COMBINED EFFECTS OF LEAF RUST AND GREENBUG ON GROWTH AND YIELDS OF WINTER WHEAT

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TABLE OF CONTENTS

LIST OF TABLES

Table | Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Diseases and insects are responsible for severe damage to small grain crops in the United States annually. In wheat cultivation areas of Oklahoma, leaf rust (Puccinia recondita f. sp. tritici Eriks. & E. Henn.) and an aphid commonly called "greenbug" (Schizaphis graminum (Rondani)) are among the major disease and insect pests which cause heavy losses of both forage and grain yield of wheat.

Leaf rust of wheat is a widely distributed disease (43). When heavy infections develop in the fall and continue through the winter, the plants may be weakened and result in severe winter injury. Also, heavy fall infections cause a reduction of fall and winter pasture (20).

Infestations of greenbugs on wheat also occur widely (31). Greenbugs frequently cause extensive losses to wheat in various areas of the Great Plains from Texas north to Canada (1). This insect injects a toxin into the plants during feeding, and a relatively small number of greenbugs can cause severe damage (36). The pest also has a high parthenogenetic reproductive rate (38, 22) which can increase the population to great numbers in a few weeks (31).

In some areas of Oklahoma, especially the southwestern part of the state, considerable losses of both forage and yield due to leaf rust and greenbugs have been observed (49). For this reason, the

most economic method of control, host-plant resistance, has received emphasis (7, 11, 15).

Since both leaf rust and greenbugs may occur simultaneously on the same plant, it was postulated that a disease-insect complex may occur. Previously, there has been no investigation concerning the combined effects of leaf rust and greenbugs on wheat. Therefore, the objective of this work was to determine if an interaction occurs between leaf rust and greenbugs on three different selected lines and one cultivar of wheat grown under greenhouse and field conditions.

CHAPTER II

LITERATURE REVIEW

Effect of Leaf Rust on Wheat

The occurrence of leaf rust and estimates of losses in foliage, root, and grain yield of infected wheat have been reported (4, 16, 17, 20, 21, 30, 32, 34, 40). In 1973, Williams (45) indicated that a leaf rust severity of 100% reduced the oven dry weight of forage and root growth of winter wheat 47% and 50%, respectively, during a six week growth chamber study. In another growth chamber study, Vanitchayangkul (40) found that smaller numbers of leaf rust infections also produced an effect on growth of wheat forage and on root systems. Foliar growth was reduced as much as 50% and root growth by as much as 70% following three inoculations, but root growth was reduced by as much as 30% following a single inoculation. Similarly, the age of wheat seedlings at the time of inoculation also affected foliar and root growth significantly. Plants inoculated at ten days of age were nearly as severely damaged as plants inoculated at 20 days of age. Finally, she found that growth of each of the susceptible cultivars was more severely affected as the disease severity increased. Resistant cultivars were much less affected by the disease than susceptible ones.

Pyzner (32) observed that 5 to 10% severity of leaf rust on 30 day old wheat seedlings reduced the growth of the winter wheat cultivar,

Danne, up to 15% and the primary leaves normally died within 20 days after inoculation.

Loegering et al. (20) stated that when heavy infection of rust occurred, it caused reductions in plant height and straw production and a serious loss of fibrous roots, especially when leaf rust developed early and persisted to maturity.

In 1934, Johnston and Miller (17) reported that straw yield was reduced more than one-third when a susceptible cultivar was rusted from seedling stage to maturity. Heavy infection not only reduced straw weight, but in a susceptible cultivar it resulted in a rapid and severe deterioration of the roots as indicated by discoloration, a decrease in the number of fibrous roots, and a marked loss in root weight.

The duration of leaf rust infection produces varied effects on vegetative parts of the wheat plant. Mains (21) found that early infections reduced vegetation 70% or more. Later infections reduced straw weight from 11 to 33% when compared with early infections.

Melchers (24) observed, in 1917, that leaf-rust in some fields in Kansas was very abundant. Careful examination of such fields indicated that no factors other than rust could have been responsible for the poor grain quality and reduction in yield. The yield of one pure line cultivar, a winter wheat called P 706, was reduced 38%. Later, in 1931, Caldwell et al. (4) studied the effects of a severe leaf rust epiphytotic on seven cultivars of winter wheat with differing degrees of susceptibility. They found that in the very susceptible cultivars grain yield reduction ranged from 14.8 to 28.4%. In most cultivars, losses were approximately proportional to the severity of rust.

