THE RESPONSE OF SEMI-DWARF AND TALL SPRING WHEAT CULTIVARS TO MANAGEMENT INPUTS

BY

THOMAS MARTIN WOLF

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

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ABSTRACT

Interest in high input cereal management systems (high fertilizer nitrogen, high seeding rates, foliar disease control) coincided with the introduction of semi-dwarf spring wheat cultivars into Canadian agriculture in the early to mid 1980's. Semi-dwarf cultivars were seen as ideal candidates for high management inputs due to their short, stiff straw, which increases their lodging resistance. As a result, small plot field experiments were conducted in 1985, 1986, and 1987 to fulfill four objectives: a) to determine the grain yield responses of semi-dwarf (HY320, Marshall, Oslo, Solar, and Wheaton) and tall spring wheat cultivars (Katepwa and Glenlea) to incremental increases in fertilizer nitrogen rate, seeding rate, as well as a foliar fungicide application, b) to determine the interactive effects of seeding rate, fertilizer nitrogen, and seeding date on the grain yield of two spring wheat cultivars (HY320 and Oslo), c) to determine the interactive effects of fertilizer nitrogen, cultivar type (semi-dwarf = Wheaton or Oslo and HY320; tall = Katepwa and Roblin), and foliar fungicide application on wheat yield and yield components, and d) to determine the profitability of management inputs by conducting an economic analysis of the data.

Semi-dwarf cultivars outyielded tall wheat cultivars by 17% averaged over all years and locations. The semi-dwarf

cultivar wheat yield advantage was site specific, ranging from a high of 27% in Minto, 1985, to a low of 4% in Swan River, 1987. Grain yield among the semi-dwarf cultivars was variable. HY320 and Marshall were the highest yielding cultivars evaluated.

Semi-dwarf wheat responded more frequently to increases in management intensity, and had greater yield increases in response to increased management intensity. The most profitable fertilizer nitrogen rate was higher for the semi-dwarf cultivars than for the tall cultivars. In general, foliar fungicide applications were economical for the semi-dwarf cultivars, but were not economical for the tall cultivars. The fungicide effect did not depend on the fertilizer nitrogen rate applied. Split applications of fertilizer nitrogen were economically justifiable for both cultivar types in 1985, but were not profitable in 1986. At Swan River, differences in cultivar responsiveness were not pronounced, and tall cultivars compared favorably with semi-dwarf cultivars.

A delay in seeding, from early May to late May, almost always reduced yields, but less so with an early than a late maturing cultivar. Plant response to increases in fertilizer nitrogen rates were not dependent on an increase in seeding rate.

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CHAPTER 1

Introduction

Semi-dwarf spring wheat cultivars became prominent in Manitoba in the early 1980's. During this time, reduced delivery quotas by the Canadian Wheat Board forced producers to sell high quality hard red spring wheat to local feed mills at comparatively low prices. Feed mills readily accepted different quality, higher yielding American semi-dwarf cultivars, offering producers increased revenues compared to conventional hard red spring cultivars. Under these market conditions, the production of semi-dwarfs flourished. They were grown on 272,500 hectares in Manitoba during the 1985 crop year, accounting for 15% of the red spring wheat acreage. Unlicensed American cultivars accounted for 54% of the area devoted to semi-dwarf cultivars at this time. The first Canadian bred semi-dwarf spring wheat, HY320, was licensed in 1985.

The introduction of semi-dwarf spring wheat cultivars into Manitoba has led to speculation that they may differ from conventional height (tall) cultivars in the agronomic treatments needed for maximum performance. Since semi-dwarf cultivars have shorter, sturdier straw than the tall cultivars, it was possible that they would show positive yield responses to levels of nitrogen fertilizer which would cause tall cultivars to lodge under Manitoba conditions. It was also possible that the optimum level of seeding rates and other agronomic inputs would change under higher nitrogen fertility. Agronomic and economic data were needed to assess the potential for more intensive management levels in spring wheat under Manitoba conditions.

The objectives of this study were: a) to determine the grain yield responses of semi-dwarf and tall spring wheat cultivars to incremental increases in management intensity, b) to determine whether higher fertilizer nitrogen levels require a simultaneous increase in seeding rates and/or adjusted seeding dates, c) to determine whether foliar fungicide application effects are similar for different wheat cultivars or varying fertilizer nitrogen levels, and d) to compare the profitability of semi-dwarf and tall spring wheat cultivars in response to increased management inputs.

Field studies were initiated to examine the stated objectives. Three experiments were designed and carried out at several locations in southern Manitoba. To carry out objective (a), four semi-dwarf cultivars and two tall cultivars were subjected to several input levels, ranging from 'low' (low seeding rate, low fertilizer nitrogen) to 'high' (high seeding rate, high fertilizer nitrogen and the use of a foliar fungicide). For objective (b), interactions between seeding dates, seeding rates, and fertilizer nitrogen were studied using two semi-dwarf cultivars. The interactive effects of cultivar type (semi-dwarf or tall) fertilizer nitrogen, and foliar fungicide were studied to carry out objective (c). An economic analysis was conducted to determine whether high levels of management were profitable, and whether profitability differed for semi-dwarf and tall cultivars.

CHAPTER 2

Literature Review

2.1 Management Effects on Crop Growth, Yield, and Yield Components

2.1.1 Fertilizer Nitrogen Effects in Wheat

Nitrogen is the nutrient most limiting to crop production on non-fallowed fields in the Canadian Prairies (Grant et al., 1991). Typical wheat plant responses to nitrogen fertilizer include increased leaf area and canopy production (Green and Dawkins, 1986; Spiertz and de Vos, 1983; Campbell et al., 1977; Pearman et al., 1977), increased net photosynthesis (Spiertz and van de Haar, 1978), delayed leaf senescence (Spiertz and de Vos, 1983; Campbell and Davidson, 1979), increased tillering and reduced tiller mortality (Campbell et al., 1977; Power and Alessi, 1978), increased soil moisture use (Campbell and Davidson, 1979; Campbell et al., 1977), higher protein content and improved baking quality of the grain (Kosmolak and Crowle, 1980; McNeal et al., 1963; Syltie and Dahnke, 1983) and higher grain yield (Caldwell and Starratt, 1987; Green and Dawkins, 1986; Penny et al., 1983, Campbell et al., 1977).

Not all effects of applied nitrogen fertilizer are positive or desirable. High amounts of fertilizer nitrogen can result in vigorous vegetative growth and a suppression of food storage and seed development, possibly reducing grain weight (Boquet and Johnson, 1987; Penny et al., 1978). Taller, lusher plants are more prone to lodging and disease infestation (Caldwell and Starratt, 1987; Penny et al., 1983; Widdowson et al., 1976; Boquet and Johnson, 1987), and more prone to insect attack (Prew et al., 1983). Increased evapotranspiration by more vigorously growing plants may cause moisture stress at anthesis, (Campbell and Davidson, 1979; Syme, 1972; Pearman et al., 1977) and reduce the plants' ability to convert nitrogen into grain yield (Campbell et al., 1977).

Nitrogen responses can vary from year to year and are largely dependent on the environmental conditions. Low soil moisture and a high degree of pest infestation both reduce the plants' ability to respond to increased nitrogen fertility (Boquet and Johnson, 1987; Rajaram and Nelson, 1984; Campbell et al., 1977;). Adequate soil moisture increases the plants' utilization efficiency of nitrogen (Clarke et al., 1990; Campbell et al., 1977).

Yield component responses to nitrogen fertilizer may vary, depending on cultivar choice and environmental conditions. However, two general statements can be made: a) the number of spikes per unit area tends to increase with increased nitrogen (McNeal et al., 1960; McNeal et al., 1971; Blackman et al., 1978); b) at high nitrogen levels, yield component compensation may occur, which could reduce the yield per spike in the face of high spike numbers. For example, Power and Alessi (1978) found an increase in the number of spikes ha^{-1} to be based on reduced tiller mortality, particularly during the latter part of the season when water was limited. They suggested that improved nitrogen nutrition enables the later developing tillers to survive and produce spikes more competitively. Thorne and Blacklock (1971) reported significant increases in spikes m^{-2} as a result of nitrogen fertilization, but reductions in kernel weight at high nitrogen rates kept yield low. Similar effects have been observed by Green and Dawkins (1986) and McNeal et al. (1971).

Split applications of nitrogen will optimize plant nutrition at important stages in its development. Adequate supplies of nitrogen early on stimulate tiller formation and leaf growth. Late top dressings promote the survival of spike-bearing tillers, grain set, and leaf area durations (Spiertz and de Vos, 1983). Also, since both high nitrogen under dry conditions and low nitrogen under wet conditions can reduce yield, two applications of nitrogen can correct potential imbalances (Rajaram and Nelson, 1984). If part of the application is made at seeding to satisfy tillering needs and drought occurs, then a second application is not needed. If there is a good supply of water at tillering, then additional nitrogen is needed to fully develop the yield potential. Effland (1981) reported that when high doses of nitrogen are applied, splitting the applications may be used simply to avoid excessive amounts of nitrogen available to the plant at any one time.

2.1.2 Seeding Rate Effects in Wheat

Most research on the effect of seeding rate on the yield of small grains has shown that yield is not greatly affected by seeding density. Interest in seeding rate studies continues because of evidence that seeding rates interact with soil moisture conditions, cultivars, dates of seeding, or fertility levels.

Soil moisture conditions are an important factor determining the optimum seeding rate. In areas of adequate moisture, high seeding rates generally result in the best yields (Wright et al., 1987; Ciha, 1983; Baker, 1982; Briggs and Aytenfisu, 1979; Briggs, 1975; Guitard et al., 1961), whereas in areas of limited moisture, low seeding rates provide the best crop performance (Read and Warder, 1982; Pelton, 1969).

There has been some interest in the study of interactions involving seeding rate. Some studies suggest that cultivars may have differing response to seeding rate (Ciha, 1983; Baker, 1982; Briggs and Aytenfisu, 1979), necessitating seeding rate studies of new cultivars. However, tillering patterns of wheat genotypes do not appear to affect relative seeding rate response (Hucl and Baker, 1990). Also, Baker (1982) reported that although cultivars were found to differ in their response to seeding rate, these differences were not consistent between years or locations.

Results on seeding date and seeding rate interactions are mixed. Ciha (1983) and McFadden (1970) reported that the optimum seeding rate did not change with later seeding dates. Briggs and Aytenfisu (1979) found some rate * date interactions, and indicated that the occurrence of significant interactions at some locations and not others emphasizes the need to collect multilocation data, with separate analysis at each location.

Most studies indicate the absence of nitrogen and seeding rate interactions (Scott et al. 1977; Syme, 1972; Thorne and Blacklock, 1971; McFadden, 1970). Sometimes, however, the degree of nitrogen fertilization can determine the yield response to seeding rate changes. Roth et al. (1984) reported that responses to seeding rate were greatest at the optimum nitrogen level. In a study near Melfort, Saskatchewan, Wright et al. (1987) found that the optimum fertilizer rate was increased with increasing seed rate. They suggested that under the relatively humid conditions of northeastern Saskatchewan, maximum yields will normally be achieved through a combination of high seed and fertilizer rates. Similar results were found by Syme (1972).

Generally, increases in seeding rate are accompanied by a decrease in the number of fertile tillers per plant, a reduction in the number of kernels per spike and a decrease in the 1000 kernel weight (Larter et al., 1971; Guitard et al., 1961; Read and Warder, 1982; Hucl and Baker, 1990).

2.1.3 Seeding Date Effects in Wheat

Time of sowing in spring is usually determined by soil and weather conditions, and usually it is assumed that earliness of sowing is a factor of prime importance for the production of high yields from spring cereals (Jessop and Ivins, 1970). Most studies confirm that later seeding reduces grain yields (Anderson and Hennig, 1964; Nass et al., 1975; Larter et al., 1971; Spiertz et al., 1971; Schmidt, 1960; Harrington and Horner, 1935).

Date of seeding affects a wheat plant's environment by subjecting the plant to a different pattern of light, temperature, and precipitation (Baker, 1982). Cutforth et al. (1990) and Jessop and Ivins (1970) suggest that the effect of seeding date on yield of spring wheat is related mainly to differences in weather at particular stages of development. When they occurred, Cutforth et al. (1990) attributed yield increases with delayed seeding to more favorable moisture conditions late in the year. Jessop and Ivins (1970) found more favorable day length and temperature conditions late in the year to be responsible for higher yields with delayed seeding. Nass et al. (1975) proposed that if anthesis of a given cereal crop occurs much beyond early to mid-July in Prince Edward Island, the optimum yield cannot be realized. This conclusion is supported by O'Leary et al. (1985), who found that early seeded crops are more likely to flower and produce seed before soil water reserves are exhausted. Anderson and Hennig (1964) suggested that early seeded crops are more likely to avoid early fall frosts and make more efficient use of spring moisture reserves.

Spiertz et al. (1971) concluded that the greater part of the assimilates available for spike filling is dependent on the size and the duration of the green organs in the period after flowering. They tested three sowing dates, and found the green area duration of late sown treatments to be distinctly lower than those of the early sown. The grain yields were also lower at the later sowing date, and regressions taking green area duration into account explained over 80% of the yield variation.

The yield reductions observed with late seeding may involve decreased hectolitre weight, 1000 kernel weight, and grain protein, increased disease severity, and delayed maturity (Ciha, 1983; Larter et al., 1971; Nass et al., 1975). Earlier seeded crops may also be less prone to lodging (Nass et al., 1975).

Other factors, notably cultivar and nitrogen fertility, may interact with dates of seeding. Harrington and Horner (1935) tested four cultivars of spring wheat at nine seeding dates near Saskatoon and noticed a strong interaction between cultivars and seeding dates. There was a tendency for Reward, an early cultivar, to yield poorly in comparison with Marquis, a late cultivar, when both were sown early, but to surpass Marquis when they were sown late. In a study of oat cultivars, Schmidt (1960) also found a differential response of cultivars to planting dates. A late maturing cultivar produced the highest average yield, but also suffered the greatest reduction at late seeding dates, at which time it was outyielded by an earlier maturing cultivar. Briggs and Aytenfisu (1979) supported the continued use of early seeding dates for central Alberta, particularly for late maturing cultivars.

The detrimental effects of late seeding can be reduced by higher nitrogen fertility. McFadden (1970) and Anderson and Hennig (1964) found delayed seeding to reduce yields most in unfertilized plots. Schmidt (1960) reported that lowered oat grain yields from delayed seeding were partially overcome by increased fertilizer rates.

2.1.4 Foliar Fungicide Effects in Wheat

Foliar fungicides are applied to protect cereal plants from potentially harmful plant diseases which could reduce both grain yield and quality. Fungicides do not create yield potential, but are rather protectors of yield potential which may have been created by inputs such as nitrogen.

Fungicide application generally results in increased yields. At Guelph, Sutton and Roke (1986) found that the fungicide propiconazole ('Tilt') increased yields of winter wheat cultivars between 9 and 17%. Jenkins and Melville (1972) reported that fungicides applied to spring barley in south western England resulted in mean yield increases of about 40%, wholly due to an increase in kernel weight. Rowell (1981), working in Minnesota, evaluated two fungicides for control of wheat stem rust. When only primary infection was present, a single spray of triadimefon increased yields between 10 and 63% over untreated checks.

Yield increases due to fungicide application are frequently associated with increases in kernel weight and the number of kernels per spike (Dannenberg, 1989; Caldwell and Starratt, 1987; Mayfield, 1985; Cook, 1980; Spiertz, 1973). Protein content of the grain may decrease by the dilution effect of increasing grain size, or remain unaffected (Caldwell and Starratt, 1987; Penny et al., 1983). However, Widdowson et al. (1976) found fungicide use increased the crop's nitrogen utilization efficiency and thus increased the grain protein content in the absence of a yield increase. Irwin (1983) reported both a grain yield increase and a grain protein content increase in Manitou wheat as a result of fungicide use. Jenkyn and Finney (1981) reported an interaction of fungicide with nitrogen. Protein content of the grain decreased as a result of fungicide use when nitrogen fertility was low, but increased with fungicide use when fertility was high.

Fungicides increase the leaf green area duration by preventing or delaying disease infection (Jordan and

Stinchcombe, 1986; Prew et al., 1983; Kettlewell and Davies, 1982; Spiertz, 1973). Green area duration of the leaves has been found to be positively correlated with grain yield (Austin, 1982; Lupton et al., 1974; Spiertz et al., 1971; Welbank et al., 1966). Spiertz (1973) used maneb and benomyl to control Septoria spp. in winter wheat. He found that 85% of the grain yield variance within the cultivars tested could be attributed to the green area of the flag leaf. Thus, the main effect of Septoria spp. seemed to be a reduction of the photosynthetic area, causing a decreased supply of assimilates to reach the grain and lowering 1000 kernel weight.

Fungicide application may increase the green area duration but not yield. Davies et al. (1984) reported that the maintenance of green leaf area and photosynthetic activity by the fungicide did not become marked until grain growth was almost complete and thus the delay of senescence did not contribute substantially to final grain weight.

Fungicides may increase yields in the absence of significant disease presence and or disease control (Darby et al., 1984; Penny et al., 1978; Penny et al., 1983). Penny et al. (1978) found a yield increase in response to broad spectrum fungicide application in 1974 in spite of poor disease control by the fungicide. The fungicide contained benomyl, maneb and mancozeb. They attributed the increases to prolonged photosynthetic activity of the flag leaf, due to control of saprophytic micro-organisms rather than of specific diseases. The same researchers again found yield increases in the absence of disease control in 1979 (Penny et al., 1983). However, disease control was difficult to assess accurately due to the natural senescence of the leaves. Darby et al. (1984) found yield increases in response to the application of captafol, carbendaxim, maneb, primicarb, and tridemorph to winter wheat. Since there was no disease pressure, they postulated that cytokinin side effects following the use of benzimidazole fungicides was responsible for the yield increases. Kettlewell and Davies (1982) could not find a consistent link between disease control, green area duration, and photosynthetic activity of the flag leaf in response to propiconazole. Although some rates of propiconazole increased yield, this effect could not be directly related to disease control.

Recognizing that yield responses to fungicide applications were variable and not always related to the degree of disease infection, Webster and Cook (1979) identified an interaction between environment and fungicide application. They suggested crop growth stage, disease presence, weather, cultivar susceptibility, and crop site topography to be important factors determining fungicide efficacy.

Cultivars differ in their response to fungicide application (Sutton and Roke, 1986; Jenkyn and Moffatt, 1975; Spiertz, 1973), with cultivars genetically susceptible to disease usually benefitting more (Mascianica, 1984; Cook, 1980; Widdowson et al., 1976). Semi-dwarf wheat cultivars are often considered more susceptible to disease due to their short internode length. Shorter internodes reduce the distance required for splash dispersal of pathogen spores from leaf to leaf. However, Spiertz (1973) found the shortest and tallest cultivars to be least infected by Septoria spp., suggesting some other cultivar characteristic besides culm length to affect resistance. Genetic resistance is the most likely characteristic determining the response to fungicide application. No evidence was found in the present literature review which would suggest that the Rht genes in semi-dwarf cultivars confer inferior disease resistance.

Timing of the spraying operation is a crucial factor determining the effectiveness of the fungicide application. Cook (1980) studied the results of 118 experiments between 1970 and 1978, and found that only those sprays applied between flag leaf emergence and the in-boot stage showed evidence of a yield increase. Applications before the start of flowering gave the largest yield responses.

When high nitrogen fertility increases the severity of disease, as reported by Bainbridge (1974), Boquet and Johnson (1987), and Jordan and Stinchcombe (1986), the benefit of fungicide applications also increases, and an interaction between nitrogen dose and fungicides occurs (Penny et al., 1983; Widdowson et al., 1976). Widdowson et al. (1976) suggested that controlling the additional leaf damage caused by brown rust with fungicide increased the efficiency with which barley utilized nitrogen fertilizer. Prew et al. (1983) supported this conclusion when they reported that larger amounts of nitrogen applied to wheat decreased grain yields in the absence of fungicide and aphicide.

2.2 Comparison of Semi-Dwarf and Tall Wheat Cultivars

Semi-dwarf wheat cultivars are characterized by comparatively short, stiff straw which reduces their lodging potential and increases their harvest index (Cutforth et al., 1988; Reitz and Salmon, 1968). In environments of high yield potential, especially with irrigation or adequate rainfall, semi-dwarf cultivars usually produce higher grain yields than tall cultivars (Cutforth et al., 1988; Brandle and Knott, 1986). However, under adverse conditions, especially drought during ear filling, semi-dwarf cultivars may be outyielded by the tall cultivars (Power and Alessi, 1978). Since semi-dwarf cultivars are predominantly developed for high rainfall areas, their poor performance in dry weather may be due to a lack of previous selection pressure under stress conditions (McNeal et al., 1972).

Semi-dwarf cultivars have variable kernel weights, equal to, higher, or lower than talls depending on the cultivar. However, they consistently produce greater numbers of kernels per unit area due to more kernels per spike (Cutforth et al., 1988; Hubbard, 1984; Spiertz and van de Haar, 1978; Syme, 1972). Brandle and Knott (1986) suggest that fluctuations in the relative number of kernels per spike in semi-dwarf and tall lines is the primary determinant of whether semi-dwarf lines outyield tall lines in different environments.

Tillering capacity of semi-dwarf cultivars is frequently found to be similar to that of the tall cultivars (McNeal et al., 1960; Power and Alessi, 1978), although it has also been determined to be higher than that of the tall cultivars in some instances (Lupton et al., 1974). Thorne and Blacklock (1971) found that the tillering behavior of semi-dwarf cultivars resembled that of the tall cultivar evaluated, with slightly more tillers surviving in the semi-dwarf cultivars. Protein content of the grain is lower for semi-dwarf cultivars (Brandle and Knott, 1986; Pepe and Heiner, 1975).

In environments with high rainfall, agronomic responses of tall wheat cultivars to nitrogen fertilizer may be limited by lodging (Caldwell and Starratt, 1987). The shorter stature of semi-dwarf cultivars may permit higher fertilizer nitrogen rates to be applied without lodging related yield reductions. As a result, the response of semi-dwarf cultivars to nitrogen fertilizer has been extensively studied. Most studies have found that semi-dwarf and tall cultivars respond in a similar way to the application of nitrogen (Blackman et al., 1978; McNeal et al., 1971; Thorne and Blacklock, 1971; McNeal et al., 1960).

