EFFECT OF LEAF WETNESS PERIOD ON INFECTION BY *PYRENOPHORA TRITICI-REPENTIS* AND THE INFLUENCE OF RESIDUE MANAGEMENT ON THE DEVELOPMENT OF LEAF SPOT DISEASES OF WHEAT

BY

NORMAN D. SISSONS

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BY

NORMAN D. SISSONS

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirements for the degree

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ABSTRACT

Pyrenophora tritici-repentis, the causal organism of tan spot or yellow spot, and *Septoria spp.* are the major leaf spot pathogens of wheat in western Canada. Both pathogens survive on crop residues and infect seedlings in the spring. Three studies were conducted to further our knowledge of the epidemiology of these pathogens. The first study investigated the effect of continuous and interrupted leaf wetness periods on the infection process of *P. tritici-repentis* in necrosis and chlorosis expressing wheat genotypes. In addition, the influence of spring tillage practices and infested wheat residues on development of leaf spot diseases were studied in two separate experiments. Control treatments were established for each tillage and residue treatment by applying Tilt fungicide. The infection process was similar in wheat genotypes expressing chlorotic or necrotic symptoms. Disease severity decreased when the leaf wetness period was interrupted between 0 and 4 h of incubation and increased between 4 and 12 h of incubation. The interruption of leaf wetness after appressorial formation, but prior to epidermal cell penetration, may irreversibly disrupt the infection process. In all tillage treatments in 1993, a yield increase of 43 to 63% and a kernel weight increase of 26 to 33% were observed compared to tillage treatments without Tilt applied. Seeds head^{-1}, heads m^{-2} and plant height were not affected by tillage practice or application of fungicide. Tillage practices did not result in significant differences in disease severity and were not an effective control method. Yield and kernel weight reduction were attributed to onset of leaf spot diseases after the flag leaf emerged. Application of Tilt to direct

seeding treatments tended to increase yield more compared to other treatments, indicating that reduced tillage may increase the effect of leaf spot diseases on wheat yield. Increasing the amount of infested residues did not consistently increase disease levels. In addition to interplot interference, periodic flooding in 1993 and 1994 caused variable results. Increasing the level of infested residues tended to reduce yield, particularly when 8000 kg residues ha^{-1} were applied.

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FORWARD

This thesis is written in manuscript style. The thesis begins with a general abstract, introduction and review of the literature. It is followed by three chapters, each representing a particular research project. The thesis is concluded with a general discussion that includes suggestions for future research, followed by the literature cited throughout the thesis and an appendix. The three chapters resprenting research projects are formated as follows: abstract, introduction, materials and methods, results and discussion. This thesis is written to conform with the requirements of the Canadian Journal of Plant Pathology.

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1. INTRODUCTION.

Pyrenophora tritici-repentis (Died.) Drechs. (anamorph *Drechslera tritici-repentis*), the causal agent of tan spot or yellow spot, has become an economically significant disease of wheat (*Triticum aestivum L.*) worldwide (Tekauz 1976, Dubin 1983, Wiese et al. 1984, Luz da & Bergstrom 1986, Cook & Yarham 1989). The leaf spot disease complex in western Canada is comprised of *P. tritici-repentis, Septoria spp.* and *Cochliobolus sativus* (Tekauz 1976). In the mid-1980's, *P. tritici-repentis* became more prevalent on wheat in western Canada than in previous years (Lamari unpublished data). A corresponding increase in the use of conservation tillage practices and retention of stubble similar to the situation that has occurred in Australia (Rees & Platz 1979), may have had an influence. In 1992, 1993 and 1994, incidence of *Septoria spp.* were at least as prevalent as tan spot (Gilbert et al. 1993, Gilbert et al. 1994, Gilbert et al. 1995) possibly due to higher rainfall than in previous years.

In the last two decades there has been a trend toward reduced tillage by farmers on the Canadian prairies. A subsequent increase in leaf spot diseases of wheat has occurred and yield losses have become more common. Although these pathogens have caused significant yield losses during the past decade, little is known about the influence of cultural practices on disease progress under Manitoba conditions. *P. tritici-repentis* survives on stubble during the winter months and infects wheat seedlings in the spring. Any practice that increases the rate of stubble decomposition or reduces the amount of stubble should decrease the incidence of disease. However, since environmental conditions play a significant role in epidemic development, predicting the progress of leaf

spot epidemics can be difficult.

Research studying the effect of interrupting the leaf wetness period is lacking. This study investigated the effect of interrupting leaf wetness periods on the infection process of *P. tritici-repentis* in a controlled environment to further our understanding of the pathogenic process of *P. tritici-repentis*. In addition, the influence of spring tillage practices and infested wheat residue levels on the development of leaf spot diseases in a field environment were studied.

2. REVIEW OF THE LITERATURE.

2.1 Host Range. The host range of *Pyrenophora tritici-repentis* has been studied extensively. Hosford (1971) reported that *P. tritici-repentis* was pathogenic on *Triticum* and *Agropyron* species as well as on brome grass and rye. He also observed that *P. tritici-repentis* was slightly pathogenic on barley, but not pathogenic on oats, corn, alfalfa and flax. Many species of grasses (*Elymus junceus, E. angustus, E. giganteus, E. cinereus, E. sibericus, E. triticoides, Agropyron smithii, A. desertorum, A. intermedium, A. spicatum, A. cristatum, Alopecurus arundinaceous, Bouteloua gracilis, Bromus inermis* and *Stipa viridula*) were later identified as hosts of *P. tritici-repentis* (Krupinsky 1982). A number of hosts (*Andropogon gerardii, Dactylis glomerata, Panicum virgatum, Sorghastrum nutans* and *Avena sativa*) with a low level of symptom expression were also identified. Brome grass (*B. inermis*) isolates had virulence levels similar to those found on wheat (Krupinsky 1987), but other isolates of *P. tritici-repentis* collected from 25 grass species differed in their ability to cause disease symptoms in wheat (Krupinsky 1992a). Smooth brome grass may also be an important alternative host of *P. tritici-repentis* and *Phaeosphaeria nodorum* across the Northern Great Plains of the United States (Krupinsky 1986). Recently, Krupinsky (1992a) identified additional grass species as hosts of *P. tritici-repentis* including: *Agropyron fragile* subsp. *sibiricum* (Siberian wheatgrass), *Andropogon gerardii* var. *paucipilus* (sand bluestem), *Bromus biebersteinii* (meadow brome), *Festuca ovina* (sheep fescue), *Koeleria pyramidata* (June grass), *Schizachyrium scoparium* (little bluestem), *Setaria viridis* (green foxtail), *Stipa comata* (needle and thread) and *Thinopyrum ponticum* (tall wheatgrass). Rees & Platz (1979) suggested that

wheat is the most important source of inoculum of *P. tritici-repentis* because only small lesions are produced on barley and other grass hosts. However, *P. tritici-repentis* is known to sporulate extensively on triticale and rye (Rees & Platz 1979).

2.2 Pathogen life cycle. The perfect state of *P. tritici-repentis* occurs on wheat and other host residues, and mature pseudothecia produce ascospores in the spring and infect the crop (Shaner 1981). Both ascospores and conidia may be a source of primary inoculum, but ascospores appear to be more important. Generally, conidia do not form until lesions are extensive or leaf tissue is dead. Unburied crop residues are the main source of primary inoculum for *Septoria* species that attack wheat (Shaner 1981). *P. nodorum* (anamorph *Stagonospora nodorum*), the causal agent of septoria leaf and glume blotch, overwinters as pycnidia on crop debris and may form perithecia in the fall. *Mycosphaerella graminicola* (anamorph *Septoria tritici*) may overwinter as pycnidia on crop debris or form ascocarps during the winter months (Shaner 1981). *Phaeosphaeria avenaria* (anamorph *Stagonospora avenae* f. sp. *triticea*) overwinters as mycelium on oat straw (Shaner 1981). In addition to pycnidia forming in the spring, perithecia may also form and produce ascospores. All species of Septoria produce pycnidiospores that act as secondary inoculum.

2.3 Host Reaction.

2.3.1 Symptoms and evaluation of host reaction. *P. tritici-repentis* typically causes spots on wheat leaves that range from small dark flecks to undefined lesions that may have a

yellow border (Hosford 1976). Lamari & Bernier (1989b) also noted the presence of chlorosis and necrosis when susceptible genotypes were evaluated. Subsequent research found that susceptible wheat genotypes may develop necrosis, chlorosis or both (Lamari et al. 1991). A rating system based on lesion type has been developed by Lamari & Bernier (1989b) to categorize symptoms induced by *P. tritici-repentis* in various wheat genotypes. Symptoms were categorized based on the presence or absence of necrosis or chlorosis surrounding a small dark infection site. Previously, symptoms of *P. tritici-repentis* were described using percent infection (Nagle et al. 1982), lesion size and percent infection (Luz da & Hosford 1980), number of lesions cm^{-2} (Nagle et al. 1982), an index combining lesion size, percent leaf area infected and leaf location (Raymond et al. 1985), lesion size alone (Cox & Hosford, 1987) and an infection type rating (Rees et al. 1987). Disease rating keys (James 1971) have been used in the past to estimate disease severity. Recently, color video image analysis has been used to measure leaf area infected, and lesion size and count (Lamari & Bernier 1994). Image analysis removes a degree of subjectivity, but must be treated with caution because of the inability of computer systems to distinguish between lesions caused by different pathogens and between diseased and senescent tissue.

Septoria spp. and *P. tritici-repentis* symptoms are visually difficult to distinguish. *P. nodorum* and *P. avenaria* cause dark, irregular shaped necrotic lesions while *M. graminicola* causes pale, necrotic lesions with small, dark pycnidia within its borders (Shaner 1981). All of these species may be present at the same time so that incubation of infected leaves is the only definitive way of identifying species based on spore type.

2.3.2 Effect of disease. Leaf spot diseases have been responsible for a significant yield reduction in wheat crops for many years in Manitoba (McDonald et al. 1969, McDonald et al. 1971). In 1969, wheat yield losses attributed to leaf spot diseases were as high as 26% (McDonald et al. 1969) while in 1970 losses were estimated at 3.2% (McDonald et al. 1971). Rees et al. (1981) reported that a loss in grain yield of up to 26% per main tiller and average of 12.7% was possible in Australia. Total loss in grain yield under optimal environmental conditions for disease may be as high as 49% in Australia (Rees et al. 1982) and as high as 30 to 50% in Kansas (Shabeer & Bockus 1988). Yield loss is greater for main stems than for other tillers, but tillers contribute up to 75% of yield (Rees et al. 1982). Rees & Platz (1983) reported that 25% of total yield loss was a result of early disease while 75% was a result of tan spot infections after jointing. Similarly, Shabeer & Bockus (1988) indicated that 17% of total yield loss was due to early ascospore infections, but they suggested that half of the total yield loss occurred prior to boot stage. Single inoculations caused the highest yield losses at the boot and flowering stages (Shabeer & Bockus 1988). Disease occurrence at tillering or elongation stages probably did not reduce yield because plants compensated for injury. Single inoculations at the milk stage or later are probably too late to cause yield loss (Shabeer & Bockus 1988). Onset of *P. tritici-repentis* after flowering only affects grain size while early disease may affect grain number (Rees et al. 1981). Plant numbers (Rees et al. 1982) and heads per plant (Rees et al. 1982, Shabeer & Bockus 1988) seemed unaffected by *P. tritici-repentis*. Severe early tan spot caused a delay in tiller production and noticeably smaller plants (Rees & Platz 1983). Early disease retarded crop development and delayed

flowering while late disease hastened maturity. Rees & Platz (1983) suggested that leaf diseases would likely be most severe in Australia when frequent rain occurs after the jointing stage in wheat.

2.4 Inoculum of *P. tritici-repentis*.

2.4.1 Primary inoculum production and survival. *P. tritici-repentis* forms pseudothecia on crop residues as a winter survival structure (Shaner 1981). In Ontario, a seasonal growth pattern was observed where ascocarps enlarged from August to October, asci formed from December to March and ascocarps differentiated beginning in late February (Wright & Sutton 1990). Mature pseudothecia capable of releasing ascospores were present from early April until mid-June when wheat growth stage ranged from late tillering to medium milk development. A linear relationship between incidence of pseudothecia that had matured and degree day accumulation was reported. Pseudothecia production in Ontario was greater after two crops than only one of wheat (Sutton & Vyn 1990). *P. tritici-repentis* produces mature asci and ascospores after 47 days at 16°C, but in North Dakota mature pseudothecia develop on stubble during spring and summer not autumn, suggesting a cool period is required (Shaner 1981). In Australia, the number of pseudothecia per gram of stubble increased between early fall and the following summer, even though the amount of wheat stubble decreased steadily (Shaner 1981). Mycelial growth of *P. tritici-repentis* is optimum at 20 to 25°C, but pseudothecia production is not temperature dependent (Summerell & Burgess 1988b). However, ascospores develop fastest at 15°C. Mycelial growth and pseudothecia numbers decline as moisture levels decrease. Pseudothecia are produced in equal numbers on wheat, oat and barley residues

regardless of reaction of the host to infection. Increased moisture results in an increase in the number of mature asci (Fernandes et al. 1991) while pseudothecia production is reduced to few small ascocarps when moisture is reduced (Pfender et al. 1988). Mature ascospores have appeared in the fall when the average temperature exceeded 15°C and were produced until the following spring (Rees & Platz 1980). Growth of conidia around the top of pseudothecia may also be a source of primary inoculum (Rees & Platz 1980).

In New South Wales, Australia, *P. tritici-repentis* has been known to survive on stubble on the soil surface for at least two years and probably longer (Summerell & Burgess 1989a). When stubble was buried or decomposition was encouraged, survival of the fungus was reduced to as little as 26 weeks. Burial or incorporation favoured decomposition of stubble because fractured pieces allow greater access for microorganisms. Decomposition of stubble was enhanced by warm, wet conditions which, in contrast, also promoted survival of *P. tritici-repentis* ascocarps (Summerell & Burgess 1989b).

Herbicides containing bromoxynil, dicamba, glyphosate, 2,4-D, or paraquat applied at label rates reduced ascocarp production of *P. tritici-repentis* significantly (Sharma et al. 1989). Glyphosate was the most effective, but became less effective if it was applied following incubation conditions good for ascocarp development. Another fungus, *Limonomyces roseipellis*, is a fast-growing basidiomycete that has the ability to degrade hyphae of *P. tritici-repentis* and internally colonize the fungus when grown on straw under laboratory conditions (Pfender et al. 1991a). *L. roseipellis* suppressed ascocarp production of *P. tritici-repentis* by 50 to 99% when incubated under warm, low-humidity conditions

(Pfender 1988). Other fungi isolated from buried straw were antagonistic to *P. tritici-repentis,* but were sensitive to water stress (Pfender et al. 1991b). Only fungi associated with straw from the soil contact area of the mulch layer inhibited pseudothecia production. Bacteria also inhibited pseudothecia production, but inhibition by all organisms occurred at the highest moisture levels tested (Pfender et al. 1991b). Decreasing the nitrogen level in a cellulose-based medium resulted in fewer and smaller pseudothecia containing fewer fertile asci (Pfender & Wootke 1987). Ascospore production was also related to nitrogen level. Cool, dry conditions favoured survival of *P. tritici-repentis* in artificially colonized wheat chaff with and without soil contact (Summerell & Burgess 1989b). Recovery of the fungus was less frequent when in contact with soil. Only *P. tritici-repentis* was recovered at the lowest water potential tested, suggesting that it is better adapted to dry conditions than many other facultative saprophytes.

2.4.2 Infection by primary inoculum. Epidemics in southern Queensland are initiated mainly by ascospores, and to a lesser extent conidia that are produced on stubble of a preceding diseased wheat crop (Rees & Platz 1980). In Ontario, ascospores seemed to infect the third leaf of plants and lower (Wright & Sutton 1990). Inoculum densities of 12700 to 31200 pseudothecia m^{-2} were required in Ontario to produce moderate to severe tan spot severity. Little is known about the infection process of ascospores and they have been difficult to catch in spore traps (Krupinsky 1992d).

2.4.3 Secondary inoculum production and survival. Production of conidia of *P. tritici-repentis* is promoted on older wheat leaves that are senescent. *P. tritici-repentis* can produce a secondary disease cycle about every 8 days under optimum conditions (Riaz et al. 1991). Summerell & Burgess (1988a) reported that conidia were only recovered from tan spot lesions prior to leaf senescence, but were recovered from all parts of a leaf after senescence. After senescence, the fungus grew saprophytically through the leaf sheath and into the stem. *P. tritici-repentis* was not recovered from the lower internodes of the plant, but was recovered from barley at levels comparable to wheat (Summerell & Burgess 1988a).

Conidiophore production occurs from 10 to 31°C while conidia are produced from 10 to 25°C (Platt et al. 1977). Optimal conidiation on V-8 juice agar occurs at 21°C. Conidiophores were formed at all times when a light period was present. Conidia were produced with 1 to 21 h of light with an optimum of 12 h +/- 1 h at 21°C on V-8 juice agar (Platt et al. 1977). On juice agar abundant conidiophores, but no conidia, were formed in continuous light and neither were formed under darkness (Khan 1971). Under favourable conditions, conidia are formed in darkness and conidiophores in light. Mycelial growth and conidiation of *P. tritici-repentis* are maximal at 100% relative humidity, but some conidiation occurs at 83 to 85% (Platt & Morrall 1980a). Light intensity of over 200 Wm^{-2} inhibited conidiation of most isolates. In Saskatchewan, light intensities of 948 Wm^{-2} have been recorded above the canopy. This may explain why conidia are most often formed on dead and senescent leaves low in the crop canopy (Platt & Morrall 1980).

Conidial isolates of *P. tritici-repentis* are most sensitive to the fungicide propiconazole followed by BAY 1608 and RH 3866 (Hunger & Brown 1987). When *P. tritici-repentis* and *Cochliobolus sativus* were inoculated onto wheat leaves, *C. sativus* appeared antagonistic (Luz da & Bergstrom 1987).

2.4.4 Dispersal of primary and secondary Inoculum. Dispersal of ascospores must first occur prior to infection by *P. tritici-repentis*. In Queensland, Australia, ascospores were detected in the air between March and October, but the numbers were small (Rees & Platz 1980). The number of airborne conidia showed a large increase the day following a rain or irrigation. Adee & Pfender (1989) reported that in Kansas the impact of primary inoculum could persist throughout an epidemic of *P. tritici-repentis*. They suggested that the importance of primary inoculum may have been underestimated because of the influence of plots being close to one another and to other fields with tan spot. Mature pseudothecia capable of releasing ascospores were evident in Southern Ontario from early April to mid June when wheat ranged from tillering to the medium milk stage (Wright & Sutton 1990). Few ascospores were collected by a trap above wheat stubble in Australia (Rees & Platz 1980). Ascospores are probably ejected to a maximum of a few centimetres under damp and still air conditions at night (Morrall & Howard 1975). Only a small number of ascospores are likely to be carried far by wind and reach tissues at the top of the crop canopy. In Saskatchewan, both ascospores and conidia were trapped, but fewer ascospores than conidia were caught (Morrall & Howard 1975). Ascospores are probably more important in initiation of tan spot than conidia (Sone et al. 1994).

Ascospores are seldom lifted into the air, although they are probably still dispersed over short distances. Peak trapping of conidia in Kansas occurred at about 1200 h which reflects the effect of light on sporulation and wind speed on spore dispersal. A 90% reduction in AUDPC 3.6 to 5.4 m from the source indicates that disease spread by primary and secondary inoculum in Kansas is limited (Sone et al. 1994). A wind speed of 3.3 ms^{-1} at various relative humidity levels resulted in nearly 100% of conidia being liberated (Platt & Morrall 1980b). Over 60% of conidia were liberated when the RH was at 35%. In still air, dehydration of conidia caused a small amount of liberation through flicking movements. Most liberation of conidia is due to changes in relative humidity that are common as day time temperatures rise.

2.4.5 Infection by secondary inoculum.

2.4.5.1 Effect of temperature and moisture. Temperature and moisture play a major role in the infection process of *P. tritici-repentis*. Increasing post inoculation wet period increases tan spot lesion size (Hosford et al. 1990). da Luz & Bergstrom (1986b) found the optimum temperature for tan spot development was between 18 and 28°C, with the exact temperature being dependent on cultivar. Similarly, Lamari & Bernier (1994) suggested that a temperature range of 20 to 25°C was optimum for disease development. The incubation period of *P. tritici-repentis* is longer for all wheat genotypes at lower temperatures (da Luz & Bergstrom 1986b). Temperature also influences the number of lesions that develop and the percentage of leaf area showing symptoms. An increase in wet period or temperature also increases the rate of infection and disease development

(Hosford et al. 1987). Few infections or lesions of visible size were produced with a wetness period of 6 h at 10, 20 or 30°C. The number and size of lesions increased with increasing wet period at 10, 20 and 30°C. Hosford reported that germ tube growth and appressoria production increased with increasing wet period and temperature. In a recent study, high temperatures of 27°C and above induced resistance in susceptible cultivars and subsequently resulted in a significant reduction in disease severity (Lamari & Bernier 1994).

2.4.5.2 Pathogenicity and aggressiveness. Isolates of *P. tritici-repentis* have been grouped into three pathotypes based on virulence (Lamari & Bernier 1989c). Pathotype 1 induced either tan necrosis or extensive chlorosis on the differential cultivars and was denoted (nec^+ chl^+). Pathotype 2 induced only tan necrosis (nec^+ chl^-) and Pathotype 3 induced only extensive chlorosis (nec^- chl^+). Specific interactions between individual isolates of *P. tritici-repentis* and wheat cultivars resulted in either necrosis or extensive chlorosis. Host resistance was not expressed until hyphae were established in the intercellular space of the mesophyll. An avirulent isolate that only induced small dark brown to black spots at the site of penetration was later classified as Pathotype 4 (Lamari et al. 1991). Isolates belonging to Pathotype 4 have the ability to penetrate and colonize the epidermal layer, but growth is halted in the mesophyll. Differences in virulence have also been evaluated by measuring the percentage of total seedling leaf area that was necrotic (Schilder & Bergstrom 1990). Since isolates from New York did not vary widely, Schilder & Bergstrom (1990) concluded *P. tritici-repentis* has only a moderate degree of physiological

specialization. Similarly, Sah and Fehrmann (1992) reported that only moderate variation in virulence existed among the isolates of *P. tritici-repentis*. Recently, Lamari et al. (1995) identified a new race of *P. tritici-repentis* that originated in Algeria and had the ability to induce chlorosis in cv. Katepwa, but not in line 6B365. This discovery has resulted in the designation of a second race of Pathotype 3. A race classification system has been established to accommodate the identification of new races, based on reactions on individual differential genotypes, rather than on the induction of necrosis and chlorosis. Currently, five races are recognized in *P. tritici-repentis* (Lamari et al. 1995). In contrast, Krupinsky has investigated aggressiveness of isolates of *P. tritici-repentis* obtained from wheat (Krupinsky 1992c) and grass and barley hosts (Krupinsky 1992b). Different levels of aggressiveness have been identified in isolates obtained from wheat (Krupinsky 1992c), barley and other grass hosts (Krupinsky 1992b). In both cases Krupinsky concluded that isolates of *P. tritici-repentis* have different levels of aggressiveness, but the possibility of physiological specialization (Krupinsky 1992b) or biotypes or races with physiological specialization (Krupinsky 1992c) is low. These contrasting publications regarding physiological specialization may be the result of differences between qualitative and quantitative data.

2.4.5.3 Toxin production. Sensitivity to a toxic filtrate of *P. tritici-repentis* has been correlated with susceptibility to *P. tritici-repentis* (Tomas & Bockus 1987). Disease resistance may be due to insensitivity to a toxin. Lamari & Bernier (1989a) reported that culture filtrates from isolates of *P. tritici-repentis* contained a heat-labile toxin. Toxin

production appeared to be associated with the ability of individual isolates to induce tan necrosis in necrosis-expressing cultivars. The toxin, which was designated Ptr-necrosis toxin, appears to be a pathogenicity factor. The Ptr-necrosis toxin was later purified and identified as a protein with a molecular weight of 13,900 (Ballance et al. 1989). Similarly, Tomas et al. (1990) reported that *P. tritici-repentis* produces a toxin in culture that induces necrosis on susceptible wheat cultivars. The toxin was also identified as a protein with a molecular weight of 14,700 that caused symptoms in leaves of a susceptible cultivar. Evidence of a host-specific chlorosis toxin has also been provided by Orolaza et al. (1995). The toxin was produced in spore germination fluid, cell-free culture and intercellular washing fluid from race 5 of *P. tritici-repentis*. The toxin induced chlorotic symptoms on chlorosis-expressing cultivars, but not on resistant cultivars. It appears to be a pathogenicity factor and was designated the Ptr-chlorosis toxin. The molecular characteristics of the Ptr-chlorosis toxin have not yet been identified.

2.5 Control of tan spot and other leaf spot diseases of wheat.

2.5.1 Tillage. Tillage practices may influence leaf spot disease development by affecting primary inoculum levels. In a comparison of conventional and conservation tillage systems, Schuh (1990) reported that final disease severity of tan spot was higher under conservation tillage. A shift from a clumped to random distribution of disease symptoms under conservation tillage indicated the importance of residue-borne inoculum. Under conventional tillage, random distribution of disease indicated the importance of airborne

inoculum. Adee & Pfender (1989) reported that reducing residue-borne primary inoculum can decrease epidemic development and crop damage caused by *P. tritici-repentis*. Increasing tillage reduces crop residues and subsequently primary inoculum. However, the importance of primary inoculum relative to incoming secondary inoculum is likely dependent on the particular epidemic (Adee & Pfender 1989). Researchers in Australia suggested that the incorporation of infected wheat stubble should control tan spot effectively in most situations (Rees & Platz 1979). Similarly, in Australia, the incidence of *P. tritici-repentis* was higher in direct seeded crops compared to other crops seeded after tilling the soil (Fischer et al. 1988). Over a four year period in Canada, researchers did not identify any consistent effects of tillage on leaf diseases of wheat (Bailey et al. 1992). In Ontario, the effects of tillage practices on leaf spot diseases of winter wheat were inconsistent (Sutton & Vyn 1990). Pseudothecia of *P. tritici-repentis* per gram of residues tended to increase and then decrease as the density of residue levels continued to increase. In Kansas, ploughing infested wheat residues significantly reduced tan spot, relative to other tillage practices under continuous wheat production (Bockus & Claassen 1992).

2.5.2 Crop Rotation. Under certain conditions, crop rotation away from wheat for as little as one year may provide control of tan spot of wheat comparable to ploughing (Bockus & Claassen 1992). Similarly, Rees & Platz (1979) reported that avoidance of infested crop residues by crop rotation may effectively control tan spot of wheat. In western Canada, tan spot and septoria leaf spots were greater on spring wheat following

a cereal than following peas or summerfallow (Bailey et al. 1992). In Ontario, continuous wheat production caused an increase in tan spot and *S. nodorum* and a decrease in *S. tritici* under minimum and zero tillage (Sutton & Vyn 1990). The reverse occurred when wheat followed other crops under all tillage systems or wheat followed wheat under conventional tillage. In Saskatchewan, leaf spot diseases were controlled by a crop rotation of one year when conditions for disease were unfavourable and a rotation of two years when conditions were favourable (Pederson & Hughes 1992).