Growth stage of the plant and time of infection play an important role in the effect of leaf rust on grain yields. Leonard and Martin (19) stated that yield of susceptible cultivars rusted in an early growth stage may be reduced as much as 94%. Also, Mains (21) reported that grain yield reduction, depending on the cultivar and time of infection, could vary from 24.7 to 97.4%. Similarly, Johnston and Miller (17) indicated that leaf rust reduced the average yield of a susceptible cultivar from 42.4 to 93.8%, depending upon the length of the infection period. In a resistant cultivar with abundant flecking of the leaves, maximum reduction of grain yield was only 15.2%. In Canada, Samborski and Peturson (34) mentioned that a heavy infection of leaf rust initiated at an early stage of plant development materially reduced the yield, kernel weight and bushel weight of one susceptible and three resistant cultivars of wheat. Yield loss in the susceptible cultivar was 58%, whereas in the resistant cultivars it ranged from 12 to 28%. Their results indicated a direct relationship between the density of inoculum and the amount of necrosis on resistant cultivars.

Epidemics of leaf rust may occur when the environmental conditions are suitable. Browder et al. (3) observed that abundant overwintering of severe fall infections, combined with a cool moist growing season, resulted in an epidemic that caused an estimated loss of 10%. Nelson (25) reported that warm and moist weather conditions during most of the winter of 1971-72 in Georgia, in conjunction with a new race of P. recondita f. sp. tritici caused an early build-up of the disease.

Weiss (42) stated that leaf rust infection resulted in a lowered

water economy of the host, whether the dry matter of entire tops or of grain alone was considered. The actual quantity of water transpired by rusted plants is of significance only when the correlative production of dry matter is taken into account.

Effect of Greenbugs on Wheat

The greenbug is a serious pest of wheat, barley, oats, rye, and sorghum in the Midwest (13, 36). It was first described in Italy in 1852 (41) and first recorded in the United States from Virginia in 1881 (6, 9, 28, 31, 41). It is an unusual pest in many ways. It is generally most abundant in winter and spring, long before most other pests appear. It is small and nearly the same green color as the leaf. Consequently, its presence goes undetected until yellow or brown areas appear in the field. These spots are areas in which the plants have died as a result of greenbug feeding (9). The greenbugs usually seen are winged or wingless females that produce their young, parthenogenetically and viviparously (31, 44). Sexual forms of this aphid do occur, but they are not commonly seen (31). Starks and Burton (36) stated in a recent review that in Eastern Europe, greenbug eggs hatch readily, whereas none have been demonstrated to be viable in the United States. The optimum temperature for the greenbug to reproduce is approximately 21 to 24 C (70 to 75 F). As many as 20 generations of viviparous aphids can be reproduced in a single season (31).

Several authors have described the feeding of greenbugs on plants. They injure the plants directly by injecting saliva and by sucking up juices. Powerful enzymes in the saliva alter the cells and their contents and eventually kill the living tissues. Leaf injury is evident

as yellow spots with necrotic centers (5, 8, 31, 35). Saxena (35) explained that a greenbug resistant plant tolerates the toxicity of the salivary secretion. The plant may accomplish this by any of three ways: 1) producing chemicals which neutralize the toxic effect; 2) developing anatomical structures which arrest the secretion, keeping it localized in that area without affecting the adjacent tissues; or 3) getting rid of the salivary secretion by some physiological process at a later stage.

In 1954, Painter et al. (28) studied the insects that attack wheat in Kansas. They categorized four types of injury caused by greenbugs in the field: 1) plants destroyed in early spring by greenbugs that overwintered there; 2) widespread damage by infestations in early spring by winged greenbugs that flew in from the south; 3) reduced yields by the stunting of heads due to feeding behind the upper leaf sheath in the boot stage in May and June; and 4) thinning of plants and prevention of tillering by late fall feeding.

Starks and Burton (36) reviewed reports of biotypes of greenbugs and concluded that there are only four important greenbug biotypes (A, B, C, and D) on field crops. Dickinson selection 28-A (DS 28-A) what was resistant to greenbug biotype A. Subsequently, a biotype designated as B overcame the resistance of Ds 28-A. Biotype B had mainly replaced biotype A in small grain fields in Oklahoma by 1966. In 1968, biotype C had largely replaced biotype B on small grains. This new biotype, according to Mayo and Starks (23), was better able to withstand summer temperatures than biotypes A and B. Also, biotype C had a higher reproductive rate than previous biotypes (36) and also utilized sorghum as a host. Later, in 1974, biotype D

was reported by Teetes et al. (39). This new biotype had as high as a thirty-fold resistance to some organosphosphorus insecticides compared to the other biotypes (29, 39).

