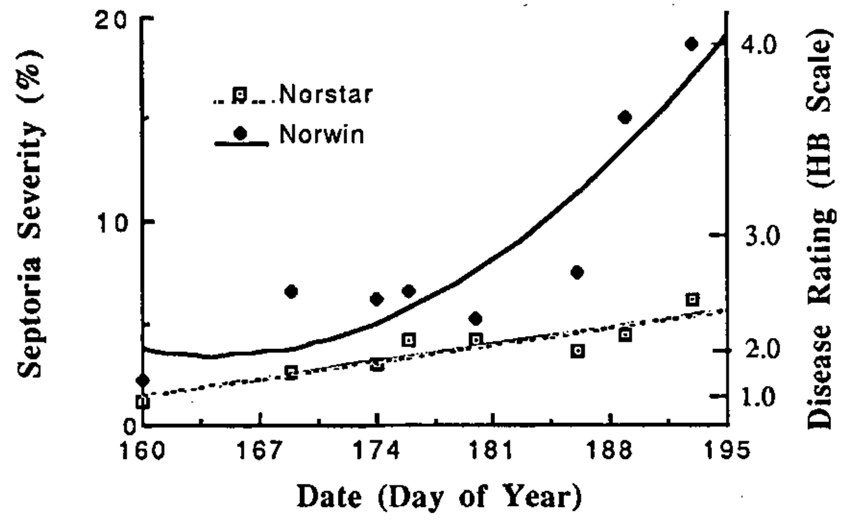

Figure 4.20 Effect of cultivar on septoria development on the flag leaf. Mean of two nitrogen levels, two seed rates and two row spacings in trial 7 (disease rating SE = 0.16).

Table 4.54 Analysis of variance for septoria development on the flag leaf and the flag leaf-1 for experiment C in trial 7.

| | | Mean Square | |
|---|---|---|---|
| Sources of Variation | df | Flag Leaf | Flag Leaf-1 |
| Rep | 1 | 3.5156 | 10.5625 |
| Fertility (F) | 1 | 16.0000 | 16.0000 |
| Rep x F | 1 | 1.0000 | 1.5625 |
| Cultivar (CV) | 1 | 74.3906 | 102.5156 |
| F x CV | 1 | 0.0000 | 0.0156 |
| Rep x CV in F | 1 | 2.2500 | 0.7656 |
| SRRS combination | 3 | 1.2552* | 0.0417 |
| RS | 1 | 0.2500 | 0.0625 |
| SR | 1 | 2.2500* | 0.0000 |
| SR x RS | 1 | 1.2656 | 0.0625 |
| F x SRRS | 3 | 0.1771 | 0.8542 |
| CV x SRRS | 3 | 0.5052 | 1.1406 |
| F x CV x SRRS | 3 | 0.4688 | 0.3073 |
| Rep x SRRS in F and CV | 12 | 0.3307 | 0.7057 |
| Time | 7 | 25.3549** | 31.1071** |
| Rep x Time | 7 | 2.2478 | 0.8929 |
| F x Time | 7 | 0.5536 | 0.8839 |
| Rep x F x Time | 7 | 1.0536 | 1.4464 |
| CV x Time | 7 | 1.9621* | 0.4174 |
| F x CV x Time | 7 | 0.7857 | 0.6853 |
| Rep x CV x Time in F | 14 | 0.4632 | 1.0871 |
| SRRS x Time | 21 | 0.3921 | 0.6220* |
| F x SRRS x Time | 21 | 0.3378 | 0.4881 |
| CV x SRRS x Time | 21 | 0.5409 | 0.3162 |
| F x CV x SRRS x Time | 21 | 0.3854 | 0.4412 |
| Error | 84 | 0.3516 | 0.3486 |

*,**Significant at p=0.05 and p=0.01, respectively.

Table 4.55 Analysis of variance for septoria development on the flag leaf and the flag leaf-1 for experiment C in trial 9.

| | | Mean Square | |
|---|---|---|---|
| Sources of Variation | df | Flag Leaf | Flag Leaf-1 |
| Rep | 1 | 5.6973 | 0.9453 |
| Fertility (F) | 1 | 3.4453 | 2.2578 |
| Rep x F | 1 | 4.8828 | 1.7578 |
| Cultivar (CV) | 1 | 0.0703 | 4.1328* |
| F x CV | 1 | 0.0703 | 0.0703 |
| Rep x CV in F | 1 | 0.3828 | 0.0078 |
| SRRS combination | 3 | 1.8828* | 0.0703 |
| RS | 1 | 0.3828 | 0.1953 |
| SR | 1 | 4.8828** | 0.0078 |
| SR x RS | 1 | 0.3828 | 0.0078 |
| F x SRRS | 3 | 0.0703 | 0.2370 |
| CV x SRRS | 3 | 0.1120 | 0.2370 |
| F x CV x SRRS | 3 | 0.3203 | 0.0078 |
| Rep x SRRS in F and CV | 12 | 0.5026 | 0.2526 |
| Time | 3 | 42.2167** | 17.6953** |
| Rep x Time | 3 | 0.0703 | 0.2578 |
| F x Time | 3 | 1.9036 | 1.4036 |
| Rep x F x Time | 3 | 0.2995 | 0.7786 |
| CV x Time | 3 | 0.7786 | 0.1536 |
| F x CV x Time | 3 | 1.0703 | 0.2995 |
| Rep x CV x Time in F | 6 | 0.5286 | 0.4036 |
| SRRS x Time | 9 | 1.1328** | 0.4245 |
| F x SRRS x Time | 9 | 0.1953 | 0.4106 |
| CV x SRRS x Time | 9 | 0.2092 | 0.2856 |
| F x CV x SRRS x Time | 9 | 0.2092 | 0.2648 |
| Error | 36 | 0.3290 | 0.2109 |

*,**Significant at p=0.05 and p=0.01, respectively.

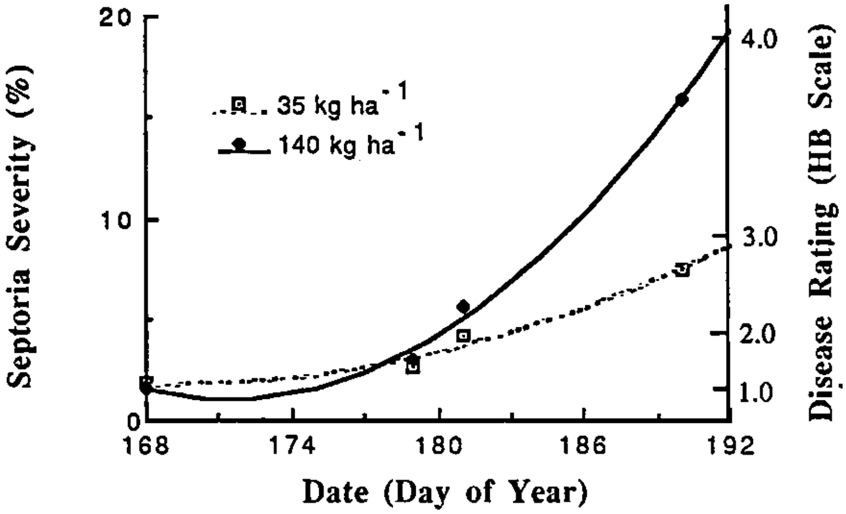

Figure 4.21 Effect of seed rate on septoria development on the flag leaf. Mean of two nitrogen levels, two cultivars and two row spacings in trial 10 (disease rating SE = 0.14).

