



Effects of systemic fungicides and potassium fertilizers on disease intensity, yield components, and grain yield of common root rot diseased barley
by Paul Arthur Shefelbine

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Plant Pathology
Montana State University
© Copyright by Paul Arthur Shefelbine (1984)

Abstract:

Common root rot(CRR), incited by *Cochliobolus sativus*, is a debilitating soil-borne disease of barley. While yield losses due to CRR are variable, they are significant due to the annual widespread occurrence of the disease in barley fields of North America. Control measures have been ineffective in reducing losses. Therefore, a study was initiated to determine if potassium fertilizers and systemic fungicides reduce CRR severity and positively influence grain yield and yield components of CRR diseased barley.

Barley plots were inoculated with *Cochliobolus sativus* infested oat kernels. Six systemic, ergosterol inhibiting fungicides were applied to separate 'Washonupana' seed lots. KCl or K₂SO₄ was added with seed and inoculum to furrows at planting. Disease ratings were determined for each plot at maturity. At the soft dough stage, the following yield data were obtained: grain yield per row, total tiller number per row, harvestable tiller number per row, 1000 kernel weight, and kernel number per spike. The number of emerged plants per 3.3 m row was determined at the three leaf stage.

Plant emergence was reduced by addition of inoculum to rows. While the potassium fertilizers did not affect plant emergence, nuarimol and imazalil seed treatment significantly($P<.05$) increased emergence in inoculated rows. Addition of inoculum to rows did not increase disease levels in mature plants. However, nuarimol seed treatment did significantly($P<.05$) reduce disease ratings in inoculated rows as did addition of KCl. Yield components were not affected by addition of inoculum to rows. While the seed treatments and the potassium fertilizers differentially affected, among themselves, yield components, neither resulted in significant $P<.05$) differences from the yield components of a population of nontreated inoculated barley plants.

Pathological effects of CRR can be negated by treatment with certain systemic fungicides or KCl fertilizer. However, disease reduction did not result in increased grain yield and yield components of a plant population of differentially diseased plants. The disease intensity of a barley plot may apparently be reduced by use of certain control agents but compensatory effects by the plant may reduce or eliminate any potential benefits.

**EFFECTS OF SYSTEMIC FUNGICIDES AND POTASSIUM FERTILIZERS
ON DISEASE INTENSITY, YIELD COMPONENTS, AND GRAIN
YIELD OF COMMON ROOT ROT DISEASED BARLEY**

by

Paul Arthur Shefelbine

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Plant Pathology

MONTANA STATE UNIVERSITY
Bozeman, Montana

May 1984

MAIN LIB.

N378

Sh38

cop. 2

APPROVAL

of a thesis submitted by

Paul Arthur Shefelbine

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

5-25-84
Date

DE Mathis
Chairperson, Graduate Committee

Approved for the Major Department

5-25-84
Date

E L Hayes
Head, Dept. of Plant Pathology *4 am*

Approved for the College of Graduate Studies

5/25/84
Date

Henry L Parsons
Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his/her absence, by the Director of Libraries when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature Paula A. Shefelborne

Date May 25, 1984

TABLE OF CONTENTS

	Page
Approval Page.....	ii
Statement of Permission to Use.....	iii
List of Tables.....	vi
Abstract.....	vii
 Chapter	
1. Introduction.....	1
2. Literature Review.....	3
Pathogens.....	3
Environmental Effects on CRR of Cereals..	4
Effects of Seeding Depth and Date on CRR	6
Effects of Fertilizers on CRR.....	8
Effects of Fungicide on CRR.....	10
Histopathology of CRR.....	13
Effect of CRR on Plant Physiology.....	16
Disease Assessment.....	19
Yield Losses Due to CRR.....	21
3. Materials and Methods.....	26
Inoculum Preparation.....	26
Fertilizer Types.....	27
Fungicides and Application Procedures...	28
Field Plot.....	29
Field Plot Design.....	30
Data Collection.....	31
Data Analysis.....	33
Results.....	34
Systemic Fungicide Seed Treatments.....	34
Potassium Fertilizers.....	37

TABLE OF CONTENTS (Continued)

Discussion.....	42.
4. Conclusion.....	52
References Cited.....	53.

LIST OF TABLES

Table		Page
1.	Chemical name, formulation, active ingredient, and application rate of systemic fungicide seed treatments.....	29
2.	Effects of systemic fungicide seed treatments on plant emergence and percent disease ratings of CRR diseased 'Washonupana' barley.....	35
3.	Effect of systemic fungicide seed treatments on 1000 kernel weight and kernel number per spike of CRR diseased 'Washonupana' barley.....	36
4.	Effects of systemic fungicide seed treatments on grain yield per row, total tiller number per row, and harvestable tiller number per row of CRR diseased 'Washonupana' barley.....	38
5.	Effects of potassium fertilizers on plant emergence and percent disease ratings of CRR diseased 'Washonupana' barley.....	39
6.	Effects of potassium fertilizers on grain yield, total tiller number per row, and harvestable tiller number per row of CRR diseased 'Washonupana' barley.....	40
7.	Effects of potassium fertilizers on 1000 kernel weight, and the number of kernels per spike of CRR diseased 'Washonupana' barley.....	42

ABSTRACT

Common root rot (CRR), incited by Cochliobolus sativus, is a debilitating soil-borne disease of barley. While yield losses due to CRR are variable, they are significant due to the annual widespread occurrence of the disease in barley fields of North America. Control measures have been ineffective in reducing losses. Therefore, a study was initiated to determine if potassium fertilizers and systemic fungicides reduce CRR severity and positively influence grain yield and yield components of CRR diseased barley.

Barley plots were inoculated with Cochliobolus sativus infested oat kernels. Six systemic, ergosterol inhibiting fungicides were applied to separate 'Washonupana' seed lots. KCl or K_2SO_4 was added with seed and inoculum to furrows at planting. Disease ratings were determined for each plot at maturity. At the soft dough stage, the following yield data were obtained: grain yield per row, total tiller number per row, harvestable tiller number per row, 1000 kernel weight, and kernel number per spike. The number of emerged plants per 3.3 m row was determined at the three leaf stage.

Plant emergence was reduced by addition of inoculum to rows. While the potassium fertilizers did not affect plant emergence, nuarimol and imazalil seed treatment significantly ($P < .05$) increased emergence in inoculated rows. Addition of inoculum to rows did not increase disease levels in mature plants. However, nuarimol seed treatment did significantly ($P < .05$) reduce disease ratings in inoculated rows as did addition of KCl. Yield components were not affected by addition of inoculum to rows. While the seed treatments and the potassium fertilizers differentially affected, among themselves, yield components, neither resulted in significant ($P < .05$) differences from the yield components of a population of nontreated inoculated barley plants.

Pathological effects of CRR can be negated by treatment with certain systemic fungicides or KCl fertilizer. However, disease reduction did not result in increased grain yield and yield components of a plant population of differentially diseased plants. The disease intensity of a barley plot may apparently be reduced by use of certain control agents but compensatory effects by the plant may reduce or eliminate any potential benefits.

CHAPTER 1

Introduction

Common root rot (CRR) is a debilitating, soil-borne disease of spring cereals. The anamorph of Cochliobolus sativus is the primary etiological agent, inciting lesions on the subcrown internode and root systems. While yield losses due to CRR are variable, they are significant due to the annual widespread occurrence of the disease in barley and wheat fields of North America.

Some diseases are controlled by the use of cultural practices and/or resistant cultivars. Tolerance to CRR does occur but yield is still reduced. The cultural practices of crop rotation, tillage and residue management have been ineffective in reducing CRR severity because the conidia of C. sativus have an extreme longevity.

This thesis deals with determining whether potassium fertilizers and systemic fungicides reduce the severity of CRR and positively influence yield and yield components of CRR diseased barley. Control of CRR must involve minimum expense with definite yield increases because of the low cash value of barley. A single application of a fertilizer or systemic fungicide at

planting resulting in protection of the subcrown internode for the entire period of susceptibility would be desirable.

Fertilizers potentially affect disease severity by altering a plant's susceptibility or by directly affecting the pathogen. The low cost of fertilizers and ease of application at seeding favor the use of fertilizers for disease control. Potassium fertilizers can increase yield of dryland barley but their effect on CRR severity, yield, and yield components needs further investigation.

Protectant fungicides provide short term protection to the plant organ treated, and subsequently formed plant organs are seldom protected from pathogen attack (e.g., the subcrown internode by the CRR pathogen). Recently, fungicides have been developed having the positive characteristics of systemic translocation, effectiveness in low concentrations, and prolonged efficacy. Since the subcrown internode is the main plant organ attacked by CRR and infection of the subcrown internode may occur at any time during the growing season, these fungicides applied to the seed may possibly be viable CRR control agents.

