Montana crop loss assessment in small grains
by Vickie Jeanne Parker

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Agronomy
Montana State University
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Abstract:
Weeds, diseases, and insect pests separately and collectively affect small grain yields. Yield effects caused by interactions among these pests are often unknown. The Montana crop loss assessment experiment was designed to measure yield constraints due to weeds, diseases, and insect pests. Significant interactions among weeds, diseases, and insect pests were shown during the three year study (1980-1982). Though yield constraints due to these pests vary with location and season, information and methodology from the crop loss assessment project may be useful for further studies on crop/pest interactions.

Crop loss assessment treatments included weed control, disease control, insect control, weed-disease control, weed-insect control, disease-insect control, weed-disease-insect control, and a check (no control). Pests were controlled by using herbicides, insecticides, fungicides, and bacterio-cides. Each treatment was replicated four times in 1980 and 1981, and eight times in 1982. Fumigation and fumigation plus weed-disease-insect control treatments were added in 1982. Pest populations were monitored, pest damage was measured, and yield component data were recorded.

In 1980, the weed-disease-insect control treatment resulted in a 44% spring wheat yield increase over the check at Bozeman, and a 21% and 45% increase at Conrad in 1981 and 1982 respectively.

In 1982, the disease control treatment produced 35 % fewer tillers/m sq. than the weed-disease-insect control treatment, even though stand counts were not significantly different among treatments. Yields of the disease control and insect control treatments were 35 % less than in treatments where both diseases and insects were controlled. Insect control treatment significantly increased volunteer barley dry weight over the dry weight in the check.

The nematode populations were 70% lower in the disease control plots than in the check plots. Nematode populations in the insect control plots were 70% higher than in the check plots.

Sawfly cutting was reduced by weed-insect control. Disease control resulted in significantly lower P. syringae infection than no disease control.

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

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Date February 24, 1983

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ABSTRACT

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CHAPTER 1

INTRODUCTION

Montana small grain yields are affected by weeds, diseases, and insect pest populations. Weeds, such as wild oats, decrease yields by successfully competing with small grain crops for limited moisture, space, and nutrients. Diseases or insect pests can infest and destroy crops either sporadically or cyclically depending on the weather, the buildup of the disease or pest populations, and the farming practices which encourage or discourage the survival of the organisms.

The crop loss assessment experiment was initiated in Montana to identify effects on small grain yields caused by interactions of weeds, diseases, and insect pests. Biologically, the interactions among these pests cannot be easily separated from each other, but scientifically, their effects on yield are often examined separately.

The Montana crop loss assessment experiment evolved from questions such as the following: 1) If weeds significantly reduce yield and diseases significantly reduce yield, will the combination of weeds and diseases decrease yield additively? Synergistically? Or will the diseases infect

the weeds, and, therefore, decrease the weeds' competitive ability, which would result in an increase in grain yields?

2) If a plant is infected by a disease, but the disease pressure does not visibly affect yield, how much weed pressure, insect pressure, or additional disease pressure would be necessary to noticeably affect yield? 3) If all stress caused by weeds, diseases, and insect pests is removed from the plant, will it produce more grain, or less? 4) Do chemicals affect crop yield when pest are not present, or are at very low populations?

A preliminary study in 1980 on crop loss assessment (W. Morrill, P. Fay, D. Sands, unpublished data) measured the effects of weeds, diseases, and insect pests on grain yield. Interactions among these factors as they affected yield were evaluated. Control of weeds, diseases, and insect pests resulted in a 44% yield increase as compared to the check.

Based on the work done in 1980, the objectives of this study were 1)to continue multidisciplinary research designed to enhance yield of small grains, and 2) to search for interactions among weeds, diseases, and insect pests.

Crop Loss Assessment Concept

Crop loss assessment illuminates opportunities for grain yield increases when adequate protection measures are used. Pest control programs (Chiarappa et.al. 1972) have been

developed without full knowledge of the relevant economic factors involved.

Chiarappa et.al. (1975) pointed out the need for crop loss assessment projects to secure reliable information about yield constraints on which to base long term planning of research progams and allocation of resources. They stated that crop loss assessment data should substantiate evidence of pest problems already occurring. Through crop loss assessment, the relationship of pest infestation to crop damage and yield can be quantified (Irving, 1970). Plant protection scientists, economists, biomathematicians and ecologists must cooperate in a continuous multidisciplinary program to reduce crop losses and increase food production.

The parameters of crop loss assessment (Chiarappa et.al., 1975) include the level of weed/disease/insect pest infestations existing in a given field or area, and the quantity (or quality) of yield reduction resulting from that particular level of infestation. To obtain useful information, the researcher should 1) design a field experiment to appraise losses, 2) record field symptoms and the effect on the crop due to infection or infestation, 3) establish a quantitative relationship between the population densities and yield losses, and 4) determine methods to prevent or reduce losses.

Population density is measured in or on a given

plant/crop/area by one of the following methods (LeClerg, 1971): 1) Actual counts of pest numbers, or weight or volume of specimens collected, 2) Visual rating of pest numbers in defined classes, 3) Actual counts of plant or crop units damaged or affected by pests, 4) Visual ratings of damaged plants or plant parts in classes defined by descriptive scales or diagrams. Crop variety, seeding rate, plot dimensions, part of plots harvested, number of replications, pest species present, time of initial infection or infestation, yield components, and any management problems should be recorded.

If these guidelines are followed, research in the development of crop loss forecasting systems and efficient pest management programs would be accelerated (Chiarappa et.al., 1975). For crops whose value does not warrant chemical application, crop loss assessment surveys are the basis for possible alternative solutions such as breeding resistant varieties or modifying cultural practices (James, 1974).

Insect Pests of Wheat

Aphids

Four species of aphids have been found in Montana small grain fields (Carroll, 1982):

Schizaphis graminum (Rondane) - greenbug

Macrosiphum avenae (Fitch) - English grain aphid

Rhopalosiphum padi (Linaeus) - Oat-bird-cherry aphid

Rhopalosiphum maidis (Fitch) - Corn leaf aphid.

These aphid species feed on the plants in stages from early tillering to ripening. They are also the vectors for barley yellow dwarf virus (BYDV).

Kieckhefer (1975) found that the greenbug, English grain aphid, and oat-bird-cherry aphid colonize spring wheat, barley, winter wheat, and rye, and the corn leaf aphid colonizes barley in the early growth stages. Apablaza (1967) reported that the greenbug and English grain aphid severely injure or kill seedlings of barley, wheat, and oats and cause reductions in kernel weight of harvested grain, even when the infested plants are advanced in maturity. He found that plants were not killed if greenbug infestation occurred 65 days after the date of seeding. Infestation occurring 35 days after seeding caused fewer tillers and lower kernel weights.

The English grain aphid killed all barley, wheat, and oats it infested at 7-27 days after seeding. The corn leaf

aphid did not damage the small grains as severely as the above two species. The loss in grain yield depended on the weather, abundance of parasites and predators, and stage of plant growth at the time of infestation (Apablaza, 1967).

The English grain aphid overwinters in the egg stage on grasses and stubble. During the growing season it moves into the edges of the field. The English grain aphid feeds on the flag leaf before ear emergence and on the wheat head after emergence (Wratten, 1974). No significant differences were noted between spikelet numbers or number and weight of grains, but grain weight was reduced by 14%. Grain protein was also significantly reduced.

A heavy infestation of the English grain aphid during flowering reduced yield by up to 30% (Kolbe, 1969). Thousand kernel weight decreased when aphids exceeded 200 aphids/head.

Oat-bird-cherry aphids overwinter in the egg stage. Alate aphids disperse into the wheat fields in late May and feed on lower plant parts and bases of blades. As few as 39 aphids/shoot decreased yield significantly (Kolbe, 1969).

Metasystox or malathion applied early in the season effectively controlled oat-bird-cherry aphids (Kolbe, 1969). Phorate and Di-Syston seed treatments effectively controlled greenbug on spring barley six weeks following planting. These chemicals increased yield significantly over untreated

checks even though plant stands were reduced significantly (DePew, 1964). Treated plots yielded 16 to 24 bu/acre, while untreated plots yielded 1.4 bu/acre.

Survey methods included the use of traps placed above the plant canopy and on the ground surface (Broadbent, 1948), sweep net samples, and visual counts and identification of aphid species on a weekly schedule from wheat emergence to harvest (Dean, 1973; Kieckhefer, 1975).

Wheat Stem Sawfly

Wheat stem sawfly, Cephus cinctus Norton, is native to wheat grasses, and has adapted well to cultivated grain fields. Parasites, which control sawflies in wheat grasses, have not successully moved into domestic grains (Davis, 1955; Holmes, 1953; Holmes et.al., 1963; Wallace & McNeal, 1966; Nelson & Farstad, 1953; Nielson, 1949; Somsen & Luginbill, 1956). Sawfly adults emerge from stubble in the late spring and move into wheat fields which are in the stem extension stages. The females oviposit into hollow areas throughout the wheat stem. The larvae hatch in one week and feed inside the stems until early August. At this time, the larvae move to the bases of the stems, and cut and plug the stubs (lower stems). They remain in these stubs throughout the winter (Criddle, 1923). Because the adult is the only stage of the insect which is outside the stem, and because

the number of female adults does not indicate the number of larvae, due to multiple ovipositing and larval cannibalism, predicting the economic losses due to the wheat stem sawfly is difficult. Cut stems/unit area is an accurate estimate of the overwintering sawfly larval population (Criddle, 1923).

Heptachlor applied to soil at planting resulted in high larval mortality if a light infestation occurred, and if sawflies were restricted to the lower nodes of the wheat stems (Holmes & Peterson, 1963). Wallace (1962) also reported effective control of sawflies (70 to 80%) by furrow application of heptachlor. Of seventeen chemical sprays, broadcast granules, and furrow treatments tested, furrow treatments were most effective, while sprays and broadcast granular treatments were ineffective (Wallace, 1962).

Hessian fly

Hessian flies, Phytophaga destructor (Say), are widely distributed in the wheat growing regions of the world. The female adults lay their eggs on wheat leaves, the eggs hatch, and larvae feed between the leaf sheaths and the stalks causing a weakening of the spring wheat stems and a decrease of 1000 kernel weight and grain quality (Pike and Antonelli, 1981). Controls include the application of insecticides (Morrill & Nelson, 1976). Sampling of damage

is done by counting infested tillers/unit area (Brown, 1960).

Wheat Stem Maggot

Wheat stem maggot, Meromyza americana Fitch, infests all small grains and some grasses. The larvae feed within the stems which causes wheat heads to die before the grain is formed. Counting white heads of stems spirally cut is a sampling method (Allen and Painter, 1937).

Wireworms

Many species of wireworms are phytophagous on seeds, roots, and young seedlings of a variety of crops. Soil treatments have been used to protect vegetable crops against wireworms. The efficacy of seed treatments depends upon the species of wireworm involved, wireworm activity, the proportion of the population attracted to the seed, and the date of planting. Lindane had little effect on seed germination even when it was combined with certain fungicidal treatments (Lange et.al., 1949).

Weed Competition

Weeds in small grains have been the focus of research projects for many years. Friessen and Shebeski (1959) found that as few as 50 weeds/m sq. would decrease grain yield, and that, specifically, wild oats, wild mustards, wild buck-

wheat, and sowthistle were highly competitive with cereal crops.

Friessen et.al. (1960) stated that weeds caused a significant drop in yield and grain protein, but Bell and Nalewaja (1968) found no influence on percent protein due to weed pressure. Bell and Nalewaja (1968) did discover, however, that a wild oat density of 10 seedlings/m sq. caused a decrease in wheat yield of 1 to 3 bu/acre. Early control of wild oats is essential (Nalewaja & Arnold, 1970).

McNamara (1976) found a reduction in wheat yield, tiller number, and dry matter at plant maturity due to wild oat competition. Competitive effect increased with increased density. Hodgson (1963) found that in Montana wheat fields, 2 Canada thistle shoots/m sq. reduced yield by 15 % and that 25 shoots/m sq. reduced yield by 60%. Samples of weeds were taken from four 30 cm. sq. plots. A meter sq. area of the field was harvested for yield determination (Hodgson, 1963).

Diseases

Viruses

Virus diseases infecting spring wheat include barley yellow dwarf virus (BYDV) which is transmitted by aphids, and wheat streak mosaic virus (WSMV) which is transmitted by mites. Control of the virus depends greatly on control of

the vector, or escape of the host plant from contact with the vector. Control of the vector by spraying insecticides seldom prevents virus introduction (Broadbent, 1969). By manipulating planting rate or the size of the field, the percent of total plants infected can be reduced.

Weeds, alternate or secondary hosts for insects, may be the key in many plant-virus interrelationships (Duffus, 1971). Early weed control is necessary because control of the weeds after vector populations have been established may force movement of the vector between hosts, and consequent virus spread.