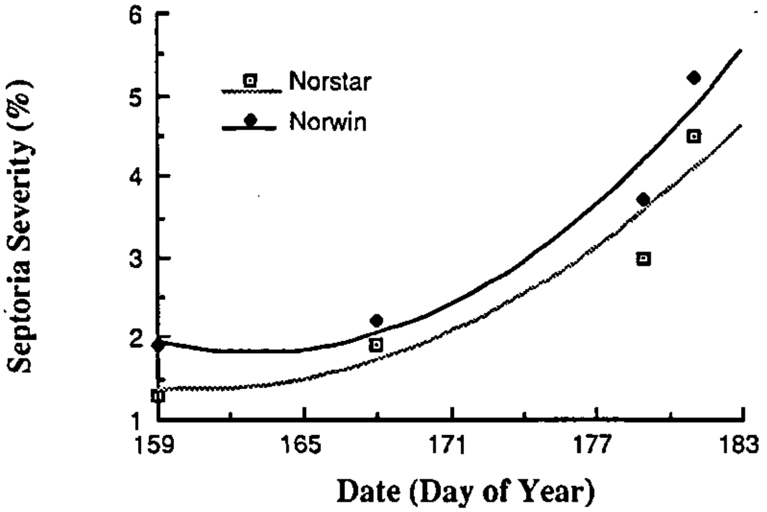

Figure 4.22 Effect of cultivar on septoria development on the flag leaf-1. Mean of two nitrogen levels, two seed rates and two row spacings in trial 10 (disease rating SE = 0.2). Differences due to cultivar were significant at p=0.05 (F-test).

cultivar differences could be due to plant height and genotypic differences. The disease developed earlier on the upper leaves of the cultivar Norwin. This suggests that at least part of the difference between cultivars is due to plant height. This conclusion is supported by Scott et al (1985) who reported that less septoria developed on winter wheat in plots raised on mounds and more septoria developed on winter wheat in plots sunk in trenches, relative to plots at ground level. They suggested that one reason, in addition to the time of spore arrival, was that less dew was deposited on flag leaves of tall varieties resulting in reduced leaf wetness.

Low N fertility promoted septoria development at trial 3. With the environmental conditions present in this trial, particularly the period of wet weather late in the growing season, the rate of lesion development may have been a more important factor in determining septoria severity than the number of lesions produced on a leaf.

## 4.7 Effect of Agronomic Treatment on Microclimate Within the Crop Canopy

### 4.7.1 Experiment C

Light intensity. The daily integral of light intensity at the base of the crop canopy was 27% higher with wide compared to narrow RS (Tables 4.56 and 4.57) indicating that less light was being intercepted by the crop canopy with wide RS.

Radiant flux density at the base of the crop canopy varied throughout the day peaking at solar noon (Fig. 4.23). The daily mean

Table 4.56 Analysis of variance of daily integral and mean daily radiant flux density for row spacing for period from Zadoks growth stage 40 to end of season in Trial 5.

| | | Mean Square | |
|---|---|---|---|
| Sources of Variation | df | Daily Integral | Radiant Flux Density |
| Day | 40 | 58.0092** | 7091.80** |
| Row Spacing | 1 | 278.0748** | 65384.64** |
| Error | 40 | 1.2233 | 144.08 |

**Significant at p=0.01.

Table 4.57 Effect of row spacing on daily integral and mean daily value for radiant flux density for period from Zadoks growth stage 40 to end of season in Trial 5.

| Row Spacing (cm) | Daily Integral (MJ $m^{-2}$) | Radiant Flux Density (Watt $m^{-2}$) |
|---|---|---|
| 9 | 13.4a | 184.8a |
| 36 | 17.0b | 241.3b |
| | | |
| Mean | 15.2 | 213.1 |
| $S_{\bar{x}}$ | 0.17 | 1.9 |

Within a column means followed by the same letter are not significantly different at p=0.05 (F-test).

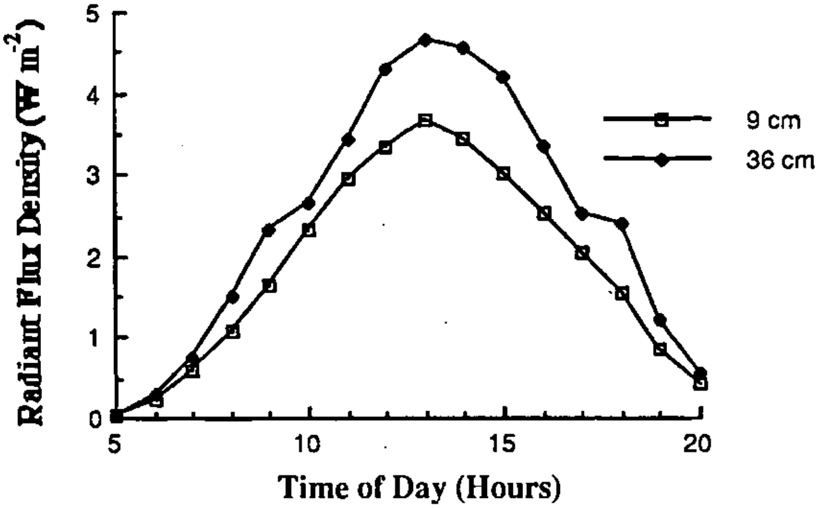

Figure 4.23 Effect of row spacing of Norstar winter wheat for on radiant flux density throughout the day in trial 5 (SE = 0.01).

of the radiant flux density was 31% higher for wide RS than for narrow RS (Table 4.57). These values for mean radiant flux density are slightly lower than those reported by Johnson, Witters and Ciha (1981) for central Washington. For example, they reported mean daily radiant flux density values around 300 W $m^{-2}$ for a row spacing of 40 cm. In the present study, the mean radiant flux density value for the 36 cm treatment was close to 250 W $m^{-2}$. These differences could have been due to the more northerly location of this experiment with rows seeded in an east-west direction.

Daily integral values represent an estimate of the total energy that passed through the crop canopy without being intercepted during the day. Radiant flux density measured the amount of light that passed through the crop canopy at a point in time. These values do not account for light that is reflected by the crop canopy.

These light intensity measurements do not provide a complete energy balance for the two RS treatments at Aylsham, Saskatchewan, Canada in the summer of 1988. However, they are useful as relative values for comparative purposes. For example, they confirm what one would intuitively expect; one advantage of narrow RS over wide RS is a better distribution of plants, with the result that a greater proportion of the incoming light energy can be intercepted by the crop. Consequently, more light energy can be utilized by the crop and less is lost or available for weed growth.