CHAPTER 2

Literature Review

CRR is a generic term describing a disease complex of wheat and barley. This disease has also been referred to as root rot, dryland root rot, foot rot, Helminthosporium disease, and wheat root and foot rot. McKinney (1923b) cites literature suggesting the disease is prevalent throughout the cereal growing areas of the world. Depending on the geographical area studied, the disease is characterized by blighting, stunting and death of seedlings; stunting of mature plants and olive-green lesions on seminal and crown roots, the subcrown internode, crown and basal stem tissues (Sallans, 1965). White heads and discolored heads may also occur (Sallans et al., 1943).

Pathogens

CRR is incited by a complex of pathogens. The anamorph of Cochliobolus sativus (Ito and Kurib) Drechs. ex Dastur (Bipolaris sorokiniana (Sacc.) = Helminthosporium sativum P.K.B.) is generally the main pathogen encountered. Many species of *Fusaria* have also

been reported to be involved, including Fusarium culmorum (W. G. Smith) Sacc. and Fusarium graminearum Schwabe (Sallans, 1965).

Two distinct diseases, both referred to as dryland root rot, may be defined according to the symptoms occurring. In many cereal areas the main symptoms are lesions on the crown and subcrown internode, incited primarily by C. sativus (Sallans, 1965). In the Pacific North West, the main symptoms are crown and crown root rot, tiller death and white heads, incited mainly by Fusarium culmorum (W. G. Smith) Sacc. (Cook, 1968). This review will deal with CRR incited mainly by C. sativus.

Environmental Effects on CRR of Cereals

Sallans (1948) investigated various environmental parameters for effect on yield of CRR diseased cereals. Data available for partial regression studies included: total rainfall per growing season, rainfall per month, air quality, air temperature, insect damage, yield, and CRR severity. Insect damage, air temperature, and air quality all affected yield but not CRR severity, according to simple regression statistics. Total rainfall had the largest impact on yield. Partial regression statistics indicated significant correlations between

yield and preseasonal moisture, yield and May-June rainfall, CRR and June-July rainfall, and CRR and yield. This suggests that CRR does indeed affect yield. However, a significant negative correlation between CRR and May-June rainfall suggests that this period of rainfall was critical to the severity of CRR. This agrees with several reports that CRR affected plants are capable of recovering from initial severe disease if moisture levels are high (Sallans, 1940; Sallans, 1959).

McKinney (1923a) investigated the effects of soil temperature on CRR of seedlings of barley, spring wheat and winter wheat in the field and in the greenhouse. Infection of cereals in controlled temperature soil benches in the greenhouse occurred over the soil temperature range of 8°C to 35°C. However, more disease consistently occurred at higher temperatures. The highest percentages of diseased seedlings occurred for spring grain at 28°C and for winter wheat at 32°C. Whether the temperatures were held constant at the above means or alternated periodically around these means had no effect on disease. Field experiments showed that early sown winter wheat was more severely attacked by C. sativus than late sown winter wheat.

Greaney (1946) studied the effects of soil

temperature on CRR ratings of mature spring wheat plants in the field. Different soil temperature regimes were provided by different dates of planting. When soil temperatures were high at planting, mature plants showed more disease.

McKinney (1923a) investigated the effects of soil moisture on CRR. Soil moisture levels were altered by adding quantities of water to the soil. McKinney found that as water availability increased the percentage of diseased plants decreased. Coupled with soil temperature studies, McKinney's results suggested that high soil temperatures favored more disease at high soil moisture levels than at low soil moisture levels, while low soil temperatures favored more disease at low soil moisture levels but not at high soil moisture levels.

Effects of Seeding Depth and Date on CRR

Johnson (1976) determined that percent yield loss, based on percent disease ratings, was not related to seeding date of spring barley at Prince Edward Island, Canada. Duczek et al. (1982) studied the effect of seeding date on CRR severity of spring barley in Saskatchewan, Canada. Percent disease ratings were not affected by seeding date.

Greaney (1946) investigated the effect of seeding date of spring wheat on CRR severity in Ottawa, Canada. Early seeding, low soil temperature, low disease rating and high yield were all significantly correlated while late seeding was significantly correlated with high disease ratings, lower yield, and warm soil temperatures.

Duczek et al. (1982) studied the effect of seeding depth and seed size on CRR severity, yield and emergence of spring barley at several locations. Seed size had no effect on disease severity, yield or emergence at all locations studied. The effect of seeding depth was variable. In general, disease ratings increased while yield and emergence decreased with increased depth of planting. This occurred at two locations in Canada consistently over several years but inconsistently at a third location.

Greaney (1946) investigated the effect of seeding depth of spring wheat on CRR at several locations. Increased depth of seeding invariably caused greater disease ratings. However, disease severity varied across locations and cultivars even though some cultivars were more resistant to CRR and some areas were not as conducive to CRR.

Effects of Fertilizers on CRR

Ledingham (1970) investigated the effects of ammonium nitrate on CRR of mature wheat and barley. Added nitrogen tended to significantly increase disease ratings. However, yield was not reduced by increased disease. Pittman et al. (1972) agreed with Ledingham's findings and found an increase in disease of barley fertilized with ammonium nitrate. Piening et al. (1969) found that use of ammonium nitrate resulted in higher disease ratings in barley while use of urea resulted in lower disease ratings. While Verma et al. (1975b) found no effect of ammonium nitrate fertilizer on disease ratings of wheat, a significant reduction in the percentage of diseased plants and the number of diseased plants per unit area early in the growing season were found. However, the effect on these variables became non-significant by midseason.

Pienings et al. (1967) observed a lower disease index for mature spring barley when grown with monoammonium phosphate. In a subsequent study by Pienings et al. (1969), phosphate fertilization generally resulted in lower disease ratings for mature spring barley. However, Pittman et al. (1972) found no effect of superphosphate on disease ratings and yields of spring

barley.

Russel and Sallans (1940) obtained disease ratings for mature wheat plants when fertilized with triple superphosphate, ammonium phosphate or ammoniated phosphate. The study was conducted over several years at different locations. Generally, use of phosphatic fertilizers caused an increase in disease ratings with no decrease in yield but inconsistencies in regard to location and time were the rule.

Verma et al. (1975b) investigated the effect of phosphatic fertilizers on CRR severity of Manitou wheat. Disease ratings were determined five times throughout the growing season. Early and late in the growing season no difference in disease ratings were noticed between checks and ammonium phosphate treated plots. However, phosphate fertilizer use resulted in a significant reduction in disease ratings at midseason.

Verma et al. (1975a) investigated the effect of phosphatic fertilizer on development of subcrown internode lesions. Coleoptiles were inoculated fifteen days after emergence by enclosing them with colonized straw pieces. Lesion length was measured approximately every five days. Lesion extension rate on a per day basis was greatest in low phosphate soils. High

phosphate soils increased the time required for lesions to reach maximum length.

Verma et al. (1975a) also investigated the effect of phosphatic fertilizer on severity class progression. Individual plants, inoculated with colonized straw pieces, were placed into disease severity classes throughout the growing season. Probabilities for progression to more severe classes were determined. The probability of plants staying in the clean, slight or moderate severity classes was highest for high phosphate soils while probabilities for conversion to a more severe class was generally higher for low phosphate soils.

Effects of Fungicides on CRR

Clark (1977) investigated the effect of several nonmercurial, seed treatment fungicides on barley seedling blight and spot blotch, both incited by C. sativus. Most seed treatments were effective in controlling the diseases but significant increases in grain yield per row were not seen. A carboxin-thiram mixture was the most successful seed treatment for reducing disease. Hampton (1978) reported that a carboxin-thiram mixture, applied as a seed treatment, was highly effective in reducing the number of C. sativus

diseased barley seedlings. Luz et al. (1980) reported the efficacy of several systemic, ergosterol inhibiting fungicides in controlling spot blotch of barley in Brazil. Fenapronil and nuarimol seed treatments were highly effective in controlling spot blotch initiated from seed and airborne inoculum.

Several systemic, ergosterol inhibiting seed treatment fungicides have been investigated for efficacy in controlling CRR of cereals. Criteria used to evaluate disease control have included disease ratings of seedling and mature plants and isolation of C. sativus from subcrown internodes. Chinn (1978) reported that of seven fungicides tested, imazalil was the most effective in reducing disease ratings of wheat seedlings and mature plants. Disease ratings were reduced to 5 percent and 16 percent from 32 percent and 51 percent for seedlings and mature plants, respectively. Percent positive isolations from subcrown internodes were reduced from 71 percent for controls to 8.8 percent for treatments of 0.3 g active ingredient per kg seed. Verma et al. (1981) reported that imazalil significantly reduced disease ratings of several wheat varieties, in the seedling and mature plant stages. A dosage response was discernible. Verma (1983) reported that nuarimol, triadimenol and imazalil

significantly reduced seedling and mature wheat disease ratings. A dosage response was discernible and nuarimol was generally highest in efficacy. Piening et al. (1983) reported that mature barley disease ratings were significantly reduced by treatment of seed with nuarimol, triadimenol or fenapanil. Significant cultivar x treatment x location x time interactions have been documented by the research workers cited above.

