



Effect of common root rot on yield components of spring barleys
by William Edward Grey

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
in Plant Pathology
Montana State University
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Abstract:

Common root rot of spring barley caused mainly by *Cochliobolus sativus* (Ito and Kurib.) Dreschal ex Dastur has been responsible for considerable losses in grain yield in the North American prairies. Four methods of inoculating barley plants with *Cochliobolus sativus* were evaluated for their effectiveness in imposing uniform disease pressure.

In 1979 at Bozeman, Montana, *C. sativus* infested oats sown in the same furrow as seed of the test cultivar did reduce plant emergence and yield. In 1980, this method was compared with the use of natural soil inoculum. Use of *C. sativus* infested oats did not substantially improve the differentiation of cultivars with intermediate disease ratings over the use of naturally infested soil at a site with a history of CRR.

The effects of Common Root Rot on components of grain yield in sixteen barley cultivars which were agronomically adapted to Montana and representative of the four barley types: Hannchen, Smyrna, Coast and Manchuria, were studied at Bozeman, Montana in 1980. In spite of the mean increase in disease ratings in *C. sativus* inoculated plots, the high soil moisture levels and moderate temperatures during maturation negated the early pathogenic effects of *C. sativus*, resulting in no net change in yield. Hannchen and Smyrna type cultivars had a significant reduction in fertile tillers due to *C. sativus* which was compensated by increased kernels per head and kernel weight. Coast and Manchuria type cultivars responded to a slight decrease in fertile tillers by increasing the number of kernels per head. A combination of increased number of kernels and increased disease rating due to Common Root Rot resulted in decreased kernel weight in Coast and Manchuria type cultivars.

A barley plant is subjectively placed in one of four disease classes based upon the extent of discoloration on the subcrown internode due to Common Root Rot. In a population of plants, the number of plants per each disease class is used to calculate a weighted average, or disease rating. Computations performed by a step-wise discriminating function on the percentage of plants in each of four disease classes, indicated that the severe class was the most discriminating class among cultivars, followed in importance by the healthy class.

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William E. Grey
August 18, 1981

EFFECT OF COMMON ROOT ROT ON YIELD

COMPONENTS OF SPRING BARLEYS

by

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

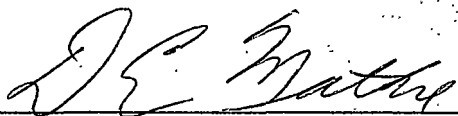
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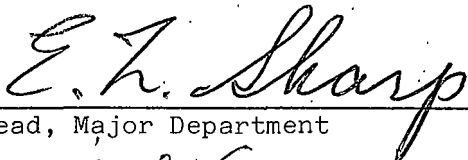
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ABSTRACT

Common root rot of spring barley caused mainly by Cochliobolus sativus (Ito and Kurib.) Dreschal ex Dastur has been responsible for considerable losses in grain yield in the North American prairies. Four methods of inoculating barley plants with Cochliobolus sativus were evaluated for their effectiveness in imposing uniform disease pressure. In 1979 at Bozeman, Montana, C. sativus infested oats sown in the same furrow as seed of the test cultivar did reduce plant emergence and yield. In 1980, this method was compared with the use of natural soil inoculum. Use of C. sativus infested oats did not substantially improve the differentiation of cultivars with intermediate disease ratings over the use of naturally infested soil at a site with a history of CRR.

The effects of Common Root Rot on components of grain yield in sixteen barley cultivars which were agronomically adapted to Montana and representative of the four barley types: Hannchen, Smyrna, Coast and Manchuria, were studied at Bozeman, Montana in 1980. In spite of the mean increase in disease ratings in C. sativus inoculated plots, the high soil moisture levels and moderate temperatures during maturation negated the early pathogenic effects of C. sativus, resulting in no net change in yield. Hannchen and Smyrna type cultivars had a significant reduction in fertile tillers due to C. sativus which was compensated by increased kernels per head and kernel weight. Coast and Manchuria type cultivars responded to a slight decrease in fertile tillers by increasing the number of kernels per head. A combination of increased number of kernels and increased disease rating due to Common Root Rot resulted in decreased kernel weight in Coast and Manchuria type cultivars.

A barley plant is subjectively placed in one of four disease classes based upon the extent of discoloration on the subcrown internode due to Common Root Rot. In a population of plants, the number of plants per each disease class is used to calculate a weighted average, or disease rating. Computations performed by a step-wise discriminating function on the percentage of plants in each of four disease classes, indicated that the severe class was the most discriminating class among cultivars, followed in importance by the healthy class.

INTRODUCTION

The term "Common Root Rot" (CRR) has been widely used to designate a group of diseases that are characterized by necrosis of the roots, crowns, and stem bases of wheat and barley. CRR generally occurs on individual plants growing in competition with healthy ones. The most important fungus of the CRR-complex is Cochliobolus sativus (Ito and Kurib.) Drechsler ex Dastur. Loss surveys in the prairie provinces of Canada have produced estimates of an average loss in wheat for the years' 1969 to 1971 of 5.7%, and in barley for the years' 1970 to 1972 of 10.3%. The incidence and severity of lesioning on subcrown internodes in a population of plants have been used as the index of disease intensity and the resistance of cultivars. The disease index based on the mature plant grown in the field has proved to be consistent over several locations and years, whereas, the seedling reaction test has not been indicative of adult plant reaction. The primary effect of severe CRR infection on the grain yield of spring wheat has been to reduce the number of fertile tillers per plant and the kernels per head.

The purpose of this study was to develop techniques to measure the response of barley to CRR utilizing 16 cultivars with good agronomic adaptation to Montana and representative of the four types of barley: Hannchen, Smyrna, Manchuria, and Coast. Three objectives were considered:

- 1) To determine the effectiveness of a screening program to improve the resistance of barley and to develop the methods to

insure uniform inoculation pressure by C. sativus.

- 2) To determine which is the most predictive or discriminating class of the standardized four disease categories in predicting a cultivar's resistance to CRR.
- 3) To determine the response of barley to CRR as measured by the plant's yield components.

The refinement of techniques in evaluating the barley plant responses to CRR by both disease reaction and yield components may increase the efficiency by which plant breeders may improve the grain yield of barley.

LITERATURE REVIEW

Common Root Rot (CRR) is a prevalent disease of wheat and barley in the prairie provinces of Canada (33,42), the Great Plains of the United States (3), New South Wales and Southern Queensland of Australia (5), and Brazil (17). Several fungi have been implicated as the cause of the discoloration and rotting of lower leaf sheaths, culms, crowns, subcrown internodes and roots. The most important is Bipolaris sorokiniana (Sacc. in Sorok.) Shoem (= Helminthosporium sativum Pammell, King and Bakke), which is the conidial state of Cochliobolus sativus (Ito and Kurib.) Drechsler ex Dastur (53). To a lesser extent the fusaria are isolated from diseased tissue. Fusarium roseum (Link emend. Snyder and Hans.) f. sp. cerealis 'Graminearum' (= F. graminearum Schwabe) and F. roseum f. sp. cerealis 'Culmorum' (= F. culmorum W. G. Smith) (2) are associated with foot rot and root rot in the Pacific Northwest (16). The Graminearum population responsible for foot rot belongs in Group I whereas Group II is responsible for head blight and scab. Only Group I is associated with foot rot in the Pacific Northwest and in Queensland, Australia (5). Both F. roseum 'Acuminatum' (= F. acuminatum Ell. and Ev.) and F. culmorum were recovered in lower percentages as compared to C. sativus in the prairies of Canada (23).

Symptoms and Histology

The first symptoms of infection on wheat (Triticum aestivum L. Thell.) and barley (Hordeum vulgare L. emend. Bowden) appear as brown lesions on the lower leaf sheaths near the soil line and/or on the sub-crown internode. In the western Canadian prairies infection originates from conidia or from mycelium in infected plant debris in the soil usually at the postseedling stage (9). Lesions appear as spots on the subcrown internode two to three days after infection, later expanding into linear streaks. Resistant cultivars of wheat and barley have more pinpoint lesions whereas susceptible cultivars have more linear lesions (28).

Cell wall degrading enzymes and sharp infection pegs under the appressoria both are involved in the penetration of the plant epidermis (28). A sheath, or lignin tuber, forms beneath the cell wall surrounding each infection peg. Lignin tubers contribute little towards host resistance since they occur in both resistant and susceptible cultivars. The infection pegs eventually grow through the lignin tuber and develop branching hyphae, both intra- and intercellularly. In severe infections the occlusion of phloem and xylem vessels is associated with lignin-like materials that may be decomposed host tissues, but the stele is often left undamaged (28). The debilitating, rather than

acute endemic nature of CRR, may be attributed in part to the cortical decay by C. sativus of subcrown internodes.

Disease Loss Assessment

Assessment of losses to CRR is a complex problem dependent upon such factors as time and intensity of infection, inoculum level, and varietal and environmental interactions. Furthermore, C. sativus is present in most fields and it has not been possible to obtain disease-free control plots for comparison. Machacek (37) was the first to estimate the percent yield loss to CRR on the basis of grain weights of clean plants as compared to CRR plants in mixed stands. Using this technique, extensive surveys have been conducted by the Canadian government with an estimated average loss in wheat for the years' 1969 to 1971 of 5.7% (33) and in barley for the years' 1970 to 1972 of 10.3% (42).

McKinney (39) was the first to separate plants with CRR into categories based upon the degree of discoloration on the subcrown internode. The generalization that the mean grain yield per plant decreases with increasing disease severity has been supported by several researchers (33,42,60). Furthermore, there is a decreased number of heads or tillers per plant in severe as compared to clean categories (29, 60).

A disease rating score has been used that attempts to quantify the relationship between disease severity and the percentage of diseased plants. Numerical values of 1, 2, and 4 for spring wheat, and 2, 5, 10

for barley, are intended to represent the proportional reduction in grain yield in the disease classes slight, moderate, and severe, respectively, relative to the yield of clean plants. Each value is multiplied by the number of plants in its respective disease category. The products of the three disease categories are added together, and the sum divided by the total number of plants times the maximum class value. This disease index does not directly calculate yield loss but is based only on past losses suffered by plants in each category (56).

In wheat, Tinline and Ledingham (56) found a good correlation between high resistance and low yield losses. In barley, on the other hand, some cultivars of intermediate disease reaction showed the least yield reduction (42). Many factors influence grain production and may mask the effect of CRR on yield. This makes a simple correlation between disease rating and yield unlikely (56).

Disease Progression

Early season infection may give rise to poor emergence or stunting of the seedlings. When C. sativus infected seed was planted in the field, the tendency of wheat plants to recover from initial stunting was measured by determining the total leaf area and grain yield (47). Once the seedlings were placed in a favorable environment, recovery in leaf area was complete by the time the fifth leaf appeared in Reward and the seventh leaf in Thatcher. Yield was enhanced by inoculation in

Reward but equal to the controls in Thatcher (47).

Recovery from early stunting due to CRR in barley with adequate moisture and nutrients has also been observed in southern Australia (44). However, Claremont barley seed, heavily infested with C. sativus and planted in Scotland, was responsible for reduced stands that contributed 24.8% and 71.2% of the total yield loss in 1973 and 1974, respectively (62). There was an overall stand reduction of 20%. The remainder of the yield loss was attributed to subsequent losses in heads per plant, seed number per head, and seed weight. Under these growing conditions, infected plants did not have more heads per plant than did healthy plants. However, increases in heads per plant occur when low populations are produced artificially by low seeding rates (62). Therefore, tillering may have been affected by C. sativus.

The exact time of the earliest initial infection is not known. Isolations from subcrown internodes of spring wheat, regardless of symptom expression, four weeks after seeding showed that 50% yielded C. sativus, and at five weeks the figure rose to 85% (59). At six weeks, 100% of the tissues exhibited discoloration and C. sativus was isolated from 100% of the subcrown internodes. Infection can also occur later in the growing season. The rate at which plants become diseased has a bearing on the overall severity of the disease at crop maturity. For example, the infection rates (as measured by the percentage of diseased plants versus time) were as follows for Manitou spring wheat in Canada:

1969, 0.99% plants per day; 1970, 1.32%; and 1971, 1.96%. The infection rate in 1969 was slower than that in both 1970 and 1971 because the onset of disease was later and there was correspondingly less disease at the end of the growing season (59). This may have been due to cooler spring temperatures and higher rainfall in 1969 (46) but no reason was proposed (59).

In controlled growth chamber tests, the vertical lesion spread on subcrown internodes of Manitou wheat was rapid at the beginning, tapering off with time, to give an average of 0.3 - 0.5mm lesion extension per day (58, 59). The disease severity and the percentage of diseased plants progressed at similar rates over the same period of time. Apparently, increases in lesion size did not occur and/or many of the initial lesions that formed during the first 60 days failed to develop. Manitou is a cultivar with fairly good resistance but too little is known about the effects of environmental factors on disease development to speculate on this cultivar's apparent ability to slow the progress of lesion development.

Interactions with the Fusaria

The frequency of isolation of C. sativus from mature plant and seedling tissue is greatest in the presence of high spore populations in the soil (9). However, there is a poor correlation ($r = 0.3 - 0.6$) between the percentage of tissue discolored and the number of subcrown

internodes yielding C. sativus (23). This may be due to the fact that other fungi are also responsible for the discoloration (23,44). Furthermore; the population of C. sativus conidia in the rhizosphere can be quite low with recovery of the fungus from subcrown internodes still possible. In the absence of C. sativus, Fusarium spp. are often recovered from 'clean' subcrown internodes and from plant tissue in soils with low numbers of C. sativus conidia (6). To answer the question of whether multiple infections by C. sativus and F. roseum can occur on subcrown internodes, Tinline (55) studied the interaction of both genera in a greenhouse experiment. There appeared to be no difference in the type of lesions produced by either C. sativus or F. culmorum and F. acuminatum, nor were there differences in disease reaction between cultivars of spring wheat as compared to the reaction normally apparent under field conditions. An antagonism between C. sativus and F. culmorum or F. acuminatum did occur, which depended upon which fungus first colonized the subcrown internode. The fusaria were capable of invading and establishing themselves on C. sativus colonized tissue. However, C. sativus was a poor invader if the fusaria were first in possession of this tissue. Therefore, in determining the causal agent for discoloration in the case of multiple pathogen infections, C. sativus can be assumed to be the primary pathogen (57). However, the role played by Fusarium spp. in discoloration of the subcrown internode can vary with the location. For instance, in Washington F. culmorum is the primary pathogen (16).

Pathogen Survival and Variability

Studies by Chinn et al., (8,9) on spore populations in 100 Canadian fields in 1959 and 47 in 1960, using the floatation-viability method, yielded consistent averages of 150 and 178 conidia per gram of soil on a dry weight basis, respectively. The correlation between seedling disease and the spore population in greenhouse tests was highly significant. This same relationship was not found for mature plants in the field. It has been suggested that in addition to inoculum density, soil type (10), moisture level (46), and other organisms in the soil may influence the severity of disease (1,40).

Evidence of microbial organisms perforating the walls of pigmented conidia has been obtained using electron microscopy. Free living mycophagous amoeba inhabiting arable soils were capable of perforating C. sativus conidia (1). The activity of perforating agents in the soil increased during high soil moisture and decreased with drier soils (40). This may help explain Chinn's earlier observation that conidia of C. sativus survived for longer periods of time in dry soils as opposed to soils at field capacity (9).

If infection is measured as the disease reaction on the mature plant, then the development of disease seems to be independent of the spore number in the soil until a threshold level is reached of approximately 27-46 conidia per gram of soil (6). The most reliable technique for determination of inoculum levels of C. sativus has been the floata-

tation-viability method (9). A selective medium has been used for tissue isolations but it is not useful in quantitative determinations of infective propagules of C. sativus in the soil (51). Infected plant debris will often yield Fusarium spp. that mask the presence of the slower growing C. sativus, even on this selective medium (51).