2.5.3 Fungicides. In the northeastern United States, fungicides are not recommended as a preventative measure for leaf spot disease control in wheat if severity is low from the beginning of stem elongation to the end of anthesis (Cox et al. 1989). The use of triadimenol seed treatment controls tan spot effectively for 20-30 days after sowing in New York state (da Luz & Bergstrom 1986c). Seed treatment does not control infections due to airborne inoculum of *P. nodorum* or *C. sativus*. Single applications of triadimefon foliar sprays at the heading and early dough stages in wheat did not have a significant effect on control of tan spot or septoria leaf spots in Kansas (Dannenberg et al. 1989). In Manitoba and Saskatchewan, application of Tilt (propiconazole) fungicide between Zadoks growth stage (Appendix) 49 and 59 reduced leaf spot disease levels in both wheat and barley when disease pressure was high (Entz et al. 1990). Tilt often increased the amount of large kernels under low disease pressure. Although fungicides can be effective, cost may be a limiting factor.

2.5.4 Burning of residues. In Australia, Rees & Platz (1979) indicated that burning wheat stubble gave the greatest reduction in primary inoculum levels of tan spot compared to mechanical cultivation or no treatment. After burning, basal internode and crown material predominated and did not harbour significant numbers of pseudothecia. In contrast, Fischer et al. (1988) reported that the incidence of *P. tritici-repentis* was greater in Australia in direct drilled crops even after stubble burning. Although burning residues may effectively control leaf spot diseases, this practice is unpopular as it represents a health hazard (smoke inhalation) and contributes to the degradation of soil structure, leaving the soil prone to wind and water erosion.

2.5.5 Genetic resistance. Resistance to tan spot of wheat has been reported by many researchers (Hosford 1982, Raymond et al. 1985, Cox & Hosford 1987, Rees et al. 1987, Lamari & Bernier 1989b). Host resistance is known to decrease with leaf age (Cox & Hosford 1987, Hosford et al. 1990). About 75% of Australian wheat cultivars are highly susceptible to *P. tritici-repentis* with few cultivars possessing adequate levels of resistance (Rees et al. 1987). Similarly, extensive resistance to tan spot of wheat is not present in current registered western Canadian cultivars. Genetic resistance is a management tool currently unavailable to Manitoba farmers, but has potential as a control measure.

3. EFFECT OF CONTINUOUS AND INTERRUPTED WETNESS PERIOD ON INFECTION BY *PYRENOPHORA TRITICI-REPENTIS* IN WHEAT

3.1 Abstract.

Pyrenophora tritici-repentis, the causal organism of tan spot of wheat, causes symptoms of chlorosis and necrosis on susceptible wheat cultivars. The effect of continuous and interrupted leaf wetness periods on the infection of *P. tritici-repentis* in wheat was studied. 6B365, a winter wheat accession that expresses chlorotic symptoms and Glenlea, a wheat cultivar that expresses necrotic symptoms, were inoculated with isolate ASC1 (Race 1) which can induce necrosis and chlorosis. Plants were incubated for 0, 2, 4, 6, 8, 12, 24, 36, 48 and 72 hours of continuous leaf wetness following inoculation. In a second experiment, plants were inoculated and incubated for 0, 2, 4, 6, 8, 10 or 12 hours of continuous wetness, dried for 6 hours, and returned to a moist chamber to complete the balance of 24 hours of leaf wetness. At least 6 hours of continuous leaf wetness was required before tan spot symptoms reached significant levels. Cytological observations indicated the infection process was similar in both 6B365 and Glenlea. An increase in severity of tan spot corresponded with penetration of epidermal cells while lesion expansion occurred during colonization of mesophyll tissue. Extensive yellowing associated with chlorotic symptoms resulted in higher disease severity measurements compared with more localized necrotic symptoms. Disease severity decreased, compared to other wetness treatments, when the leaf wetness period was interrupted between 0 and 4 h of incubation and increased between 4 and 12 h of incubation. The interruption of

leaf wetness after appressorial formation, but prior to epidermal cell penetration, may irreversibly disrupt the infection process. As a result, disease severity may be lower than expected with continuous leaf wetness.

3.2 Introduction.

Pyrenophora tritici-repentis (Died.) Drechs., anamorph *Drechslera tritici-repentis* (Died.) Shoem., the causal agent of tan spot of wheat (*Triticum aestivum L.*), has been observed in fields across the Canadian prairies since the early 1970s (Tekauz 1976) and is recognized worldwide as a major leaf spot disease of wheat (Hosford 1982). Initial infections of *P. tritici-repentis* generally occur in the spring when ascospores are discharged from pseudothecia that overwinter on wheat residues. Secondary infections occur when conidia are released from infected leaf tissue (Rees & Platz 1980).

Isolates of *P. tritici-repentis* have been characterized and grouped into four pathotypes based on their ability to induce tan necrosis and chlorosis in appropriate differential wheat cultivars (Lamari & Bernier 1989c). Pathotype 1 induces a tan-coloured necrosis and/or extensive chlorosis, pathotype 2 induces necrosis without chlorosis, pathotype 3 induces extensive chlorosis without necrosis, and pathotype 4 causes a small dark-coloured fleck on the differential cultivars (Lamari et al. 1991). Host resistance is not expressed until hyphae are established in the intercellular space of the mesophyll (Lamari & Bernier 1989c, Larez et al. 1986). The classification has recently been extended into races to accommodate newly identified virulence (Lamari et al. 1995). Five races are presently recognized.

Environmental conditions play a major role in the development of leaf spot epidemics (Shaner 1981). An increase in leaf wetness duration and temperature, during incubation in a moist chamber, increases infection and disease development of *P. tritici-repentis* on both resistant and susceptible wheat lines (Hosford et al. 1987). Hosford et

al. (1987) reported that disease severity increased with longer wet periods on both resistant and susceptible wheat lines, but was always lower on a resistant line. Percent of conidia germination, number and length of germ tubes, number of appressoria, papillae and percent host colonization increased on both resistant and susceptible lines when leaf wetness duration and/or temperature was increased. Infection occurred after 6 h of continuous leaf wetness at 10°C and higher temperatures and longer leaf wetness periods increased infection efficiency (Hosford et al. 1987). Intercellular hyphae generally grow from vesicles throughout penetrated epidermal cells after only 6 h of leaf wetness (Loughman & Deverall 1986). After 12 h, and occasionally 6 h, hyphae grow through walls of epidermal cells and colonize the intercellular space of the mesophyll. Direct evidence of hyphae penetrating mesophyll cells has not been observed (Dushnicky, 1993). Previous reports have also suggested that continued growth of hyphae in the mesophyll tissue of a susceptible cultivar may involve a host-specific toxin (Hosford et al. 1987, Larez et al. 1986), which has been identified (Lamari & Bernier 1989a, Tomas & Bockus 1987) and characterized (Ballance et al. 1989, Tomas et al. 1990). The objectives of this study were to investigate the effect of continuous and interrupted leaf wetness on tan spot development in wheat genotypes showing necrotic and chlorotic symptoms, and to characterize the stages most sensitive to drying in the infection process of *P. tritici-repentis*.

3.3 Materials and methods.

3.3.1 Terminology. The terms *necrosis* and *chlorosis* are used to describe the symptoms

induced in susceptible wheat as described by Lamari and Bernier (1989a). A wheat genotype is said to be *necrotic* if it developed tan necrosis in response to infection by nec+ isolates and *chlorotic* if it developed chlorosis to chl+ isolates. *Disease severity* is the proportion of diseased leaf tissue to the total leaf area and is expressed as a percentage.

3.3.2 Plant preparation. Winter wheat accession 6B365 and spring wheat cultivar, Glenlea, were each planted in pots containing a 2:1:1 (v/v/v) soil:sand:peat mixture at the rate of four seeds per pot and amended with 17-20-0 fertilizer. Isolates of Race 1 (Lamari et al. 1995) of *P. tritici-repentis* induce extensive chlorosis (Lamari & Bernier 1989b) on 6B365 and tan necrosis symptoms on Glenlea, a cultivar grown commercially in the Canadian prairies. In all experiments, treatments were arranged in a split-plot design with four replications. Leaf wetness duration was the main plot and wheat genotype the subplot. Throughout this study, plants were kept in a walk-in growth room with a temperature regime of 22/18°C (day/night) and a 16 hour photoperiod ($\approx$ 180 $\mu Em^{-2}s^{-1}$). The temperature settings were within 1°C and relative humidity was set at about 60%.

3.3.3 Inoculum preparation. Preparation and inoculation of isolate ASC1 of race 1 (nec^+ chl^+) were carried out as described previously (Lamari & Bernier 1989b). Single conidia were cultured on V8-PDA medium and incubated at 20°C in the dark until the colony reached 3-4 cm in diameter. These cultures were stored at 4°C and used within three weeks as stock cultures for inoculum production. Seven days prior to inoculation, small

plugs, 0.5 cm in diameter, were transferred from the stock cultures to 9 cm petri plates containing V8-PDA medium. These cultures were incubated in the dark until the colonies reached ca. 4 cm in diameter. The plates were then flooded with sterile distilled water and mycelia flattened with the bottom of a flamed test tube. The water was decanted and cultures were placed under fluorescent light at 22°C +/- 2°C for 12-18 hours, followed by a 18-24 hour dark period at 15°C +/- 2°C to induce formation of conidiophores and conidia, respectively. Colonies were flooded with sterile distilled water and the conidia dislodged with a sterile wire loop. Two or three additional water rinses were made to resuspend and recover the conidia that had settled. The concentration of the spore suspension was determined by using a cell counter (Hausser Scientific, Blue Bell, Pa.) and adjusted with sterile distilled water to about 3.5 X 10^3 conidia/ml. Ten drops of Tween 20 (polyoxyethylene sorbitan monolaurate) were added per litre of conidial suspension, to reduce surface tension. About 30 ml of spore suspension was applied until run-off to seedlings in each pot, using a DeVilbiss sprayer, operated at an air pressure of about 100 kPa.

3.3.4 Continuous leaf wetness. Following inoculation at the 2-leaf stage, plants were placed in a moist chamber consisting of a polyvinyl chloride frame (2.5 m X 1 m X 1.4 m) covered with a clear polyethylene sheet, and assembled inside a growth room. Leaf wetness was provided by two ultrasonic humidifiers under microcomputer control (Lamari & Bernier 1989b). Plants were always inoculated between 7 and 8 am about 1 to 2 hours after the beginning of the photoperiod. In the continuous leaf wetness experiment,

inoculated plants were subjected to 0, 1, 2, 3, 4, 6, 12, 24, 36, 48 and 72 hours of continuous wetness. Pots were removed from the moist chamber at the end of each wetness treatment, placed under fans until dry, and sampled for cytological observation by removing one leaf/pot/genotype. Leaf samples were cut into 2-4 pieces and placed for 24 hours in a clearing and staining solution consisting of 300 ml ethanol (95%), 150 ml chloroform, 130 ml lactic acid (85%), 165 ml phenol (90%), 450 g chloral hydrate and 0.6 g aniline blue. Leaves were destained in a concentrated chloral hydrate solution (2.5 g/ml) for a minimum of 48 hours, following the method of Bruzzese & Hasan (1983). This experiment was repeated twice to ensure consistency and the results of the first experiment are presented.

3.3.5 Interrupted leaf wetness. Plants were placed in the moist chamber for 0, 2, 4, 6, 8, 10 and 12 hours of continuous wetness, fan-dried and stored in a growth room at 22°C +/- 2°C under fluorescent light to complete 6 hours. All pots were then returned to the moist chamber to complete the balance of 24 hours of leaf wetness. A control treatment consisting of 24 hours of continuous leaf wetness was included for comparison. The second fully expanded leaf of the 2, 4 and 6 hour treatments was sampled following the initial wetness period, and stained and cleared for cytological observation as described above. This experiment was repeated five times to ensure consistency and the results of one experiment are presented.

For cytological observation, leaf pieces were mounted in lactophenol on a microscope slide and examined for development of the infection process under light

microscope. About 150 conidia from each treatment were observed for germination, formation of appressoria, penetration of epidermal cells and colonization of mesophyll. Digital photographs were taken using the imaging system described below, and printed on a film recorder (Montage FR1, Presentation Technologies, Fresno, Ca).

3.3.6 Disease measurement. The second fully expanded leaf of each of three seedlings were sampled from each of four replicates (pots) for all treatments, 6-8 days after inoculation. Disease severity, number of lesions per square centimetre of leaf and average lesion size were determined using a true colour image processing system. This system uses a DT2871 HSI-Colour frame grabber (Data Translation, Marlboro, MA) and the ImageX software package developed by Lamari (unpublished). The accuracy of the system is typically within 1% in area measurement and lesion detection, based on hue. Analysis of variance, means comparison procedures, and correlations were carried out using the SAS (Version 6.04) statistical package (SAS Institute, Raleigh, NC).

3.4 Results.

3.4.1 Continuous leaf wetness. Germination of conidia (Figure 1a) was observed after only 1 h of continuous leaf wetness with about 90% of conidia germinating after 6 h (data not shown). Appressorial formation (Figure 1b) was evident after 4 h of continuous leaf wetness and about 75% of germ tubes had developed appressoria when observed after 24 h of leaf wetness (Figures 2 & 3). Penetration of epidermal cells, as indicated by staining of the cell wall (Figure 1c), was observed when leaves were subjected to 12 h or more

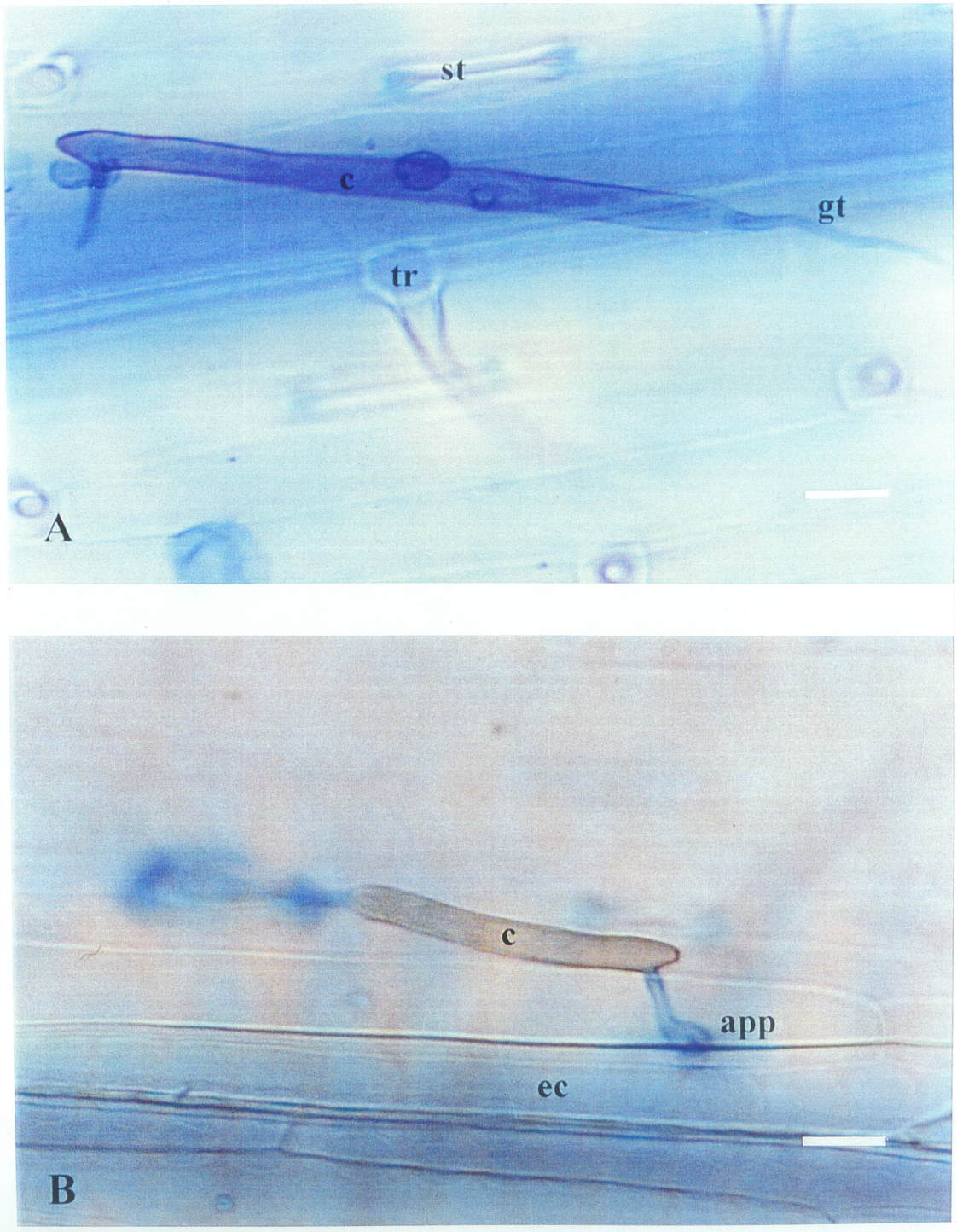

Figure 1. **A,** A germinating conidium. **B,** A conidium has germinated and formed an appressorium. **app** = appressorium, **c** = conidium, **ec** = epidermal cell, **gt** = germtube, **st** = stomate, **tr** = tracheole Scale bars = 31µm.

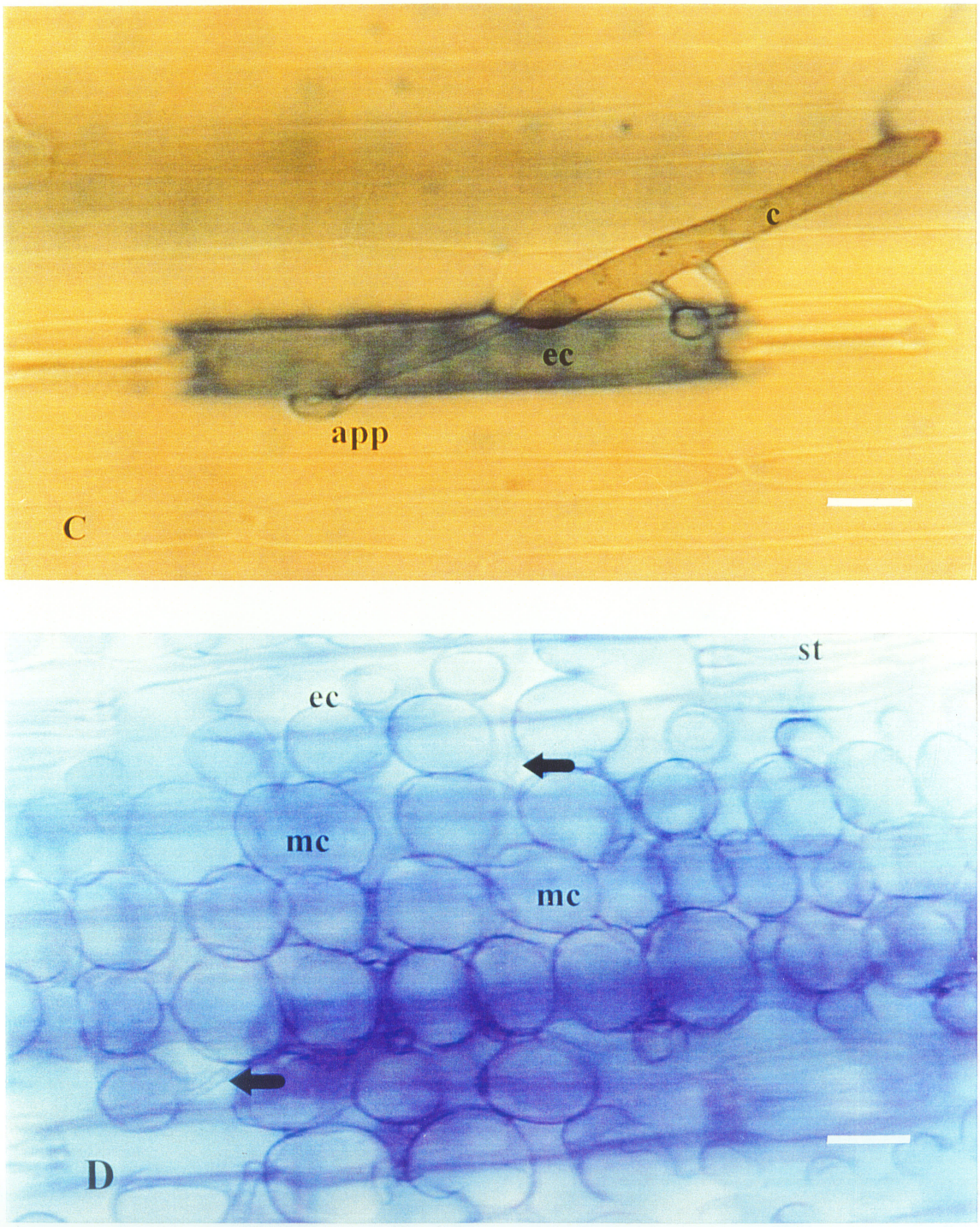

Figure 1. **C,** Retention of stain indicates that an epidermal cell has been penetrated by *P. tritici-repentis*. **D,** Colonization of the intercellular space of the mesophyll tissue is evident by the presence of hyphae. **app** = appressorium, **c** = conidium, **ec** = epidermal cell, **mc** = mesophyll cell, **st** = stomate. Arrows point to hyphae. Scale bars = 31µm.

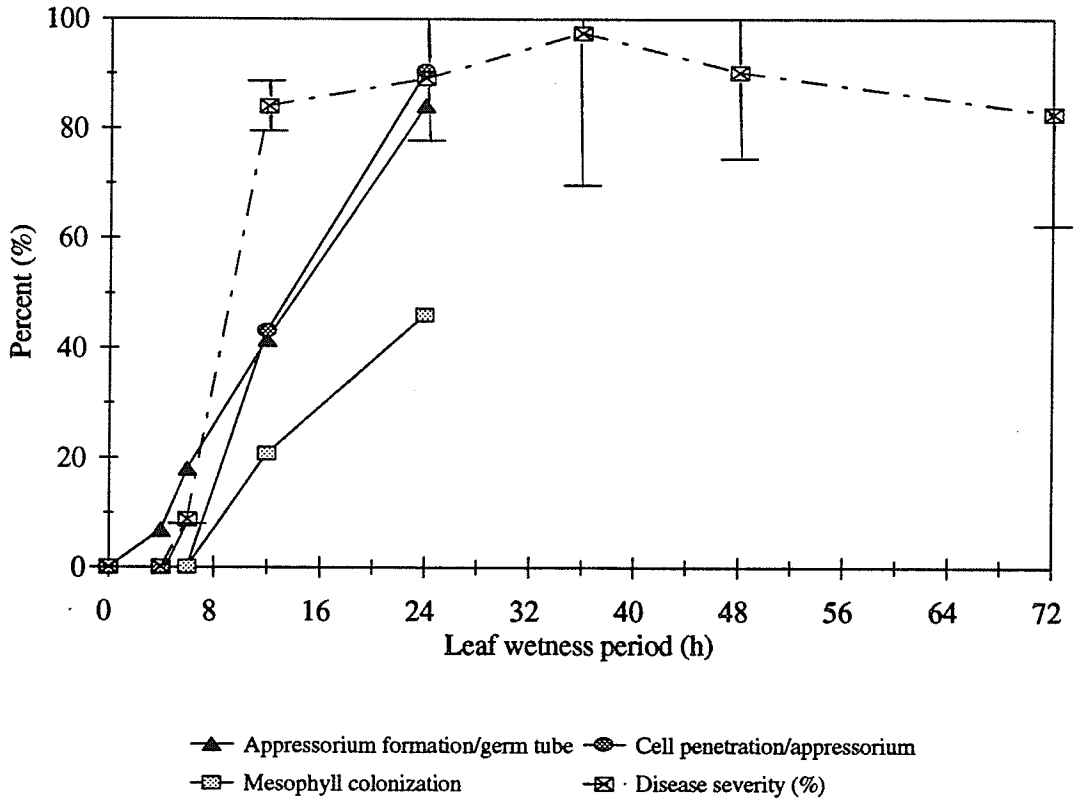

Figure 2. Effect of increasing continuous leaf wetness period on the infection process of *P. tritici-repentis* and subsequent disease severity in wheat line 6B365. Error bars indicate the standard deviation.

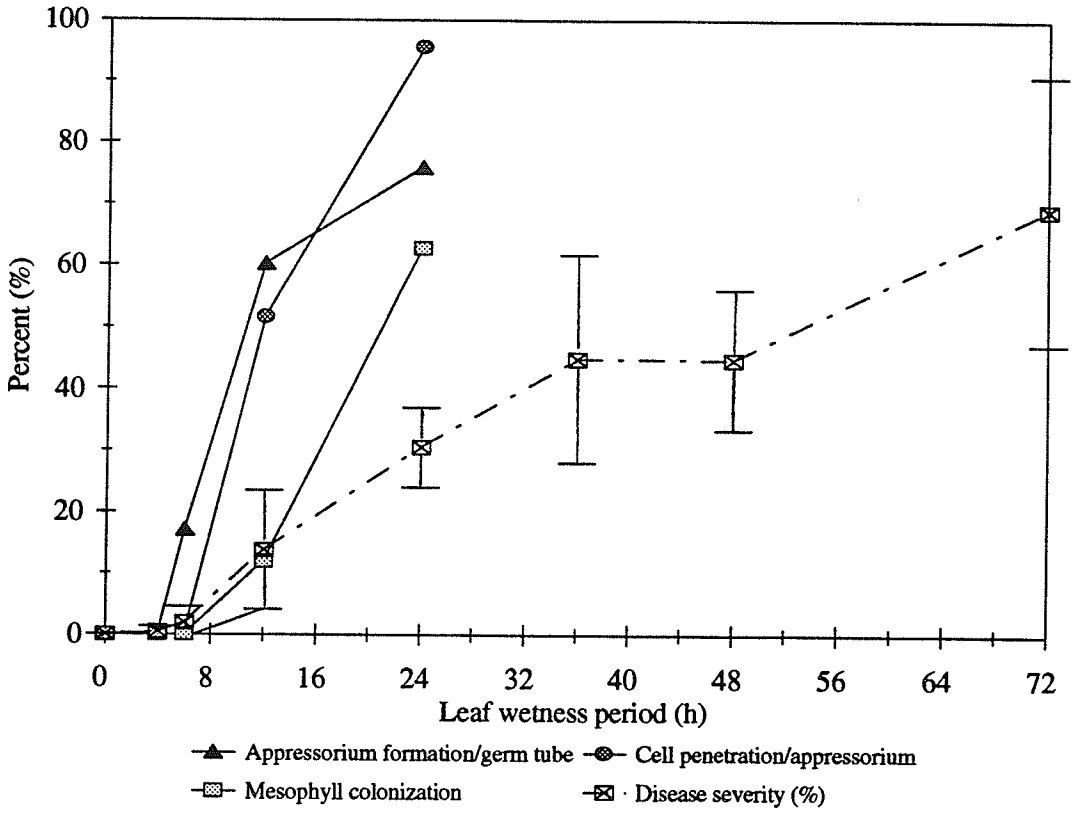

Figure 3. Effect of increasing continuous leaf wetness period on the infection process of *P. tritici-repentis* and subsequent disease severity in wheat line Glenlea. Error bars indicate the standard deviation.

of continuous leaf wetness. About 90% of conidia that formed appressoria had penetrated epidermal cells after 24 h of continuous leaf wetness. Growth of hyphae from penetrated epidermal cells to the intercellular space of the mesophyll (Figure 1a-d) was observed after 12 h and increased to 40 and 60% after 24 h in 6B365 and Glenlea, respectively (Figures 2 & 3). Penetration of mesophyll cells was not observed throughout this study. The frequency of all cytological events showed a constant increase from their initiation until the last observation. Glenlea and 6B365 showed similar development in the infection process at each leaf wetness interval.