Verma (1983) reported that seed treatment with nuarimol or triadimenol significantly reduced plant emergence one year out of two while imazalil at 0.2 g active ingredient per kg of seed did not reduce plant emergence. Verma et al. (1981) reported that plant emergence was significantly reduced by imazalil at 0.3 g active ingredient per kg of seed but not at 0.2 g active ingredient per kg of seed. Hulless barley was more susceptible to phytotoxic effects from imazalil than hulled barley. Piening et al. (1983) reported that plant emergence was significantly reduced by ectaconazole, triadimenol, nuarimol and fenapanil. Chinn et al. (1980) and Chinn (1978) reported that percent plants with coleoptile node tillering (cnt), and firm cnt increased with increasing dosage of imazalil and that subcrown internode thickness was increased and subcrown

internode length was decreased with imazalil treatment. Overall, most researchers have reported variability in phytotoxicity in regard to locations, cultivars and time with use of these systemic seed treatments.

Grain yield per harvested row has not been increased by reduced disease ratings resulting from seed treatments with systemic fungicides. Verma et al. (1981) reported a significant decrease in grain yield per row with imazalil treated seed and Verma (1983) reported no significant increases or decreases in grain yield per row with plots planted with seed treated with nuarimol, triadimenol or imazalil. Peining et al. (1983) have reported significant yield decreases with plots treated with systemic fungicides as seed treatments. In all cases reviewed above, the degree of yield reduction resulting from seed treatments was variable in regard to location, time and cultivar.

Histopathology of CRR

Root excavation studies conducted by Simmonds et al. (1935) provided information on which root system of wheat is primarily attacked by C. sativus. All underground parts of the plant contained lesions. However, lesions were most severe on the subcrown internode and seminal

roots although basal parts of the culm developed a moderate number of lesions. There were few lesions on rootlets.

Fitt et al. (1978) investigated physiological effects of various root infecting fungi on cereals. One parameter investigated was extent of colonization and disruption of roots. By week one, seminal roots of wheat had been penetrated and the cortices were colonized by C. sativus. By week five the root steles of crown and seminal roots of wheat had been colonized. However, no disruption of cortices and steles were noted, even though shoot water content, carbon-14 root assimilation, and shoot mineral content had been affected.

Huang et al. (1976) investigated the infection process and extent of colonization of subcrown internodes of greenhouse and field grown wheat and barley. Subcrown internodes were infected by C. sativus through specialized cells of the epidermis, such as stomatal and hair cells. An infection cushion formed over the site of penetration with a concomitant formation of a lignituber beneath the site of penetration. Penetration appeared to be physical and enzymatic. The cortex and endodermis were colonized readily. The stele was colonized and xylem

and phloem tissues were sometimes occluded by dark-staining objects. Disruption of the cortex often occurred after colonization of the stele.

Huang et al. (1976) used cultivars of wheat and barley that differed in resistance to CRR as assessed by disease ratings. However, no differences were observed in the penetration and colonization of cultivars that differed extensively in resistance.

The development of individual lesions incited by C. sativus on subcrown internodes, of various wheat and barley cultivars has been investigated. Verma et al. (1975a) inoculated Manitou wheat by placing colonized straw pieces around coleoptiles. Lesion length and width were recorded every five days. Lesions extended vertically before laterally. Significant lateral lesion extension did not occur until vertical extension was maximum. Verma (1982) conducted a similar study on wheat and barley varieties differing in resistance to the disease. Vertical extension was generally maximal before lateral extension of lesions occurred. Barley required fewer days for lesions to reach maximum vertical length than wheat, indicating that barley is more susceptible to CRR. Mean daily rates of extension were highest in wheat and barley cultivars deemed less tolerant when assessed

by disease ratings of mature plants.

Effect of CRR on Plant Physiology

Investigations of C. sativus infected cereals have centered on the effects on plant yield, grain or biomass. Studies of physiological processes that may be affected by C. sativus infection, with resultant effect on yields, have been limited. Sallans (1940) followed the total leaf areas of inoculated and uninoculated wheat plants from seedling to mature plant stages in the greenhouse. Regardless of soil moisture available for growth, C. sativus infection reduced total leaf area per plant from early growth stages to stem elongation. At stem elongation, the leaf areas of inoculated plants surpassed the leaf areas of uninoculated controls when water availability for growth was high. Apparently, inoculated plants are able to recover from initial stunting and leaf area reduction.

Sallans (1940) investigated the effect of C. sativus infection on individual leaves of wheat. Leaf areas and width and length measurements were determined for individual leaves in order of appearance. Individual leaf areas of uninoculated plants surpassed leaf areas of inoculated plants, up to the appearance of the seventh

leaf. From the seventh leaf through the last measured tenth leaf, areas of individual leaves were greatest for inoculated plants. Leaf lengths were reduced by inoculation while leaf widths were not greatly affected. The seventh through tenth leaves were much larger than control leaves. However, width of leaves on inoculated plants never surpassed control plant leaf widths.

Sallans (1959) described the recovery of field grown wheat plants from CRR. The areas of individual leaves were determined on leaves one through eight. As reported by Sallans (1940) leaves from uninoculated plants surpassed leaves from inoculated plants in area, up to leaf five. Leaves six through eight from inoculated plants were greatest in area. The same results were found for F. culmorum infected plants and for plants infected with both C. sativum and F. culmorum.

Fitt et al. (1978) investigated the effect of various pathogenic, soil-borne fungi on wheat physiological processes. Parameters investigated included: shoot water content, distribution of carbon-14 in roots, mineral composition of shoots, and plant dry weight. C. sativus decreased plant dry weight but not as dramatically as F. culmorum throughout all five weeks of measurements. Carbon-14 assimilation in seminal roots was

not affected by C. sativus. However, C. sativus infection increased assimilation of carbon-14 in crown roots as did F. culmorum. F. culmorum reduced assimilation of carbon-14 in seminal roots at all stages of measurements. At week one shoot K⁺ content was less in plants infected by C. sativus and F. culmorum. C. sativus infected plants recovered by week five while F. culmorum infected plants contained much less K⁺ than controls at week five. A recent report by Fitt et al. (1982) supports the contention that C. sativus diseased plants do not have reduced shoot K⁺ content after week one. C. sativus and F. culmorum both decreased shoot water content at week one. While F. culmorum continued to reduce shoot water content throughout the measurement periods, C. sativus did not.

Sallans (1940) followed the transpirational histories of wheat plants in the greenhouse as affected by CRR. Water use was measured gravimetrically for inoculated and uninoculated plants. Inoculation reduced transpiration initially and up to day thirty. From day thirty to maturity, inoculated plants surpassed controls in transpiration but this only occurred if large quantities of water were supplied. When low quantities of water were supplied, inoculated plants never surpassed

uninoculated plants in degree of transpiration. This suggests that water uptake of C. sativus affected plants is reduced but is not serious unless plants are not able to recover, due to drought.

Disease Assessment

Researchers have evaluated CRR occurrence as the isolation percentage of the pathogen from subcrown internode tissue (Tinline, 1977; Scardaci et al., 1981; Diehl, 1979; Harding, 1973; Scardaci et al., 1982). However, since clean plants as determined visually may yield the pathogen, isolation percentage is of limited value in assessing disease (Harding, 1973).

Broadfoot (1934) based disease assessment on the color of the crowns and secondary roots using a scale of zero for normal color to ten for black, diseased tissue. Andrew et al. (1960) and Greaney (1946) rated the basal portion of plants on a scale of zero to five or ten, respectively. Zero equaled no lesions while five or ten equaled a dead plant. Diehl (1979) rated the entire root system for disease. Four classes of clean, slight, moderate, and severe were developed representing the area of the system lesioned. Verma et al. (1975a) have reported the percentage of diseased plants in a sample

and the number of diseased plants per unit area. Diseased plants were plants showing lesions on the subcrown internode. For rapid assays Grey et al. (1984) have suggested that disease may be expressed merely as the percentage plants rated severe.

Researchers have developed a disease rating system in which four disease severity classes are described, based on the percentage of subcrown internode tissue lesioned (Tinline et al., 1973). Ratings of clean, slight, moderate and severe represent no lesions, 1 percent to 25 percent lesioned, 25 percent to 50 percent lesioned, and greater than 50 percent lesioned or circumvention of the subcrown internode, respectively. McKinney (1923) used five classes while Sallans (1968) combined the moderate and severe classes, and the slight and clean classes, into two classes. Sallans et al. (1943) developed four classes based on lesions of the subcrown internode and the degree of crown discoloration. Slight, moderate, severe and clean ratings of the subcrown internode as described above were used as were 11 classes of crown discoloration.