The fertilized Norstar plots with the 9-140 combination yielded

18% higher than the 36-140 combination in trial 5. Increased light interception by the crop canopy is one factor involved in the yield advantage of narrow RS. The better spatial distribution of the crop would also enable better competition for water and nutrients, and perhaps better competition with weeds. For example, results from experiment B (Table 4.13) indicated that plants grown in the 9-140 combination took up more soil water during the pre-anthesis growth period than plants grown in the 36-140 combination. Ultimately, increased light interception and increased water uptake during the pre-anthesis growth period was translated into higher dry matter production at anthesis and higher dry matter production and grain yield at harvest for the narrow RS plots.

Leaf wetness. High SR significantly lengthened the period of leaf wetness in trials 5 and 10 (Table 4.58). At high SR the proportion of time the leaves were wet was higher during the night, and was prolonged during the day (Figures 4.24 and 4.25).

Narrow RS significantly lengthened the period of leaf wetness in trial 10 (Table 4.59; Figure 4.26). As with high SR, the proportion of time the leaves were wet was higher during the night, and the leaf wetness period was prolonged during the day. In trial 7, however, dry conditions would have produced a thinner canopy and RS had no significant effect on the leaf wetness period (Figure 4.27).

Powdery mildew development is not enhanced by the presence of moisture as the spores do not need water to germinate (Wiese, 1977). In contrast, septoria spores do require a period of wetness to germinate.

Table 4.58 Analysis of variance for effect of seed rate on frequency of leaf wetness in Norstar winter wheat in trials 5 and 10.

| | Mean Square - Frequency of Leaf Wetness | | | |
|---|---|---|---|---|
| Sources of Variation | df | Trial 10 | df | Trial 5 |
| Day | 21 | 2163.08** | 14 | 471.26** |
| Seed Rate | 1 | 2660.22** | 1 | 111.81* |
| Error | 21 | 332.53 | 14 | 25.49 |

*,**Significant at p=0.05 and p=0.01, respectively.

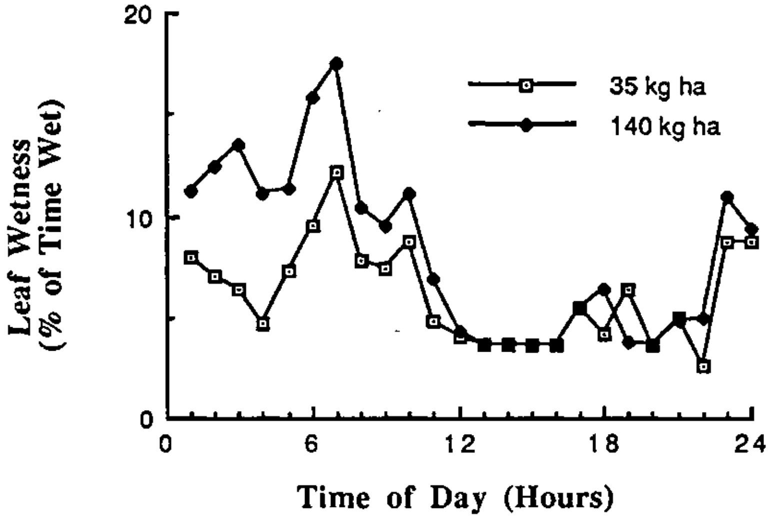

Figure 4.24 Effect of seed rate of Norstar winter wheat on daily leaf wetness period in trial 5. Mean of two row spacings (SE = 1.3).

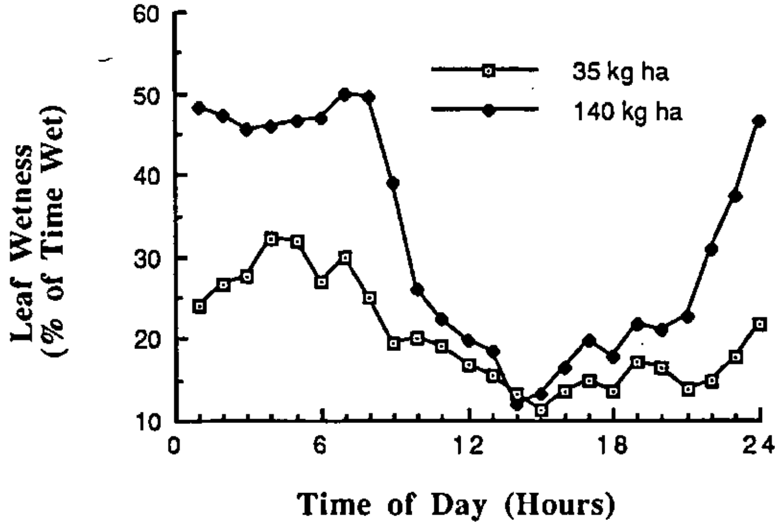

Figure 4.25 Effect of seed rate of Norstar winter wheat on daily leaf wetness period in trial 10. Mean of two row spacings (SE = 3.9).

Table 4.59 Analysis of variance for effect of row spacing on frequency of leaf wetness in Norstar winter wheat in trials 7 and 10.

| | Mean Square - Frequency of Leaf Wetness | | | |
|---|---|---|---|---|
| Sources of Variation | df | Trial 10 | df | Trial 7 |
| Day | 21 | 2175.41** | 22 | 1206.27** |
| Row Spacing | 1 | 2803.35* | 1 | 355.94 |
| Error | 21 | 405.14 | 22 | 93.10 |

*,**Significant at p=0.05 and p=0.01, respectively.

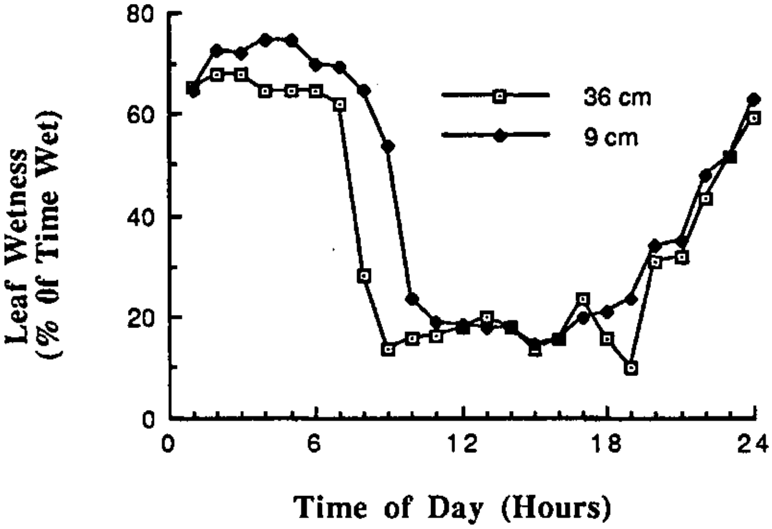

Figure 4.27 Effect of row spacing of Norstar winter wheat on daily leaf wetness period in trial 7. Mean of two row spacings (SE = 2.0).