Six to eight days after inoculation, disease symptoms were evident on plants that had received 6 h or more of continuous leaf wetness. Disease severity increased rapidly from 6 to 12 h of leaf wetness on 6B365 to about 80% (Figure 2). Lesion expansion on 6B365 was minimal after 12 h leaf wetness as most leaf tissue exhibited chlorosis. Disease severity on Glenlea increased slowly after 6 h to a peak of about 60% after 72 h leaf wetness. Unlike 6B365, disease symptoms on Glenlea consisted of small restricted tan lesions that enlarged and coalesced as the leaf wetness duration increased. Disease severity on Glenlea was significantly lower than 6B365 under all wetness durations.

3.4.2 Interrupted leaf wetness. Drying leaves for 6 h, after an initial leaf wetness period of up to 4 h, reduced severity of tan spot in both cultivars compared to the 24 h control, and corresponded to the formation of appressoria prior to penetration of epidermal cells (Figures 4 & 5). Disease severity decreased when leaf wetness was interrupted after 2 h, reached its lowest level at 4 h, and then increased when leaf wetness was interrupted

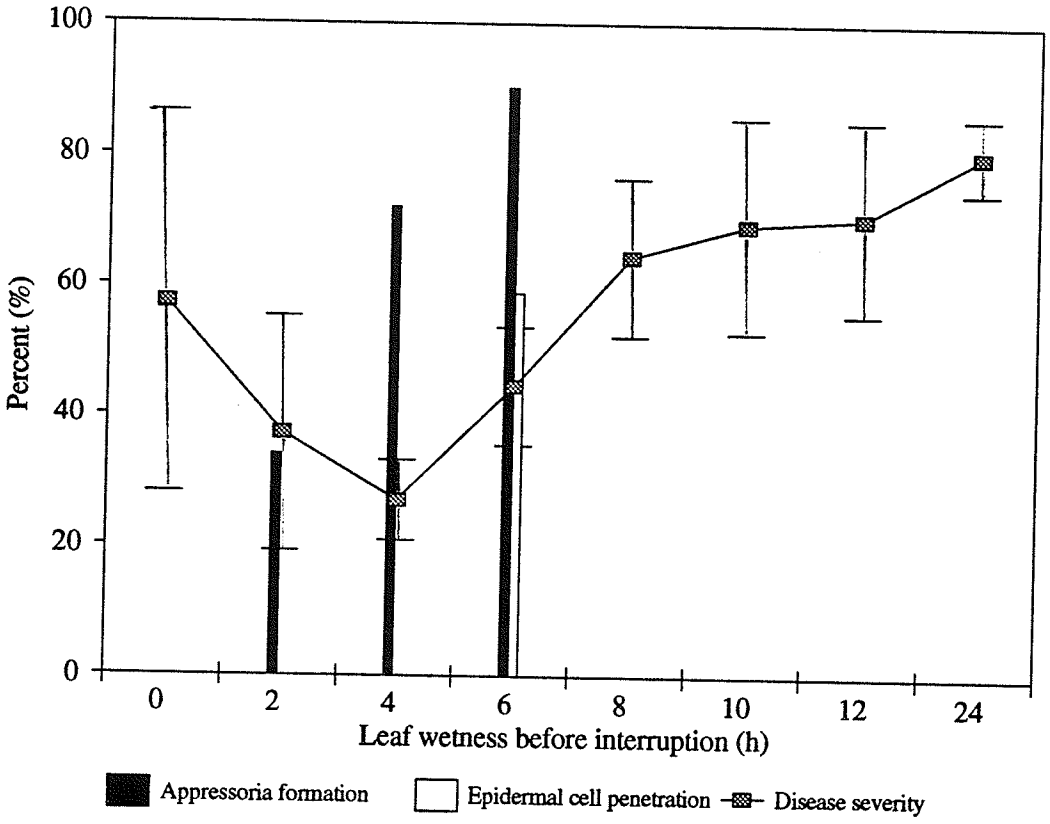

Figure 4. Effect of interrupting leaf wetness on mean disease severity in wheat line 6B365. Mean percentages of germtubes that formed appressoria and penetration of epidermal cells by conidia that formed appressoria are plotted for the 2, 4 and 6 h treatments. Error bars indicate the standard deviation.

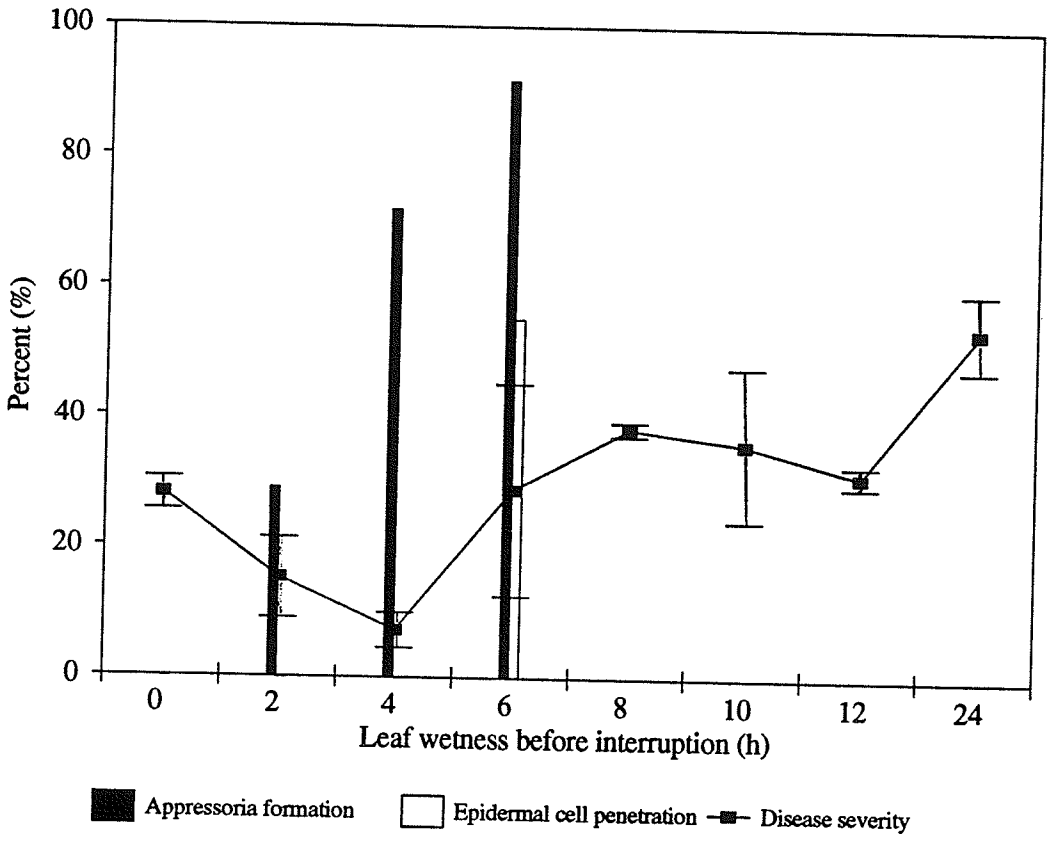

Figure 5. Effect of interrupting leaf wetness on mean disease severity in wheat line Glenlea. Mean percentages of germtubes that formed appressoria and penetration of epidermal cells by conidia that formed appressoria are plotted for the 2, 4 and 6 h treatments. Error bars indicate the standard deviation.

after 6 h.

Cytological observations indicated that about 30% of germtubes had formed appressoria after 2 h of leaf wetness, with no evidence of epidermal cell penetration. At 4 h and 6 h of leaf wetness, 70% and 90% of germtubes had formed appressoria, respectively. Penetrations were not evident at 4 h, but about 60% of appressoria had penetrated epidermal cells after 6 h of continuous wetness. Interrupting the leaf wetness period after 6 h did not reduce disease severity significantly ($P<0.01$) compared to the 24 h control. When plants were dried for 6 h immediately after inoculation (0 h), disease severity was quite variable (Figure 4) and lower than may have been expected (Figures 4 & 5). Disease severity was generally lower in Glenlea than in 6B365, but all cytological events were similar.

3.5 Discussion. Increasing continuous leaf wetness duration beyond 6 h increased disease severity in both 6B365 and Glenlea. Cytological observation showed that most (70-90%) conidia had germinated after 6 h of continuous leaf wetness. Previous reports involving *P. tritici-repentis* (Hosford et al. 1987, Loughman & Deverall 1986) indicated that most conidia germinated after 6 h of leaf wetness. Similar to other research (Loughman & Deverall 1986), germination, formation of appressoria and penetration of epidermal cells by conidia was observed after 12 h of continuous leaf wetness. Disease severity in both 6B365 and Glenlea was well correlated with formation of appressoria, penetration of epidermal cells and colonization of the intercellular space of the mesophyll. Cytological observations did not reveal significant differences in the infection process

between 6B365 and Glenlea. As previously reported with *P. tritici-repentis* (Larez et al. 1986) and *Septoria nodorum* (Eyal et al. 1977), disease severity increased with longer wet periods. Since most conidia germinated within 12 h continuous leaf wetness, any subsequent increase in disease severity associated with longer durations of wetness is due to increased appressorial formation, cell penetration and/or lesion expansion.

Observed differences in disease severity between the necrotic and chlorotic cultivars can be attributed to symptom characteristics. Wheat cultivars showing chlorotic symptoms express diffuse yellowing around dark brown infection sites while those showing necrosis express more localized tan necrotic lesions (Lamari & Bernier 1989b). Discolouration caused by extensive chlorosis results in high disease severity with only a few infection sites because of the low proportion of green tissue remaining. Absolute values of disease severity will depend on the symptoms induced by the isolate used and the symptoms expressed by the host, in addition to the level of host resistance.

When leaf wetness was interrupted for 6 h immediately after inoculation (0 h), disease severity levels were similar to the 24 h control in 6B365, but not Glenlea (Figures 4 & 5). The 0 h treatment may be similar to field conditions where conidia are dispersed when leaves are dry. Lower disease severity than anticipated in the 0 h treatment may be a result of dehydration of conidia or detachment during the 6 h dry period. The presence of leaf wetness immediately after conidia are dispersed in a field may accelerate disease development.

Significant levels of appressorial formation were present before penetration of epidermal cells or disease severity increased substantially. An increase in penetration of

epidermal cells coincided with a significant increase in disease severity, suggesting penetration is the most sensitive event in the infection process. Appressoria are formed while the fungus is still present on the leaf surface so that a dry period may promote dehydration. Interrupting the leaf wetness period after formation of appressoria, but prior to epidermal cell penetration could, therefore, irreversibly disrupt the infection process. A sharp drop in disease severity was observed when leaf wetness was interrupted after 4 h. This period coincided with maximum appressorial formation but prior to epidermal cell penetration, suggesting that epidermal cell penetration was the most critical event in successful establishment of *P. tritici-repentis* on its wheat host. This may be expected in view of the fact that the colonization of the epidermal cell is a non-specific event (Loughman & Deverall 1986, Lamari & Bernier 1989b) and that once the fungus had penetrated and colonized the epidermal cell, its dependence on external moisture may be greatly reduced. This is supported by the fact that no substantial drop in disease severity was observed, in this study, when leaf wetness was interrupted at 6 h and later. The results of this experiment confirm that epidermal cell penetration was the most sensitive event to leaf wetness in the infection process of *P. tritici-repentis*. Most appressoria formed between 2 and 8 h of continuous leaf wetness and cell penetration began after 4 h. In the field, it is not uncommon for leaves to experience alternating wet and dry periods of short duration as a result of overnight dew or brief thunderstorms. The interruption of a wet period during appressoria formation, but prior to cell penetration, may result in disease severity levels lower than expected with continuous leaf wetness, due to failed penetrations by formed appressoria. Since *P. tritici-repentis* is a diurnal

sporulator (Shaner 1981), the result of interrupting leaf wetness would be dependent upon timing as well as temperature and other environmental factors. The occurrence of evening thunderstorms does not always promote a tan spot epidemic even when conditions appear favourable. While thunderstorms may promote conidia formation, an uninterrupted period of leaf wetness is still required once conidia are dispersed. Under the conditions of our experiments, at least 6 h of continuous wetness is needed for successful infection. The irreversible disruption of the infection process following interruption of leaf wetness must be taken into account by plant pathologists seeking to develop epidemiological models for tan spot of wheat.

4. INFLUENCE OF SPRING TILLAGE PRACTICES ON SEVERITY OF LEAF SPOT DISEASES IN HARD RED SPRING WHEAT

4.1 Abstract.

Tan spot or yellow spot (*Pyrenophora tritici-repentis*) and septoria leaf and glume blotch are leaf spot diseases of wheat, of significance in western Canada, that survive on crop residues. The influence of spring tillage practices on the development of leaf spot diseases was studied in 1992, 1993 and 1994. Treatments included conventional tillage, direct seeding and spring burning. An additional conventional tillage treatment had Tilt fungicide applied in 1992 and fungicide was applied to conventional tillage, direct seeding and spring burning treatments in 1993 and 1994 to provide a 'disease-free' control. *Mycosphaerella graminicola* was the most prevalent leaf spot pathogen in 1993 and 1994. Effects of leaf spot diseases were inconsistent over the three years, but a yield increase of 43 to 63% and a kernel weight increase of 26 to 33% were observed in 1993. Seeds head^{-1}, heads m^{-2} and plant height were not affected by tillage practice or application of fungicide. Tillage practices did not result in significant differences in disease severity and were not an effective control method. Yield and kernel weight reduction was attributed to onset on leaf spot diseases after wheat heads emerged. Disease control achieved by Tilt application to direct seeded crop tended to increase yield more compared to other tillage practices, suggesting that reduced tillage may increase the effect of leaf spot diseases on wheat yield.

4.2 Introduction.

Pyrenophora tritici-repentis (Died.) Drechs., anamorph *Drechslera tritici-repentis* (Died.) Shoem., the causal agent of tan spot of wheat (*Triticum aestivum L.*) and *Mycosphaerella graminicola* (Fuckel) Schroeter, anamorph *Septoria tritici* and *Phaeosphaeria nodorum* (Muller) Hedja., anamorph *Stagonospora nodorum*, causal agents of Septoria leaf and glume blotch are the major stubble-borne leaf spot diseases of wheat in western Canada (Tekauz 1976, Gilbert et al. 1993, Gilbert et al. 1994, Gilbert et al. 1995). Tan spot causes crop injury in most wheat growing regions of the world (Dubin 1983, Wiese et al. 1984, Luz da & Bergstrom 1986, Cook & Yarham 1989, Schilder 1989). In Manitoba, the leaf spot complex is a combination of septoria leaf spots and tan spot with differing proportions of each pathogen depending on environmental conditions (Tekauz 1976, Gilbert et al. 1993, Gilbert et al. 1994, Gilbert et al. 1995). Yield reductions of 10% due to leaf spot diseases are common, with the potential for losses as high as 50% (Rees et al. 1982).

Most infections by *P. tritici-repentis* are initiated in the spring by ascospores, with fewer infections occurring from conidia (Morrall & Howard 1975). Secondary cycles of infections by *P. tritici-repentis* are generally caused by wind-borne conidia, originating from dead leaf tissue (Shaner 1981).

Septoria leaf diseases, *P. nodorum*, *M. graminicola* and *Phaeosphaeria avenaria* f. sp. *triticea* (anamorph *Stagonospora avenae*) all occur on the Canadian prairies given the proper environmental conditions (Pederson & Hughes 1992). Both *P. nodorum* and *M. graminicola* form pycnidia that overwinter on wheat residues (Shaner 1981). In the spring

pycnidiospores are dispersed by rainsplash and infect wheat leaves. *M. graminicola* can also produce pseudothecia on wheat residues and release ascospores in the spring, but most infections occur via pycnidiospores (Shaner 1981). *P. avenaria* may overwinter as mycelium and form micropycnidia in the spring, or perithecia may form in the spring and eventually develop ascospores (Shaner 1981).

Temperature and leaf wetness period influence the development of leaf spot diseases and their occurrence relative to each other. *P. tritici-repentis* requires six hours of continuous leaf wetness (Hosford et al. 1987) combined with temperatures of 18-28°C (da Luz & Bergstrom 1986) for disease severity to reach visible levels. Longer periods of leaf wetness will increase the number and severity of infections on susceptible wheat genotypes (Hosford et al. 1987, Sissons Chapter 2). Low temperatures slow disease progress (da Luz & Bergstrom 1986, Hosford et al. 1987) while high temperatures (>28°C) can decrease severity (Lamari & Bernier 1994).

P. nodorum, M. graminicola, and *P. avenaria* have been observed in Manitoba (Tekauz 1976, Gilbert et al. 1993, Gilbert et al. 1994, Gilbert et al. 1995). *M. graminicola* and *P. avenaria* require high relative humidity for longer than 15 hours for infection to occur (Shaner 1981) so that they are usually not as prevalent in Manitoba as *P. nodorum*. By contrast, *P. nodorum* requires only 3-6 hours of high humidity for disease development when temperatures are 10-28°C. Research indicates that *M. graminicola* is more prevalent under a combination of low temperatures and long periods of high humidity (Shaner 1981).

Control of leaf spot diseases is currently limited to cultural practices (Bockus &

Claassen 1992, Rees & Platz 1979) and/or application of fungicides (da Luz & Bergstrom 1986, Dannenberg et al. 1989, Entz et al. 1990). Ploughing and burning wheat residues reduced the severity of tan spot in the United States and Australia (Bockus & Claassen 1992, Rees & Platz 1979). Adee & Pfender (1989) showed that primary inoculum levels influence disease development in Kansas, demonstrating that reducing the amount of surface residue should impede leaf spot disease development. However, continuous wheat production suppressed the development of *M. graminicola* in both Ontario and Saskatchewan (Pedersen & Hughes 1992, Sutton & Vyn 1990). A crop rotation of two years between wheat was effective in reducing severity of the septoria disease complex (Pedersen & Hughes 1992). A further reduction in the level of initial inoculum, by increasing the time between wheat crops, may not give additional disease reduction (Pedersen & Hughes 1992). In Manitoba, omitting wheat from a crop rotation for one year did not reduce primary inoculum levels enough to significantly lower leaf spot severity levels (Sissons unpublished data).

Fungicides effectively control leaf spot diseases (da Luz & Bergstrom 1986, Dannenberg et al. 1989, Entz et al. 1990), but their cost may be prohibitive. Genetic resistance may be the best control method in the long term, but is not extensively available in commercial cultivars in Canada. In the last two decades, producers across western Canada have reduced tillage and subsequently increased residue levels on the soil surface. The objective of this study was to examine the influence of spring tillage practices on the development of leaf spot diseases in hard red spring wheat.

4.3 Materials and methods.

4.3.1 Experimental design. In 1992, an experiment involving different spring tillage practices was established near Glenlea, Manitoba on an Osbourne clay soil. Fall tillage did not occur in 1991 and the field was seeded to wheat in 1990 and 1991. Ascocarps of *P. tritici-repentis* were present on wheat residues at about 15000 ascocarps m^{-2} and symptoms of leaf spot diseases had been observed in previous years. The four treatments consisted of spring burning followed by direct seeding, direct seeding into stubble, conventional tillage and conventional tillage with Tilt (propiconazole) fungicide applied, beginning soon after wheat reached Zadoks growth stage 21, at a level of 0.5 L ha^{-1} at 14-21 day intervals. Conventional tillage plots were cultivated twice prior to seeding with a light duty cultivator. Plots (2 m wide by 5 m long) were separated by a 2 m buffer of wheat which was sprayed every 14-21 days with Tilt to control leaf spot diseases.

In 1993 and 1994, the tillage experiment was located near Basswood, Manitoba on a Newdale clay loam. The site was direct seeded to wheat in the previous three years and had not been cultivated for the previous seven years. In addition to the treatments included in 1992 at Glenlea, Tilt was applied at 14-21 day intervals to direct seeding and spring burning plots providing 'disease-free' controls for each of the tillage treatments and making a total of six treatments. Two passes with a tandem discer were performed for conventional tillage treatments. Plots (4 m wide by 7 m long) were separated by a 4 m wide buffer plot that was kept disease-free with repeated Tilt application. In all years, hard red spring wheat cultivar, Katepwa, was planted at a level of 100 kg ha^{-1} in 18 cm row spacings.

4.3.2 Disease measurement. In 1992 and in 1994, leaves from 10 different plants were arbitrarily selected from each plot on three dates after flag leaf emergence. At each sampling date, the upper three leaves from the main tiller of each of 10 plants were collected for assessment of disease severity (eg. - 30 leaves per plot). The top leaf is defined as the uppermost leaf on the main tiller of a wheat plant at one particular sampling date. In this study, the top leaf at the tillering stage may become the second leaf from the top on the next sampling date. Similarly, the second leaf from the top of the plant is defined as the second leaf from the top of a main tiller at one particular sampling date. The third leaf is the third leaf from the top of a main tiller on one particular sampling date. In this study, the third leaf was only sampled early in the growing season as leaf senescence prevented sampling at later dates. Sampling began in late June or early July and was completed in early August. In 1993, disease assessment began in late June and occurred at intervals of 7-14 days until leaf senescence. On several occasions leaf pieces were incubated under high relative humidity to allow isolation and identification of the pathogens associated with disease symptoms.

Leaves were dried or refrigerated until disease severity was measured using a true colour image processing system. This system uses a DT2871 HSI-Color frame grabber (Data Translation, Marlboro, MA) and the ImageX software package developed by Lamari (unpublished). The accuracy of the system is typically within 1% in area measurement and lesion detection, based on hue. Tips of leaves were removed before measurement to eliminate naturally senescent tissue. Disease severity was obtained by measuring the proportion of leaf tissue discoloured by leaf spot diseases. In 1993, the

area under the disease progress curve (AUDPC) was computed for all treatments using the following formula:

$$\sum_{i=1}^{n}[(Y_{i+1} + Y_i)/2)][X_{i+1} - X_i]$$

where Y_i = severity at the i^{th} observation, X_i = time (days) at the i^{th} observation and n = total number of observations.

4.3.3 Plant growth and environmental measurements. Emerged plants were counted 10-15 days after seeding and plant height, heads m^{-2} and seeds $head^{-1}$ were evaluated prior to harvest. In mid to late September, the centre six rows of each plot were harvested using a Hege Model 125A plot combine. Grain samples were cleaned to remove all foreign material, weighed and the 1000 kernel weight was determined from a subsample.

4.3.4 Statistical analysis. Analysis of variance, means comparison and correlation analysis were computed using the SAS (Version 6.04) statistical package (SAS Institute, Raleigh, NC). Disease severity data was tested for normality and log transformed where appropriate. In all analyses, only differences significant at $\alpha = 0.05$ were considered meaningful.

4.4 Results.

4.4.1 Effect of spring tillage on leaf spot disease development.

1992. Leaf spot disease development was slow due to cooler than normal weather from

May to September (Appendix). Early in the growing season, *P. tritici-repentis* and *P. nodorum* were present at significant levels on lower leaves. Symptoms were prominent in the lower portion of the canopy, but severity never exceeded 10% on the second leaf (Figure 6). Significant differences in disease severity were not evident between tillage treatments. Flooding in late June and early July caused leaf discolouration making disease symptoms difficult to distinguish.

1993. The dominant pathogens were *P. tritici-repentis* and *P. nodorum* and disease symptoms were most evident on lower leaves. However, by late June and early July, *M. graminicola* was present and became the most prominent pathogen on the upper leaves. Disease severity was up to 20% (Figure 7) on the top leaf in unsprayed tillage treatments, 78 days after planting. Earlier in the growing season, disease symptoms on the top leaf were negligible. As the crop neared maturity, disease symptoms became severe on upper leaves. Final disease ratings showed that plots sprayed with Tilt had a disease severity of 30-50% on the top leaf (Figure 7), whereas unsprayed plots had a disease severity of up to 85%.

Disease progress on the second leaf from the top of the plant began increasing about 70 days after planting (Figure 8). Disease severity was significantly higher in plots without fungicide. Disease levels were similar in all tillage treatments except that disease severity in the direct seeding treatment increased substantially between the second last and last sampling date (Figure 8).

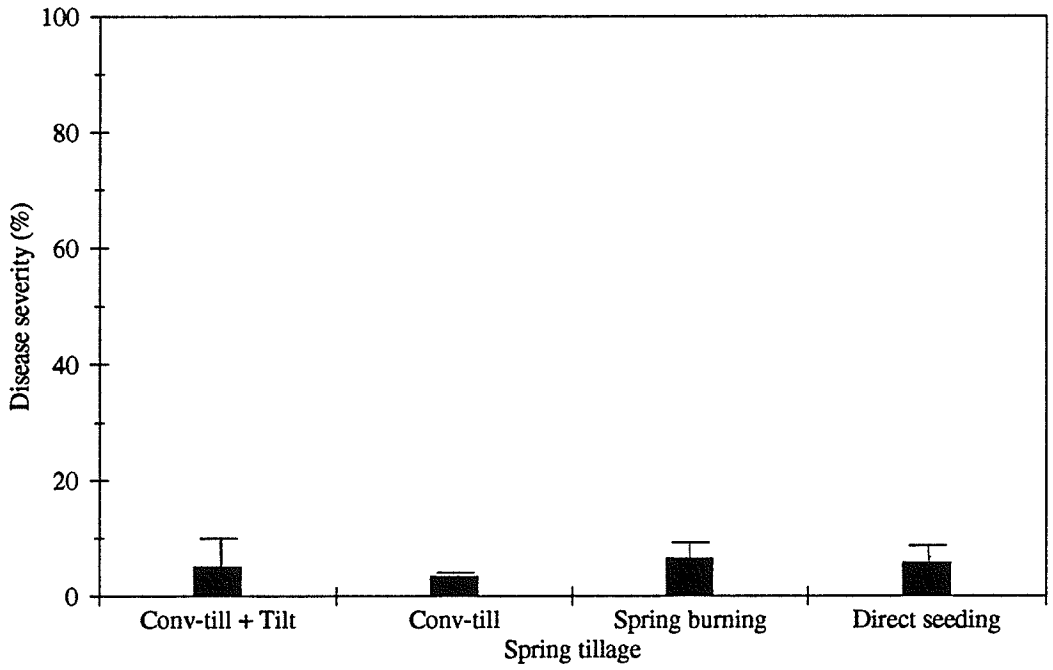

Figure 6. Effect of spring tillage practices on leaf spot disease severity of the second leaf in 1992 at Winnipeg. Error bars indicate the standard deviation.