Percent disease rating integrates the number of diseased plants in a severity class with a category factor for that severity class (Tinline et al., 1973).

The category factor is a relative number based on the yield reduction, as compared to clean plants, of plants in that severity class. The sum of the products of the category factor and the number of plants in that class is divided by the product of the number of plants rated and the maximum category value. The number obtained, the percent disease rating, is actually the predicted percentage yield reduction.

McKinney (1923a) used five severity classes and reported category values of 0, 0.75, 1.00, 2.00 and 3.00 for both wheat and barley. Sallans et al. (1942) reported values of 0, 3, 3 and 4 for the four classes derived from subcrown internode lesioning and crown discolorations. Verma et al. (1974) reported the Canadian standard category values of 1, 2 and 4 for wheat and 2, 5 and 10 for barley, for slight, moderate, and severe classes, respectively. Sallans (1973) obtained a percent disease rating for wheat or barley from the percentage of plants in the class encompassing moderate and severe subcrown internodes.

Yield Loss Due to CRR

Yield loss due to CRR for areas and years has been based on potential yield originally developed from a

formula by Machacek (1943). Percent loss in yield equals $100 - (W \text{ divided by } (W_1 \text{ times } N) \text{ times } 100)$ where W equals total weight of grain from an area, W_1 equals the average weight of grain from individual healthy plants, and N equals the total number of plants in the collection. W divided by $(W_1 \text{ times } N)$ is essentially the potential yield, based on the yield obtained from clean plants.

From a three year survey of many wheat fields in Manitoba, Machacek (1943) estimated yield loss to CRR at 12.1 percent. From the results of a comprehensive survey of wheat (Ledingham et al., 1973) and barley (Piening et al., 1976) fields throughout the prairie provinces of Canada, the Canadians estimated yield losses due to CRR. For wheat, the average annual yield losses approximated 5.7 percent equalling 30 million bushels total for the three years. For barley, an average annual yield loss of 10.3 percent was estimated, totaling 54 million bushels for the three years.

Yield of grain from infected plants is significantly reduced by lesions on the subcrown internode. For wheat, Verma et al. (1976b) found a consistent reduction in the number of tillers, the number and weight of grains per head, and 1000 kernel weight with increasing disease severity. Differences

between slight and moderate classes were generally non-significant. Piening (1973) observed that reaction of barley cultivars to CRR was not consistent in reduction of yield and yield components. A reduction in the number of heads per rated plant and weight of grain per rated plant was not seen for all severely rated plants of all cultivars.

Verma et al. (1976a) investigated the effects of CRR on wheat grain yield and biomass production throughout the growing season. Parameters were collected for individual plants in each severity class. In general the biomass per rated plant decreased with increasing severity class, over time. Grain yield per plant decreased with increasing severity class. Significant differences between all severity classes, except slight and moderate, were seen for biomass per plant and grain yield per plant.

For a population of wheat or barley plants containing differing amounts of clean, slight, moderate and severe rated plants, differences in grain yield are generally not seen. Grey et al. (1984) found no significant decrease in yield of inoculated barley plots compared to uninoculated barley plots although disease ratings were significantly higher for inoculated plots.

Even though the number of harvestable tillers per m of row was significantly reduced by increased disease, later formed yield components (i.e., kernels per head and seed size) apparently compensated for initial loss. Verma (1983), Verma et al. (1981), and Chinn (1978) have found that a significant decrease in the disease rating of fungicide treated plots of wheat and barley did not result in an increase in yield per row.

Comparisons between disease ratings, calculated yield loss, and measured yield have been made. Piening (1973) reported that a low potential yield loss was not necessarily indicated by a low disease rating for barley. Tinline et al. (1979) reported a high correlation between disease ratings and calculated yield loss for wheat but a more variable relation for barley. Significant correlations between measured yield per unit area and percent disease ratings were seldom seen.

The question of competition between healthy and diseased plants in a population has been raised by researchers (Verma, 1982; Machacek, 1943; Grey et al., 1984; Tinline et al., 1973).

"It is possible that the healthy plants profited somewhat in their competition with diseased plants for food and moisture and that their yield per plant was higher than it would have been if all plants had been healthy." (Machacek, 1943)

Nonsignificant correlations between disease ratings and yield per row suggest that competitive effects are occurring in a population of differentially diseased plants.

Chapter 3

Introduction

In the summer of 1981 an experimental field plot was established to determine if: various systemic fungicides and/or potassium fertilizers reduce percent disease ratings of CRR diseased barley and affect yield data on a whole plot scale. Also to be determined was the question of whether the chloride anion or the potassium cation is the effective agent against CRR.

Materials and Methods

Inoculum Preparation

One liter canning jars were each filled with 140 g of oat kernels and 90 ml of distilled water. A 7 cm diameter disk of #4 Whatman filter paper was placed on top of a canning jar metal lid which had a 2 cm diameter hole in the center. The assembly was subsequently held in place with the screw top lid of the jar. This arrangement allowed gas exchange with the outside environment while limiting outside contamination. The jars and contents were sterilized at 121° C for 60 min in an autoclave.

A mass transfer of C. sativus, isolate number 214, obtained from a severely diseased subcrown internode of spring wheat in a field near Dutton, MT, was used. It was grown for 10 days in petri plates containing acidified (pH 5) Difco potato dextrose agar. Two, 8 mm diameter plugs, containing a mass of spores and mycelium, were used to inoculate each jar of sterilized oat kernels (Mathre et al., 1975).

Colonization of the oat kernel medium proceeded for 40 days at room temperature. Infested oats, containing mycelium and spores, were then air dried for 7 days and subsequently sieved through a 1 cm square mesh screen. The sieved inoculum was packaged, by volume, into aliquots of approximately 20 g each. For controls, a quantity of these packages were autoclaved for 60 min at 121°C.

Fertilizer Types

Two potassium fertilizers were used: potassium chloride (KCl) and potassium sulfate (K_2SO_4). Potassium chloride was 100% KCl while the K_2SO_4 formulation was 43% K_2SO_4 and 57% inert materials. The rate of application was 22.4 kg of potassium per hectare which amounted to 4.4 g of KCl per 3.3 m seeded row and 11.9 g of K_2SO_4

formulation per 3.3 m seeded row. The fertilizer was added simultaneously to the furrow with the seed.

Fungicides and Application Procedures

Six experimental fungicides were applied as seed treatments (Table 1). Five hundred g of seed were treated with a fungicide at one time. Seed was treated using a Gustafson bench top seed treater. A 17,800 l metal drum, containing inner fins to aid the separation and exposure of seed, was used to tumble the seed during fungicide application. Fungicides applied as a liquid were brought to a 5 ml total volume with distilled water and aspirated onto tumbling seed. Powder fungicides were sprinkled onto tumbling seed. Ten per cent additional fungicide was applied to seed to offset adherence of the fungicide to equipment. Control seed lots were treated with distilled water. Treated seed tumbled at 20 drum revolutions per min for 30 min.

Field Plot

'Washonupana', a two row, hulless, waxy, Smyrna type barley was obtained from R. F. Eslick, barley breeder, Montana State University, Bozeman, Montana. Seed remaining on a 0.22 cm by 1.9 cm mesh screen after passage through a 0.26 cm by 1.9 cm mesh screen was used

Table 1. Chemical name, formulation, active ingredient, and application rate of systemic fungicide seed treatments.

Chemical Class	Product	Formulation	Active Ingredient	Application Rate (units A.I./Kg seed)
Triazole	CGA 64251	13.5% A.I.;L. ¹	Etaconazole ²	0.015 ml
	Baytan 150FS	14.0% A.I.;FL.	Triadimenol	0.15 ml
	Gus 215	50.0% A.I.;L.	Furmecyclox	0.98 ml
Imidazole	Fungaflor	5.0% A.I.;FL.	Imazalil	0.1 ml
	BTZ 40502	40.0% A.I.;L.	Prochloraz	0.2 ml
Pyrimidine	EL 228	98.0% A.I.;P.	Nuarimol	0.3 g

¹ A. I. = Active Ingredient; L. = Liquid, FL. = Flowable, P. = Powder

² Etaconazole:1-((2-(2,4-dichlorophenyl)-4-ethyl-1,3-dioxolan-2-yl)methyl)-1H-1,2,4-triazole
 Triadimenol :BETA-(4-chlorophenyl)-ALPHA-(1,1-dimethyl-2-ethyl)-1H-1,2,4-triazole-1-ethanol
 Imazalil:1-(2-(2,4-dichlorophenyl)-2-(2-propenyloxy)ethyl)-1H imidazole
 Prochloraz:N-propyl-N(2-(2,4,6-trichlorophenoxy)ethyl)imidazole-1-carboxamide
 Nuarimol:ALPHA-(2-chlorophenyl)-ALPHA-(4-fluorophenyl)-5-pyrimidine-methanol
 Furmecyclox:2,5-dimethyl-N-cyclohexyl-N-methoxy-3-furan-carboxamide

for planting. One hundred and fifty seeds or 7 g of seed (approximately 150 seeds) were planted in each 3.3 m row.