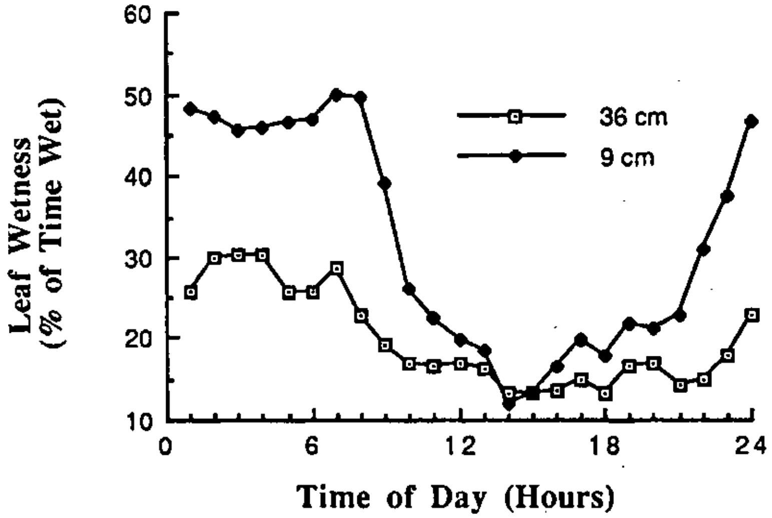

Figure 4.26 Effect of row spacing of Norstar winter wheat on daily leaf wetness period in trial 10. Mean of two row spacings (SE = 4.3).

Laboratory studies indicate that *Septoria nodorum* and *S. tritici* each have a critical moisture requirement period for their spores to germinate (Holmes and Colhoun, 1974). In general, the longer the duration of the leaf wetness period the greater the frequency of spore germination.

Observations made in the present study demonstrate that the combination of high SR and narrow RS produces longer periods of leaf wetness in Norstar winter wheat. High SR was of particular importance. This correlates with observations of septoria severity both in experiment C and experiment A (Figure 4.12 and Table 4.49). For example, in experiment C, septoria severity on the flag leaf-1 of Norstar was 17% for the 9-140 combination compared to 10% when either SR was lowered (9-35) or RS was increased (36-140) (Table 4.49).

There are two factors that must be taken into consideration when interpreting the above results. First, leaf wetness was measured on a sensor that simulates a leaf surface. This sensor has a flat surface with very different properties as compared to a leaf surface. Consequently, the sensor does not simulate the many microsite differences that occur on a leaf surface. However, if viewed as a rough approximation, these measurements indicate that large differences in microclimate can be produced within the crop canopy by simply varying seed rate and row spacing.

Secondly, the measurements of leaf wetness were all taken at the base of the crop canopy. The leaves, particularly the flag leaf, are exposed to a very different microclimate. *Septoria nodorum*, can cause severe yield losses when the pathogen attacks the glumes, which are even further removed from inside the canopy. Readings of leaf wetness, taken at the base of the canopy, indicate differences in microclimate within the crop canopy. These differences may be minimized as one proceeds from the base of the plant to the flag leaf. However, septoria appears first on the lower leaves of the plant and progresses up the plant throughout the growing season. Consequently, the lower leaves of the plant are important as a septoria inoculum source reaching the upper leaves via rain splash. Increasing the inoculum load increases the possibility of a severe infestation on the upper leaves when the right environmental conditions are present. Also, any leaf, including a flag leaf, is not a completely flat horizontal surface. The leaf rises and droops through different strata within the crop canopy providing many different microsites with different microenvironments. Consequently, while the leaf wetness readings taken in this experiment demonstrate differences within the crop canopy, they are only useful as a rough approximation of the multitude of different microenvironments that may exist.

Wind speed. Row spacing had a significant influence on wind speed within the crop canopy (Table 4.60). Higher wind speeds were associated with wide RS (Figures 4.28 to 4.30). Difference between RS treatments were largest in trial 10 where more favourable moisture conditions produced a thicker canopy.

The wind speed measurements should be interpreted with some caution. In the narrow RS treatment, several plants were pruned to allow the anemometer to rotate without interference. This had the effect of minimizing differences between treatments. Unfortunately, at

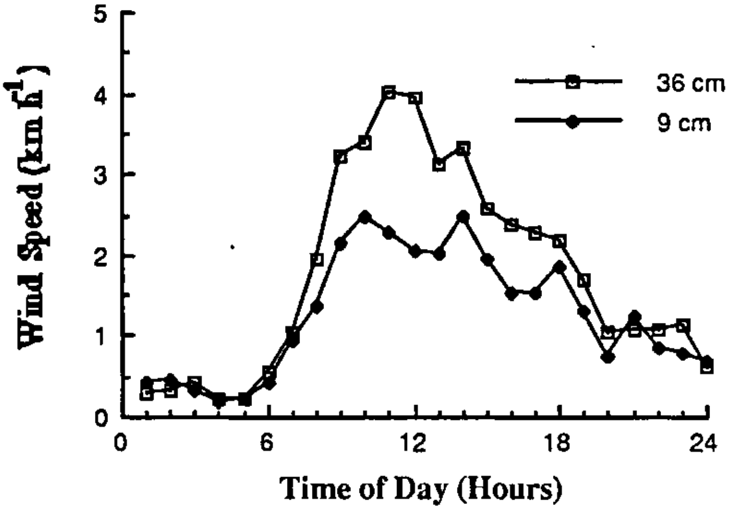

Figure 4.28 Effect of row spacing of Norstar winter wheat on wind speed throughout the day in trial 5 (SE = 0.44).

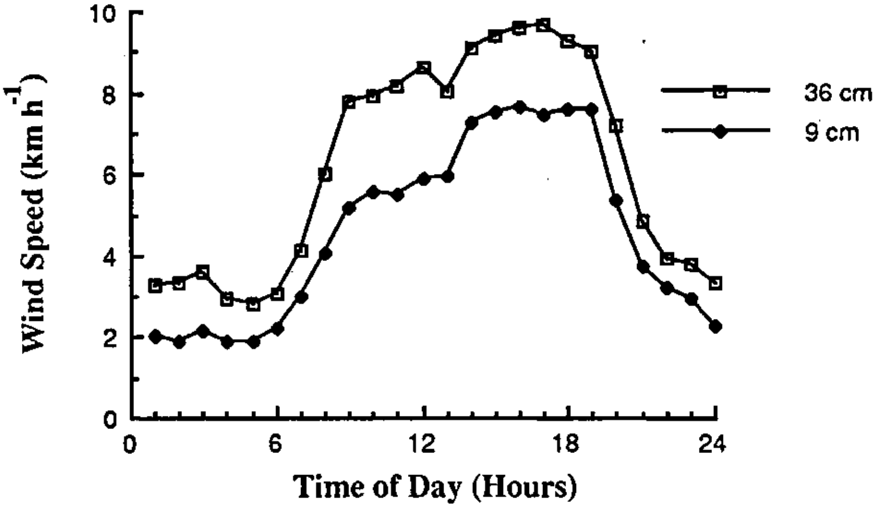

Figure 4.29 Effect of row spacing of Norstar winter wheat on wind speed throughout the day in trial 7 (SE = 0.35)

Table 4.60 Analysis of variance for effect of row spacing on wind speed within the crop canopy of Norstar winter wheat in three trials, 1988.

| | | Mean Square |
|---|---|---|
| Sources of Variation | df | Within Crop Canopy Wind Speed |
| Day | 35 | 25.8999 |
| Trial | 2 | 157.0922* |
| Trial x Day | 28 | 29.9729 |
| Row Spacing | 1 | 79.0192** |
| Trial x Row Spacing | 2 | 6.5787 |
| Error | 63 | 3.2395 |

*,**Significant at p=0.05 and p=0.01, respectively.