Symptoms of BYDV and WSMV have been reviewed in the literature (Wiese, 1977; Smith, 1963). Smith stated that more aphids are necessary later in the growth stages of cereals to cause a similar degree of severity inflicted by fewer aphids earlier in the season. Panayotou (1979) reported that wheat yield was reduced more from a late infection. Gill (1980) confirmed Smith's findings with his report that later inoculation resulted in lower losses, but that grain size and milling properties were affected. In spring wheat, the stem extension growth stage is the most susceptible stage to virus infection.

Doodson and Sanders (1970) rated leaves showing BYDV symptoms as 0=no discoloration through 8=total necrosis. Monitoring of the BYDV vector movement may be done by visual

examination of plants showing symptoms. Infected plants can be pulled and aphids counted. Sweeps of the field can be made to determine the aphid species present and the stage of maturity of the aphids (Gill, 1970).

Carbofuran was found to control mites, the vector of WSMV. Its application reduced the incidence of WSMV and increased grain yields (Harvey et.al., 1979). While neither a phytotoxic nor stimulating effect on plant growth was observed, carbofuran may have caused plants to produce more grain. Wheat streak mosaic virus incidence was determined by counting the number of infected plants in 9.2 meters of row.

Bacteria

Pseudomonas syringae decreases yields of semidwarf spring wheats and some winter wheats (Otta, 1974). Symptoms have been described in the literature (Otta, 1974; Sellam & Wilcoxson, 1976). Field evaluation of infection was done by Sellam and Wilcoxson (1976) after heading, when dry weather stopped the bacterial spread. They measured plant resistance to P. syringae by rating the percent of necrosis occurring on the upper three leaves. Resistance equalled small lesions, or 5 to 10% of the surface infected, moderataly susceptible equalled 10 to 15% of the leaf surface infected, and susceptible equalled more than 25% of the leaf

surface blighted. Fryda and Otta (1978) isolated P. syringae from the upper leaves of wheat plants and determined it was from epiphytic populations from nearby weeds or crop plants. They surveyed P. syringae presence by sampling the first, second, and third wheat leaves of 1050 plants.

Fungi

Common root rot, Cochliobolus sativus, reduces the number of tillers/plant and the number of kernels/spike (Verma et.al., 1976). Sampling plants from each of 6 adjacent rows from 6-9 locations/field is the most efficient root rot surveying method (Stack & McMullen, 1977).

CHAPTER 2

MATERIALS AND METHODS

Experimental Year One - 1981

The experimental design was a randomized block containing eight treatments replicated four times. The experimental plots were planted at the Central Montana Agricultural Research Center near Moccasin, MT and at the Western Triangle Agricultural Research Center north of Conrad, MT. The treatments were weed (W) control, disease (D) control, insect (I) control, WD control, WI control, DI control, WDI control, and a check (no controls). Cultivars included Newana spring wheat and Hector barley. Each plot consisted of 8 border rows, 4 yield rows, and 8 working rows for a total of twenty 6.0 meter rows. The area per cultivar per location, therefore, was .33 acres.

The Moccasin plots were planted on 4/10/81 into moist fallow at a rate of 140 barley seeds/6 m row and 160 wheat seeds/6 m row. Conrad plots were planted on 4/24/81 (same rates as Moccasin) to a depth of 5 cm to reach the available soil moisture. Soil tests showed 75 lb. (34 kg)/acre NO3, and 30 lb. (13.5 kg)/acre additional NO3 was applied at

Moccasin. Soil tests at Conrad showed 32 lb. (14.4 kg)/acre NO3. Sixty lb. (27 kg)/acre additional NO3 was applied.

Weed Control (W)

Bi-monthly hoeing and hand pulling controlled weeds. At wheat maturity, a weed survey was taken in the four yield rows of each plot. Weed species were noted, and the number of each species was counted (Klingman, 1971).

Disease Control (D)

Seed of the disease control treatment was treated with 3 oz./100 lb (85g/45 kg) carboxin 30 days before planting. After emergence, the disease control plots were sprayed every two weeks with benomyl at the rate of 1 lb. (.45 kg)/acre active ingredients (AI), triadimefon at 1/4 lb. (.11 kg)/acre AI, manzeb at 2 lb. (.9 kg)/acre (80% AI), oxytetracycline hydrochloride at .04 oz. (1.1 g)/acre, and streptomycin at .13 oz. (3.7 g)/acre (three applications each).

In the first week of July, a foliar disease survey was conducted in the yield rows of all plots. The diseases were identified, and their frequency of occurance was rated using a standarized scale of 0=no disease present, 1=few plants infected and 2=very visible (Slykhius et.al., 1959).

Just before harvest, a root rot survey was conducted on 10 plants/plot pulled at random. The severity of

lesions on the subcrown internode was rated on a scale of 0=no lesions to 4=completely black (Verma et.al., 1974).

Insect Control (I)

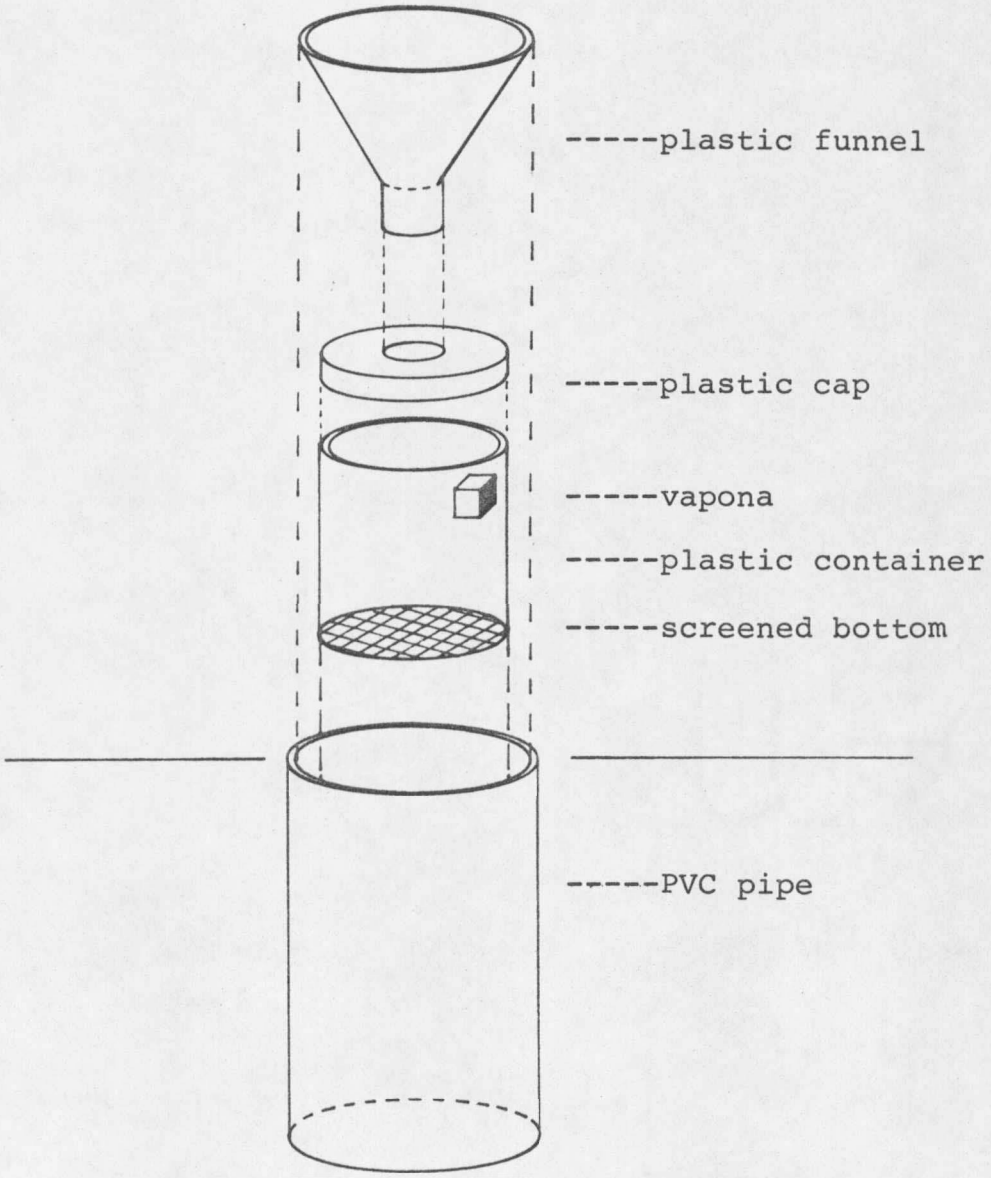
Seed of the insect control treatment was treated with 2 oz. (56.7 g)/bush lindane (18% AI) 30 days before planting. After emergence, insect control plots were sprayed every two weeks with acephate at the rate of 1/4 lb. (.11 kg)/acre AI. Carbofuran was sprayed at the rate of 1/4 lb. (.11 kg)/acre AI at the grain ripening stage.

Sticky traps (3 x 5 white card stapled lengthwise to a 40 cm wooden stake, and covered with Tack Trap) monitored the flying insects in every plot. The traps were changed every two weeks, and trapped insects were identified and counted.

Pitfall traps (Figure 1) also were placed in all plots to monitor the movement of ground insects. These were emptied every week, and the insects were identified and counted.

Insect damage, as it occurred, was identified. The number of white heads in each plot caused by wheat stem maggots was counted. After harvest, the number of stubs, in the four yield rows, containing wheat stem sawfly larvae was counted.

Figure 1. Pitfall Trap



WD, WI, DI, WDI Controls

These treatments are combinations of the first three described above, so controls and monitoring methods were those of the respective treatments.

Check - no control

Seed of check plots was not treated. No chemicals were used for control of insects or diseases during the growing season, nor were weeds pulled. Insects and insect damage were monitored. Weed and disease surveys were taken.

Stand Counts, Yield Components, Grain Protein Content

At the two to three leaf stage, plants in the middle two yield rows of each plot were counted to determine stand densities. The middle 2.5 m of the four yield rows were harvested with a small combine to determine yield. Tillers/plant per plot (10 plants/plot), head length (10 heads/plot), kernels/spike (10 heads/plot), 1000 kernel weight (calculated from number of kernels/30 g. wheat), kernel plumpness (percent of grain remaining on a 6/64 screen from a 100 g. sample), test weight, grain protein content (Dye-binding method, AACC 46-14A), number and identity of weed seeds contained in 100 g. of seed, and percent yellow berries contained in 100 g. of seed were also recorded.

Experimental Year Two-1982

The experimental design was randomized block. The experimental plots were planted at the Western Triangle Agr. Research Center nine miles north of Conrad MT, and on a cooperator's land one mile northeast of the station. The barley stubble was burned and disced once before Solar spring wheat was planted. Seeding rate was 16 g seed/6 m row. Soil sample results indicated 24 lbs. (11 kg) NO3/acre. Sixty pounds (27 kg) of N was applied as a top dressing. Dates of planting were 5/20 for the on-station plots (plots on the research center's land) and 5/30 for the off-station plots (plots on the cooperator's land).

The off-station location contained eight treatments (same treatments as in 1981) replicated eight times. Each replication contained twenty 6 m rows for a total of 120 m sq/replication. Plots were irrigated on 7/4 (5 cm) and 7/28 (5 cm), at tillering and flowering respectively. Hail destroyed 70% of the plants in the off-station plots on 8/10, so yields were not taken.

The on-station experiment consisted of ten treatments replicated eight times, for a total of 80 120 m sq. plots. Treatments were weed (W) control, disease (D) control, in-

sect (I) control, WD control, WI control, DI control, WDI control, fumigation (F), F + WDI control, and a check (no-control).

Weed Control

Weed control plots were sprayed with diclofop methyl at the rate of 3/4 lb. (.34 kg)/acre AI to control wild oats. Wild oats were sprayed when the majority were in the three leaf stage. Chlorosulfuron was tank mixed with diclofop methyl at a rate of 1/2 oz. (14.2 g)/acre AI to control broadleaf weeds, mainly Canada thistle. Weeds which escaped chemical control were hand pulled.

Weed surveys were taken when the wheat was in the early stem extension stage and in the ripening stage. A 30 cm. sq. frame was used to sample three randomly selected areas within the eight working rows of each plot. Data collected included the percent ground area covered by wheat and weeds within the frame and notation of weed species (wild oats, volunteer barley, Canada thistle). All weed species and the wheat within the frame were harvested, dried down, and weighed (Klingman, 1971).

Disease Control

Seed of disease control plots was treated with carboxin 30 days before planting. Tilt (Ciba Geigy) was sprayed at the rate of 3.5 oz. (99 g)/acre AI and streptomycin at the rate of 13 oz. (368.6 g)/acre AI when wheat was in the early boot stage, and again at flowering. Samples of plants with possible disease symptoms were sent to the Extension plant pathologist at Montana State University for disease identification. Verified plant diseases included P. syringae and tan spot.