Since the first report of greenbugs appeared in this county, several outbreaks have been recorded (10). Pfadt (31), in 1971, said that the country has suffered 22 outbreaks. In 1942, the outbreak was centered in Texas and Oklahoma and losses in these states totaled more than 61 million bushels of grain valued at 38 million dollars. Fenton and Dahms (14) reported that a 1950 greenbug outbreak in Oklahoma caused an estimated loss of 42 million dollars on wheat alone. Recently, Starks and Merkle (37) reported that in the spring of 1976, the Oklahoma Agricultural Extension Service estimated that damage and control of the greenbug and other insect pests cost Oklahoma wheat producers 80 million dollars.

In tests with wheat, Dahms and Wood (8) found that the least damage occurred when early control measures were taken. However, the amount of damage/greenbug was similar whether the infestation occurred in February, March, or April. An average infestation of 100 greenbugs/foot caused a reduction from 2.1 to 4.6 pounds of grain/acre/day.

In greenhouse experiments, Daniels (12) observed that greenbug feeding did more damage to the roots than to the tops of five commercial wheat cultivars. However, not all cultivars were equally damaged. Seedlings of the Tascosa cultivar were the most tolerant of greenbug damage compared to Wichita, Red Chief, Concho, and Westar.

Ortman and Painter (27) reported results that differed from those of Daniels. They reported that the root systems and above-ground plant parts were approximately equally damaged. The dry root weight of four

wheat cultivars showed a maximum loss that ranged from 32 to 55% compared with the control.

The greenbug causes not only loss in grain yield, foliage and root systems, but it also makes the plant more susceptible to winter killing. Kantack and Dahms (18) documented that plants infested with greenbugs were more susceptible to freeze damage than noninfested plants.

CHAPTER III

MATERIALS AND METHODS

Greenhouse Experiments

Three different greenhouse experiments were made. Experiments 1 and 2 were made in March of 1978. In December,1979, experiment 3 was made. A culture of Puccinia recondita f. sp. tritici designated race "6B" was used in all experiments. This race was isolated from a susceptible cultivar in the field in Oklahoma. To combine the disease-insect interaction effects on wheat, a culture of greenbug biotype C was used in these experiments. This biotype is widespread on small grains in much of the Great Plains region (36, 47). All wheats and wheat hybrids (known when this work was begun) are susceptible (46). Only the wheat-rye hybrid germplasm line, Amigo, was resistant to it (36).

The greenbug was cultured on growing plants simularly to the techniques of Starks and Burton (36). About 30 seeds of a sorghum and barley mixture were grown in the greenhouse in 20 cm plastic pots containing a 3:1:1 mixture of soil, sand, and peat moss. A 35 cm cylindrical plastic cage was placed over the plants to exclude extraneous insects and to confine the greenbugs. Each cage had two ventilation holes about 7.5 cm in diameter across from each other. The ventilation holes and the top of the cage were covered cloth cut about 1.5 cm

larger than the diameter of the opening and glued in place. Two weeks after planting, the plants were infested by putting two or three plants harboring greenbugs from previous cultures into the cage. In about two or three weeks, the culture had the maximum number of greenbugs the plants could support and was ready to be used to infest the test plants

One cultivar and three selected lines of wheat, Triticum aestivum L. em. Thell., were used. Triumph 64, hereafter abbreviated TMP-64, was the only cultivar tested. It is a cultivar that dominated the wheat acreage in Oklahoma for many years prior to 1978 (26). This cultivar has no known genes for resistance to leaf rust in the seedling or early stages of growth, but it appears to have some general or non-specific type of resistance to leaf rust in the field (48). Besides the TMP-64 cultivar, the greenbug selection lines (Triticum species/Agropyron elongatum//Pn/a/3/Wi/b) F1XR/4/Wi/5/2*Tmp 64/c/6/Tmp 64/5/Gaucho/Tcs/d/4/Wi/3/(Wi//Triticum species/Agropyron elongatum//Pn/3/Wi) F1XR/4/Wi/5/Tmp 64)/6/2*Tmp 64/5/Gaucho/Tcs/4/Wi/3/(Wi//Triticum species/Agropyron elongatum//Pn F1XR), hereafter called GBS-2 were used. Thse materials were preliminarily tested in the greenhouse with leaf rust and greenbugs for reaction to these pests (Table 1).