Genetics of Virulence

Genetic studies involving C. sativus have been hindered by its production of multinucleate, heterokaryotic conidia, and intertwining ascospores (54). Sexual reproduction is controlled by one gene but modified by additional genes (54). Progeny of single haploid ascospores had varying colony morphologies, but all were highly virulent. Virulence was epistatic over avirulence. On spring and durum wheat, virulence was controlled by at least two genes while on barley there were two to four genes (26). Although the sexual stage has not been detected in the field, recombination to produce new strains is possible since parasexual recombination has been observed in somatic hyphae that have double the number of chromosomes and consistent pairing of homologous chromosomes (27). At present there is no indication of distinct biotypes within C. sativus since the cultivars tested exhibit no differential response to infection (11,20).

Effects of Cultural Practices

The effects of stubble management, soil fertility, and water retention as they influence CRR have been examined (34,61). The early practice of moldboard plowing with the complete inversion of the soil often resulted in a reduction of root rot in the seedling stage when compared to that occurring with surface tillage. In the mature crop, however, the differences in root rot frequency were no longer observed (31).

In Manitoba, there was no obvious change in the percent of root rot infection (75% infected roots) after six years of continuous wheat, except that in the first year following a fallow period there was a slight reduction (45% infected roots) (18). Continuous cropping of barley had no effect on root rot (12).

There are conflicting reports on the effects of nitrogen fertilizer on CRR. The use of ammonium fertilizer, when compared to no added fertilizer, slightly increased the severity of root rot (19% vs. 15%) on spring wheat growing on residue-free soil (32). On the other hand, in Saskatchewan, with Manitou wheat, nitrogen applied to stubble reduced the percentage of diseased plants but not the disease severity early in the season, but subsequently no effect was observed (61).

Excess phosphorus generally had little effect on the final yield and severity of root rot in barley (43) and Manitou wheat (61). Phosphate fertilizer did have the tendency to reduce root rot severity at midseason but by harvest, differences were no longer present (61).

Decreasing fertilizer concentration below the optimum for growth predisposed the plant to more severe disease damage while the use of fertilizer in excess of recommended rates did not materially affect the plants' response to the pathogen and is impractical as a means of control for CRR (4,61).

Herbicide (2,4-D ester) had no effect on CRR (61). On a crop grown on summer fallow, supplemental irrigation 71 and 84 days after planting had no appreciable effect on the percent of diseased plants compared to non-irrigated checks (61). However, the disease severity on plants growing on dryland as compared to irrigation can be greater and can have an adverse effect on yield greater than that due to drought alone (46).

Seeding date had little effect on the percent yield loss due to CRR in eastern Canada (29) but in the western provinces a delay of ten days after the average time for planting resulted in reduced infection. But late seeding cannot be safely used on the western prairies because of autumn frost hazard (3).

The seedling blight phase of CRR on the prairies is not considered to be of great importance since there is little evidence of seed borne inoculum. Stand reduction of up to 38% from seeds heavily infested by C. sativus resulted in no yield loss (13).

The depth of seeding may vary during planting and some seed are left near the soil surface. These plants have short internodes and may or may not be invaded by C. sativus and Fusarium spp. Observations

indicate that shallow seeding results in lower root rot severity (33), but there has not been a reliable method developed to assess the effects of CRR on plants with a short or nonexistent subcrown internode.

Crop rotation as a means of controlling CRR in wheat has been studied utilizing disease ratings and tissue isolations (3), and measurements of conidial populations in the soil (6). Disease ratings based on the discoloration of subcrown internode decreased with each successive year of a non-susceptible crop (31,34). However, various crop sequences did not alter the frequency of isolation of C. sativus from tissue of wheat. This is interesting in view of the fact that summer fallow, a crop of oats, sweet clover, or some non-susceptible crop, actually reduced the CRR damage, or severity, on the following crop of spring wheat (3). Oats are highly resistant to C. sativus, but will still maintain a significant number of conidia in the soil (6). Rape is not considered to be a host crop for CRR since the level of conidia per gram of soil decreased from 235 to 46 after a three year rotation. But the decline of conidial populations following the cultivation of rape was not any faster than a decline attributal to aging and various environmental and microbial factors (7). Enough conidia appear to survive, even after five years of a non-host crop, making crop rotation an impractical means of control (3,6).

Inoculation Techniques with *C. sativus*

Artificial inoculation techniques with *C. sativus* have been used to overcome the inherent variability in inoculum density of this pathogen in soil and to produce uniform inoculation pressure for screening the resistance of wheat and barley cultivars. Sallans in 1933 reviewed the then current methods used and recommended soaking seed in conidial suspensions for 18 to 27 hours at 24°C prior to planting as a means of insuring uniform infection for field testing of seedling reaction (45). Workers have continued to use this method for seedling reaction tests (21). The addition to soil of a solid medium overgrown with the fungus has been tested utilizing various substrates such as oats and vermiculite or sand amended with cornmeal or potato broth (20,21). Although there appears to be a poor relationship between seedling and adult plant reaction, the seedling test has continued to be used for screening the aggressiveness of isolates (21). Use of naturally infested soil, however, is relied upon for determining mature plant reactions to CRR in most current studies. The seed is deeply sown to a maximum depth of 9 cm to encourage the development of a long subcrown internode (49,52,59).

Resistance in Barley

Researchers at Ottawa, Canada, have utilized a sand-cornmeal inoculum in greenhouse pots to evaluate root rot and seedling blight in barley (35,36). Based upon the general vigor of seedlings grown for 21

days in a controlled growth chamber, the seedlings were subjectively placed in one of five disease categories. Over 770 cultivars and selections of barley were tested. Anoidium, Br3962-4, Lenta, and Opal B showed the highest resistance, while Olli was used as a universal susceptible cultivar for comparison. The reaction of F_3 families from crosses between two resistant cultivars, Anoidium and Br3962-4, with Olli suggested the presence of dominant genes for resistance in Anoidium and Br3962-4. However, the disease development was strongly linked with climatic conditions as the cultivar resistance was not clear cut, suggesting that additional genes may play a role in resistance (25).

Another method of evaluating cultivar response to CRR has been to determine yield reduction. In some cases a cultivar may yield well in spite of being heavily infected. This appears to be the case for Betzes and Galt (41). The discrepancy between a yield test and a seedling reaction test for the evaluation of cultivar resistance can be illustrated with Betzes. In the yield test Betzes had the smallest yield reduction; however, in a greenhouse seedling reaction test it was classified as susceptible (15,20). Screening for disease reaction alone may have overlooked this cultivar's ability to yield well in the presence of C. sativus. CI 8969 showed the reverse reaction in that resistance was observed in seedlings while the mature plants were rated as susceptible in the field (14,15).

Barley seed size strongly influenced the seedling reaction to CRR

(15). Increased kernel weight was proportional to decreased disease index. The large seed of Olli, the susceptible standard, produced seedlings with greater resistance than seedlings from smaller seeds. However, no correlation was found between seed size and adult plant reaction (15). A seedling test in which the mean height of each clump of plants was determined, along with the mean length of the root system, indicated that winter types of barley had a higher level of resistance to CRR than the spring types (11).

Resistance in Spring Wheat

The discrepancy between seedling reaction and adult plant reaction to CRR was also observed in spring wheat. The wheat line 680 from Canada has the highest field resistance but is very susceptible as a seedling (21,22,48). Earlier work with Marquis, Thatcher, and McMurachy showed a seedling mortality of 10, 19, and 79%, respectively (50). The reverse was true for their field ratings based on the percentage of sub-crown internode discoloration, i.e., 47, 46, and 32%, respectively (57). Line 680 has McMurachy as one of its parents. While seedling reaction does not seem to always be a reliable indicator of mature plant resistance, disease ratings based on the discoloration of the subcrown internode of mature plants have remained consistent in field tests over several locations (49). The selections 680, 635, and 1639 have had one fourth the number of diseased plants as the relatively resistant

and widely grown Thatcher, indicating that selection for resistance can be accomplished (49).

During the three year period 1969 to 1971, Manitou was the most widely grown cultivar on the Canadian prairies, averaging an annual loss of 5.7% due to CRR. Lines have been developed with better resistance than Manitou but their agronomic qualities are relatively poor. A screening of 5500 lines of T. aestivum from around the world indicated that good sources of resistance are available, but no commercial varieties have yet been released that are highly resistant (24). Progress in developing resistance to CRR in hard red wheat has been made in Canada when their lines are compared with cultivars from North America, Australia, Kenya, and Mexico (24). Line 680, highly resistant in Canada, was also the most resistant in Australia (44). There also appears to be good resistance in the soft white wheats, e.g., Festival (63) and the durum wheats, e.g., Edmore and Wakooma (52).

Depending upon the parental material used, the resistance in spring wheat has been interpreted as being either polygenically or simply inherited. Because of the problem with plant escapes, the selections chosen with high resistance must be screened in subsequent years to insure consistent reaction type. Sallans and Tinline (48), being careful not to select plants that were disease escapes, have been able to develop wheat lines more resistant or more susceptible than either parent. These selected lines were consistent in their reaction for two

years at four locations. The parental lines were Thatcher, Willet, McMurachy, PI 94562-1, and PI 4309. The inheritance of resistance in progeny from these parents was concluded to be polygenic in nature (49).

Utilizing a different combination of parents, workers at Lethbridge found resistance to root rot in Thatcher to be simply inherited. The solid stem line, CT 733, is resistant to wheat stem sawfly (Cephus cinctus Norton), but very susceptible to CRR. This line was crossed to the hollow stem, root rot resistant cultivars, Thatcher and Pembina. The F₃ progeny were screened for resistance to CRR in greenhouse seedling tests. The progeny did not appear to segregate for reaction to CRR. The mean disease rating of the F₃ progenies was 96%, indicating that resistance was recessive. A theoretical model based on one gene did not fit the observed data; therefore they postulated that a major recessive gene working in conjunction with one to two minor genes lowers the disease reaction (38).

Cytological analysis confirmed the existence of a major gene for susceptibility of the line S-615. The minor genes that were postulated by McKenzie and Atkinson (38) appear to be on chromosomes 2B and 2D. The substitution of chromosome 2B and 2D from Apex (root rot resistant and hollow stem) for their homologs in S-615 (root rot susceptible and solid stem) increased the resistance of S-615, but not to the same extent as did the substitution of chromosome 5B (38). Fortunately the genes for hollow stem that are on chromosome 2B and 2D are not linked to the minor

genes for CRR resistance on these same chromosomes. Fortuna is an example of a cultivar with increased resistance to CRR combined with sawfly resistance (30).

Effects of CRR on Yield Components

Except for the work on seed borne inoculum of C. sativus on Claremont barley (62), the only work on the effects of CRR on yield components of wheat and barley for dryland conditions has been with spring wheat on the Canadian prairies (46,60). The progress of disease on Manitou was followed for each of the four disease categories over a three year period as measured by its effects on number of tillers per plant, weight per head, weight of grains per head, number of grains per head, and 1000 kernel weight. There was a good correlation between increased disease severity and decreased values of all five variables. The severe disease class stood out as the one most affected in all variables except 1000 kernel weight. The f value from an analysis of variance for each yield component studied separately, was largest for number of tillers per plant and number of grains per head, suggesting that these two components are the ones most affected by CRR (60).

CHAPTER I

INOCULATION METHODS TO INSURE

UNIFORM DISEASE PRESSURE

Procedures for screening cultivars or lines of barley for resistance to CRR are complicated by the variability of naturally occurring inoculum in the soil which results in 'mixed stands' of infected and healthy plants. To avoid this variation in inoculum, four methods of inoculating field grown barley with C. sativus were evaluated for their effectiveness in reducing the number of plant escapes and insuring uniform infection.

Materials and Methods

Inoculation was done with a mixture of two isolates of C. sativus, #214 and 195, taken from discolored subcrown internode tissue of barley from Highwood, Montana. Each isolate was grown separately on 2% potato dextrose agar (HPDA)(Difco) adjusted to pH 5-6, for four to five days at room temperature, ~22°C.

Inoculation Methods

Method #1 -- Infested oat kernels were prepared by adding 90 ml of distilled water to 140 g of oat kernels in a one quart canning jar. The jar mouth was covered by a metal lid with a 2 cm diameter hole, on top of which was placed a #4 Whatman filter-paper, 7 cm diameter, for ventilation of gases and minimization of microbial contamination. The

jar with oats was autoclaved at 121°C for 45 minutes. Plugs of C. sativus mycelium and conidia from both isolates, #214 and 195, were added to the cooled oat kernels and allowed to grow for 14 days. The infested oats were spread to air-dry, sieved through a 1 cm square mesh, and individually packaged into 20 g lots. One 20 g packet of oat kernels infested with C. sativus was sown in the same furrow as the test cultivar. The control row was sown with 20 g of non-infested autoclaved oat kernels. Both rows were 3 m long.

Method #2 -- A straw medium was prepared by stripping dried Cheyenne winter wheat culms of the outer leaf material, cutting the stems to 13 cm lengths, and placing 20 g of stem material in a clean one quart canning jar. Lid, filter-paper, and autoclaving procedure were the same as in Inoculation Method #1 above. A heavy conidial suspension in 40 ml of sterile water was added to the bottom of the jar and wicked up by the dry straw. By the end of 14 days at room temperature the stems were completely colonized by sporulating conidia and mycelium of C. sativus. The infested straw was air-dried and chopped into 1 cm pieces for packaging. Two 10 g packets of chopped straw, either infested or autoclaved, were sown in each 3 m row with the test cultivar, inoculated and control, respectively.

Method #3 -- A heavy conidial suspension was harvested by rinsing the surface of PDA cultures of both isolates with sterile water and combining the suspension before soaking the barley seed in it. One

hundred grams of seed of each cultivar was soaked four hours, air dried, and planted the following day. Four replications of each cultivar were taken from the 100 g infested seed lot. All test cultivars were inoculated with a sample from the stock conidial suspension. A fresh conidial suspension was prepared for each planting date. Excessive handling of the infested seed was kept to a minimum but 150 infested seeds per replication of a cultivar were counted and packaged individually. The dried seed, either infested or sterile water control, was sown in the inoculated or non-inoculated rows, respectively.

Method #4 -- Because of the inability of the seeder used in the 1979 experiment to penetrate deeply into the prepared seed bed, soil was mounded over the furrow in an attempt to produce a long subcrown internode on the barley plant. Oat kernels infested with C. sativus were placed on top of the furrow after planting of the test cultivar. Additional soil was then mounded over the furrow to a height of 8 cm to simulate deep planting.

Seed Source and Preparation

Test seed of 'Bonanza', 'Betzes', 'Galt', and 'Centennial' were obtained from Dr. E. A. Hockett, USDA-ARS, Bozeman, Montana. Seed of each cultivar were sieved to pass through a 6.5/64 x 3/4" (0.26 x 1.91 cm) mesh and remain on a 5.5/64 x 3/4" (0.22 x 1.91 cm) mesh. One hundred fifty seeds were counted with an electronic seed counter, packaged, and planted in each 3 m row (rate ~7 g/3 m row).

Field Plot Design

The plot design was a split-split plot. The first major split was the two planting dates, May 3 and June 5, 1979. Each planting date was randomly split among the four cultivars, Bonanza, Betzes, Galt, and Centennial. Within each cultivar a basic 12 row plot consisted of eight treatment rows enclosed by two border rows on each side. The four inoculation methods as paired rows, i.e., inoculated with C. sativus and its adjacent non-inoculated row, were randomized within a test cultivar. The experimental design was replicated four times and planted at the Montana Agricultural Experiment Station Farm 5 miles west of Bozeman, hereafter referred to as Bozeman, Montana.

Data Collection

Emergence data were collected at the two leaf stage of growth. May 3 and June 5 seeding dates were counted 22 and 19 days after planting, respectively. One week before harvest a uniform 60 cm section of plants in each row was uprooted and bundled in newspaper to keep the heads and roots intact. The plants were stored under cover for evaluation of subcrown internode discoloration. The remainder of the row was cut and threshed for yield using a Vogel plot thresher. Total grain yield was calculated as the summation of the 60cm section plus the remainder of the 3 m row.