A foliar disease survey was taken during wheat anthesis. A visual estimate of the percent of necrotic area on the top of the flag and second leaves of ten main tillers in the yield rows of each plot was taken (Sellam and Wilcoxson, 1976; James, 1974).

A root rot survey was also taken by pulling the plants in 1 m of three adjacent rows of the eight working rows of each plot (Stack & McMullen, 1977). The subcrown internodes of these plants were visually rated for presence of lesions with 1=no lesions to 4=completely black (Verma et.al., 1974).

Insect Control

Seed used in the insect control treatment was treated with lindane one month before planting. Acephate at the

rate of 1/4 lb. (.11 kg)/acre AI was applied at tillering, and carbofuran was sprayed at the rate of 1 lb. (.45 kg)/acre AI at flowering.

A sticky trap (described in 1981 experimental year) was placed in each plot to monitor flying insects. One set was used at tillering and another set was used two weeks later when the plants were in the boot stage. Insects were identified and counted.

Sweep net samples were taken in each plot (4 sweeps/ 6 m in working rows) to monitor movement of wheat stem sawflies, and to identify and monitor movement of aphid species into the plots. Other insects from sweeps were also recorded.

Aphid biology (alate vs. apterous) and aphid movement were also monitored by counting the number of aphids/head (10 heads/working rows). By examining heads for the presence of insects, chemical persistance could be monitored to determine if the insect control treatment should be repeated.

The top 30 cm of soil in the working rows of the check plots were sampled with a soil core remover, and the soil was sieved to determine if wireworms were present. The numbers of adults and larvae found were recorded.

Plants were examined continually for the presence of economically important insects. For example, white heads

were examined to see if they were caused by wheat stem maggots or hail; curled flag leaves were examined for the presence of mites or aphids.

At harvest, the stems cut by wheat stem sawfly larvae were collected from the middle two yield rows of each plot. Yield from the heads of these stems was calculated, and the percent of yield lost to sawflies was determined.

Fumigation (F)

Four 1.5 lb. (.68 kg) cans of methyl bromide plus 15% chloropicrin (DOW) were partially buried 1 m in from the corners of each plot. Plastic sheets were placed over the plot areas to be fumigated, and edges of the plastic were covered with soil. When the soil temperature reached 15 degrees C., the cans were punctured. The plastic sheets were removed after three days. All plots were planted 11 days after the plastic sheets were removed. Soil samples were taken at planting from the top 30 cm. of fumigated and nonfumigated plots. No chemical or manual controls of weeds, diseases, or insects were used on these plots during the growing season.

WD, WI, DI, WDI, F + WDI Controls

These treatments are combinations of those described above. Controls and monitoring methods were those of the respective treatments.

Check - no control

Procedure was the same as the 1981 experimental year.

Nematode Sampling

The top 45 cm of soil in each plot were randomly sampled (Burlando, 1982) for nematodes by use of an oak field tube (2 subsamples/plot). Soil was mixed (8 replications /treatment x 2 subsamples/replication), and a one liter sample was taken from each treatment, for a total of 18 soil samples.

Plant samples were also taken for determination of nematode populations in the following manner: Ten plants/replication were pulled for a total of 80 plants/treatment. From the 80 plants, a subsample was taken consisting of 80 longitudinal parts including the root, crown, and leaf areas. Soil and plant samples were shipped to Western Diagnostic Service in Davis, CA for analysis.

Environmental Monitoring

Soil temperature was recorded at the time of fumigation, weed, insect, and disease surveys, and at the time of each chemical application. Soil moisture was recorded weekly using a Brown's soil probe. A raingauge monitored rainfall. Rain totalled 22 cm. from May 15 - Aug. 15.

Stand Counts, Yield Components, and Grain Protein Content

At the two to three leaf stage, wheat plants in the

middle two yield rows of each plot were counted to determine stands. Yield was taken from the middle 2.5 m of two rows/plot. These rows were hand pulled when grain moisture was approximately 20%, were allowed to dry for a week, and then were threshed. Yield was taken on dockage-free grain. Tillers/m sq., head length (10 heads/plot), kernels/spike (10 heads/plot), 1000 kernel weight (number of kernels in 30 g. of wheat), kernel plumpness, test weight, and grain protein content (Dye-Binding method, AACC 46-14A) were also recorded.

Statistical Analyses - 1981 and 1982

Data from all treatments were analyzed by analyses of variance (AVMF). Unequal error variances were corrected (Snedecor & Cochran, 1967). Orthoginal comparisons analyzed main effects of and interactions among weed, disease, and insect controls. Two-way and three-way interactions were graphed. Three dimensional graphs were produced to aid in identifying pest infestations and infection trends.

Weed control's main effect (WME) included weed control treatment, weed-disease control treatment (WD), weed-insect control treatment (WI) and weed-disease-insect control treatment (WDI) for a total of 16 replications in 1981 and 32 replications in 1982.

Disease control's main effect (DME) included disease control treatment, WD control treatment, disease-insect control treatment (DI), and WDI control treatment for a total of 16 replications in 1981 and 32 replications in 1982.

Insect control's main effect (IME) included insect control treatment, WI control treatment, DI control treatment, and WDI control treatment for a total of 16 replications in 1981 and 32 replications in 1982.

Two way interactions included weed x insect interactions, disease x insect interactions, and weed x disease interactions. Each of these interactions included 8 replications in 1981 and 16 replications in 1982. Weed x insect interactions included weed, insect control (W x I), weed, no insect control (W x NI), no weed, insect control (NW x I), and no weed, no insect control (NW x NI). Weed x disease interactions included weed, disease control (W x D), weed, no disease control (W x ND), no weed, disease control (NW x D), and no weed, no disease control (NW x ND). Disease x insect interactions included disease, insect control (D x I), disease, no insect control (D x NI), no disease, insect control (ND x I), no disease, no insect control (ND x NI).

CHAPTER 3

RESULTS AND DISCUSSION

Conrad Spring Wheat, 1981

Yield

Plot size was increased from 12 rows in 1980 to 20 rows in 1981 to reduce edge effect between adjacent plots and, therefore, to decrease experimental variability. Yield components and pest populations were measured.

The statistical significance of the variables related to yield are summarized in Table 1. Treatment differences were significant in 5 of the 13 variables measured. Seven WME, IME, and DME on these variables were measured. Two 2-way interactions and one 3-way interaction were also significant.

Weed control treatment (4 replications) resulted in a 17% yield loss from the check (Table 2). Wild oats were not controlled early enough to prevent their competing with the wheat seedlings (Nalawaja & Arnold, 1970). Hand pulling and hoeing reduced wheat stands.

WI control treatment increased yield from 32.9 bu/a (weed control only) to 41.9 bu/a. With the addition of disease control to weed and insect controls (WDI), yield

Table 1. Treatment Effects on Yield, Yield Components, Protein, and Pest Populations and Single Degree of Freedom Comparisons. Conrad Spring Wheat, 1981.

	Treatment		Single Degree of Freedom Comparisons (S.S.)						
	S.S.	M.S.	WME	DME	IME	WxD	WxI	DxI	WxDxI
Yield	654.40	93.48**	-[1]	-	-	-	433.7**	-	-
Kernels/Spk	93.47	13.350	-	-	30.03*	-	-	26.28*	-
Test Weight	2.08	.2971*	-	0.5*	.98**	-	-	-	-
Protein Content	6.03	.8610	3.063*	-	-	-	-	-	-
Weeds /yield rows	24020	3431**	23,650**	-	-	-	-	-	-
BYDV Index[2]	11.00	1.571**	-	-	-	-	-	-	3.125*
WSMV Index[2]	4.47	.6384	1.531**	-	-	-	-	-	-
Avg Insects/Plots	3290	470.0*	-	-	3.92**	-	-	-	-

[1] dash indicates nonsignificance.
[2] visual rating of presence of BYDV or WSMV in plots: 0=none present to 2=high incidence.
*Significant at .05.
**Significant at .01.

Table 2. Treatment Effects on Newana Spring Wheat Yields. Conrad, 1981.

Treatment	Yield (bu/a)		% of Checks
Weed Control (W)	32.9	bc*	-17
Disease " (D)	42.0	a	+ 6
Insect " (I)	35.6	bc	-10
WD "	38.6	ab	- 2
WI "	41.9	a	+ 6
DI "	34.8	bc	-12
WDI "	47.9	a	+21
Check	39.5	ab	-

LSD = 7.1

$\bar{X}$ = 39.1 bu/a
M.S.E. = 23.56
C.V. = 12.4
*Means followed by the same letter within the same column are not significantly different at the .05 level as determined by LSD test.

increased from 32.9 bu/a (weed control only) to 47.9 bu/acre (Table 2). These data suggest that even though weed control treatment resulted in a lower yield than the check, when weed control was combined with insect control or with insect and disease control, resulting yield was significantly higher than weed control alone, and higher than the check.

Weed x insect interactions' effects on yield were significantly different from zero (Table 3). W x I control resulted in a higher yield than W x NI or NW x I controls. Yield increase due to W x I control may be due to a decrease in stems cut by sawfly.

Table 3. Weed x Insect Interactions ** on Newana Spring Wheat Yield. Conrad, 1981.

	Yield (bu/acre)
Weed, Insect Control	44.9 1/
Weed, No Insect Control	35.7
No Weed, Insect Control	35.2
No Weed, No Insect Control	40.7

LSD = 6.1 bu/acre
**Significantly different from 0 at .01 level
1/Each number in table is an average of 8 replications.

Kernels/Spike

IME was to reduce kernels/spike from no insect control (Table 4). These results disagree with the findings of Harvey et.al. (1979) that carbofuran increased kernels/spike.

Disease x insect interactions' effects on kernels/spike were significantly different from zero (Table 5). ND x NI control resulted in the highest number of kernels/spike of the disease x insect interactions. D X I control resulted

Table 4. Main Effects 1/ of Weeds, Diseases, and Insect Pests on Kernels/Spike (K/Spk). Conrad Spring Wheat, 1981.

	Weeds	Diseases	Insects
Control	40 K/Spk	39	38*
No Control	39	39	40

LSD = 1.8 K/Spk
*Significantly different from 0 at .05 level.
1/Each number in the table is an average of 16 replications.

in 39 k/spk, and ND x NI control resulted in 42 k/spk(Table 5). Chemical controls of diseases or insects may be responsible for this decrease. No other yield components were significantly affected by insect or disease controls.

Table 5. Disease x Insect Interactions* Effects on Kernels/Spike (K/Spk). Conrad Spring Wheat, 1981.

	K/Spk
Disease, Insect Control	39 1/
Disease, No Insect Control	39
No Disease, Insect Control	38
No Disease, No Insect Control	42

LSD = 3 K/Spk

*Significantly different from zero at .05 level.
1/ Each number in the table is the average of 8 replications.

Pest Populations

WME on weeds/yield row was significantly different from zero (Table 6), which indicates that weeds were controlled in the weed control plots. Weeds in the highest numbers in the no weed control plots included wild oats, Canada thistle, sow thistle and mustards.

IME on insects/plot was significantly different from zero which indicates that insects were controlled in the insect control plots (Table 7). Major insect pests in 1981 included wheat stem sawfly, English grain aphid, and greenbug. Since sweep net samples were taken once every two

weeks, insect movement through the plots was not adequately monitored.

Table 6. Main Effects[1/] of Weeds, Diseases, and Insect Pests on Weeds/Yield Row. Conrad Spring Wheat, 1981.

	Weeds	Diseases	Insects
Control	36**	37	38
No Control	63	36	35

LSD = 18 weeds/Yield Rows
**Significantly different from 0 at .01 level.
1/Each number in the table is an average of 16 replications.

Table 7. Main Effects[1/] of Weeds, Diseases, and Insect Pests on Insects/Plot. Conrad Spring Wheat, 1981.

	Weeds	Diseases	Insects
Control	76	75	65**
No Control	75	74	84

LSD = 10 insect/plot
**Significantly different from zero at .01 level.
1/Each number is a average of 16 replications.

Weed control treatment was associated with a significant increase in barley yellow dwarf virus (BYDV) (Table 8) over the check. Since aphid populations were not controlled in the weed control treatment, removal of weeds in these plots may have increased the percent of aphids feeding on the wheat and, therefore, increased the percent of wheat plants infected with BYDV.

Other diseases present in 1981 were wheat streak mosaic virus, Pseudomonas syringae, and barley scald. No significant differences among treatments were caused by these diseases.

Table 8. Treatment Effects on Barley Yellow Dwarf Virus Incidence. Conrad Spring Wheat, 1981.