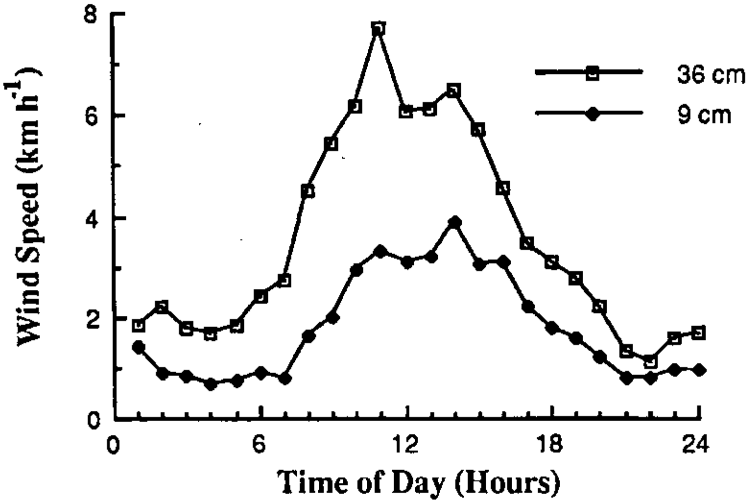

Figure 4.30 Effect of row spacing of Norstar winter wheat on wind speed throughout the day in trial 10 (SE = 0.35).

both row spacings, the crop canopy interfered with the anemometers, particularly at high wind speeds. Questionable values were not included in the analysis, but this meant that results from times when there were high winds were not included. Therefore, the reported measurements do not provide an absolute measure of wind speed within the crop canopy. They do, however, support the suggestion that higher wind speed within the crop canopy is associated with wide RS.

Higher wind speed within the crop canopy may aid the dispersal of PM spores. Eversmeyer et al (1973) noted that high wind velocities were necessary to dislodge spores when the foliage was wet or the inoculum source was lower in the canopy. The disease ratings taken in this study indicated that wider RS contributed to PM development, particularly early in the epidemic (Section 4.5.2.1). Therefore, it is suggested that higher wind speed with wide RS may have contributed to the dispersal phase of PM development in the present study.

The plots in this study were all seeded in an east-west direction to maximize the effect of wind speed as the prevailing winds are from the west. Although that was not tested in this study, it would be expected that seeding in a north-south direction would minimize the wind speed within the crop canopy.

The lower wind speed at narrow RS may be a factor in the prolonged period of leaf wetness associated with narrow RS in trial 10 (Figure 4.26).

Temperature. Seed rate/row spacing combination had a significant effect on both mean daily temperature and maximum daily temperature measured at trials 3, 5, 7, and 10 (Table 4.61). Narrow RS and high SR

Table 4.61 Analysis of variance of mean and maximum daily temperatures for cultivar Norstar in four trials, 1987 to 1988.

| | | Mean Square - Daily Temperature | |
|---|---|---|---|
| Sources of Variation | df | Mean Temperature | Maximum Temperature |
| Trial | 3 | 341.07** | 1019.35** |
| Date in trials | 86 | 30.59 | 75.00 |
| SRRS Combination | 3 | 9.35** | 22.13** |
| RS | 1 | 25.19** | 55.01** |
| SR | 1 | 2.50** | 9.88** |
| SR x RS | 1 | 0.38* | 1.49 |
| Trial x SRRS | 9 | 0.52** | 2.85** |
| Error | 258 | 0.59 | 0.57 |

*,**Significant at p=0.05 and 0.01, respectively.

were associated with lower temperatures. However, the magnitude of differences between treatments, particularly for mean daily temperature was not very large (Table 4.62). The mean differential across all trials between the highest and lowest mean daily temperature was 0.8° C. Typically, this differential was the least overnight and rose to a maximum in the early afternoon (Fig. 4.31). Consequently, the difference in maximum daily temperature was larger than the mean daily temperature (Table 4.63). The mean maximum difference across all trials was 1.1° C with a range of 0.8 (Trial 5) to 1.9° C (Trial 10). Trial 10 had a denser crop canopy due to better moisture conditions. Lowest maximum daily temperatures were associated with the 9-140 treatment and highest maximum daily temperatures were associated with the 36-35 treatment.

Air temperature values were recorded in the shade. This may have minimized some differences in temperature between treatments as it negates the direct warming action of sunlight on the soil or leaves. Warming of the soil would be promoted by wide RS due to the difference in light intensity penetrating the crop canopy.

Relative humidity. Seed rate/row spacing combination had a significant influence on both mean daily RH and the minimum daily RH (Table 4.64). Differences in RH between treatments were minimal overnight and rose to a maximum in the early part of the afternoon (Figure 4.32). Lower values for RH were associated with wide RS and low SR. Therefore, narrow RS and high SR produced RH levels that were more conducive to disease development. The difference in mean daily RH among the SRRS combinations considered was 3.1% (Table 4.65). This

Table 4.62 Effect of trial and seed rate and row spacing combination on mean daily temperature in four trials.

| | Mean Daily Temperature (°C) | | | | |
|---|---|---|---|---|---|
| | Trial | | | | |
| Row Spacing-Seed Rate (cm) (kg ha$^{-1}$) | 3 | 5 | 7 | 10 | Mean[1] |
| 36-35 | 16.6a | 21.9a | 20.6a | 20.3a | 20.2a |
| 36-140 | 16.5a | 21.8a | 20.4b | 20.2a | 20.1b |
| 9-35 | 16.4a | 21.5b | 19.9c | 19.6b | 19.7c |
| 9-140 | 16.2b | 21.3c | 19.5d | 19.5c | 19.4d |
| Mean | 16.4 | 21.6 | 20.1 | 19.9 | |
| $S_{\bar{x}}$ | 0.7 | 0.6 | 0.6 | 0.5 | |

[1] Within a column means followed by the same letter are not significantly different at p=0.05 by LSD ($S_{\bar{x}}$=0.08).