Data Analysis

The data were analyzed in two ways. In the first, the yield from the inoculated row was calculated as a percentage of the control row. In the second method, the controls were treated as a fifth treatment in addition to the four inoculation methods. The single value from comparison of paired rows can be used to find differences among inoculation methods since each inoculated row is compared to its control row that has been treated in a similar fashion except for the absence of the pathogen. If it is assumed that the control rows act in a similar fashion, then the mean of the four non-inoculated rows can be used as a fifth treatment for comparison to the four inoculation methods with C. sativus. This will be referred to as the overall control. Percentages are used in the first case, and absolute values in the second.

Results and Discussion

Plant emergence was not different for either seeding dates or cultivars with approximately 75% emergence of the 150 seeds planted per 3 m row. Differences did occur as the result of inoculation. Both infested oats and infested straw added to the furrow decreased the plant emergence of the test cultivar by 11% and 4%, respectively (Table 1.1). Use of infested oats was responsible for a 11% reduction in emergence. Although Sallans (46) recommended soaking the seed in a conidial suspension for a seedling blight test, this method was not responsible for

Table 1.1. Effect of four methods of inoculation with Cochliobolus sativus on mean plant emergence, yield, and 1000 kernel weight (Kwt) of four barley cultivars planted on two dates at Bozeman, Montana 1979.

| Parameter | Emergence | Yield | 1000 Kwt |
|-----------------------------------------|----------------------|---------|----------|
| | % of Control | | |
| <u>Seeding Date</u> ^{2/} | | | |
| May 3 | 99.7 a ^{1/} | 92.2 a | 101.0 a |
| June 5 | 98.4 a | 114.1 b | 99.0 a |
| <u>Cultivar</u> ^{3/} | | | |
| Bonanza | 103.0 a | 110.0 b | 97.5 a |
| Betzes | 101.0 a | 108.0 b | 101.0 a |
| Galt | 97.1 a | 96.6 a | 101.0 a |
| Centennial | 95.5 a | 97.0 a | 101.0 a |
| <u>Inoculation Method</u> ^{4/} | | | |
| Infested Oats | 89.3 a | 95.7 a | 99.6 a |
| Infested Straw | 96.4 b | 98.6 b | 101.0 a |
| Conidial Suspension | 104.0 c | 114.0 c | 100.0 a |
| Infested Oats and Mounding | 106.0 c | 105.0 d | 99.3 a |

1/ $P < 0.01$ Column means within seeding date, cultivar, or inoculation method followed by the same letter are not significantly different using Student Newman Keul's (Stu.N.K.) range test. See Appendix 2 for error mean square (EMS) and degrees of freedom (df).

2/ Averaged across all cultivars and inoculation methods.

3/ Averaged across seeding dates and inoculation methods.

4/ Averaged across seeding dates and cultivars. See text for explanation of inoculation methods.

a stand different from the overall control (Table 1.2). The mounding of soil over the seed furrow, for inoculated and control rows, substantially improved emergence of the test cultivars (Table 1.3). Confusion may arise as to why the stand of plants grown in the presence of infested oat kernels was higher than that of the overall control (Table 1.3). The overall control is an average of the four non-inoculated rows, three of which were shallow planted and one was treated with soil mounded over the furrow. Since the three other inoculation methods resulted in stand reduction as compared to the overall control, the soil mounding must have had an effect. The benefits of deep planting for uniform stand establishment appear to outweigh those of possible reduction in severity of CRR due to shallow seeding (34).

Over all the treatments and cultivars, the yield from the inoculated compared to non-inoculated rows was 8% lower in the early seeded plots. However, in the late seeded plot, the yield of inoculated rows was 14% higher as compared to non-inoculated rows (Table 1.1). A slight reduction in yield was expected in early seeded inoculated rows since they were presumably exposed to the pathogen for a longer period of time (60). It is difficult to explain the increase in yield of inoculated versus non-inoculated rows for all inoculation methods and cultivars planted on June 5 (Table 1.1). Delayed seeding for up to 10 days was reported to reduce severity of CRR (4). Sallans and Tinline reported increased yields from early infections of C. sativus if the

Table 1.2. Effect of four methods of inoculation with Cochliobolus sativus on the absolute mean values^{1/} for plant emergence, yield, and 1000 kernel weight (Kwt) of four barley cultivars planted on two dates at Bozeman, Montana 1979.

| Parameter | Emergence | Yield | 1000 Kwt |
|-----------------------------------------|-----------|-------|----------|
| | no. | g | g |
| <u>Seeding Date</u> ^{2/} | | | |
| May 3 | 110 a | 486 a | 35.4 a |
| June 5 | 115 a | 289 b | 38.1 b |
| <u>Cultivar</u> ^{3/} | | | |
| Bonanza | 115 a | 346 a | 33.2 a |
| Betzes | 107 a | 414 b | 38.5 b |
| Galt | 117 a | 418 b | 34.1 a |
| Centennial | 113 a | 371 a | 41.0 c |
| <u>Inoculation Method</u> ^{4/} | | | |
| Infested oats | 104 a | 376 a | 36.5 a |
| Infested straw | 108 a | 365 a | 37.3 a |
| Conidial suspension | 113 b | 395 b | 36.4 a |
| Infested oats + soil mounding | 124 c | 405 b | 36.5 a |
| <u>Overall Control</u> | 116 b | 397 b | 37.0 a |

^{1/} Number of plants and gram yield per 3m row, gram kernel weight is the mean of two samples of 250 seeds multiplied by four to give 1000 Kwt. $P \leq 0.05$ Column means within seeding date, cultivar, or inoculation method followed by the same letter are not significantly different using Stu.N.K. range test. See Appendix 1 for error mean square and degrees of freedom.

^{2/} Averaged across all cultivars and inoculation methods.

^{3/} Averaged across seeding dates and inoculation methods.

^{4/} Averaged across seeding dates and cultivars. Average of four non-inoculated control rows used as a fifth inoculation method, called Overall Control.

Table 1.3. Effect of four methods of inoculation with Cochliobolus sativus on absolute mean values for plant emergence of four barley cultivars planted on two dates at Bozeman, Montana 1979.

| Early Seeding May 3 | | | | | |
|--------------------------------------|--------------------------------|--------|------|------------|--------------------|
| Inoculation ^{2/} Methods | Number of Plants ^{1/} | | | | Mean ^{4/} |
| | Bonanza | Betzes | Galt | Centennial | |
| 1) Infested oats | 98 | 99 | 104 | 105* | 102* |
| 2) Infested straw | 100 | 94* | 102 | 109 | 101* |
| 3) Conidial suspension | 101 | 110 | 120 | 117 | 112 |
| 4) Infested oats with soil mounding | 127* ^{3/} | 120 | 123 | 125 | 124* |
| 5) Overall control | 109 | 108 | 115 | 121 | 113 |
| Late Seeding June 5 | | | | | |
| 1) Infested oats | 115 | 97 | 116 | 102 | 108* |
| 2) Infested straw | 119 | 109 | 113 | 116 | 114 |
| 3) Conidial suspension | 127 | 109 | 128 | 96 | 116 |
| 4) Infested oats with soil mounding | 131 | 119 | 124 | 122 | 124* |
| 5) Overall control | 122 | 109 | 126 | 115 | 118 |

^{1/} Number of plants that emerged per 3m row of four replications, 150 seeds per row.

^{2/} See text for explanation of inoculation methods.

^{3/} $t \leq 0.05$ Column means within each cultivar are compared to the overall control mean by least significant test (LSD) = 13, df 96.

^{4/} $t \leq 0.05$ Column means among inoculation methods for all cultivars are compared to the overall control mean by LSD = 4.6, df 96.

environmental conditions were favorable for barley growth (48). Verma has reported that the number of fertile tillers is the yield component most affected by CRR (61). Since infection of the crown region could affect the formation of tiller buds (29), perhaps the plants within the inoculated rows, although producing fewer number of tillers, were allocating the mineral and water resources to the 1-2 main fertile tillers. On the other hand, plants within the non-inoculated rows were continuing to produce excess leaf material in the form of late tillers, thereby diverting some minerals and nutrients that would otherwise go into filling the primary fertile tillers. In comparison then, inoculated rows would produce greater yield than the control rows for the late planting. But as a means of CRR control, late seeding of up to 30 days is unlikely to be acceptable to growers since the grain yield produced is much lower than that for early seeding, e.g., 289 g versus 486 g per 3 m for late versus early seeding, respectively (Table 1.2).

The overall yield response of inoculated Bonanza and Betzes compared to their respective controls was an increase of 11% and 8%, respectively. This differed from that of Galt and Centennial in which the inoculated rows had an overall yield reduction of 3% relative to their non-inoculated controls (Table 1.1). Piening observed under conditions of natural inoculum in Canada, that the grain yield of Bonanza was highest, Betzes was intermediate and Gateway was the least (42). Gateway is susceptible to CRR, and both Gateway and Galt have the com-

mon parent, Newal, in their background. This may explain why Galt in my tests suffered a slight yield reduction. Screening cultivars on the basis of yield response to infection by C. sativus may not always increase the level of resistance to CRR but it would provide an indication of a cultivar's ability to respond to this particular stress.

With the four inoculation methods, yield was consistently lower for the early seeding as compared to the control (Table 1.4). Utilizing either infested oats or straw in the furrow, the reduction in yield may be attributal in part to the reduction in plant emergence and subsequent infection. If we subtract the number of plants that emerged as a result of both methods from the overall control, e.g., 113 minus 102, (Table 1.3) then 11 plants were lost to seedling blight. The mean yield using these same two methods was 459 g and the emergence was 102 plants giving 4.5 g per plant. If we assume no competitive interaction among plants, then the 11 plants may have yielded 50 g of additional grain. But the average yield for both methods was 459 g as compared to 529 g for the control, for a yield loss of 70 g. This would suggest a 20 g grain loss due to subsequent infection and 50 g grain loss to the initial seedling blight. The method using a conidial suspension resulted in a yield of 490 g, or 39 g less than the control. This method did not produce a significant plant reduction as compared to the control, and the 39 g yield loss can be attributed to both seedling and mature plant infections. Infections subsequent to seedling blight resulted in yield

Table 1.4. Effect of four methods of inoculation with Cochliobolus sativus on the absolute mean values for yield of four barley cultivars planted on two dates at Bozeman, Montana 1979.

| Early Seeding May 3 | | | | | |
|--------------------------------------|--------------------------|--------|------|------------|--------------------|
| Inoculation ^{2/} Methods | Gram Yield ^{1/} | | | | Mean ^{4/} |
| | Bonanza | Betzes | Galt | Centennial | |
| 1) Infested oats | 403 | 529 | 497* | 428* | 464* |
| 2) Infested straw | 393* ^{3/} | 486* | 511* | 428* | 454* |
| 3) Conidial Suspension | 453 | 503 | 532* | 477 | 490* |
| 4) Infested oats with soil mounding | 464 | 514 | 532* | 455* | 491* |
| 5) Overall control | 462 | 544 | 599 | 510 | 529 |
| Late Seeding June 5 | | | | | |
| 1) Infested oats | 246 | 320 | 291 | 290 | 287* |
| 2) Infested straw | 244 | 315 | 292 | 251 | 275 |
| 3) Conidial suspension | 267 | 311 | 309 | 310 | 299* |
| 4) Infested oats with soil mounding | 312* | 348* | 331 | 286 | 319* |
| 5) Overall control | 224 | 273 | 290 | 280 | 267 (289) |

1/ Mean grain yield per 3m row of four replications.

2/ See text for explanation of inoculation methods.

3/ $t \leq 0.05$ Column means within each cultivar are compared to the overall control mean by LSD = 52, df 96.

4/ Column means among inoculation methods, for all cultivars, are compared to the overall control mean by LSD = 18, df 96.

losses of between 4% and 7% (20 g and 39 g/529 g x 100). This compares favorably to yield losses of barley, as estimated by the Canadian Disease Survey (4% to 10.7%), in naturally infested soil, based upon the yield of clean plants in mixed stands with infected plants (56).

The 1000 kernel weight of grain from inoculated rows as compared with that from their respective non-inoculated control row was not different across seeding date, cultivar, or inoculation method (Table 1.1). Absolute values for early seeding showed lower kernel weights (35.40 g), than for later seeding (38.08 g). The six row cultivars, Bonanza and Galt, had lower kernel weights (33.24 g and 34.12 g, respectively) than the two row cultivars, Betzes and Centennial (38.5 g and 41.00 g, respectively). None of the four inoculation methods significantly affected the kernel weight as compared to the overall control (Table 1.2).

Problems arose with trying to sow the seed deeply to insure development of a long subcrown internode. Both a compacted seed bed and a lightweight tractor and seeder resulted in relatively shallow seeding. Few plants had sufficiently long subcrown internodes for the assessment of disease reaction based on the percent discoloration of this tissue.

Conclusions

Maximum infection and yield reduction occurred with early seeding and C. sativus infested oat kernels sown in the same furrow as seed of the test cultivar. This method did not result in substantial plant per row variability and yet uniform infection was assured. There were no inoculation by cultivar interactions that were significant, indicating that Bonanza, Betzes, Galt, and Centennial reacted in a similar fashion to each of the four inoculation methods. Betzes and Bonanza, however, yielded more in the inoculated rows as compared to their non-inoculated control rows. Although the total grain yield was reduced using either infested oats or straw, the ease of handling oat kernels as opposed to pieces of straw in large field plots makes the former method the one of primary choice. Kernel weight does not appear to be affected by CRR but no data were collected on number of fertile tillers and number of kernels per head to suggest which yield component(s) was responsible for the yield reduction due to C. sativus infection.

CHAPTER II

DISEASE RATING AND YIELD COMPONENTS OF BARLEY

AS AFFECTED BY COMMON ROOT ROT

The screening of barley cultivars in a breeding program for resistance to CRR would be simplified if there were above ground symptoms of the disease. Since there are none, Canadian researchers have developed a disease rating system for spring wheat and barley which is calculated on the extent of discoloration of the subcrown internode. A large number of plants must be scored because of the variation in inoculum density of C. sativus. In the preceding chapter, the use of C. sativus infested oats to insure infection was described. The purpose of this experiment was to answer two questions: (1) Is artificial inoculation with C. sativus better than the use of natural soil inoculum to differentiate cultivars? (2) Which yield component of barley is most affected by CRR and could this component be used in identifying resistant germplasm?

Materials and Methods

Inoculation Method

For artificial inoculation, two isolates of C. sativus were used, one from soil at Glasgow, Montana, #370, and the other from an infected subcrown internode of barley at Conrad, Montana, #371. Both were mass transferred to autoclaved oat kernels, and eventually used to inoculate

test cultivars of barley in the field by sowing the inoculum with the seed as described in Chapter I. Oats infested with C. sativus or autoclaved oats were sown in the same furrow as the test cultivar in inoculated and non-inoculated controls, respectively, as a rate of 20 g per 3 m row.

Seed Source and Preparation

Seed of 'Pirolina', 'Hector', 'Klages', 'Shabet', 'Lewis', 'Clark', 'Betzes', 'Hypana', 'Glenn', 'Unitan', and 'Larker' were obtained from Dr. E. A. Hockett, USDA-ARS, Bozeman, Montana. Seed of 'Compana', 'Wapana', 'Wanupana', and 'Washonupana' were obtained from Professor R. F. Eslick, Montana State University, Bozeman, Montana. Seed of 'Melvin' was obtained from Dr. H. Harding, Agriculture Canada, Saskatoon, Saskatchewan, Canada. The quantity of Melvin seed was increased at Bozeman in 1979 and used for the 1980 experiment. Each seed lot was air blown to remove lightweight seed and debris, and sieved to pass through 6.5/64 x 3/4" (0.26 x 1.90 cm) mesh and not to pass through a 5.5/64 x 3/4" (0.22 x 1.90 cm) mesh. Seed was packaged by volume at a rate of 7 g per 3 m row, i.e., about 170 seeds per 3 m row. Preparation of seed for Bozeman and Glasgow was identical.