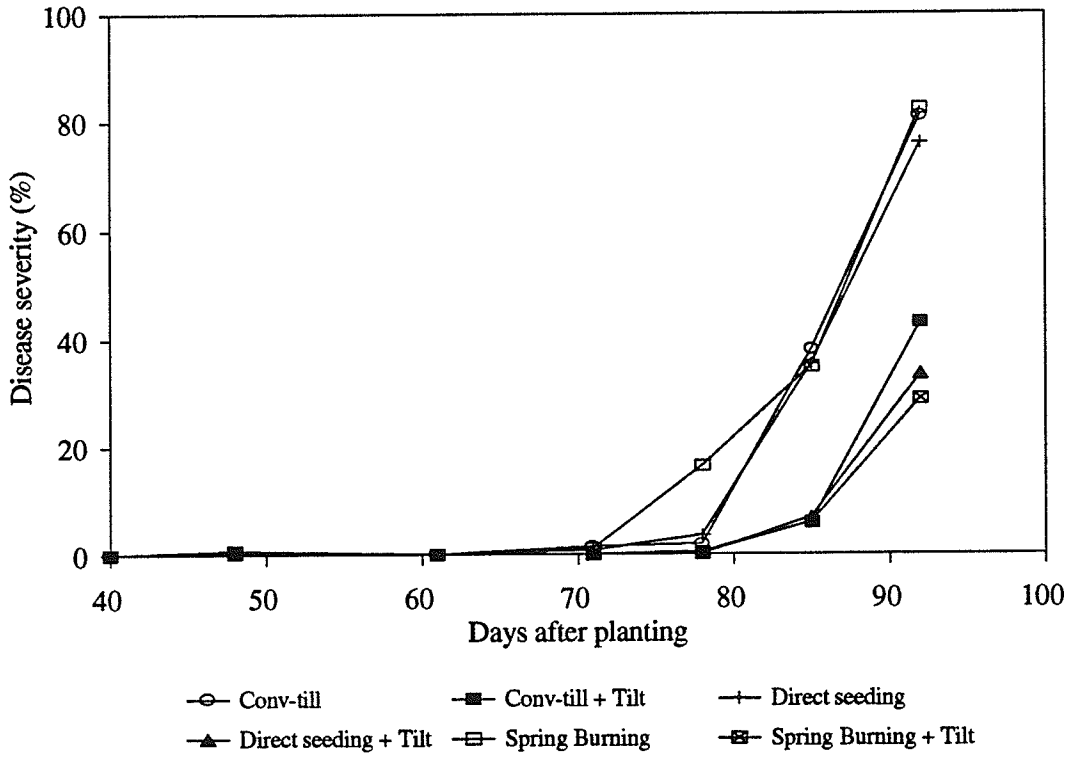

Figure 7. Effect of spring tillage practices on leaf spot disease severity of the top leaf on plants at each sampling date during 1993.

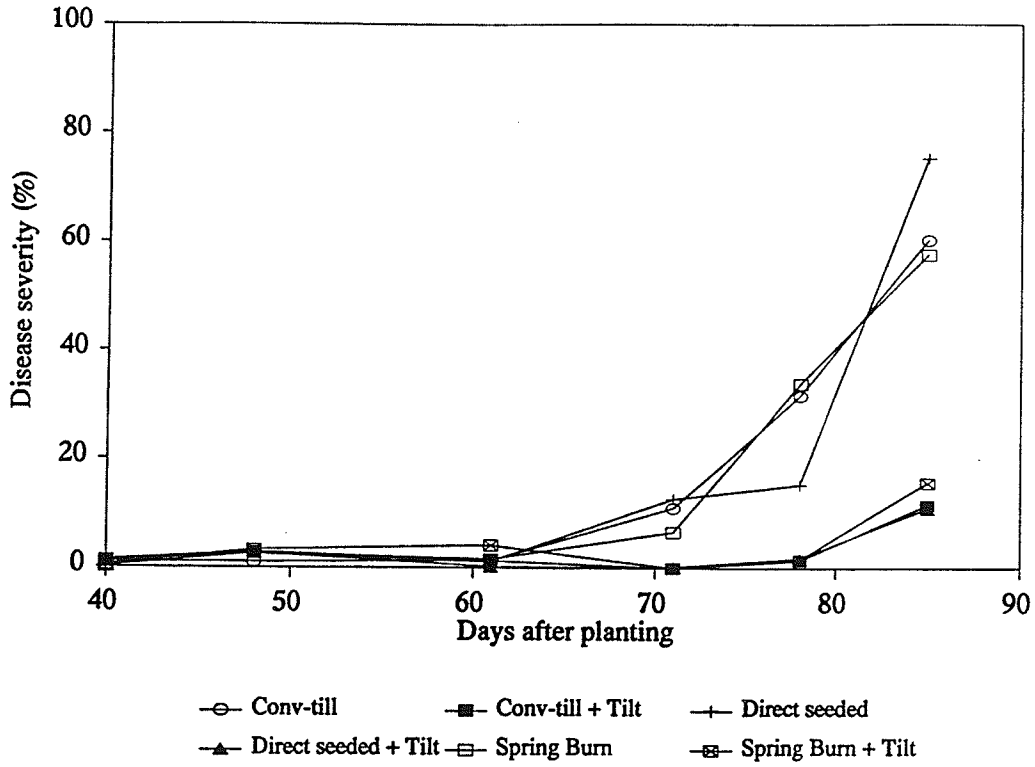

Figure 8. Effect of spring tillage practices on leaf spot disease severity of the second leaf from the top of plants at each sampling date during 1993.

The third leaf from the top of the plant was sampled four times prior to leaf senescence. Leaves from the third sampling date did not dry properly which prevented measurement of disease severity. Disease severity on the third leaf (Figure 9) was variable and significant differences between tillage practices were not observed. On the last sampling date, however, direct seeding plots had the highest disease severity ranking followed by conventional tillage and spring burning. Fungicide did not significantly reduce disease severity on the third leaf in any of the tillage treatments (Figure 9).

Tillage practices ranked spring burning, conventional tillage and direct seeding in order of increasing AUDPC, but were not significantly different (Table 1). The ranking of tillage practices were similar when Tilt was applied, but AUDPC was reduced significantly on all leaves evaluated.

1994. Temperatures were slightly warmer in 1994 than in the two previous years and rainfall was lower (Appendix). Leaf sampling did not begin until wheat plants were at Zadoks growth stage 45 (Appendix). Only the third leaf from the top of the plant was sampled because disease symptoms were not evident on upper leaves. Disease severity tended to decrease as a result of Tilt application, but differences were not significant. Fungicide reduced disease severity significantly in the spring burning treatment compared to direct seeding and conventional tillage treatments without fungicide (Figure 10).

When wheat heads were fully emerged, the top three leaves of plants were sampled. Disease severity was highest on the third leaf (Figure 11), but was not significantly different between tillage treatments. Disease severity decreased significantly in direct seeding and conventional tillage treatments when Tilt was applied. A reduction

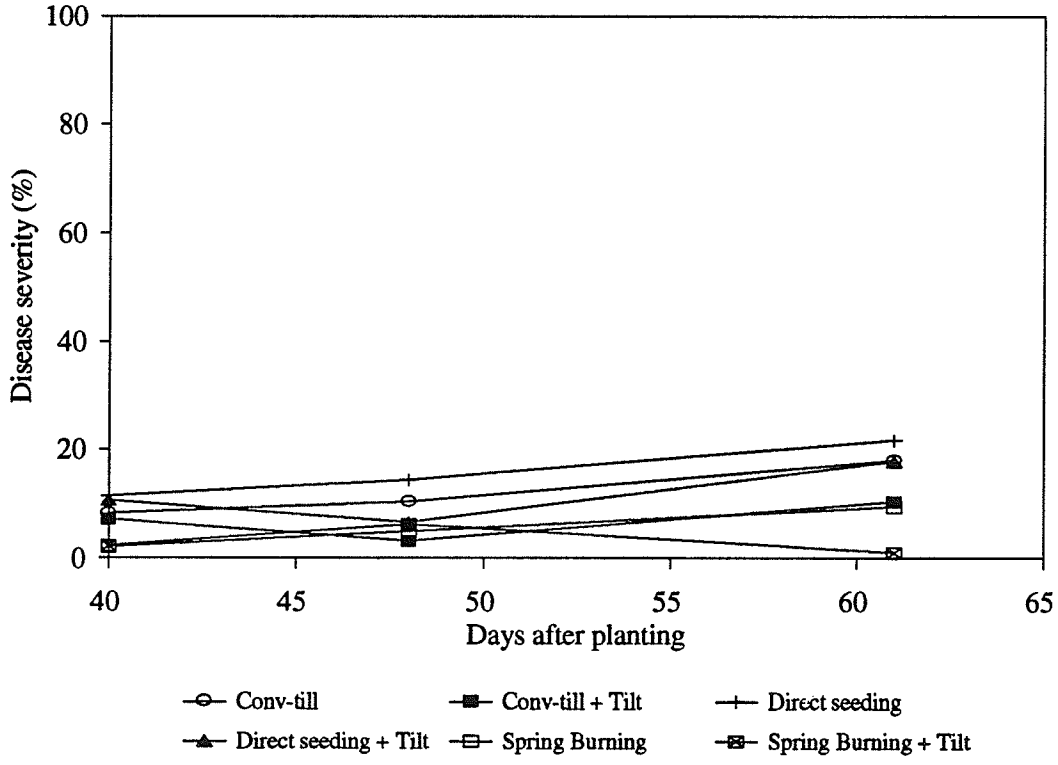

Figure 9. Effect of spring tillage practices on leaf spot disease severity of the third leaf from the top of plants at each sampling date during 1993.

Table 1. Effect of spring tillage practices on leaf spot development on the top three leaves of Katepwa wheat at Minnedosa in 1993.

Tillage Treatment	AUDPC[1]			
	Leaf 1[2]	Leaf 2	Leaf 3	Total
Spring burning	666.7	543.7	121.7	1332.1
Conventional	579.3	557.6	258.1	1395.0
Direct seeding	553.3	526.0	336.4	1415.7
Spring burning + Tilt[3]	147.7	150.7	81.7	380.1
Conventional + Tilt	201.4	101.3	128.2	430.9
Direct seeding + Tilt	172.8	87.9	227.0	487.7

[1]Area Under the Disease Progress Curve (AUDPC) calculated using the formula:

$$\sum_{i=1}^{n}[(Y_{i+1} + Y_i)/2)][X_{i+1} - X_i]$$

where Y_i = severity at the *i*th observation, X_i = time (days) at the *i*th observation and n = total number of observations.

[2] Leaf 1 was the top leaf of the plant at each sampling date.
Leaf 2 was the second leaf from the top at each sampling date.
Leaf 3 was the third leaf from the top at each sampling date.

[3] Tilt (propiconazole).

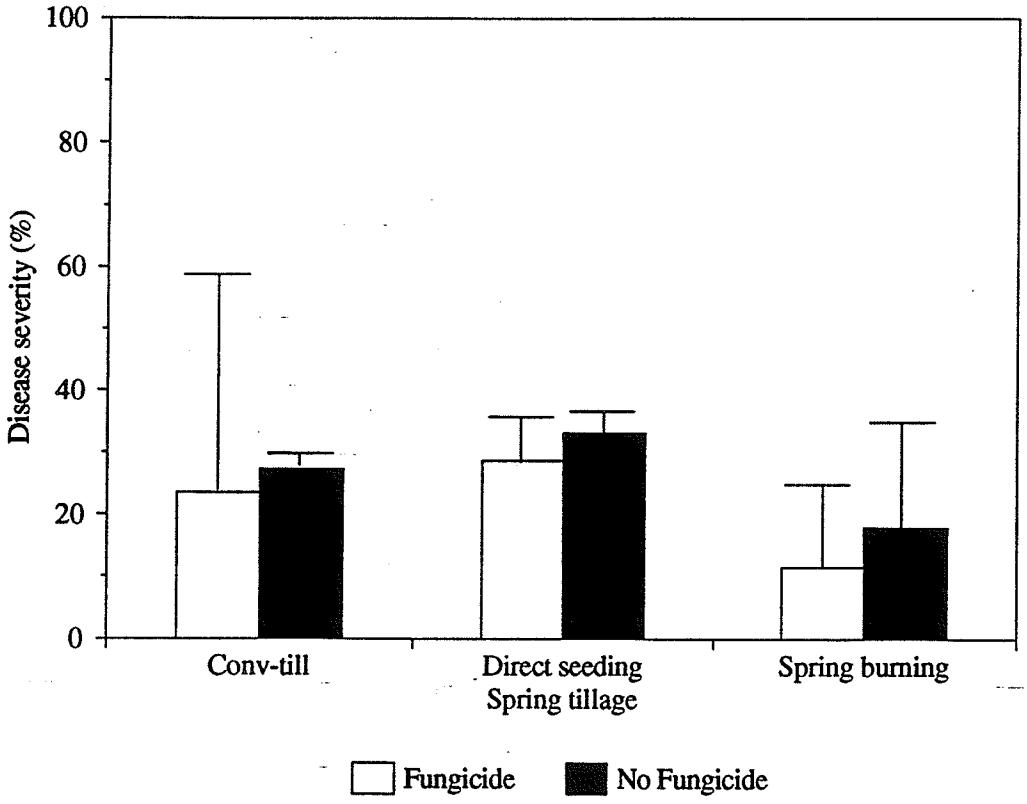

Figure 10. Effect of spring tillage practices on leaf spot disease severity of the third leaf from the top of the plant sampled at the swollen boot stage in 1994. Error bars indicate the standard deviation.

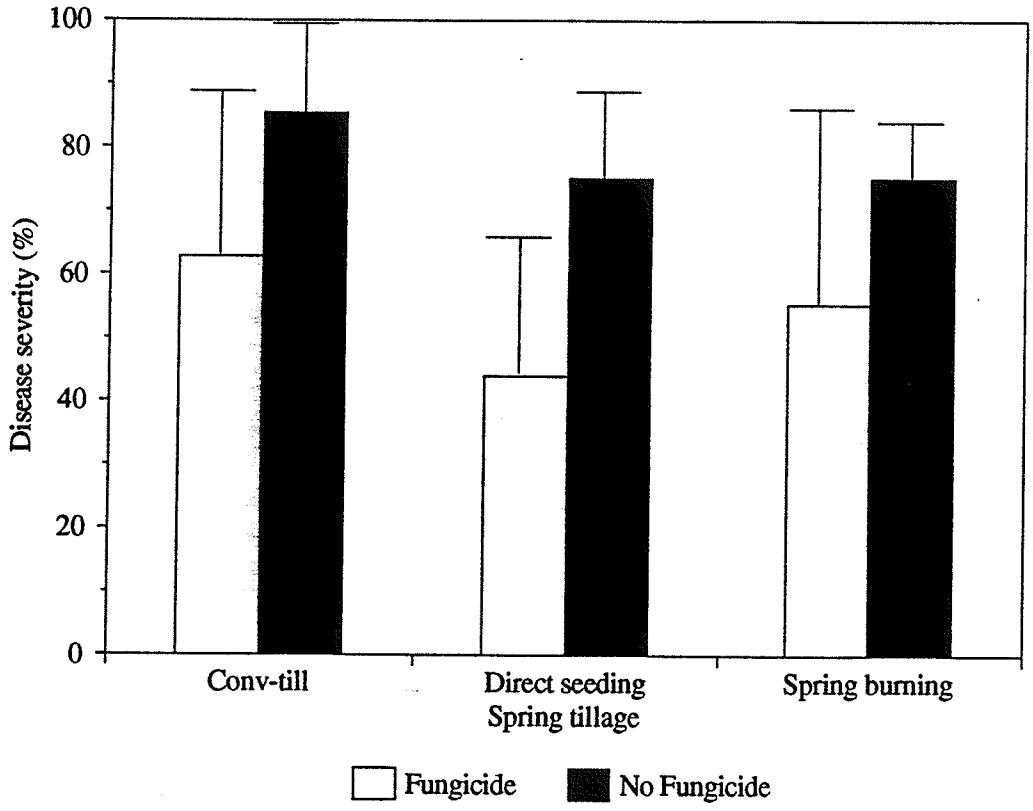

Figure 11. Effect of spring tillage practices on leaf spot disease severity of the third leaf from the top of the plant sampled after wheat heads emerged in 1994. Error bars indicate the standard deviation.

in disease severity was observed when Tilt was applied to the spring burning treatment, but was not significant. Disease severity on the third leaf ranged from 40 to 85% and leaves were nearing senescence.

Disease severity on the second leaf ranged from 20 to 45% (Figure 12) and there were no significant differences between tillage treatments. However, disease severity was at least 10% higher in the direct seeding treatment without Tilt application than all remaining treatments.

Disease symptoms on the top leaf were low (Figure 13) and significant differences were not observed. Plants in all tillage treatments had disease severity ratings of less than 5% and application of Tilt did not have a significant effect.

At the end of anthesis, only the top leaf was sampled (Figure 14) because lower leaves had become senescent. Disease severity was not significantly different between tillage treatments and reached 35 to 50% when Tilt was not applied. Disease severity decreased significantly in all tillage treatments when Tilt was applied.

4.4.2 Yield components.

1992. Only three replicates of data were analyzed in 1992 due to flooding. Significant differences in yield were not observed between tillage practices (Table 2). However, the thousand kernel weight was significantly lower in the direct seeding treatment compared to other tillage treatments. The number of heads m^{-2} was significantly lower in the direct seeding treatment compared to the spring burning treatment. The number of seeds $head^{-1}$ were not counted and plant height was unaffected by tillage practices.

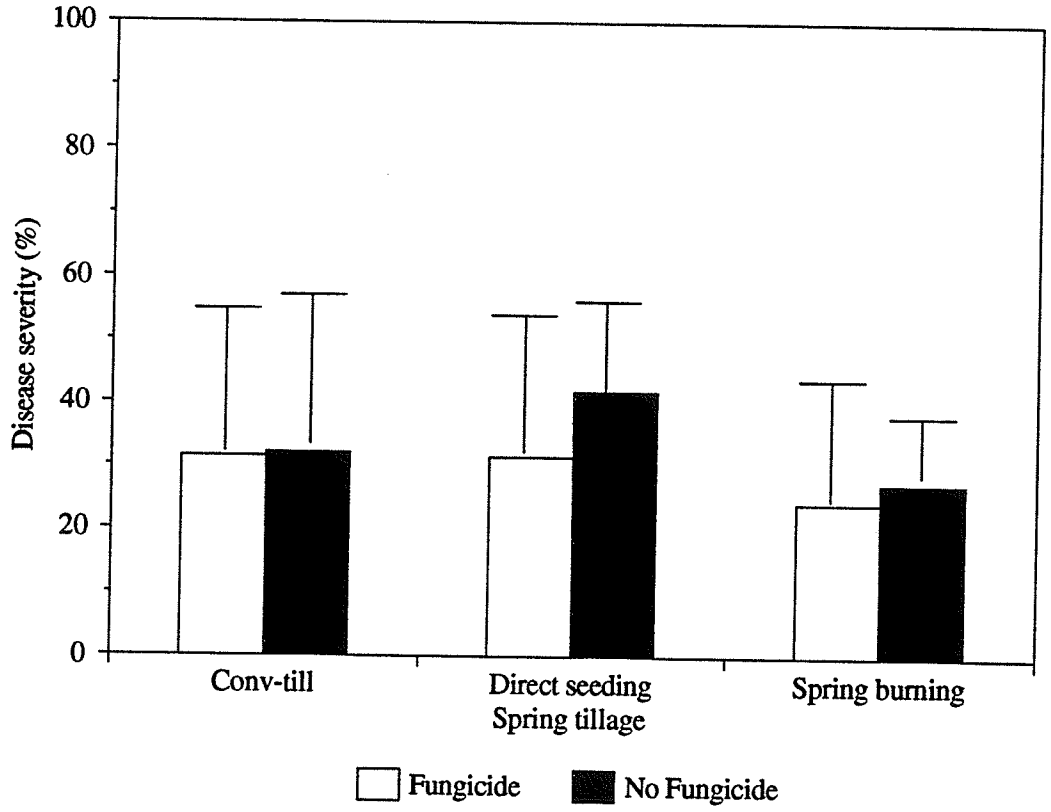

Figure 12. Effect of spring tillage practices on leaf spot disease severity of the second leaf from the top of the plant sampled after wheat heads emerged in 1994. Error bars indicate the standard deviation.

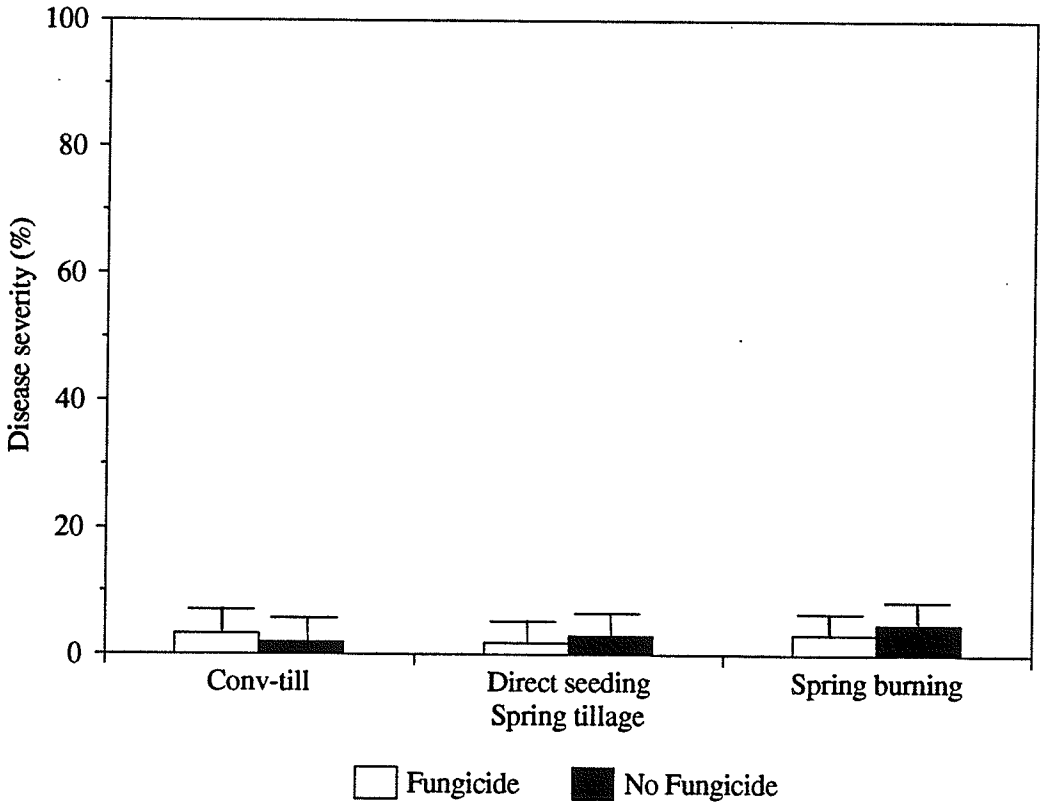

Figure 13. Effect of spring tillage practices on leaf spot disease severity of the top leaf of the plant sampled after wheat heads emerged in 1994. Error bars indicate the standard deviation.

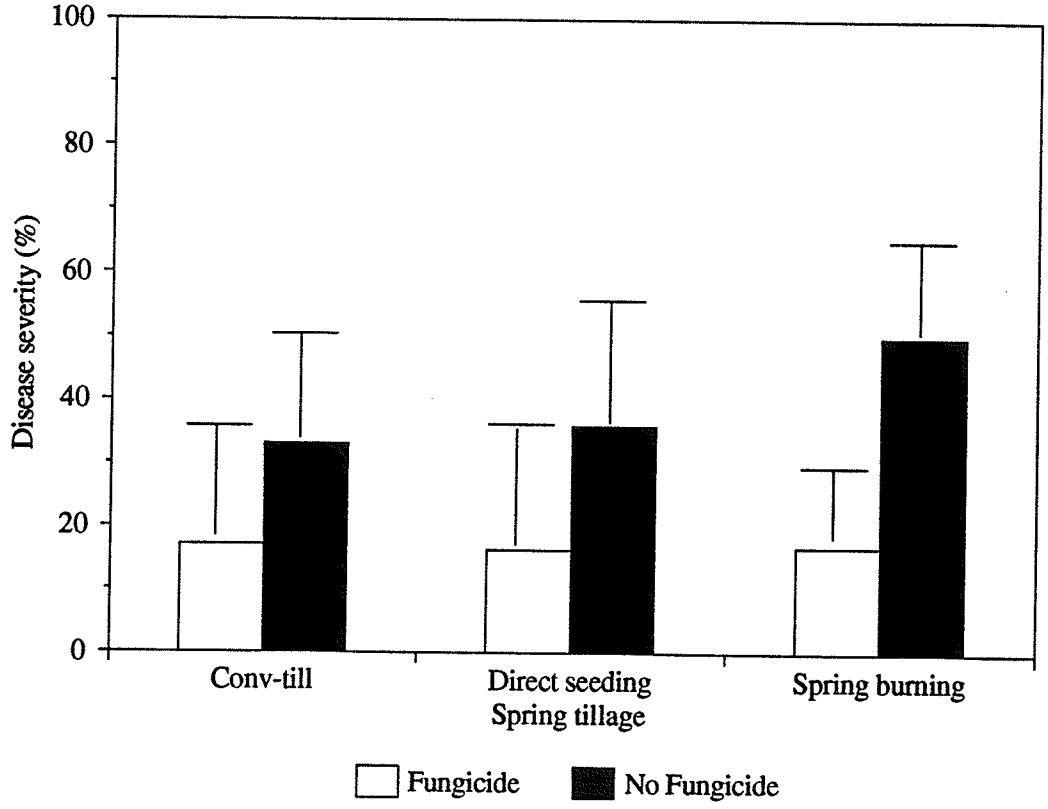

Figure 14. Effect of spring tillage practices on leaf spot disease severity of the top leaf of the plant sampled at the end of anthesis in 1994. Error bars indicate the standard deviation.

Table 2. Effect of spring tillage practices on growth and yield of Katepwa wheat in 1992[†].

Tillage treatment	Height (cm)	Heads m^{-2}	Yield (g $plot^{-1}$)	1000 kernel weight (g)
Conventional	116.0	501.2	1802.0	33.3
Conventional + Tilt	111.8	460.8	1558.3	34.2
Spring burning	116.0	547.6	1623.3	32.8
Direct seeding	109.1	402.6	1352.3	30.0
$LSD_{0.05}$=	7.9	135.5	560.8	2.0

[†]Only 3 replicates were used to calculate means due to flooding.

1993. Leaf spot diseases had a significant effect on wheat development in the tillage practice experiment in 1993 (Table 3). Plant height was significantly higher in the spring burning treatments compared to the direct seeding treatment where no Tilt was applied. Plant height was not significantly different in all remaining treatments. The number of heads m^{-2} was not affected by tillage practice or Tilt application in 1993. The number of seeds $head^{-1}$ increased significantly when Tilt was applied to conventional tillage plots, but the remaining tillage treatments were unaffected.