Treatment	INDEX 1/		% of CK
Weed Control (W)	2.00	b*	+300
Disease " (D)	.75	a	+ 50
Insect " (I)	.50	a	-
WD "	.50	a	-
WI "	.25	a	- 50
DI "	.50	a	-
WDI "	.75	a	+ 50
Check	.50	a	-

LSD = 1.03

$\bar{X}$ = .75
M.S.E. = .488
C.V. = 93
1/ Index used was 0=no disease present, 1=few plants infected, 2 = disease very visible.
*Means followed by same letter within same column are not significantly different at the .05 level as determined by LSD test.

Moccasin Spring Wheat, Moccasin Barley, Conrad Barley, 1981

Spring wheat yields were not significantly different among treatments at Moccasin in 1981 (Table 9). Barley yields at Moccasin and Conrad were not significantly different among treatment (Tables 10 & 11).

Table 9. Treatment Effects on Newana Spring Wheat Yields. Moccasin, 1981.

Treatment	Yield*	% of Check
Weed Control (W)	30.1 bu/a	+14
Disease " (D)	30.8	+17
Insect " (I)	26.5	+ 1
WD "	33.9	+29
WI "	24.7	- 6
DI "	33.5	+27
WDI "	30.7	+17
Check	26.3	-

* No significant treatment differences at .05.

Table 10. Treatment Effects on Hector Barley Yields. Moccasin, 1981.

Treatment	Yield*	% of Check
Weed Control (W)	48.8 bu/a	+16
Disease " (D)	44.0	+ 5
Insect " (I)	50.7	+21
WD "	49.6	+18
WI "	46.9	+12
DI "	46.1	+10
WDI "	50.4	+20
Check	42.0	-

*No significant treatment differences at .05.

Table 11. Treatment Effects on Hector Barley Yields. Conrad, 1981.

Treatment	Yield*	% of Check
Weed Control (W)	66.7 bu/a	+19
Disease " (D)	53.9	+ 4
Insect " (I)	64.2	+14
WD "	57.3	+ 2
WI "	67.9	+21
DI "	67.0	+19
WDI "	66.1	+18
Check	56.1	-

*Not significantly different at .05.

Conrad Spring Wheat, 1982

Yield

The statistical significance of the variables related to yield are summarized in Table 12. The precision of the experiment in measuring interactions increased over that in 1981 because the treatment replications were increased from 4 in 1981 to 8 in 1982. The daily monitoring of field conditions and pest movements also increased precision. WME was responsible for most of the differences among treatments (Table 12).

Yields were significantly different among treatments (Table 13). Yield of the check was not significantly different from the yield of the insect control treatment and the disease control treatment. Disease control and insect control treatments produced significantly lower yields than DI control treatment.

Table 12. Treatment Effects on Yield, Yield Components, and Protein, and Single Degree of Freedom Comparisons. Conrad Spring Wheat, 1982.

	Treatment		Single Degree of Freedom Comparisons (S.S.)						
	S.S.	M.S.	WME	DME	IME	WxD	WxI	DxI	WxDxI
					1/				
Yield	2051.0	227.9**	319.1**	-	-	-	-	-	671.5**
Tillers/m sq.	97560.0	10840.0**	39640.0**	-	-	-	-	-	-
Wheat Dry Weight (% of total-6/27)	15680.0	1743.0**	6006.0**	-	-	-	-	-	-
Wheat Dry Weight (% of total-7/20)	25870.0	2875.0**	19950.0**	-	-	-	-	-	-
Spike Length	1.5	0.2*	-	-	-	-	-	-	-
Kernals/Spk	537.8	59.8**	-	-	-	-	-	-	-
1000 Kernel Weight	161.9	18.0**	28.5**	-	-	-	-	-	36.3**
Percent Plump Kernels	648.1	72.0**	162.9**	-	-	-	-	-	217.9**
Test Weight	2.9	14.4**	2.0**	-	-	-	-	-	-
Kernel Protein Content	6.2	0.7**	-	-	-	-	1.145**	-	-

* Significant at 0.05
** Significant at 0.01
1/ Dash indicates insignificance

Table 13. Treatment Effects on Solar Spring Wheat Yield. Conrad, 1982.

Treatment	Yield		% of Check
Weed Control (W)	37.01bu/a	bcd*	+27.1
Disease " (D)	30.80	ab	+ 5.8
Insect " (I)	29.22	a	+ .4
WD "	38.67	cd	+32.8
WI "	43.26	d	+48.6
DI "	39.42	cd	+35.4
WDI "	42.54	d	+46.1
Check	29.11	a	-
Fumigation	31.91	ab	+ 9.6
F + WDI Control	33.52	abc	+15.1

LSD = 7.72 bu/a

$\bar{X}$ = 35.55 bu/a
M.S.E. = 59.55
C.V. 21.7
*Means followed by same letter within same column are not significantly different at the .05 level as determined by LSD.

Weed control increased yield by 27% over the check. When weed control was combined with disease control (WD), yield increased by 22% over weed control alone. WDI control treatment's yield was 3% lower than WI control treatment's yield.

These results indicate that weeds were a very important yield constraint. The major weeds in 1982 were wild oats and volunteer barley.

Even though weed control increased yields significantly from the check, when weed control was combined with disease

control or insect control, a further yield increase occurred. Solar spring wheat is very yield responsive. The wheat plants were able to put more of their energy into grain production when two yield constraints were controlled (weeds and insects; diseases and insects; weeds and diseases).

The control of diseases, when insects and weeds were controlled (WDI) did not increase yield over that of WI control in 1982. Since foliar diseases moved into the field late in the season, the control of wild oats and wheat stem sawflies increased yields more than the control of Pseudomonas syringae or Pyrenophora trichostoma. This statement is supported by the fact that WME and IME on yield was significantly different from zero (Table 14).

Table 14. Main Effects 1/ of Weeds, Diseases, and Insect Pests on Solar Spring Wheat Yield. Conrad, 1982.

	Weeds	Diseases	Insects
Control	40.4 bu/a**	37.9 bu/a	38.6 bu/a*
No Control	32.1	34.7	33.9

LSD = 3.9 bu/a
*Significantly different from zero at .05 level.
**Significantly different from zero at .01 level.
1/Each number is an average of 32 replications.

Stand Counts

Stand counts were not significantly different among treatments.

Tillering

The disease control treatment resulted in 23.3% fewer tillers than the WD control treatment and 35.9% fewer tillers than the WDI control treatment (Table 15).

Carboxin seed treatment was found to reduce barley tillering but not wheat (Dewey & Albrechtson, 1977). However, if carboxin seed treatment did stress the Solar spring wheat seedlings during primordial bud formation, fewer buds would develop so fewer tillers could be initiated. Conversely, carboxin may have increased apical dominance, surpressing tillering (Mitchell, 1979).

DI control treatment resulted in more tillers than disease control alone but fewer tillers than the WDI control treatment. The seed of the DI control treatment was treated with carboxin and lindane. If lindane adversely affected the wheat (Hance, 1981) it may have diminished carboxin's effect on apical dominance. A decrease of apical dominance would result in increased tillering which is what occurred in the DI control treatment.

Table 15. Treatment Effects on Solar Spring Wheat Tillering. Conrad, 1982.

Treatment	Tillers/m sq.		% of Check
Weed Control (W)	308	cdef*	+19.7
Disease " (D)	226	a	-12.1
Insect " (I)	260	bc	+ 1.0
WD "	286	bcde	+11.2
WI "	305	bcdef	+15.6
DI "	275	abcd	+ 5.9
WDI "	318	def	+23.8
Check	257	ab	-
Fumigation	327	ef	+27.1
F + WDI Control	346	f	+34.6

LSD = 60 tillers

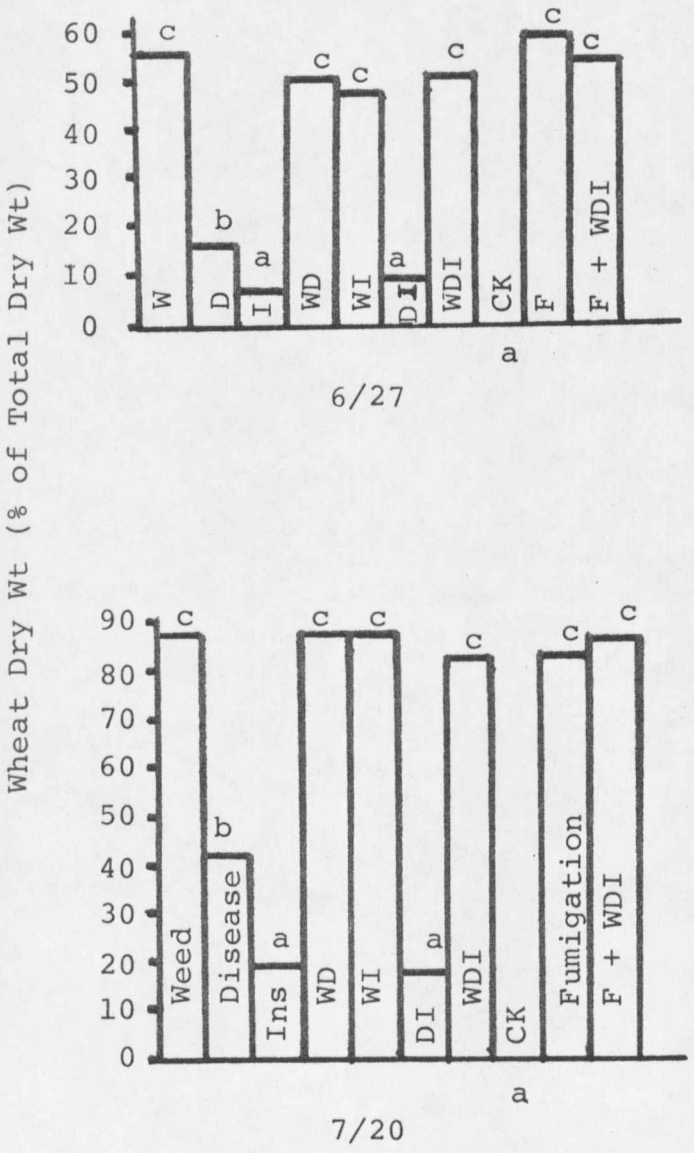
$\bar{X}$ = 291 tillers
M.S.E. = 3623.
C.V. = 20.7
*Means followed by same letter within same column are not significantly different at the .05 level as determined by LSD test.

Wheat Dry Weight

WME increased the wheat dry weight's percent of the total dry weight over the check (Figure 2). WME eliminate interspecies competition for space, water, and nutrients, resulting in the production of more tillers than in the no weed control treatments.

Disease control treatment resulted in significantly higher wheat dry weight than insect control treatment, DI control treatment, or the check. These data support the explanation that carboxin favors apical dominance. The wheat in the disease control treatment produced fewer

Figure 2. Treatment Effects on Wheat Dry Weight on 6/27 and 7/20, measured as a Percent of the Check. Conrad, 1982.



tillers than the other treatments, but the leaves and stems were larger than those in the other treatments.

Spike Length

Fumigation and fumigation + WDI control treatments reduced spike length by 4.4% and 4.7% respectively from the check. Spike lengths in all other treatments were not significantly different (Table 16).

Table 16. Treatment Effects on Solar Spring Wheat Spike Lengths. Conrad, 1982.

Treatment	Head length (cm)		% of Check
Weed Control (W)	6.65	c*	+1.92
Disease " (D)	6.53	c	-
Insect " (I)	6.45	abc	-1.10
WD "	6.51	bc	- .20
WI "	6.44	abc	-1.30
DI "	6.59	c	+ .95
WDI "	6.68	c	+2.30
Check	6.53	c	-
Fumigation	6.24	a	-4.40
F + WDI Control	6.26	ab	-4.00

LSD = .31 cm

$\bar{X}$ = 6.49 cm
M.S.E. = .0947
C.V. = 4.7
*Means followed by same letter within same column are not significantly different at the .05 level as determined by LSD test.

Soil nitrogen was higher in the fumigated plots than in the nonfumigated plots (Table 17). Fumigation with methyl bromide destroys microorganisms, and their decomposition

caused an increase in soil nitrogen. Soil sample results also showed differences in the amounts of micronutrients. Sulfur, potassium, and phosphorus increased dramatically when soil was fumigated.

Table 17. Soil Test Results from Fumigated Plots and Nonfumigated Plots before Solar Wheat was Planted. Conrad, 1982.

	Fumigated	Nonfumigated
PH	7.7	7.8
OM	2.9%	2.7%
N	8.0 ppm	6.0 ppm
P	28.0 ppm	15.0 ppm
K	483.0 ppm	393.0 ppm
Zinc	.6 ppm	.5 ppm
Manganese	10.0 ppm	6.3 ppm
Copper	.8 ppm	.9 ppm
Iron	8.9 ppm	6.3 ppm
Sulfur	13.0 ppm	<4.0 ppm
Boron	.5 ppm	.4 ppm

Plants in the fumigation and fumigation + WDI control treatments were visibly greener and had 1 to 2 more tillers than plants in the other treatments, until the middle of the stem extension growth stage. During the stem extension stage, the bottom wheat leaves started yellowing. Wheat in the other treatments did not turn yellow. Two possible reasons for this yellowing are nutrient deficiency due to the decrease of nitrifiers and cellulose decomposers in the fumigated soil (Wensely, 1953), or bromine toxicity (Van-

Gundy, 1974). Leaf samples were not analyzed for bromine content. Even though spike length is determined very early in plant growth, stress due to fumigation may have inhibited spike growth.