The experimental plot was planted on May 22, 1981, on the Arthur H. Post Research Farm, approximately five miles west of Bozeman. Seed, fertilizer and inoculum were drilled together, approximately 4 cm deep, in 3.3-m long rows spaced on 30 cm centers, with a four row cone seeder. Autoclaved inoculum was added to noninoculated rows. No additional material was applied to unfertilized rows.

The soil type of the plot was an Amsterdam silty clay loam (fine-silty, mixed typic Cryoboroll). Growing conditions, soil and seasonal moisture and temperature were considered normal for the season and area. The plot was sprayed with Bronate 35 days after planting to control broad-leaf weeds. Weeds and volunteer plants were also pulled by hand throughout the growing season.

Field Plot Design

Twenty four treatment combinations from two factors were arranged in a randomized complete block design. Factor one contained three fertilizer treatments (no fertilizer, KCl fertilizer, and K_2SO_4 fertilizer). Factor two contained eight fungicide-inoculum treatments

(untreated plus autoclaved inoculum, untreated plus inoculum, and treatment with six fungicides, all inoculated). Each block represented one replication. The field plot was arranged in a two block by two block square with each block containing four ranges of six, four row plots. The center two rows of each four row plot were planted with counted seed while the outer two rows were planted with 7 g of packaged seed.

Data Collection

Data were collected from only three blocks due to rodent destruction of block four.

At the three leaf stage, Feekes' scale 1, (Large, 1954) emerged plants in the center two rows of each four row plot were counted. Yield data were obtained for each row of the middle two rows of each plot and included: total number of tillers per row, number of harvestable tillers per row, number of kernels per spike, total grain yield per row, and 1000 kernel weight. Total number of tillers per row and number of harvestable tillers per row were counted during the soft dough stage (Feekes' scale 11.2). Harvestable tillers were considered to be those tillers with spikes in the upper one-third of the plant canopy. During the hard dough

stage (Feekes' scale 11.3), 20 harvestable heads were collected at random from each row to determine number of kernels per spike. The remaining plants of each row were cut for grain and threshed with a Vogel plot thresher. Grain harvested, plus kernels obtained from the kernels per spike determinations, constituted total grain yield per row. A 250 kernel sample was counted and weighed. The weight was multiplied by a factor of four to obtain 1000 kernel weight.

Due to unknown factors the majority of plants in yield rows did not have discernible subcrown internodes. Therefore, subcrown internodes obtained from all four rows of each plot were used to determine percentage disease ratings after harvest. A minimum of 50 subcrown internodes from three replications were rated for each treatment.

Subcrown internodes were rated for disease severity on a two class scale developed by Sallans (Sallans et al, 1968). Subcrown internodes rated as moderate or severe were placed in the diseased class while subcrown internodes rated as clean or slight were placed in the healthy class. The percentage of diseased plants was considered the percent disease rating.

Data Analysis

Yield data obtained from each of the two middle rows were averaged to obtain one value per plot. Percent disease ratings, 1000 kernel weight, kernel number per spike, and emergence data were analyzed statistically using an analysis of variance of multiple factors (Snedecor and Cochran, 1980). An analysis of covariance was conducted, with grain yield per row, total number of tillers per row, and number of harvestable tillers per row all as dependent covariables and plant emergence as the independent covariable. When the covariance was significant at the 5% level, the adjusted treatment means were analyzed for significant differences at that 5% level using Newman-Keuls (Sequential Studentized Range) multiple comparison method. Differences between means within a factor were tested for significant differences at the 5% level using Newman-Keuls (Sequential Studentized Range) multiple comparison method. Treatment combination means were analyzed for significant differences at the 5% level when a significant interaction was indicated between the factors. All three fertilizer treatments with inoculum or autoclaved inoculum were analyzed for significant differences at the 5% level.

RESULTS

Results of Systemic Fungicide Treatments

Significant ($P < .05$) interactions were not detected between the fertilizer factor and the fungicide-inoculum factor for all parameters. Covariance analysis was significant ($P < .05$) only for the fungicide factor and not for the fertilizer factor or the six fertilizer means.

The number of emerged plants was significantly ($P < .05$) reduced by inoculation with C. sativus (Table 2). However, seed treatment with imazalil or nuarimol significantly ($P < .05$) increased the plant emergence of inoculated rows. The degree of protection was sufficient to cause untreated, uninoculated rows and treated, inoculated rows to have a similar emergence per row. Furmecyclox was apparently phytotoxic at the rate used since inoculated rows treated with furmecyclox had a significantly ($P < .05$) reduced emergence compared to that of untreated, inoculated rows.

Addition of inoculum to rows did not cause more disease in mature plants than addition of autoclaved inoculum to rows (Table 2). However, treatment of inoculated rows with nuarimol did significantly ($P < .05$) reduce disease ratings compared to those of nontreated,

inoculated rows. Rows treated with imazalil or triadimenol tended to have reduced disease ratings, although not significantly ($P < .05$) reduced compared to that of inoculated, nontreated rows. Rows treated with furmecyclox had the highest disease ratings observed although not significantly ($P < .05$) greater than ratings of inoculated or uninoculated, nontreated rows.

Table 2. Effect of systemic fungicide seed treatments on plant emergence and percent disease ratings of CRR diseased 'Washonupana' barley.

Inoculation Treatment	Fungicide Treatment	Emergence (# plts/row) ¹	Disease Rating (%) ²
Inoc.	Furmecyclox	35.4 A ³	64.3 C
Inoc.	Etaconazole	37.6 AB	44.1 AB
Inoc.	Prochloraz	43.6 AB	47.2 AB
Inoc.	Nuarimol	55.8 DE	36.0 A
Inoc.	Triadimenol	53.7 CD	49.4 ABC
Inoc.	Imazalil	62.6 DE	45.4 AB
Inoc.	No Fung.	45.5 BC	53.3 BC
Uninoc.	No Fung.	64.9 E	56.8 BC

¹ The number of plants from the center two rows were averaged and analyzed across the three fertilizer treatments.

² The percentage of diseased plants from a four row plot constituted the disease rating and was analyzed across the three fertilizer treatments.

³ Column means followed by common letters are not significantly different ($P < .05$) according to Newman-Keuls multiple comparison method.

The number of kernels per spike and 1000 kernel weight were not affected by inoculation with *C. sativus* (Table 3). Rows treated with furmecyclox had a significantly ($P < .05$) greater kernel number per spike than rows treated with prochlorz, and rows treated with triadimenol had a significantly ($P < .05$) greater 1000 kernel weight than rows treated with prochloraz or nuarimol. However, no rows treated with a fungicide had values that differed significantly ($P < .05$) from rows, inoculated or uninoculated, not treated with a fungicide.

Table 3. Effect of systemic fungicide seed treatments on 1000 kernel weight and kernel number per spike of CRR diseased 'Washonupana' barley.

Inoculation Treatment	Fungicide Treatment	Kernels Per Spike ¹ (#)	1000 kernel Weight ² (g)
Inoc.	Furmecyclox	20.5 B ³	39.6 AB
Inoc.	Etaconazole	19.6 AB	39.4 AB
Inoc.	Prochloraz	19.2 A	39.1 A
Inoc.	Nuarimol	19.7 AB	39.2 A
Inoc.	Triadimenol	19.4 AB	40.7 B
Inoc.	Imazalil	19.8 AB	39.8 AB
Inoc.	No Fung.	20.0 AB	39.2 AB
Uninoc.	No Fung.	19.5 AB	39.5 AB

¹ The number of kernels per spike (obtained from twenty spikes per center two rows) was averaged and analyzed across the three fertilizer treatments.

² The weight of 250 kernels from the center two rows was averaged, multiplied by a factor of four, and analyzed across the three fertilizer treatments.

³ Column means followed by common letters are not significantly different ($P < .05$) according to Newman-Keuls multiple comparison method.

Inoculation with C. sativus did not reduce grain yield per row and none of the seed treatments affected grain yield per row (Table 4). The total tiller and harvestable tiller number per row was not reduced by inoculation with C. sativus. Rows treated with furmecycloz had a significantly ($P < .05$) less total tiller number per row than inoculated rows or rows treated with nuarimol or imazalil. Rows treated with nuarimol had a significantly ($P < .05$) greater harvestable tiller number per row than all other rows, including inoculated or uninoculated rows, except rows treated with imazalil.

Potassium Fertilizers

When only KCL and inoculum were added to rows, emergence was significantly ($P < .05$) reduced compared to that of rows having no additions at all (Table 5). However, potassium fertilizers did not affect plant emergence when added to inoculated, fungicide treated rows.