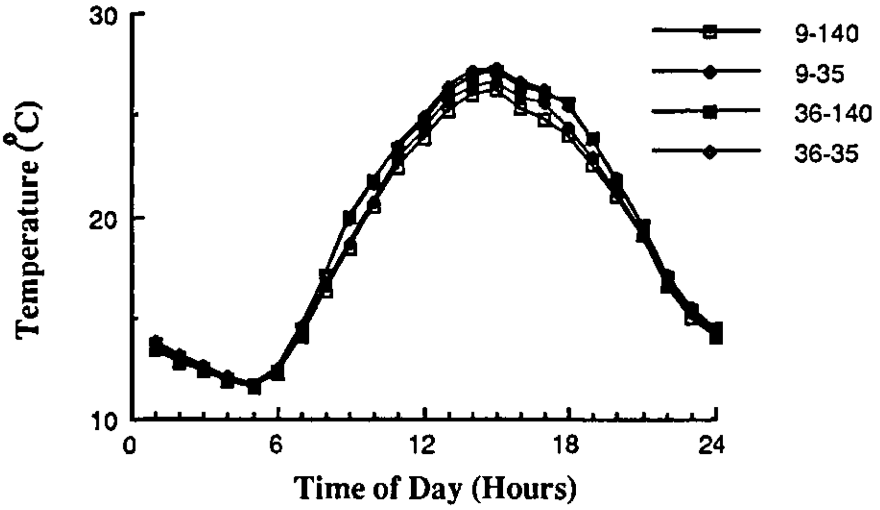

Figure 4.31 Effect of seed rate/row spacing of Norstar winter wheat on diurnal temperature in trials 3, 5, 7 and 10 (SE = 0.1).

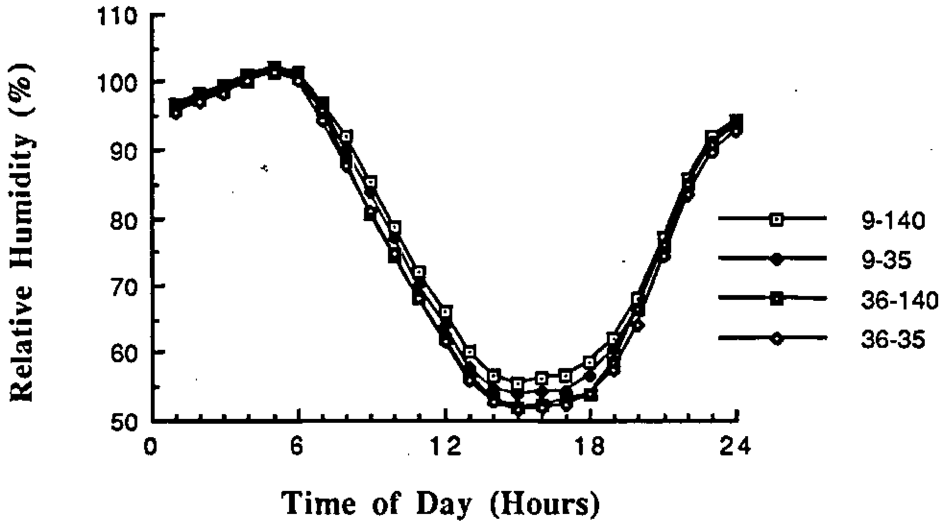

Figure 4.32 Effect of seed rate/row spacing of Norstar winter wheat on daily relative humidity in trials 3, 5, 7 and 10 (SE = 0.1).

Table 4.63 Effect of trial and seed rate and row spacing combination on maximum daily temperature in four trials.

| | Maximum Daily Temperature (°C) | | | | |
|---|---|---|---|---|---|
| | Trial | | | | |
| Row Spacing-Seed Rate (cm) (kg $ha^{-1}$) | 3 | 5 | 7 | 10 | Mean[1] |
| 36-35 | 23.5a | 32.6a | 30.3a | 29.3a | 29.5a |
| 36-140 | 23.4a | 32.1b | 30.5a | 28.8b | 29.2b |
| 9-35 | 23.2a | 31.9b | 29.3b | 28.6b | 28.8c |
| 9-140 | 22.6b | 31.8b | 28.4c | 28.3b | 28.4d |
| Mean | 23.2 | 32.1 | 29.6 | 28.8 | |
| $S_{\bar{x}}$ | 1.1 | 0.9 | 0.9 | 0.8 | |

[1] Within a column means followed by the same letter are not significantly different at p=0.05 by LSD ($S_{\bar{x}}$=0.08).

Table 4.64 Analysis of variance of mean and minimum daily relative humidity for cultivar Norstar in three trials.

| | | Mean Square - Daily Relative Humidity | |
|---|---|---|---|
| Sources of Variation | df | Mean RH | Minimum RH |
| Trial | 2 | 25624.26** | 27377.05** |
| Date in trials | 44 | 392.76 | 1161.75 |
| SRRS Combination | 3 | 59.47** | 114.01** |
| RS | 1 | 145.39** | 263.10** |
| SR | 1 | 29.98** | 52.77** |
| SR x RS | 1 | 3.03 | 26.17* |
| Trial x SRRS | 6 | 13.02** | 34.50** |
| Error | 132 | 1.15 | 4.48 |

*,**Significant at p=0.05 and 0.01, respectively.

Table 4.65 Effect of trial and seed rate and row spacing combination on mean daily relative humidity in three trials.

| | Mean Daily Relative Humidity (%) | | | |
|---|---|---|---|---|
| | Trial | | | |
| Row Spacing-Seed Rate (cm) (kg $ha^{-1}$) | 3 | 5 | 7 | Mean[1] |
| 36-35 | 83.8a | 47.7a | 86.7a | 76.6a |
| 36-140 | 84.2a | 47.9ab | 87.8b | 77.3b |
| 9-35 | 84.4a | 48.6bc | 89.8c | 78.5c |
| 9-140 | 85.5b | 49.1c | 91.5d | 79.7d |
| Mean | 84.5 | 48.4 | 89.0 | |
| $S_{\bar{x}}$ | 2.6 | 3.0 | 2.2 | |

[1] Within a column means followed by the same letter are not significantly different at p=0.05 by LSD ($S_{\bar{x}}$=0.16).

ranged from 4.2% at trial 5 to 7% at trial 7 (Table 4.66). The highest daily minimum RH was associated with the 9-140 treatment and the lowest minimum daily RH with the 36-35 treatment.

Higher RH promotes the development of PM and affects septoria indirectly by prolonging the period of leaf wetness. For the trials where RH was recorded, the greatest differences among SRRS combinations occurred in trial 7. There was no PM present at trial 5 and trial 7 produced greater differences among SRRS combinations than did trial 10 (Figures 4.8 and 4.10).

The daily RH and temperature patterns were similar. RH levels declined earlier in the day and to lower levels for the wide RS and low SR treatments (Figure 4.32). Therefore, if low RH was a limiting factor for PM development, the combination of narrow RS and high SR would be more conducive to PM development. This suggests the following hypothesis: PM dispersal is promoted by wide RS, but once the PM is established on the upper leaves of the canopy disease development is promoted by high SR and narrow RS. In the intermediate stages of an epidemic, the effects of wide RS on dispersal and narrow RS on development would be confounding effects.