However, other studies have suggested that semi-dwarf cultivars are more responsive to fertilizer additions than tall cultivars (Syltie and Dahnke, 1983; Gehl et al., 1990). Gehl et al (1990) explained that semi-dwarf cultivars have a higher harvest index and smaller reductions in harvest index with incremental N fertilization. Hence, they convert fertilizer nitrogen to grain yield more efficiently than the tall cultivars. Clarke et al. (1990) reported that nitrogen and phosphorus utilization efficiencies were greater for HY320 than Neepawa.

Some semi-dwarf cultivars, particularly the Canada Prairie Spring (CPS) cultivars, require more days to reach maturity and are thus susceptible to early frost damage. For these cultivars, late seeding should be avoided (Cutforth et al., 1990). Baker (1990) found that the higher yielding cultivars, whether they are semi-dwarf or not, tend to require more days to mature and might require earlier seeding on that basis.

2.3 Economics of Production Systems

Recommendations to farmers from agricultural research are mainly based on tests of statistical significance related to purely technical information. In themselves, such tests have no economic orientation and imply that farmers operate in an economic vacuum (Dillon and Officer, 1971). The farmer is not necessarily interested in maximum yields, but rather in maximum profits (Pearson, 1981).

In a calculation of profitability in agronomic studies, the cost of an input (marginal cost, MC) is subtracted from the value of the additional production due to that input (marginal revenue, MR). MR minus MC equals Net Returns.

In southern Ontario, a high input management system for barley produced greater grain yields relative to a low input system in 8 out of 10 trials, but produced a greater profit in only one of ten trials (Zebarth and Sheard, 1991). Because of low disease pressure and lack of intense summer rainfall, the need for crop protection through the use of a growth regulator and a fungicide was minimal and its use was therefore not cost-effective. Zebarth and Sheard emphasized the need for decision making aids regarding which crop protection inputs to use.

In the southeastern Coastal Plain in the U.S., production of wheat under high nitrogen fertility and adequate plant-available water returned a profit of $125 to $225 per acre, compared to a net loss of $24 to $59 per acre under average yield levels (Karlen and Gooden, 1990). The primary management practices required to achieve higher profit levels were selection of optimum cultivars and prevention of water and nitrogen stress.

In Europe, the semi-intensive 'Laloux System' was compared with the very intensive 'Schleswig-Holstein System' for the production of winter wheat (Falisse and Bodson, 1984). The variable results across regions suggested to the authors that profitable intensive cereal growing can only be obtained by constant adaptation of 'systems' to environmental conditions, technical progress, and economic climate.

In a study by Cook (1980), fungicide use in the UK paid for itself in 40% of the cases on the average, but 62% if Septoria spp. were present. A yield increase of 200 kg/ha was necessary to recover the cost of the fungicide plus application costs. Mayfield (1985) reported that yield increases of 270 kg/ha were barely enough to cover the cost of the fungicide treatment. However, grain quality was improved with the use of a fungicide, increasing the value of the grain by $6/tonne.

CHAPTER 3

Materials and Methods

3.1 Description of Locations

Experiments were conducted at four locations in southern Manitoba: Portage la Prairie (Portage), Minto, Morris, and Swan River. Portage is 80 km west of Winnipeg, in an area characterized by abundant rainfall and fertile medium textured soil. Morris is located in the Red River Valley approximately 70 km south of Winnipeg, a region where heavy clay soils predominate. Minto is located 60 km south of Brandon, in a region which receives less rainfall on the average than the Red River Valley. Swan River is located 250 km north of Brandon. It is characterized by fertile soils, a short growing season and abundant growing season precipitation.

In 1985, the experimental sites were near Portage, Morris, and Minto. In 1986, the experimental sites were Portage la Prairie, Minto, and Swan River. In 1987, experiments were conducted at Portage and Swan River only. The soil types at the various locations are listed in Table 3.1.

Table 3.1: Soil types of experimental sites

Experiment Location	Year of Study	Soil Type
Minto	1985, 1986	Waskada Heavy Loam
Morris	1985	Red River Clay
Portage	1985 1986, 1987	Dugas Clay Neuhorst Clay Loam
Swan River	1986, 1987	Lenswood Fine Sandy Loam

3.2 Experimental Design

Three separate experiments, each at several locations, were conducted. Seeding, sampling, and harvesting procedures are outlined in section 3.3 (Experimental Procedure). Each experiment will be described in detail in sections 3.2.1 to 3.2.3.

3.2.1 Experiment 1: Management Response of Several Wheat Cultivars.

The purpose of this experiment was to determine the grain yield responses of semi-dwarf and tall spring wheat cultivars to incremental increases in management intensity. Each of the wheat cultivars were subjected to a total of five treatments, where each treatment represented an increment in management intensity over the previous treatment (Table 3.2). This was accomplished through a change in the seeding rate and nitrogen fertility, by splitting the fertilizer nitrogen application, and by applying a foliar fungicide. In 1985, the 'Low' level of management treatment consisted of a seeding rate of 300 viable seeds m^{-2} and 50 kg ha^{-1} actual fertilizer nitrogen (N). The 'Med' level of management consisted of a seeding rate of 400 seeds m^{-2} and 100 kg actual N ha^{-1}. The 'High' level of management consisted of a 500 seeds m^{-2} seeding rate and 150 kg actual N ha^{-1}. The 'HiF' management level was identical to the 'High' treatment except for the addition of a foliar fungicide spray during the heading stage (Zadoks 50-59). The 'HFS' treatment was identical to the 'HiF' treatment, but the fertilizer nitrogen was split into three applications, one at seeding (75 kg ha^{-1} actual N), a second at tillering (50 kg ha^{-1}), and a third during the heading stage (25 kg ha^{-1}). Four semi-dwarf cultivars and two tall cultivars were evaluated. The semi-dwarf cultivars were HY320, a Canadian medium quality wheat (Canada Prairie Spring or CPS) developed at the Swift Current Research Station (DePauw et al., 1987), and three American cultivars, Marshall, Oslo, and Solar (NDSU, 1988). The tall cultivars were Katepwa, a Canada Western Red Spring (CWRS) eligible cultivar and Glenlea, a Canada Utility cultivar. The experiments were conducted at Morris, Minto, and Portage. In 1986, the seeding rate was reduced by 100 viable seeds m^{-2} for each treatment (Table 3.2) because seeding rates were found to have been too high to detect differences in 1985 (based on data from Experiment 2).

Also, the semi-dwarf cultivar Solar was eliminated from the trials because it displayed poor agronomic performance in 1985. It was replaced by the semi-dwarf cultivar Wheaton (NDSU, 1988). The experimental sites in 1986 were Minto, Portage, and Swan River.

The experiment was designed as a split block, with cultivars as the main effect and management intensity as the sub effect (Figure A.1). Cultivars were seeded straight through five plots, randomly arranged beside each other. Management levels (sub-effect) were stripped straight across all cultivars, also randomly arranged beside each other. All plots were 2.5 m wide and 7.5 m long, and each treatment was replicated four times.

Table 3.2: Description of management levels (seeding rates, nitrogen rates, fungicide applications), list of cultivars tested and experimental site locations for Experiment 1.

Year	Management Level	Seeding Rate (seeds/m^2)	Nitrogen Rate (kg/ha)	Location	Cultivars	Cultivar Type	Seeding Date
1985	Low	300	50	Minto	HY320	S.dwarf	May 4
	Med	400	100		Marshall	S.dwarf	
	High	500	150		Oslo	S.dwarf	
	HiF*	500	150		Solar	S.dwarf	
	HFS**	500	150		Katepwa	Tall	
				Morris	HY320	S.dwarf	May 18
					Marshall	S.dwarf	
					Oslo	S.dwarf	
					Solar	S.dwarf	
					Katepwa	Tall	
					Glenlea	Tall	
				Portage	HY320	S.dwarf	May 8
					Marshall	S.dwarf	
					Oslo	S.dwarf	
					Solar	S.dwarf	
					Katepwa	Tall	
					Glenlea	Tall	
1986	Low	200	50	Minto	HY320	S.dwarf	May 23
	Med	300	100		Marshall	S.dwarf	
	High	400	150		Oslo	S.dwarf	
	HiF*	400	150		Wheaton	S.dwarf	
	HFS**	400	150		Katepwa	Tall	
					Glenlea	Tall	
				Portage	HY320	S.dwarf	May 23
					Marshall	S.dwarf	
					Oslo	S.dwarf	
					Wheaton	S.dwarf	
					Katepwa	Tall	
					Glenlea	Tall	
				Swan River	HY320	S.dwarf	May 30
					Marshall	S.dwarf	
					Oslo	S.dwarf	
					Wheaton	S.dwarf	
					Katepwa	Tall	
					Glenlea	Tall	

* Includes a foliar fungicide at flag leaf stage

** Includes a foliar fungicide at flag leaf stage as well as splitting of nitrogen: 75 kg ha^{-1} at seeding, 50 kg ha^{-1} at tillering, and 25 kg ha^{-1} at the heading stage

3.2.2 Experiment 2: Interactive Effects of Seeding Rate, Fertilizer Nitrogen, Seeding Date and Cultivars on Yield of Wheat

The objective of this study was to determine whether an increase in fertilizer nitrogen rate necessitates a change in seeding rate and/or an adjustment in seeding dates under Manitoba conditions. To achieve these objectives, three levels of nitrogen fertilization, three seeding rates, two cultivars, and two seeding dates were compared in a single experiment in 1985 and 1986 (Table 3.3). Oslo and HY320 were the two cultivars evaluated in 1985 and 1986. Seeding rates in 1985 were 300, 400, and 500 viable seeds m^{-2}. These rates were reduced to 200, 300, and 400 seeds m^{-2} in 1986 because it was concluded, based on experimental data, that the 1985 seeding rates had been too high for differences to be detected. Fertilizer nitrogen rates were 50, 100, and 150 kg actual N ha^{-1}. Two seeding dates were selected. Early seeding occurred as soon as moisture and temperature conditions permitted field work, and late seeding was timed to occur approximately two weeks later, depending on weather conditions. The cultivars, seeding rates and seeding dates were arranged as factorial treatments and laid out in a randomized complete block design (Figure A-2). The fertilizer nitrogen treatments were randomly blocked across these treatments as in a split block. In 1986 and 1987, the Swan River experiment was limited to a single seeding date. In 1987, the CWRS cultivars Katepwa and Roblin were evaluated at Portage, and, due to limited quantities of Roblin seed available, Katepwa and Oslo were evaluated at Swan River. Seeding rates were 200, 250, and 300 viable seeds m^{-2}. Fertilizer nitrogen rates were changed from 1985 and 1986 levels to 40, 80, and 120 kg actual N ha^{-1} to better reflect soil test results. The trial at Portage was split in two, with each seeding date in a separate trial. All plots were 2.5 m wide and 7.5 m long, and each treatment was replicated four times.

Table 3.3: Seeding rates, nitrogen rates, cultivars tested, experimental site locations and seeding dates for Experiment 2.

Year	Seeding Rates (Seeds/m^2)	Nitrogen Rates (kg/ha)	Cultivars	Location	Seeding Dates
1985	300	50	HY320	Minto	May 4
	400	100	Oslo		May 21
	500	150			
				Morris	May 18
					June 5
				Portage	May 8
					May 21
1986	200	50	HY320	Minto	May 23
	300	100	Oslo		June 2
	400	150			
				Portage	May 23
					June 2
				Swan River	May 30
1987	200	40	Katepwa	Portage	May 4
	250	80	Roblin		May 25
	300	120			
			Katepwa	Swan River	May 12
			Oslo		

3.2.3 Experiment 3: Interactive Effects of Nitrogen, Foliar Fungicide and Cultivar on Yield, Yield Components, and Grain Protein Content of Wheat

In Experiment 1, fungicide was only applied in treatments which had received high amounts of fertilizer nitrogen. It was not known what the fungicide effect would be at lower nitrogen levels. The objective of Experiment 3, therefore, was to determine whether the benefit of a fungicide application is similar at high and low fertilizer nitrogen levels, and also, whether there is a differential cultivar response to fungicide application. Four cultivars, each at four nitrogen levels, and each nitrogen level with and without a fungicide treatment, were evaluated at Portage and Swan River in 1987 (Table 3.4). The four nitrogen levels were 40, 80, 120, and 160 kg actual N ha^{-1}. The seeding rate was 250 viable seeds m^{-2}. Two tall cultivars (Katepwa and Roblin) were compared to two semi-dwarf cultivars (HY320 and Wheaton at Portage, HY320 and Oslo at Swan River). The experiment was set up as a split strip block design (Figure A-3). Cultivar treatments were randomized and seeded in adjacent rows, and fertilizer treatments were randomly blocked across the cultivars as in a split block. These fertilizer blocks were split in half, with one half receiving a foliar fungicide treatment, the other half remaining untreated. The half receiving the fungicide treatment was randomly selected, but extended across all the cultivars. All plots were 2.5 m wide and 7.5 m long, and each treatment was replicated four times.

Table 3.4: Nitrogen rates, fungicide applications, cultivars tested, experimental site locations and seeding dates for Experiment 3.

Year	Nitrogen Rates (kg/ha)	Fungicide	Location	Cultivars	Seeding Date
1987	40	yes	Portage	HY320	May 4
	80	no		Wheaton	
	120			Katepwa	
	160			Roblin	
			Swan River	HY320	May 12
				Oslo	
				Katepwa	
				Roblin	

3.3 Experimental Procedure

3.3.1 Seeding

The experimental sites were tilled with field cultivators and harrowed prior to seeding. Tillage and seeding was done with commercially available equipment. Seed drills were the hoe type with 18.5 cm row spacing, except at Minto, where a double disk press drill with 15 cm row spacing was used. The kernel weight and germination percentage of the seed was determined, and seeding rates were calculated to yield the desired number of viable seeds m^{-2}. All fertilizer was the granular type, and the nitrogen form was ammonium nitrate (34-0-0). Fertilizing was done as follows: In 1985 and 1986, every plot received a base application of granular nitrogen, phosphorus, and potassium with the seed (Table 3.5). Additional applications of nitrogen (34-0-0) were broadcast after seeding. The treatment fertilizer nitrogen rates for each experiment do not include the nitrogen reserves in the soil.

In 1987, fertilizers were applied with a hoe-drill: all nitrogen in excess of 20 kg/ha was deep banded in the spring prior to seeding, and the remainder was applied with the seed. Every plot also received a base treatment of phosphorus, potassium, and sulphur with the seed (Table 3.5). Plots were maintained weed free using post emergence herbicides.

Table 3.5: Fertilizer macronutrients other than nitrogen applied to the experiments (kg ha-1).

Year	Location	Phosphorus	Potassium	Sulphur
1985	All	50	30	-
1986	All	50	30	-
1987	Portage	46	17	10
	Swan River	15	11	15

3.3.2 Nitrogen Split Applications

Split applications of nitrogen for the 'HFS' management level in Experiment 1 were broadcast applied. After a base application of 75 kg ha^{-1} at seeding, an additional 50 kg ha^{-1} was applied to the plots at the tillering stage, and a further 25 kg ha^{-1} was applied at the heading stage.

3.3.3 Fungicide Application

Foliar fungicides used were propiconazole (1985 & 1986) and mancozeb (1987), at label rates (0.125 kg a.i./ha and 1.8 kg a.i./ha, respectively). Propiconazole (Trade name 'Tilt') is registered for use in semi-dwarf spring wheats for the control of Septoria spp., tanspot, and leaf rust. Mancozeb (Trade name 'Dithane M-45') is registered for the control of Septoria spp., tanspot, and leaf rust in semi-dwarf and tall spring wheat. The fungicide application occurred between the completion of flag leaf emergence and the onset of anthesis. Fungicide was applied using tractor mounted field sprayers with adjustable boom height, except at Swan River in 1986, where a hand held CO_2 sprayer was used.

3.3.4 Grain Harvest

Harvest was done with a Hege small plot combine as treatments became ripe, or by hand harvest and subsequent threshing where necessary. If the grain was moist, it was dried down under aeration until it had a moisture content of approximately 15% before cleaning and weighing (See also Section 3.4: Measurements of Crop Performance).

3.4 Measurements of Crop Performance

Plant counts, grain yield, yield components, and grain protein content were measured for all experiments at all locations. However, for Experiments 1 and 2, these data are not formally reported in the results section, but a summary is available in the appendix.

Plant counts: Plant counts were taken when plant emergence was complete. Three 50 cm rows, not including any outside rows, were counted at four random locations in each plot.

Spike counts: Spike counts were taken between the completion of anthesis and grain harvest. At this time, 5 adjacent 1 m rows were chosen at random near the centre of the plot, and every seed-bearing culm was counted.

Kernels per Spike: Kernels were calculated using the formula: Kernels per Spike = (kg grain/ha*100)/(spikes/m^2 * 1000 kernel weight).

Grain Yield: The central 1.2 m of each plot were harvested using a Hege small plot combine. Where this was not possible, 1 m^2 samples were hand cut, bagged, and threshed with a stationary combine. The grain was cleaned, moisture tested and weighed, and this weight was then adjusted to 14.5% moisture before being expressed as kg/ha.

Thousand Kernel Weight: A subsample was taken from the grain harvested from each plot. The samples were allowed to equilibriate for several weeks in dry storage before 1000 kernels were counted and weighed.

Protein Content: A subsample of harvested grain was ground and tested for protein content using a Dickey-John infrared analyzer (American Association of Cereal Chemists, 1983).

Hectolitre Weight: The cleaned grain samples were allowed to equilibriate in moisture content for several weeks, after which a 0.5 L sample was removed and weighed, and converted to kg hL^{-1}.

3.5 Economic Analysis

A partial economic analysis was conducted to determine the profitability of incremental management inputs. Experiments 1 and 3 were evaluated. The costs used in the analysis are presented in Table 3.6, and are an attempt to represent commercial levels paid by producers. The fungicide prices are actual market prices during the time of the studies i.e., fungicide prices for Experiment 1 and 3 reflect 1985/1986 and 1987 levels, respectively. Nitrogen and seed prices are for 1985.

Table 3.6: Input prices and costs used in the economic analysis.

Nitrogen ($/kg actual)	Seed ($/tonne)	Fungicide ($/ha)[1]	Split application of Nitrogen ($/ha)[2]
0.55	200	33.35 (Expt. 1) 38.81 (Expt. 3)	19.76

1. Includes custom application charges by aircraft
2. Custom charges

A typical increase in management intensity from 'Low' to 'Medium' and 'Medium' to 'High' was 50 kg ha^{-1} more of actual nitrogen applied coupled with a 100 seeds m^{-2} seeding rate increase. Additional management required the use of a foliar fungicide treatment on top of the 'High' treatment (HiF), and finally, splitting the application times of the nitrogen in this fungicide treatment (HFS). The incremental costs of each management level above 'Low", for Experiment 1, are shown in Table 3.7. For Experiment 3, the fungicide treatment and the nitrogen fertilizer rates were evaluated for profitability. It was assumed that all other variable and fixed costs for the production of the grain were constant.

Table 3.7: Cost increases for incremental management levels in Experiment 1.

Management Level	Incremental Cost Increase ($/ha)	Cost Increase above 'Low' mgmt ($/ha)
Med	35.50	35.50
High	35.50	71.00
HiF	33.35	104.35
HFS	19.76	124.11

Commodity prices used in the economic analysis were Canadian Wheat Board prices paid to producers (initial and final), basis Winnipeg, Manitoba. The price of #1 Canada Western Red Spring wheat (CWRS) was used for the tall cultivars, and the price of #3 CWRS was used for the semi-dwarf cultivars (Carter et al., 1986; Table 3.8). The yield data for a given year were evaluated using that year's commodity prices.

Table 3.8: Commodity price regimes for spring wheat used in the economic analysis in Experiments 1 and 3.

Cultivar Type	Commodity Price ($/tonne)		
	1985	1986	1987
Tall	147.00	121.00	129.00
Semi-Dwarf	133.00	97.00	103.00

The economic analysis consisted of the calculation of three parameters which would indicate the profitability of management inputs for each cultivar type (semi-dwarf or tall):

A) Net returns:

Net returns were defined as the revenue derived from an input or combination of inputs minus the cost of that input or inputs (marginal revenue minus marginal cost). To determine the profitability of each management level in Experiment 1, the base level of production was considered to be the 'Low' management level. To determine the profitability of each nitrogen level in Experiment 3, the base level of production was considered to be the 40 kg ha^{-1} treatment. Net returns were calculated as follows:

$$\underset{(\$/ha)}{\text{Net Returns}} = \underset{(t/ha)}{\text{Grain yield inc. due to input}} * \underset{(\$/t)}{\text{Comm. price}} - \underset{(\$/ha)}{\text{Cost of input}} \qquad \text{(Equation 1)}$$

For example, to determine the profitability of producing grain at the 'HiF' management level, the yield difference between the 'Low' and the 'HiF' management level was multiplied by the commodity price, and the total combined cost of the inputs required to move from the 'Low' to the 'HiF' management level were subtracted from this product. For the application of an input to pay, net returns must be greater than 0. The most profitable input level was the one which resulted in the largest net returns.

B) Break Even Cost:

Break-even cost for inputs (BEC) was defined as the cost at which an input would result in a zero net return. It therefore represents the maximum cost a producer could afford to incur for an input without losing profitability. In Experiment 1, a move from the 'Low' to the 'Med' or 'High' management level was accomplished by a change in both the seeding rate and the fertilizer nitrogen rate. Based on data for Experiment 2, it was concluded that nitrogen fertility, and not seeding rate, was responsible for the observed yield increases in moves from the 'Low' to the 'Med' or 'High' management levels. For these situations, the BEC was calculated for the nitrogen fertilizer used in these inputs only. To determine the break-even cost of the fungicide treatment and the split nitrogen application, the base levels were taken to be the 'High' and 'HiF' treatments, respectively. The BEC was calculated using the following formula:

$$\underset{(\$/ha)}{\text{BEC}} = \underset{(\$/ha)}{\text{Returns from input}} + \underset{(\$/ha)}{\text{Cost of input}} \qquad \text{(Equation 2)}$$

C) Break Even Price:

The break even price (BEP) was defined as the commodity price required for an increase in management level to result in zero profit. Any commodity price above the BEP would result in profit. The break-even price was determined as follows:

$$\underset{(\$/t)}{\text{BEP}} = \underset{(\$/ha)}{\text{(Cost of input)}} \, / \, \underset{(t/ha)}{\text{(Yield increase due to input)}} \qquad \text{(Equation 3)}$$

As in the calculation of the net returns, the base level for the BEP calculation was considered to be the lowest management input. The cost of an input or combination of inputs over the lowest management level was divided by the yield increase over the lowest management level yield. For example, to determine the BEP required for producing grain at the 'HiF' management level, the yield difference between the 'Low' and the 'HiF' management level was didvided into the total combined cost of the inputs required to move from the 'Low' to the 'HiF' management level.