Table 4. Effects of systemic fungicide seed treatments on grain yield per row, total tiller number per row, and harvestable tiller number per row of CRR diseased 'Washonupana' barley.

Inoculation Treatment	Fungicide Treatment	Grain Yield per row ¹ (g)	Tiller Number Per Row	
			Total ² (#)	Harvestable ³ (#)
Inoc.	Furmecyclox	208.3 A ⁴	357.2 A	193.9 A
Inoc.	Etaconazole	210.4 A	386.1 AB	192.5 A
Inoc.	Prochloraz	198.1 A	411.4 AB	189.0 A
Inoc.	Nuarimol	219.2 A	441.0 B	235.7 B
Inoc.	Triadimenol	196.0 A	413.3 AB	187.7 A
Inoc.	Imazalil	202.5 A	444.5 B	207.2 AB
Inoc.	No Fung.	212.0 A	441.0 B	188.9 A
Uninoc.	No Fung.	188.3 A	412.4 AB	177.9 A

¹ Grain weight from the two center rows was averaged and analyzed across the three fertilizer treatments, after adjusted for plant population per row.

² The number of tillers from the center two rows was averaged and analyzed across the three fertilizer treatments, after adjusted for plant population per row.

³ The number of harvestable tillers from the center two rows was averaged and analyzed across the three fertilizer treatments, after adjustment for plant population per row.

⁴ Column means followed by common letters are not significantly different ($P < .05$) according to Newman-Keuls multiple comparison method.

Rows treated only with KCl had reduced disease levels, whether inoculum or autoclaved inoculum was added (Table 5). This reduction was not significant ($P < .05$). However, disease ratings were significantly ($P < .05$) reduced by application of KCl to inoculated, fungicide treated rows.

Table 5. Effect of potassium fertilizers on plant emergence and percent disease ratings of CRR diseased 'Washonupana' barley.

		Emergence (# plants/row) ¹	Disease Rating (%) ²
I. Fertilizer Treatment			
	KCl	47.9 A ³	36.9 A
	K ₂ SO ₄	49.5 A	57.2 B
	No Fert.	52.2 A	54.6 B
II. Fertilizer Inoculation Treatment Treatment			
	No Fert. Inoc.	47.2 AB	59.7 A
	No Fert. Uninoc.	69.8 B	57.4 A
	KCl Inoc.	42.3 A	39.9 A
	KCl Uninoc.	65.3 AB	47.1 A
	K ₂ SO ₄ Inoc.	47.2 AB	60.2 A
	K ₂ SO ₄ Uninoc.	59.5 AB	66.0 A

¹ The number of plants from the center two rows were averaged, and analyzed across the fungicide-inoculum factor for I but not II.

² The percentage of diseased plants from a four row plot constituted the disease rating, and was analyzed across the fungicide-inoculum factor for I but not II.

³ Column means followed by a common letter are not significantly different ($P < .05$) according to Newman-Keuls multiple comparison method.

Addition of only potassium fertilizers to inoculated or uninoculated rows did not affect grain yield or the number of harvestable tillers of those rows but did affect the total number of tillers per row (Table 6). When only KCl and inoculum were added to rows, the total number of tillers per row was significantly ($P < .05$) reduced compared to that of rows having only KCl addition. However, potassium fertilizers did not affect

grain yield per row, and the number of harvestable or total tillers per row when added to inoculated, fungicide treated rows.

Table 6. Effect of potassium fertilizers on grain yield per row, total tiller number per row, and harvestable tiller number per row of CRR diseased 'Washonupana' barley.

		Grain Yield per row ¹ (g)	Tiller Number Total ² (#)	Per Row Harvestable ³ (#)
I. Fertilizer Treatment				
	KCl	199.7 A ⁴	401.3 A	198.1 A
	K ₂ SO ₄	207.3 A	409.0 A	192.0 A
	No Fert.	206.1 A	422.2 A	199.6 A
II. Fertilizer Inoculation Treatment				
	No Fert. Inoc.	207.1 A	439.3 AB	177.2 A
	No Fert. Uninoc.	217.9 A	464.7 AB	227.7 A
	KCl Inoc.	170.6 A	352.3 A	162.7 A
	KCl Uninoc.	228.2 A	503.2 B	225.5 A
	K ₂ SO ₄ Inoc.	232.9 A	425.7 AB	191.0 A
	K ₂ SO ₄ Uninoc.	206.0 A	424.3 AB	203.0 A

¹ Grain weight from the two center rows was averaged, and analyzed across the fungicide-inoculum factor for I but not II and was not adjusted for plant population per row.

² The number of tillers from the center two rows was averaged, and analyzed across the fungicide-inoculum factor for I but not II and was not adjusted for plant population per row.

³ The number of harvestable tillers from the center two rows was averaged, and analyzed across the fungicide-inoculum factor for I but not II and was not adjusted for plant population per row.

⁴ Column means followed by common letters are not significantly different (P<.05) according to Newman-Keuls multiple comparison method.

Addition of only potassium fertilizers to inoculated or uninoculated rows did not affect 1000 kernel weight or the number of kernels per spike (Table 7). However, K_2SO_4 and KCl did differentially affect these parameters when added to fungicide treated rows. K_2SO_4 addition significantly ($P < .05$) increased the kernel number per spike from that of KCl treated rows while KCl addition significantly ($P < .05$) increased the 1000 kernel weight from that of nonfertilized rows.

Table 7. Effect of potassium fertilizers on 1000 kernel weight and the number of kernels per spike of CRR diseased 'Washonupana' barley.

		Kernels Per Spike ¹ (#)	1000 kernel Weight ² (#)
I. Fertilizer Treatment			
	KCl	19.4 A ³	40.3 B
	K ₂ SO ₄	19.9 B	39.6 AB
	No Fert.	19.8 AB	38.8 A
II. Fertilizer Inoculation Treatment			
	No Fert. Inoc.	20.5 A ³	37.8 A
	No Fert. Uninoc.	19.3 A	39.3 A
	KCl Inoc.	19.3 A	38.9 A
	KCl Uninoc.	19.3 A	39.7 A
	K ₂ SO ₄ Inoc.	20.3 A	40.8 A
	K ₂ SO ₄ Uninoc.	20.3 A	39.3 A

¹ The number of kernels per spike (obtained from twenty spikes per center two rows) was averaged, and analyzed across the fungicide-inoculum factor for I but not II.

² The weight of 250 kernels from the center two rows was averaged, multiplied by a factor of four, and analyzed across the fungicide-inoculum factor for I but not II.

³ Column means followed by common letters are not significantly different (P<.05) according to Newman-Keuls multiple comparison method.

Discussion

Treatment with most of the systemic, ergosterol inhibiting fungicides resulted in a tendency for the percent disease ratings to be reduced below ratings obtained from plots, inoculated or uninoculated, not treated with a fungicide. However, only nuarimol

significantly ($P < .05$) reduced percent disease ratings. Only one fungicide, furmecyclox, did not reduce percent disease ratings.

Three of the systemic fungicides used in this study (nuarimol, triadimenol, and imazalil) have been reported to be effective in reducing disease ratings of CRR diseased mature spring wheat and barley (Verma, 1983; Piening et al., 1983; Verma et al., 1981). My results also suggest that these fungicides do tend to reduce percent disease ratings but only nuarimol had a statistically significant ($P < .05$) effect. Reports from Canada, however, showed consistently variable results (Verma, 1983; Piening et al., 1983; Verma et al., 1981). Location, cultivar, time, dosage, and formulation all apparently affect efficacy of the fungicides.

There have been reports that the systemic fungicide seed treatments used in this research exhibit phytotoxicity (Verma, 1981; Verma, 1983; Piening et al., 1983). Apparently, plant emergence may be reduced and reportedly (Verma et al., 1981) hulless barley types may be affected more than hulled barley types. In these tests, however, treatment with imazalil or nuarimol did not reduce plant emergence below the emergence occurring in inoculated or uninoculated, nonfungicide treated rows.

In fact, addition of these fungicides resulted in a significant ($P < .05$) increase in the plant emergence of inoculated rows above the emergence observed in nonfungicide treated, inoculated rows. Apparently, hulless cultivars are sensitive to addition of inoculum but are protected by seed treatment with imazalil or nuarimol. Whether these fungicides would have increased plant emergence of uninoculated rows (only natural inoculum present) above the emergence of uninoculated, nonfungicide treated rows, cannot be answered by this study. Regardless, these fungicides did not act in a phytotoxic manner at the rates used in this study but rather acted in a protective mode.