Kernels/Spike

Fumigation and fumigation + WDI control treatments were associated with reduced kernels/spike. The kernels/spike in these treatments were 14% and 15.6% below the check (Table 18).

Counts were taken of actual numbers of kernels/spike rather than numbers of florets formed. Since kernel filling is associated with enviromental conditions, the stress placed on the wheat plants (as evidenced by yellowing leaves) may have decreased the number of florets which actually produced kernels.

Thousand Kernel Weight

Insect control resulted in significantly lower 1000 kernel weight than the check (Table 19). The combination treatments of WD, WI, DI, and WDI controls increased 1000 kernel weight as compared to the check, but not significantly. Fumigation and fumigation + WDI control treatments significantly decreased 1000 kernel weight (8%) from the check. WME increased 1000 kernel weight over that of the check (Table 20).

Table 18. Treatment Effects on Solar Spring Wheat Kernels/Spike (K/Spk). Conrad, 1982.

Treatment	K/Spk	% of Check
Weed Control (W)	41 c*	+ 7.62
Disease " (D)	37 b	- 1.70
Insect " (I)	38 bc	+ .32
WD "	39 bc	+ 2.31
WI "	37 b	- 1.00
DI "	38 bc	+ 1.65
WDI "	38 bc	+ 1.33
Check	38 bc	-
Fumigation	32 a	-14.00
F + WDI Control	32 a	-15.60

LSD 4 Kernels

$\overline{X}$ = 37 kernels
M.S.E. = 13.07
CV. = 9.8
*Means followed by same letter within same column are not significantly different at the .05 level as determined by LSD test.

Table 19. Treatment Effects on 1000 Kernel Weight, (KWT). Conrad, 1982.

Treatment	1000 KWT (g)	% of Check
Weed Control (W)	31.1 cd*	- .06
Disease " (D)	30.5 bc	-2.09
Insect " (I)	29.3 ab	-6.00
WD "	32.5 d	+4.10
WI "	32.3 d	+3.80
DI "	32.1 cd	+2.90
WDI "	32.4 d	+4.04
Check	31.2 cd	-
Fumigation	28.7 a	-7.90
F + WDI Control	28.8 a	-7.50

LSD = 1.9 g

$\bar{X}$ = 30.9 g
M.S.E = 3.763
C.V. = 6.2
*Means followed by same letter within same column are not significantly different at the .05 level as determined by LSD test.

Table 20. Main Effects 1/ of Weeds, Diseases, and Insect Pests on 1000 Kernel Weight. Conrad, 1982.

	Weeds	Diseases	Insects
Control	32.1 g**	32.0 g	31.5 g
No Control	30.8	31.0	31.3

LSD = 1.0 g
**Significantly different from zero at .01 level.
1/ Each number is an average of 32 replications.

Test Weight

Although not significant, DI control, WI control, and WD control treatments increased test weight over the single treatments of weed control, disease control, and insect control (Table 21).

Table 21. Treatment Effects on Solar Spring Wheat Test Weights. Conrad, 1982.

Treatment	Test Weight (lb/bu)	% of Check
Weed Control (W)	62.2 cde*	+1.64
Disease " (D)	61.7 bc	+ .82
Insect " (I)	60.8 a	- .57
WD "	62.3 cde	+1.88
WI "	62.7 c	+2.53
DI "	62.2 cde	+1.64
WDI "	62.4 de	+2.04
Check	61.2 ab	-
Fumigation	61.8 bcd	+ .98
F + WDI Control	61.5 ab	+ .49

LSD = 1.0 lb/bu
$\bar{X}$ = 61.9 lb/bu
M.S.E. = .688
C.V. = 1.34
*Means followed by same letter within same column are not significantly different at the .05 level as determined by LSD test.

Table 22. Main Effects of Weeds, Disease, and Insect Pests on Test Weight. Conrad, 1982.

	Weeds	Diseases	Insects
Control	62.41b/bu**	62.1 lb/bu	62.0 lb/bu
No Control	61.4	61.7	61.8

LSD = .4 lb/bu
**Significantly different from 0 at .01 level.

WME increased test weight as compared to the check (Table 22, previous page).

Percent Plump Kernels

Insect control and disease control resulted in significantly lower numbers of plump kernels than the combination treatments of DI control, WI control, WD control, or WDI control (Table 23). These effects are

Table 23. Treatment Effects on Solar Spring Wheat Kernel Plumpness. Conrad, 1982.

Treatment	% Plump Kernels	% of Check
Weed Control (W)	85.7 bc*	+3.92
Disease " (D)	82.9 ab	+ .57
Insect " (I)	80.4 a	-2.54
WD "	88.2 c	+8.20
WI "	87.8 c	+6.50
DI "	87.7 c	+6.50
WDI "	88.1 c	+6.80
Check	82.4 ab	-
Fumiation	84.1 b	+1.97
F + WDI Control	82.9 ab	+ .58

LSD = 4.4%

$\bar{X}$ = 85.1%
M.S.E. = 19.67
C.V. = 5.2
*Means followed by same letter within same column are not significantly different at the .05 level as determined by LSD test.

similar to the treatment effects on 1000 kernel weight. Although not significant, WDI control treatment resulted in a decreased percent plump seed as compared to WD control treat-

ment. This reduction (by the addition of insect control) may be due to the interactions affect on wheat's ability to take up N, P, & K (Hance, 1981). WME increased percent plump kernels (Table 24).

Table 24. Main Effects 1/ of Weeds, Diseases, and Insect Pests on Kernel Plumpness. Conrad, 1982.

	Weeds	Diseases	Insects
Control	87.5%**	86.1%	86.0%
No Control	83.4	84.1	84.8

LSD = 2.1%
**Significantly different at .01 level.
1/ Each number is an average of 32 replications.

Kernel Protein Content

WI control treatment significantly decreased protein percent from that of weed control treatment or insect control treatment (Table 25). Grain yield and protein content are often negatively correlated (Mitchell, 1979). WI control treatment, though producing a similar yield to weed control, WD control, and WDI control treatments, resulted in a significant drop in protein content. Seed protein content is affected by nutrient uptake. Seed in the WI control treatment was treated with lindane and the plants were sprayed with acephate and carbofuran. The other treatments were not treated with the insecticides, or were treated with a combination of insecticides, fungicides, and

bacteriocides (an antagonistic effect?). The insecticides may have caused a decrease in nutrient uptake (Hance, 1981) and the resulting decrease in seed protein content.

Treatment effects on yield, yield components, and kernel protein content are summarized in Figure 3.

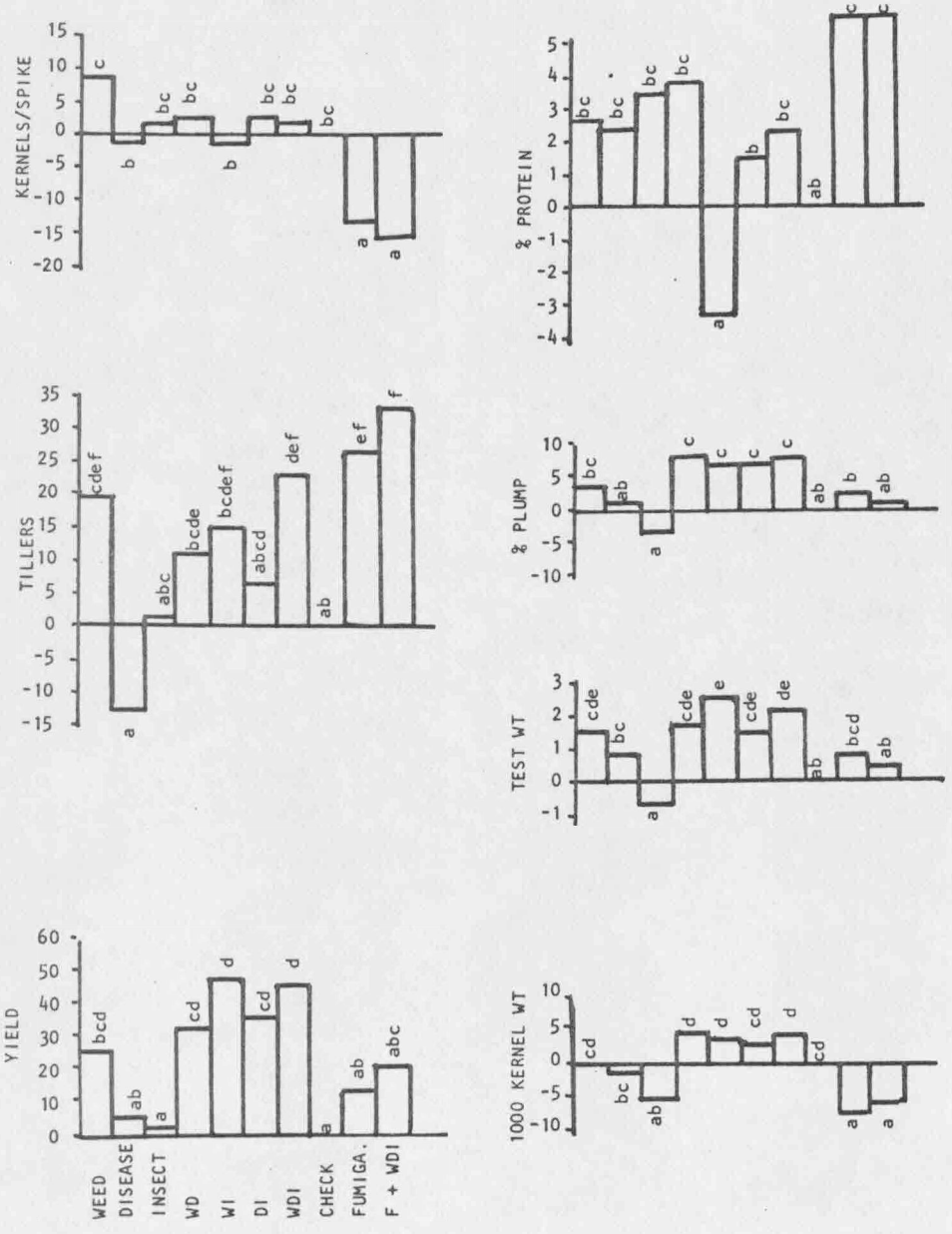
Table 25. Treatment Effects on Solar Spring Wheat Kernel Protein Content. Conrad, 1982.

Treatment	Protein %	% of Check
Weed Control (W)	11.1 bc*	+2.69
Disease " (D)	11.0 bc	+2.22
Insect " (I)	11.2 bc	+3.33
WD "	11.2 bc	+3.80
WI "	10.5 a	-3.20
DI "	11. b	+1.37
WDI "	11.0 bc	+2.22
Check	10.8 ab	-
Fumigation	11.4 c	+5.90
F + WDI Control	11.4 c	+5.90

LSD = .5%

$\bar{X}$ = 11.01%
M.S.E. = .25
C.V. = 4.5
*Means followed by same letter within same column are not significantly different at the .05 level as determined by the LSD test.

Figure 3. Treatment Effects on Solar Spring Wheat Yield, Yield Components, and Grain Protein Content measured as a Percent of the Check. Conrad, 1982.



Pest Populations

Treatment effects and their interactions' effects on pest populations are summarized in Table 26. WME was responsible for most of the treatment effects on wild oat dry weight and volunteer barley dry weight. DME was responsible for most of the treatment effects on leaf area infected with Pyrenophora trichostoma (tan spot).

Because natural infections and invasions were relied upon rather than equal, artificial distributions of pest populations, variability among treatment replications was high. Part of this variability was adjusted for as described in the Statistical Analyses section. Even though variability was high in some of the pest populations measured, important trends were evident and should be discussed.

Wild Oat Dry Weight. Disease control and DI control treatments decreased wild oat dry weight by 12.6% and 11.9% as compared to the check on 6/27, and by 18.9% and 11.9% on 7/20 (Table 27). This decrease may have resulted from increased wheat competition if the seed treatments, fungicides, and bacteriocides helped produce healthier wheat plants.

Table 26. Treatment Effects on Pest Populations, and Single Degree of Freedom Comparisons. Conrad, 1982.