For Experiment 1, the net returns were reported for each management level at each location in both 1985 and 1986. Net returns and BEC were also determined for the average of all locations in a given year. For Experiment 3, the net returns were reported for the fungicide and nitrogen inputs. The fungicide effect was averaged over all nitrogen levels, whereas the nitrogen effect was reported only for plots that had not been sprayed with fungicide. The BEP was calculated for incremental management increases in Experiment 1 and for fungicide application and incremental increases in nitrogen fertility in Experiment 3. BEP results were not discussed in the body of this thesis, but were reported in Tables A-31 to A-34.

3.6 Statistical Analysis

Data for all experiments was analyzed using SAS version 5.16 installed at the University of Manitoba mainframe computer. An analysis of variance was conducted on all data. A 5% level of probability or less for a greater F-value was considered statistically significant for main effects and interactions. The means of those qualitative variables which had F-values significant at 5% or better were separated using the Least Significant Difference (LSD) test at the 5% level of probability. This test was chosen because of its wide acceptance and general recommendation by statisticians (Gilligan, 1986; Carmer and Walker, 1982). Quantitative data were subjected to regression analysis using orthogonal polynomials. In this way, it could be determined whether a response was significantly linear or quadratic. When a quantitative response was both significantly linear and quadratic, the response was reported as quadratic. No further regression analysis was conducted on the quantitative data.

When interactions between treatments occurred, a separate analysis of variance was conducted using the treatments involved in the interaction. The resulting data were presented in the Appendix. For Experiment 2, three and four-way interactions were not discussed.

Bartlett's test for homogeneity of variance was conducted to determine whether locations and years for Experiment 1 and Experiment 2 could be combined (Little and Hills, 1978). Due to non-homogeneity of variances for both experiments, data for different locations were analyzed separately. Data across locations for a given year were pooled for economic analysis in Experiment 1. In these cases, comparisons were made without the aid of statistical procedures.

To determine whether the source of variation within the cultivar effect and the cultivar*management interaction in Experiment 1 was due to variation within or between cultivar types (semi-dwarf or tall), an analysis of variance was conducted to partition out cultivar effects. The cultivar effect was separated into components consisting of: a) variation within tall cultivars, b) variation within semi-dwarf cultivars, and c) variation between cultivar types. The same approach was taken with the cultivar*management interaction.

CHAPTER 4

Results

4.1 Experiment 1: Management Response of Several Wheat Cultivars

4.1.1 1985:

The results of the analyses of variance conducted on the data for this experiment are shown in Table A-1. Grain yields were generally high in 1985, most likely a result of cool summer temperatures and timely precipitation in June and August (Figures A-4 to A-6). The semi-dwarf cultivars had higher overall yields than the tall cultivars at all locations (Table 4.1, Table 4.2, Table 4.3). The semi-dwarf and tall wheat cultivars differed in their response to management inputs at two of the three locations. The semi-dwarf cultivar grain yields increased significantly with higher levels of management at both Morris and Portage, (Table 4.2 and Table 4.3), but the tall wheat grain yields did not change significantly due to management inputs at any location. The lack of response of the semi-dwarf cultivars at Minto (Table 4.1) could be due overall high grain yields, even at the low management level compared to those at Morris and Portage.

Table 4.1: The effect of management intensity on the grain yield and net returns of tall and semi-dwarf cultivars, Minto, 1985[1].

Management Level	Yield (kg/ha) Tall	Yield (kg/ha) S. Dwarf	Net Returns ($/ha) Tall	Net Returns ($/ha) S. Dwarf
Low	4040	5060		
Med	4070	5125	-31.09	-26.86
High	4620	5300	14.26	-39.08
HiF	3930	5385	-120.52	-61.13
HFS	4195	5515	-101.33	-63.60

1. Commodity prices for tall and semi-dwarf cultivars are $147 and $133/tonne, respectively.

In general, in 1985 the semi-dwarf cultivars had larger yield increases in response to increases in management intensity than the tall cultivars. As a result, the most profitable management level was higher for the semi-dwarf than the tall cultivars in two of three locations. At Minto, production of the tall cultivar was most profitable at the 'High' management level, whereas the semi-dwarf cultivars were most profitably produced at the 'Low' management level (Table 4.1). At Morris, the most profitable management level for the semi-dwarf cultivars was the 'Med' management level (Table 4.2). The tall cultivars at Morris had the best return at the 'Low' management level. At Portage, the tall cultivars were most profitable at the lowest management level. The semi-dwarf cultivars were profitable at all management levels, however, the highest net returns were obtained at the 'Med' management level.

Table 4.2: The effect of management intensity on the grain yield and net returns of tall and semi-dwarf cultivars, Morris, 1985[1].

Management Level	Yield (kg/ha) Tall	Yield (kg/ha) S. Dwarf	Net Returns ($/ha) Tall	Net Returns ($/ha) S. Dwarf
Low	3615	4075 d[2]		
Med	3665	4560 c	-28.15	29.01
High	3710	4510 c	-57.04	-13.15
HiF	3745	4840 b	-85.24	-2.61
HFS	3970	5100 a	-71.93	12.22

1. Commodity prices for tall and semi-dwarf cultivars are $147 and $133/tonne, respectively.
2. Means within a column followed by the same letter do not differ significantly (LSD, 5%).

Table 4.3: The effect of management intensity on the grain yield and net returns of tall and semi-dwarf cultivars, Portage, 1985[1].

Management Level	Yield (kg/ha) Tall	Yield (kg/ha) S. Dwarf	Net Returns ($/ha) Tall	Net Returns ($/ha) S. Dwarf
Low	3025	2920 b[2]		
Med	2590	3655 a	-99.45	62.26
High	3125	3830 a	-56.30	50.03
HiF	3090	4025 a	-94.80	42.62
HFS	3525	4115 a	-50.61	34.83

1. Commodity prices for tall and semi-dwarf cultivars are $147 and $133/tonne, respectively.
2. Means within a column followed by the same letter do not differ significantly (LSD, 5%).

When all locations were averaged in 1985, production of the semi-dwarf cultivars was most profitable at the 'Med' management level, whereas production of the tall cultivars was most profitable at the 'Low' management level (Table 4.4). The maximum input cost for nitrogen fertilizer permissible without causing a net loss was \$14.50/50 kg for the tall cultivars, well below the market cost of \$27.50/50 kg and \$35.50/50 kg to \$57.00/50 kg for the semi-dwarf cultivars, depending on the management level. Fungicide application did not cause a yield increase for the tall cultivars, but caused a large enough yield increase for the semi-dwarf cultivars to justify a fungicide expense of no greater than \$26.87 ha^{-1} (market cost = \$33.35 ha^{-1}). The tall cultivars benefitted more from a split application of nitrogen than the semi-dwarf cultivars. The nitrogen split application was economically justifiable for the tall and semi-dwarf cultivars at an application cost less than \$46.89 ha^{-1} and \$21.28 ha^{-1}, respectively (market cost = \$19.76 ha^{-1}).

Table 4.4: Maximum input cost permissible without causing a net loss (Break-even cost), and net returns at each management level, averaged over all locations in 1985[1].

Mgmt. Level	Yield (kg/ha)		Net Returns ($/ha)		Break Even Cost: Nitrogen ($/50 kg)		Break Even Cost: Fungicide ($/trtmt)		Break Even Cost: Split App. ($/split)	
	Tall	S. Dwarf	Tall	S. Dwarf	Tall	S. Dwarf	Tall	S. Dwarf	Tall	S. Dwarf
Low	3464	4017								
Med	3315	4447	-57.40	21.69	-[2]	57.00				
High	3659	4547	-42.34	-0.51	14.50	35.50				
HiF	3518	4749	-96.41	-6.99			-	26.87		
HFS	3837	4909	-69.28	-5.47					46.89	21.28

1. Commodity prices: Tall = $147/tonne; Semi-dwarf = $133/tonne.
2. Break Even Cost could not be calculated due to a negative yield response

Cultivars differed significantly from each other in grain yield. The two tall wheats, Katepwa and Glenlea, always yielded less than the semi-dwarf cultivars (Table 4.5). Among the semi-dwarf cultivars, HY320 and Marshall were the highest yielding at all locations.

When cultivar effects were partitioned, it could be determined that semi-dwarf and tall cultivars varied significantly between each other, and that in two out of three locations (Minto and Morris), semi-dwarf cultivars varied significantly among themselves (Tables A-7 to A-9). The tall cultivars did not vary among themselves significantly.

Table 4.5: Grain yield of tall and semi-dwarf spring wheat cultivars, grown at three locations, 1985. Yields were averaged over all management levels.

Cultivar	Yield (kg/ha) Minto	Morris	Portage
HY320	5860 a[1]	4670 b	3925 a
Marshall	5300 b	4940 a	3845 ab
Solar	4980 b	4370 c	3480 bc
Oslo	4970 b	4480 c	3585 abc
Katepwa	4170 c	3710 d	2945 d
Glenlea	-	3780 d	3195 cd

1. Means within a column followed by the same letter do not differ significantly (LSD, 5%).

4.1.2 1986:

The results of the analyses of variance conducted on the data for this experiment are shown in Table A-2. The 1986 growing season was characterized by abundant precipitation in June and July, and dry weather in August (Figures A-7 to A-9). Overall grain yields were highest at Portage and lowest at Swan River. Grain yield and quality were reduced by an early frost at Swan River. As in 1985, the semi-dwarfs had higher grain yields than the tall cultivars, but this effect was least pronounced at Swan River. Both semi-dwarf and tall cultivars responded significantly to increases in management intensity at Minto and Swan River (Table 4.6 and Table 4.8). Neither cultivar type responded significantly to management intensity at Portage, although yield increases did occur (Table 4.7).

The lack of a statistically significant management effect at Portage could partly be explained by poor spring soil conditions. The soil at Portage was waterlogged in late April and early May, which delayed seeding and created a hard, crusted soil surface. The poor seedbed caused an erratic crop stand, and subsequently variable grain yields.

Table 4.6: The effect of management intensity on the grain yield and net returns of tall and semi-dwarf cultivars, Minto, 1986[1].

Management Level	Yield (kg/ha)		Net Returns ($/ha)	
	Tall	S. Dwarf	Tall	S. Dwarf
Low	2985 c[2]	3535 c		
Med	3500 b	4310 b	26.82	39.68
High	3815 ab	4465 b	29.43	19.21
HiF	4190 a	5125 a	41.46	49.88
HFS	3875 ab	4950 a	-16.42	13.15

1. Commodity prices for tall and semi-dwarf cultivars are $121 and $97/tonne, respectively.
2. Means within a column followed by the same letter do not differ significantly (LSD, 5%).

Table 4.7: The effect of management intensity on the grain yield and net returns of tall and semi-dwarf cultivars, Portage, 1986[1].

Management Level	Yield (kg/ha) Tall	S. Dwarf	Net Returns ($/ha) Tall	S. Dwarf
Low	4060	4460		
Med	4520	5210	20.16	37.25
High	4685	5325	4.63	12.91
HiF	4510	5355	-49.90	-17.54
HFS	4690	5410	-47.88	-31.96

1. Commodity prices for tall and semi-dwarf cultivars are $121 and $97/tonne, respectively.

Table 4.8: The effect of management intensity on the grain yield and net returns of tall and semi-dwarf cultivars, Swan River, 1986[1].

Management Level	Yield (kg/ha) Tall	S. Dwarf	Net Returns ($/ha) Tall	S. Dwarf
Low	2660 c[2]	2800 c		
Med	3100 b	3340 b	17.74	16.88
High	3100 b	3380 b	-17.76	-14.74
HiF	3430 a	3890 a	-11.18	1.38
HFS	3655 a	3820 a	-3.72	-25.17

1. Commodity prices for tall and semi-dwarf cultivars are $121 and $97/tonne, respectively.
2. Means within a column followed by the same letter do not differ significantly (LSD, 5%).

Management levels above "Low" were generally profitable for both tall and semi-dwarf wheat cultivars, especially at Minto, where the most profitable management level was 'HiF'. At both Portage and Swan River, production at the 'Med' management level provided the largest net returns. The largest net returns occurred at the same management level for both the tall and the semi-dwarf cultivars at all locations. However, in two of the three locations (Minto and Portage), the semi-dwarfs had larger net returns than the tall cultivars at the most profitable management level.

It should be noted that in 1986, the semi-dwarf cultivars had a larger price disadvantage compared to the tall cultivars than in 1985. In 1985, the tall cultivars were assumed to be marketed at a price that was 11% higher than the semi-dwarf price, while in 1986, the tall cultivar price was 25% larger than the semi-dwarf price. This shift in price relationships put the semi-dwarf cultivars at a relative disadvantage when profitability was calculated.

When the grain yields of all locations in 1986 were averaged, the semi-dwarf and tall cultivars both had the highest net returns at the 'Med' management level, although at that management level, the returns were higher for the semi-dwarf cultivars (Table 4.9). As a result, the break-even cost of fertilizer nitrogen was well above market prices (market price = \$27.50/50 kg). Fungicide application resulted in yield increases for both cultivar types in 1986, most likely due to the strong disease pressure from tanspot and Septoria spp. common in 1986. However, the maximum fungicide expense permissible without incurring a net loss was only \$25.17 ha^{-1} for the tall cultivars, below the actual costs of \$33.35 ha^{-1} in 1986. Fungicide application was profitable for the semi-dwarf cultivars, permitting an expense of \$39.87 ha^{-1}. Split application of nitrogen was not profitable for either cultivar type in 1986.

Table 4.9: Maximum input cost permissible without causing a net loss (Break-even cost), and net returns at each management level, averaged over all locations in 1986[1].

Mgmt. Level	Yield (kg/ha) Tall	Yield (kg/ha) S. Dwarf	Net Returns ($/ha) Tall	Net Returns ($/ha) S. Dwarf	Break Even Cost: Nitrogen ($/50 kg) Tall	Nitrogen ($/50 kg) S. Dwarf	Fungicide ($/trtmt) Tall	Fungicide ($/trtmt) S. Dwarf	Split App. ($/split) Tall	Split App. ($/split) S. Dwarf
Low	3158	3518								
Med	3633	4203	21.98	30.95	57.50	66.50				
High	3792	4327	5.71	7.47	38.50	39.50				
HiF	4000	4738	-2.47	13.99			25.17	39.87		
HFS	4034	4663	-18.11	-13.05					4.11	-[2]

1. Commodity prices: Tall = \$121/tonne; Semi-dwarf = \$97/tonne.
2. Break Even Cost could not be calculated due to a negative yield response

Cultivars differed significantly in grain yield at all locations. At Minto, Wheaton and Marshall had the highest yields (Table 4.10). At Portage, HY320, Wheaton and Marshall had the highest yields, and Oslo had grain yields similar to the tall wheats. At Swan River, all cultivars yielded less than Oslo. This may have been partly due to an early frost which affected Oslo the least due to its comparatively early maturity.

Table 4.10: Grain yield of tall and semi-dwarf spring wheat cultivars, grown at three locations, 1986. Yields were averaged over all management levels.

Cultivar	**Yield (kg/ha)**		
	Minto	**Portage**	**Swan River**
Wheaton	4705 a[1]	5595 a	3255 b
Marshall	4680 a	5345 a	3290 b
Oslo	4280 b	4055 b	3800 a
HY320	4240 b	5605 a	3435 b
Glenlea	3765 c	4325 b	3190 b
Katepwa	3580 c	4660 b	3165 b

1. Means within a column followed by the same letter do not differ significantly (LSD, 5%).

Cultivar effect partitioning showed that semi-dwarf and tall cultivars varied significantly between each other in one trial (Minto), and that semi-dwarf cultivars varied significantly among themselves in two out of three locations (Portage and Swan River), (Tables A-10 to A-12). As in 1985, there was no significant variation among tall cultivars.

4.2 Experiment 2: Interactive Effects of Seeding Rate, Fertilizer Nitrogen, Seeding Date and Cultivars on Yield of Wheat

4.2.1 1985:

The results of the analyses of variance conducted on the data for this experiment are shown in Table A-3. Seeding rate did not significantly affect grain yield of wheat at any of the three locations in 1985. Grain yield was also not affected significantly by fertilizer nitrogen, although the highest yields at Minto and Portage were obtained with the highest nitrogen rate (Table 4.11). In the analyses of variance, partitioning of the seeding rate and fertilizer nitrogen rate using orthogonal polynomials did not reveal significant linear or quadratic yield responses to these management inputs. There was no interaction between seeding rate and fertilizer nitrogen rate at any of the locations.

Table 4.11: The main effects of seeding rate, fertilizer nitrogen, and seeding date on the grain yield of HY320 and Oslo at three locations, 1985.

Input Type and Level	Yield (kg/ha) Minto	Morris	Portage
Seeding rate (seeds/m^2)			
300	4870	4055	4085
400	4890	4155	4145
500	4985	4110	4160
Nitrogen (kg/ha)			
50	4710	4150	4085
100	4970	4125	4050
150	5065	4045	4260
Cultivar			
HY320	5205 a[1]	3845 b	4150
Oslo	4625 b	4365 a	4115
Seeding date			
Early	5455 a	4615 a	4760 a
Late	4375 b	3595 b	3500 b

1. Means within a column and within an input type followed by the same letter do not differ significantly (LSD, 5%).

Cultivars differed significantly in grain yield at Minto and Morris. HY320 had higher grain yields than Oslo at Minto, but at Morris, Oslo had the highest grain yields (Table 4.11). There was no grain yield difference between the two cultivars at Portage. Cultivars differed in their seeding rate response at Minto. HY320 did not respond to seeding rate, but Oslo had a significant quadratic response in which grain yield was lowest at the medium seeding rate (Table A-15)

Seeding date affected yield at all locations. Late seeding reduced yield by over 1000 kg/ha at Minto and

Morris, and by over 1200 kg/ha at Portage. Seeding date was also involved in several interactions. At Morris, higher seeding rate increased grain yield at the early seeding date, but had no effect at the late seeding date (Table A-16). The cultivars differed in their response to seeding date at Morris. At the early seeding date, both cultivars yielded similarly, while at the late seeding date Oslo outyielded HY320 (Table A-17). At Portage, seeding date affected fertilizer nitrogen response. Although the effect was not statistically significant, grain yield increases due to applied nitrogen were greater at the early seeding date (Table A-18).

4.2.2 1986

The results of the analyses of variance conducted on the data for this experiment are shown in Table A-4. Seeding rate caused significant linear yield increases at Minto only. Yield increased by 600 kg/ha as seeding rate was increased from 200 to 400 seeds/m^2 (Table 4.12). The addition of fertilizer nitrogen caused linear grain yield increases at Portage and Swan River, but not at Minto. There was no interaction between seeding and nitrogen rates.

Cultivars tended to differ in yield, but this effect depended on location. HY320 had higher grain yields than Oslo at Portage, but the opposite was true at Swan River (an early frost damaged the crop at Swan River, and the subsequent yield reduction was less pronounced with the earlier maturing Oslo). Both cultivars yielded about the same at Minto. Cultivars did not differ in their seeding rate or fertilizer nitrogen responses.

Seeding date had a pronounced effect on grain yield, but the nature of this effect depended on the location of the experiment. At Minto, late seeding reduced yield by 600 kg/ha, but at Portage, late seeding increased yield by 1100 kg/ha. Only one seeding date was evaluated at Swan River.

Cultivar performance depended on seeding date. At the early seeding date at Minto, HY320 had higher yields than Oslo, but at the late seeding date, Oslo had the highest yield. At Portage, HY320 had the highest grain yield at both seeding dates, but the yield advantage of HY320 over Oslo was not as large at the late seeding date (Table A-17).

Table 4.12: The main effects of seeding rate, fertilizer nitrogen, and seeding date on the grain yield of HY320 and Oslo at three locations, 1986.

Input Type and Level	Yield (kg/ha)		
	Minto	Portage	Swan River
Seeding rate (seeds/m^2)			
200	3970	4965	3155
300	4370	5065	3225
400	4585	5170	3210
Nitrogen (kg/ha)			
50	4190	4565	2805
100	4345	5175	3285
150	4395	5455	3505
Cultivar			
HY320	4345	5515 a	3050 b
Oslo	4270	4615 b	3345 a
Seeding date			
Early	4610 a[1]	4635 b	n/a
Late	4005 b	5500 a	n/a

1. Means within a column and within an input type followed by the same letter do not differ significantly (LSD, 5%).

4.2.3 1987

Weather conditions were favorable at Portage in 1987 (Figure A-10). Although most of June was dry, the crop did not suffer noticeable moisture stress (personal observation) and high overall yields were obtained. Diseases were not as threatening to yield as they had been in 1986. At Swan River, frequent and abundant rains throughout the growing season characterized the weather in 1987 (Figure A-11). Cool and moist conditions in August delayed crop maturity of

Oslo and HY320 into early September, but no killing frost occurred before harvest.

The results of the analyses of variance conducted on the data for this experiment are shown in Table A-5. Seeding rate had no effect on grain yield at any location or seeding date (Table 4.13). Fertilizer nitrogen increased grain yields significantly at Portage, but did not affect yields at Swan River. At the early seeding date at Portage, the treatment with the highest applied nitrogen rate had the highest yield. At the late seeding date, maximum yields were reached at the medium nitrogen rate. There was no interaction between seeding and nitrogen rates.

Cultivar yield differences depended on the seeding date at Portage. At the early seeding date, Katepwa yielded 250 kg/ha more than Roblin (Table 4.13). However, at the late seeding date, Roblin yielded 400 kg/ha more than Katepwa. At Swan River, Oslo and Katepwa had similar yields.

Table 4.13: The main effects of seeding rate and fertilizer nitrogen, on the grain yield of Katepwa and Roblin (Portage) and Katepwa and Oslo (Swan River), 1987.

Input Type and Level	Yield (kg/ha) Portage Early	Portage Late	Swan River Early
Seeding rate (seeds/m^2)			
200	4575	3515	3080
250	4540	3615	2885
300	4575	3558	3415
Nitrogen (kg/ha)			
40	4120	3355	3000
80	4645	3680	3080
120	4920	3650	3300
Cultivar			
Katepwa	4690 a[1]	3360 b	3185
Roblin	4435 b	3765 a	3065 (Oslo)

1. Means within a column and within an input type followed by the same letter do not differ significantly (LSD, 5%).

Two interactions that affected grain yield occurred at Portage at the late seeding date. Roblin and Katepwa differed in their response to fertilizer nitrogen and seeding rate: Roblin responded significantly to applied nitrogen, while Katepwa did not respond (Table A-19). Although differences were not significant, Roblin appeared to respond more to an increase in seeding rate (Table A-20).