Generally, spring burning plots outyielded conventional tillage and direct seeded plots. When Tilt was applied, the spring burning plots yielded significantly higher compared to conventional tillage and direct seeding. In the absence of Tilt, both spring burning and conventional tillage yielded significantly higher than direct seeding. A significant increase in 1000 kernel weight was evident when Tilt was applied (Table 3). Kernel weight increased significantly in the spring burning treatment compared to direct seeding when Tilt was applied. Kernel weight in the spring burning treatment was significantly higher than in both direct seeding and conventional tillage treatments in the absence of Tilt. A yield increase of up to 63% (Table 4) and a 1000 kernel weight increase of up to 33% was obtained when Tilt was applied. The increase in yield and kernel weight due to fungicide application was greatest in the direct seeding treatment.

Yield and 1000 kernel weight of tillage treatments were correlated with disease severity (Table 5) and AUDPC totals (Table 6) late in the growing season. The relationship between AUDPC and yield or 1000 kernel weight was most evident after the wheat head emerged from the sheath.

Table 3. Effect of spring tillage practices on growth and yield of Katepwa wheat in 1993[1].

Tillage treatment	Height (cm)	Heads m^{-2}	Seeds $head^{-1}$	Yield (g $plot^{-1}$)	1000 kernel weight (g)
Conventional	120.9	644.5	15.9	1701.1	24.5
Conventional + Tilt	121.6	643.2	18.2	2430.5	32.5
Direct seeding	118.8	678.5	16.9	1445.9	24.0
Direct seeding + Tilt	121.1	644.7	16.7	2355.3	32.0
Spring burning	122.7	672.0	16.6	1806.0	26.7
Spring burning + Tilt	123.9	724.3	17.1	2618.4	33.7
$LSD_{0.05}$=	3.5	159.7	1.8	171.8	1.5

[1] Data are the mean of six replicates.

Table 4. Percent yield and 1000 kernel weight increase observed in spring tillage treatments with Tilt fungicide applied in 1993 and 1994 compared to treatments without Tilt applied[1].

Tillage treatment	Percent Yield Increase		Percent 1000 Kernel Weight Increase	
	1993	1994	1993	1994
Conventional	43	-2	33	4
Direct seeding	63	19	33	11
Spring burning	45	11	26	-4

[1] Data were computed as follows:

$$\% \text{ Increase} = [(Y_f - Y)/Y] * 100$$

where Y_f = tillage treatment with fungicide applied and Y represents tillage treatments without fungicide.

Table 5. Correlation (r) of yield and 1000 kernel weight of spring tillage treatments with disease severity during 1993.

Zadoks growth stage	Correlation coefficent (r)	
	Yield	1000 kernel weight
22-23	-0.09	-0.08
24-31	0.03	-0.04
45-50	-0.19*	-0.18
50-55	-0.74**	-0.72**
55-60	-0.46**	-0.45**
60-70	-0.59**	-0.55**
70-75	-0.79**	-0.74**
Over all growth stages	-0.26**	-0.25**

* $LSD_{0.05}$
** $LSD_{0.01}$

Table 6. Correlation (r) of yield and 1000 kernel weight of spring tillage treatments with AUDPC[1] during 1993.

Zadoks growth stage	Correlation coefficient (r)	
	Yield	1000 kernel weight
24-31	0.01	-0.04
45-50	-0.12	-0.08
50-55	-0.38**	-0.32
55-60	-0.64**	-0.64**
60-70	-0.65**	-0.66**
70-75	-0.86**	-0.81**
Over all growth stages	-0.25**	-0.25**

[1] Area Under the Disease Progress Curve
* $LSD_{0.05}$
** $LSD_{0.01}$

1994. The effect of leaf spot diseases on crop development was less pronounced in 1994 than 1993 (Table 7). The number of seeds head^{-1}, heads m^{-2} and plant height were not significantly different between treatments. Yield did not increase significantly when Tilt was applied (Table 7). Spring burning plots tended to yield higher than conventional tillage and direct seeding. In the direct seeding treatment, yield and 1000 kernel weight were 19% and 11% higher, respectively, when fungicide was applied (Table 4). Yield and 1000 kernel weight in conventional and spring burning plots did not increase significantly when Tilt was applied (Table 4). However, when Tilt was not applied, 1000 kernel weight was significantly higher in the spring burning treatment compared to direct seeding (Table 7).

4.5 Discussion. Septoria leaf spots were at least as pronounced as tan spot in this experiment. In western Manitoba, *M. graminicola* appeared to be the most common leaf spot pathogen with lower levels of *P. tritici-repentis* and *P. nodorum*. The distribution of these pathogens is difficult to interpret, but environmental conditions probably played a significant role. Western Manitoba experienced extended moist periods in 1993. The presence of *M. graminicola* in western Manitoba caused substantial yield reductions in 1993. Historically, *M. graminicola* has not been as prevalent as *P. nodorum* and *P. tritici-repentis* in Manitoba (Tekauz 1976). The combination of temperature, moisture and cultural practices favouring this sudden change in pathogen population is not presently understood.

Interplot interference may have accounted for the similar disease levels observed

Table 7. Effect of spring tillage practices on growth and yield of Katepwa wheat in 1994[1].

Tillage treatment	Height (cm)	Heads m^{-2}	Seeds $head^{-1}$	Yield (g $plot^{-1}$)	1000 kernel weight (g)
Conventional	113.5	462.0	19.7	1656.7	31.7
Conventional + Tilt	112.7	416.5	19.0	1629.6	33.0
Direct seeding	114.3	450.7	19.6	1457.7	30.6
Direct seeding + Tilt	113.7	418.0	21.0	1729.4	33.9
Spring burning	115.3	443.3	20.9	1868.5	34.0
Spring burning + Tilt	115.4	434.0	20.2	2082.8	32.7
$LSD_{0.05}$=	5.3	80.9	2.8	294.8	2.6

[1] Data are the mean of six replicates.

when different tillage practices were implemented. Separation between plots in 1992 and 1993 was 2 m and plot width was 2 m. Previous findings indicate that a 90% reduction in AUDPC of tan spot occurs within 3.6 to 5.4 m from the source of inoculum (Sone et al. 1994). A 60-70% reduction occurs 2 m away from the source of inoculum. Tan spot was one of the pathogens present, but Septoria leaf blotch was present at higher levels. Wind dispersal of tan spot inoculum would likely promote spread over longer distances than splash dispersal of *Septoria spp.* In 1994, tillage treatments were separated by 4 m buffers that should have reduced interplot interference. Prior to interplot interference becoming a factor, spread via conidia must occur. Since most lesions were isolated in the lower canopy early in the growing season, it is unlikely that spread to adjacent plots could have occurred until late in the growing season.

Applying Tilt provided a useful method of comparing disease levels between treatments. This comparison was based on the untested assumption that Tilt efficacy on leaf spot diseases is 100%. Disease, yield or kernel weight measurements made when Tilt was applied may not be representative of disease-free plants. However, for economic reasons Manitoba wheat producers seldom apply fungicides more than once in a season. The wheat yield increase, attributed to disease control by Tilt application in 1993, is probably an overestimation compared to the yield a farmer could expect with only one application of fungicide. However, the efficacy of Tilt was most evident in 1993 when large yield and 1000 kernel weight increases were observed.

In this experiment, seeds head^{-1}, plant height and heads m^{-2} were generally not reduced by leaf spot diseases. Under low disease levels, 1000 kernel weight sometimes

decreased. Disease severity of 40-50% on the flag leaf late in the growing season reduced 1000 kernel weight substantially and gave a subsequent yield reduction. Similarly, Rees & Platz (1983) reported that yield loss due to tan spot was usually attributed to grain weight reduction, but in this study only 50% of the yield loss in 1993 can be attributed to a decrease in grain weight. At low disease levels, farmers could expect a consistent bushel weight reduction and possibly a lower grade for shrivelled seed. In years when leaf spot diseases are severe, substantial yield reductions due to loss in grain weight will be present. In Manitoba, leaf spot diseases most often progress after emergence of the flag leaf. Prior to this stage in crop development, environmental conditions are more conducive to crop growth than disease progress.

The effect of tillage practices on leaf spot disease development was inconsistent over the three years. Burning residues in the spring tended to slow disease development, but did not reduce levels significantly throughout the entire growing season. Crop yield was generally higher in plots which had been burned. Previous research (Rasmussen & Rohde 1988) indicated that stubble burning did not increase crop yield or nitrogen uptake, but tended to increase straw yield. Disease development may have been slower in spring burned plots due to vegetative growth keeping ahead of disease progress. Other researchers (Rees & Platz 1979, Bockus & Claassen 1992) have reported that burning the residues of the previous crop effectively controlled leaf spot diseases. However, incomplete burning of subcrown internodes has been reported as a source of inoculum even after residues are burned (Rees & Platz 1979). In this experiment a few pieces of subcrown internode and short straw remained after burning. The remaining straw may

have permitted the survival of overwintering fruiting bodies. Incomplete burning or a fast burn may reduce the heat on the soil surface so that enough primary inoculum would survive to cause significant levels of disease. As well, disease-infested residues may have been moved from plots by wind and deposited on adjacent plots.

Evidence of the influence of low levels of infested residues was evident in the comparison of tillage practices. Direct seeding did not give a substantial increase in disease levels when compared to conventional tillage or spring burning even though the density of infested residues was high. Conventional tillage practices in Manitoba usually involves retaining a significant level of residues so that disease levels in direct seeded fields may be similar. In 1993, weather conditions were conducive to leaf spot disease development in western Manitoba and a significant yield increase was observed when Tilt was applied to tillage treatments. Differences in disease levels between tillage practices were not large enough to warrant their use as a control measure. However, it is interesting to note that in 1993 and 1994, fungicide application to the direct seeding treatment tended to increase yield more compared to the conventional tillage and spring burning treatments. Although none of the tillage treatments appeared to control leaf spot diseases, direct seeding may be resulting in slighter higher yield losses when leaf spot diseases are present at moderate to high levels. Clearly, further study is required to determine the long term effects of tillage practices on the incidence and severity of leaf spot diseases of wheat.

5. THE INFLUENCE OF INFESTED WHEAT RESIDUES ON SEVERITY OF LEAF SPOT DISEASES IN HARD RED SPRING WHEAT

5.1 Abstract.

Tan spot or yellow spot (*Pyrenophora tritici-repentis*) and septoria leaf and glume blotch are leaf spot diseases of wheat of significance in western Canada that survive on crop residues. The influence of infested wheat residues on the development of leaf spot diseases was studied in 1992, 1993 and 1994. Treatments included 0, 500, 4000 and 8000 kg infested residues ha^{-1} spread on bare soil. Tilt fungicide was applied to an additional residue-free treatment in 1992 and to all residue treatments in 1993 and 1994, to provide a 'disease-free' control. *Phaeosphaeria nodorum* and *P. tritici-repentis* were the dominant pathogens in all three years. Increasing the amount of infested residues did not consistently increase disease levels. Periodic flooding in 1993 and 1994 caused variable results and may have contributed to interplot interference. Tilt application did not reduce disease levels or increase crop yield consistently. Increasing the level of infested residues tended to reduce yield, particularly when 8000 kg residues ha^{-1} were applied.

5.2 Introduction.

Pyrenophora tritici-repentis (Died.) Drechs., anamorph *Drechslera tritici-repentis* (Died.) Shoem., the causal agent of tan spot of wheat (*Triticum aestivum L.*) and *Mycosphaerella graminicola* (Fuckel) Schroeter, anamorph *Septoria tritici* and *Phaeosphaeria nodorum* (Muller) Hedja., anamorph *Stagonospora nodorum*, causal agents of Septoria leaf and glume blotch are the major stubble-borne leaf spot diseases of wheat in western Canada (Tekauz 1976, Gilbert et al. 1993, Gilbert et al. 1994, Gilbert et al. 1995). Unburied crop residues are the main source of primary inoculum for tan spot and septoria leaf spots. Yield reductions of 10% due to leaf spot diseases are common with the potential for losses as high as 50% (Rees et al. 1982).

Mature pseudothecia of *P. tritici-repentis* are present from early April until mid-June in Ontario (Wright & Sutton 1990). Most infections are initiated by ascospores, with fewer occurring from conidia (Morral & Howard 1975, Rees & Platz 1980). Secondary cycles of infections by *P. tritici-repentis* are generally caused by wind-borne conidia, originating from dead leaf tissue (Shaner 1981). *P. nodorum* and *M. graminicola* form pycnidia that overwinter on wheat residues (Shaner 1981). *M. graminicola* can also produce pseudothecia on wheat residues and release ascospores in the spring, but most infections occur via pycnidiospores (Shaner 1981). *P. avenaria* may overwinter as mycelium and form pycnidia in the spring, or perithecia may form in the spring and eventually develop ascospores (Shaner 1981).

Increasing moisture level results in an increase in the number of mature asci (Fernandes et al. 1991) and ascospore development is fastest at 15°C (Summerell &

Burgess 1988b). *P. tritici-repentis* is known to survive on stubble for at least two years (Summerell & Burgess 1989a) and decomposition of stubble is enhanced by warm, wet conditions (Summerell & Burgess 1989b). Secondary infections by *P. tritici-repentis* require at least six hours of continuous leaf wetness (Hosford et al. 1987, Chapter 2) and develop optimally at temperatures of 18-28°C (da Luz & Bergstrom 1986) for disease severity to reach visible levels. Low temperatures slow disease development (da Luz & Bergstrom 1986, Hosford et al. 1987) while high temperatures (>28°C) induce resistance in susceptible cultivars (Lamari & Bernier 1994).

Leaf spot diseases can be controlled by cultural practices (Bockus & Claassen 1992, Rees & Platz 1979) and/or application of fungicides (da Luz & Bergstrom 1986, Dannenberg et al. 1989, Entz et al. 1990). Adee & Pfender (1989) reported that the influence of primary inoculum could persist throughout a tan spot epidemic. The number of naturally produced pseudothecia of *P. tritici-repentis* per gram of wheat residues increased and then decreased, as the density of wheat residues continued to increase (Sutton & Vyn 1990). Ploughing and burning wheat residues reduces the severity of tan spot (Bockus & Claassen 1992, Rees & Platz 1979). A crop rotation of two years between wheat was effective in reducing severity of the septoria disease complex (Pedersen & Hughes 1992).

The trend across western Canada has been to reduce tillage which results in increased residue levels on the soil surface. Although fungicides can be used to control leaf spot diseases (da Luz & Bergstrom 1986, Dannenberg et al. 1989, Entz et al. 1990), their cost is often prohibitive. Genetic resistance is currently not extensively available in

commercial cultivars in Canada. Research investigating the influence of increased wheat residue levels on leaf spot diseases in Manitoba is lacking. The objective of this study was to examine the influence of different levels of infested wheat residues on the development of leaf spot diseases in hard red spring wheat.

5.3 Materials and methods.

5.3.1 Experimental design. The experiment was conducted at the University of Manitoba, Winnipeg research station on bare summerfallow ground in 1992, 1993 and 1994. Naturally infested wheat residues were collected in the spring from a field with a history of leaf spot diseases in previous wheat crops.

Infested wheat residues were spread over the soil surface at a level of 0, 500, 4000 and 8000 kg ha^{-1} following planting, but prior to crop emergence. Residues were examined and assessed for the presence of fruiting bodies of *P. tritici-repentis* in 1993. Pseudothecia density was about 2500, 18000 and 36000 m^{-2} for the 500, 4000 and 8000 kg ha^{-1} treatments, respectively. In 1992, Tilt was applied at 14-21 day intervals to an additional plot free of residues, providing a 'disease-free' control. Duplicate plots of all residue treatments had Tilt applied in 1993 and 1994 creating a total of eight treatments. Plots (2 m wide by 5 m long) were separated by 2 m buffers of wheat maintained disease-free with Tilt in 1992 and by 2 m oat buffers in 1993 and 1994. The treatments were arranged in a randomized complete block design and replicated 6 times. Katepwa wheat was planted at a rate of 100 kg ha^{-1} in all 3 years using a direct seeding hoedrill. Ammonium diphosphate (11-52-0) was placed with the seed and ammonium nitrate (34-0-

0) was broadcast after crop emergence according to fertilizer recommendations.

5.3.2 Disease measurement. In 1992, leaves from 10 different plants were arbitrarily selected from each plot on three dates, and on two dates in 1994 on two dates, after flag leaf emergence. At each sampling date, the upper three leaves from the main tiller of each of 10 plants were collected for assessment of disease severity (eg. - 30 leaves per plot). The top leaf is defined as the uppermost leaf on the main tiller of a wheat plant at one particular sampling date. In this study, the top leaf at the tillering stage may become the second leaf from the top on the next sampling date. Similarly, the second leaf from the top of the plant is defined as the second leaf from the top of a main tiller at one particular sampling date. The third leaf is the third leaf from the top of a main tiller at one particular sampling date. In this study, the third leaf was only sampled early in the growing season as leaf senescence prevented sampling at later dates. Sampling began in late June or early July and was completed in early August.

In 1993, disease assessment began in late June and occurred at intervals of 7-14 days until leaf senescence. The top three leaves of 10 wheat plants were arbitrarily selected from each plot. This procedure was followed until each successive leaf became senescent. On several occasions leaf pieces were incubated under high relative humidity to allow isolation and identification of the pathogens associated with disease symptoms.

Leaves were dried or refrigerated until disease was measured using a true colour image processing system. This system uses a DT2871 HSI-Colour frame grabber (Data Translation, Marlboro, MA) and the ImageX software package developed by Lamari

(unpublished). The accuracy of the system is typically within 1% in area measurement and lesion detection, based on hue. Tips of leaves were removed before measurement. Disease severity was obtained by measuring the proportion of leaf tissue discoloured by leaf spot diseases. In 1993, the area under the disease progress curve (AUDPC) was computed for all treatments using the following formula:

$$\sum_{i=1}^{n}[(Y_{i+1} + Y_i)/2)][X_{i+1} - X_i]$$

where Y_i = severity at the i^{th} observation, X_i = time (days) at the i^{th} observation and n = total number of observations.

5.3.3 Plant growth and environmental measurements. Emerged plants were counted 10-15 days after seeding and plant height, heads m^{-2} and seeds $head^{-1}$ were evaluated prior to harvest. In mid to late September, the centre six rows of each plot were harvested using a Hege Model 125A plot combine. Grain samples were cleaned to remove all foreign material, weighed and 1000 kernel weight was determined.

5.3.4 Statistical analysis. Analysis of variance, means comparison and correlation analysis were computed using the SAS (Version 6.04) statistical package (SAS Institute, Raleigh, NC). Disease severity data was tested for normality and log transformed where appropriate. In all analyses, only differences significant at $\alpha = 0.05$ were considered meaningful.

5.4 Results.

5.4.1 Effect of stubble density on leaf spot disease development.

1992. Disease development was slow due to temperatures that were cooler than normal and average precipitation in 1992 (Appendix). These conditions promoted vigorous crop growth and disease symptoms were limited to the lower leaves. Disease severity was measured on the second leaf at the swollen boot stage (Figure 15) and top leaf when the wheat heads were fully emerged (Figure 16). Disease severity was less than 10% in all treatments on the second leaf and significant differences between treatments were not observed (Figure 15). Although disease severity tended to decrease when Tilt was applied, significant differences between treatments were not present (Figure 16).

1993. Disease severity among leaves was variable in 1993 and significant differences were not evident between infested residue levels (Figures 17, 18 & 19). Extensive flooding in early July confounded disease measurement. Disease severity did not reach moderate levels on upper leaves (Figures 17 & 18) until about 80 days after planting. *P. nodorum* and *P. tritici-repentis* were the dominant pathogens at that time, with *P. nodorum* present on about 60% of lesions observed after incubation. Disease severity decreased significantly on the top and second leaves, when Tilt was applied, on the last two sampling dates (Figures 17 & 18). Disease severity on the second and third leaves (Figures 18 & 19) tended to decrease at 55 days after planting and increased again 80 days after planting. Disease severity on the third leaf (Figure 19) was not measured on the second sampling date due to improper storage. Disease progress on the third leaf did not show any trends and remained below 25% on all sampling dates. Leaf senescence

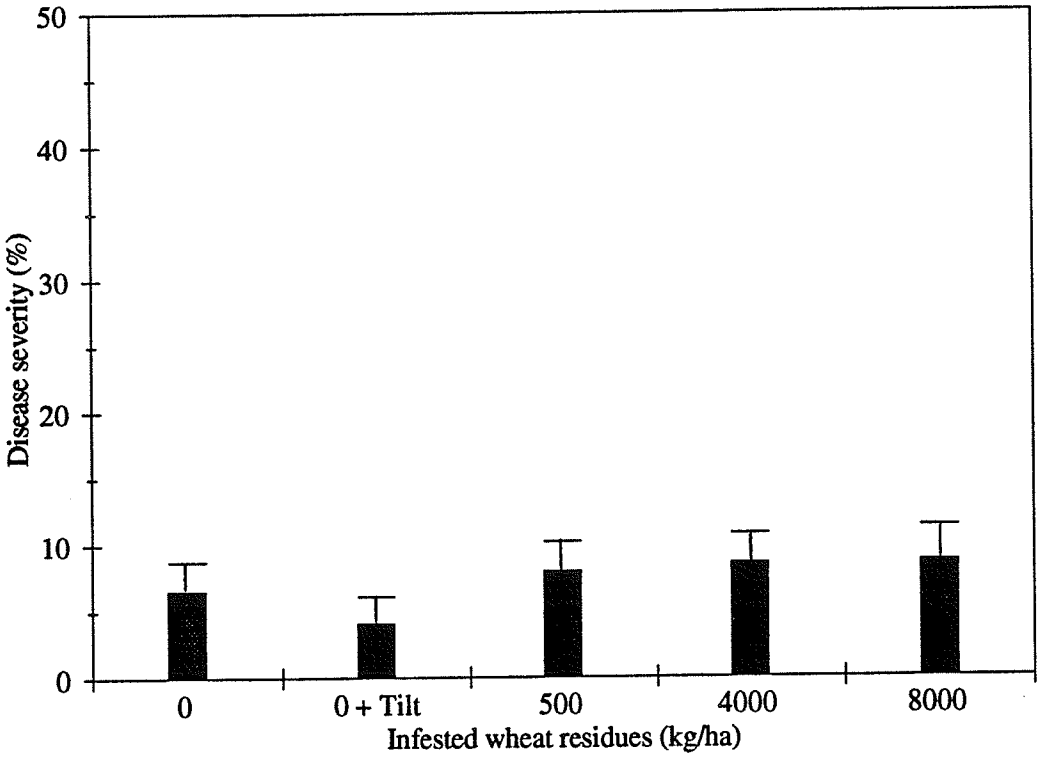

Figure 15. Effect of infested wheat residues on leaf spot disease severity of the second leaf in 1992. Error bars indicate the standard deviation.

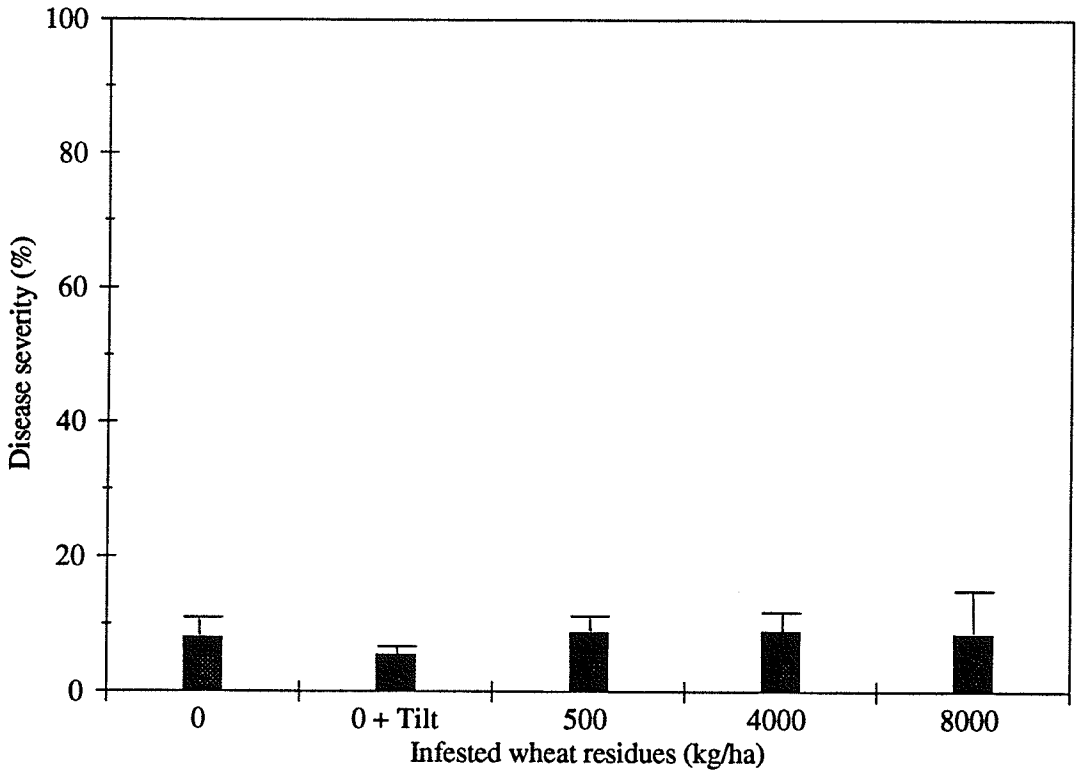

Figure 16. Effect of infested wheat residues on leaf spot disease severity of the top leaf in 1992. Error bars indicate the standard deviation.

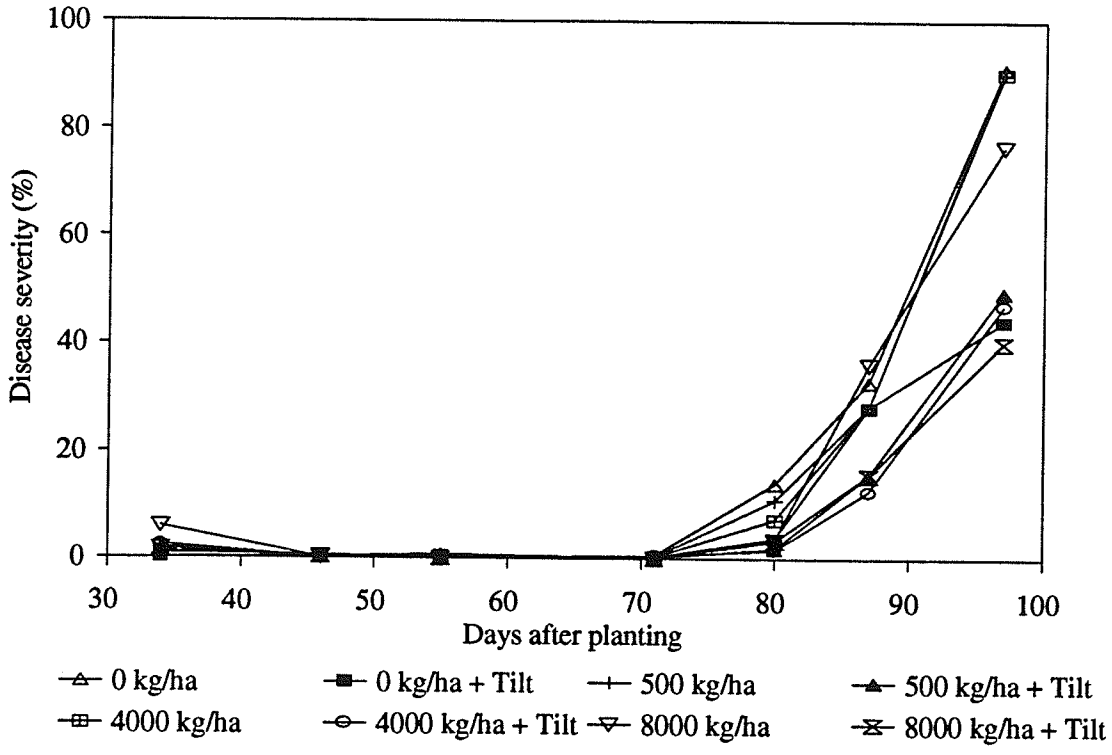

Figure 17. Effect of infested wheat residues on leaf spot disease severity of the top leaf on plants at each planting date during 1993.