	Treatment		Single Degree of Freedom Comparisons (S.S.)						
	S.S.	M.S.	WME	DME	IME	WxD	WxI	DxI	WxDxI
Wild Oat Dry Weight (% of total-6/27)	3765.0	418.8**	826.6**	- [1]	-	-	-	-	-
Wild Oat Dry Weight (% of total-7/20)	8779.0	200.9**	3721.0**	-	-	-	-	-	-
Volunteer Barley DW (% of total-6/27)	2808.0	312.0**	643.9*	-	-	-	606.4*	500.6*	-
Volunteer Barley DW (% of total-7/20)	2436.0	270.7**	798.1**	-	-	-	506.2**	-	-
Percent Yield Lost to Sawflies	413.2	45.9**	-	-	-	97.52*	-	78.77*	112.9**
% P. syringae [2]	0.5	0.1**	-	0.05**	-	-	-	-	-
% Tan Spot [3]	0.03	0.003**	-	0.02**	-	-	-	-	-
C. sativus [4] incidence	1.1	.1167	-	-	0.56*	-	-	-	-

* Significant at .05.
**Significant at .01.
1/ Dash indicates nonsignificance.
2/ % leaf necrosis caused by Pseudomonas syringae.
3/ % leaf area showing signs of Tan Spot.
4/ Subcrown internode rated as 1=no lesions, 4=completely black.

Table 27. Treatment Effects on Wild Oat Dry Weight. Conrad, 1982.

Treatment	Dry Weight 6/27 1/		Percent of Check	Dry Weight 7/20 2/		Percent of Check
Weed Control (W)	.38%	a* 3/	-97.9	-	a* 3/	-100.0
Disease " (D)	15.62	b	-12.6	20.38%	b	- 18.9
Insect " (I)	3.38	a	-81.1	18.50	b	- 26.4
WD "	1.38	a	-92.3	-	a	-100.0
WI "	4.75	a	-73.4	-	a	-100.0
DI "	15.75	b	-11.9	22.13	b	- 11.9
WDI "	2.13	a	-88.1	-	a	-100.0
Check	17.88	b	-	25.13	b	-
Fumigation	-	a	-100.0	-	a	-100.0
F + WDI Control	0.50	a	-97.2	-	a	-100.0
LSD =	10.60 g			14.20 g		
$\bar{X}$ =	6.18 g			8.88 g		
M.S.E. =	113.30			200.90		
C.V =	172			52		

*Means followed by same letter within same column are not significantly different at the 0.05 level as determined by LSD test.
1/Survey completed at Spring Wheat Stem extension growth stage.
2/Survey completed at Spring Wheat Heading growth stage.
3/Percent of total dry weight.

Insect control treatment reduced wild oat dry weight as compared to the check on 6/27 (81%), but by 7/20 the wild oat dry weight was only 26.4% less than the check Since in the insect control treatment wheat seeds were treated with lindane, soil organisms may have shifted their feeding to wild oat seeds, which resulted in a decrease in the wild oats' competitive ability.

WME reduced wild oat dry weight (Table 28) which indicates that wild oats were successfully controlled. Substantial variability existed among treatment replications (Figure 4).

Table 28. Main Effects 1/ of Weeds, Diseases, and Insect Pests on Wild Oat Dry Weight, 2/ June 27. Conrad, 1982.

	Weeds	Diseases	Insects
Control	2.2%**	8.7%	6.5%
No Control	13.2	6.6	8.8

LSD = 5.3%
**Significantly different from zero at .01 level.
1/Each number is an average of 32 replications.
2/Dry weight is measured as percent of total dry weight/plot.

Volunteer Barley Dry Weight. WME reduce volunteer barley dry indicating successful volunteer barley control (Table 29). Insect control treatment increased volunteer barley dry weight on 6/27 and 7/20 (Figure 5).

Carbofuran, used for insect control during flowering, may have increased volunteer barley dry weight, or an insect predator of barley could have been controlled by foliar applications of acephate and carbofuran (systemic insecticides).

Figure 4. Distribution of Wild Oats. Conrad, 1982. (High bar = high wild oat dry weight; graph = experimental area.)

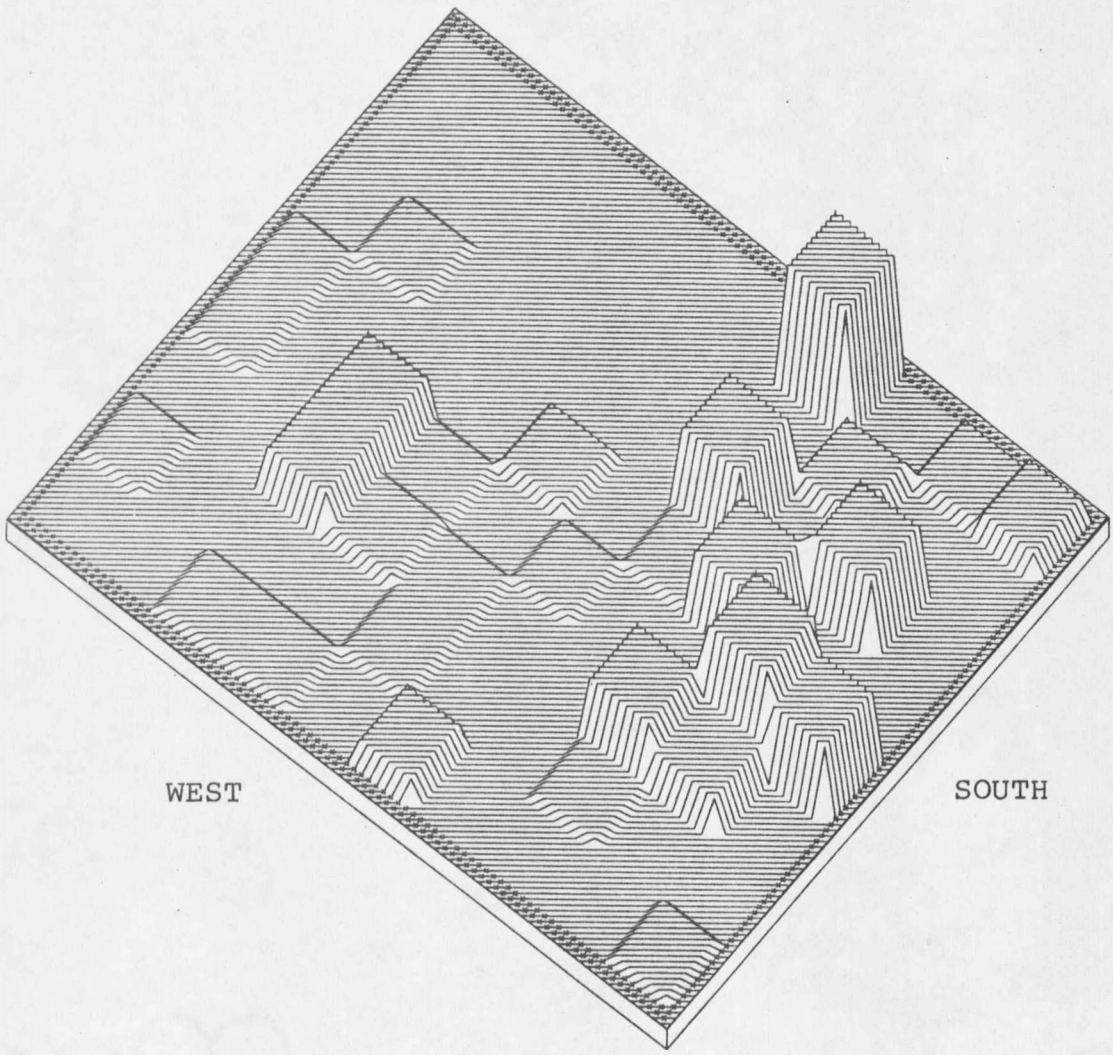


Table 29. Treatment Effects on Volunteer Barley Dry Weight. Conrad, 1982.

Treatment	Dry Weight 6/27 1/		Percent of Check	Dry Weight 7/20 2/		Percent of Check
Weed Control (W)	2.5%	a* 3/	-78.0	-	a* 3/	-100.0
Disease " (D)	5.3	ab	-53.8	2.9%	ab	- 66.2
Insect " (I)	22.1	c	+94.6	15.9	d	+ 35.1
WD "	5.1	ab	-54.9	-	a	-100.0
WI "	2.9	a	-74.7	-	a	-100.0
DI "	6.8	ab	-40.6	11.8	a	+ 38.2
WDI "	4.0	ab	-64.8	0.1	a	- 98.5
Check	11.4	b	-	8.5	bc	-
Fumigation	1.0	a	- 91.2	2.3	ab	- 73.5
F + WDI Control	2.8	a	-75.8	-	a	-100.0
LSD =	9.8 g			8.3 g		
$\bar{X}$ =	6.4 g			4.1 g		
M.S.E. =	97.4			68.8		
C.V =	155			200		

*Means followed by same letter within same column are not significantly different at the 0.05 level as determined by LSD test.
1/Survey completed at Spring Wheat Stem extension growth stage.
2/Survey completed at Spring Wheat Heading growth stage.
3/Percent of total dry weight.

Canada Thistle Dry Weight. WME decreased Canada thistle dry weight on 6/27. However, no significant dry weight differences occurred among the no weed control treatments, and no treatment interactions were significant. Canada thistle plants were found in the eastern 1/3 of the experimental area (Figure 6).

Wheat Stem Sawfly. A definite "edge effect" of sawfly cutting was observed (Figure 7), so even though significant

Figure 5. Treatment Effects on Volunteer Barley Dry Weight measured as a Percent of the Check. Conrad, 1982.

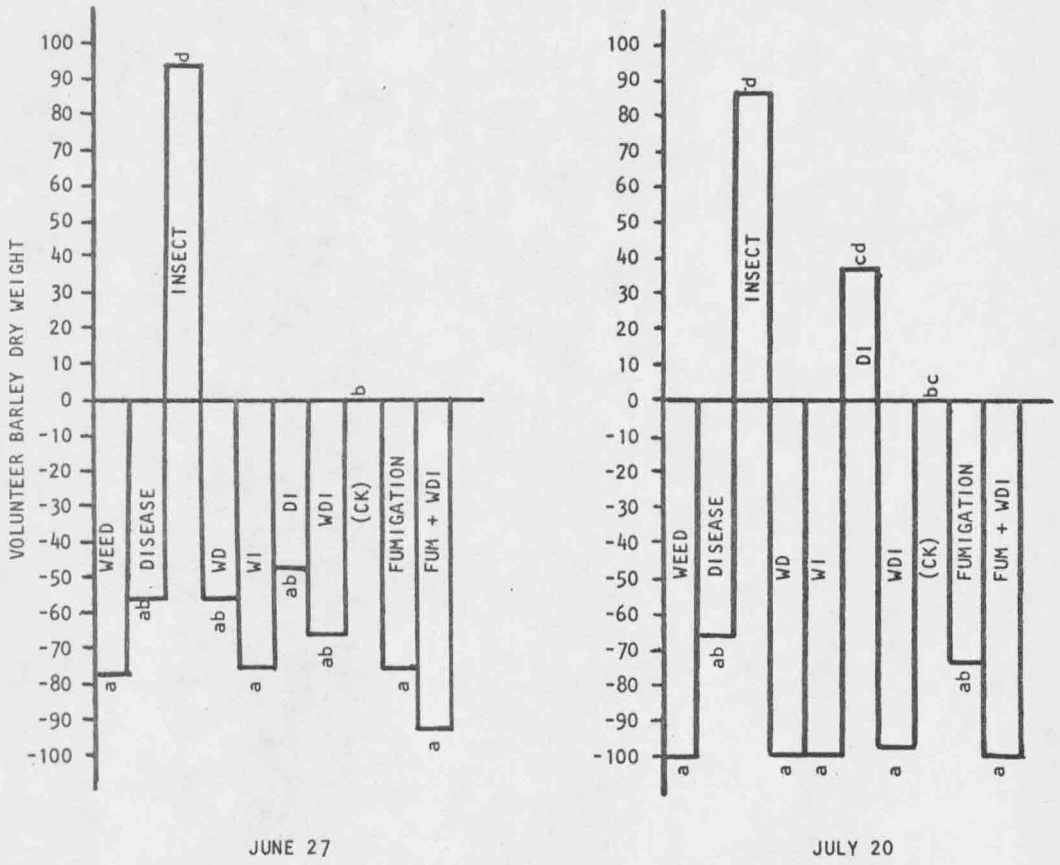


Figure 6. Distribution of Canada Thistle in Conrad Experiment, 1982. (High bar = high Canada thistle dry weight; graph = experimental area.)