4.3 Experiment 3: Interactive Effects of Fertilizer Nitrogen, Foliar Fungicide and Cultivar on Yield, Yield Components, and Grain Protein Content of Wheat

4.3.1 Portage la Prairie, 1987

A partial summary of the analyses of variance conducted for this experiment is found in Table 4.14. A complete listing of means squares, error terms, and three-way interactions for grain yield are located in Table A-6. Applied nitrogen had a significant effect on grain yield, thousand kernel weight (TKWT), grain protein content, and the number of spikes m^{-2}. Grain yield increased over 900 kg/ha as fertilizer nitrogen was increased from 40 to 120 kg/ha (Table 4.15). Thousand kernel weights decreased in a linear fashion with increases in fertilizer nitrogen. Grain protein content as well as the number of spikes m^{-2} increased linearly with increases in applied nitrogen.

Nitrogen response differed among cultivars for thousand kernel weight, grain protein content, and the number of spikes m^{-2}. Thousand kernel weight was reduced with higher nitrogen rates for HY320, but remained unchanged for the other cultivars (Table A-21). Protein content of the grain increased with increased nitrogen fertilizer for all cultivars, but the increase was more pronounced with the tall cultivars (Table A-22). The number of spikes m^{-2}

increased with increasing nitrogen rates for the semi-dwarfs, but not for the tall cultivars (Table A-23).

Table 4.14: Partial summary of analyses of variance for Experiment 3. Portage, 1987.

Source of Variation	Grain Yield	TKWT	HLWT	Grain Protein	Spikes per m^2	Kernels per spike
Nitrogen (N)	*[1]	*	/	*	*	/
Cultivar (Cult)	*	*	*	*	*	*
N*Cult	/	*	/	*	*	/
Fungicide (Fung)	*	*	*	/	/	*
N*Fung	/	/	/	/	/	/
Cult*Fung	*	*	*	/	/	/
N linear	*	*	/	*	*	*
N quadratic	*	/	/	/	/	/

1. * indicates F value is significant at 5% level,
   / indicates F value is not significant at 5% level

Cultivars differed significantly from each other in all observed parameters. The semi-dwarfs outyielded the talls by over 1000 kg of grain/ha on the average (Table 4.15). HY320 had the highest thousand kernel weight, Wheaton and Roblin were intermediate, and Katepwa had the lowest kernel weight. Roblin had the highest grain protein content, significantly higher than Katepwa. The semi-dwarfs had the lowest grain protein contents. The tall cultivars produced significantly more spikes m^{-2} than the semi-dwarfs, but the semi-dwarfs had significantly more kernels per spike than the talls.

Table 4.15: Nitrogen and fungicide effects on yield, yield components, and grain protein content of four wheat cultivars. Portage, 1987.

Input Type and Level	Yield (kg/ha)	TKWT (g)	HLWT (kg)	Protein (%)	Spikes per m^2	Kernels per spike
Nitrogen (kg/ha)						
40	4605	40.2	76.3	11.7	477	25.0
80	5140	40.0	76.5	13.1	490	27.1
120	5540	39.4	76.8	13.7	523	27.7
160	5525	39.5	76.7	14.3	513	28.0
Fungicide						
No	5040 b[1]	39.2 b	76.2 b	13.2	502	26.5 b
Yes	5375 a	40.3 a	77.0 a	13.2	500	27.4 a
Cultivar						
HY320	5900 a	42.2 a	76.5 b	11.8 d	405 d	34.9 a
Wheaton	5735 a	40.0 b	76.1 b	12.2 c	484 c	29.7 b
Katepwa	4720 b	36.7 c	75.6 c	13.6 b	602 a	21.4 c
Roblin	4490 b	40.2 b	78.1 a	15.3 a	511 b	22.0 c

1. Means followed by the same letter do not differ significantly (LSD, 5%).

The plants treated with fungicide had higher grain yield, higher thousand kernel weight, higher hectolitre weight (HLWT), and more kernels per spike than untreated plants. Grain protein content and the number of spikes m^{-2} remained unchanged.

The degree of yield response due to the fungicide depended on the cultivar, as indicated by a significant cultivar*fungicide interaction in the analysis of variance (Table 4.14). Although all cultivars had significant yield increases in the plots treated with fungicide compared to untreated plots, the semi-dwarfs as a group, but especially HY320, had larger yield increases than the talls (Table

A-24). Fungicide application was only economical for HY320 (Table 4.16).

A significant interaction occurred between cultivars and fungicide application for thousand kernel weight and hectolitre weight. Fungicide caused a significant increase in the thousand kernel weight and hectolitre weight of HY320, Wheaton, and Katepwa, but did not change the thousand kernel weight or hectolitre weight of Roblin (Table A-25 and Table A-26).

Table 4.16: Net returns resulting from a fungicide application on several wheat cultivars and two locations, 1987.

	Net Returns ($/ha)				
	Cultivar				
Location	HY320	Wheaton	Oslo	Katepwa	Roblin
Portage	31.23	-5.85	-	-17.53	-9.79
Swan River	48.23	-	12.18	34.08	37.95

The fertilizer nitrogen level yielding the highest net returns for the semi-dwarf cultivars was 120 kg ha^{-1} actual N (Table 4.17). For the tall cultivars, the highest returns were were obtained at both 80 and 120 kg ha^{-1} actual N. Since no higher net return could be achieved by increasing the nitrogen rate above 80 kg N ha^{-1}, this rate was considered to be the optimal nitrogen level. The net returns resulting from the application of the optimum nitrogen fertilizer rate were larger for the semi-dwarf cultivars.

Table 4.17: The effect of nitrogen rate on the grain yield and net returns of tall and semi-dwarf cultivar, Portage, 1987[1].

Nitrogen Rate (kg/ha)	Yield (kg/ha)		Net Returns ($/ha)	
	Tall	S. Dwarf	Tall	S. Dwarf
40	3997	4919		
80	4551	5494	49.47	37.25
120	4726	6040	50.11	71.46
160	4767	5845	33.40	29.38

1. Commodity prices for tall and semi-dwarf cultivars are $129 and $103/tonne, respectively.

4.3.2 Swan River, 1987

A partial summary of the analyses of variance conducted for this experiment is found in Table 4.14. A complete listing of means squares, error terms, and three-way interactions for grain yield are located in Table A-6. The response to increased amounts of fertilizer nitrogen at Swan River was limited to hectolitre weight and grain protein content. Hectolitre weight decreased in a linear fashion with increasing levels of applied nitrogen (Table 4.19). Grain protein content increased slightly with increased nitrogen. This response was quadratic in nature.

Table 4.18: Partial summary of analyses of variance for Experiment 3. Swan River, 1987.

Source of Variation	Grain Yield	TKWT	HLWT	Grain Protein	Spikes per m^2	Kernels per spike
Nitrogen (N)	/	/	*	*	/	/
Cultivar (Cult)	*	/	*	*	*	*
N*Cult	/	/	/	/	/	/
Fungicide (Fung)	*	*	*	/	/	*
N*Fung	/	/	/	/	/	/
Cult*Fung	*	*	*	*	/	/
N linear	/	/	*	*	/	/
N quadratic	/	/	/	*	/	/

1. * indicates F value is significant at 5% level,
/ indicates F value is not significant at 5% level

Cultivars differed significantly from each other in grain yield. HY320 yielded the highest and Oslo yielded the lowest, while Katepwa and Roblin were intermediate in yield. The semi-dwarfs had lower hectolitre weights and protein contents than the tall cultivars, and tended to produce fewer spikes m^{-2}. The semi-dwarfs, especially HY320, tended to have more kernels per spike than the tall cultivars.

Table 4.19: Nitrogen and fungicide effects on yield, yield components, and grain protein content of four wheat cultivars. Swan River, 1987.

Input Type and Level	Yield (kg/ha)	TKWT (g)	HLWT (kg)	Protein (%)	Spikes per m^2	Kernels per spike
Nitrogen (kg/ha)						
40	3890	33.6	72.6	13.4	551	21.4
80	4055	33.7	72.2	13.7	589	20.6
120	3990	32.5	71.6	13.8	560	22.1
160	3965	33.1	71.3	13.7	585	20.7
Fungicide						
No	3660 b[1]	32.0 b	71.1 b	13.7	568	20.5 b
Yes	4290 a	34.5 a	72.8 a	13.7	575	21.9 a
Cultivar						
HY320	4640 a	34.0	69.8 c	12.3 c	524 c	26.2 a
Oslo	3570 c	31.9	69.2 c	13.3 b	552 bc	20.3 b
Katepwa	3855 b	32.9	75.0 a	14.4 a	636 a	18.6 c
Roblin	3840 b	34.2	73.6 b	14.7 a	573 b	19.7 bc

1. Means followed by the same letter do not differ significantly (LSD, 5%).

Cultivars differed from each other in the level of yield change from plants treated with fungicide and those not treated. HY320 demonstrated an 800 kg/ha grain yield increase due to the fungicide, while the other cultivars were limited to 500 to 600 kg/ha yield increases (Table A-27). Fungicide applications were economical for all cultivars, but the highest net returns were obtained with HY320 (Table 4.16). However, production of either the tall or the semi-dwarf wheat was not profitable above a nitrogen fertilizer rate of 40 kg/ha (Table 4.20).

There were significant interactions between cultivars and fungicide for thousand kernel weight, hectolitre weight, and grain protein content. Fungicide increased the thousand kernel weight and the hectolitre weight of all cultivars, but the increase in thousand kernel weight was the smallest for Oslo (Table A-28), and the increase in hectolitre weight was the smallest for Katepwa (Table A-29). Fungicide decreased the protein content of HY320 and Oslo, had no effect on the protein content of Katepwa, and increased the protein content for Roblin (Table A-30).

Table 4.20: The effect of nitrogen rate on the grain yield and net returns of tall and semi-dwarf cultivars, Swan River, 1987[1].

Nitrogen Rate (kg/ha)	Yield (kg/ha)		Net Returns ($/ha)	
	Tall	S. Dwarf	Tall	S. Dwarf
40	3594	3706		
80	3512	3859	-32.51	-6.24
120	3585	3817	-45.16	-32.57
160	3540	3687	-72.97	-67.91

1. Commodity prices for tall and semi-dwarf cultivars are $129 and $103/tonne, respectively.

Since the fertilizer nitrogen effect at Swan River was not statistically significant, little grain yield change resulted from increasing the nitrogen rate for either cultivar type, and the most profitable nitrogen rate was 40 kg N ha^{-1} for both the semi-dwarf and the tall cultivars (Table 4.20).

CHAPTER 5

General Results and Discussion

During three years of study, the semi-dwarf cultivars evaluated had significantly different productivity characteristics than the standard tall cultivars. The semi-dwarfs had higher overall grain yields than the tall cultivars, they had their largest net returns at higher fertilizer nitrogen rates, and were more likely than the tall cultivars to benefit economically from the use of foliar fungicides.

5.1 Overall Grain Yield:

The average grain yield of all semi-dwarf cultivars evaluated was 24, 15, and 17 % higher than tall cultivar yields in 1985, 1986, and 1987, respectively. Such grain yield advantages have been reported in the literature (Blackman et al., 1978; Cutforth et al., 1988; Gehl and Sadler, 1990), although in some instances, semi-dwarf grain yields have also been found to be equal to (Pepe and Heiner, 1975; Thorne et al., 1969), or lower than, tall cultivars (Brandle and Knott, 1986).

Relative yield advantages of the semi-dwarfs varied from location to location each year, and ranged from an average of 26% at Minto in 1985 and Portage in 1987, to 7% at Swan River in 1987. Individual semi-dwarf cultivar yield advantages over tall cultivars ranged from 40% for HY320 at Minto in 1985 to -10% for Oslo at Portage in 1986. In these tests, the semi-dwarf cultivars HY320 and Marshall had consistently higher yields than the other cultivars. Oslo had variable performance, especially at Swan River, where in 1986, it was the highest yielding cultivar, but the lowest yielding in 1987. Considering the variable grain yield characteristics of the semi-dwarfs, it may be misleading to consider them as a homogeneous group distinct from other cultivars (Thorne and Blacklock,1971). In Experiment 1, it was determined that semi-dwarf cultivars varied among themselves in grain yield and management responsiveness as much as they varied from the tall cultivars as a group. Therefore, each individual cultivar, semi-dwarf or tall, must be evaluated for adaptability to a certain region or management practice.

The semi-dwarf yield advantage over tall cultivars was greatest during cool and moist weather (1985), and lower during drier seasons (1986 and 1987). This could be explained by the findings of Cutforth et al. (1988), Brandle and Knott (1986), and Power and Alessi (1978), who suggest that semi-dwarfs perform best under conditions of abundant moisture. McNeal et al. (1972) attributed the semi-dwarfs' moisture dependence to a lack of previous selection pressure on these cultivars under stress conditions.

At 7-9%, the semi-dwarf yield advantage was not as great at Swan River in 1986 and 1987 as it was at other test sites. It was observed that at these sites, the semi-dwarfs had delayed maturity compared to the other more southern locations (personal observation, no data). Higher yielding cultivars tend to require more days to mature (Baker, 1990), and the lower relative advantage of the semi-dwarfs may be due to the shorter growing season and its associated frost risk at Swan River (Cutforth et al., 1990).

5.2 Management Intensity (Nitrogen)

Since, in Experiment 1, a move from the 'Low' to 'Medium' to 'High' management levels involves a simultaneous increase in both seeding and nitrogen rates, it is not possible to discern the reason for the observed yield changes. However, results from the seeding rate trials (Experiment 2) indicate that the range of seeding rates used in these studies had little effect on grain yield, and did not interact with nitrogen fertilizer rates. Therefore, the addition of fertilizer nitrogen was most likely responsible for any observed yield changes.

Cultivar types differed in their response to management inputs in the majority of trials conducted over three years. Statistically significant yield increases due to changes in management intensity occurred more frequently for the semi-dwarf than the tall cultivars (there were four significant responses to management intensity in six trials for the semi-dwarf cultivars, and only two significant responses to management intensity in six trials for the tall cultivars).

Although maximum yields were obtained at similar management levels for both cultivar types, incremental yield changes from one management level to the next were larger for the semi-dwarfs. Hence, production of the semi-dwarfs yielded the highest net returns at the 'Medium' management level, whereas tall cultivars had the highest net returns at the 'Low' management level. Higher grain yield responses to applied nitrogen by semi-dwarf cultivars have been reported by others (Gehl et al., 1990; Syltie and Dahnke, 1983), but similar responses have also been found (McNeal et al., 1960; McNeal et al., 1971).

Although as a group the semi-dwarf cultivars had similar responses to management intensity, there were still significant differences in the response of individual cultivars. HY320 was generally the most responsive cultivar, while the responses of the other semi-dwarfs varied from location to location, at times similar to but rarely worse than the tall cultivars. These results support the assertion by Blackman et al. (1978) and Thorne and Blacklock (1971) that varietal differences within each group of cultivars can be as large as differences between cultivar types. Results from Gehl et al. (1990) further support this observation. In their studies, semi-dwarfs were the highest and the lowest yielding cultivars in comparisons with tall cultivars, and also needed the highest and the lowest nitrogen rates to achieve maximum grain yield.

Splitting the application of the highest fertilizer nitrogen rate only increased grain yields significantly in 1986. Poor yield responses to the splitting of fertilizer nitrogen applications have also been reported by Boquet and Johnson (1987) and Roth and Marshall (1987). Since split applications of nitrogen are dependent on subsequent rainfall to wash the fertilizer into the root zone, the lack of response could have been due to low precipitation after application. Indeed, precipitation was low during the time that split applications were carried out (July) in 1985, and high in 1986 for the same time frame. Also, maximum grain yields may already have been reached with the initial fertilizer application, making subsequent applications unnecessary. Although split applications of nitrogen will optimize plant nutrition at important stages in its development (Spiertz and de Vos, 1983), split fertilizer applications may be more appropriate in regions where high nitrogen rates may be excessive when applied at one time (Effland, 1981), or where leaching of unused nitrogen may be high (Kirby and Appleyard, 1984).

5.3 Fungicide Application

The application of a foliar fungicide had mixed results. Tall cultivars treated with a fungicide did not have higher grain yields than the checks at any location in 1985, and at only one location in 1986. In contrast, statistically significant yield increases due to fungicide application occurred more frequently for the semi-dwarf cultivars in both years, and the yield increases were larger for the semi-dwarfs. In 1987, both cultivar types had significant yield increases in response to fungicide application, but the semi-dwarf yield increases were larger.

Generally, fungicide applications were profitable or nearly profitable for the semi-dwarf cultivars. For tall cultivars, fungicide applications were almost never economical. Among all cultivars in all years, HY320 benefitted the most from a fungicide application, and Katepwa benefitted the least. These results are supported by other researchers (Wright and Arnott, 1988; Rourke and Doell, 1986; Warkentin and Wright, 1986; Kharbanda and Turnbull, 1988; Kharbanda and Turnbull, 1987).

The reasons for differential responses of wheat cultivars to fungicide application are often attributed to varying degrees of disease resistance in the cultivars. Since susceptible cultivars suffer greater yield losses due to disease (Cook et al., 1981; Samborski and Peturson, 1960), they are more likely to benefit from the protection a fungicide can offer (Spiertz, 1970). However, genetic disease resistance does not fully explain yield response to fungicide applications in these or other tests (Cook, 1980). Although personal field observations suggest that HY320 is more susceptible to leaf spot diseases than Katepwa, HY320 is considered equivalent to Katepwa in stem rust resistance, superior to Katepwa in leaf rust resistance (Manitoba

Agriculture, 1989) and along with American semi-dwarf varieties similar to Katepwa in tanspot and Septoria spp. resistance (Lamamri, personal communication). It is therefore not possible to attribute HY320's greater benefit from a fungicide application to documented disease resistance. Instead, semi-dwarfs may benefit more than talls from a fungicide application because their shorter stature and internode length gives a denser canopy favoring splash dispersal of fungal spores of tanspot and Septoria spp., contributing to the more rapid spread of infection within a plant (Blackman et al., 1978).

At 1985 commodity prices, a yield increase of 227 and 251 kg ha^{-1} for tall and semi-dwarf cultivars, respectively, would have been necessary to cover the cost of fungicide treatment. Actual yield increases were -141 and 202 kg ha^{-1} for tall and semi-dwarf cultivars, respectively. At 1986 commodity prices, yield increases of 276 and 344 kg ha^{-1} would have been necessary to cover the cost of treatment. Actual yield increases in 1986 were 208 and 411 kg ha^{-1} for tall and semi-dwarf cultivars, respectively. Finally, at 1987 commodity prices, yield increases of 301 and 377 kg ha^{-1} for tall and semi-dwarf cultivars, respectively, would have been necessary to cover the cost of treatment. At Portage, actual yield increases for the semi-dwarf cultivars were 500 kg ha^{-1}, and 195 kg ha^{-1} for the tall cultivars. At Swan River, semi-dwarf yields increased by 670 kg ha^{-1} as a result of the fungicide application, while tall cultivar yields increasedd by 580 kg ha^{-1}. Cook (1980) considered fungicide application of winter wheat in Britain to be economical only 40% of the time on the average (118 experiments between 1970 and 1978), but 62% of the time if Septoria spp. were severe. A yield increase of 200 kg/ha was considered necessary to cover the cost of treatment. Mayfield (1985), also in Britain, found increases in spring wheat grain yield of 270 kg/ha to be barely sufficient to cover the cost of treatment. However, Eureopean cultivars, climatic conditions, commodity prices are significantly different from Canadian cultivars, climate, and commodity prices, therefore direct comparisons cannot accuratrely be made.

In Experiment 3, yield increases due to fungicide application were associated with increases in kernel weight, the number of kernels per head, and hectolitre weight of the grain. These results are in agreement with those reported by Dannenberg (1989), Mayfield (1985), Cook (1980), and Spiertz (1973). Protein content of the grain was sometimes reduced in Experiment 3, and at other times remained unchanged.

Although grain quality is not accounted for in the economic analyses, the larger, more uniform kernels produced by plants treated with a fungicide may be important to seed growers attempting to achieve lower cleanout losses and generally higher quality seed. Entz et al. (1990) showed that spring wheat treated with a foliar fungicide had a larger proportion of kernels in the >0.26 cm size class. It was suggested that kernel size may be an important factor affecting seedling vigor and crop performance. Therefore, fungicide use may be appropriate even if grain yield is not significantly affected.

The lack of an interaction between fungicide application and nitrogen fertility in 1987 indicates that fungicide responses are likely to occur under both high and low nitrogen fertility. Much of the literature suggests that increased nitrogen fertility aggravates disease severity, and that fungicides will therefore be of greater benefit at the high nitrogen rates (Prew et al., 1983; Jenkyn and Finney, 1981; Penny et al., 1983; Penny et al., 1978; Widdowson et al., 1976). These data were collected in the UK, under climatic conditions much more conducive to the growth of dense foliage and the development of disease. Therefore, nitrogen fertility may be of greater importance to the development of disease in the UK than in the drier climate of southern Manitoba.

Despite the absence of strong disease pressure in 1987 (personal observation), fungicides significantly increased yields of all cultivars. There are several possible reasons for this: The green leaf area duration may have been increased by the fungicides (Kettlewell and Davies, 1982), contributing to higher yields regardless of disease pressure (Austin, 1982; Spiertz et al., 1971). As well, soils with a high pH, such as those in southern Manitoba, may experience manganese deficiencies under certain conditions (Reid and Racz, 1985; Geering et al., 1969). Since mancozeb, the fungicide used in 1987, contains manganese, its foliar application may have increased yields by acting as a foliar fertilizer (Takkar et al., 1986). No soil or plant tissue analysis was conducted to verify this theory.

5.4 Seeding Rate

Changes in seeding rate did not affect grain yield significantly, although there were trends towards higher grain yields at high seeding rates. Most studies show yield responses to seeding rate changes (Pelton, 1969; Guitard et al., 1961;), but few evaluate narrow ranges in seeding rate. In these trials, grain yield differences may have been unpronounced because seeding rates were generally high and varied only slightly from recommended values. This may have allowed plants to compensate for changes in population density by altering the amount of grain produced per plant (Scott et al., 1977). Yield component analysis showed that as seeding rate increased, the number of heads m^{-2} increased, but the number of kernels per head decreased, keeping grain yield constant (data not shown). These yield component observations are in agreement with those found by Hucl and Baker (1990), Read and Warder (1982), Thorne and Blacklock (1971), and Guitard et al. (1961). Direct comparison of these results with existing literature is difficult because seeding rates are often expressed as kg/ha, with no mention of seed size or germination test results. This denies the reader knowledge of the actual seed density.