Field Plot at Bozeman, Montana

A split-plot design was used with each cultivar as the same split randomly divided into two treatments, C. sativus inoculated and the non-

inoculated control. Sixteen barley cultivars were randomly assigned to blocks in a 4 x 4 matrix and replicated four times. Each treatment within the cultivar consisted of four rows, the center two for yield data and the outer two as border rows and for sampling of plants for disease rating. Each four rows, 3 m x 0.3 m, of the inoculated plot and control plots were sown with 20 g of C. sativus infested oats or autoclaved oats, respectively, in the same furrow as the test cultivar.

The seeds were planted 8 cm deep on May 2, 1980, with a four row cone seeder. Because of better seedbed preparation than in 1979, the seed was planted at a depth sufficient for a long subcrown internode and uniform stand establishment. Volcanic ash from the Mt. St. Helens, Washington eruption fell on the plot May 18 to a depth of 1 mm but appeared to cause no serious problems to the seedlings. From July 7 to 14, at ripening stage, the number of fertile tillers in the yield row was counted. On July 25 the length of the two center yield rows was measured and the rows trimmed on each end to a standard 2.4 m length. From August 11 to 15 one entire border row was uprooted in each treatment for evaluation of discoloration on the subcrown internode. By September 15 the harvesting of the plot was completed. During the growing season plot maintenance involved the removal of volunteer plants by hand and the control of broad leaf weeds with one application of 2-4D ester prior to heading.

Yield Data Collection Techniques

The number of fertile tillers per 3 m row and the number of kernels per head were counted in the field. Tillers with heads in the upper 50% of the plant row canopy were considered harvestable tillers and were counted. Fertile tillers for each of the two yield rows were recorded separately. The number of kernels per head was determined on 25 randomly selected heads in the upper 50% of the canopy within the two yield rows. The mean number of kernels per head for the 25 samples was recorded. Data collection on fertile tillers was completed before beginning the determination of number of kernels per head. In both cases one replication was finished before collecting data from the next.

Harvesting was done by replication. The two yield rows were separately cut with a single row binder. Threshing was done with a Vogel thresher designed for barley. The harvested grain and debris was oven dried at 32°C for 24 hours, cleaned, and the resulting grain weighed and the data recorded as yield per 2.4 m row. The mean of both yield rows within a treatment was used in yield analysis.

A 500 kernel sample from each yield row was electronically counted and then weighed. The weight was multiplied by a factor of two to obtain the 1000 kernel weight. The mean 1000 Kwt of two yield rows within a treatment was used in yield component analysis.

Field Plot at Glasgow, Montana

A randomized block design was used with 15 barley cultivars randomly assigned to blocks and replicated six times. The same cultivars were used as at Bozeman except for the absence of Larker. A basic six row plot was used for each cultivar. Two rows were for sampling and were adjacent to the standard four row yield plot. The center two rows for yield were enclosed by two border rows. Natural inoculum of C. sativus in the soil was relied upon for infection.

The test plot was located near Larsian, Montana, 45 miles northeast of Glasgow, Montana on the farm of H. J. Fuhman. The field had a history of CRR and had been in continuous spring wheat production for at least five years. A stubble management system had been utilized. Such a cultural history is considered favorable for the occurrence of CRR (49). After discing and harrowing in the spring, the terrain was considered to be too uneven to plant our test seed at a uniform depth. An additional cultivation of harrowing using our small tractor was performed in an attempt to smooth the plot. The rows were planted on April 19, 1980 perpendicular to the harrowing operation. Upon returning to the plot when the plants were at the seedling stage, May 22, no plants had emerged in the wheel tracks left from the final harrowing cultivation, but good stands did emerge in the remainder of the row. The uneven stand establishment and the resulting drought caused us to abandon the plot as a yield test. However, plants were sampled on July 1 and

a disease rating score was calculated.

Disease Data Collection Methods

At the firm dough stage (11.3 on the Feeke's scale) of plant development, plants were uprooted, wrapped, labelled and the soil rinsed from the roots. At Bozeman one entire border row of the four row yield plot was uprooted. After the soft dough stage the competitive effects between plants is minimal (V. Smail, personal communication). Therefore, removing plants at this time should have had no effect on the two center yield rows. At Glasgow, at least 50 plants were sampled from one row of each of the six replications. All plants of a plot sample were individually scored for disease on the basis of subcrown internode lesioning (34). The four disease classes were:

1. Healthy: No discoloration of the subcrown internode.
2. Slight: Pinpoint lesions on the subcrown internode.
3. Moderate: Extended linear lesions but without going around the entire circumference of the subcrown internode.
4. Severe: Complete discoloration of the tissue circumference involving more than 50% of the length of the subcrown internode.

The number of plants and total tillers in the healthy, slight, moderate, and severe classes was recorded. A small percentage of plants lacked subcrown internodes either because the crown had formed close to the seed piece or the internode had broken and remained in the soil when a

plant was pulled. Such plants were not rated for disease although their numbers and tillers were taken. Information was therefore available on the number of plants per disease class and the tillers per plant in each disease class.

Using numerical values of 0, 2, 5, and 10, for healthy, slight, moderate, and severe classes, respectively, disease ratings (DR) were determined. The numerical values are ratios based on past yield losses incurred by the respective class relative to the healthy class (57).

$$DR (\%) = \frac{\sum (\text{number of plants in class} \times \text{numerical value}) \times 100}{\text{total number of plants} \times \text{maximum class value}}$$

The disease rating is a weighted average based on the number of diseased plants and their severity of discoloration.

Data Analysis

Analysis of variance of the absolute values was performed for each yield component and grain yield as it was affected by cultivar, treatment, and cultivar by treatment interaction. In addition, the correlations between DR and yield, and DR and the three yield components, i.e., fertile tillers, kernels per head, and kernel weight, were derived. Multiple regression statistics with yield as the dependent variable and the independent variables of yield components and the DR was done to determine their relative merits in predicting yield. The amount of variation was accounted for in the yield by measuring these variables and computing an overall R^2 value.

Results and Discussion

The barley cultivars selected for the 1980 experiment were agronomically adapted to Montana growing conditions. All the cultivars were selected to have similar heading dates and all were at the firm dough stage of plant development within three days of each other. This minimized the variation in exposure time to the pathogen.

Yield components vary in their sensitivity to the environment (19). Tillering is most affected by changes in the weather or competition with adjacent plants. The least environmentally sensitive yield components are number of kernels and kernel weight. Wide variation in yield because of environmental effects is normally corrected for by increased replications. To detect the subtle effects of CRR on yield components would involve an even greater number of replications if each cultivar was analyzed separately. In order to gain precision in the Bozeman, 1980 experiment the cultivars were grouped according to their yielding characteristics (Table 2.1). Fortunately, the barleys split into two groups based on the number of fertile florets per rachis node. Two row barley types have one fertile floret per rachis node, fewer kernels per head, and they tiller more than the six row barley types. The three florets per rachis node of six row barleys are fertile, the two lateral florets being smaller in size than the central floret. Because of sterility in six row types there is a wider variation in number of kernels per head than in the two row types which tend to be more consistent

Table 2.1. Barley Cultivars used in 1979 and 1980 Experiments

| Name and Row Number | Type | CI or MT No. | Background | Origin |
|--------------------------|-----------|--------------|---------------------------------------------------------------------------|-----------------------|
| Piroline ² | Hannchen | 9558 | Weihenstephaner Meh- taunesistente C.P. x Morgenrot | Germany |
| Hector ² | Hannchen | 15514 | Betzes x Palliser | Alberta, Can. |
| Klages ² | Hannchen | 15478 | Betzes x Domer | Canada |
| Lewis ² | Hannchen | Mt 547123 | Hector x Klages | Montana |
| Clark ² | Hannchen | 15857 | Hector x Klages | Montana |
| Shabet ² | Hannchen | 13827 | (Glacier x Compana) 7 x BCBetzes | Montana |
| Betzes ² | Hannchen | 6398 | - - - | Poland |
| Hypana ² | Hannchen | 11772 | Glacier x Compana | Montana |
| Centennial ² | Hannchen | 13625 | Sanalta x Lenta | Alberta, Can. |
| Glenn ⁶ | Manchuria | 15769 | (B-57553 x Trophy x NDB138 | North Dakota |
| Larker ⁶ | Manchuria | 10648 | Trail x U.M. 570 | North Dakota |
| Melvin ⁶ | Manchuria | | Galt x York | Saskatchewan, Can. |
| Galt ⁶ | Manchuria | 11770 | (Glacier x Newa 2) x Husky | Alberta, Can. |
| Bonanza ⁶ | Manchuria | 14003 | Vantage x Jet 2 x Vantmore 3 x Park- land ² 4 x Conquest | Canada |
| Unitan ⁶ | Coast | 10421 | Glacier x Titan | Montana |
| Compana ² | Smyrna | 5438 | Selection from CI4116 | Montana |
| Wapana ² | Smyrna | | Waxy Compana | Montana |
| Wanupana ² | Smyrna | | Waxy, nude, Compana | Montana |
| Washonupana ² | Smyrna | Mt 73331 | Waxy, nude, short- awned, Compana | Montana |

in the number of fertile central florets. The six row barleys are of three types: Coast, Manchuria, and Tennessee Winter, the latter having a winter type of growth and was not represented in this study. Unitan represented the Coast type, and Glenn, Larker, and Melvin represented the Manchuria type. The two row barleys are Hannchen and Smyrna types. Within the Hannchen group, there were Piroline, Hector, Klages, Shabet, Lewis, Clark, and Betzes. Hypana is considered a Hannchen type but it is different from the seven cultivars listed in that it acts like a six row type since it has limited tillering and also has florets that remain open longer. The cultivars representing the Smyrna type were Compana, Wapana, Wanupana, and Washonupana. These were grouped together because they produce larger seed and fewer numbers of kernels than the Hannchen cultivars. Compana and its related waxy cultivars are also earlier in maturity than the Hannchen cultivars.

Disease Ratings

The differentiation of cultivars by disease ratings was not substantially improved by using C. sativus infested oat inoculum as compared to natural soil inoculum. A comparison of the data from Bozeman and Glasgow was done by simply plotting the cultivar's mean disease ratings for the two locations. Points of intersection that fall close to a 1:1 slope are cultivars with similar disease ratings for both locations (Figure 2.1).

The Hannchen barleys (Piroline, Hector, Klages, Shabet, Lewis,

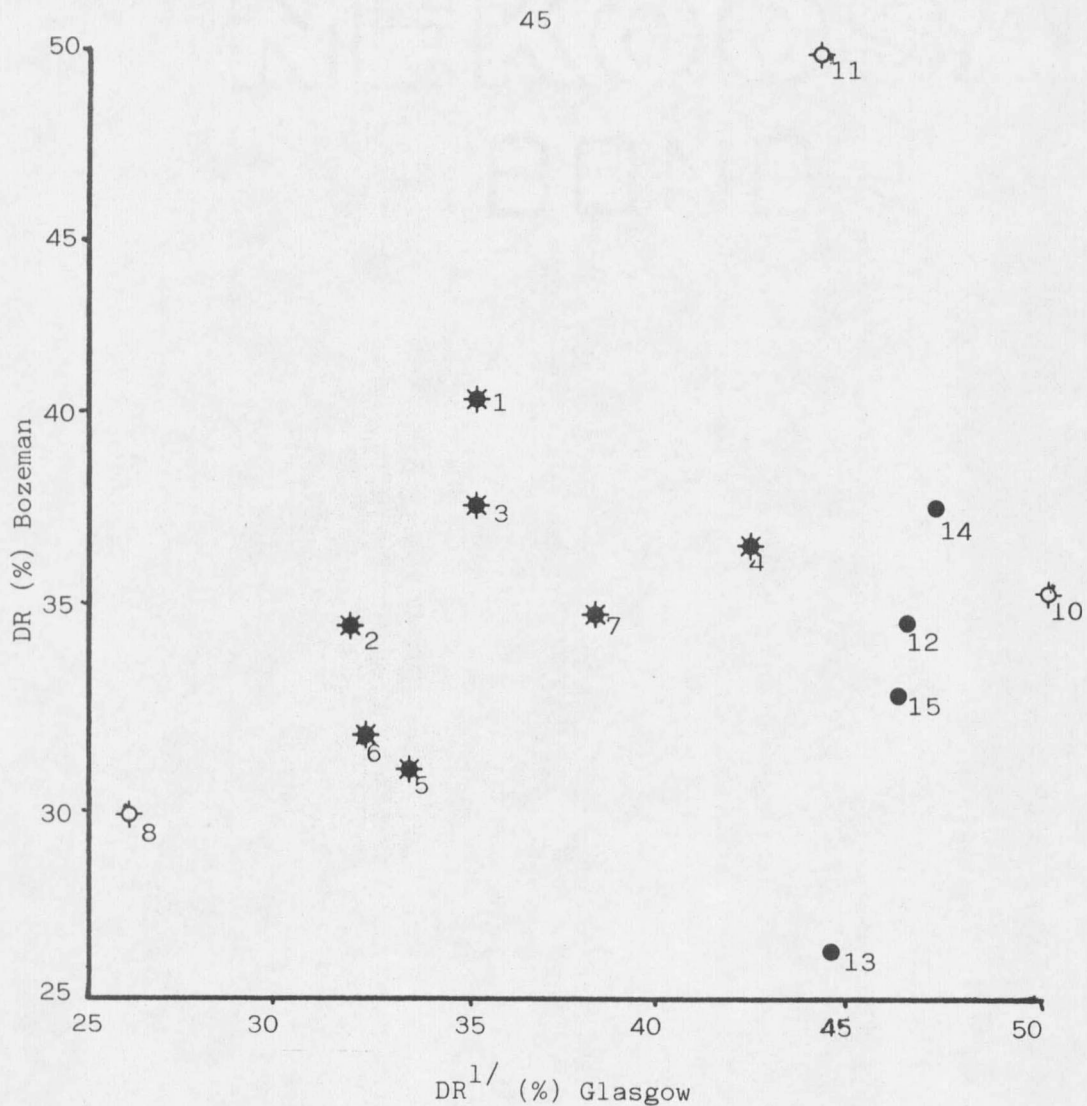


Figure 2.1. Disease Rating (DR) for fourteen barley cultivars^{2/} grown in soil with *Cochliobolus sativus* infested oats at Bozeman as compared to natural soil inoculum at Glasgow, Montana 1980.

^{1/} DR: 0 = Healthy to 100 = Severe.

^{2/} ★ Hamchen types were ¹Pirolina, ²Hector, ³Klages, ⁴Shabet, ⁵Lewis, ⁶Clark, ⁷Betzes, ¹⁶Hypana

◇ Coast type was ¹⁰Unitan. Manchuria types were ⁸Glenn and ¹¹Melvin.

● Smyrna types were ¹²Compana, ¹³Wapana, ¹⁴Wanupana, ¹⁵Washonupana. Hypana was excluded because it did not form a subcrown internode.

⁹Larker was not grown at Glasgow.

Clark, and Betzes) all had been released to growers on the basis of consistency in yield response over widely different growing conditions. They also seem to be consistent in their CRR disease rating as seen in Figure 2.1. The recently released cultivar Clark had a disease rating of 32% at Glasgow, similar to both its parents Hector (32%) and Klages (35%). At Bozeman the disease ratings were 39%, 39%, and 43% for Clark, Hector, and Klages, respectively. Betzes and Shabet, both closely related, had disease ratings of 37% and 42% at Bozeman and 42% and 44% at Glasgow, respectively (Tables 2.2 and 2.3). The point to be made is that without conscious effort on the part of breeders to select for CRR resistance, the disease rating of the progeny was at least as low as that of the parents. Hypana formed its crown very close to the seed at Bozeman and therefore did not form a subcrown internode, but at Glasgow there were sufficient plants for scoring. Hypana had a lower disease rating (35%) than one of its parents, Compana, with 46%. Unfortunately, its other parent, Titan, was not included in this study.