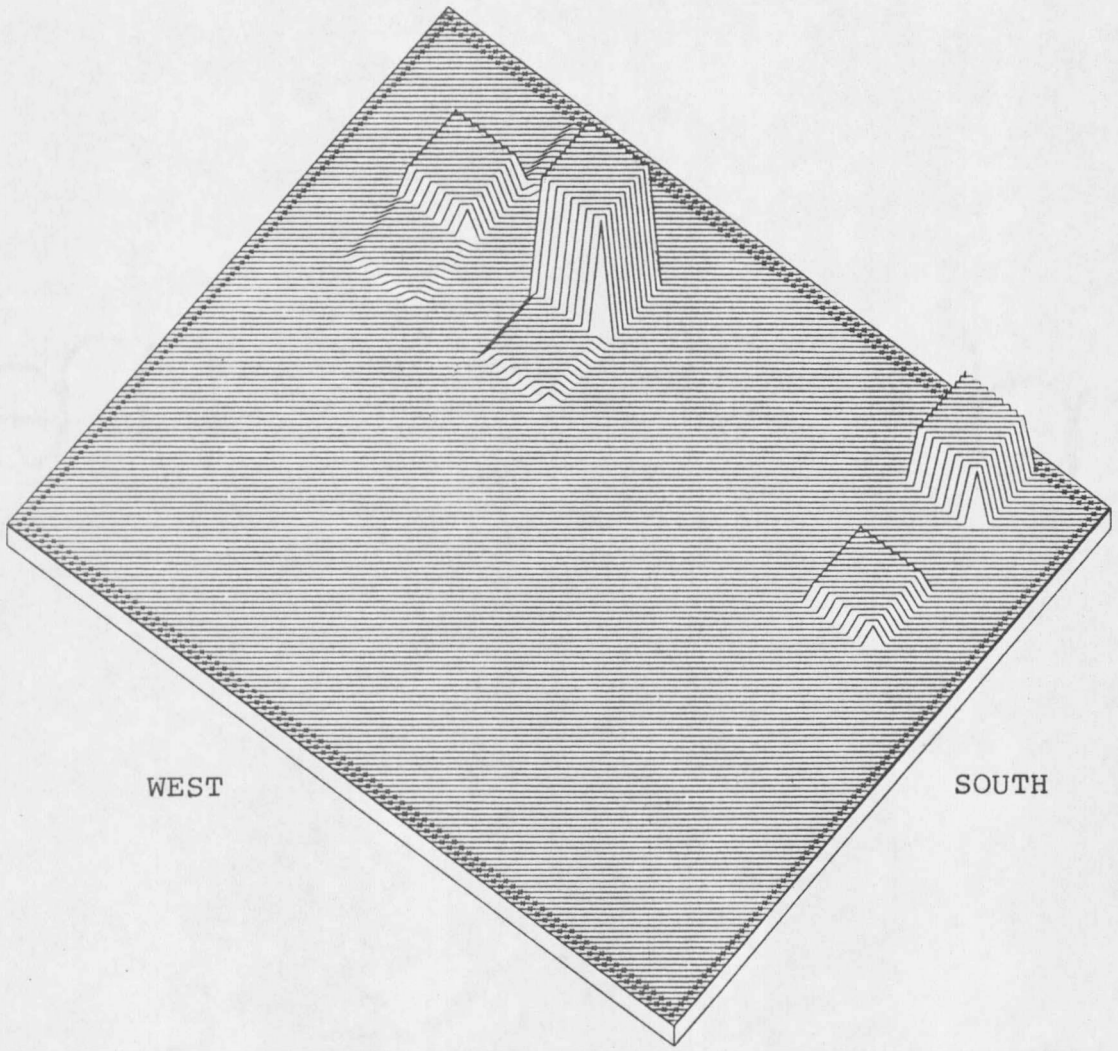
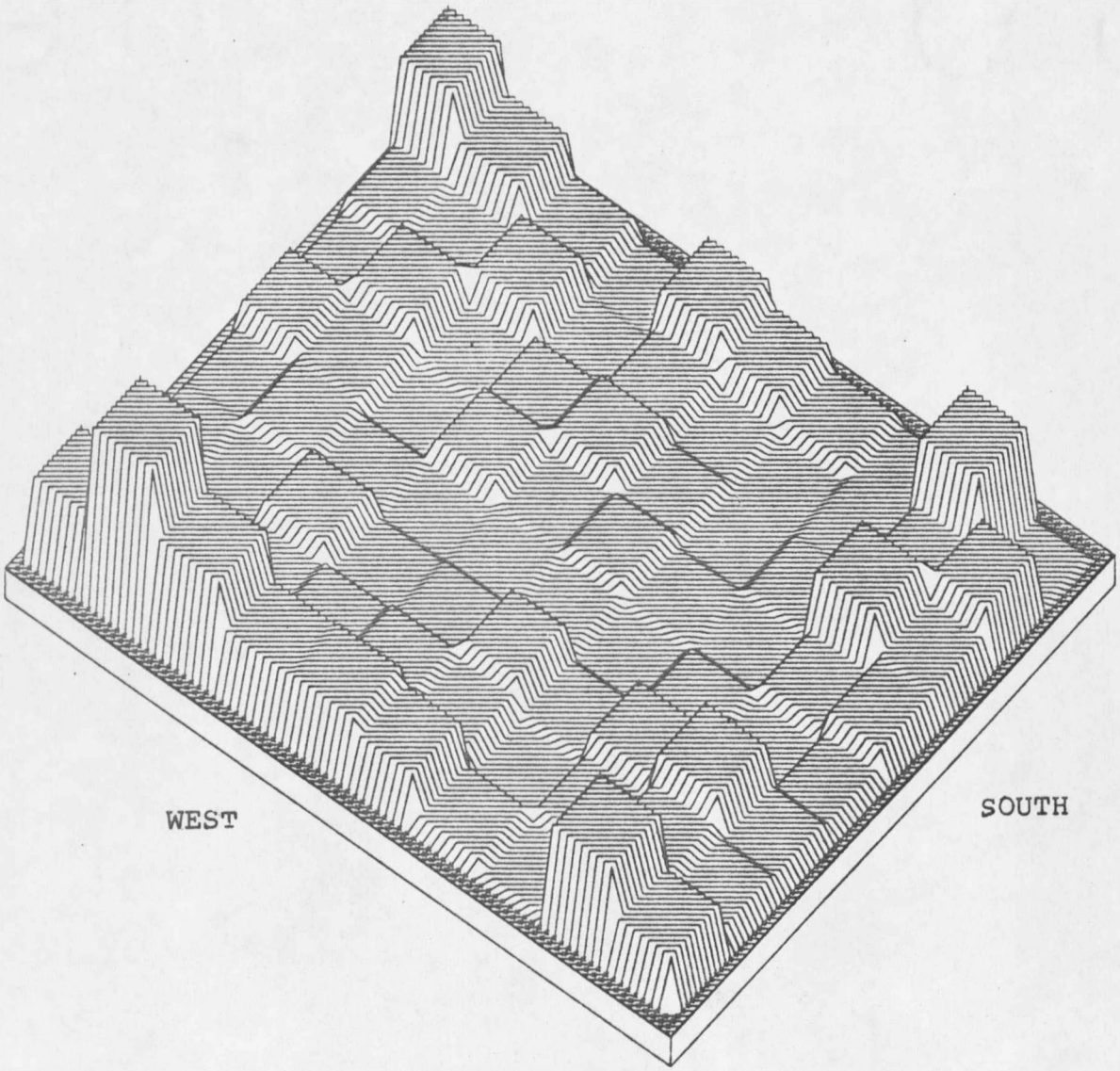


Figure 7. Distribution of Stems Cut by Wheat Stem Sawfly. Conrad, 1982. (High bar = high number of stems cut; graph = experimental area.)



treatment differences occurred, variability among the replications of each treatment was extreme. The WI control and WDI control treatment in the west block of the experiment were associated with decreased sawfly cutting (Figure 7). Overall, however, WI control treatment did not reduce sawfly cutting from the check. WDI control treatment was associated with the highest numbers of cut stems (Table 30).

Table 30. Treatment Effects on Number of Stems Cut by Wheat Stem Sawflies. Conrad, 1982.

Treatment	Stems Cut	% of Check
Weed Control (W)	26 e*	+36.8
Disease " (D)	28 e	+47.4
Insect " (I)	20 cd	+ 5.3
WD "	19 cd	-
WI "	14 c	-26.3
DI "	15 c	-21.1
WDI "	30 e	+57.9
Check	19 cd	-
Fumigation	4 a	-78.9
F + WDI Control	6 ab	-68.4

LSD = 4 stems

$\bar{X}$ = 5 stems
M.S.E. = 16.89
C.V. = 87
*Means followed by same letter within same column are not significantly different at the .05 level as determined by LSD test.

Sawflies may have selected weeds taller than wheat for resting places. Therefore, they could have been more likely to oviposit in the no-weed control plots.

If a high weed population interfered with the coverage of the wheat by carbofuran, removal of the weeds would have increased the insecticide's effectiveness. Sawflies will oviposit into oats and barley plants (Criddle, 1923). Removal of wild oats and volunteer barley could have decreased the sawflies' attraction to weed control plots. Conversely, WDI control treatment resulted in increased tillering, and sawflies are attracted to plants with high numbers of tillers (Luginbill & McNeal, 1954).

English Grain Aphid. English grain aphids moved into the experimental plots on 7/21 and dispersed from west to east. The 1st generation of apterous aphids was evident on 8/3. Single plant examinations revealed an average of 15 aphids/head in the plots not sprayed with carbofuran, and no aphids present in insect control plots.

Since aphids moved into the plots late in the season and were below economic threshhold, they did not appear to have effected yield.

Other Insects. Insects found on sticky traps and in sweep net samples included several types of leafhoppers, thrips, ladybird beetles, and a variety of flies. The leafhoppers, thrips, and flies were present throughout the growing season. The lady bird beetle population was low until after 8/3.

Pseudomonas syringae. DME reduced P. syringae (Table 31). WI control treatment resulted in the highest percent P. syringae infection of the weed, disease, and insect control treatments, and combination treatments (Table 32).

The plots were on a slight north to south slope. The wind usually blew across the plots from west to east. An irrigated experiment was approximately 20 m south of the crop loss assessment experiment. P. syringae can be epiphytically spread from plant to plant (Fryda & Otta, 1978), but moisture on the leaf is needed for bacterial survival. The combination of slope and irrigation may have resulted in higher humidity, which favored bacterial growth in the southern half of the plots.

Table 31. Main Effects[1/] of Weeds, Diseases, and Insect Pests on Leaf Necrosis[2/] caused by Pseudomonas syringae. Conrad, 1982.

	Weeds	Diseases	Insects
Control	5.9%	2.3%**	5.4%
No Control	4.5	7.9	4.9

LSD = 3.5%
**Significantly different from zero at .01.
1/Each number is an average of 32 replications.
2/Measured as a percent of flag and second leaf covered with nercrosis.

Table 32. Treatment Effects on Percent Leaf Area Exhibiting Pseudomonas syringae Symptoms. Conrad, 1982.

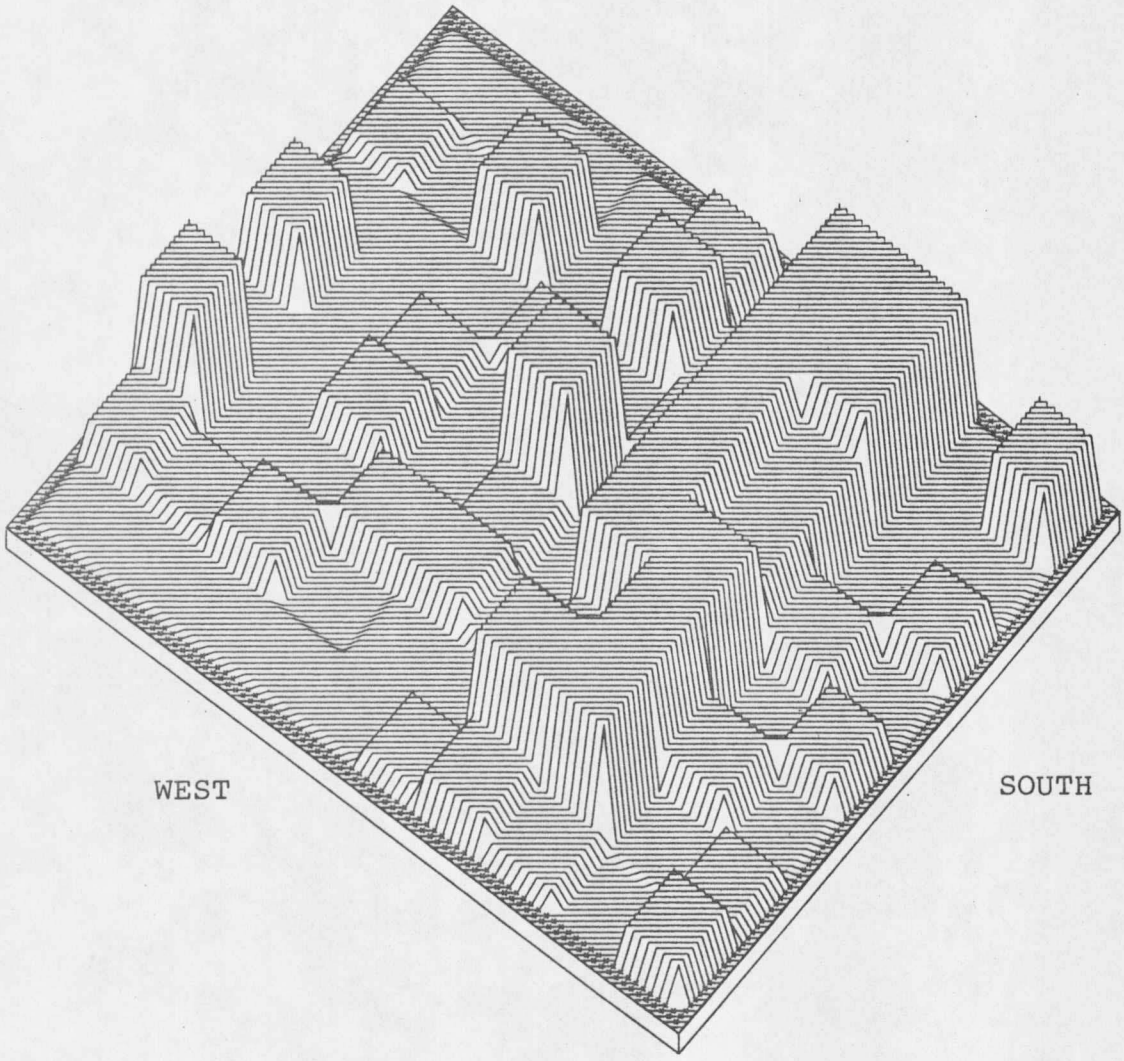
Treatment	% of leaf necrosis		% of Check
Weed Control (W)	8.6	bc*	+19.0
Disease " (D)	1.4	a	-81.0
Insect " (I)	6.0	abc	-17.2
WD "	2.3	a	-69.0
WI "	9.8	c	-34.5
DI "	2.6	a	-63.8
WDI "	3.1	ab	-56.9
Check	7.3	abc	-
Fumigation	25.0	d	+244.8
F + WDI Control	24.4	d	+236.1