Several recent reports (Verma et al., 1981; Piening et al., 1983; Verma, 1983) suggest that even though percent disease ratings of a plot containing a mixture of healthy and diseased plants may be altered by use of systemic fungicide seed treatments, grain yield of the plot is not subsequently increased and may, in fact, be decreased. Results of this study support that contention. Reduction in disease ratings did not result in increased grain yield. Even when the plant stand was accounted for by covariance statistics, an increase in grain yield of a plot containing a mixture of

differentially diseased plants was not detected even though disease had been reduced.

The effect of systemic fungicides on yield components of CRR diseased barley has not been reported. My results suggest that certain yield components of a row containing a mixture of differentially diseased plants could be increased by seed treatment. However, when yield components were adjusted for plant population, significant ($P < .05$) differences in fungicide and nonfungicide treated rows were not detected except when triadimenol was used. The number of harvestable tillers per row was significantly ($P < .05$) increased when triadimenol was used and plant stand was accounted for. However, triadimenol did not significantly ($P < .05$) reduce percent disease ratings and a cause and effect relationship, as determined by correlation statistics, could not be shown to exist between increased yield components and decreased disease, when disregarding plant stand. Therefore, increased yield components were probably not induced by a reduction in disease.

Use of KCl fertilizer resulted in significantly ($P < .05$) reduced percent disease ratings only when analyzed over the inoculum-fungicide factor. When analyzed over only the inoculated and uninoculated

treatments (no addition of fungicide), treatment with KCl did not result in percent disease ratings significantly ($P < .05$) below percent disease ratings resulting from treatment with K_2SO_4 or no fertilizer. For reasons unknown, the percent disease rating of uninoculated rows was not lowered by treatment with KCl, whereas treatment of inoculated rows with KCl did result in lower percent disease ratings, although not significantly ($P < .05$) lower. Thus, when the fertilizer treatments were analyzed over only the inoculated fungicide treatments, addition of KCl to rows resulted in significantly ($P < .05$) reduced percent disease ratings while use of K_2SO_4 or no fertilizer did not affect percent disease ratings. These results suggest that the chloride anion, not the potassium cation, is the effective agent against CRR.

Even though KCl reduced percent disease ratings, subsequent increases in yield or yield components were not detected. Addition of KCl did significantly ($P < .05$) increase 1000 kernel weight but significant ($P < .05$) differences between inoculated and uninoculated rows were not detected. This suggests that the response to KCl was a fertilizer response and not a response to disease control. Apparently, KCl addition reduces the proportion of diseased subcrown internodes in a plot but does not

affect yield and yield components through this reduction in disease.

Because 'Washonupana' did not form discernable subcrown internodes at a consistent level in any plot, percent disease ratings could only be determined by examining less than a total of 100 subcrown internodes for three replications. Most researchers of CRR examine a minimum of 50 subcrown internodes per replication when determining percent disease ratings. Nonetheless, results of this study suggest that percent disease ratings can be reduced by treatment with KCl or certain systemic fungicides. A greater proportion of the subcrown internodes were of the healthy class when treated with KCl or nuarimol than those not treated with these agents.

Fertilization with KCl or seed treatment with nuarimol reduced percent disease ratings. However, significant ($P < .05$) interactions were not detected between the two treatments. Plots treated with KCl and nuarimol showed no less disease than plots treated only with KCl or nuarimol. In my study, disease intensity was based on subcrown internode discoloration. Both KCl and nuarimol reduced this disease symptom but did not act synergistically in further reducing this disease symptom

when used together, suggesting that the two agents reduce subcrown internode discoloration through different mechanisms.

Since symptom expression (i.e., subcrown internode discoloration) was reduced with KCl use, protection of the subcrown internode was probably occurring, suggesting an effect on the plant by the chloride anion or, perhaps, translocation of an effective fungitoxic agent to the subcrown internode. Protection of the subcrown internode may be due to optimum plant nutrition as reports suggest that chloride anion availability reduces nitrate uptake (Younts et al., 1958). Canadian researchers have determined that the form of nitrogen used in the fertilization of cereals may affect CRR intensity (Ledingham, 1970; Piening et al., 1969). Apparently, urea fertilizer either does not affect CRR intensity or results in decreased CRR intensity while nitrate usage results in increased CRR intensity. The possibility exists that the chloride anion reduced CRR intensity by reducing the amount of nitrate taken up by a plant.

Use of chloride fertilizers results in more negative leaf osmotic and water potentials than normal (Christensen et al., 1981). Increased chloride anion concentrations in leaf tissue were measured and shown to

be a potential cause of the lowered potentials. Use of chloride fertilizers also reduced take-all. Other researchers have reported that fertilization with chloride reduces natural root necrosis of corn and stalk rot of corn (Martens et al., 1967; Younts et al., 1958). The distinct possibility exists that in my study KCl reduced subcrown internode discoloration by inhibiting C. sativus growth through more negative osmotic potentials in the subcrown internode.

Use of the systemic fungicide, nuarimol, did result in reduced percent disease ratings. Presumably being translocatively ambimobile, nuarimol, or its by-product, would be present in the symplast and apoplast of the subcrown internode. Therefore, fungal growth within the subcrown internode would be stopped or reduced. However, reports suggest that these new generation, ergosterol inhibiting fungicides may also have hormonal effects, resulting in shorter and wider subcrown internodes than normal (Chinn, 1978; Chinn et al., 1980). If this were the case, then reduced discoloration of the subcrown internode would occur, apparently through an escape mechanism. In this study the subcrown internodes were short but any reduction in length was probably due more to cultivar effects than to fungicide effects as all

subcrown internodes, regardless of treatment, were short or nonexistent. The supposition that the fungicide, or its by-product, is translocated to the subcrown internode and that the fungicide or its by-product is fungicidal in vitro (Lilly Research Laboratories, 1976), suggests that the fungicide is reducing disease by restricting growth of the CRR pathogen within the subcrown internode tissue, not by some prophylactic mechanism.

The question of competitive effects on yield is raised by the results of this study. The disease intensity in a population of plants could be lowered by addition of control agents but yield of that population of plants was not subsequently increased. Even when yield and yield components were adjusted for plant population, increases in yield and yield components were not detected even though disease was reduced. Rows containing a large proportion of diseased plants did not yield less than rows containing a significantly lower proportion of diseased plants. The disease does affect the yield and yield components of individual plants but reports (Grey et al., 1984; Verma, 1983; Verma et al., 1981) have suggested that the yield and yield components of a group of differentially diseased plants are not reduced even though the disease is present and is

intense. For this to occur, some plants in a group of differentially diseased plants must be growing better and yielding more than normally. The likelihood exists that clean plants, adjacent to diseased plants, benefit as increased amounts of water and nutrients are likely available, due to reduced use by neighboring diseased plants.

Chapter 4

Conclusions

Pathological effects, due to inoculation of barley with the CRR pathogen, were negated by use of certain systemic fungicides and KCl fertilizer. Emergence of inoculated rows was increased when planted with seed treated with nuarimol, imazalil, or triadimenol. Percent disease ratings were reduced by treatment with nuarimol or KCl. However, increases in grain yield per row and yield components did not result from reduction in disease intensity, even when adjusted for plant stand per row. The disease intensity of a barley plot may apparently be reduced by use of certain control agents but compensatory effects may reduce or eliminate any potential benefits.

REFERENCES CITED

- Andrews, J. E., J. S. Horricks, and D. W. A. Roberts. 1960. Interrelationships between plant age, root rot infection, and cold hardiness in winter wheat. *Can. J. Bot.* 38:601-611.
- Broadfoot, W. C. 1934. Studies on foot rot and root rot of wheat. IV. Effects of crop rotation and cultural practice on the relative prevalence of Helminthosporium sativum and Fusarium spp. as indicated by isolation from wheat plants. *Can. J. Res.* 10:95-114.
- Chinn, S. H. F. 1978. Influence of seed treatment with imazalil on common root rot and the size of the subcrown internode of wheat. *Phytopathology* 68:1662-1666.
- Chinn, S. H. F., P. R. Verma, and D. T. Spurr. 1980. Effects of imazalil seed treatment on subcrown internode lengths and coleoptile-node-tillering in wheat. *Can. J. Plant Sci.* 60:1467-1472.
- Christensen, N. W., R. G. Taylor, T. L. Jackson, and B. L. Mitchell. 1981. Chloride effects on water potentials and yield of winter wheat infected with take-all root rot. *Agron. J.* 73:1053-1058.
- Clark, R. V. 1977. Field tests of cereal seed treated with nonmercurial fungicides. *Can. Plant Dis. Surv.* 57:45-48.
- Cook, R. J. 1968. Fusarium root and foot rot of cereals in the Pacific Northwest. *Phytopathology* 58:127-131.
- Diehl, J. A. 1979. Common root rot of wheat in Brazil. *Plant Dis. Repr.* 63:1020-1022.