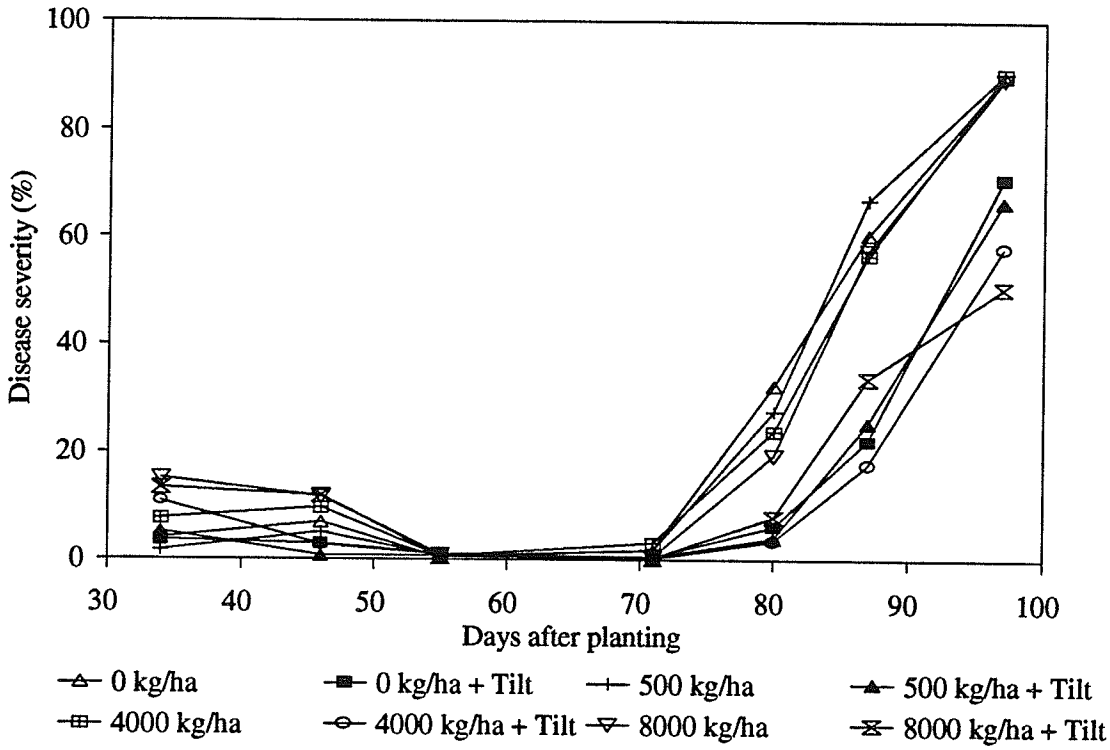

Figure 18. Effect of infested wheat residues on leaf spot disease severity of the second leaf from the top of the plants at each sampling date during 1993.

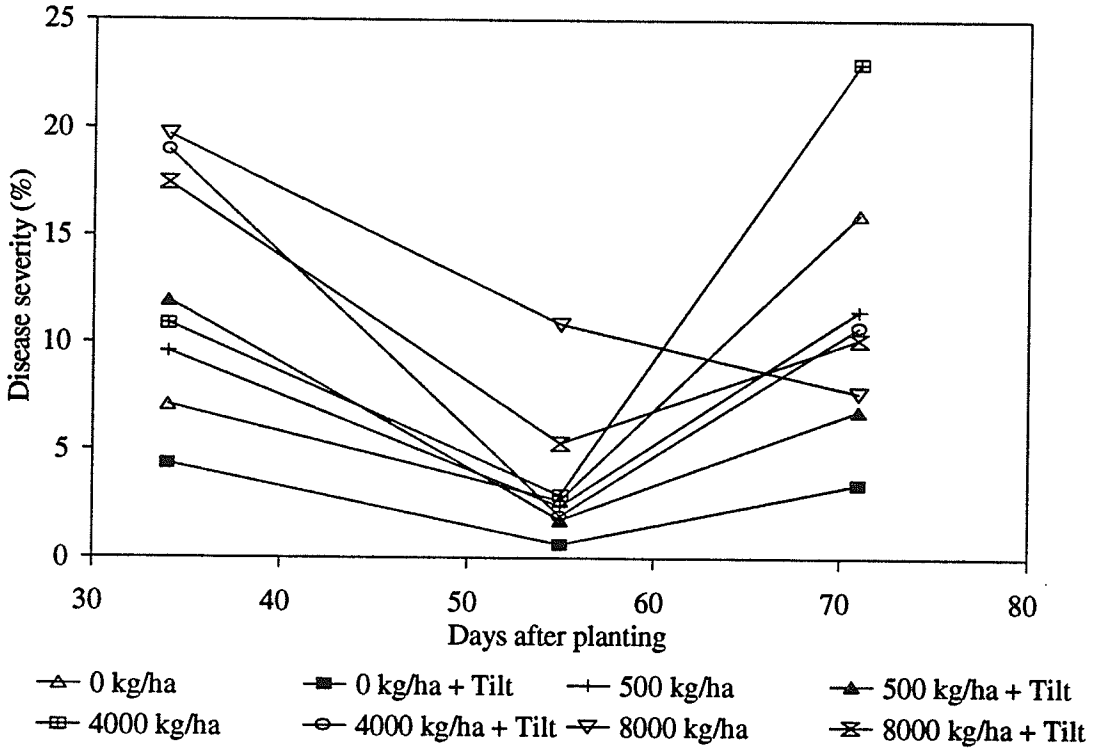

Figure 19. Effect of infested wheat residues on leaf spot disease severity of the third leaf from the top of plants at each sampling date during 1993.

prevented further sampling of the third leaf 70 days following planting.

In 1993, a significant reduction in total AUDPC was evident when Tilt was applied to all wheat residue treatments (Table 8). Significant differences in AUDPC were not observed between different levels of residue on either the top or second leaf (Table 8). On the third leaf, AUDPC for the 8000 kg ha^{-1} treatment was significantly higher than the 0 and 500 kg ha^{-1} treatments.

1994. In 1994, the top three leaves were sampled when wheat heads had fully emerged. Disease severity on the third leaf from the top of the plant ranged from 35 to 70% (Figure 20). Disease severity decreased significantly in the 4000 kg ha^{-1} treatment when Tilt was applied. All remaining treatments were not significantly different from each other. Disease severity tended to increase as infested residue level increased in the absence of Tilt, but was variable when Tilt was applied. On the second leaf sampled (Figure 21), disease severity tended to increase with higher levels of infested residues. The 4000 kg ha^{-1} residue level had significantly higher disease severity than all other treatments except the 8000 kg ha^{-1} treatment. Disease severity decreased significantly in all residue treatments when Tilt was applied. Disease severity on the top leaf was low (Figure 22). Trends were not evident, but disease severity on the top leaf was significantly lower in the absence of infested residues than the remaining treatments.

The top leaf was sampled a second time in 1994 when wheat was nearing the end of anthesis (Figure 23). When Tilt was not applied, disease severity was not significantly different between treatments. Disease severity decreased significantly at all residue levels when Tilt was applied.

Table 8. Effect of infested wheat residue levels on leaf spot development on the top three leaves of Katepwa wheat at Winnipeg in 1993.

Residue Treatment (kg ha^{-1})	AUDPC[2]			
	Leaf 1[3]	Leaf 2	Leaf 3	Total
0	868.2	1344.4	142.6	2355.2
500	799.6	1332.8	134.2	2266.6
4000	768.7	1317.9	199.5	2286.1
8000	754.7	1322.9	266.4	2344.0
0 + Tilt	502.7	662.0	48.3	1213.0
500 + Tilt	414.7	633.8	121.0	1169.5
4000 + Tilt	377.4	575.5	182.3	1135.2
8000 + Tilt	371.9	816.3	206.0	1394.2

[1] Numbers represent kg/ha of wheat residues spread over the soil surface. Tilt (propiconazole).

[2] Area Under the Disease Progress Curve (AUDPC) calculated using the formula:

$$\sum_{i=1}^{n}[(Y_{i+1} + Y_i)/2)][X_{i+1} - X_i]$$

where Y_i = severity at the *i*th observation, X_i = time (days) at the *i*th observation and n = total number of observations.

[3] Leaf 1 was the top leaf of the plant at each sampling date.
Leaf 2 was the second leaf from the top at each sampling date.
Leaf 3 was the third leaf from the top at each sampling date.

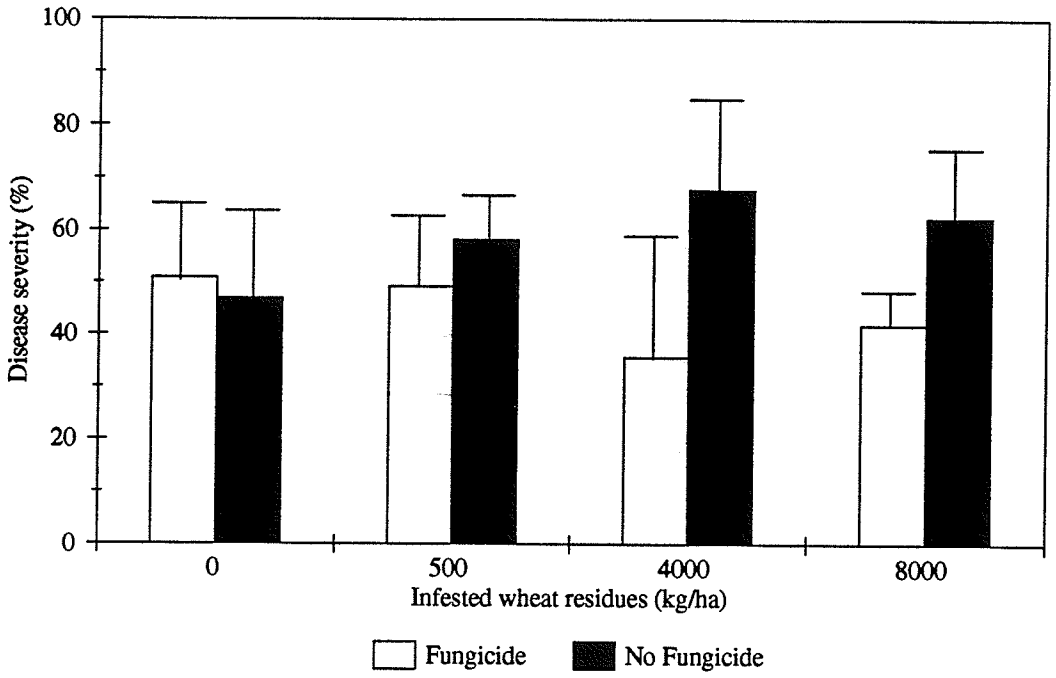

Figure 20. Effect of infested wheat residues on leaf spot disease severity of the third leaf from the top of the plant sampled when wheat heads were fully emerged in 1994. Error bars indicate the standard deviation.

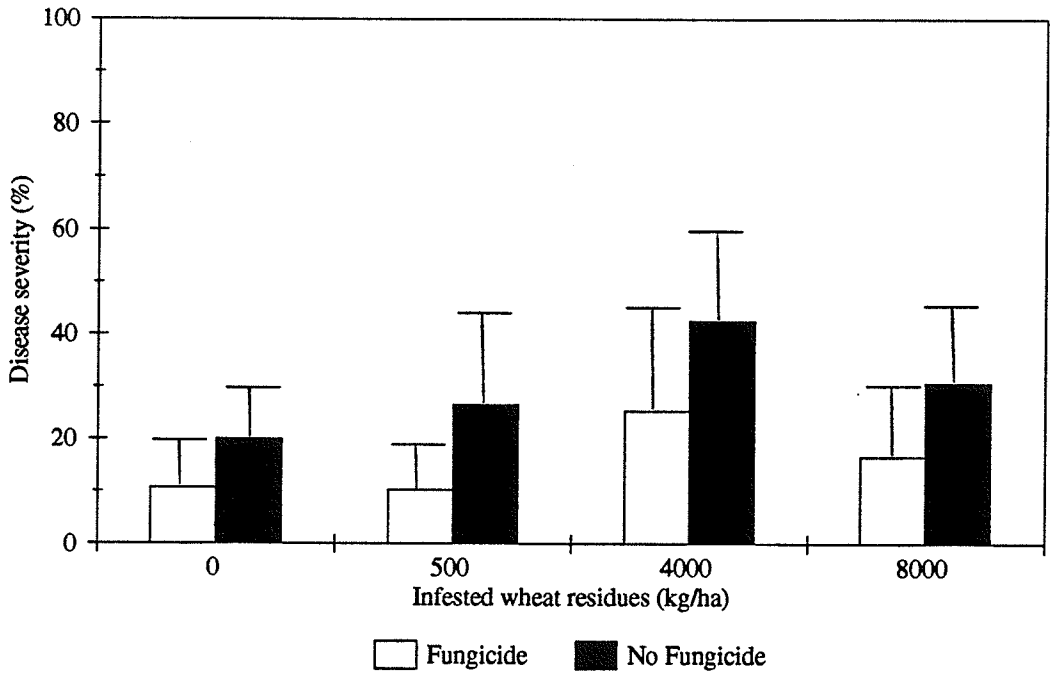

Figure 21. Effect of infested wheat residues on leaf spot disease severity of the second leaf from the top of the plant sampled when wheat heads were fully emerged in 1994. Error bars indicate the standard deviation.

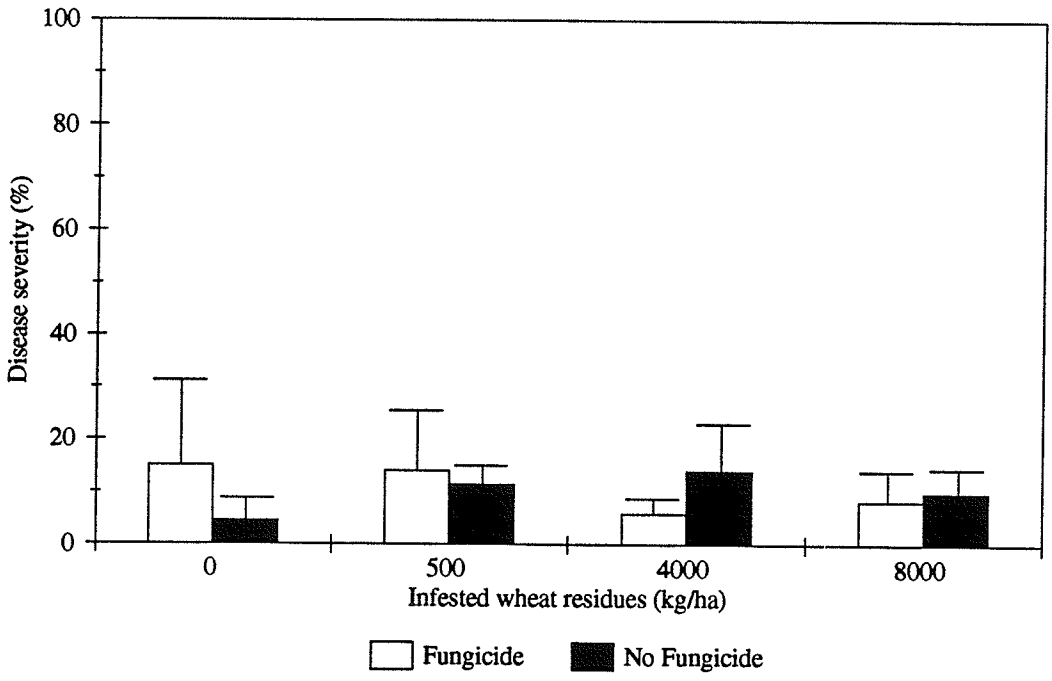

Figure 22. Effect of infested wheat residues on leaf spot disease severity of the top leaf of the plant sampled when wheat heads were fully emerged in 1994. Error bars indicate the standard deviation.

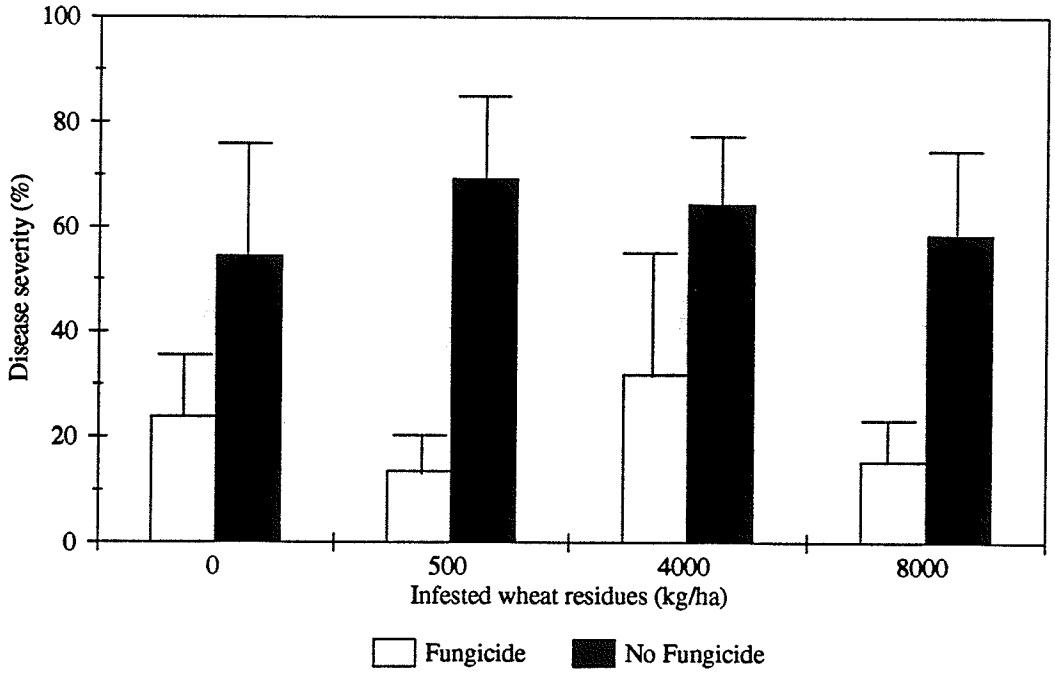

Figure 23. Effect of infested wheat residues on leaf spot disease severity of the top leaf of the plant sampled when wheat was near the end of anthesis in 1994. Error bars indicate the standard deviation.

5.4.2 Yield components.

1992. In 1992, cooler than normal weather promoted rapid growth of the crop and impeded disease development (Table 9). Plant height was significantly lower in the 0 + Tilt and 8000 kg ha^{-1} treatments compared to all other treatments, with significantly reduced plant height in the 8000 kg ha^{-1} treatment than the 0 + Tilt treatment. The number of heads m^{-2} was not reduced by increasing infested residue level or application of Tilt. However, increasing infested residue levels to 8000 kg ha^{-1} reduced the number of seeds $head^{-1}$ in the absence of Tilt.

A significant increase in yield was evident in plots that had Tilt applied compared to all other treatments (Table 9). The 8000 kg ha^{-1} treatment yielded significantly lower compared to when no residues were applied. Tilt application increased thousand kernel weight significantly compared to all treatments except when 500 kg ha^{-1} infested residues were applied.

1993. Crop development in 1993 was inhibited by heavy rains and flooding in early July when wheat was at the jointing stage. Crop height was significantly reduced when 8000 kg ha^{-1} of infested residues were applied (Table 10). Crop height was not affected by application of Tilt. The number of heads m^{-2} was also significantly reduced when 8000 kg ha^{-1} of residues were applied, with no effect when Tilt was applied (Table 10). Increasing infested residues to 4000 kg ha^{-1} or higher tended to reduce the number of seeds $head^{-1}$. Residue treatments were not affected significantly by Tilt application.

Wheat yield was highest in plots which had no residues and decreased significantly as the residue level increased (Table 10). Control of leaf spot diseases by Tilt application

Table 9. Effect of infested wheat residue levels on growth and yield of Katepwa wheat in 1992[1].

Residue treatment (kg ha^{-1})	Height (cm)	Heads m^{-2}	Seeds $head^{-1}$	Yield (g $plot^{-1}$)	1000 kernel weight (g)
0	123.9	726.0	34.2	3101.5	33.8
0 + Tilt	121.3	708.6	35.0	3342.2	34.7
500	123.5	726.4	33.1	2973.9	34.2
4000	124.1	723.8	32.1	3023.8	33.2
8000	117.3	702.0	31.2	2909.6	33.4
$LSD_{0.05}$=	1.9	65.1	3.4	178.8	0.8

[1] Data are the mean of six replicates.

Table 10. Effect of infested wheat residue levels on growth and yield of Katepwa wheat in 1993[1].

Residue treatment (kg ha^{-1})	Height (cm)	Heads m^{-2}	Seeds $head^{-1}$	Yield (g $plot^{-1}$)	1000 kernel weight (g)
0	105.7	743.8	20.3	1363.7	29.5
0 + Tilt	104.4	734.6	22.7	1514.0	31.9
500	105.3	720.8	20.0	1251.3	29.3
500 + Tilt	105.6	695.8	21.0	1481.2	30.6
4000	104.6	708.8	17.5	1091.1	28.3
4000 + Tilt	105.1	745.8	18.1	1162.6	29.1
8000	98.8	675.8	13.6	871.3	28.2
8000 + Tilt	100.6	669.0	15.0	993.3	28.3
$LSD_{0.05}$=	2.8	54.9	3.9	142.8	2.0

[1] Data are the mean of six replicates.

caused a significant yield advantage when little (500 kg ha^{-1}) or no infested residues were applied. Yield differences when Tilt was applied to the 4000 or 8000 kg ha^{-1} treatments were not significant.

Thousand kernel weight was highest in the absence of infested residues and tended to decrease with increased residue levels (Table 10). Disease control achieved by Tilt application resulted in a significant increase in kernel weight in plots to which wheat residues were not added.

In 1993, correlation between yield and disease severity was evident at Zadoks growth stage 22-23 (tillering) and again at Zadoks growth stage 70-75 (watery ripe) (Table 11). Disease severity was correlated with 1000 kernel weight at Zadoks growth stage 22-23 and again after the crop reached Zadoks growth stage 65 (mid-flowering). Over the entire growing season, yield and 1000 kernel weight were correlated with disease severity. Yield was correlated with AUDPC values after the crop reached Zadoks growth stage 70 (Table 12). Correlation between total AUDPC levels and 1000 kernel weight was inconsistent. When correlation between total AUDPC and yield or 1000 kernel was tested, the results were not significant.

1994. In 1994, temperatures were warmer than in 1993 and 1992 with moderate levels of precipitation. Plant height in the 500 kg ha^{-1} treatment with Tilt applied decreased significantly compared to the 8000 kg ha^{-1} treatment (Table 13). The number of heads m^{-2} and number of seeds $head^{-1}$ were not significantly affected by infested residues or Tilt application, although the number of wheat heads m^{-2} tended to decrease with Tilt application. The number of seed $head^{-1}$ were unaffected by residue treatment or Tilt

Table 11. Correlation (r) of yield and 1000 kernel weight of infested wheat residue treatments with disease severity during 1993.

Zadoks growth stage	Correlation coefficient (r)	
	Yield	1000 kernel weight
22-23	-0.25**	-0.19*
31-32	-0.10	-0.04
50-55	-0.09	0.02
60-65	0.08	-0.04
65-70	-0.10	-0.26**
70-75	-0.36**	-0.29**
73-77	-0.15	-0.19*
Over all growth stages	-0.08*	-0.08*

* $LSD_{0.05}$
** $LSD_{0.01}$

Table 12. Correlation (r) of yield and 1000 kernel weight of infested wheat residue treatments with AUDPC[1] during 1993.

Zadoks growth stage	Correlation coefficient (r)	
	Yield	1000 kernel weight
31-32	-0.09	-0.07
50-55	-0.02	-0.04
60-65	-0.04	-0.03
65-70	-0.08	-0.24*
70-75	-0.31**	-0.19
73-77	-0.24**	-0.24*
Over all growth stages	-0.05	-0.06

[1] Area Under the Disease Progress Curve
* $LSD_{0.05}$
** $LSD_{0.01}$

Table 13. Effect of infested wheat residue levels on growth and yield of Katepwa wheat in 1994[1].

Residue treatment (kg ha^{-1})	Height (cm)	Heads m^{-2}	Seeds $head^{-1}$	Yield (g $plot^{-1}$)	1000 kernel weight (g)
0	110.5	527.3	25.9	2227.5	36.5
0 + Tilt	110.0	495.3	26.7	2256.4	37.8
500	111.7	526.3	27.3	2143.7	34.9
500 + Tilt	108.3	490.0	28.5	2338.0	36.4
4000	110.3	516.0	25.4	2173.1	34.3
4000 + Tilt	110.5	484.7	25.7	2186.5	36.9
8000	111.6	529.2	24.7	1932.0	34.3
8000 + Tilt	112.9	520.3	23.3	2147.1	35.8
$LSD_{0.05}$=	3.5	45.3	5.8	196.4	1.5

[1] Data are the mean of six replicates.

application.

Yield was significantly lower in the 8000 kg ha^{-1} treatment without Tilt applied than in all other treatments (Table 13). Yield tended to decrease when infested residue level increased. Increasing the level of infested residues also tended to reduce 1000 kernel weight. Thousand kernel weight increased significantly when Tilt was applied to 500, 4000 and 8000 kg ha^{-1} treatments.

5.5 Discussion. In this experiment, *P. nodorum* and *P. tritici-repentis* were present at similar levels in all three years. Low levels (0 or 500 kg ha^{-1}) of infested crop residues resulted in disease levels similar to those observed under heavy residues (8000 kg ha^{-1}). The 4000 kg ha^{-1} treatment is probably most representative of the residue levels that could be found in Manitoba in direct seeded fields where residues were not removed. Interplot interference may, in part, account for the similar disease levels observed when different levels of infested wheat residues were implemented. Although plots were 2 m wide and separated by only 2 m, a 90% reduction in AUDPC of tan spot occurs within 3.6 to 5.4 m from the source of inoculum (Sone et al. 1994). Both tan spot and septoria leaf spots were observed in all three years. In most cases conidia of *P. tritici-repentis* would be dispersed further by wind than secondary inoculum of *Septoria spp.* which are splash dispersed. Early in the growing season, lesions are generally restricted to the lower crop canopy. Inoculum reaches the top of the canopy late in the growing season and would not be distributed above the crop until late in the growing season. Another cause of interference in the residue experiment was the movement of infested residues to adjacent

plots. Minimal ground cover caused a few pieces of infested residues to be displaced by wind to adjacent plots. These few pieces of infested residues were sufficient to cause significant levels of disease severity under optimum environmental conditions. Periodic flooding in 1993 and 1994 may have also contributed to movement of infested residues from adjacent plots. In 1993, about 30 cm of water was present in wheat residue plots for a period of three to four days. Flooding also prevented timely application of Tilt to plots and added additional stress to the crop. Fusarium head blight was present in many Manitoba wheat field at moderate to severe levels in 1993. However, we estimated that only a very low percentage (<1%) of heads in our plots showed evidence of fusarium head blight.