Seeding rate did not interact with nitrogen in any of the trials, suggesting that there is no benefit in accompanying increases in nitrogen fertility with increases in seeding rates above those currently recommended. This result is in agreement with much of the literature (Read and Warder, 1982; Pearman et al, 1977; Scott et al., 1977; Syme, 1972; Thorne and Blacklock, 1971). Wright et al. (1987) found that the optimum fertilizer rate was increased with increasing seed rate. They suggested that under the relatively humid conditions of northeastern Saskatchewan, maximum yields will be normally be achieved through a combination of high seed and fertilizer rates. Their seeding rates ranged from 22 to 124 kg/ha, which is a considerably wider span than that evaluated in these studies. It is possible that seeding rates evaluated in the present studies were already near optimum for high fertility situations.

5.5 Seeding Date

Grain yields decreased by an average of 18% as a result of a two week delay in seeding from the first week in May. Only in one instance (Portage, 1986) did delayed seeding result in a higher yield. These results re-emphasize the importance of early seeding previously pointed out by Ciha

(1983), Larter et al. (1971), Nass et al. (1975), and Anderson and Hennig (1964).

The assertion by Jessop and Ivins (1970), that the effect of seeding date on yield of spring wheat is related mainly to differences in weather at particular stages of development, could explain the unexpected yield increase at Portage in 1986. More favorable moisture or temperature conditions may have occurred for the late seeded crop. The weather data shows a hot and dry May (Figure A-8), a time during which an early seeded crop would be trying to get established. A later seeded crop would have avoided much of this moisture stress, and emerged in time for the cooler temperatures and the more abundant rainfall of June. As suggested by Cutforth et al. (1990), differences in yield responses to delayed seeding serve to emphasize that in any year, responses can differ from the norm and are primarily dependent upon the weather, especially rainfall.

These studies indicate that in most years, early seeding best provides the conditions necessary for high yields. These conditions could be a combination of the following: The use of spring moisture resulting from snow melt is maximized, plant stress at growth stages such as tillering, which is important for the development of yield potential is minimized (O'Leary et al., 1985), disease incidence may be reduced by avoiding incoming rust spores (Nass et al., 1975) and a longer green leaf area duration for the crop is provided (Spiertz et al., 1971). Seeding too early, however, may reduce seedling emergence due to cold spring conditions (Baker, 1990).

There were frequent interactions between cultivars and seeding dates. In 1985 and 1986, HY320 consistently yielded more than Oslo at the early seeding date. At the late seeding date, HY320 and Oslo yielded similarly. In 1987, Katepwa outyielded Roblin at the early seeding date, but Roblin outyielded Katepwa at the late seeding date. The required days to maturity of the cultivars may explain these interactions, as yield depression from late sowing may be less for early maturing varieties (Schmidt 1960). The late maturing cultivars HY320 and Katepwa performed better when seeded early, but lost their comparative advantage to the early maturing cultivars Oslo and Roblin when seeded late. This reasoning is supported by Harrington and Horner (1935). As well, HY320 requires more days to reach maturity, making it more susceptible to early fall frost damage and requiring earlier seeding on that basis (Baker, 1990; Cutforth et al, 1990).

Seeding date interactions with seeding rate or nitrogen fertilization occurred only once each in six trials. In both cases, wheat yields increased significantly with increases in fertilizer nitrogen (Portage, 1985) or seeding rate (Morris, 1985) at the early seeding date, but not at the late seeding date. This would indicate that early seeded crops are more likely to respond to higher levels of management than late seeded crops. This observation is contrary to those reported by Ciha (1983) and Schmidt (1960), who found non-significant seeding rate*seeding date and nitrogen*seeding date interactions.

CHAPTER 6

Conclusions

In these studies, semi-dwarf cultivars had significantly higher grain yields than tall cultivars. Generally, higher management levels were profitable for the semi-dwarf cultivars, but not for the tall cultivars. In particular, increased nitrogen fertilization and the use of a foliar fungicide were profitable more frequently for the semi-dwarfs than for the tall cultivars. On the average, when significant yield responses to management inputs occurred, the semi-dwarf cultivars earned the highest net returns with an application of 100 kg N ha^{-1} (Experiment 1) or 120 kg N ha^{-1} (Experiment 3). Tall cultivars earned the highest net returns with an application of 50 kg N ha^{-1} (Experiment 1) or 80 kg N ha^{-1} (Experiment 3).

Significant differences in agronomic performance within the group of semi-dwarf cultivars were noted throughout these studies. It was found that semi-dwarf cultivars varied among each other in overall yield and yield responsiveness to management inputs nearly as much as the semi-dwarfs varied from the tall cultivars. HY320 was consistently the highest yielding cultivar, the most responsive to applications of fertilizer nitrogen, and benefitted most from the application of a foliar fungicide. Katepwa and Glenlea had the lowest grain yields and were the least responsive to increases in fertilizer nitrogen rate and the application of a foliar fungicide. At Swan River, differences between cultivars in response to fungicide application were not as pronounced as at Portage in 1987.

Application of higher amounts of fertilizer nitrogen did not necessitate an increase in seeding rates and did not increase the benefits of a foliar fungicide application.

Delaying seeding by two to three weeks from the first week in May reduced yields significantly in five out of six trials, however, the yields of earlier maturing cultivars (Oslo and Roblin) were not reduced as much as those of late maturing cultivars (HY320 and Katepwa). The late maturing cultivars always had higher yields than the early maturing cultivars when seeded early (first week in May), but when seeded late, the early maturing cultivars at times outyielded the late maturing cultivars.

LIST OF REFERENCES

American Association of Cereal Chemists. 1983. Standard AACC method 39-10. In: Approved Methods of the American Association of Cereal Chemists, 8th edition. St.Paul, Minn, AACC Inc.

Anderson, C.H. and A.M.H. Hennig. 1964. The effect of date of seeding and fertility level on the yield of wheat, oats, and barley in northwestern Alberta. Can.J.Plant Sci. 44:15-20.

Austin, R.B. 1982. Crop characteristics and the potential yield of wheat. J.Agric.Sci.,Cambr. 98:447-453.

Bainridge, A. 1974. Effect of nitrogen nutrition on the host of barley powdery mildew. Pl.Path. 23:160-161.

Baker, R.J. 1990. Agronomic performance of semi-dwarf and normal height spring wheats seeded at different dates. Can.J.Plant Sci. 70:295-298.

Baker, R.J. 1982. Effect of seeding rate on grain yield, straw yield and harvest index of eight spring wheat cultivars. Can.J.Plant Sci. 62:285-291.

Baker, R.J. 1977. Yield of pure and mixed stands of two spring wheat cultivars sown at five rates of seeding. Can.J.Plant Sci. 57:1005-1007.

Blackman, J.A., J. Bingham and J.L. Davidson. 1978. Response of semi-dwarf and conventional winter wheat varieties to the application of nitrogen fertilizer. J.Agric.Sci.,Cambr. 90:543-550.

Boquet, D.J. and C.C. Johnson. 1987. Fertilizer effects on yield, grain composition, and foliar disease of doublecrop soft red winter wheat. Agron.J. 79:135-141.

Brandle, J.E. and D.R. Knott. 1986. The effect of a gene for semi-dwarfism (Rht1) on various characteristics in a spring wheat cross. Can.J.Plant Sci. 66:529-533.

Briggs, K.G. 1975. Effects of seeding rate and row spacing on agronomic characteristics of Glenlea, Pitic 62 and Neepawa wheats. Can.J.Plant Sci. 55:363-367.

Briggs, K.G and A. Aytenfisu. 1979. The effects of seeding rate, seeding date and location on grain yield, maturity, protein percentage and protein yield of some spring wheats in central Alberta. Can.J.Plant Sci. 59:1139-1145.

Caldwell, C.D. and C.E. Starratt. 1987. Response of Max spring wheat to management inputs. Can.J.Plant Sci. 67:645-652.

Campbell, A.B. and E. Czarnecki. 1987. Roblin hard red spring wheat. Can.J.Plant Sci. 67:803-804.

Campbell, C.A., D.R. Cameron, W. Nicholaichuk and H.R. Davidson. 1977. Effects of fertilizer N and soil moisture on growth, N content, and moisture use by spring wheat. Can.J.Soil Sci. 57:289-310.

Campbell, C.A. and H.R. Davidson. 1979. Effects of temperature, nitrogen fertilization and moisture stress on growth, assimilate distribution and moisture use by Manitou spring wheat. Can.J.Plant Sci. 59:603-626.

Campbell, C.A., H.R. Davidson and F.G Warder. 1977. Effects of fertilizer N and soil moisture on yield, yield components, protein content and N accumulation in the aboveground parts of spring wheat. Can.J.Soil Sci. 57:311-327.

Carlson, G.A. 1970. A decision theoretic approach to crop disease prediction and control. Am.J.Agr.Econ. 52:216-226.

Carmer, S.G. 1976. Optimal significance levels for application of the least significant difference in crop performance trials. Crop Sci. 16:95-99.

Carmer, S.G. and W.M. Walker. 1982. Baby Bear's dilemma: A statistical tale. Agron.J. 74:122-124.

Carter, C.A., R.M.A. Loyns and Z.F. Ahmadi-Esfahani. 1986. Varietal licensing standards and Canadian wheat exports. Can.J.Agric.Econ. 34:361-377.

Ciha, A.J. 1983. Seeding rate and seeding date effects on spring seeded small grain cultivars. Agron.J. 75:795-799.

Clarke, J.M., C.A. Campbell, H.W. Cutforth, R.M. DePauw and G.E Winkleman. 1990. Nitrogen and phosphorus uptake, translocation, and utilization efficiency of wheat in relation to environment and cultivar yield and protein levels. Can.J.Plant Sci. 70:965-977.

Cook, R.J. 1981. The deployment of fungicides in cereals. p. 91-99. In: J.F. Jenkyn and R.T.Plumb (ed.) Strategies for the Control of Cereal Disease. London, Blackwell Scientific Publications.

Cook, R.J. 1980. Effect of late-season fungicide sprays on yield of winter wheat. Pl.Path. 29:21-27.

Cook, R.J. 1977. Effect of timed fungicide sprays on yield of winter wheat in relation to Septoria infection periods. Pl.Path. 26:30-34.

Cutforth, H.W., C.A. Campbell, S.A Brandt, J. Hunter, D. Judiesch, R.M DePauw and J.M. Clarke. 1990. Development and yield of Canadian Western Red Spring and Canada Prairie Spring wheats as affected by delayed seeding in the brown and dark brown soil zones of Saskatchewan. Can.J.Plant Sci. 70:639-660.

Cutforth, H.W., C.A. Campbell, Y.W. Jame, J.M. Clarke and R.M. DePauw. 1988. Growth characteristics, yield components and rate of grain development of two high-yielding wheats, HY320 and DT367, compared to two standard cultivars, Neepawa and Wakooma. Can.J.Plant Sci. 68:915-928.

Dannenberg, M.D., M.G. Eversmeyer and C.L. Kramer. 1989. Effect of timing of foliar fungicides on wheat disease control and yield increases. Plant Dis. 73:227-229.

Darby, R.J., F.V. Widdowson and M.V. Hewitt. 1984. Comparisons between the establishment, growth and yield of winter wheat on three clay soils, in experiments testing nitrogen fertilizer in combination with aphicide and fungicides, from 1980 to 1982. J.Agric.Sci.,Cambr. 103:595-611.

Davies, W.P., P.S. Kettlewell and H.J. Green. 1984. Senescence and net photosynthesis of the flag leaf and grain growth of wheat in response to fungicide. Ann.Appl.Biol. 105:303-312.

DePauw, R.M., E.A. Hurd, T.F Townley-Smith, G.E McCrystal and C.W.B. Lendrum. 1987. HY320 red spring wheat. Can.J.Plant Sci. 67:807-811.

Dillon, J.L. and R.R. Officer. 1971. Economic v. statistical significance in agricultural research and extension: A pro-Bayesian view. Fm. Econ. 12:31-45.

Effland, H.C. 1981. Disease management in high-input cereal growing in Schleswig-Holstein. p. 189-195. In: J.F. Jenkyn and R.T.Plumb (ed.) Strategies for the Control of Cereal Disease. London, Blackwell Scientific Publications.

Entz, M.H., C.G.J. Van den Berg, G.P. Lafond, E.H. Stobbe, B.G. Rossnagel and H.M. Austenson. 1990. Effect of late-season fungicide application on grain yield and seed size distribution in wheat and barley. Can.J.Plant Sci. 70:699-706.

Evans, S.A. 1981. Constraints on cereal production and strategies of disease control. p. 197-203. In: J.F. Jenkyn and R.T.Plumb (ed.) Strategies for the Control of Cereal Disease. London, Blackwell Scientific Publications.

Falisse, A. and B. Bodson. 1984. Development of high-input systems of cereal production in Europe. p. 273-283. In: E.J. Gallagher (ed.) Cereal Production. Butterworths, London.

Geering, H.R., J.F. Hodgson and C. Sdano. 1969. Micronutrient cation complexes in soil solution: IV. The chemical state of manganese in soil solution. Soil Sci. Soc. Amer. Proc. 33:81-85.

Gehl, D.T. and J.M. Sadler. 1987. Nitrogen requirements of spring wheats - do the semi-dwarfs need more? p. 45-48. In: Technical and Scientific Papers presented at Manitoba Agri-Forum, December, 1987, Winnipeg, Manitoba.

Gehl, D.T., L.D. Bailey, C.A. Grant and J.M. Sadler. 1990. Effects of incremental N fertilization on grain yield and dry matter accumulation of six spring wheat (Triticum aestivum L.) cultivars in southern Manitoba. Can.J.Plant Sci. 70:51-60.

Gilligan, C.A. 1986. Use and misuse of the analysis of variance in plant pathology. p. 226-261. In: Advances in Plant Pathology. Academic Press, London.

Green, C.F. and T.C.K. Dawkins. 1986. Influence of nitrogen fertilizer and chlormequat on two spring wheat cultivars. Crop Res. 25:89-101.

Guitard, A.A., J.A. Newman and P.B. Hoyt. 1961. The influence of seeding rate on the yield and the yield components of wheat, oats and barley. Can.J.Plant Sci. 41:751-758.

Grant, C.A., L.E. Gauer, D.T. Gehl and L.D Bailey. 1991. Yield response of semidwarf and conventional height barley cultivars to nitrogen fertilizer under varying moisture conditions. Can.J.Plant Sci. 71:361-371.

Harrington, J.B. and W.H. Horner. 1935. The reaction of wheat varieties to different dates of sowing. Scientific Agriculture 16:127-133.

Hubbard. K.R. 1984. Cereal production systems-the English experience. p.285-296. In: E.J. Gallagher (ed.) Cereal Production. Butterworths, London.

Hucl, P. and R.J. Baker. 1990. Seeding rate effects on low-tillering spring wheat in a semiarid environment. Can.J.Plant Sci. 70:9-17.

Irwin, R.D. 1983. Fungicide control of leaf rust and leaf spots of hard red spring wheat, 1982. Fungic.Nematic.Tests 38:56.

Jenkins, J.E.E. and S.C. Melville. 1972. The effect of fungicides on leaf diseases and on yield in spring barley in south-west England. Pl.Path. 21:49-58.

Jenkyn, J.F. and M.E. Finney. 1981. Fungicides, fertilizers and sowing date. p. 179-188. In: J.F. Jenkyn and R.T.Plumb (ed.) Strategies for the Control of Cereal Disease. London, Blackwell Scientific Publications.

Jenkyn, J.F. and J.R. Moffatt. 1975. The effect of ethirimol seed dressings on yield of spring barley grown with different amounts of nitrogen fertilizer 1969-71. Pl.Path. 24:16-21.

Jessop, R.S. and J.D. Ivins. 1970. The effect of date of sowing on the growth and yield of spring cereals. J.Agric.Sci.,Cambr. 75:553-557.

Jordan, V.W.L. and G.R. Stinchcombe. 1986. Interactions between fungicide, plant growth regulator, nitrogen fertiliser applications, foliar disease and yield of winter barley. Ann.Appl.Biol. 108:151-165.

Karlen, D.L. and D.T. Gooden. 1990. Intensive management practices for wheat in the southeastern Coastal Plains. J.Prod.Agric. 3:558-563.

Kettlewell, P.S. and W.P. Davies. 1982. Disease development and senescence of the flag leaf of winter wheat in response to propiconazole. J.Agric.Sci.,Cambr. 99:661-663.

Kharbanda, P.D. and G. Turnbull. 1987. Effectiveness of foliar applied fungicides on septoria leaf and glume blotch and leaf rust of wheat. Expert Committee on Pest.Use in Agric.Res.Rep., p. 280.

Kharbanda, P.D. and G. Turnbull. 1988. Evaluation of foliar applied fungicides to control septoria leaf and glume blotch of wheat. Expert Committee on Pest.Use in Agric.Res.Rep., p. 252.

Kirby, E.M.J. and M. Appleyard. 1984. Cereal plant development and its relation to crop management. p. 161-173. In: E.J. Gallagher (ed.) Cereal Production. Butterworths, London.

Kosmolak, F.G. and W.L Crowle. 1980. An effect of nitrogen fertilization on the agronomic traits and dough mixing strengths of five Canadian hard red spring wheat cultivars. Can.J.Plant Sci. 60:1071-1076.

Larter, E.N., P.J. Kaltsikes and R.C. McGinnis. 1971. Effect of date and rate of seeding on the performance of triticale in comparison to wheat. Crop Sci. 11:593-595.

Lupton, F.G.H., R.H. Oliver and P. Ruckenbauer. 1974. An analysis of the factors determining yields in crosses between semi-dwarf and taller wheat varieties. J.Agric.Sci.,Cambr. 82:483-496.

Manitoba Agriculture. 1989. 1989 field crop variety recommendations for Manitoba. Manitoba Agriculture Publications Division, Winnipeg, MB.

Mascianica, M.P. 1985. Rust susceptibility and fungicide response in three spring wheat cultivars, 1984. Fungic.Nematic.Tests 40:137.

Mayfield, A.H. 1985. Efficacies of fungicides for control of stem rust of wheat. Aust.J.Exp.Agric.Anim.Husb. 25:440-443.

McFadden, A.D. 1970. Influence of seeding dates, seeding rates, and fertilizers on two cultivars of barley. Can.J.Plant Sci. 50:693-699.

McNeal, F.H., M.A. Berg, P.L. Brown and C.F. McGuire. 1971. Productivity and quality response of five spring wheat genotypes, Triticum aestivum L., to nitrogen fertilizer. Agron.J. 63:908-910.

McNeal, F.H., M.A. Berg and M.G. Klages. 1960. Evaluation of semidwarf selections from a spring wheat breeding program. Agron.J. 52:710-712.

McNeal, F.H., M.A. Berg, V.R. Stewart and D.E. Baldridge. 1972. Agronomic response of three height classes of spring wheat, Triticum aestivum L., compared at different yield levels. Agron.J. 64:362-364.

McNeal, F.H., C.A. Watson and H.A. Kittams. 1963. Effects of dates and rates of nitrogen fertilization on the quality and field performance of five hard red spring wheat varieties. Agron.J. 55:470-472.

Nass, H.G., H.W. Johnston, J.A. McLeod and J.D.E. Sterling. 1975. Effects of seeding date, seed treatment and foliar sprays on yield and other agronomic characters of wheat, oats and barley. Can.J.Plant Sci. 55:41-47.

O'Leary, G.J., D.J. Conner and D.H. White. 1985. Effect of sowing time on growth, yield and water-use of rain-fed wheat in the Wimmera, Vic. Aust.J.Agric.Res. 36:187-196.

Pearman, I., S.M Thomas and G.N Thorne. 1977. Effects of nitrogen fertilizer on growth and yield of spring wheats. Ann.Bot. 41:93-108.

Pearson, T.D.G. 1981. Disease control on the farm. p. 205-209. In: J.F. Jenkyn and R.T.Plumb (ed.) Strategies for the Control of Cereal Disease. London, Blackwell Scientific Publications.

Pelton, W.L. 1969. Influence of low seeding rates on wheat yield in southwestern Saskatchewan. Can.J.Plant Sci. 49:607-614.

Penny, A., F.V. Widdowson and J.F. Jenkyn. 1983. Experiments with solid and liquid N-fertilizers and fungicides on winter wheat at Saxmundham, Suffolk. J.Agric.Sci.,Cambr. 100:163-173.

Penny, A., F.V. Widdowson and J.F. Jenkyn. 1978. Spring top dressings of 'Nitro-Chalk' and late sprays of liquid N-fertilizer and a broad spectrum fungicide for consecutive crops of winter wheat at Saxmundham, Suffolk. J.Agric.Sci.,Cambr. 90:509-516.

Pepe, J.F. and R.E. Heiner. 1975. Plant height, protein percentage, and yield relationships in spring wheat. Crop Sci. 15:793-797.

Petersen, R.G. 1977. Use and misuse of multiple comparison procedures. Agron.J. 69:205-208.

Pew, B.V., M.E. Wetzstein, J.E. Epperson and D.J. Robertson. 1982. Economics of selected integrated pest management production systems in Georgia. The University of Georgia College of Agriculture Experimental Stations Research Report #395.

Platford, G. 1987. Occurrence of plant diseases in Manitoba crops in 1987. p. 17-18. In: Technical and Scientific Papers presented at Manitoba Agri-Forum, December, 1987, Winnipeg, Manitoba.

Power, J.F. and J. Alessi. 1978. Tiller development and yield of standard and semidwarf spring wheat varieties as affected by nitrogen fertilizer. J.Agric.Sci.,Cambr. 90:97-108.

Prew, R.D. 1981. Cropping systems in relation to soil-borne and trash-borne diseases of cereals. p. 149-156. In: J.F. Jenkyn and R.T.Plumb (ed.) Strategies for the Control of Cereal Disease. London, Blackwell Scientific Publications.

Prew, R.D., B.M. Church, A.M. Dewar, J. Lacey, A. Penny, R.T. Plumb, G.N. Thorne, A.D. Todd and T.D. Williams. 1983. Effects of eight factors on the growth and nutrient uptake of winter wheat and on the incidence of pests and diseases. J.Agric.Sci.,Cambr. 100:363-382.

Rajaram, S and W.L. Nelson. 1984. Wheat production systems in arid and semi-arid regions. p.305-324. In: E.J. Gallagher (ed.) Cereal Production. Butterworths, London.

Read, D.W.L. and F.G. Warder. 1982. Wheat and barley responses to rates of seeding and fertilizer in southwestern Saskatchewan. Agron.J. 74:33-36.