The moderating effect of narrow RS and high SR on RH during the day would promote longer periods of leaf wetness and consequently, more septoria development. Septoria spore germination would be promoted, and there may also be an effect on lesion development.

Table 4.66 Effect of trial and seed rate and row spacing combination on minimum daily relative humidity at three trials.

| Row Spacing-Seed Rate (cm) (kg ha$^{-1}$) | Minimum Daily Relative Humidity (%) | | | |
|---|---|---|---|---|
| | Trial | | | |
| | 3 | 5 | 7 | Mean[1] |
| 36-35 | 64.1a | 19.4a | 51.1a | 47.8a |
| 36-140 | 64.6a | 20.0a | 51.0a | 48.1a |
| 9-35 | 65.6ab | 19.9a | 54.2b | 49.8b |
| 9-140 | 67.0b | 20.4a | 57.8c | 52.0c |
| Mean | 65.3 | 20.0 | 53.5 | |
| $S_{\bar{x}}$ | 4.4 | 5.1 | 3.7 | |

[1] Within a column means followed by the same letter are not significantly different at p=0.05 by LSD ($S_{\bar{x}}$=0.3).

## 4.8 Fungicide Study

Grain yield and kernel weight. Differences among trials were significant for both grain yield and kernel weight (Table 4.67). Trials where better moisture conditions were present had higher grain yield and higher kernel weight.

Fungicide type did not have a significant influence on grain yield, but it did influence kernel weight (Table 4.67). Kernel weight was greater with propiconazole application than with the other fungicides (Table 4.68). Fungicide application significantly improved grain yield and kernel weight over the check (Table 4.69). Split applications and the two early single applications of all fungicides produced the highest grain yield. The split application and later single applications of all fungicides produced the highest kernel weight.

Critical point disease evaluations. Septoria and PM severity on the flag leaf were significantly influenced by trial location (Table 4.70). These differences were related to moisture differences among sites.

Fungicide and timing (growth stage) of fungicide application had a significant effect on septoria and PM severity (Table 4.70). Propiconazole provided the best control of septoria and PM (Table 4.71). Fungicide application reduced disease severity over the check (Table 4.72). The split application times provided the best control of septoria while the best stage for single application was at Feekes

Table 4.67 Analysis of variance for effect of fungicide and timing of application on grain yield and kernel weight in fungicide study in six trials, 1986 to 1988.

| | | Mean Square | |
|---|---|---|---|
| Sources of Variation | df | Grain Yield | Kernel Weight |
| Trial | 5 | 30451009** | 461.64** |
| Rep in trials | 18 | 713862 | 5.30 |
| Fungicide (F) | 2 | 466643 | 70.56** |
| Trial x F | 10 | 111863 | 3.39 |
| Rep x F in trials | 36 | 270238 | 3.82 |
| Time (T) | 4 | 1059284** | 26.50** |
| F x T | 8 | 55757 | 3.33* |
| Trial x T | 20 | 123651 | 3.40** |
| Trial x F x T | 40 | 72483 | 2.88** |
| Error | 211 | 83640 | 1.63 |

*,**Significant at p=0.05 and p=0.01, respectively.

Table 4.68 Effect of fungicide on grain yield and kernel weight on winter wheat for fungicide study (mean of five application times in six trials, 1986 to 1988).

| Fungicide | Grain Yield ($kg\ ha^{-1}$) | Kernel Weight ($g\ 1000^{-1}$) |
|---|---|---|
| Propiconazole | 2454a[1] | 33.0a |
| Triadimefon | 2346a | 31.7b |
| Mancozeb | 2341a | 31.5b |
| $S_{\bar{x}}$ | 48 | 0.2 |

[1] Within a column means followed by the same letter are not significantly different at p=0.05 (LSD).

Table 4.69 Effect of time of fungicide application on grain yield and kernel weight on winter wheat for the fungicide study (mean of three fungicides in six trials, 1986 to 1988).

| Application Time (Feeke's GS) | Grain Yield (kg $ha^{-1}$) | Kernel Weight (g $1000^{-1}$) |
|---|---|---|
| GS 5+10 | 2508a[1] | 32.6a |
| GS 8 | 2444a | 32.4a |
| GS 5 | 2427a | 31.8b |
| GS 10 | 2314b | 32.5a |
| Check | 2212c | 31.1c |
| $S_{\bar{x}}$ | 34 | 0.2 |

[1] Within a column means followed by the same letter are not significantly different at p=0.05 (LSD).

Table 4.70 Analysis of variance for effect of fungicide and timing of application on severity of septoria and powdery mildew on the flag leaf for fungicide study (mean of five trials, 1986 to 1988).

| | | Mean Square - Disease Severity | | |
|---|---|---|---|---|
| Sources of Variation | df | Septoria | df | Powdery Mildew[1] |
| Trial | 4 | 23.99** | 3 | 31.51** |
| Rep in trials | 15 | 1.87 | 12 | 2.36 |
| Fungicide (F) | 2 | 59.58** | 2 | 51.10** |
| Trial x F | 8 | 7.56 | 6 | 2.65 |
| Rep x F in trials | 30 | 0.55 | 24 | 1.31 |
| Time (T) | 4 | 17.56** | 4 | 8.53** |
| F x T | 8 | 3.86** | 8 | 0.61 |
| Trial x T | 16 | 1.98** | 12 | 0.59 |
| Trial x F x T | 32 | 1.27** | 24 | 0.23 |
| Error | 178 | 0.57 | 142 | 0.48 |

[1] Powdery mildew analyzed at four trials.

*,**Significant at p=0.05 and p=0.01, respectively.

Table 4.71 Effect of fungicide on severity of septoria and powdery mildew on the flag leaves of winter wheat for the fungicide study (mean of five application times in five trials, 1986 to 1988).

| | Disease Severity (% leaf area covered) | | | |
|---|---|---|---|---|
| Fungicide | Septoria | $S_{\bar{x}}$ | Powdery Mildew[1] | $S_{\bar{x}}$ |
| Mancozeb | 16a[2] | 1.0 | 5a | 0.5 |
| Triadimefon | 8b | 0.5 | 2b | 0.1 |
| Propiconazole | 6c | 0.5 | 2b | 0.1 |

[1] Powdery mildew values represent the mean of four trials.

[2] Within a column means followed by the same letter are not significantly different at $p=0.05$ (LSD).

Table 4.72 Effect of time of fungicide application on severity of septoria and powdery mildew on the flag leaves of winter wheat for the fungicide study (mean of three fungicides in five trials, 1986 to 1988).

| Application Time (Feekes's GS) | Disease Severity (% flag leaf covered) | | | |
|---|---|---|---|---|
| | Septoria | $S_{\bar{x}}$ | Powdery Mildew[1] | $S_{\bar{x}}$ |
| Check | 17a[2] | 1.0 | 5a | 0.3 |
| GS 5 | 9b | 0.7 | 2c | 0.3 |
| GS 10 | 9b | 0.5 | 3b | 0.2 |
| GS 8 | 8c | 0.5 | 2c | 0.1 |
| GS 5+10 | 6d | 0.5 | 2c | 0.1 |

[1] Powdery mildew values represent the mean of four trials.