The Smyrna barleys were heavily affected by CRR at the Glasgow location. This may have more to do with the objectives involved in their development rather than to greater effectiveness of soil inoculum at Glasgow. The three waxy isogenics, Wapana, Wanupana, and Washonupana, were recently developed with the primary purpose of utilizing them for syrup production. They were intended for limited geographical areas with either high rainfall or irrigation. Compana is a widely adapted

Table 2.2 Disease rating (DR)^{1/} of 15 barley cultivars grown in Cochliobolus sativus inoculated and non-inoculated control plots at Bozeman, Montana 1980

| <u>Inoculated</u> | | | <u>Control</u> | | |
|----------------------|--------------------|-----|----------------|------|----|
| Cultivar | DR | | Cultivar | DR | |
| Wapana ^{3/} | 27.6 ^{2/} | a | Glenn | 22.4 | a |
| Glenn | 36.7 | b | Wapana | 23.2 | ab |
| Lewis | 36.8 | b | Washonupana | 24.0 | ab |
| Clark | 38.6 | bc | Compana | 24.0 | ab |
| Hector | 39.2 | bcd | Clark | 25.3 | ab |
| Larker | 40.5 | bcd | Lewis | 25.6 | ab |
| Unitan | 40.6 | bcd | Betzes | 27.4 | bc |
| Wanupana | 42.0 | cde | Hector | 30.7 | cd |
| Betzes | 42.3 | cde | Shabet | 30.7 | cd |
| Washonupana | 42.9 | cde | Unitan | 31.0 | cd |
| Klages | 43.3 | cde | Larker | 31.2 | cd |
| Shabet | 43.8 | de | Wanupana | 33.0 | d |
| Pirolina | 46.4 | e | Klages | 33.1 | d |
| Compana | 46.4 | e | Pirolina | 34.9 | d |
| Melvin | 57.4 | f | Melvin | 56.1 | e |
| Mean ^{4/} | 39.0** | | Mean | 28.3 | |

^{1/} DR 0 = Healthy to 100 = Severe.

^{2/} $P < 0.05$ Column means not followed by the same letter are significantly different by Student Newman Keuls range test. Error means square used in multiple comparison was 5.06 (df 46) with four replications.

^{3/} Hypana was excluded because it did not form a subcrown internode at Bozeman.

^{4/} $P < 0.01$. Overall mean values for inoculated and control.

Table 2.3. Disease rating (DR) ^{1/} of 15 barley cultivars under natural conditions of infection by Cochliobolus sativus at Glasgow, Montana 1980.

| Cultivar | DR | |
|---------------------|-----------------|----|
| | % ^{3/} | |
| Glenn ^{2/} | 26.2 | a |
| Hector | 32.3 | b |
| Clark | 32.3 | b |
| Lewis | 33.3 | b |
| Pirolina | 35.1 | bc |
| Klages | 35.2 | bc |
| Hypana | 35.2 | bc |
| Betzes | 37.3 | c |
| Shabet | 41.8 | d |
| Melvin | 43.6 | d |
| Wapana | 44.5 | e |
| Compana | 46.1 | e |
| Washonupana | 46.1 | e |
| Wanupana | 46.9 | e |
| Unitan | 52.0 | f |

^{1/} DR 0 = Healthy to 100 = Severe.

^{2/} Larker was not planted at Glasgow.

^{3/} $P < 0.05$ Column means not followed by the same letter are significantly different by Student Newman Keuls range test. Error means square used in multiple comparison was 3.66 (df 70) with six replications.

cultivar, particularly for drought areas, where it escapes the hotter and drier periods by maturing early and filling the grain before moisture becomes limiting. The Compana root system may simply have already begun to senesce in response to the severe drought conditions by the time we sampled on July 1.

The disease ratings for Melvin and Glenn were 44% and 26% at Glasgow, respectively, and 57% and 37% at Bozeman, respectively (Tables 2.2 and 2.3). Melvin is considered the universal susceptible and Glenn had at least better resistance to CRR than Larker. Both cultivars were consistent in disease ratings between locations (Figure 2.1).

A closer examination of the effects of CRR on six row barleys should consider Melvin and Glenn because of their extremes in disease ratings. Compared to Melvin and Glenn, both Manchuria types, Unitan appeared to be affected to a greater extent by CRR at Glasgow than at Bozeman (Figure 2.1). Coast type barleys are adapted to the dryland conditions of the southwestern United States. Unitan, a Coast type, may be responding to the drought at Glasgow in a manner similar to Compana by maturing early. The extensive discoloration on the subcrown internode may have been due to the advancement of decay caused by C. sativus or other fungi on senesced tissue. Barley isogenics with progressive maturing dates might give information on the interaction of CRR and the age of the root system.

At Bozeman, the residual inoculum in the soil resulted in a mean

disease rating for the cultivars of 28% as compared to 39% for the cultivars inoculated with C. sativus infested oat kernels. Figure 2.2 illustrates the problem of residual inoculum in the control sites. There appears to always be some inoculum present in most soils involved with cereal production. In a previous experiment (unpublished), we attempted to use a soil sterilant, methyl bromide, to eliminate the soil microflora and establish a 'pathogen free' control plot. Increases in yield were evident over the non-fumigated plots with the use of this broad spectrum fumigant. However, additional variables other than pathogen control were introduced into the experiment because of the use of methyl bromide. These included a sudden release of nitrogen from decomposition of the soil microflora and the elimination of competition with weeds. There was excessive tillering in the test barleys, probably due to the increased availability of nitrogen. A specific plant protectant against C. sativus would be the ideal system for field tests.

The control plot at Bozeman did separate the extremely susceptible cultivar, Melvin, and the highly resistant cultivar, Glenn, from the other cultivars (Figure 2.2). However, the residual soil inoculum at Bozeman was not as efficient in separating the cultivars with intermediate disease ratings. The Glasgow site at which there had been a history of CRR problems placed sufficient pressure on the cultivars to evenly disperse the disease ratings of such intermediate types as Hector, Klages, Betzes, Shabet, Clark, and Lewis (Figure 2.1, Table 2.3).

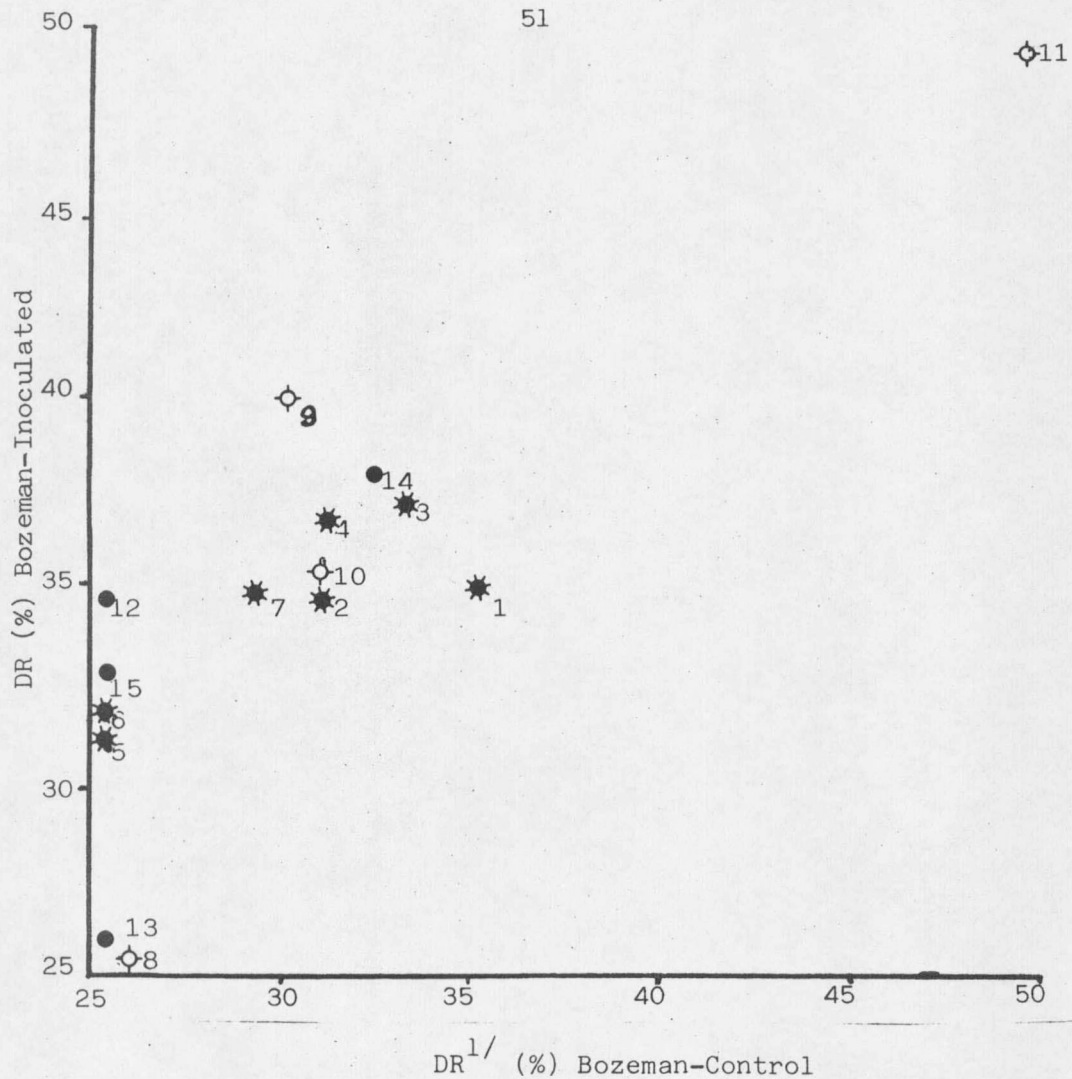


Figure 2.2. Disease Rating (DR) for fifteen barley cultivars in soil with *Cochliobolus sativus* infested oat kernels (inoculated) as compared to residual soil inoculum (control) at Bozeman, Montana 1980.

^{1/}DR: 0 = Healthy to 100 = Severe.

^{2/}★Hannchen types were ¹Pirolina, ²Hector, ³Klages, ⁴Shabet, ⁵Lewis, ⁶Clark, ⁷Betzes, ⁹Hypana.

◇Coast type was Unitan. Manchuria types were ⁸Glenn, ¹¹Melvin, ⁹Larker.

●Smyrna types were ¹²Compana, ¹³Wapana, ¹⁴Wanupana, ¹⁵Washonupana.

¹⁶Hypana was excluded because it did not form a subcrown internode at Bozeman.

Yield Components

The inoculation technique employed at Bozeman in 1980 did substantially increase the disease ratings of cultivars over their disease ratings in the control. In spite of the greater discoloration of the subcrown internode tissue of plants in the inoculated plots, their yields were no different than the yields from control plants growing in the presence of residual inoculum (Table 2.4). The yield of Pirolina was higher by 80 g in the inoculated as compared to the control plots. This particular instance may be the exception but the disease rating was 35% in the control plot as compared to 46% in the inoculated plot. Apparently, Pirolina yields well in spite of the presence of severe discoloration on the subcrown internode (Table 2.5).

The Hannchen type cultivars in the inoculated plots had reduced fertile tillers and an increased number of kernels and heavier kernel weight as compared to the controls. The Coast-Manchuria type cultivars had a decrease in fertile tillers, although not statistically significant, and an increase in number of kernels per head and kernel weight as compared to the controls. The Smyrna type cultivars showed a different trend for the yield components in the inoculated plots. After the reduction in fertile tillers early within the growth of the plants in the inoculated plots, there was an increase in the number of kernels per head but no change in the kernel weight (Table 2.4). The value of using infested oat inoculum at Bozeman may not have been important for

Table 2.4. Effects of Common Root Rot on yield components of four barley types: Hannchen, Coast, Manchuria, and Smyrna. Treatment means for fertile tillers per 2.4 m (X), number of kernels per head (Y), 1000 kernel weight (Z), grain yield (W), and disease rating (DR). Inoculated with Cochliobolus sativus versus non-inoculated control at Bozeman, Montana 1980.

| Barley Type | (X) no. | (Y) no. | (Z) g | (W) g | (DR) % |
|-------------------------------|-------------------|---------|--------------------|-------------------|--------|
| Hannchen ^{1/} | | | | | |
| Inoc. | 404** | 25.8** | 41.6** | 386 ^{NS} | 41.5** |
| Control | 442 | 24.7 | 40.3 | 371 | 29.7 |
| Coast-Manchuria ^{2/} | | | | | |
| Inoc. | 239 ^{NS} | 62.8** | 36.6** | 362 ^{NS} | 43.8** |
| Control | 254 | 60.3 | 35.6 | 386 | 35.2 |
| Smyrna ^{3/} | | | | | |
| Inoc. | 365** | 20.7** | 45.9 ^{NS} | 326 ^{NS} | 43.0** |
| Control | 433 | 19.9 | 45.2 | 336 | 26.0 |

** $P \leq 0.01$. NS = nonsignificant. 4 replications. See Appendix 3 for the error mean squares.

^{1/} Hannchen barleys were Pirolina, Hector, Klages, Shabet, Lewis, Clark, Betzes.

^{2/} Coast-barley was Unitan. Manchuria barleys were Glenn, Larker, Melvin.

^{3/} Smyrna barleys were Compana, Wapana, Wanupana, Washonupana.

Table 2.5. Population means^{1/} for number of fertile tillers per 2.4 m (X), number of kernels per head (Y), 1000 kernel weight (Z), grain yield per 2.4 m (W), and disease rating (DR). Inoculated with Cochliobolus sativus versus non-inoculated control at Bozeman, Montana 1980.

| Cultivar | (X) no. | | (Y) no. | | (Z) g | | (W) g | | (DR) % | |
|----------------------|---------|-------|---------|-------|-------|-------|-------|-------|--------|-------|
| | Inoc. | Cont. | Inoc. | Cont. | Inoc. | Cont. | Inoc. | Cont. | Inoc. | Cont. |
| Piróline | 406 | 440 | 25.9 | 25.3 | 38.7* | 36.6 | 425* | 344 | 46.4 | 34.9 |
| Hector | 357* | 451 | 24.1 | 23.3 | 44.5 | 42.9 | 426 | 411 | 39.2 | 30.7 |
| Klages | 379 | 403 | 28.2 | 27.0 | 37.7 | 38.1 | 312 | 286 | 43.3 | 33.1 |
| Shabet | 383* | 462 | 27.2 | 24.8 | 43.2* | 40.2 | 405 | 397 | 43.8 | 30.8 |
| Lewis | 428 | 462 | 24.6 | 22.3 | 43.9 | 44.1 | 411 | 395 | 36.8 | 25.6 |
| Clark | 485 | 453 | 23.9 | 23.5 | 43.8 | 43.1 | 328 | 356 | 38.6 | 25.3 |
| Betzes | 388 | 427 | 27.0 | 26.1 | 39.4 | 37.5 | 393 | 379 | 42.3* | 27.4 |
| Hypana ^{2/} | 248 | 289 | 24.7 | 24.7 | 56.8 | 55.6 | 426 | 417 | -- | -- |
| LSD ^{3/} | 77 | | 2.97 | | 1.57 | | 79 | | 14.5 | |
| Glenn | 180 | 207 | 65.1 | 65.6 | 36.0 | 34.8 | 355 | 369 | 36.7 | 22.4 |
| Larker | 249 | 284 | 62.8* | 57.8 | 35.8 | 34.1 | 333 | 377 | 40.5 | 31.2 |
| Unitan | 282 | 258 | 55.0 | 54.2 | 41.2 | 41.0 | 391 | 417 | 40.6 | 31.0 |
| Melvin | 245 | 271 | 68.4* | 63.6 | 33.5 | 32.5 | 370 | 381 | 57.4 | 56.1 |
| LSD ^{4/} | 59 | | 4.46 | | 3.31 | | 71 | | 15.7 | |
| Compana | 343* | 409 | 20.4 | 19.9 | 51.5 | 51.9 | 385 | 385 | 46.4* | 24.0 |
| Wapana | 383 | 401 | 19.7* | 18.5 | 48.9 | 48.0 | 315 | 328 | 40.5* | 23.2 |
| Wanupana | 380* | 450 | 20.5 | 20.0 | 42.9 | 42.7 | 311 | 336 | 42.0 | 33.0 |
| Washonupana | 353* | 475 | 22.1 | 21.4 | 40.5* | 38.4 | 293 | 293 | 42.9* | 24.0 |
| LSD ^{4/} | 66 | | 0.97 | | 2.04 | | 48 | | 13.8 | |

* P < 0.05 Comparison between treatment and control for same cultivar.