Reid, J.M and G.J. Racz. 1985. Effects of soil temperature on manganese availability to plants grown on organic soil. Can.J.Soil Sci. 65:769-775

Reitz, L.P. and S.C. Salmon. 1968. Origin, history, and use of Norin 10 wheat. Crop Sci. 8:686-689.

Roth, G.W. and H.G. Marshall. 1987. Effects of timing of nitrogen fertilization and a fungicide on soft red winter wheat. Agron.J. 79:197-200.

Roth, G.W., H.G. Marshall, O.E. Hatley and R.R. Hill, Jr. 1984. Effect of management practices on grain yield, test weight, and lodging of soft red winter wheat. Agron.J. 76:379-383.

Rourke, D.R.S. 1986. Intensive management of wheat in western Canada. p. 69-86. In: A.E. Slinkard and D.B Fowler (ed.). Wheat Production in Canada-a Review. Saskatoon, SK, University of Saskatchewan.

Rourke, D.R.S. and R.J. Doell. 1987. Control of foliar diseases in HY320 wheat grown at six densities. Expert Committee on Pest.Use in Agric.Res.Rep., p. 269.

Rourke, D.R.S. and R.J. Doell. 1987. Control of foliar diseases in Katepwa wheat grown at six densities. Expert Committee on Pest.Use in Agric.Res.Rep., p. 270.

Rourke, D.R.S. and R.J. Doell. 1986. Control of foliar diseases in Katepwa wheat. Expert Committee on Pest.Use in Agric.Res.Rep., p. 291.

Rourke, D.R.S. and R.J. Doell. 1986. Control of foliar diseases in HY320 wheat. Expert Committee on Pest.Use in Agric.Res.Rep., p. 292.

Rowell, J.B. 1981. Control of stem rust on spring wheat by triadimefon and fenapanil. Plant Dis. 65:235-236.

Samborski, D.J. and B. Peturson. 1960. Effect of leaf rust on the yield of resistant wheats. Can.J.Plant Sci. 40:620-622.

Schmidt, D.R. 1960. Response of spring oat varieties to different planting dates and soil fertility levels. Agron.J. 52:695-696.

Scott, W.R., C.T. Dougherty and R.H.M. Langer. 1977. Development and yield components of high-yielding wheat crops. N.Z.J.Agric.Res. 20:205-212.

Spiertz, J.H.J. 1973. Effects of successive applications of maneb and benomyl on growth and yield of five wheat varieties of different heights. Neth.J.Agric.Sci. 21:282-296.

Spiertz, J.H.J. and N.M. de Vos. 1983. Agronomical and physiological aspects of the role of nitrogen in yield formation of cereals. Plant Soil 75:379-391.

Spiertz, J.H.J., B.A. ten Hag and L.J.P. Kupers. 1971. Relation between green area duration and grain yield in some varieties of spring wheat. Neth.J.Agric.Sci. 19:211-222.

Spiertz, J.H.J. and H. van de Haar. 1978. Differences in grain growth, crop photosynthesis and distribution of assimilates between a semi-dwarf and a standard cultivar of winter wheat. Neth.J.Agric.Sci. 26:233-249.

Sutton, J.C. and G. Roke. 1986. Interactive effects of foliar diseases and fungicide sprays in cultivars of winter wheat in Ontario. Can.Plant Dis.Surv. 66:37-41.

Swallow, W.H. 1984. Those overworked and oft-misused mean separation procedures-Duncan's, LSD, etc. Plant Dis. 10:919-921.

Syltie, P.W. and W.C. Dahnke. 1983. Mineral and protein content, test weight, and yield variations of hard red spring wheat grain as influenced by fertilization and cultivar. Qual. Plant Foods Hum.Nutr. 32:37-50.

Syme, J.R. 1972. Features of high-yielding wheats grown at two seed rates and two nitrogen levels. Aust.J.Exp.Agric.Anim.Husb. 12:165-170.

Takkar, V.K., V.K. Nayyar and U.S. Sadana. 1986. Response of wheat on coarse textured soils to mode and time of manganese application. Expl. Agric. 22:149-152.

Thorne, G.N. and J.C. Blacklock. 1971. Effects of plant density and nitrogen fertilizer on growth and yield of short varieties of wheat derived from Norin 10. Ann.Appl.Biol. 78:93-111.

Thorne, G.N., P.J. Welbank and G.C. Blackwood. 1969. Growth and yield of six short varieties of spring wheat derived from Norin 10 and of two European varieties. Ann.Appl.Biol. 63:241-251.

Walker, G.K. 1989. Weather sensitivity of western Canada wheat yield, 1900-1988. Can.J.Soil Sci. 69:857-865.

Walsh, E.J. 1984. Developing yield potential of cereals. p.69-93. In: E.J. Gallagher (ed.) Cereal Production. Butterworths, London.

Warkentin, T.D and E.B. Wright. 1987. Evaluation of Tilt and Tilt plus mixtures for foliar disease control on Oslo spring wheat. Expert Committee on Pest.Use in Agric.Res.Rep., p. 294.

Warkentin, T.D and E.B. Wright. 1986. Evaluation of foliar applications of Tilt for disease control in HY320 wheat. Expert Committee on Pest.Use in Agric.Res.Rep., p. 294.

Webster, J.P.G. 1975. The analysis of risky farm management decisions: Advising farmers about the use of pesticides. J.Agric.Econ. 28:243-259.

Webster, J.P.G. and R.J. Cook. 1979. Judgmental probabilities for the assessment of yield response to fungicide application against septoria on winter wheat. Ann.Appl.Biol. 92:39-48.

Welbank, P.J., S.A.W. French and K.J. Witts. 1966. Dependence of yields of wheat varieties on their leaf area durations. Ann.Bot. 30:291-299.

Widdowson, F.V., J.F. Jenkyn and A. Penny. 1976. Results from two barley experiments at Saxmundham, Suffolk, measuring effects of the fungicide benadonil on three varieties, given three amounts of nitrogen at two times 1973-4. J.Agric.Sci.,Camb. 86:271-280.

Wright, A.T., L.H. Gutek and W.F. Nuttall. 1987. Effect of seed and fertilizer rate on yield of spring wheat grown on fallow and stubble. Can.J.Plant Sci. 67:813-816.

Wright, E.B. and R.G. Arnott. 1988. Evaluation of Tilt and Tilt plus mixtures for foliar disease control in HY320 spring wheat. Expert Committee on Pest.Use in Agric.Res.Rep., p. 265.

Zebarth, B.J. and R.W. Sheard. 1991. Response of barley yield and yield components to nitrogen rate under low and high input management systems. Can.J.Plant Sci. 71:71-80.

Table A-1: Analysis of variance for grain yield, Experiment 1, 1985.

Source of Variation	Minto D.F.	Minto Mean Square		Morris D.F.	Morris Mean Square		Portage D.F.	Portage Mean Square	
Replication	3	534739		3	80776		3	5496972	
Management	4	555513	ns	4	2128331	**	4	3394792	ns
Error a: Rep.*Mgmt.	12	1548693		12	78092		12	1524125	
Cultivar	4	7522364	**	5	4824473	**	5	2832883	**
Error b: Rep.*Cult.	12	228906		15	67620		15	413106	
Mgmt.*Cult.	16	315389	ns	20	125092	**	20	491342	ns
Error c: Rep.*Mgmt.*Cult	48	191690		60	50891		60	503675	

Table A-2: Analysis of variance for grain yield, Experiment 1, 1986.

Source of Variation	Minto D.F.	Minto Mean Square		Portage D.F.	Portage Mean Square		Swan River D.F.	Swan River Mean Square	
Replication	3	9482020		2	1493590		3	1016730	
Management	4	7667040	**	4	2155557	ns	4	4108149	**
Error a: Rep.*Mgmt.	12	537207		12	752229		12	110431	
Cultivar	5	4261855	**	5	6836253	**	5	1073255	**
Error b: Rep.*Cult.	15	287694		15	581739		15	185387	
Mgmt.*Cult.	20	292633	**	20	331417	ns	20	104909	ns
Error c: Rep.*Mgmt.*Cult.	60	80324		40	295670		58	65308	

Table A-3: Analysis of variance for grain yield, Experiment 2, 1985.

Source of Variation	Minto D.F.	Minto Mean Square		Morris D.F.	Morris Mean Square		Portage D.F.	Portage Mean Square	
Replication	3	912192		3	447358		3	4049519	
Nitrogen	2	1641473	ns	2	144569	ns	2	593871	ns
Nit. Linear	1	3055921	ns	1	267903	ns	1	735700	ns
Nit. Quadratic	1	227026	ns	1	21234	ns	1	452042	ns
Error a:									
Rep.*Nit.	6	1473351		6	231460		6	900372	
Cultivar	1	12147548	**	1	9689856	**	1	38025	ns
Seedrate (SR)	2	178228	ns	2	121152	ns	2	72853	ns
SR Linear	1	310879	ns	1	67450	ns	1	133355	ns
SR Quadratic	1	45577	ns	1	174853	ns	1	12351	ns
Seeddate (SD)	1	41733753	**	1	37350025	**	1	56997467	**
Cult.*Nit.	2	371991	ns	2	22764	ns	2	75187	ns
Cult.*SR	2	690568	*	2	167129	ns	2	103183	ns
Cult.*SD	1	10955	ns	1	7197273	**	1	486506	ns
Nit.*SR	4	183338	ns	4	23074	ns	4	19058	ns
Nit.*SD	2	127152	ns	2	114312	ns	2	820103	*
SR*SD	2	387826	ns	2	434172	*	2	817	ns
Cult.*SR*SD	2	50239	ns	2	61271	ns	2	4038	ns
Nit.*SR*SD	4	366505	ns	4	5590	ns	4	59692	ns
Cult.*Nit.*SR	4	177935	ns	4	8574	ns	4	15299	ns
Cult.*Nit.*SD	2	223017	ns	2	138878	ns	2	643137	*
Cult.*Nit.*SR*SD	4	312693	ns	4	4204	ns	4	43007	ns
Error b:	99	202151		99	97708		99	205094	

Table A-4: Analysis of variance for grain yield, Experiment 2, 1986.

Source of Variation	Minto D.F.	Minto Mean Square		Portage D.F.	Portage Mean Square		Swan River D.F.	Swan River Mean Square	
Replication	3	1967705		3	2805247		3	99961	
Nitrogen	2	546843	ns	2	9927088	**	2	3070817	**
Nit. Linear	1	994301	ns	1	18974817	**	1	5866008	**
Nit. Quadratic	1	99384	ns	1	879359	ns	1	275625	ns
Error a: Rep.*Nit.	6	311792		6	484959		6	260493	
Cultivar	1	204003	ns	1	29184305	**	1	1540012	**
Seedrate (SR)	2	4681811	**	2	490141	ns	2	30279	ns
SR Linear	1	9102017	**	1	980104	ns	1	35752	ns
SR Quadratic	1	261606	ns	1	177	ns	1	24806	ns
Seeddate (SD)	1	13189003	**	1	26895460	**			
Cult.*Nit.	2	218255	ns	2	249132	ns	2	52650	ns
Cult.*SR	2	502078	ns	2	387974	ns	2	86129	ns
Cult.*SD	1	6208403	**	1	3618555	**			
Nit.*SR	4	326878	ns	4	52128	ns	4	74227	ns
Nit.*SD	2	68651	ns	2	1110864	ns			
SR*SD	2	292411	ns	2	29577	ns			
Cult.*SR*SD	2	21545	ns	2	441602	ns			
Nit.*SR*SD	4	236415	ns	4	532988	ns			
Cult.*Nit.*SR	4	104605	ns	4	170751	ns	4	49411	ns
Cult.*Nit.*SD	2	3613	ns	2	386634	ns			
Cult.*Nit.*SR*SD	4	212267	ns	4	95519	ns			
Error b:	99	169513		99	399095		45	87239	

Table A-5: Analysis of variance for grain yield, Experiment 2, 1987.

Source of Variation	Portage (Early Seeding) D.F.	Portage (Early Seeding) Mean Square		Portage (Late Seeding) D.F.	Portage (Late Seeding) Mean Square		Swan River D.F.	Swan River Mean Square	
Replication	3	140996		3	44888		3	839713	
Nitrogen	2	3944362	**	2	722912	**	2	584206	ns
Nit. Linear	1	7626494	**	1	1050462	**	1	1088416	*
Nit. Quadratic	1	262229	ns	1	395361	*	1	79995	ns
Error a: Rep.*Nit.	6	68616		6	51099		6	145903	
Cultivar	1	1156467	**	1	2270228	**	1	261485	ns
Seedrate (SR)	2	20723	ns	2	74824	ns	2	1729483	**
SR Linear	1	11	ns	1	44420	ns	1	1359124	ns
SR Quadratic	1	20712	ns	1	117388	*	1	2099843	*
Cult.*SR	2	91707	ns	2	204159	**	2	158901	ns
Nit.*SR	4	102770	ns	4	11947	ns	4	537538	ns
Cult.*Nit.	2	23764	ns	2	138825	*	2	37290	ns
Cult.*Nit.*SR	4	98631	ns	4	44266	ns	4	109791	ns
Error b:	45	57768		41	34018		45	341334	

Table A-6: Analysis of variance for grain yield, Experiment 3, 1987.

Source of Variation	Portage D.F.	Portage Mean Square		Swan River D.F.	Swan River Mean Square	
Replication	3	380029		3	361161	
Cultivar	3	15562616	**	3	6803063	**
Error a: Rep.*Cult.	9	173053		9	165243	
Nitrogen	3	5326140	**	3	144451	ns
Nit. Linear	1	14042705	**	1	41072	ns
Nit. Quadratic	1	2065011	**	1	278351	ns
Error b: Rep.*Nit.	9	68516		9	165243	
Cult.*Nit.	9	109966	ns	9	81995	ns
Error c: Rep.*Cult.*Nit.	27	54662		27	95586	
Fungicide	1	3615044	**	1	12573232	**
Fung.*Nit.	3	55727	ns	3	328603	ns
Error d: Rep.*Fung. +Rep.*Fung.*Nit.	12	55861		12	203528	
Cult.*Fung.	3	363636	**	3	188360	*
Cult.*Nit.*Fung.	9	12990	ns	9	33604	ns
Error e: Rep.*Fung.*Cult. +Rep.*Fung.*Cult.*Nit.	35	44742		36	48633	

Table A-7: Partial analysis of variance for grain yield, Experiment 1, Minto, 1985.

Source of Variation	D.F.	Sums of Squares	Mean Square	
Cultivars	4	30,089,456	7,522,364	**
Conventional	0	0	-	
Semi-Dwarf	3	10,505,291	3,501,764	**
Semi vs. Con.	1	19,584,165	19,584,165	**
Cultivar*Mgmt	16	5,046,219	315,389	ns
Con.*Mgmt	0	0	-	
Semi*Mgmt	12	3,894,397	324,533	ns
Type*Mgmt	4	1,151,823	287,956	ns

Table A-8: Partial analysis of variance for grain yield, Experiment 1, Morris, 1985.

Source of Variation	D.F.	Sums of Squares	Mean Square	
Cultivars	5	24,122,363	4,824,473	**
Conventional	1	49,472	49,472	ns
Semi-Dwarf	3	3,658,838	1,219,613	**
Semi vs. Con.	1	20,414,053	20,414,053	**
Cultivar*Mgmt	20	2,501,849	125,092	**
Con.*Mgmt	4	320,376	80,094	ns
Semi*Mgmt	12	606,825	50,819	ns
Type*Mgmt	4	1,571,648	392,912	**

Table A-9: Partial analysis of variance for grain yield, Experiment 1, Portage, 1985.

Source of Variation	D.F.	Sums of Squares	Mean Square	
Cultivars	5	14,164,417	2,832,883	**
Conventional	1	625,000	625,000	ns
Semi-Dwarf	3	2,659,375	886,458	ns
Semi vs. Con.	1	10,880,042	10,880,042	*
Cultivar*Mgmt	20	9,826,833	491,342	ns
Con.*Mgmt	4	1,367,500	341,875	ns
Semi*Mgmt	12	3,998,750	333,229	ns
Type*Mgmt	4	4,460,583	1,115,146	ns

Table A-10: Partial analysis of variance for grain yield, Experiment 1, Minto, 1986.

Source of Variation	D.F.	Sums of Squares	Mean Square	
Cultivars	5	21,309,277	4,261,855	**
Conventional	1	338,560	338,560	ns
Semi-Dwarf	3	3,711,510	1,237,170	ns
Semi vs. Con.	1	17,259,207	17,259,207	**
Cultivar*Mgmt	20	5,852,659	292,633	**
Con.*Mgmt	4	1,250,003	312,501	*
Semi*Mgmt	12	3,649,956	304,163	**
Type*Mgmt	4	952,701	238,175	ns

Table A-11: Partial analysis of variance for grain yield, Experiment 1, Portage, 1986.

Source of Variation	D.F.	Sums of Squares	Mean Square	
Cultivars	5	34,181,267	6,836,253	**
Conventional	1	833,333	833,333	ns
Semi-Dwarf	3	24,662,313	8,220,771	**
Semi vs. Con.	1	8,685,620	8,685,620	ns
Cultivar*Mgmt	20	6,628,344	331,417	ns
Con.*Mgmt	4	947,633	236,908	ns
Semi*Mgmt	12	5,255,120	437,927	ns
Type*Mgmt	4	425,591	106,398	ns

Table A-12: Partial analysis of variance for grain yield, Experiment 1, Swan River, 1986.

Source of Variation	D.F.	Sums of Squares	Mean Square	
Cultivars	5	5,366,277	1,073,255	**
Conventional	1	47,108	47,108	ns
Semi-Dwarf	3	3,663,741	1,221,247	**
Semi vs. Con.	1	1,728,311	1,728,311	ns
Cultivar*Mgmt	20	2,098,181	104,909	ns
Con.*Mgmt	4	37,419	9,355	ns
Semi*Mgmt	12	1,969,980	141,415	*
Type*Mgmt	4	341,927	85,482	ns

Table A-13: Effect of management level on grain yield (kg ha^{-1}) of several wheat cultivars. Morris, 1985.

Management Level	Cultivar HY320	Marshall	Oslo	Solar	Katepwa	Glenlea
Low	4120 d[1]	4265 d	3995 d	3920 c	3410	3825
Med	4585 bc	5040 bc	4350 c	4265 b	3635	3695
High	4395 cd	4825 c	4490 bc	4330 b	3750	3675
HiF	4960 ab	5175 ab	4730 ab	4490 b	3735	3750
HFS	5275 a	5400 a	4855 a	4870 a	4005	3940

1. 1. Means within a column followed by the same letter do not differ significantly (LSD, 5%).

Table A-14: Effect of management level on grain yield (kg ha^{-1}) of several wheat cultivars. Minto, 1986.

Management Level	Cultivar HY320	Marshall	Oslo	Wheaton	Katepwa	Glenlea
Low	3150 c[1]	3755 b	3715 b	3515 d	2825 c	3140 b
Med	3860 b	4715 a	4235 ab	4430 c	3245 b	3755 a
High	4035 b	4845 a	4225 ab	4755 bc	3570 b	4060 a
HiF	4980 a	5235 a	4785 a	5505 a	4170 a	4205 a
HFS	5190 a	4840 a	4450 a	5315 ab	4090 a	3655 ab

1. 1. Means within a column followed by the same letter do not differ significantly (LSD, 5%).

Table A-15: Effect of seeding rate on grain yield (kg ha^{-1}) of two wheat cultivars. Minto, 1985.

Seeding rate (seeds/m^2)	Cultivar	
	HY320	Oslo
300	5075	4668
400	5320	4463
500	5225	4745
Linear	/[1]	/
Quadratic	/	*

1. * indicates F value is significant at 5% level, / indicates F value is not significant at 5% level

Table A-16: Effect of seeding date on response to seeding rate as measured by grain yield (kg ha^{-1}). Morris, 1985.

Seeding rate (seeds/m^2)	Seeding Date	
	Early	Late
300	4455	3655
400	4700	3610
500	4690	3525
Linear	*[1]	/
Quadratic	/	/

1. * indicates F value is significant at 5% level, / indicates F value is not significant at 5% level

Table A-17: Effect of seeding date on grain yield (kg ha^{-1}) of two wheat cultivars at Morris, 1985, Minto, 1986 and Portage, 1986.

	Seeding Date					
	Morris, 1985		Minto, 1986		Portage, 1986	
Cultivar	Early	Late	Early	Late	Early	Late
HY320	4580	3115 b[1]	4855 a	3835 b	5275 a	5790 a
Oslo	4650	4080 a	4365 b	4175 a	4025 b	5205 b

1. Means within a column followed by the same letter do not differ significantly (LSD, 5%).

Table A-18: Effect of seeding date on grain yield response (kg ha^{-1}) to fertilizer nitrogen. Portage, 1985.

Nitrogen (kg/ha)	Seeding Date	
	Early	Late
50	4570	3600
100	4715	3390
150	5000	3520
Linear	/[1]	/
Quadratic	/	/

1. / indicates F value is not significant at 5% level

Table A-19: Effect of fertilizer nitrogen rate on grain yield (kg ha^{-1}) of two wheat cultivars. Portage, 1987, late seeding date.

Nitrogen (kg/ha)	Cultivar Katepwa	Cultivar Roblin
40	3230	3490
80	3450	3910
120	3380	3915
Linear	/[1]	*
Quadratic	/	*

1. * indicates F value is significant at 5% level,
/ indicates F value is not significant at 5% level

Table A-20: Effect of seeding rate on grain yield (kg ha^{-1}) of two wheat cultivars. Portage, 1987, late seeding date.

Seeding rate (seeds/m^2)	Cultivar Katepwa	Cultivar Roblin
200	3395	3630
250	3395	3830
300	3270	3835
Linear	/[1]	/
Quadratic	/	/

1. / indicates F value is not significant at 5% level

Table A-21: Effect of fertilizer nitrogen rate on thousand kernel weight (g) of four wheat cultivars. Portage, 1987.

Nitrogen (kg/ha)	Cultivar			
	HY320	Wheaton	Katepwa	Roblin
40	43.3	40.9	36.7	40.0
80	43.1	40.0	36.4	40.4
120	41.3	39.7	36.8	39.7
160	41.0	39.5	36.8	40.7
	*[1]	/	/	/

1. * indicates F value is significant at 5% level,
/ indicates F value is not significant at 5% level

Table A-22: Effects of fertilizer nitrogen rate on grain protein content (%) of four wheat cultivars. Portage, 1987.