In all three years, leaf spot diseases did not have a significant influence on crop development until late in the growing season. While seeds head^{-1}, plant height and heads m^{-2} were generally not reduced by leaf spot diseases, 1000 kernel weight sometimes decreased. Yield and 1000 kernel weight reductions were most evident when leaf spot diseases were moderate (30%) to severe (60%) on the flag leaf and after wheat heads emerged. Similarly, Rees & Platz (1983) found that 75% of yield losses attributed to leaf spot diseases were a result of infections after jointing. Although Shabeer & Bockus (1988) reported that half of the total yield loss occurred prior to the boot stage, they also indicated that single inoculations caused the most damage at the boot and flowering stages. Our data suggest that late infections, after flag leaf emergence, are generally the most significant in leaf spot epidemic development. Although primary inoculum may influence disease progress, the effects may not be evident until late in the season.

Increasing the level of infested residues did not result in a corresponding increase in severity of leaf spot diseases. However, it does appear that even a small amount of infested residues has the ability to cause moderate disease levels. Further research will be required to determine the conditions required for small amounts of infested residues to initiate severe leaf spot epidemics.

6. GENERAL DISCUSSION.

From these studies, it was evident that using Tilt fungicide was an effective method of evaluating the influence of different tillage and residue treatments on leaf spot disease development. It allowed us to simulate 'disease-free' conditions and estimate the effects disease pressure had on crop development. The drawback to this method is that fungicides generally do not provide 100% control and, therefore, permit the production of inoculum. Application schedules must be strict to ensure that disease levels are kept at the lowest possible level. The use of at least two cultivars, one resistant and the other susceptible to leaf spot diseases, could be a more efficient and realistic means of evaluating tillage practices. Growing a resistant cultivar would be feasible for wheat growers, whereas, applying fungicide to wheat several times during a growing season would be too costly.

The challenge in designing field experiments involving leaf spot diseases is to maintain the integrity of each treatment while determining an appropriate method of evaluation. In this case, we evaluated tillage practices and infested residue levels by applying fungicide every 14-21 days throughout the growing season. We attempted to maintain the integrity of each treatment by providing adequate separation of plots so that interplot interference would be minimized. Although research indicates (Sone et al. 1994) that movement of tan spot is limited to a few metres, movement of residues can inevitably create additional problems. A plot size of 4 m by 7 m in the final two years of the tillage study seemed sufficient for a small plot experiment. Maneuvering tillage equipment in and between plots may require larger plot sizes in future studies to prevent spread of

infested residues and maintain consistent tillage treatments in all replicates. In contrast, studying the influence of infested wheat residues probably dictates the use of small plots due to the volume of residues required. Increasing the distance between plots and replicates to at least 5 m may be necessary to reduce interplot interference. Extensive tillage around plots prior to seeding or careful removal of crop residues could also reduce movement of residues or inoculum between plots. We attempted to minimize inoculum from adjacent plots by planting oat buffers. This was useful because oats are not a host of *P. tritici-repentis* and still permit the use of broadleaf herbicides, normally used on wheat, for weed control. It is also a crop tall enough to prevent movement of some inoculum over it. A potential disadvantage of oats are their susceptibility to *L. avenaria.* In the future, the use of herbicide tolerant crops such as bromoxynil resistant canola may provide another method of limiting interplot interference.

One of the limitations of the results of the field studies conducted are their short term nature. In 1992, summer temperatures in Manitoba were equal to some of the coolest on record (Appendix) and in 1993 heavy rainfall events caused extensive flooding. In 1993 and 1994 in western Manitoba, moderate to high disease levels were observed and *M. graminicola* was the dominant pathogen. Previous reports (Tekauz 1976, Gilbert et al. 1993) suggested that *M. graminicola* has not historically been a major leaf spotting pathogen in Manitoba. Higher incidence of *M. graminicola* than in past years (Gilbert et al. 1993) may be temporary due to weather. However, an increase in aggressiveness or a permanent change in the genetic makeup of the pathogen population, may result in a long term increase in the incidence of *M. graminicola.* Such a change would have

implications for wheat breeding and pathology programs. It is also apparent from our 1993 data that wheat production could be devastated in a wet year.

Abnormal weather conditions in 1992 and 1993 also contributed to variable results in the infested residue experiment. Results obtained in all years indicated that small amounts of infested residue can cause disease levels similar to higher residue levels. Considering that the highest level of infested wheat residues (8000 kg ha^{-1}) is about double what could be expected in a field in Manitoba, the increase in prevalence of leaf spot diseases in Manitoba in the last two decades may not be related to an increase in conservation tillage alone. However, further research is required to ensure that our results were not only a consequence of the extreme conditions experienced in 1992 and 1993.

Colour video image analysis was an effective method of measuring disease severity of leaf spot diseases. Although differentiation between symptoms of different pathogens is not possible, quantification of disease is fast and accurate. Measurement does not exclude senescent tissue so that leaves that have suffered mechanical damage or have dried must be discarded or trimmed accordingly. In contrast to subjective visual rating based on disease rating keys, image analysis provides consistent results that do not depend on the expertise of the individual evaluating disease symptoms. However, technical staff must still be trained in proper leaf sampling techniques and the use of the computer software. In our experiments, leaves were either dried or refrigerated after collection. Refrigeration was effective when disease symptoms on wheat leaves could be measured within two or three days. Otherwise, wilting and discolouration occasionally resulted in difficulty conducting measurements or a few leaves being discarded. Drying

leaves was effective when they were placed flat in unsealed paper envelopes and dried within 24 hours over a fan.

The interactions between tillage practices, leaf spot pathogens and the environment are not clearly understood. Our study in a controlled environment indicates that an uninterrupted period of leaf wetness of at least 6 h is required for the infection process of *P. tritici-repentis* to progress. However, the duration of leaf wetness required under different temperature regimes is not known. Alternate wetting and drying of leaves often occurs in a wheat field. The duration of the dry period can vary from a few hours in periods of wet weather to several days after a thunderstorm. In our study, a six hour dry period was chosen as a starting point, as the objective was simply to demonstrate the irreversible disruption of the infection process and to determine the most critical stage in the infection process of *P. tritici-repentis* on wheat. Further research is needed to evaluate the effect of a shorter and longer interruption of a wet period on tan spot development. In 1993, long uninterrupted wetness periods occurred during July, but development of tan spot symptoms was slow in comparison to septoria leaf spots. In the context of field experiments it is evident that the entire leaf spot complex must be considered rather than focusing on an individual pathogen. Year to year variation in weather conditions may dictate which pathogens are predominant. Extensive research will be required to adequately develop an epidemiological model describing these complex interactions.

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8.0 APPENDIX

Clearing and Staining Solution for Microscopic Observation of *P. tritici-repentis*

300 ml ethanol (95%)

150 ml chloroform

130 ml lactic acid (85%)

165 ml phenol (90%)

450 g chloral hydrate

0.6 g aniline blue

Source: Bruzzese, E. and S. Hasan. 1983. A whole leaf clearing and staining technique for host specificity studies of rust fungi. Plant Pathol. 32: 335-338.

Cereal Grain Development Stages By Zadoks, Feekes And Haun

Zadoks Scale	Feekes Scale	Haun Scale	Description
			Germination
00			Dry seed
01			Start of imbibition
03			Imbibition complete
05			Radicle emerged from seed
07			Coleoptile emerged from seed
09		0.0	Leaf just at coleoptile tip
			Seedling growth
10	1		First leaf through coleoptile
11		1.÷	First leaf unfolded
12		1.÷	2 leaves unfolded
13		2.÷	3 leaves unfolded
14		3.÷	4 leaves unfolded
15		4.÷	5 leaves unfolded
16		5.÷	6 leaves unfolded
17		6.÷	7 leaves unfolded
18		7.÷	8 leaves unfolded
19			9 or more leaves unfolded
			Tillering
20			Main shoot only
21	2		Main shoot and 1 tiller
22			Main shoot and 2 tillers
23			Main shoot and 3 tillers
24			Main shoot and 4 tillers
25			Main shoot and 5 tillers
26	3		Main shoot and 6 tillers
27			Main shoot and 7 tillers
28			Main shoot and 8 tillers
29			Main shoot and 9 or more tillers
			Stem elongation
30	4-5		Pseudo stem erection
31	6		1st node detectable
32	7		2nd node detectable
33			3rd node detectable
34			4th node detectable
35			5th node detectable
36			6th node detectable
37	8		Flag leaf just visible
39	9		Flag leaf ligule/collar just visible

Zadoks Scale	Feekes Scale	Haun Scale	Description
			Booting
40			—
41		8-9	Flag leaf sheath extending
45	10	9.2	Boots just swollen
47			Flag leaf sheath opening
49		10.1	First awns visible
			Inflorescence Emergence
50	10.1	10.2	First spikelet of inflorescence visible
53	10.2		1/4 of inflorescence emerged
55	10.3	10.5	1/2 of inflorescence emerged
57	10.4	10.7	3/4 of inflorescence emerged
59	10.5	11.0	Emergence of inflorescence completed
			Anthesis
60	10.51	11.4	Beginning of anthesis
65		11.5	Anthesis half-way
69		11.6	Anthesis complete
			Milk development
70			—
71	10.54	12.1	Kernel watery ripe
73		13.0	Early milk
75	11.1		Medium milk
77			Late milk
			Dough development
80			—
83		14.0	Early dough
85	11.2		Soft dough
87		15.0	Hard dough
			Ripening
90			—
91	11.3		Kernel hard "(difficult to divide by thumbnail)
92	11.4	16.0	Kernel hard (can no longer be dented by thumbnail)
93			Kernel loosening in daytime
94			Overripe, straw dead and collapsing
95			Seed dormant
96			Viable seed giving 50% germination
97			Seed not dormant
98			Secondary dormancy induced
99			Secondary dormancy lost

**The Haun scale stages used in this example from boot through ripening are based on a seven-leaf plant.

May 1992

Day	Temperature (degrees celsius) Mean	Minimum	Maximum	Precipitation (mm)
1	14.4	6.0	20.1	0.0
2	5.3	1.5	7.8	0.0
3	5.1	-1.9	11.8	1.3
4	8.4	0.6	15.4	0.0
5	12.5	3.0	20.3	0.0
6	21.7	10.1	33.1	0.0
7	19.1	9.7	27.2	0.0
8	12.2	7.8	17.9	0.8
9	20.1	9.0	31.2	0.0
10	-	-	-	-
11	18.4	12.5	25.3	0.0
12	7.8	0.9	12.4	0.0
13	7.4	-0.8	14.8	0.0
14	12.7	7.3	19.4	2.8
15	12.6	4.9	19.6	0.0
16	10.1	8.1	12.8	4.1
17	11.7	3.0	19.6	0.0
18	18.4	9.2	26.2	0.0
19	25.2	16.3	35.5	0.0
20	26.5	17.2	33.2	0.0
21	19.7	6.2	26.4	0.8
22	4.4	1.9	7.6	2.3
23	5.3	0.1	10.9	0.0
24	6.8	1.7	11.3	0.0
25	10.4	0.3	18.6	0.0
26	12.7	6.9	18.6	0.0
27	15.2	3.4	24.2	0.0
28	18.6	9.3	25.0	0.0
29	21.1	13.0	30.6	0.0
30	18.4	13.1	26.7	2.3
31	20.2	12.4	29.0	0.0

Maximum Temperature	35.5
Minimum Temperature	-1.9
Mean Temperature	13.6
Total Precipitation(mm)	14.2

Weather data, Winnipeg, Manitoba

June 1992

Day	Temperature (degrees celsius) Mean	Minimum	Maximum	Precipitation (mm)
1	21.9	13.7	29.2	0.0
2	22.4	17.3	27.0	0.0
3	20.2	13.3	29.9	22.6
4	14.8	11.7	22.5	23.4
5	9.8	6.1	13.7	0.5
6	8.2	6.2	10.9	0.0
7	9.8	5.2	14.7	0.3
8	15.1	4.0	23.6	0.0
9	19.7	12.6	26.7	0.0
10	23.6	14.3	31.6	0.0
11	24.7	15.5	34.2	0.0
12	18.5	14.2	23.9	0.0
13	19.1	14.9	25.5	0.0
14	16.4	10.5	21.7	0.0
15	18.3	9.1	25.4	0.0
16	16.9	14.2	20.3	8.4
17	20.8	17.1	25.6	24.6
18	12.1	9.1	18.0	0.0
19	13.0	9.2	17.7	0.0
20	14.7	5.7	22.3	0.0
21	13.4	9.3	17.4	7.6
22	15.1	11.7	21.3	8.1
23	16.4	13.4	19.4	1.0
24	14.9	12.2	19.7	19.8
25	13.1	8.9	16.7	0.0
26	15.7	7.4	22.4	0.0
27	18.6	13.4	29.2	1.5
28	14.8	8.4	16.9	0.0
29	13.5	5.3	20.3	0.0
30	13.2	7.2	17.4	0.0

Maximum Temperature	34.2
Minimum Temperature	4.0
Mean Temperature	16.3
Total Precipitation(mm)	117.9

July 1992

	Temperature(degrees celsius)			
Day	Mean	Minimum	Maximum	Precipitation (mm)
1			15.2	11.7
2	14.6	13.5	16.1	9.7
3	14.0	12.5	15.6	26.4
4	14.9	11.8	18.9	0.0
5	17.2	9.9	23.4	0.0
6	16.1	12.4	19.8	0.8
7	21.1	15.1	27.7	0.3
8	19.8	16.1	23.7	3.3
9	17.5	14.2	21.4	0.0
10	16.0	10.4	21.8	0.0
11	16.3	9.5	23.4	1.8
12	18.5	12.2	24.8	0.0
13	20.3	13.5	27.3	0.0
14	20.7	15.7	26.0	29.7
15	19.6	14.8	23.7	0.0
16	18.1	12.6	24.4	0.0
17	17.3	12.5	23.1	0.0
18	18.2	13.0	24.2	0.0
19	16.8	13.5	19.2	10.2
20	15.6	10.6	21.0	0.0
21	17.5	10.3	24.5	0.0
22	18.6	9.3	25.6	0.0
23	20.3	11.4	26.7	0.0
24	17.9	14.3	20.3	0.0
25	19.8	13.9	24.0	6.9
26	15.4	11.9	21.3	0.0
27	15.9	10.2	20.7	10.9
28	15.6	11.2	21.0	0.5
29	17.1	9.7	24.3	0.0
30	18.8	11.4	25.7	0.0
31	19.8	13.8	27.4	0.8

Maximum Temperature	27.7
Minimum Temperature	9.3
Mean Temperature	17.5
Total Precipitation(mm)	112.8

August 1992

Day	Temperature(degrees celsius) Mean	Minimum	Maximum	Precipitation (mm)
1	19.5	14.9	24.1	0.0
2	17.8	13.4	22.9	0.0
3	16.0	10.7	22.6	0.0
4	18.8	11.0	24.9	0.0
5	18.9	12.0	25.1	0.0
6	20.7	13.6	27.6	0.0
7	21.4	15.9	26.8	0.0
8	24.7	16.8	32.6	1.5
9	23.2	15.5	28.5	13.7
10	18.0	13.4	24.3	0.0
11	14.3	11.2	16.1	4.6
12	14.8	8.3	21.5	0.0
13	18.2	10.3	26.1	0.0
14	20.4	11.2	28.7	0.0
15	20.5	14.0	26.6	0.0
16	22.0	15.5	28.9	0.0
17	18.7	14.1	24.3	9.9
18	19.1	10.6	27.8	0.0
19	20.2	11.0	27.6	0.0
20	19.7	14.0	25.9	5.3
21	16.8	11.6	23.6	0.0
22	19.4	13.9	26.5	7.1
23	13.8	10.8	17.1	7.4
24	11.3	10.1	13.1	0.3
25	12.8	8.4	17.4	0.5
26	13.7	5.0	21.2	0.0
27	-	-	-	-
28	-	-	-	-
29	14.1	11.4	16.8	30.7
30	13.3	11.2	14.7	2.8
31	12.2	9.5	15.8	0.0

Maximum Temperature	32.6
Minimum Temperature	5.0
Mean Temperature	16.6
Total Precipitation(mm)	83.8

September 1992

Day	Temperature(degrees celsius) Mean	Minimum	Maximum	Precipitation (mm)
1	13.5	6.1	19.3	0.0
2	16.3	10.5	20.9	5.6
3	13.2	5.9	19.6	0.0
4	17.3	12.3	23.1	0.0
5	14.9	7.2	24.3	14.2
6	9.2	5.0	13.9	0.8
7	9.6	5.4	13.4	0.0
8	10.3	1.8	19.1	0.0
9	11.0	9.9	12.6	35.3
10	11.6	6.4	17.5	0.0
11	14.7	8.0	24.1	0.0
12	15.5	7.0	22.4	1.0
13	17.8	11.0	22.1	3.8
14	11.9	6.9	17.2	0.0
15	13.0	6.5	22.1	2.8
16	9.9	5.3	13.6	0.0
17	7.2	1.9	12.6	20.3
18	7.6	2.6	11.1	0.3
19	11.1	1.5	19.8	0.0
20	16.2	9.0	24.5	0.0
21	9.9	3.3	14.6	0.0
22	5.5	-1.9	12.4	0.0
23	12.8	4.2	21.1	0.0
24	20.0	14.3	26.0	0.0
25	17.4	13.3	22.8	0.8
26	10.3	5.6	14.4	0.0
27	3.5	-0.0	8.1	4.1
28	5.1	-1.6	12.0	0.0
29	9.8	1.5	19.9	0.0
30	12.4	2.8	25.1	0.0

Maximum Temperature	26.0
Minimum Temperature	-1.9
Mean Temperature	11.9
Total Precipitation(mm)	88.9

May 1993

Day	Temperature (degrees celsius) Mean	Minimum	Maximum	Precipitation (mm)
1	5.6	-0.3	9.3	0.0
2	7.8	-0.8	15.9	0.0
3	12.8	4.5	23.1	0.0
4	14.7	3.0	25.3	0.0
5	18.3	10.3	27.3	0.0
6	21.0	9.6	30.0	0.0
7	18.4	13.5	23.8	20.8
8	18.1	15.0	22.6	16.0
9	15.1	10.5	19.0	3.0
10	17.0	8.6	25.5	0.0
11	20.3	12.2	29.6	0.0
12	15.5	10.5	22.2	0.0
13	18.4	10.8	27.4	0.0
14	9.4	4.2	14.2	0.0
15	4.6	1.2	9.6	0.0
16	7.2	-0.1	13.1	0.0
17	7.4	4.8	11.6	0.0
18	7.2	2.2	10.8	0.0
19	9.3	5.6	13.0	0.0
20	11.0	4.3	16.7	0.0
21	11.8	-0.8	21.0	0.0
22	18.3	11.4	29.2	0.3
23	12.8	10.6	14.2	0.0
24	11.9	6.8	16.4	0.0
25	8.8	4.5	13.7	1.0
26	8.6	-1.0	15.9	0.0
27	9.6	8.0	12.3	0.8
28	12.7	4.3	20.0	0.0
29	12.5	6.0	16.7	1.3
30	11.3	5.1	16.1	0.8
31	11.5	6.0	16.0	0.0

Maximum Temperature	30.0
Minimum Temperature	-1.0
Mean Temperature	12.5
Total Precipitation(mm)	43.9

Weather data, Winnipeg, MB

June 1993

	Temperature (degrees celsius)			
Day	Mean	Minimum	Maximum	Precipitation (mm)
1	12.0	4.9	18.2	0.0
2	11.6	4.3	16.6	0.0
3	13.6	5.7	19.6	0.0
4	15.4	4.8	23.6	0.0
5	17.7	10.8	24.2	1.0
6	14.9	11.4	20.0	0.0
7	15.0	7.1	21.7	1.3
8	15.1	12.1	18.7	27.7
9	18.7	14.6	24.8	1.0
10	19.9	11.6	28.9	9.1
11	23.8	16.2	30.4	0.0
12	24.3	18.4	29.9	7.6
13	18.4	14.4	21.7	3.0
14	11.6	8.4	14.3	0.5
15	14.9	6.5	22.2	0.0
16	12.7	11.5	13.5	5.1
17	15.2	8.9	20.4	0.0
18	17.4	7.9	24.6	0.0
19	19.3	9.6	25.7	0.0
20	22.3	13.2	30.6	1.0
21	23.0	17.7	28.0	1.8
22	22.2	15.9	30.7	20.1
23	21.0	16.6	27.4	5.1
24	16.3	12.7	20.8	8.4
25	13.1	11.4	16.1	3.3
26	11.7	10.0	13.8	0.0
27	10.7	9.0	13.0	0.0
28	12.5	10.0	15.5	0.0
29	15.3	10.3	19.7	0.0
30	14.7	12.3	16.9	15.8

Maximum Temperature	30.7
Minimum Temperature	4.3
Mean Temperature	16.5
Total Precipitation(mm)	11.8

July 1993

Day	Temperature (degrees celsius) Mean	Minimum	Maximum	Precipitation (mm)
1	18.5	13.2	24.3	1.8
2	20.2	14.4	26.5	0.0
3	20.3	15.8	25.8	5.1
4	20.5	17.2	25.7	4.3
5	17.0	13.5	19.3	1.3
6	12.7	11.0	14.3	5.1
7	16.9	14.1	20.0	0.0
8	17.5	12.4	23.6	0.0
9	18.6	11.7	26.3	1.3
10	17.1	12.7	22.0	0.0
11	14.1	9.1	18.1	0.0
12	15.5	11.1	19.8	0.3
13	14.9	9.8	18.8	0.0
14	17.1	10.7	24.3	0.0
15	16.4	9.5	24.1	10.9
16	19.0	15.6	23.6	3.8
17	21.6	18.1	26.0	4.3
18	19.5	14.4	27.2	37.3
19	16.9	13.8	21.1	0.3
20	16.2	12.2	21.6	0.0
21	18.4	10.8	26.4	0.0
22	20.0	17.2	25.3	12.5
23	19.0	16.5	23.3	5.8
24	22.2	18.8	27.4	104.9
25	21.7	20.7	22.7	75.7
26	20.8	17.5	24.7	10.2
27	18.6	16.9	20.1	20.3
28	19.1	15.8	23.7	2.5
29	22.9	14.8	29.6	0.0
30	23.5	17.6	28.7	0.0
31	21.5	14.1	27.5	0.0

Maximum Temperature	29.6
Minimum Temperature	9.1
Mean Temperature	18.6
Total Precipitation(mm)	307.6

August 1993

Day	Temperature (degrees celsius) Mean	Minimum	Maximum	Precipitation (mm)
1	17.3	15.1	20.1	0.8
2	15.1	12.0	19.0	4.8
3	15.2	10.6	19.8	1.0
4	14.8	11.5	18.6	5.1
5	16.0	11.1	21.3	0.0
6	18.0	10.0	25.1	0.0
7	19.7	12.3	26.1	0.0
8	21.4	15.0	28.3	61.5
9	24.3	19.1	29.1	0.8
10	25.2	17.1	33.0	0.0
11	24.0	20.2	30.2	1.8
12	17.5	13.1	20.3	21.3
13	17.9	10.4	25.2	0.0
14	18.9	14.8	26.4	95.5
15	18.5	15.1	21.0	0.0
16	20.2	14.0	27.3	0.0
17	19.0	14.9	24.9	21.1
18	19.2	13.2	24.9	1.0
19	18.2	14.8	22.6	5.1
20	19.0	13.4	25.8	0.0
21	21.2	14.8	28.4	0.0
22	22.1	19.1	26.5	1.8
23	21.8	19.6	25.8	6.4
24	23.4	17.6	30.0	0.0
25	19.8	15.7	24.5	3.8
26	18.3	15.2	21.5	0.0
27	16.3	13.5	20.1	16.3
28	16.1	12.1	25.0	12.7
29	15.0	12.2	17.7	1.3
30	14.4	10.5	19.4	4.1
31	14.3	5.8	22.7	0.0

Maximum Temperature	33.0
Minimum Temperature	5.8
Mean Temperature	18.8
Total Precipitation(mm)	265.9

September 1993

Day	Temperature (degrees celsius) Mean	Minimum	Maximum	Precipitation (mm)
1	15.3	11.5	18.3	1.3
2	12.8	8.0	15.6	2.3
3	15.5	8.2	25.5	9.4
4	11.3	7.7	14.2	1.3
5	11.1	7.9	16.1	2.8
6	11.5	4.7	18.3	0.0
7	12.8	7.3	19.7	0.0
8	15.6	11.1	20.3	8.9
9	12.8	8.2	15.4	0.0
10	10.3	4.0	16.4	0.0
11	15.0	6.5	23.9	0.0
12	11.6	5.2	15.5	2.8
13	5.7	4.0	7.7	2.3
14	-	-	-	-
15	-	-	14.1	0.0
16	10.2	7.2	14.8	1.0
17	9.6	1.9	18.5	0.0
18	10.1	4.1	17.5	0.0
19	11.6	3.5	21.2	0.0
20	12.2	6.4	20.1	0.0
21	12.8	9.6	16.7	4.3
22	10.3	5.2	14.4	1.3
23	11.8	4.5	21.1	0.0
24	14.0	6.5	23.2	0.0
25	14.3	7.6	22.5	0.0
26	7.5	2.8	13.4	0.8
27	8.8	2.7	15.8	0.0
28	5.5	1.5	8.3	0.0
29	6.2	-0.2	13.5	0.0
30	10.5	5.4	17.7	1.5

Maximum Temperature	25.5
Minimum Temperature	-0.2
Mean Temperature	10.6
Total Precipitation(mm)	39.9

Environment Canada / Environnement Canada
Atmospheric Environment Service / Service de l'environnement atmosphérique