1/ A standard four row yield plot was used with the center two rows for yield. Values for fertile tillers and yield are the mean of two rows.

2/ Hypana values were not analyzed because of lack of subcrown internodes.

3/ 4 replications df 21.

4/ 4 replications df 12.

cultivar differentiation based on disease ratings, but it did significantly reduce the number of fertile tillers in the Hannchen and Smyrna barley types. The Coast-Manchuria cultivars showed a similar but not significant trend. The infection of the inoculated rows occurred at the same time in plant development for all the cultivars as evidenced by the reduction of fertile tillers.

Changes in the number of fertile tillers can trigger a chain reaction affecting all later-formed organs in the plant. The strength of the relation that fertile tillers have with number of kernels, kernel weight and yield can be measured by correlation coefficients between pairs of these variables. The reduction in number of fertile tillers due to CRR may have an effect on the other yield components. The magnitude of that change can be modified by the environment including nutrients, water, temperature (19), and by subsequent disease severity. Examination of the correlation coefficients for the control plots shows the expected competition between kernels per head and kernel weight: $-.54^{**}$, $-.62^{**}$, and $-.50^{*}$, for Hannchen, Coast-Manchuria, and Smyrna types, respectively. Both kernels per head and kernel weight are competing for moisture. Kernel weight is positively correlated with yield regardless of barley type as would be expected (Tables 2.6, 2.7, and 2.8). The comparison of yield components among the four types of barley, as affected by CRR, stops with these generalities since each barley type responded to increased disease pressure in the inoculated plots

Table 2.6. Effects of Common Root Rot on Hannchen Barleys.^{1/} Correlation coefficients for pairs of the following characters: grain yield per 2.4 m (W), number of fertile tillers per 2.4 m (X), number of kernels per head (Y), 1000 kernel weight (Z), and disease rating (DR). Inoculated with Cochliobolus sativus versus non-inoculated control at Bozeman, Montana 1980.

| <u>Inoculated</u> | | | | |
|-------------------|----------|----------|----------|----------|
| | <u>W</u> | <u>X</u> | <u>Y</u> | <u>Z</u> |
| X | -.29 | | | |
| Y | -.01 | -.48** | | |
| Z | .53** | -.15 | -.34 | |
| DR | .27 | -.39* | .36 | .07 |
| <u>Control</u> | | | | |
| X | .07 | | | |
| Y | -.42* | -.48* | | |
| Z | .55** | -.02 | -.54** | |
| DR | -.35 | -.29 | .32 | -.30 |

*, ** $P \leq 0.05$ and 0.01 , respectively, df 26.

^{1/} Hannchen barleys were Piroline, Hector, Klages, Shabet, Lewis, Clark, Betzes.

Table 2.7. Effects of Common Root Rot on Coast and Manchuria Barleys.^{1/} Correlation coefficients for pairs of the following characters: grain yield per 2.4 m (W), number of fertile tillers per 2.4 m (X), number of kernels per head (Y), 1000 kernel weight (Z), and disease rating (DR). Inoculated with Cochliobolus sativus versus non-inoculated control at Bozeman, Montana, 1980.

| <u>Inoculated</u> | | | | |
|-------------------|----------|----------|----------|----------|
| | <u>W</u> | <u>X</u> | <u>Y</u> | <u>Z</u> |
| X | .21 | | | |
| Y | .01 | -.56* | | |
| Z | .60* | .29 | -.63** | |
| DR | -.26 | .17 | .14 | -.50* |
| <u>Control</u> | | | | |
| X | .01 | | | |
| Y | -.35 | -.44 | | |
| Z | .58* | -.29 | -.62** | |
| DR | -.26 | .43 | .19 | -.48 |

*, ** $P \leq 0.05$ and 0.01 , respectively, df 14.

^{1/} Coast barley was Unitan. Manchuria barleys were Glenn, Larker, Melvin.

Table 2.8. Effects of Common Root Rot on Smyrna Barleys.^{1/} Correlation coefficients for pairs of the following characters: grain yield per 2.4 m (W), number of fertile tillers per 2.4 m (X), number of kernels per head (Y), 1000 kernel weight (Z), and disease rating (DR). Inoculated with Cochliobolus sativus versus non-inoculated control at Bozeman, Montana, 1980.

| <u>Inoculated</u> | | | | |
|-------------------|----------|----------|----------|----------|
| | <u>W</u> | <u>X</u> | <u>Y</u> | <u>Z</u> |
| X | .05 | | | |
| Y | -.30 | -.33 | | |
| Z | .68** | -.08 | -.56* | |
| DR | -.09 | -.76** | .36 | .05 |
| <u>Control</u> | | | | |
| X | -.29 | | | |
| Y | -.23 | .27 | | |
| Z | .74** | -.58* | -.50* | |
| DR | -.29 | -.02 | -.07 | -.30 |

*, ** $P \leq 0.05$ and 0.01 , respectively, df 14.

^{1/}Smyrna barleys were Compana, Wapana, Wanupana, Washonupana.

with a different strategy of yield compensation.

If we closely examine the correlation coefficients for the Coast-Manchuria types (Table 2.7) in the inoculated plots, there are three negative correlations: between fertile tillers and number of kernels, between number of kernels and kernel weight, and between kernel weight and disease rating, $-.56^*$, $-.63^{**}$, and $-.50^*$, respectively. On the other hand, in controls, the number of kernels and kernel weight were negatively correlated, $-.62^{**}$. Although there is a poor correlation between disease rating and the number of fertile tillers, evidence suggests that fertile tillers are reduced in a manner similar to the two row barleys, but not to the same extent (Table 2.4). During growth conditions of sufficient moisture, which did occur in Bozeman in 1980, the developed heads had an increased number of kernels because of the slight reduction in competing tillers. These additional kernels strongly competed with the next developing yield component, kernel weight. The grain filling period of plant growth is later in the season and overlaps the period when severity of CRR infection is greatest on the subcrown internode. The severe decay of the cortex and stele tissues and the excess number of kernels may have taxed the plant's ability to fill the existing kernels. With adequate moisture the shallow crown roots could provide the needed moisture, thus bypassing the need for water to pass through the subcrown internode. The relative merits or Beta weights of each yield component and

disease rating on yield of Coast-Manchuria types point out that the contribution of number of kernels to yield is more than twice that of fertile tillers, 0.91** and 0.38*, respectively. In control plots, both variables shared equal contribution towards yield, 0.73 (Table 2.9). The amount of variation that was accounted for by measuring the four variables, i.e., the yield components plus disease ratings, increased from 46% in control plots to 73% in inoculated plots. The initial and subsequent infection by C. sativus in the inoculated plots of Coast-Manchuria types resulted in a unified response by the three yield components to this particular stress.

Hannchen barleys have a two row character and will continue to tiller late in the growing season if the moisture and nutrients are available. However, infection by C. sativus has been shown to reduce the number of fertile tillers (Table 2.4). The reduction in tillers of inoculated Hannchen cultivars at Bozeman may have eliminated an inter-organ competition rather than contributing to additional stress as occurs in the Coast-Manchuria cultivars. The correlation coefficient for disease rating and fertile tillers was $-.39^*$ in the inoculated plots and $-.29$ in the control plots. However, the competition between kernel weight and number of kernels was eliminated in the inoculated plots as compared to the control plots with correlation coefficients of -0.34 and -0.54^{**} , respectively. The negative correlation between the number of kernels and fertile tillers remained unchanged in

Table 2.9. Direct effects of *Cochliobolus sativus* inoculated versus non-inoculated control on yield components of four barley types: Hannchen, Coast-Manchuria, and Smyrna at Bozeman, Montana 1980. Multiple regression statistics for yield per 2.4 m row (W) as the dependent variable, and number of fertile tillers per 2.4 m (X), number of kernels per head (Y), 1000 kernel weights (Z), and disease rating (DR) as independent variables.

| Hannchen Barleys ^{1/} | | | | Control | | | |
|--------------------------------|--------------|----------------|---------|-----------|--------------|----------------|---------|
| Variables | Inoculated | | | Variables | Control | | |
| | Beta Weights | R ² | F-ratio | | Beta Weights | R ² | F-ratio |
| Z | .51 | .28 | 9.63** | Z | .40 | .30 | 3.26* |
| X | -.21 | .35 | 1.36 | DR | -.20 | .34 | 1.15 |
| DR | .16 | .37 | 0.77 | Y | -.17 | .35 | 0.45 |
| Y | .01 | .37 | 0.01 | X | -.06 | .35 | 0.09 |
| Coast-Manchuria ^{2/} | | | | Control | | | |
| Variables | Inoculated | | | Variables | Control | | |
| | Beta Weights | R ² | F-ratio | | Beta Weights | R ² | F-ratio |
| Z | 1.12 | .36 | 22.2** | Z | 1.17 | .33 | 6.10** |
| Y | .91 | .61 | 15.4** | X | .73 | .34 | 2.68 |
| X | .38 | .73 | 3.7* | Y | .73 | .45 | 1.95 |
| DR | .11 | .73 | 0.3 | DR | -.15 | .46 | 0.29 |
| Smyrna Barleys ^{3/} | | | | Control | | | |
| Variables | Inoculated | | | Variables | Control | | |
| | Beta Weights | R ² | F-ratio | | Beta Weights | R ² | F-ratio |
| Z | .85 | .47 | 9.71** | Z | .92 | .55 | 11.39** |
| DR | -.15 | .48 | .21 | X | .19 | .57 | .67 |
| Y | .26 | .52 | .82 | Y | .17 | .60 | .57 |
| X | .01 | .52 | .07 | DR | -.09 | .61 | .20 |

*, ** P ≤ 0.05 and 0.01, respectively.

^{1/} Hannchen barleys were Pirolina, Hector, Klages, Shabet, Lewis, Clark, Betzes.

^{2/} Coast barley were Unitan. Manchuria barleys were Glenn, Larker, Unitan.

^{3/} Smyrna barleys were Compana, Wapana, Wanupana, Washonupana.

the control and inoculated plot (correlation coefficient = -0.48^*). With fewer fertile tillers, the available moisture and nutrients could be used to fill the increased number of kernels. The relative value of 1000 kernel weight in contributing to yield increased from 0.40^* in the control plots to 0.51^{**} in the inoculated plots (Table 2.9). Only 37% of the variation in yield was accounted for by the four variables measured in the inoculated plots of Hannchen cultivars. The Hannchen cultivars must not have been stressed to the same extent that the Coast-Manchuria cultivars were to inoculum of C. sativus at Bozeman.

The Smyrna cultivars showed a similar reduction in fertile tillers as did the Hannchen cultivars (Table 2.4). There was also a negative correlation between disease rating and fertile tillers in the inoculated plots, $-.73^{**}$. The reduction in fertile tillers in the inoculated plots resulted in the elimination of competition between fertile tillers and kernel weight; in the control plots the correlation coefficient was $-.58^*$ and was $-.08$ in the inoculated plots. The usual negative correlation between number of kernels and kernel weight was similar in both inoculated and control plots, $-.56^*$ and $-.50^*$, respectively (Table 2.8). However, without the extra tillers, the increased number of kernels did not show a significant increase in their kernel weight (Table 2.4). In fact, the Smyrna cultivars did not appear to take advantage of the decreased competition with tillers to increase the contribution of kernel weight to yield. The relative merit of kernel weight actually decreased

in the inoculated plot, 0.85**, as compared to the control plot, 0.92**.

The amount of variation in yield accounted for by the four variables also decreased from 61% in the control plots to 52% in the inoculated plots. Compana has the same background as the four Smyrna cultivars tested and is believed to escape drought by maturing early. Therefore, the Smyrna cultivars inoculated with C. sativus may not have been able to take advantage of the increased availability of nutrients and moisture because of their shortened period of grain filling. From the values given for their 1000 kernel weight in Table 2.5, it does not appear that their genetic potential had been reached since Compana had an average of 51.6 g per 1000 kernels and the overall mean for the Smyrna cultivars was 45.5 g per 1000 kernels. I suspect that the three waxy isogenics from Compana are not as efficient as Compana itself in compensating for decreased tillers.

CHAPTER III

DISEASE CLASSIFICATION

The extent to which the four disease classes used for assessment of a plant's resistance to CRR overlap one another or diverge from one another can be studied using the multivariate technique called the discriminate function. The researcher's measurements of the extent of discoloration on the subcrown internode are used to place the plant in a particular disease class. Confusion arises when there are no clearly defined borders between disease classes. The disease rating of a cultivar might easily involve misclassification. It would be helpful, then, to determine which disease classes are most effective in distinguishing between cultivars, how best to combine the disease classes, and how successfully the distinction can be made.

Materials and Methods

A number of plants in each of the four disease classes were collected for cultivars grown at Bozeman in the presence of C. sativus infested oats and at Glasgow in naturally infested soil in 1980. The methodology used in classifying the disease reaction of a cultivar with one of four disease classes was described in Chapter II.

The number of plants in a particular disease class was calculated as a percentage of the total number of plants read for CRR infection. Those plants without a subcrown internode that either broke off during

the uprooting and washing of the roots or had a crown that formed next to the seed, were recorded as a fifth class, but not used in the analysis.

Fifteen barley cultivars were grown at Glasgow. The cultivars were Pirolina, Hector, Klages, Shabet, Lewis, Clark, Betzes, Wapana, Hypana, Glenn, Unitan, Melvin, Compana, Wanupana, and Washonupana. At Bozeman, four replications of fifteen cultivars were studied in inoculated plots. The cultivars used were the same as those at Glasgow except for the addition of Larker and the exclusion of Hypana, which formed its crown next to the seed in the majority of cases.

A stepwise discriminant function was performed using the percentage of plants in each of four disease classes of a cultivar. Data from Bozeman and Glasgow were handled separately. The computations were performed by a program in the Biomedical Computer Programs P-Series (BMDP), 1979, developed at the Health Sciences Computing Facility, University of California, Los Angeles and sponsored by NIH Special Research Resources, Grant RR-3.

At Bozeman the total number of tillers, including fertile tillers and those that had elongated but had not developed heads, were recorded for each disease class of a cultivar. Both the number of plants scored and the average number of total tillers per disease class were recorded for the inoculated and the control plots in two replications.

To determine if CRR affected the tillering of plants in one par-

ticular disease class more than in another class, a multiple factor analysis of variance was performed for the two factors of disease class and treatment, i.e., the inoculated and control plots. The fifteen cultivars were grouped according to their barley type: Hannchen, Coast-Manchuria, and Smyrna, as a means of gaining precision when dealing with an environmentally sensitive character such as tillering.

Results and Discussion

During the later tillering and early stem elongation stage, those plants growing in the inoculated plots appeared to be stunted in comparison with the control plots. The differences were slight but noticeable until heading, about June 23, 1980, when plants in the inoculated plots were equal in height to the controls.

The inoculated plants seemed to be either tillering less or the tillers were being retarded in their development. There was a lower number of fertile tillers of Hannchen and Smyrna type cultivars in the inoculated plots as compared to the controls as reported earlier in Chapter II. The difference in fertile tillers was not obvious by looking at the plots during the heading and maturation stages. Only careful but extensive counts of fertile tillers could detect the differences between the inoculated and control plots (Table 2.4).

At Bozeman in 1980, when the border row of each plot was uprooted and the individual plants scored for extent of discoloration on the sub-

crown internode, I noticed that plants in the severe disease class had fewer total tillers than any of the other three disease classes. The Hannchen type cultivars had significantly fewer total tillers per plant in the severe class (3.78) as compared to the healthy class (6.90). There were no differences in tillers per plant between the slight (5.56) and moderate classes (5.29). The Coast-Manchuria type cultivars also had fewer tillers per plant in the severe class (1.96) than the healthy class (3.17) (Table 3.1). Apparently, the healthy plants growing adjacent to the severe plants could take advantage of the reduced competition for space and continue the development of the fertile and late tillers.