- Duczek, L. J., and L. J. Piening. 1982. Effect of seeding depth, seeding date, and seed size on common root rot of spring barley. *Can. J. Plant Sci.* 62:885-891.
- Fitt, B. D. L., and D. Hornby. 1978. Effect of root-infecting fungi on wheat transport processes and growth. *Physiol. Plant Pathol.* 13:335-346.
- Garvin, J. P. 1982. The effects of nitrogen, phosphorus, potassium, sulfur, chloride, and their interactions, on the agronomic and quality characteristics of dryland small grains. Unpub. M. Sc. Thesis. Montana State University. Bozeman, Montana.
- Greaney, F. J. 1946. Influence of time, rate, and depth of seeding on the incidence of root rot in wheat. *Phytopathology* 36:252-263.
- Grey, W. E., and D. E. Mathre. 1984. Reaction of spring barleys to common root rot and its effect on yield components. *Can. J. Plant Sci.* 64:245-253.
- Hampton, J. G. 1978. Seed treatments for the control of Drechslera sorokiniana in barley. *New Zealand J. Exp. Agr.* 6:85-89.
- Harding, H. 1973. Fungi associated with subcrown internodes of wheat (Triticum aestivum). *Can. J. Bot.* 51:2514-2516.
- Huang, H. C., and R. D. Tinline. 1976. Histology of Cochliobolus sativus infection in subcrown internodes of wheat and barley. *Can. J. Bot.* 54:1344-1354.
- Johnston, H. W. 1976. Influence of spring seeding date on yield loss from root rot of barley. *Can. J. Plant Sci.* 56:741-743.
- Large, E. C. 1954. Growth stages in cereals. Illustration of the Feekes' scale. *Plant Pathol.* 3:128-129.

- Ledingham, R. J. 1970. Effects of straw and nitrogen on common root rot of wheat. *Can. J. Plant Sci.* 50:175-179.
- Ledingham, R. J., T. G. Atkinson, J. S. Horricks, J. T. Mills, L. J. Piening, and R. D. Tinline. 1973. Wheat losses due to common root rot in the prairie provinces of Canada, 1969-71. *Can. Plant Dis. Surv.* 53:113-122.
- Lilly Research Laboratories. 1976. Technical report on EL-228.
- Luz, W. C., and J. C. Vierira. 1982. Seed treatment with systemic fungicide to control Cochliobolus sativus on barley. *Plant Dis.* 66:135-136.
- Machacek, J. E. 1943. An estimate of loss in Manitoba from common root rot in wheat. *Sci. Agr.* 24:70-77.
- Martens, J. W., and D. C. Arny. 1967. Effects of potassium and chloride ion on root necrosis, stalk rot, and pith condition in corn(Zea mays L.). *Agron. J.* 59:499-502.
- Mathre, D. E., and R. H. Johnston. 1975. Cephalosporium stripe of winter wheat: Procedures for determining host response. *Crop Sci.* 15:591-594.
- McKinney, H. H. 1923a. Influence of soil temperature and moisture on infection of wheat seedlings by Helminthosporium sativum. *J. Agr. Res.* XXVI:195-217.
- McKinney, H. H. 1923b. The foot-rot caused by Helminthosporium sativum. U.S.D.A. bulletin 1347:17-40.
- Piening, L. J. 1973. Differential yield response of ten barley cultivars to common root rot. *Can. J. Plant Sci.* 53:763-764.
- Piening, L. J., L. J. Duczek, T. G. Atkinson, and J. G. N. Davidson. 1983. Control of common root rot and loose smut and the phytotoxicity of seed treatment fungicides on Gateway barley. *Can. J. Plant Pathol.* 5:49-53.

- Piening, L. J., R. Edwards, and D. Walker. 1969. Effects of some cultural practices on root rot of barley in central Alberta. *Can. Plant Dis. Surv.* 49:95-97.
- Piening, L. J., T. G. Atkinson, J. S. Horricks, R. J. Ledingham, J. T. Mills, and R. D. Tinline. 1976. Barley losses due to common root rot in the prairie provinces of Canada, 1970-72. *Can. Plant Dis. Surv.* 56:41-45.
- Pittman, U. J., and J. S. Horricks. 1972. Influence of crop residue and fertilizers on stand, yield, and root rot of barley in southern Alberta. *Can. J. Plant Sci.* 52:463-469.
- Russell, R. C., and B. J. Sallans. 1940. The effect of phosphatic fertilizers on common root rot. *Sci. Agr.* XXI:44-51.
- Sallans, B. J. 1940. The use of water by wheat plants when inoculated with Helminthosporium sativum. *Can. J. Res. C*, 18:178-198.
- Sallans, B. J. 1948. Interrelations of common root rot and other factors with wheat yields in Saskatchewan. *Sci. Agr.* 28:6-20.
- Sallans, B. J. 1959. Recovery in wheat from early infections by Helminthosporium sativum and Fusarium culmorum. *Can. J. Plant Sci.* 39:187-193.
- Sallans, B. J. 1965. Root rots of cereals. III. The *Bot. Rev.* 31:505-535.
- Sallans, B. J., and R. J. Ledingham. 1943. An outbreak of common root rot in southwestern Saskatchewan in 1942. *Sci. Agr.* 23:589-597.
- Scardaci, S. C., and R. K. Webster. 1981. Antagonism between the cereal root rot pathogens Fusarium graminearum and Bipolaris sorokiniana. *Plant Dis.* 65:965-967.
- Scardaci, S. C., and R. K. Webster. 1982. Common root rot of cereals in California. *Plant Dis.* 66:31-34.

- Simmonds, P. M., R. C. Russell, and B. J. Sallans. 1935. A comparison of different types of root rot of wheat by means of root excavation studies. *Sci. Agr.* 15:680-700.
- Snedecor, G. W., and W. G. Cochran. 1980. *Statistical Methods*. 7th ed. The Iowa State University Press. Ames, Iowa. 507 p.
- Tinline, R. D. 1977. Multiple infections of subcrown internodes of wheat (*Triticum aestivum*) by common root rot fungi. *Can. J. Bot.* 55:30-34.
- Tinline, R. D., and R. J. Ledingham. 1979. Yield losses in wheat and barley cultivars from common root rot in field tests. *Can. J. Plant Sci.* 59:313-320.
- Tinline, R. D., R. J. Ledingham, and B. J. Sallans. 1973. Appraisal of loss from common root rot in wheat, p.22-26. in G.W. Bruehl, [ed.], *Biology and control of soil-borne plant pathogens*. The American Phytopathological Society. St. Paul, MN.
- Verma, P. R. 1982. Temporal progression of common root rot (*Cochliobolus sativus*) lesions on subcrown internodes of wheat and barley cultivars. *Can. J. Plant Pathol.* 4:349-352.
- Verma, P. R. 1983. Effect of triadimenol, imazalil, and nuarimol seed treatment on common root rot and grain yields in spring wheat. *Can. J. Plant Pathol.* 5:174-176.
- Verma, P. R., R. A. A. Morrall, and R. D. Tinline. 1974. The epidemiology of common root rot in Manitou wheat: disease progression during the growing season. *Can. J. Bot.* 52:1757-1764.
- Verma, P. R., R. A. A. Morrall, and R. D. Tinline. 1976a. The epidemiology of common root rot in Manitou wheat. IV. Appraisal of biomass and grain yield in naturally infected crops. *Can. J. Bot.* 54:1656-1665.

- Verma, P. R., R. A. A. Morrall, and R. D. Tinline. 1976b. The effect of common root rot on components of grain yield in Manitou wheat. *Can. J. Bot.* 54:2888-2892.
- Verma, P. R., R. A. A. Morrall, R. L. Randell, and R. D. Tinline. 1975a. The epidemiology of common root rot in Manitou wheat. III. Development of lesions on subcrown internodes and the effect of added phosphate. *Can. J. Bot.* 53:2568-2580.
- Verma, P. R., R. D. Tinline, and R. A. A. Morrall. 1975b. The epidemiology of common root rot in Manitou wheat. II. Effects of treatments, particularly phosphate fertilizer, on incidence and intensity of disease. *Can. J. Bot.* 53:1230-1238.
- Verma, P. R., S. H. F. Chinn., W. L. Crowle, D. T. Spurr, and R. D. Tinline. 1981. Effects of imazalil seed treatment on common root rot and grain yields of cereal cultivars. *Can. J. of Plant Pathol.* 3:239-243.
- Younts, S. E., and R. B. Musgrave. 1958. Chemical composition, nutrient absorption, and stalk rot incidence of corn as affected by chloride in potassium fertilizer. *Agron. J.* 50:426-429.



3 1762 10015470 5

MAIN LIB.
N378
Sh38 Shefelbine, P. A.
cop.2 Effects of systemic
fungicides and potassium...

DATE	ISSUED TO
	[REDACTED] <i>OCW</i>
	[REDACTED]
	[REDACTED]
JUN 26 1985	JUN 26 1985
	[REDACTED]

MAIN LIB.
N378
Sh38
cop.2