[2] Within a column means followed by the same letter are not significantly different at p=0.05 (LSD).

growth stage 8. The split application or earlier application times provided the best control of PM.

There was a significant interaction between fungicide and stage of application for septoria control (Table 4.70). For the single application times, the earlier applications of triadimefon and the later applications of propiconazole gave the best control.

There was a significant trial by time of fungicide application interaction for septoria control. This was at least partly related to moisture differences that resulted in septoria epidemics developing at different times in different trials.

Propiconazole applied at growth stage 8 generally provided the best disease control and highest yield and kernel weight, of the single applications. These results are consistent with findings by Guy et al, (1989). Typically more than one disease at a time is present in a wheat crop (Dannenberg, 1989). Consequently, it is preferable to choose a fungicide like propiconazole that provides a broad control spectrum. The optimum time of application for disease control and yield may be at an earlier GS than is commonly practised (Spadafora et al, 1987). Powdery mildew, in particular, may be best controlled by an early application of fungicide, but the tendency is to delay application until a disease problem has been verified. However, even then fungicide application is often only marginally economically feasible.

# 5. SUMMARY AND CONCLUSIONS

The highest SR (140 kg $ha^{-1}$) and narrowest RS (9 cm) considered in this study produced the highest winter wheat grain yields. Increasing the SR and decreasing the RS together produced a 21% increase in grain yield over the more conventional SRRS combination of 70 kg $ha^{-1}$ SR and 18 cm RS. The tall cultivar Norstar outyielded the semi-dwarf Norwin under the conditions present in this study. In this study two of the three years experienced below average moisture conditions.

All yield components were affected by the SRRS combination. The number of heads $m^{-2}$ increased as SR increased and RS decreased. This was the yield component that was primarily responsible for the increase in grain yield associated with the combination of high SR and narrow RS. Kernel weight and the number of kernels per head both decreased as SR increased and kernels per head decreased as RS decreased.

Dry matter yield at harvest increased with increase in SR. Seed rate had a greater effect on dry matter yield, while RS had a greater effect on grain yield. This suggests that the efficiency of dry matter yield conversion into grain yield was not uniform under the relatively dry conditions of this study.

The effect of SRRS on maturity was only measured in one trial. High SR and wide RS were found to hasten maturity, probably due to increased intra-row competition. The effect of SR on maturity was of greater importance. Winter wheat grown at the 9-140 combination matured two days earlier than winter wheat grown at the 18-70 combination. Favourable moisture conditions were present in this trial. It would be expected that the effect of SRRS on maturity would be smaller in a dry year than in a wet year.

Nitrogen rate, SR and RS all affected the pattern of soil moisture use. Increased N rate promoted increased WU throughout the growing season. High SR also promoted increased WU over the course of the growing season. Increased SR promoted greater WU in the pre-anthesis growth period compared to the post-anthesis growth period. Narrow RS also promoted increased WU over the course of the growing season primarily due to increased WU in the pre-anthesis growth period. Under the relatively dry conditions present in this study, low SR and wide RS treatments conserved more moisture for the post-anthesis growth period. This was reflected by the fact that higher kernel weights were associated with low SR. However, higher grain yield and highest WUE was associated with the combination of high SR and narrow RS.

Increased N rate, high SR and to a lesser extent narrow RS produced higher GP levels. This was related to the pattern of soil moisture use and N assimilation. At high SR the plants extracted more soil moisture in the pre-anthesis growth period, producing greater dry matter accumulation by anthesis. This would have resulted in greater N uptake, which could later be translated into higher GP as the N was partitioned. The combination of high SR and narrow RS produced the highest grain and protein yield.

The high SR treatment extracted more water from throughout the soil profile indicating that greater competition for water in the pre-anthesis growth period stimulated root growth for this SR treatment. A higher yield of grain P also indicated that more extensive rooting was associated with high SR.

Powdery mildew development was promoted by high N rate, and high SR. Wide RS was also found to aid PM development, particularly in the dispersal phase of its infection cycle as the effect of wide RS was most evident in the early stages of the epidemic. Narrow RS may promote PM development once the pathogen is established on a leaf. Septoria development was promoted by high SR while low N rate promoted septoria development under some environmental conditions. Both PM and septoria were a greater problem on the semi-dwarf cultivar Norwin than the tall cultivar Norstar. However, it was not possible to determine whether this was due to shorter plant height, a more susceptible genotype, or a combination of both factors.

Radiant flux density measured at the base of the crop canopy was greater for wide RS than for narrow RS indicating that less light was being intercepted by the crop canopy with wide RS. Consequently, more light can be intercepted by the crop and utilized for yield production and less light is available for weed growth with narrow RS.

Increased duration of leaf wetness was favoured by high SR and to a lesser extent, by narrow RS. Increased duration of leaf wetness could be particularly important for septoria development, as spore germination requires the presence of water. This would account for the fact that higher levels of septoria were associated with high SR.

Higher wind speed within the crop canopy was associated with wide RS. This could be of importance in aiding the dispersal of PM spores and could explain the higher levels of PM that were associated with wide RS in the early stages of an epidemic.

The mean maximum daily temperature measured at the base of the crop canopy was lowest for the combination of narrow RS and high SR.

The difference between the 9-140 combination and the 36-35 combination averaged 1.1°C over all trials, and ranged from 0.8°C to 1.9°C.

Minimum daily relative humidity was highest for the 9-140 combination. The differential in minimum RH between the 9-140 and 36-35 combination was 4.2% and ranged from 1% to 7% for the trials considered. The higher RH associated with the combination of 9-140 should promote PM development and indirectly promote septoria development as higher RH would prolong the period of leaf wetness.

Propiconazole applied at Feekes GS 8 provided better disease control and produced higher grain yield and kernel weight than single applications of tridimefon or mancozeb. Split applications of fungicide provided only marginally better results than the single application at Feekes GS 8.

The results of these studies strongly support the use of 140 kg $ha^{-1}$ SR and 9 cm RS for winter wheat grown in the Parkbelt regions of Saskatchewan. This would provide higher grain yield in years when moisture conditions are not seriously limiting. It would also provide slightly earlier maturity in wet years, higher GP levels and better weed control. However, higher SR may be expected to result in increased problems with septoria in years when environmental conditions are favourable. Powdery mildew severity may also increase, although the use of narrow RS may delay the onset of an epidemic. The combination of narrow RS and high SR promotes increased interception of light, reduced wind speed, prolonged duration of leaf wetness, lowered air temperature and increased RH within the crop canopy. These conditions which are favourable for crop growth, may also be favourable for foliar disease development.

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