LSD = .1

$\bar{X}$ = .1
M.S.E. = .0051
C.V. = 79
*Means followed by same letter within the same column are not significantly different at the .05 level as determined by LSD test.

Symptoms of P. syringae were evident on 7/20 when plants were heading. A west wind may have spread the bacteria through the plots (Figure 8). The plots were sprayed with a backpack sprayer. Therefore, the sprayer operator could have spread P. syringae through plots not protected by streptomycin. Weed escapes were hand pulled from weed control plots (W; WD; WI; WDI), so plots not protected by streptomycin (W and WI) could have been infected during the weed control process. Aphids moved into the plots beginning 7/21. They may have been associated with the spread of

Figure 8. Pattern of P. syringae Infection in Conrad Experiment, 1982. (High bar = high % leaf necrosis; graph = experimental area.)



P. syringae. Northern plots were dry enough to prevent a uniform infection by the above methods.

Fumigation and fumigation + WDI control treatments showed the highest infection by P. syringae (Table 32, previous page). Yellowing occurred in the fumigation plots before heading indicating that the plants were stressed. P. syringae severely infected these stressed plants.

Nematode Populations. Nematode samples were taken to detect types of nematodes present and to gain preliminary data on the effects of weed, disease and insect controls on the nematode populations. The sampling method (Burlando, 1982) resulted in the analysis of one liter of soil/treatment. Plant material, which decomposed due to a delay in transit, could not be analyzed.

The nematode population consisted of Quinisculcius acutus, Pratylenchus species, and Xiphinema species, Pratylenchus sp. and Xiphinema sp. numbers were similar to each other and much lower than Q. acutus. (Table 33). Pratylenchus genus contains root lesion producers, and Xiphinema genus includes virus vectors (Laughlin, 1971). Females, which were not present in the June soil samples, are needed to determine the species of Pratylenchus and Xiphinema.

Table 33. Nematodes per liter of soil.[1/] Conrad 1982

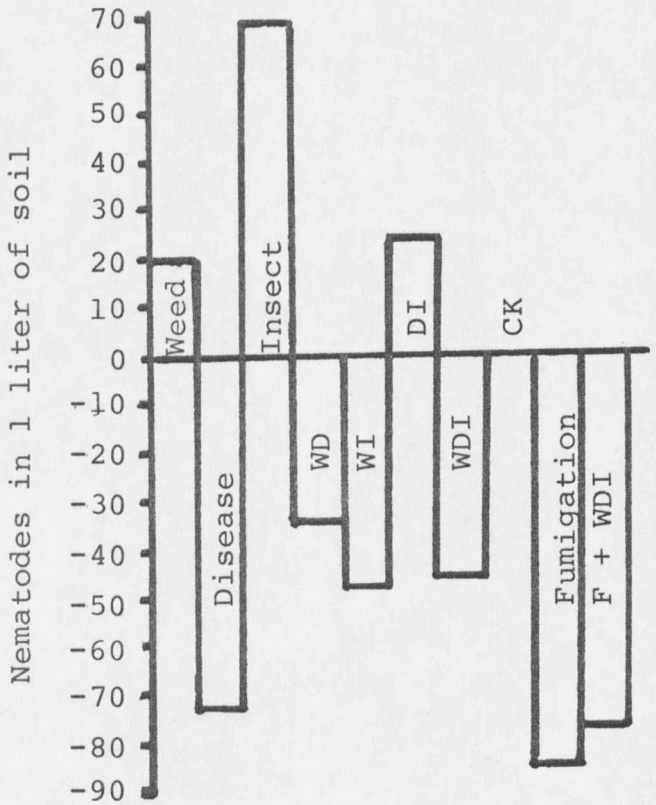
Treatment	Q. acutus	Pratylenchus sp.	Xiphinema sp.
Weed Control (W)	441	22	88
Disease " (D)	121	11	0
Insect " (I)	713	22	44
WD "	308	0	0
WI "	242	0	0
DI "	484	44	44
WDI "	264	0	0
Check	400	60	0
Fumigation	70	10	0
F + WDI Control	110	0	0

1/Nematode sampling consisted of 2 subsamples/replication in 8 replications/treatment (8 liters of soil) from which a 1 liter soil sample was extracted.

The threshhold for lesion nematodes is 420/liter of soil (VanGundy, 1974). Pratylenchus sp. was not at economic threshhold. Very little is known about Q. acutus (Burlando, 1982).

The insect control treatment was associated with the highest number of nematodes/liter of soil (Figure 9), while the disease control treatment contained the lowest number of nematodes. When insects were controlled, using systemic insecticides, nematode numbers increased. An arthropod predator of the nematodes (Dropkin, 1980) may have been removed by the insecticides. The decrease in nematode numbers due to disease control may indicate that the primary

Figure 9. Treatment Effects on Nematode Numbers (based on Percent of Check). Conrad,]982.



food source of Q. acutus is soil fungi. If soil fungi were affected by Tilt systemic fungicide, the nematode populations feeding on the fungi would have decreased.

Fumigation and fumigation + WDI control treatments decreased nematode numbers from the check. These results indicate that the amount of methyl bromide used effectively decreased nematode numbers from the middle of May until at least the first week of July.

Cochliobolus sativus

IME significantly reduced lesions on the subcrown internodes of the wheat plants as compared to no insect control (Table 34). This data suggests that the systemic insecticides prevented soil organisms' feeding on the wheat roots which resulted in decreased root injury and root susceptibility to fungal infection. Samples for wireworms were taken, and none were found in the plots.

Table 34. Treatment Effects on Cochliobolus sativus Incidence in Solar Spring Wheat. Conrad, 1982.

Treatment	Root Rot Index	% of Check
Weed Control (W)	2.00 ab*	-
Disease " (D)	2.13 b	+ 7
Insect " (I)	1.75 a	-13
WD "	2.00 ab	-
WI "	2.00 ab	-
DI "	1.88 ab	- 6
WDI "	1.75 a	-13
Check "	2.00 ab	-
Fumigation	2.00 ab	-
F + WDI Control	2.00 ab	-

LSD = .05

$\bar{X}$ = 1.95
M.S.E. = .098
C.V. = 16.02
1/Subcrown internode rated as 1 = no lesions to 4 = completely black.
*Means followed by same letter within same column are not significantly different at the .05 level as determined by LSD test.

CHAPTER 4

SUMMARY

The crop loss assessment experimental design was gradually modified over the three year period. In 1980, yield was the only variable measured. In 1981, yield, yield components, and pest populations were measured qualitatively and quantitatively. The modification of the design in 1982 which increased the number of replications from 4 to 8 resulted in increased precision. Therefore, 26 main effects or interactions were shown to be significant in 1982 as compared to 10 in 1981.

The mobility of insect pests and their feeding patterns and the movement of diseases with wind and moisture caused variability among treatment replications. Three dimensional graphs (SYMAP) were helpful in determining variability. They also revealed patterns of infection or infestation which otherwise may have been overlooked.

Small grain yield constraints due to weeds, diseases, and insect pests are occurring in Montana. The Montana crop loss assessment experiment data from a total of three years and five locations indicated that when weeds, diseases, and insect pests were controlled, yields were significantly

increased. When two of the three contraints were controlled, yields increased more than when only one of the constraints was controlled, indicating a compounding of constraints (weed/disease, weed/insect, or disease/insect) was occurring. The 2-way interaction which affected yield the most varied with location, weather, and pest populations.

Weeds constrained yields more than insects or diseases in 1981 and 1982. Increases were still evident in yield, tillers, 1000 kernel weight, test weight, and percent plump kernels when weed control was combined with one or both of the other controls, or when the other controls (disease control and insect control) were used together. These results support the plant breeders' efforts to develop varieties that are resistant to insects and diseases. The data also emphasize the importance of interdisciplinary communication and research efforts.

Chemical interactions seem to have occurred. The decrease of Solar spring wheat tillering associated with disease control in 1982, but no such decrease of Newana spring wheat tillering in 1981, may illustrate a chemical x variety interaction. Carbofuran may not have affected wild oats and wheat, but may have affected barley. Lindane may have affected Solar spring wheat germination and seedling growth, but may not affect other spring wheat varieties.

Effects of single controls and combinations of controls on pest populations are not easily explained. Wild oats and volunteer barley were controlled by and application of diclofop methyl and by hand pulling, and also by methyl bromide. The decrease of wild oat dry weight early in the growing season due to insect control was not expected. If the primary food source of microorganisms or soil insects was the wheat seeds, but these seeds were treated with lindane, the microorganisms or soil insects may have shifted to the wild oat population. The increase in volunteer barley dry weight associated with insect control was also not expected. The types of insects in all the plots were uniform according to sweep net samples, single plant examinations and sticky traps. A ground insect or other arthropod (either nocturnal or diurnal) may have been feeding on the barley plants. If so, its feeding habit seems to have been specific to barley.

Sawflies were not controlled by acephate or carbofuran unless weeds were also controlled. If, however, wheat plants were protected from weeds, diseases, and insects (WDI), sawfly cutting seemed to increase, because sawflies are attracted to plants which have a large number of tillers.

Sawfly cutting in the fumigated plots was almost non-existant at the time of sawfly adult flight. The wheat in the fumigated and fumigated + WDI control treatments was taller and had more tillers than the wheat in the other treatments. Sawflies should have been attracted to the wheat in the fumigated plots. Unless the sawflies were repelled by a chemical in the wheat resulting from the fumigation, they probably did oviposit in these plants. Since the wheat in the fumigated plots dried down in early July, sawfly larvae, if present in the stems, would have been trapped in the upper internodes.

Tan spot was controlled by Tilt, and P. syrinage infection was lower in plots sprayed with streptomycin and Tilt than in plots that weren't sprayed. BYDV symptoms were more visible when weeds were controlled, and C. sativus incidence was lower when insects were controlled.

The nematode populations were low at the Conrad locations, so they did not seem to decrease wheat yield. However, since little is known about the nematode which was in the highest numbers, O. acutus, little is known about how its reaction to changes in its environment may affect the microenvironment of a wheat field.

CHAPTER 5

CONCLUSIONS

The crop loss assessment project produced a vast amount of information on the yield constraints caused by weeds, diseases, and insect pests, and quantitatively measured 2 and 3-way interactions. Areas of further research may include:

1. The effects of carboxin and lindane on Solar spring wheat tillering.
2. Fungicide, insecticide interaction on nutrient uptake of Solar spring wheat (kernel protein content).
3. Effect of seed treatments on feeding preference of soil microoganisms and soil insects.
4. Insect or other arthropod predator on barley.
5. Interaction of sawflies and wild oats.
6. Methyl bromide's effect on Solar spring wheat and on wheat stem sawflies.
7. Nematode populations in small grain fields.
8. Effect of fungicides on nematodes' feeding preferences.
9. Insect or other arthropod predator of nematodes.
10. Insect spread of diseases such as P. syringae.
11. The role weeds play in the spread of P. syringae

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