MINNEDOSA, MB

AES National Headquarters Identification: 5011760
Regional Identification: 5340M

May, 1993

Day	TEMPERATURE (Degrees Celsius) Maximum	Minimum	Mean	PRECIPITATION Rain (mm)	Snow (cm)	Total (mm)	DAY WITH Thund.	Frz Rn	Hail	SNOW ON GND (cm)	RMKS
1	14.0	-4.0	5.0							0	
2	16.5	-4.0	6.3	1.0		1.0				0	
3	21.0	3.0	12.0	4.0		4.0				0	
4	21.0	4.0	12.5				X			0	
5	24.5	4.0	14.3							0	
6	26.0	5.0	15.5							0	X
7	16.0	10.0	13.0	7.8		7.8				0	
8	19.0	7.0	13.0	4.0		4.0	X			0	
9	17.0	9.0	13.0	15.0		15.0				0	
10	24.0	1.0	12.5							0	
11	29.0	4.0	16.5							0	X
12	28.0	5.0	16.5							0	
13	26.0	5.0	15.5							0	
14	10.0	2.0	6.0							0	
15	11.0	-0.5	5.3							0	
16	14.0	-3.0	5.5	T		T				0	
17	14.0	-1.0	6.5	T		T				0	
18	10.0	-1.0	4.5	T		T				0	
19	12.0	-2.0	5.0							0	
20	17.0	2.0	9.5							0	
21	23.0	-3.0	10.0							0	
22	24.0	6.0	15.0							0	
23	12.0	8.0	10.0							0	
24	14.0	5.0	9.5							0	
25	12.0	2.0	7.0	1.0		1.0				0	
26	15.0	-5.0	5.0	2.0		2.0				0	
27	9.0	3.0	6.0	5.8		5.8				0	
28	16.0	-1.0	7.5							0	
29	15.5	2.0	8.8							0	
30	15.0	0.5	7.8	4.0		4.0				0	
31	15.0	0.0	7.5							0	
TOTAL	540.5	63.0		44.6	0.0	44.6	2				
MEAN	17.4	2.0	9.7								

Monthly Maximum Temperature: **29.0** on Day: **11**
Monthly Minimum Temperature: **-5.0** on Day: **26**
Highest Rainfall: **15.0** on Day: **9**
Highest Snowfall: **0.0**
Highest TOTAL Precipitation: **15.0** on Day: **9**

Heating Degree-Days: **256.0** (Base 18°)
Cooling Degree-Days: (Base 18°)
Growing Degree-Days: **147.5** (Base 5°)
Corn Heat Units: **49.3** (Base 10°)
Freezing Degree-Days: (Base 0°)
Thawing Degree-Days: **302.0** (Base 0°)

Abbreviations: Thund. - Thunder; Frz Rn - Freezing Rain; SNOW ON GND - Depth of Snow on Ground; RMKS - Remarks Recorded

Codes Which May Appear:
A - Value Accumulated over more than 1 day
L - Precipitation Uncertain
N - Missing Temperature ABOVE Freezing
+ - Extreme Value Occurred Also Later in Month
M - Missing Value
F - Value Accumulated and Estimated
T - Trace of Precipitation
X - "occurred" or "exists"
E - Estimated Value
C - Precipitation Occurred, Amount Unknown
Y - Missing Temperature BELOW Freezing
I - Incomplete Data

Environment Canada / Environnement Canada
Atmospheric Environment Service / Service de l'environnement atmosphérique

MINNEDOSA, MB

AES National Headquarters Identification: 5011760
Regional Identification: 5340M

June, 1993

Day	TEMPERATURE (Degrees Celsius) Maximum	Minimum	Mean	PRECIPITATION Rain (mm)	Snow (cm)	Total (mm)	DAY WITH Thund.	Frz Rn	Hail	SNOW ON GND (cm)	RMKS
1	17.5	0.5	9.0	T		T				0	
2	14.5	1.5	8.0	T		T				0	X
3	17.0	0.0	8.5							0	X
4	21.0	2.0	11.5							0	X
5	23.0	5.0	14.0							0	X
6	17.5	5.0	11.3							0	X
7	18.0	1.0	9.5	5.6		5.6				0	
8	16.5	9.5	13.0							0	
9	25.0	10.0	17.5	T		T				0	
10	27.0	11.0	19.0							0	
11	29.5	8.0	18.8	2.8		2.8	X		X	0	
12	27.0	16.0E	21.5E	18.0		18.0	X		X	0	
13	17.5	8.0	12.8	T		T				0	X
14	19.0E	7.0	13.0E							0	X
15	21.0	7.0	14.0							0	X
16	13.0	9.5	11.3	6.0		6.0				0	
17	20.0	3.0	11.5							0	
18	23.0	6.0E	14.5E							0	
19	24.0	5.0	14.5							0	
20	32.0	11.0	21.5	3.0		3.0	X			0	X
21	25.0	14.5E	19.8E							0	X
22	28.0	15.0	21.5	16.8		16.8	X			0	
23	20.0	8.5	14.3	8.8		8.8				0	
24	16.5	8.0	12.3	3.0		3.0				0	
25	14.0E	8.0	11.0E	T		T				0	
26	12.0	7.5	9.8	T		T				0	X
27	12.0	6.0	9.0							0	
28	13.0	6.5	9.8							0	X
29	13.0	9.0	11.0	M		M				0	
30	20.0	11.0	15.5	M		M				0	X
TOTAL	596.5E	220.0E		I	0.0	I	4		2		
MEAN	19.9E	7.3E	13.6E								

Monthly Maximum Temperature: **32.0** on Day: **20**
Monthly Minimum Temperature: **0.0** on Day: **3**
Highest Rainfall: **I**
Highest Snowfall: **0.0**
Highest TOTAL Precipitation: **I**

Heating Degree-Days: **145.4E** (Base 18°)
Cooling Degree-Days: **14.1E** (Base 18°)
Growing Degree-Days: **258.7E** (Base 5°)
Corn Heat Units: **115.1E** (Base 10°)
Freezing Degree-Days: (Base 0°)
Thawing Degree-Days: **408.7E** (Base 0°)

Abbreviations: Thund. - Thunder Frz Rn - Freezing Rain SNOW ON GND - Depth of Snow on Ground RMKS - Remarks Recorded

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Environment Canada / Environnement Canada
Atmospheric Environment Service / Service de l'environnement atmosphérique

MINNEDOSA, MB

AES National Headquarters Identification: 5011760
Regional Identification: 5340M

July, 1993

Day	TEMPERATURE (Degrees Celsius) Maximum	Minimum	Mean	PRECIPITATION Rain (mm)	Snow (cm)	Total (mm)	DAY WITH Thund.	Frz Rn	Hail	SNOW ON GND (cm)	RMKS
1	22.0	11.0	16.5	1.4		1.4				0	X
2	25.0	9.0	17.0	40.0		40.0	X			0	X
3	19.0	11.0	15.0	41.0		41.0	X			0	X
4	21.0	14.0	17.5	11.0		11.0				0	
5	18.0	15.0	16.5	6.2		6.2				0	
6	14.0	9.0	11.5	1.0		1.0				0	X
7	24.0E	3.0	13.5E							0	
8	21.0	6.0	13.5							0	
9	22.0	8.0	15.0							0	X
10	18.0	8.0	13.0							0	X
11	15.0	7.0	11.0							0	X
12	19.0	8.0	13.5							0	X
13	17.0	5.0	11.0	1.0		1.0				0	X
14	20.0	6.0	13.0							0	X
15	17.0	6.0	11.5	5.0		5.0				0	X
16	17.5	12.0	14.8	4.0		4.0				0	X
17	22.0	11.0	16.5				X			0	
18	22.0	9.0	15.5	14.6		14.6				0	X
19	20.0	10.0	15.0				X			0	X
20	20.0	6.0	13.0							0	
21	19.0	6.0	12.5	16.0		16.0				0	X
22	18.0	11.0	14.5	2.6		2.6				0	X
23	22.0	14.0	18.0							0	X
24	24.0	8.0	16.0							0	X
25	22.0	N								0	X
26	25.0	16.0	20.5							0	X
27	18.0	15.0	16.5	29.0		29.0				0	X
28	24.0	13.0	18.5							0	
29	27.0	10.0	18.5							0	X
30	25.5	14.0	19.8							0	X
31	25.0	8.0	16.5							0	X
TOTAL	643.0E	289.0E		172.8	0.0	172.8	4				
MEAN	20.7E	9.6E	15.2E								

Monthly Maximum Temperature: **27.0** on Day: **29**
Monthly Minimum Temperature: **3.0** on Day: **7**
Highest Rainfall: **41.0** on Day: **3**
Highest Snowfall: **0.0**
Highest TOTAL Precipitation: **41.0** on Day: **3**

Heating Degree-Days: **90.2E** (Base 18°)
Cooling Degree-Days: **5.6E** (Base 18°)
Growing Degree-Days: **318.4E** (Base 5°)
Corn Heat Units: **163.4E** (Base 10°)
Freezing Degree-Days: (Base 0°)
Thawing Degree-Days: **473.4E** (Base 0°)

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Atmospheric Environment Service / Service de l'environnement atmosphérique

MINNEDOSA, MB

AES National Headquarters Identification: 5011760
Regional Identification: 5340M

August, 1993

Day	TEMPERATURE (Degrees Celsius) Maximum	Minimum	Mean	PRECIPITATION Rain (mm)	Snow (cm)	Total (mm)	DAY WITH Thund.	Frz Rn	Hail	SNOW ON GND (cm)	RMKS
1	20.0E	12.0	16.0E							0	
2	18.0	10.0	14.0	3.0		3.0				0	
3	19.0	8.0	13.5	T		T				0	X
4	20.0	9.0	14.5	2.0		2.0				0	X
5	19.0	9.0	14.0							0	
6	22.0	6.0	14.0							0	X
7	23.0	6.0	14.5							0	X
8	23.0	11.0	17.0	28.2		28.2				0	X
9	30.0	12.0	21.0				X			0	X
10	32.0E	13.0	22.5E							0	
11	27.0	15.0	21.0	6.6		6.6				0	
12	19.0	9.0	14.0							0	X
13	21.0	7.0	14.0	8.6		8.6				0	X
14	19.0	12.0E	15.5E				X			0	X
15	20.0	11.0	15.5							0	X
16	23.0	9.0	16.0	6.4		6.4				0	
17	24.0	12.0	18.0	2.0		2.0	X			0	X
18	21.0	10.0	15.5	2.0		2.0				0	X
19	23.0	11.0	17.0							0	X
20	25.0	8.0	16.5							0	
21	25.0	10.0	17.5	3.4		3.4				0	
22	21.0	19.0	20.0	9.2		9.2	X			0	X
23	24.0	16.0	20.0				X			0	
24	27.0E	12.5	19.8E	2.0		2.0				0	
25	25.0	11.0	18.0				X			0	
26	23.0	7.0	15.0	5.2		5.2				0	
27	20.0	8.0	14.0	2.8		2.8				0	
28	18.0	12.0	15.0	6.8		6.8				0	
29	14.0	8.0	11.0	1.4		1.4	X			0	
30	16.0	7.0	11.5	1.4		1.4				0	
31	20.0	2.0	11.0	2.0		2.0	X			0	X
TOTAL	681.0E	312.5E		93.0	0.0	93.0	8				
MEAN	22.0E	10.1E	16.1E								

Monthly Maximum Temperature: **32.0E** on Day: **10**
Monthly Minimum Temperature: **2.0** on Day: **31**
Highest Rainfall: **28.2** on Day: **8**
Highest Snowfall: **0.0**
Highest TOTAL Precipitation: **28.2** on Day: **8**

Heating Degree-Days: **77.5E** (Base 18°)
Cooling Degree-Days: **16.3E** (Base 18°)
Growing Degree-Days: **341.8E** (Base 5°)
Corn Heat Units: **186.8E** (Base 10°)
Freezing Degree-Days: (Base 0°)
Thawing Degree-Days: **496.8E** (Base 0°)

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MINNEDOSA, MB

AES National Headquarters Identification: 5011760
Regional Identification: 5340M

September, 1993

Day	TEMPERATURE (Degrees Celsius) Maximum	Minimum	Mean	PRECIPITATION Rain (mm)	Snow (cm)	Total (mm)	DAY WITH Thund.	Frz Rn	Hail	SNOW ON GND (cm)	RMKS
1	18.0	8.0	13.0	8.0		8.0	X			0	
2	12.0	7.5	9.8	1.0		1.0	X			0	
3	21.0	6.0	13.5	1.4		1.4				0	X
4	13.0	4.0	8.5	T		T				0	
5	14.0	2.0	8.0	1.6		1.6				0	X
6	16.0	0.0	8.0	1.0		1.0				0	
7	18.0	1.0	9.5							0	X
8	22.0	7.0E	14.5E	1.4		1.4				0	
9	14.0	9.0	11.5	1.2		1.2				0	
10	16.0	-1.0	7.5							0	
11	23.0	1.0	12.0	1.2		1.2				0	
12	8.0	3.0E	5.5E	5.5		5.5	X			0	X
13	7.0	0.5	3.8							0	
14	11.0	-3.5	3.8							0	
15	11.0	0.0	5.5	T		T				0	X
16	13.0	4.0	8.5	1.0		1.0				0	
17	16.0	-2.0	7.0							0	X
18	17.0	1.0	9.0							0	X
19	17.0	0.0	8.5							0	X
20	20.0	1.0	10.5	1.0		1.0				0	X
21	8.5	2.0	5.3	15.0		15.0	X			0	X
22	13.0	2.5	7.8							0	
23	18.0	1.5	9.8							0	
24	20.0	1.0	10.5							0	X
25	15.0	2.0	8.5							0	X
26	8.0	3.0	5.5							0	X
27	15.0	2.0	8.5							0	X
28	8.0	0.0	4.0							0	
29	11.0	-5.5	2.8							0	
30	15.0	2.0E	8.5E							0	
TOTAL	438.5	59.0E		39.3	0.0	39.3	4				
MEAN	14.6	2.0E	8.3E								

Monthly Maximum Temperature: **23.0** on Day: **11**
Monthly Minimum Temperature: **-5.5** on Day: **29**
Highest Rainfall: **15.0** on Day: **21**
Highest Snowfall: **0.0**
Highest TOTAL Precipitation: **15.0** on Day: **21**

Heating Degree-Days: **290.9E** (Base 18°)
Cooling Degree-Days: (Base 18°)
Growing Degree-Days: **104.7E** (Base 5°)
Corn Heat Units: **15.5E** (Base 10°)
Freezing Degree-Days: (Base 0°)
Thawing Degree-Days: **249.1E** (Base 0°)

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MINNEDOSA, MB

AES National Headquarters Identification: 5011760
Regional Identification: 5340M

May, 1994

Day	TEMPERATURE (Degrees Celsius) Maximum	Minimum	Mean	PRECIPITATION Rain (mm)	Snow (cm)	Total (mm)	DAY WITH Thund.	Frz Rn	Hail	SNOW ON GND (cm)	RMKS
1	14.0	-7.0	3.5							0	
2	16.0	-4.0	6.0	1.0		1.0				0	X
3	18.5	0.0	9.3	T		T				0	X
4	10.0	-1.5	4.3							0	X
5	12.0	-6.0	3.0							0	X
6	16.0	-5.0	5.5							0	X
7	24.0	-1.0	11.5							0	X
8	16.5	6.0	11.3							0	X
9	17.5	0.0	8.8							0	X
10	23.0	-1.0	11.0							0	X
11	18.0	5.0	11.5							0	X
12	21.0	-3.0	9.0	0.5		0.5				0	
13	21.0	2.0	11.5							0	X
14	20.0	7.5	13.8							0	X
15	14.0	0.0	7.0							0	
16	13.5	2.0	7.8	1.0		1.0				0	
17	27.5	7.0	17.3	6.5		6.5				0	X
18	24.0	9.0	16.5				X			0	
19	14.0	9.0	11.5	8.0		8.0				0	
20	8.0	6.0	7.0	16.0		16.0	X		X	0	
21	17.0	4.0	10.5							0	
22	19.0	6.0	12.5	1.0		1.0				0	X
23	20.0	6.0	13.0	2.5		2.5				0	
24	18.0	4.0	11.0	22.0		22.0	X			0	X
25	17.0	6.0	11.5				X		X	0	X
26	19.0	-1.0	9.0							0	X
27	24.0	4.0	14.0							0	X
28	24.0	9.0	16.5	1.2		1.2				0	X
29	20.0	6.0	13.0	3.6		3.6				0	X
30	19.0	10.0	14.5	1.0		1.0				0	X
31	22.0	6.0	14.0							0	
TOTAL	567.5	85.0		64.3	0.0	64.3	4		2		
MEAN	18.3	2.7	10.5								

Monthly Maximum Temperature: 27.5 on Day: 17
Monthly Minimum Temperature: -7.0 on Day: 1
Highest Rainfall: 22.0 on Day: 24
Highest Snowfall: 0.0
Highest TOTAL Precipitation: 22.0 on Day: 24

Heating Degree-Days: 231.4 (Base 18°)
Cooling Degree-Days: (Base 18°)
Growing Degree-Days: 175.8 (Base 5°)
Corn Heat Units: 56.4 (Base 10°)
Freezing Degree-Days: (Base 0°)
Thawing Degree-Days: 326.6 (Base 0°)

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MINNEDOSA, MB

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June, 1994

Day	TEMPERATURE (Degrees Celsius) Maximum	Minimum	Mean	PRECIPITATION Rain (mm)	Snow (cm)	Total (mm)	DAY WITH Thund.	Frz Rn	Hail	SNOW ON GND (cm)	RMKS
1	20.0	3.0	11.5							0	
2	20.5	5.0	12.8	T		T				0	
3	22.0	10.0	16.0							0	X
4	25.0	10.0	17.5							0	X
5	22.5	10.0	16.3	17.0		17.0				0	
6	21.0	7.0	14.0				X		X	0	
7	19.0	11.0	15.0							0	X
8	20.0	4.0	12.0	T		T				0	X
9	17.0	7.0	12.0	7.0		7.0				0	X
10	16.0	11.0	13.5	6.8		6.8				0	
11	22.0	9.0	15.5	0.5		0.5				0	
12	22.5	7.0	14.8	T		T				0	
13	16.0	9.0	12.5	6.0		6.0				0	X
14	20.0	10.0	15.0	0.6		0.6				0	
15	17.5	8.0	12.8							0	
16	19.0	5.0	12.0	19.0		19.0				0	X
17	19.0	8.5	13.8	2.0		2.0	X		X	0	
18	19.0	3.0	11.0	2.8		2.8				0	
19	20.0	8.0	14.0	T		T	X		X	0	
20	24.0	13.0	18.5							0	
21	21.0	10.0	15.5	5.8		5.8				0	X
22	25.0	7.0	16.0				X			0	
23	28.0	8.0	18.0	3.4		3.4				0	
24	26.0	11.0	18.5	11.0		11.0	X			0	
25	20.0	14.0	17.0	7.8		7.8				0	
26	23.0	11.0	17.0	4.0		4.0				0	
27	21.5	14.0	17.8	2.8		2.8				0	
28	22.0	14.0	18.0							0	
29	16.0	8.5	12.3	10.0		10.0				0	
30	19.0	11.0	15.0	1.0		1.0	X			0	
TOTAL	623.5	267.0		107.5	0.0	107.5	6		3		
MEAN	20.8	8.9	14.9								

Monthly Maximum Temperature: **28.0** on Day: **23**
Monthly Minimum Temperature: **3.0** on Days: **1 18**
Highest Rainfall: **19.0** on Day: **16**
Highest Snowfall: **0.0**
Highest TOTAL Precipitation: **19.0** on Day: **16**

Heating Degree-Days: **95.4** (Base 18°)
Cooling Degree-Days: **1.0** (Base 18°)
Growing Degree-Days: **295.6** (Base 5°)
Corn Heat Units: **145.6** (Base 10°)
Freezing Degree-Days: (Base 0°)
Thawing Degree-Days: **445.6** (Base 0°)

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MINNEDOSA, MB

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July, 1994

Day	TEMPERATURE (Degrees Celsius) Maximum	Minimum	Mean	PRECIPITATION Rain (mm)	Snow (cm)	Total (mm)	DAY WITH Thund.	Frz Rn	Hail	SNOW ON GND (cm)	RMKS
1	20.0	5.0	12.5							0	
2	21.0	10.0	15.5	10.0		10.0				0	
3	24.0	10.0	17.0	3.5		3.5	X			0	X
4	25.0	7.0	16.0	1.4		1.4				0	X
5	24.0	7.5	15.8							0	X
6	21.0	8.5	14.8							0	X
7	17.0	8.5	12.8							0	X
8	16.5	8.0	12.3							0	X
9	19.5	6.0	12.8							0	X
10	28.5	11.0	19.8	5.0		5.0				0	X
11	22.0	13.0	17.5	6.7		6.7	X			0	X
12	19.0	11.0	15.0	5.4		5.4				0	X
13	19.0	8.0	13.5	4.0		4.0				0	X
14	23.0	10.5	16.8							0	X
15	24.0	9.5	16.8	4.4		4.4				0	X
16	21.0	10.0	15.5				X			0	X
17	23.0	6.0	14.5	15.0		15.0				0	X
18	24.0	10.0	17.0	3.0		3.0	X			0	X
19	20.0	13.0	16.5	11.4		11.4	X			0	X
20	19.0	15.0	17.0	20.0		20.0	X			0	X
21	24.0	15.0	19.5							0	X
22	27.0	10.0	18.5							0	X
23	24.0	11.0	17.5							0	X
24	21.0	9.0	15.0							0	X
25	20.0	5.0	12.5							0	X
26	22.0	9.0	15.5							0	X
27	25.0	7.0	16.0							0	X
28	28.0	10.0	19.0	T		T				0	X
29	29.0	10.0	19.5	T		T	X			0	X
30	23.0	15.0	19.0				X			0	X
31	25.0	10.5	17.8							0	X
TOTAL	698.5	299.0		89.8	0.0	89.8	8				
MEAN	22.5	9.6	16.1								

Monthly Maximum Temperature: **29.0** on Day: **29**
Monthly Minimum Temperature: **5.0** on Days: **1 25**
Highest Rainfall: **20.0** on Day: **20**
Highest Snowfall: **0.0**
Highest TOTAL Precipitation: **20.0** on Day: **20**

Heating Degree-Days: **66.1** (Base 18°)
Cooling Degree-Days: **7.3** (Base 18°)
Growing Degree-Days: **344.2** (Base 5°)
Corn Heat Units: **189.2** (Base 10°)
Freezing Degree-Days: (Base 0°)
Thawing Degree-Days: **499.2** (Base 0°)

Abbreviations: Thund. - Thunder Frz Rn - Freezing Rain SNOW ON GND - Depth of Snow on Ground RMKS - Remarks Recorded

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Environment Canada / Environnement Canada
Atmospheric Environment Service / Service de l'environnement atmosphérique

MINNEDOSA, MB

AES National Headquarters Identification: 5011760
Regional Identification: 5340M

August, 1994

Day	TEMPERATURE (Degrees Celsius) Maximum	Minimum	Mean	PRECIPITATION Rain (mm)	Snow (cm)	Total (mm)	DAY WITH Thund.	Frz Rn	Hail	SNOW ON GND (cm)	RMKS
1	26.0	9.5	17.8	3.6		3.6				0	
2	28.0	N		2.0		2.0	X			0	
3	21.0	13.0	17.0				X			0	
4	20.0	3.0	11.5							0	
5	25.0	5.0	15.0	T		T				0	
6	27.5	9.0	18.3	11.0		11.0				0	
7	15.0	9.0	12.0							0	
8	17.0	3.0	10.0							0	
9	19.0	4.0	11.5							0	
10	22.0	N								0	
11	25.0	7.0	16.0	14.0		14.0				0	
12	24.0	9.0	16.5	1.0		1.0	X			0	
13	16.0	6.0	11.0				X			0	
14	22.0	7.0	14.5							0	
15	29.0	5.0	17.0							0	
16	24.0	N								0	
17	20.0	9.0	14.5	13.6		13.6				0	
18	24.0	10.0	17.0	23.0		23.0			X	0	
19	19.0	10.0	14.5				X		X	0	
20	22.5	9.0	15.8							0	
21	25.0	9.0	17.0							0	
22	27.0	11.0	19.0	1.0		1.0				0	
23	25.0	12.0	18.5	1.0		1.0				0	
24	25.0	10.0	17.5	1.0		1.0				0	
25	25.0	13.0	19.0							0	
26	17.0	6.0	11.5	16.0		16.0				0	
27	13.0	9.0	11.0	5.0		5.0	X			0	
28	18.5	8.0	13.3	11.0		11.0				0	
29	14.0	9.0	11.5	2.0		2.0	X			0	
30	14.0	5.0	9.5	1.0		1.0				0	
31	15.0	3.0	9.0							0	
TOTAL	664.5	222.5E		106.2	0.0	106.2	7		2		
MEAN	21.4	7.9E	14.7E								

Monthly Maximum Temperature: **29.0** on Day: **15**
Monthly Minimum Temperature: **3.0** on Days: **4 8 31**
Highest Rainfall: **23.0** on Day: **18**
Highest Snowfall: **0.0**
Highest TOTAL Precipitation: **23.0** on Day: **18**

Heating Degree-Days: **107.1E** (Base 18°)
Cooling Degree-Days: **2.8E** (Base 18°)
Growing Degree-Days: **298.7E** (Base 5°)
Corn Heat Units: **145.2E** (Base 10°)
Freezing Degree-Days: (Base 0°)
Thawing Degree-Days: **453.7E** (Base 0°)

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Environment Canada / Environnement Canada
Atmospheric Environment Service / Service de l'environnement atmosphérique

MINNEDOSA, MB

AES National Headquarters Identification: 5011760
Regional Identification: 5340M

September, 1994

Day	TEMPERATURE (Degrees Celsius) Maximum	Minimum	Mean	PRECIPITATION Rain (mm)	Snow (cm)	Total (mm)	DAY WITH Thund.	Frz Rn	Hail	SNOW ON GND (cm)	RMKS
1	18.0	N								0	
2	19.0	1.0	10.0							0	X
3	15.0	3.0	9.0	30.0		30.0				0	X
4	21.0	N		2.0		2.0				0	X
5	18.0	10.0	14.0							0	X
6	23.0	9.0	16.0							0	X
7	24.0	5.0	14.5							0	X
8	25.0	7.0	16.0							0	X
9	28.0	9.0	18.5							0	X
10	26.0	11.0	18.5	T		T				0	X
11	17.0	8.0	12.5	2.0		2.0	X		X	0	
12	18.5	6.0	12.3				X			0	X
13	22.0	3.5	12.8							0	X
14	21.0	5.0	13.0	15.6		15.6				0	X
15	20.0	12.0	16.0				X			0	X
16	22.0	7.0	14.5							0	X
17	26.0	6.0	16.0							0	X
18	26.0	7.0	16.5							0	X
19	26.0	6.0	16.0							0	X
20	23.0	5.0	14.0	1.0		1.0				0	X
21	13.0	6.0	9.5				X			0	X
22	16.5	N								0	
23	28.0	N								0	X
24	19.0	6.0	12.5							0	X
25	14.0	1.0	7.5							0	X
26	19.0	0.5	9.8							0	X
27	15.0	N								0	X
28	15.0	2.0	8.5							0	X
29	14.0	0.0	7.0							0	X
30	12.0	1.0	6.5							0	X
TOTAL	604.0	137.0E		50.6	0.0	50.6	4		1		
MEAN	20.1	5.5E	12.8E								

Monthly Maximum Temperature: **28.0** on Days: **9 23**
Monthly Minimum Temperature: **0.0** on Day: **29**
Highest Rainfall: **30.0** on Day: **3**
Highest Snowfall: **0.0**
Highest TOTAL Precipitation: **30.0** on Day: **3**

Heating Degree-Days: **165.9E** (Base 18°)
Cooling Degree-Days: **1.0E** (Base 18°)
Growing Degree-Days: **225.1E** (Base 5°)
Corn Heat Units: **88.1E** (Base 10°)
Freezing Degree-Days: (Base 0°)
Thawing Degree-Days: **375.1E** (Base 0°)

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