Nitrogen (kg/ha)	Cultivar			
	HY320	Wheaton	Katepwa	Roblin
40	10.8	11.0	11.8	13.4
80	11.6	12.0	13.3	15.3
120	12.1	12.7	14.2	16.0
160	12.5	13.1	15.1	16.6
	*[1]	*	*	*

1. * indicates F value is significant at 5% level,
/ indicates F value is not significant at 5% level

Table A-23: Effects of fertilizer nitrogen rate on the number of spikes per m^2 of four wheat cultivars. Portage, 1987.

Nitrogen (kg/ha)	Cultivar			
	HY320	Wheaton	Katepwa	Roblin
40	354	457	570	512
80	401	460	608	494
120	428	521	620	523
160	430	499	610	515
	*[1]	*	/	/

1. * indicates F value is significant at 5% level,
/ indicates F value is not significant at 5% level

Table A-24: Effect of foliar fungicide application on grain yield (kg ha^{-1}) of several wheat cultivars. Portage, 1987.

Fungicide	Cultivar			
	HY320	Wheaton	Katepwa	Roblin
No	5575 a[1]	5575 a	4640 a	4380 a
Yes	6255 b	5895 b	4805 b	4605 b
Difference	680	320	165	225

1. 1. Means within a column followed by the same letter do not differ significantly (LSD, 5%).

Table A-25: Effect of foliar fungicide application on the thousand kernel weight (g) of several wheat cultivars. Portage, 1987.

	Cultivar			
Fungicide	HY320	Wheaton	Katepwa	Roblin
No	41.0 a[1]	39.2 a	36.4 a	40.3
Yes	43.3 b	40.9 b	36.9 b	40.2

1. 1. Means within a column followed by the same letter do not differ significantly (LSD, 5%).

Table A-26: Effect of foliar fungicide application on the hectolitre weight (kg) of several wheat cultivars. Portage, 1987.

	Cultivar			
Fungicide	HY320	Wheaton	Katepwa	Roblin
No	75.7 a[1]	75.6 a	75.5 a	78.1
Yes	77.4 b	76.6 b	75.8 b	78.1

1. 1. Means within a column followed by the same letter do not differ significantly (LSD, 5%).

Table A-27: Effect of foliar fungicide application on grain yield (kg ha^{-1}) of several wheat cultivars. Swan River, 1987.

	Cultivar			
Fungicide	HY320	Oslo	Katepwa	Roblin
No	4215 a[1]	3320 a	3570 a	3545 a
Yes	5060 b	3815 b	4135 b	4140 b
Difference	845	495	565	595

1. 1. Means within a column followed by the same letter do not differ significantly (LSD, 5%).

Table A-28: Effect of foliar fungicide application on the thousand kernel weight (g) of several wheat cultivars. Swan River, 1987.

Fungicide	Cultivar			
	HY320	Oslo	Katepwa	Roblin
No	32.6 a[1]	31.1 a	31.4 a	32.8 a
Yes	35.5 b	32.7 b	34.3 b	35.5 b

1. 1. Means within a column followed by the same letter do not differ significantly (LSD, 5%).

Table A-29: Effect of foliar fungicide application on the hectolitre weight (kg) of several wheat cultivars. Swan River, 1987.

Fungicide	Cultivar			
	HY320	Oslo	Katepwa	Roblin
No	68.5 a[1]	68.5 a	74.5 a	72.8
Yes	71.1 b	70.0 b	75.6 b	74.5

1. 1. Means within a column followed by the same letter do not differ significantly (LSD, 5%).

Table A-30: Effect of foliar fungicide application on the grain protein content (%) of several wheat cultivars. Swan River, 1987.

Fungicide	Cultivar			
	HY320	Oslo	Katepwa	Roblin
No	12.4 a[1]	13.4 a	14.3	14.5 a
Yes	12.2 b	13.2 b	14.4	14.8 b

1. 1. Means within a column followed by the same letter do not differ significantly (LSD, 5%).

Table A-31: Break-even price required for a move from the "Low" management level to another management level, Experiment 1, 1985.

Management Level	Break-Even Price ($/tonne)					
	Minto		Morris		Portage	
	Tall	S. Dwarf	Tall	S. Dwarf	Tall	S. Dwarf
Low						
Med	1185	545	710	75	-	50
High	120	295	745	165	710	80
HiF	-[1]	320	805	135	1605	95
HFS	800	273	350	120	248	105

1. Break even price could not be determined due to negative return.

Table A-32: Break-even price required for a move from the "Low" management level to another management level, Experiment 1, 1986.

Management Level	Break-Even Price ($/tonne)					
	Minto		Portage		Swan River	
	Tall	S. Dwarf	Tall	S. Dwarf	Tall	S. Dwarf
Low						
Med	70	45	75	45	80	65
High	85	75	115	80	160	120
HiF	85	65	230	115	135	95
HFS	140	90	195	130	125	120

Table A-33: Break-even price required for a fungicide application on several wheat cultivars and two locations, Experiment 3, 1987.

Location	Break-even Price ($/tonne) Cultivar HY320	Wheaton	Oslo	Katepwa	Roblin
Portage	57	121	-	235	172
Swan River	46	-	78	69	65

Table A-34: Break-even price (BEP) required for a move from 40 kg ha-1 fertilizer nitrogen rate to another fertilizer nitrogen rate, Experiment 3, 1987.

Management Level	Break even Price ($/tonne) Portage Tall	Portage S. Dwarf	Swan River Tall	Swan River S. Dwarf
40				
80	39.71	38.26	-[1]	144
120	60.32	39.25	-	396
160	85.66	71.27	-	-

1. Break-even price could not be calculated due to a negative return

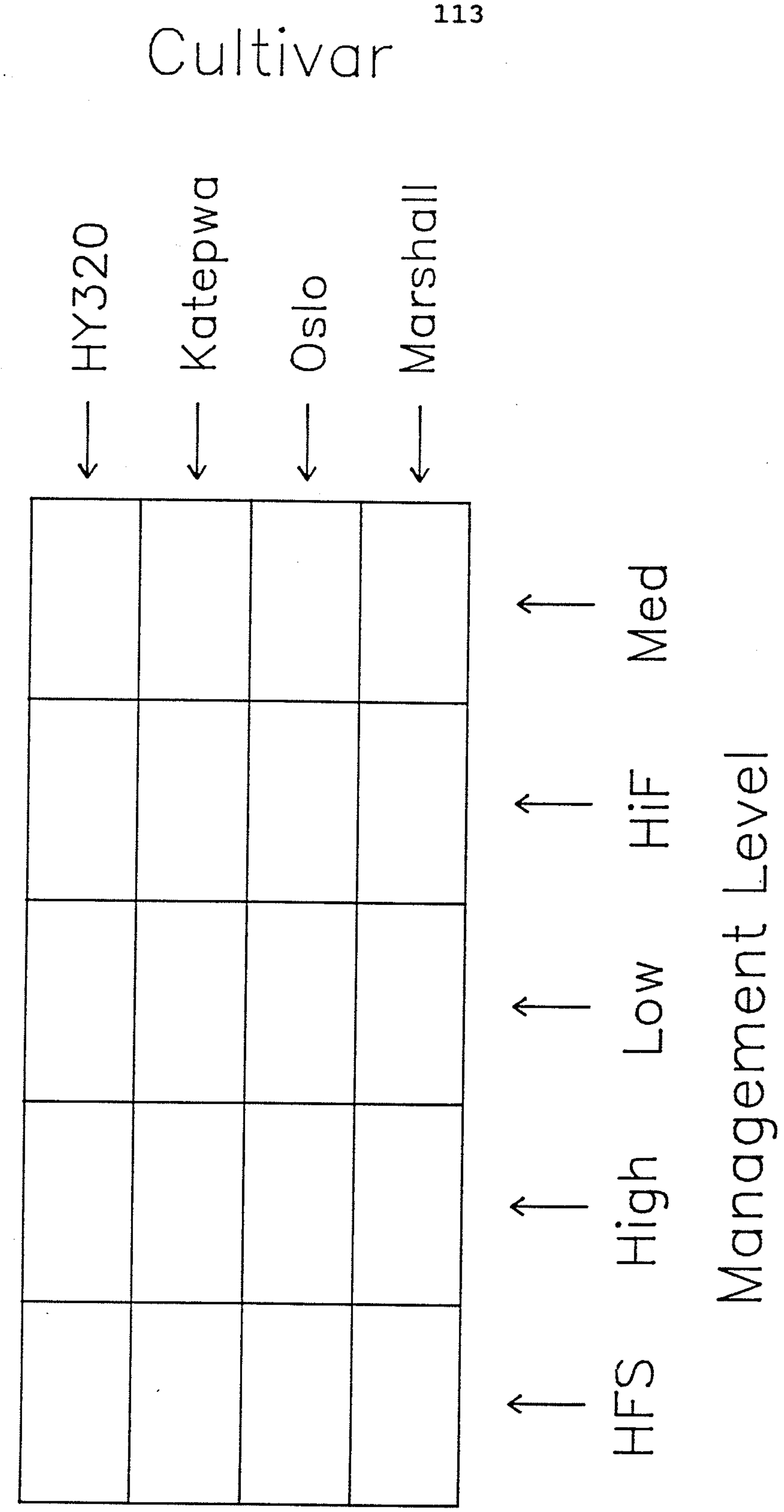

Figure A-1: Treatment layout of Experiment 1, 1985 and 1986.

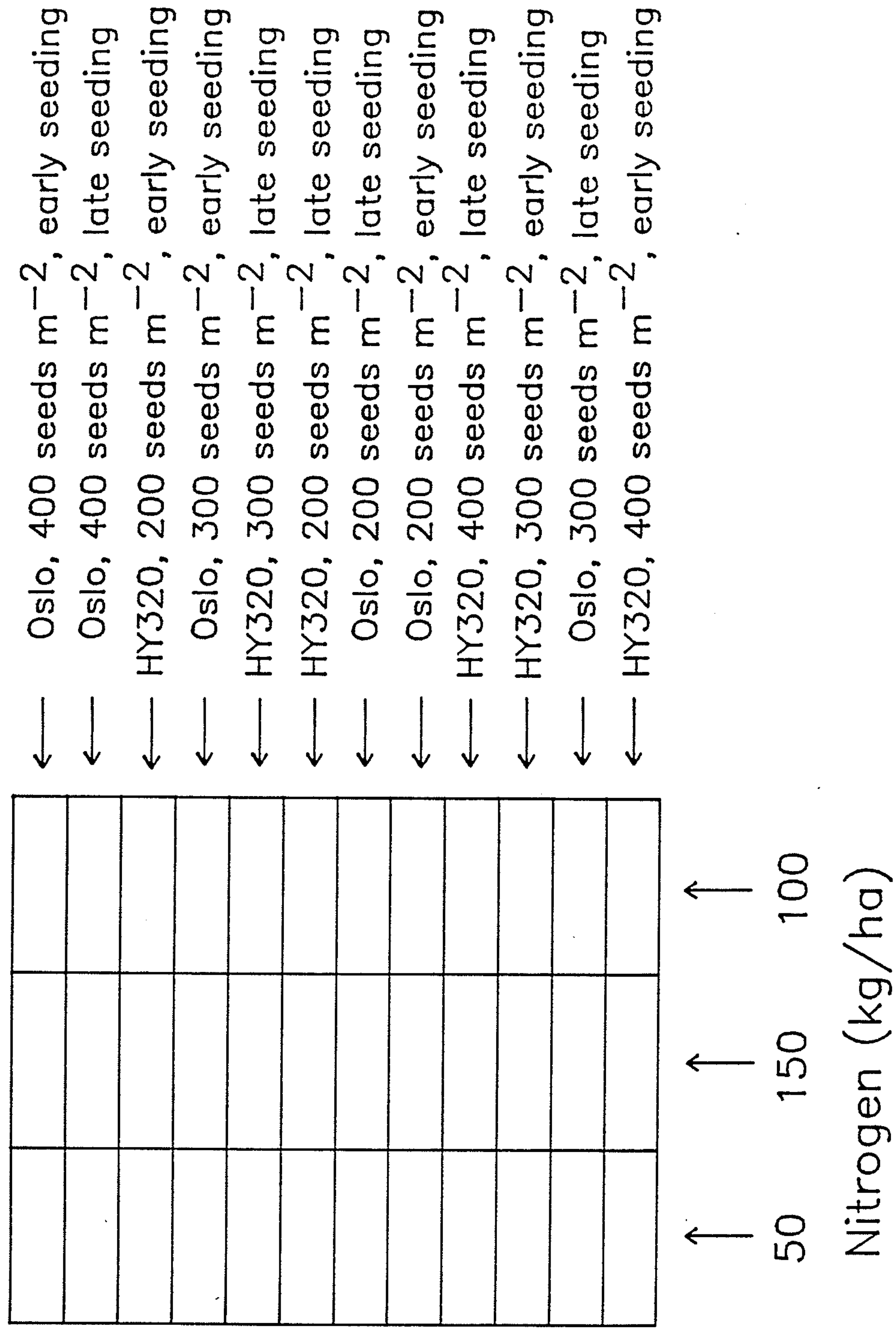

Figure A-2: Treatment layout of Experiment 2, 1985 and 1986. At Swan River in 1986 and 1987, seeding date was not evaluated. At Portage in 1987, seeding date was not evaluated as a factor in this experiment.

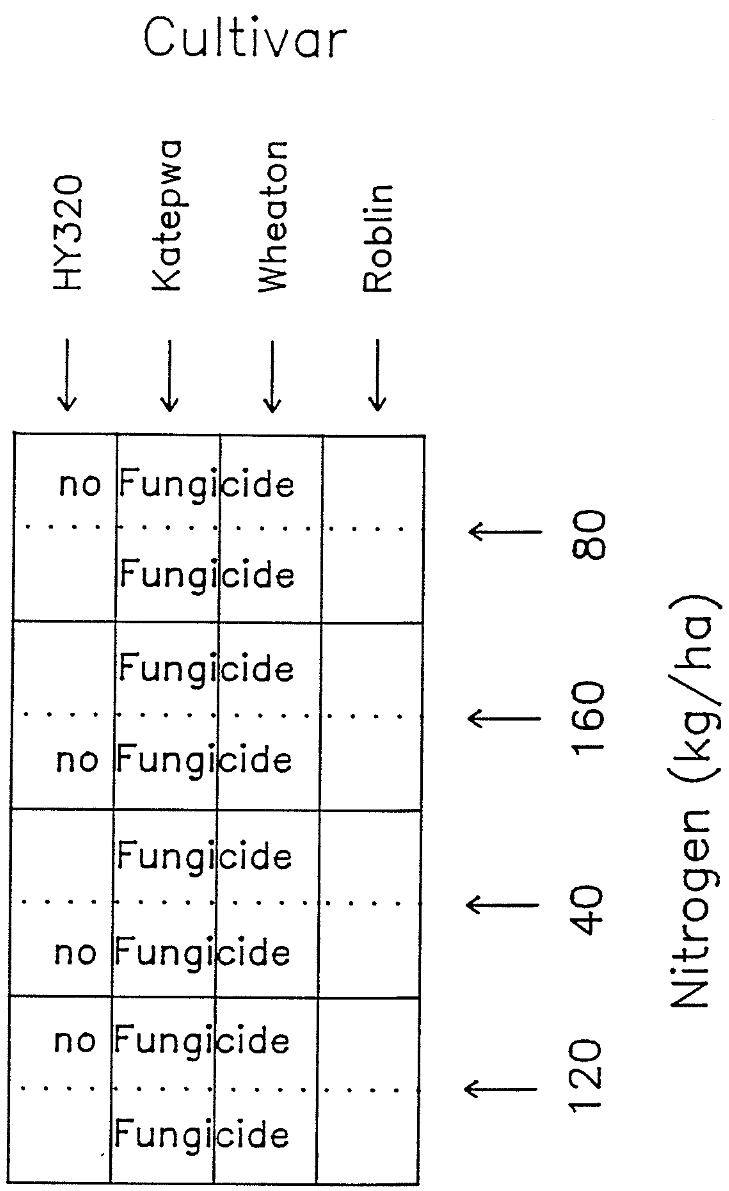

Figure A-3: Treatment layout of Experiment 3, 1987.