The observation that plants with severely discolored subcrown internodes tillered far less than plants in any of the three other disease classes led me to consider the importance of the severe class as a discriminating category for cultivar differentiation. The computations performed by the BMDP program for stepwise discriminant function verified my suspicions of the usefulness of the severe class in differentiating cultivar susceptibility to CRR. At the Glasgow site, the percentage of plants in the severe class (F ratio = 3.606**, df 14,217) was the most discriminating category for cultivar differentiation. The healthy class (F ratio = 3.221**, df 28,148) was second in importance. The slight class (F ratio = 2.539**, df 42,217) was also significant in a statistical sense, but as far as being of practical use, it is

Table 3.1. Total number of tillers, including fertile and late tillers, per plant in each disease class based on the percent discoloration of the subcrown internode in inoculated rows with Cochliobolus sativus as compared to non-inoculated control rows for Hannchen, Coast, Manchuria, and Smyrna Barley Types^{1/} at Bozeman, Montana 1980.

| Barley Type | Disease Class ^{2/} | | | | |
|------------------------|-----------------------------|---------|----------|---------|--------------------|
| | Healthy | Slight | Moderate | Severe | \bar{x} |
| <u>Hannchen</u> | | | | | |
| Inoc. | 6.90 c ^{3/} | 5.56 b | 5.29 b | 3.78 a | 5.38** |
| Control | 5.00 b | 5.26 b | 4.54 ab | 3.70 a | 4.63 |
| \bar{x} | 5.95 | 5.41 | 4.91 | 3.75 | |
| <u>Coast-Manchuria</u> | | | | | |
| Inoc. | 3.17 c | 2.80 bc | 2.74 bc | 1.96 a | 2.67 ^{NS} |
| Control | 3.16 c | 2.81 bc | 2.37 ab | 2.37 ab | 2.79 |
| \bar{x} | 3.17 | 2.81 | 2.77 | 2.16 | |
| <u>Smyrna</u> | | | | | |
| Inoc. | 5.78 b | 5.65 b | 5.27 ab | 4.33 ab | 5.26 ^{NS} |
| Control | 5.82 b | 5.47 b | 4.79 ab | 3.64 a | 4.93 |
| \bar{x} | 5.80 | 5.56 | 5.03 | 3.98 | |

^{1/} Hannchen barleys were Piroline, Hector, Klages, Shabet, Lewis, Clark, Betzes.

Coast barley was Unitan.

Manchuria barleys were Glenn, Larker, and Melvin.

Smyrna barleys were Compana, Wapana, Wanupana, Washonupana.

^{2/} Clean: No discoloration on the subcrown internode.

Slight: Pinpoint lesions on the subcrown internode.

Moderate: Linear lesions on one side of the subcrown internode.

Severe: 50% discolored with lesions on the whole circumference of the subcrown internode.

^{3/} $P < 0.1$ Compare means within Barley type. Means not followed by the same letter are significantly different by Student Newman Keuls range test. Error means squares for Hannchen, Coast-Manchuria and Smyrna barleys are 0.84, 0.15, and 0.93, respectively; with 21 df.

NS = Nonsignificant.

just as difficult to categorize plants into the slight class as into the moderate class. The combining of slight and moderate disease classes for evaluation of CRR would simplify the methodology and not lose any discriminating ability.

Computations performed from the percentage of plants per disease class in the inoculated plots at Bozeman showed a similar trend. The severe class (F ratio = 1.434 NS, df 14,45) was first in importance, followed by the healthy class (F ratio = 1.447 NS, df 28,88) in discriminating ability. The statistical non-significance of the F ratios may be due to the variation within the experiment because of non-uniform inoculum pressure at Bozeman. The discriminating ability of severe and healthy classes is still valid.

At Glasgow, the range in percentage of plants per class among cultivars was greatest in the severe class. Glenn (1.8%) was the lowest and Unitan (27.8%) was the highest in the percentage of plants in the severe class (Table 3.2). Although the range in percentage of plants in the healthy class (4.1 to 22.3%) was less than in the severe class, the accuracy of placing plants of a cultivar in this class was much higher among the six replications. The experimental error (EMS) was lowest for the healthy (EMS = 3.51), followed by the severe (EMS = 4.91), moderate (EMS = 5.53), and slight (EMS = 5.72) classes (Table 3.2). If the experimental error was low for plants in the healthy class, then a cultivar had a similar number of plants in this class for each of the

Table 3.2. Percentage of plants in each of four disease classes based on discoloration of the subcrown internode for 15 barley cultivars grown in soil with natural inoculum of Cochliobolus sativus at Glasgow, Montana 1980.

| Code Cultivar | Disease Class ^{1/} | | | |
|-----------------|-----------------------------|---------|----------|---------|
| | Healthy | Slight | Moderate | Severe |
| 1) Piroline | 6.3 ab ^{2/} | 48.2 d | 40.2 f | 5.5 b |
| 2) Hector | 9.8 c | 55.2 f | 27.6 b | 7.6 bc |
| 3) Klages | 14.5 d | 41.6 c | 30.3 bc | 13.6 e |
| 4) Shabet | 9.9 c | 37.6 c | 36.5 e | 16.0 e |
| 5) Lewis | 10.7 c | 48.6 d | 34.5 de | 6.2 bc |
| 6) Clark | 22.3 e | 40.0 cd | 27.2 b | 10.5 d |
| 7) Betzes | 16.5 d | 33.0 b | 34.8 de | 15.7 e |
| 16) Hypana | 6.3 ab | 52.3 e | 32.5 cd | 8.9 cd |
| 8) Glenn | 14.2 d | 60.0 g | 24.0 a | 1.8 a |
| 10) Unitan | 7.2 b | 27.9 a | 37.1 ef | 27.8 i |
| 11) Melvin | 9.4 c | 40.0 cd | 30.0 bc | 20.6 fg |
| 12) Compana | 7.0 b | 38.2 c | 32.6 cd | 22.2 gh |
| 13) Wapana | 4.5 ab | 41.8 c | 35.2 de | 18.5 f |
| 14) Wanupana | 4.1 a | 37.5 c | 38.2 ef | 20.2 fg |
| 15) Washonupana | 4.2 a | 34.6 b | 37.6 ef | 23.6 h |
| Overall mean | 9.78 | 42.4 | 33.2 | 14.6 |

1/ Clean: No discoloration on the subcrown internode.
 Slight: Pinpoint lesions on the subcrown internode.
 Moderate: Linear lesions on one side of the subcrown internode.
 Severe: 50% (of the subcrown internode) discolored with lesions on the whole circumference of the subcrown internode.

2/ $P < 0.05$ Compare means within disease class. Means not followed by the same letter are significantly different by Student Newman Keuls range test. Mean value of six replications in a randomized block design. Error mean square values for clean, slight, moderate, and severe are 3.51, 5.72, 5.53, and 4.91, respectively, with 70 df.

six replications. If plant escapes were a random event, then the experimental error would be larger because of the variation among the replications from lack of uniform disease pressure. The differences among cultivars in the percentage of plants in the healthy class might then be due to cultivar resistance to CRR and not due to plant escape.

At Bozeman, the range of variation in percentage of plants per class was largest for the severe class. Melvin, the susceptible cultivar, had the highest (35.2%) and Lewis (11.1%) had the lowest percentage of plants in the severe class. Once again, experimental error was lowest for the severe class (EMS = 4.02). However, the healthy class (EMS = 5.58) had as large an experimental error as the slight (EMS = 4.96) and as the moderate class (EMS = 5.54). There is good reason to suspect that errors in measurement in the slight class are due to problems of delineating it from the moderate class. The healthy class is easy to detect since the subcrown internode is without any discoloration and there should be consistent placement of plants in this class by a researcher. The experimental error with the healthy class at Bozeman could be due to lack of uniform inoculum pressure within the inoculated rows and the problem of plant escapes entering the healthy class (Table 3.3). This is in contrast to the low variation found in Glasgow among the percentage of plants in the healthy class (Table 3.2).

The summarization of these relations is best visualized in Figure 3.1 for the experiment conducted at Glasgow. The severe class, along

Table 3.3. Percentage of plants in each of four disease classes based on discoloration of the subcrown internode for 15 barley cultivars inoculated with Cochliobolus sativus versus non-inoculated control^{1/} at Bozeman, Montana 1980.

| Code Cultivar | Disease Class ^{2/} | | | | | | | |
|---------------------------|-----------------------------|-------|---------|-------|-----------|-------|----------|-------|
| | Healthy | | Slight | | Moderate | | Severe | |
| | Inoc. | Cont. | Inoc. | Cont. | Inoc. | Cont. | Inoc. | Cont. |
| 1) Pirolina ^{3/} | 11.8 ab ^{4/} | 21.2 | 25.0 bc | 29.3 | 43.6 gh | 41.0 | 19.6 cde | 8.5 |
| 2) Hector | 21.8 f | 28.9 | 26.3 bc | 29.5 | 36.0 cdef | 33.4 | 15.9 bc | 8.1 |
| 3) Klages | 15.0 bcde | 22.2 | 29.8 c | 37.4 | 36.0 cdef | 29.7 | 19.3 cde | 10.8 |
| 4) Shabet | 17.3 cde | 24.1 | 23.3 b | 36.7 | 40.8 fg | 31.7 | 18.8 cde | 7.5 |
| 5) Lewis | 20.0 ef | 34.7 | 29.8 c | 33.6 | 39.4 ef | 25.9 | 11.1 a | 6.0 |
| 6) Clark | 16.7 cdef | 37.6 | 34.8 d | 31.3 | 33.9 cd | 24.1 | 14.6 ab | 7.0 |
| 7) Betzes | 18.0 def | 32.6 | 28.2 bc | 34.4 | 34.5 cde | 25.2 | 19.3 cde | 6.7 |
| 8) Glenn | 19.0 ef | 41.5 | 27.0 bc | 28.9 | 33.0 c | 26.0 | 21.1 de | 3.6 |
| 9) Larker | 13.4 bcd | 25.1 | 29.1 c | 33.6 | 45.5 h | 33.7 | 11.9 a | 7.6 |
| 10) Unitan | 12.0 abc | 27.2 | 35.2 d | 36.9 | 38.5 def | 23.7 | 14.4 ab | 11.4 |
| 11) Melvin | 8.5 a | 8.9 | 19.8 a | 19.6 | 36.5 cdef | 38.2 | 35.2 g | 33.1 |
| 12) Compana | 18.7 def | 38.9 | 25.4 bc | 31.1 | 29.2 b | 24.6 | 26.8 f | 5.5 |
| 13) Wapana | 21.9 f | 40.3 | 29.7 c | 30.4 | 25.5 a | 29.4 | 23.0 e | 5.0 |
| 14) Wanupana | 17.4 def | 28.8 | 26.1 bc | 31.8 | 36.1 cdef | 25.9 | 20.5 de | 13.7 |
| 15) Washonupana | 16.8cdef | 40.1 | 26.1 bc | 31.6 | 39.1 def | 20.8 | 18.2 cd | 7.1 |
| Mean | 16.5 | 30.1 | 27.7 | 31.7 | 36.5 | 28.6 | 19.3 | 9.4 |
| ^{5/} LSD (45df) | 14.3 | | 14.0 | | 16.8 | | 6.5 | |

^{1/} Cochliobolus sativus infested oat kernels compared with autoclaved oat kernels in inoculated and control rows, respectively, were sown in the furrow with the test cultivar at a rate of 20 g per 7 g of seed per 3 m row.

^{2/} Hypana was excluded because it did not form a subcrown internode at Bozeman.

Table 3.3. (Continued)

- 3/ Clean: No discoloration on the subcrown internode.
Slight: Pinpoint lesions on the subcrown internode.
Moderate: Linear lesions on one side of the subcrown interode.
Severe: 50% discolored with lesions on the whole circumference of the
subcrown internode.
- 4/ $P \leq 0.05$ Compare means within a disease class. Means not followed by the same letter are significantly different by Student Newman Keuls range test. Mean value of four replications in a split-plot design.
- 5/ $t \leq 0.05$ Least significant difference (LSD) between inoculated and control for the same cultivar.

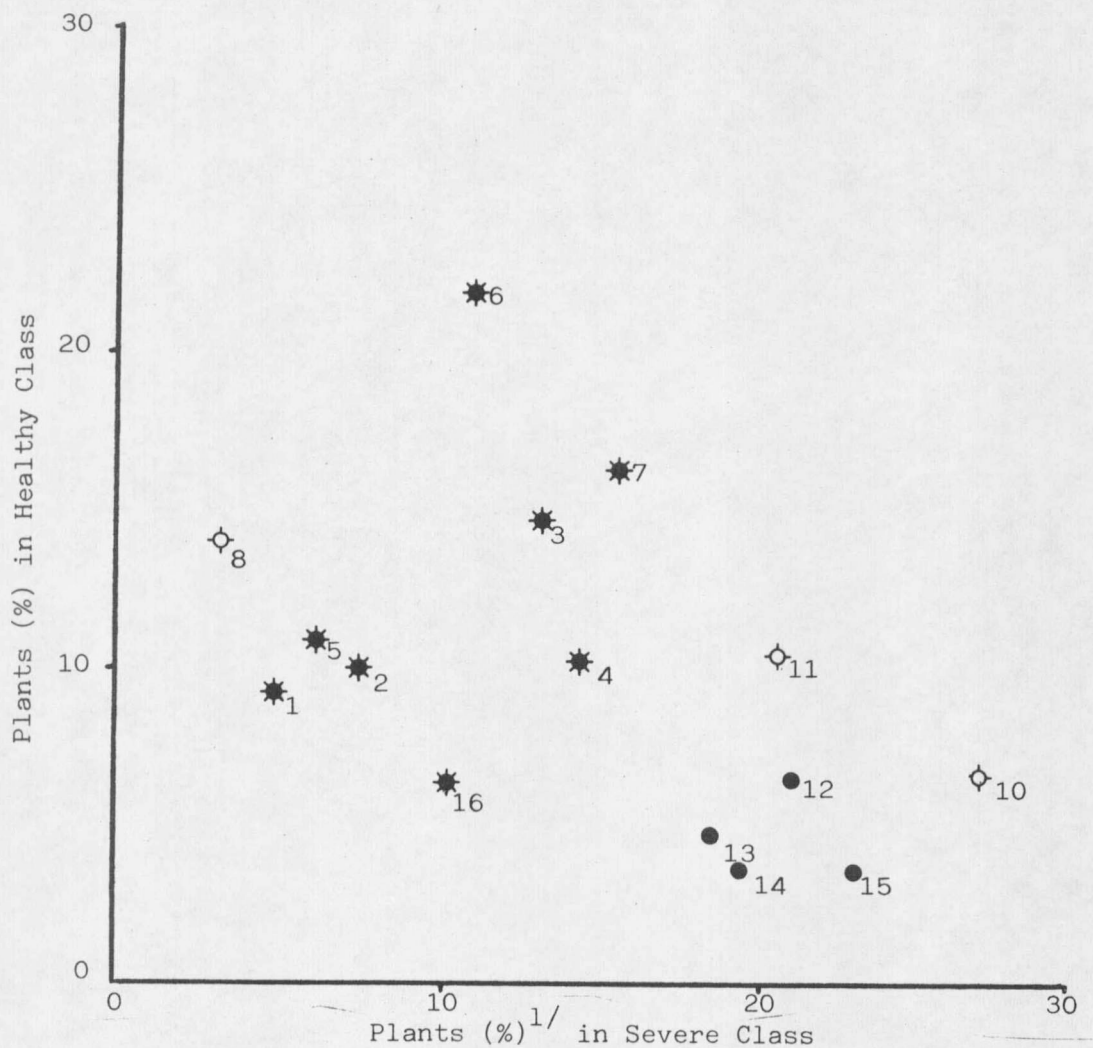


Figure 3.1. Percentage of plants in the healthy and severe disease classes for fifteen cultivars^{2/} grown in soil with natural inoculum of *Cochliobolus sativus* at Glasgow, Montana 1980.