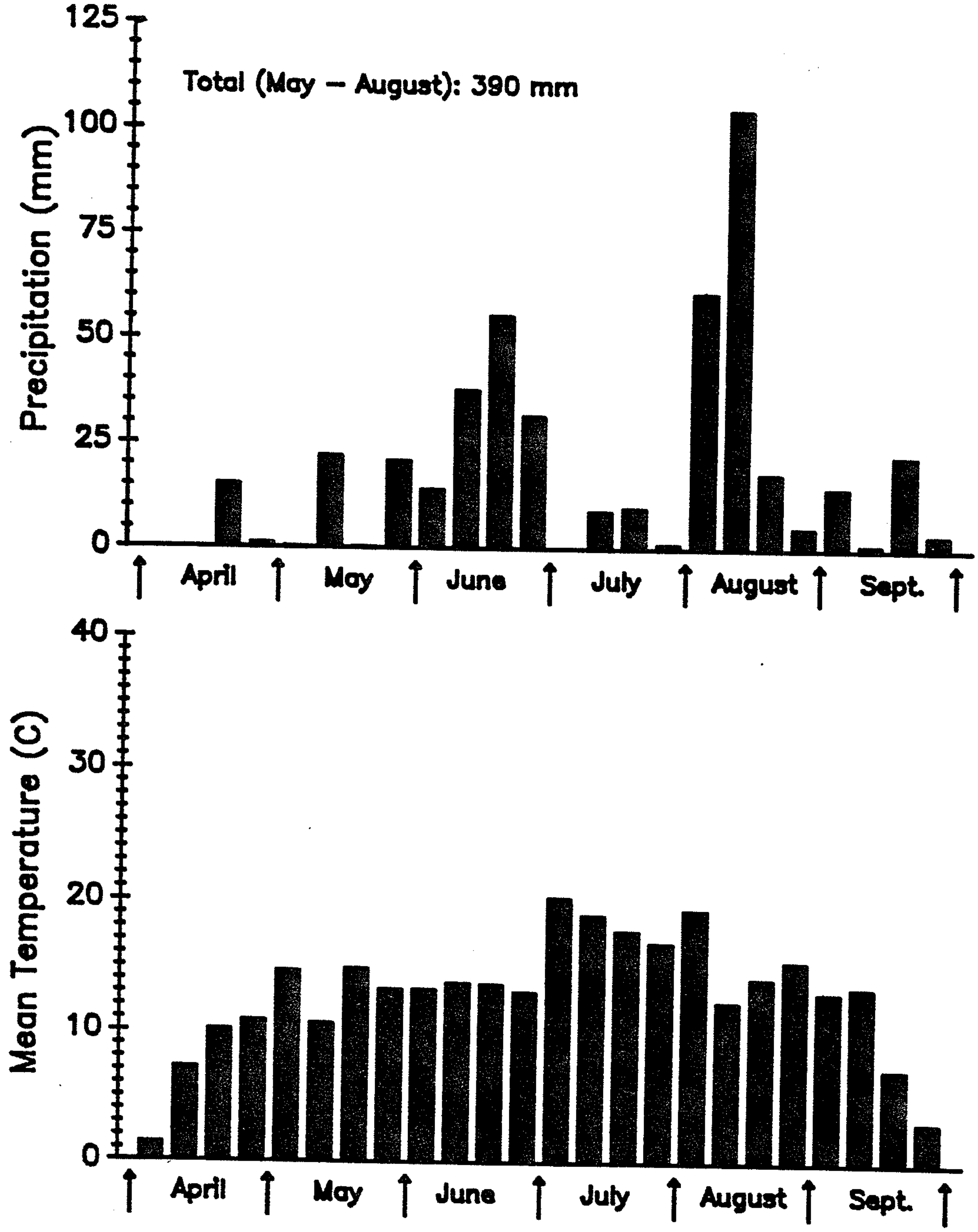

Figure A-4: Growing season temperature and precipitation. Minto, 1985

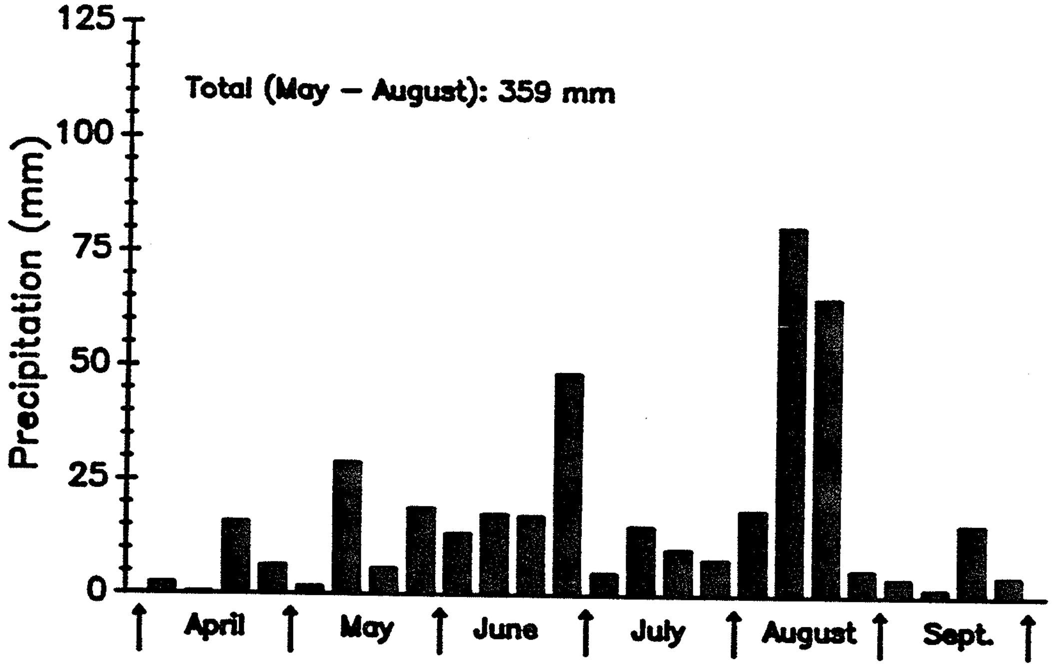

Figure A-5: Growing season precipitation. Morris, 1985

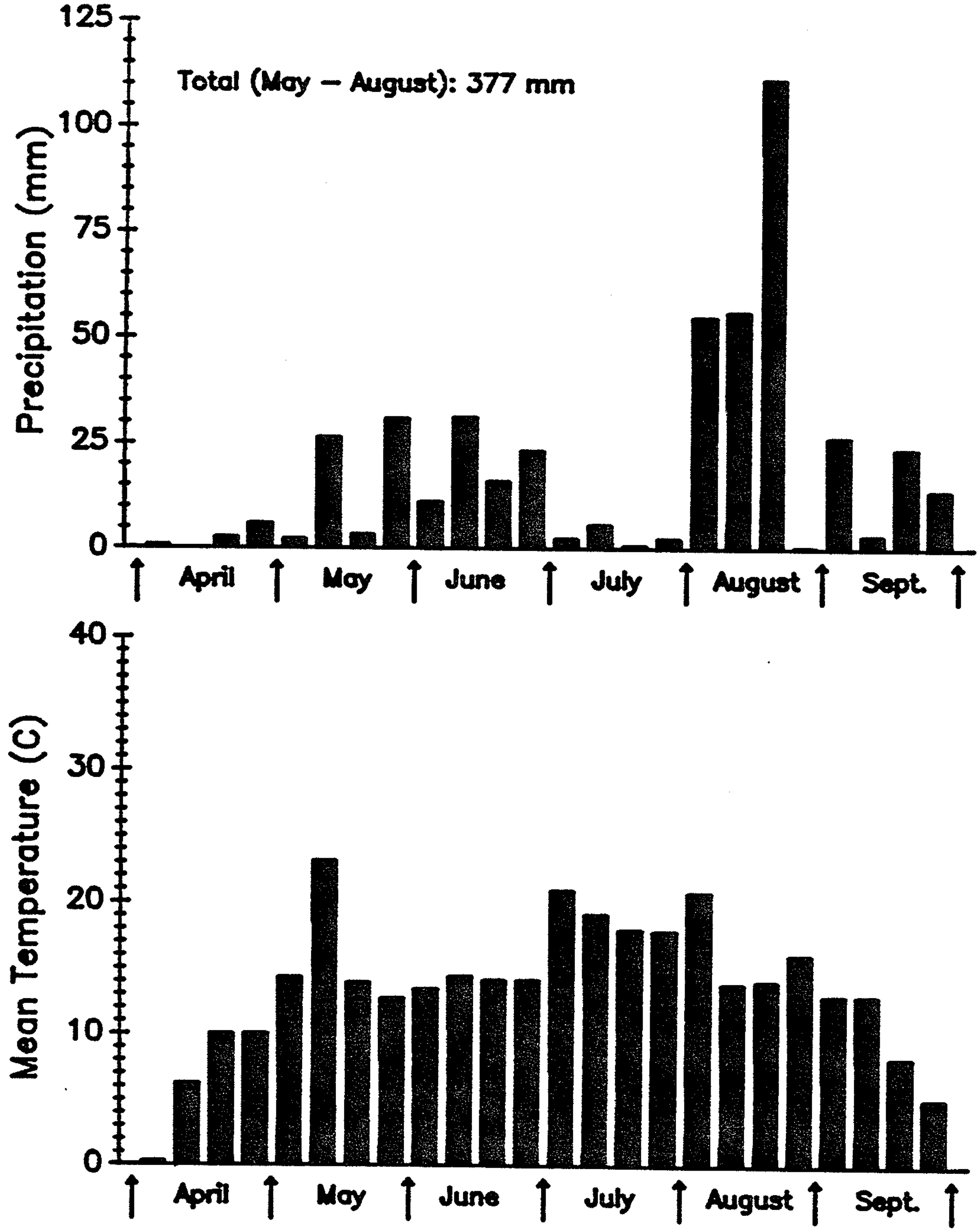

Figure A-6: Growing season temperature and precipitation. Portage, 1985

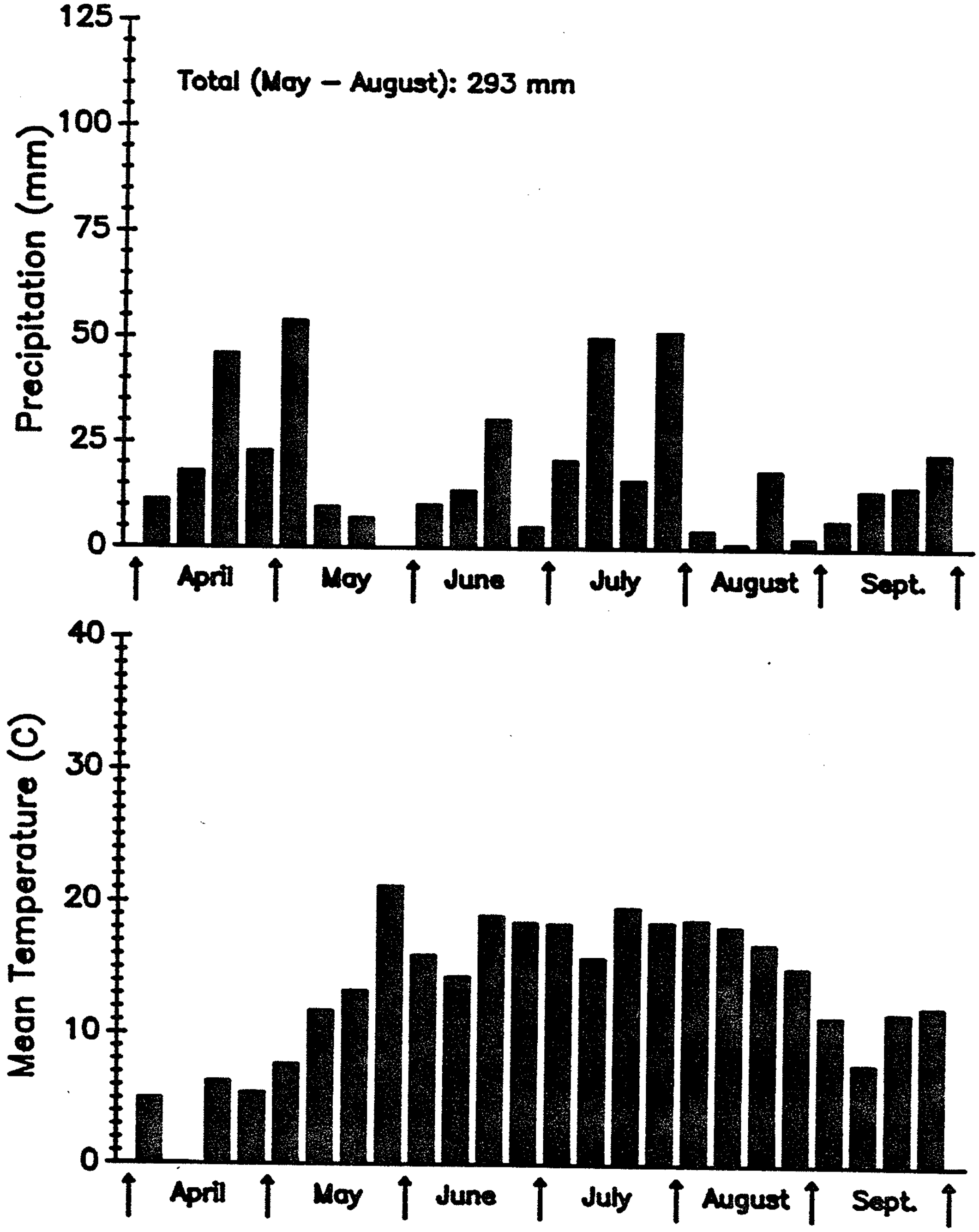

Figure A-7: Growing season temperature and precipitation. Minto, 1986

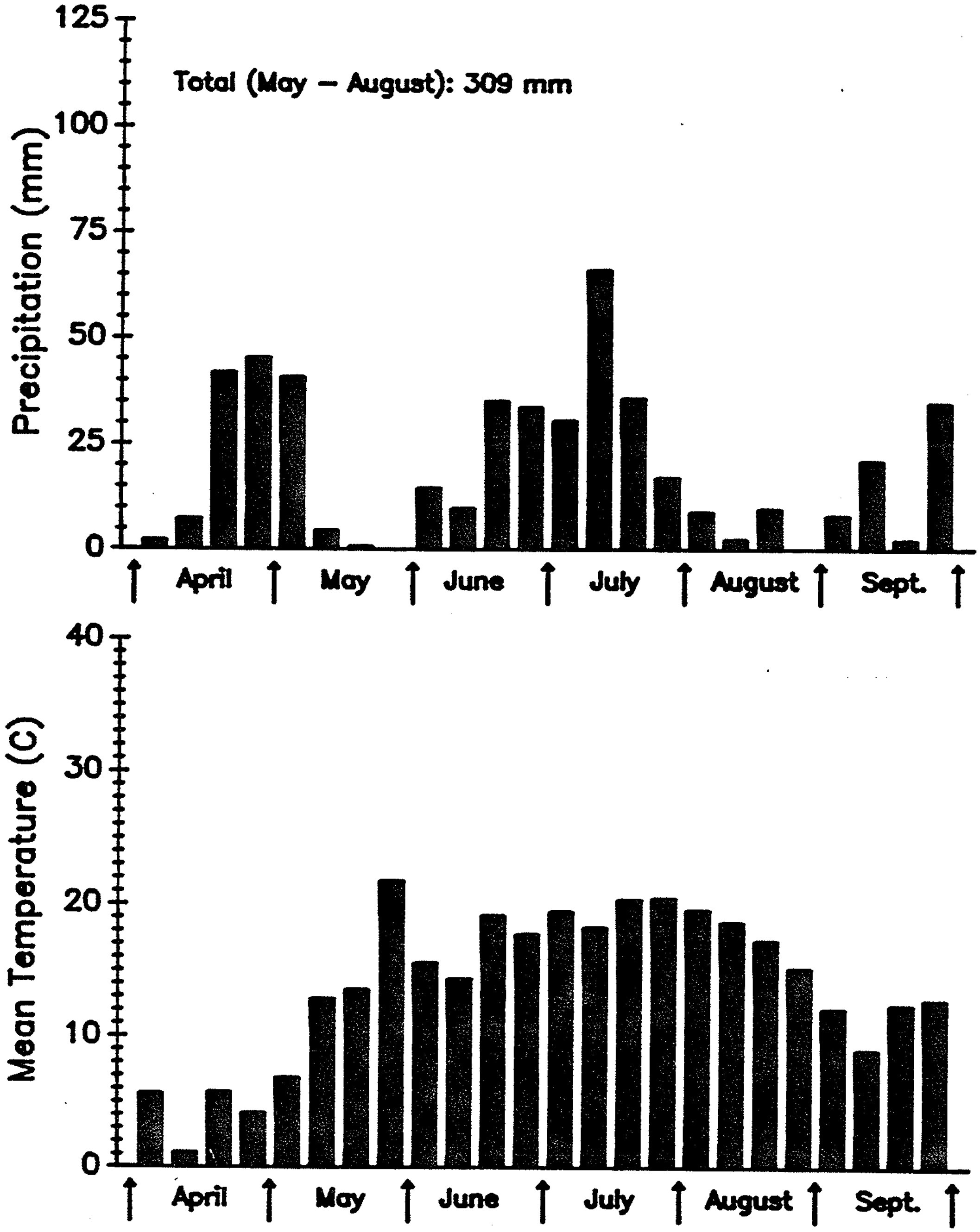

Figure A-8: Growing season temperature and precipitation. Portage, 1986

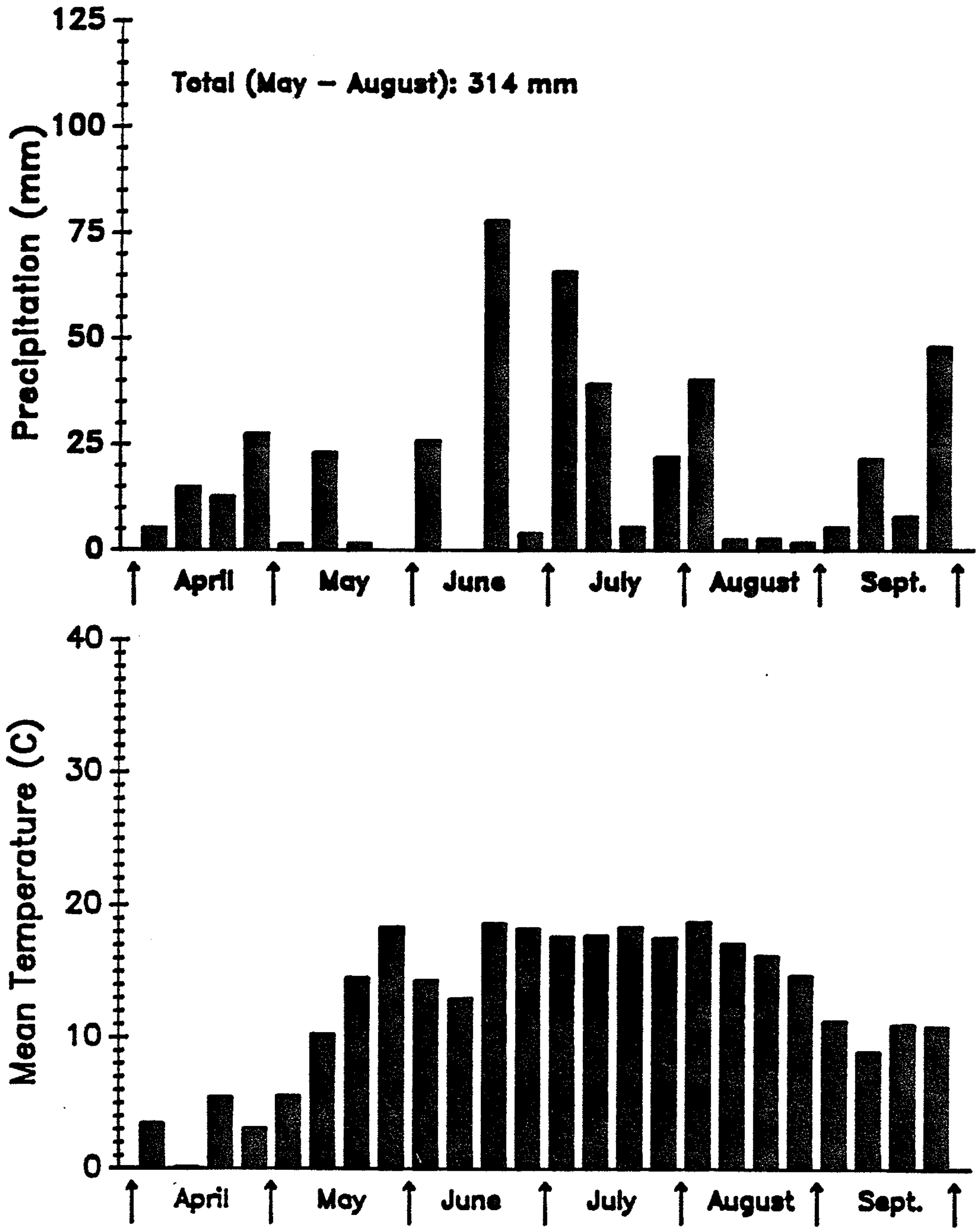

Figure A-9: Growing season temperature and precipitation. Swan River, 1986

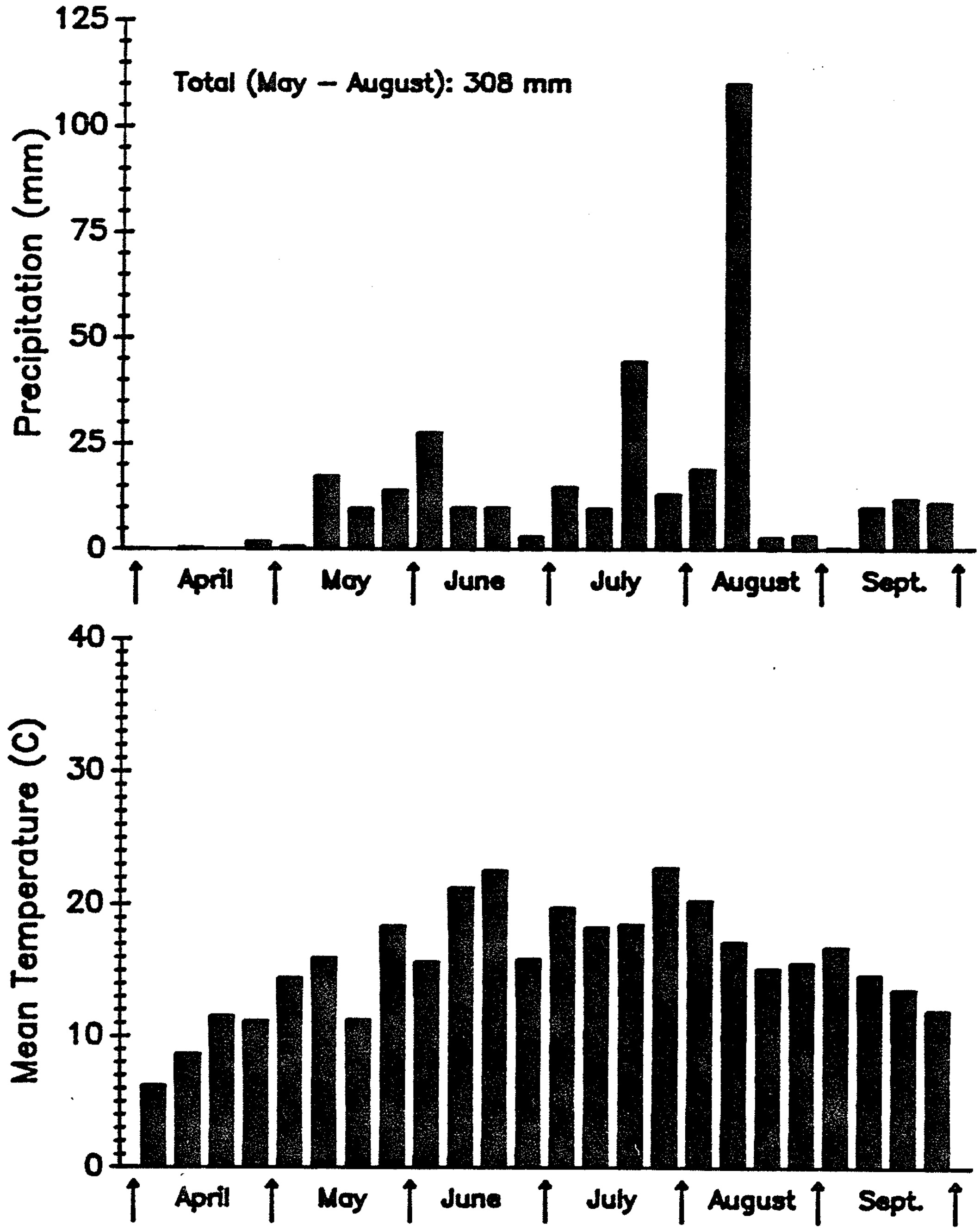

Figure A-10: Growing season temperature and precipitation. Portage, 1987

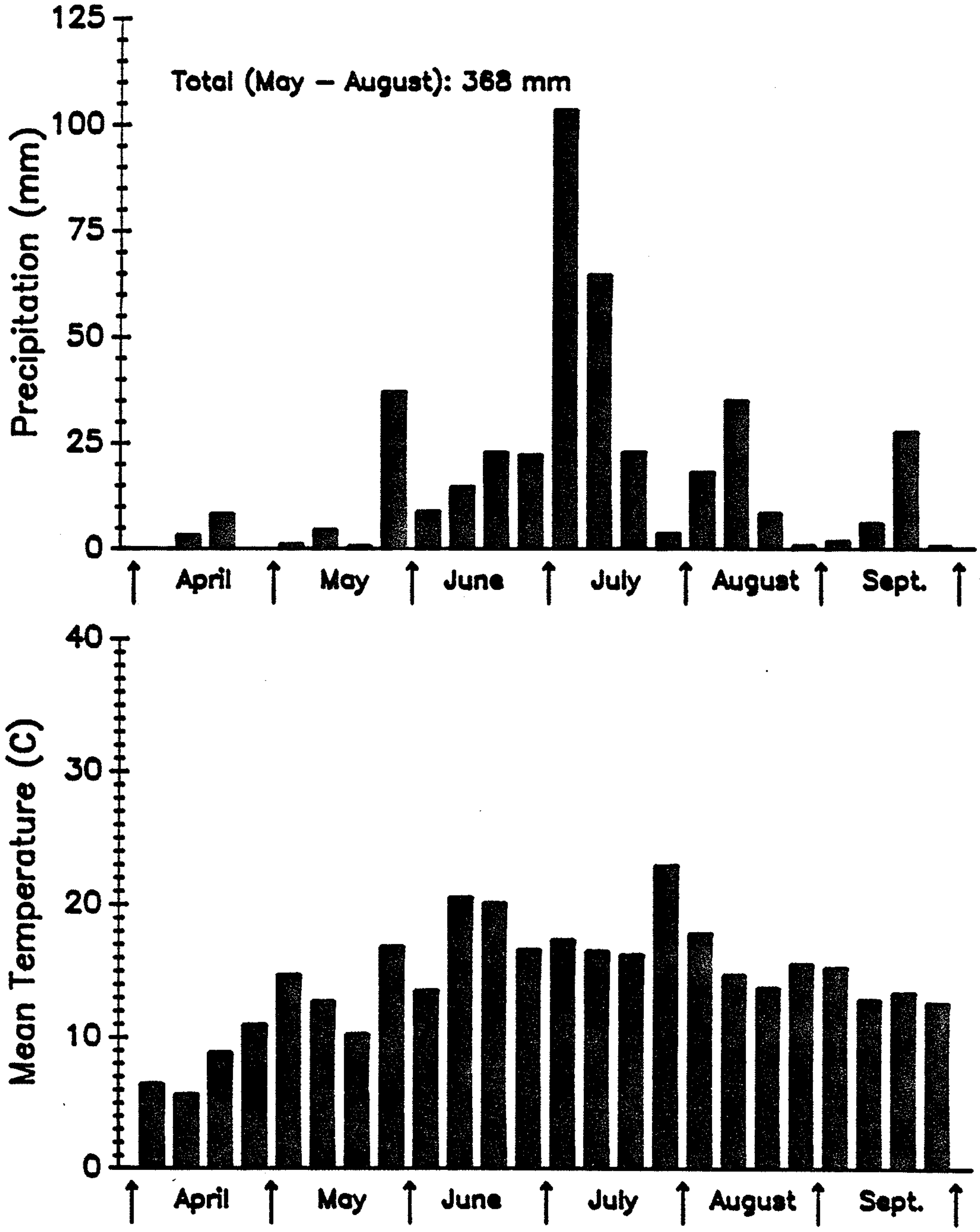

Figure A-11: Growing season temperature and precipitation. Swan River, 1987