^{1/} Healthy: No discoloration on the subcrown internode.

Severe: 50% or more discoloration on the full circumference of the subcrown internode.

^{2/} Hanncchen types were ¹Piroline, ²Hector, ³Klages, ⁴Shabet, ⁵Lewis, ⁶Clark, ⁷Betzes, ¹⁶Hypana.

◇ Coast type was ¹⁰Unitan. Manchuria types were ⁸Glenn, ¹¹Melvin and ⁹Larker; the latter was not grown at Glasgow.

● Smyrna types were ¹²Compana, ¹³Wapana, ¹⁴Wanupana, ¹⁵Washonupana.

the abscissa, is the primary discriminating class. The cultivar with the lowest percentage of plants in the severe class is Glenn (1.8%), whereas, Melvin, a susceptible cultivar, had 20.6% in the severe class. The Smyrna type cultivars are grouped together close to Melvin, ranging from Wapana (18.5%) to Washonupana (23.6%). The Hannchen type cultivars show a wide variation of plants in the severe class and are less susceptible than the Smyrna type cultivars. Pirolina (6.3%) is similar to Glenn, which is moderately resistant, while Betzes (16.5%) is the most susceptible of the Hannchen type cultivars but is still more resistant than either Melvin or the Smyrna type cultivars.

Clark and Lewis are both progeny of a Hector x Klages cross. Although Lewis has a lower percentage of diseased plants in the severe class than Clark, the fact that Clark has a high percentage of healthy plants might suggest why its overall disease rating is slightly lower than that of Lewis. The accuracy of classifying cultivars is improved when both the severe and healthy classes are considered.

The use of C. sativus infested oats to inoculate plants as measured by the percentage of plants in the severe and healthy classes can be visualized in Figure 3.2. The points of all cultivars are lumped in the center of the graph for Bozeman with a scattering of points for the Glasgow site. Melvin (35.2%) was the most susceptible which is consistent with its use as a universal susceptible, and both Lewis (11.1%) and Clark (14.6%) were in the moderately resistant range. The large

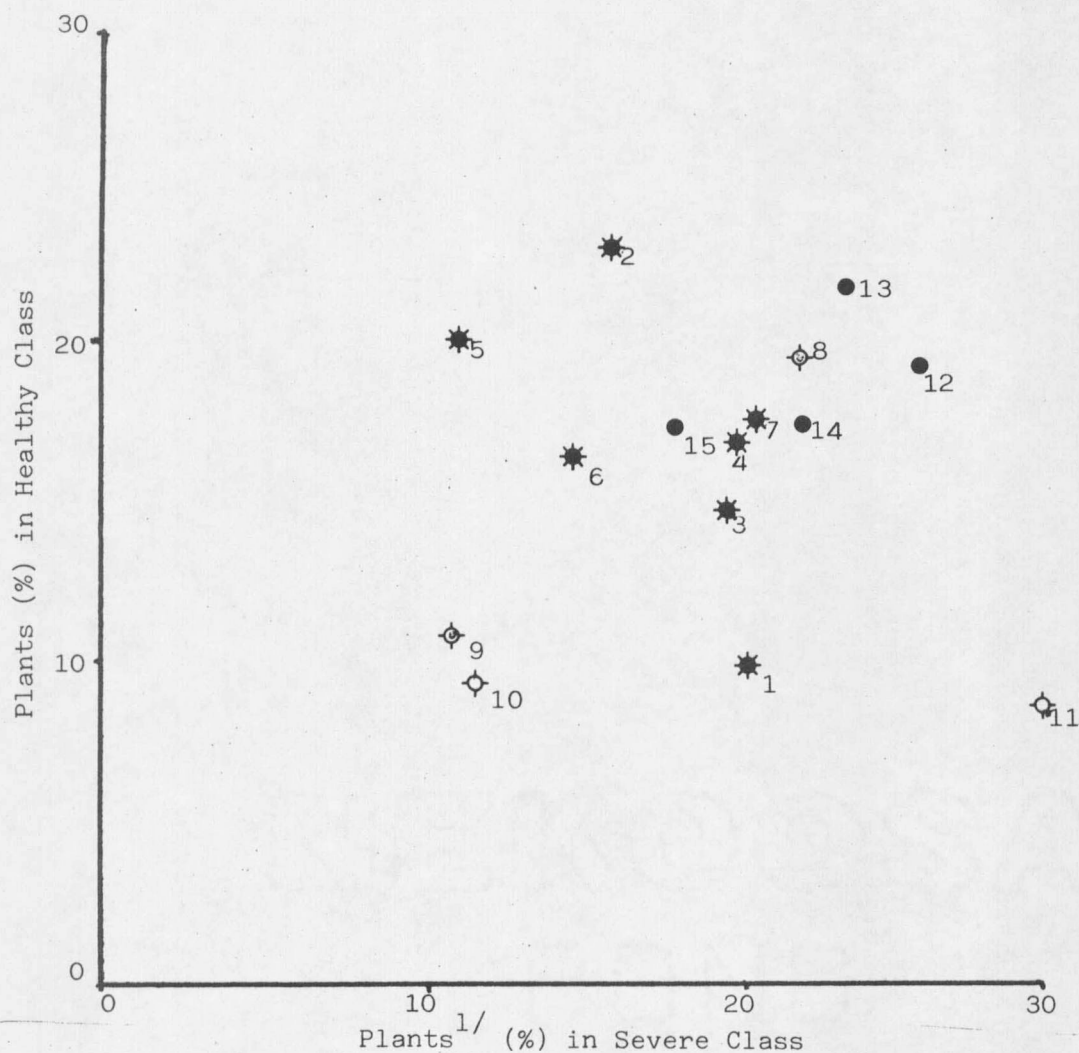


Figure 3.2. Percentage of plants in the healthy and severe disease classes for fifteen barley cultivars^{2/} grown in soil with infested oat kernels of *Cochliobolus sativus* at Bozeman, Montana 1980.

^{1/} Healthy: No discoloration on the subcrown internode.
 Severe: 50% or more discoloration on the full circumference of the subcrown internode.

^{2/} ★Hannchen types were ¹Piroline, ²Hector, ³Klages, ⁴Shabet, ⁵Lewis, ⁶Clark, ⁷Betzes, ¹⁶Hypana, the latter not included because it did not form a subcrown internode at Bozeman.

◇Coast type was ¹⁰Unitan. Manchuria types were ⁸Glenn, ⁹Larker, ¹¹Melvin.

●Smyrna types were ¹²Compana, ¹³Wapana, ¹⁴Wanupana, ¹⁵Washonupana.

experimental error within the healthy class and the lack of cultivar differentiation for both disease ratings (Figure 2.2) and percentage of plants per severe and healthy classes (Figure 3.3) argue against the use of C. sativus infested oats in determining resistance and/or susceptibility compared to use of a location such as Glasgow, where there is a history of CRR.

DISCUSSION

Common Root Rot is a problem in the major small cereal producing areas of North America where it has been estimated to cause yield losses in spring barley and spring wheat of 10% and 7%, respectively. Cultural practices have not proved to be effective in controlling CRR. The use of resistant cultivars holds the greatest promise for higher grain yields when small grain cereals are grown in CRR infested soils. This thesis has examined the present techniques for screening cultivar resistance to CRR and has proposed a three class disease system for field screening of barley cultivars.

A system of screening for resistance to CRR must deal with 'mixed stands' of healthy plants and severely diseased plants growing adjacent to one another. The four class system used by recent workers (34,57) calculates a disease rating based on the extent of discoloration of the subcrown internode. The three disease classes in this system -- slight, moderate, and severe -- are weighted by a numerical value proportional to the yield loss suffered in each of these classes relative to the healthy class. The healthy class is given less importance relative to the other three disease classes and in this manner the possibility of plant escapes entering the disease rating is minimal.

In 1979 I attempted to eliminate the problem of plant escapes by imposing uniform disease pressure on barley cultivars with the use of artificial inoculation. C. sativus infested oats when sown in the same furrow as seed of the test cultivar did reduce the plant emergence and

yield. There was no way of knowing how uniform the inoculum pressure had been without information on an individual plant basis. Therefore, in 1980 the test cultivars were inoculated in the same manner with C. sativus infested oats and individual plants scored on the extent of discoloration of the subcrown internode. As a comparison the experiment was duplicated on a site at Glasgow, Montana with a history of CRR. The disease ratings of cultivars grown in naturally infested soil were effective in differentiating among cultivars of intermediate and severe disease reactions. Artificial inoculation only helped in the separation of the high susceptibility of Melvin from the remainder of the test cultivars. The addition of infested oats did not reduce the possibility of plant escapes. The number of plants in the healthy class in naturally infested soil was consistent, indicating a uniform inoculum pressure at the site in Glasgow. In screening for resistance to CRR, therefore, the use of natural soil inoculum provided the most consistent results as far as minimizing the number of plant escapes.

The most discriminating disease class for the differentiation of cultivars was the severe class, followed in importance by the healthy class. The percentage of plants in both severe and healthy classes should be considered when evaluating the cultivar's resistance to CRR. The two intermediate classes, slight and moderate, can be grouped together into a third intermediate class. The separation of slight and moderate is difficult when the length of subcrown internodes is only

four to six centimeters. Also, a distinction of pinpoint lesions for the slight class as compared to extended lesions for the moderate class is highly subjective. The additional effort spent in trying to distinguish between these two classes did not improve the separation of cultivars with intermediate reactions. The system described in this thesis to be used with spring barley places greater importance on the number of healthy plants of a cultivar than the disease rating system used by the Canadian workers based on the four class system of healthy, slight, moderate, and severe classes (34,57).

The fact that the severe class is the most discriminating and easily recognized would lend itself to early screening of promising barley lines in the F_3 or F_4 generations. There is evidence that the inheritance of resistance to CRR in barley is quantitative in nature, so the progeny of crosses would best be screened for resistance in the F_3 , F_4 , and F_5 generations. Elimination of only the plants within the severe class would not be placing too great a pressure upon the population of plants. The F_3 plants would have to be screened again in the F_4 or even in the F_5 to be certain of no plant escapes. The elimination of extreme susceptibility by the time the lines are in the F_5 and F_6 generations may improve resistance.

The selection of lines based on yield over many locations may also improve the tolerance of cultivars to CRR. Clark, a recent release by Dr. E. A. Hockett, in Montana had never been screened for resistance to

CRR, but is a higher yielder and has a lower disease rating than either of its parents, Hector and Klages.

CRR does affect the Hannchen and Smyrna type cultivars by reducing the number of fertile tillers, and the Coast and Manchuria type cultivars by reducing the kernel weight. Both of these yield components are important to the total yield. Those selections in yield trials which either produce more fertile tillers or continue to produce heavy kernels in spite of C. sativus infection on the subcrown internode, should have a good level of tolerance to CRR.

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APPENDIX

Table 1. Effects of four methods of inoculation with Cochliobolus sativus on the absolute values^{1/} for plant emergence, yield, and 1000 kernel weight (Kwt) of four barley cultivars planted on two dates at Bozeman, Montana 1979.

| Parameter ^{2/} | df | Emergence | Yield | 1000 Kwt |
|-------------------------|----|-----------|------------|----------|
| | | no. | g | g |
| Date (D) | 1 | 1227. | 1540760.** | 18.00** |
| error a | 3 | 317. | 6644. | 0.71 |
| Cultivar (C) | 3 | 670. | 48778.** | 33.71** |
| error b | 9 | 439 | 6908. | 0.40 |
| D x C | 3 | 798. | 7185. | 6.13** |
| error c | 9 | 296. | 4948. | 0.30 |
| Inoculation (I) | 4 | 1808.** | 8917.** | 0.28 |
| D x I | 4 | 174. | 11167.** | 0.20 |
| C x I | 12 | 121. | 2170. | 0.27 |
| D x C x I | 12 | 103. | 427. | 0.31 |
| error d | 96 | 88. | 1362. | 0.26 |

**, $P \leq 0.01$ 4 replications. Separate analysis of variance for emergence, yield and 1000 Kwt.

1/ Mean square values with the non-inoculated controls were handled as a fifth inoculation method.

2/ See Chapter I for explanation of seeding date, cultivar, and inoculation methods.

Table 2. Effects of four methods of inoculation with Cochliobolus sativus on mean plant emergence, yield and 1000 kernel weight (Kwt) of four barley cultivars planted on two dates at Bozeman, Montana 1979.

| Parameter ^{2/} | df | Emergence | Yield | 1000 Kwt |
|-------------------------|----|-----------|------------------------|----------|
| | | no. | g | g |
| % of Control | | | | |
| Date (D) | 1 | 53.8 | 15243.** ^{1/} | 4.50 |
| error a | 3 | 315.0 | 353. | 140.00 |
| Cultivar (C) | 3 | 384.0 | 1736.* | 7.65 |
| error b | 9 | 225.0 | 319. | 66.70 |
| D x C | 3 | 92.1 | 196 | 86.10 |
| error c | 9 | 210.0 | 156. | 52.89 |
| Inoculation (I) | 3 | 1938.0** | 1999.* | 23.76 |
| D x I | 3 | 1766.0* | 347. | 31.49 |
| C x I | 9 | 508.0 | 631. | 49.16 |
| D x C x I | 9 | 343.0 | 486. | 30.12 |
| error d | 72 | 338.0 | 704. | 35.34 |

^{1/} *, ** $P \leq 0.05$ and 0.01 , respectively. Four replications. Separate analysis of variance for emergence, yield, and 1000 Kwt.

^{2/} See Chapter I for explanation of seeding date, cultivar, and inoculation methods.

Table 3. Effects of Common Root Rot on yield components of four barley types: Hannchen, Coast, Manchuria, and Smyrna. Cultivar and Treatment means square values for number of fertile tillers per 2.4 m (X), number of kernels per head (Y), 1000 kernel weight (Z), grain yield (W), and disease rating (DR). Inoculated with Cochliobolus sativus versus non-inoculated control at Bozeman, Montana 1980.

| Barley Type | df | X | Y | Z | W | DR |
|--------------------------|----|----------|----------|---------|----------|-----------|
| Hannchen ^{1/} | 6 | 5576. | 20.44** | 66.35** | 14446. | 92.4 |
| error a | 18 | 4404. | 2.19 | 7.85 | 5044. | 131.9 |
| Treatments ^{4/} | 1 | 21060.** | 19.40** | 22.14** | 3120. | 1948.00** |
| Trt x Var | 6 | 3303. | 1.10 | 3.14 | 1112. | 9.17 |
| error b | 21 | 1188. | 0.59 | 2.00 | 783. | 62.68 |
| Coast- | | | | | | |
| Manchuria ^{2/} | 3 | 10352.* | 224.60** | 96.15** | 3763. | 1131.00** |
| error a | 9 | 2178. | 11.43 | 7.11 | 2660. | 146.50 |
| Treatments | 1 | 2080. | 51.41** | 8.30* | 4536. | 596.00** |
| Trt x Var | 3 | 1428. | 15.26 | 0.75 | 434. | 59.23 |
| error b | 12 | 807. | 5.35 | 1.15 | 1510. | 62.55 |
| Smyrna ^{3/} | 3 | 2813. | 9.61** | 243.2** | 11956.** | 46.54 |
| error a | 9 | 2370. | 0.41 | 2.58 | 941. | 76.12 |
| Treatments | 1 | 37607.** | 4.40** | 4.13 | 761. | 2290.00** |
| Trt x Var | 3 | 3579. | 0.16 | 2.24 | 289. | 65.04 |
| error b | 12 | 1342. | 0.39 | 0.93 | 1004. | 83.39 |

*, ** $P \leq 0.05$ and 0.01 , respectively.

1/ Hannchen barleys were Pirolina, Hector, Klages, Lewis, Clark, Shabet, Betzes.

2/ Coast barley were Unitan. Manchuria barleys were Glenn, Larker, Melvin.

3/ Smyrna barleys were Compana, Wapana, Wanupana, Washonupana.

4/ Treatments: C. sativus inoculated versus control plots.