Each 15 cm pot was firmly packed with 550 grams of a uniformly mixed soil composed of six parts of clay loam, one part fine sand, and

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/a Pn = Pawnee

/b Wi = Wichita

/c Tmp 64 = Triumph 64

/d Tcs = Tascosa

TABLE I

REACTIONS OF TMP-64, GBS-1, GBS-2, AND GBS-3
TO PUCCINIA RECONDITA F. SP. TRITICI
(RACE 6B) AND GREENBUG
(BIOTYPE C)

Cultivar or line[1]	Reaction to Leaf Rust	Reaction to Greenbug
TMP-64	Susceptible	Susceptible
GBS-1	Susceptible	Resistant
GBS-2	Resistant	Resistant
GBS-3	Resistant	Susceptible

[1] Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

one part peat moss. Fifteen "Arasan" (50% Thiram) treated seeds of TMP-64 and the selected lines were sown in each pot and firmly covered with an additional 140 grams of the soil mixture. Water was slowly added to each pot until it began to drain from the base. Soil moisture was maintained near optimum and the plants never were subjected to moisture stress throughout the experiment.

The pots were placed on a table in a greenhouse and arranged in 4 replications. TMP-64 and the three lines of wheat were designated the main plots in a randomized complete block design, and the different dates of leaf rust inoculations and infestations with greenbugs were then randomly designated the sub-plots or treatments. In each experiment, the wheat seedlings were inoculated with leaf rust, infested with greenbugs, and harvested at different ages as indicated in Tables II, III, and IV. Each replication was surrounded by a border of pots of plants. The temperature in the greenhouse was maintained at approximately 21 C.

The seedlings were thinned to 10 plants per pot five days after planting. The test plants were sprayed from a distance of 30 cm with P. recondita f. sp. tritici spores suspended in 0.1 ml of Mobilsol 100, an isoparaffinic non-phytotixic oil (33). The spore suspension was placed in a 00 gelatin capsule and attached to an atomizer developed and described by Browder (2). The spraying was performed at a force of 211 gm per cm. After inoculation, the pots were put in a glass covered moisture chamber containing a thin layer of water in the bottom to maintain a relatively high humidity. The plants were sprayed with a tap water solution of a surfactant, "Tween 20" (Polyoxyethelene 20 sorbitan monolaurate) at the rate of three to four drops per 1000 ml

TABLE II

DESIGNATION OF TREATMENTS ACCORDING TO THE AGE, IN DAYS, OF WHEAT SEEDLINGS WHEN INOCULATED WITH LEAF RUST, INFESTED WITH GREENBUGS, SPRAYED WITH INSECTICIDE, AND HARVESTED IN GREENHOUSE EXPERIMENT 1

	Treatment				
	1	2	3	4	5
Inoculated with Leaf Rust	10	14	21	28	35
Infested with Greenbugs	12	16	23	30	37
Sprayed with Insecticide	20	24	31	38	45
Harvested[1]	42	46	53	60	67

[1]Each treatment was harvested 32 days after inoculated with leaf rust.

TABLE III

DESIGNATION OF TREATMENTS ACCORDING TO THE AGE, IN DAYS, OF WHEAT SEEDLINGS WHEN INOCULATED WITH LEAF RUST, INFESTED WITH GREENBUGS, SPRAYED WITH INSECTICIDE, AND HARVESTED IN GREENHOUSE EXPERIMENT 2

	Treatment					
	1	2	3	4	5	6
Inoculated with Leaf Rust	10	10	10	10	10	10
Infested with Greenbugs	--	12	17	24	31	38
Sprayed with Insecticide	--	20	25	32	39	46
Harvested[1]	45	47	52	59	66	73

[1]Treatment 2, 3, 4, 5, and 6 were harvested 35 days after infested with greenbugs.

TABLE IV

DESIGNATION OF TREATMENTS ACCORDING TO THE AGE, IN DAYS, OF WHEAT SEEDLINGS WHEN INOCULATED WITH LEAF RUST, INFESTED WITH GREENBUGS, SPRAYED WITH INSECTICIDE, AND HARVESTED IN GREENHOUSE EXPERIMENT 3

	Treatment					
	1	2	3	4	5	6
Inoculated with Leaf Rust	--	10	10	10	10	10
Infested with Greenbugs	--	--	17	24	31	38
Sprayed with Insecticide	--	--	25	32	39	46
Harvested	50	50	50	50	50	50

of water. The plants were left in the moisture chamber for 12 hours and then returned to a bench in the greenhouse.

At different ages, the wheat seedlings were infested with greenbugs by using a small moist camel hair brush to individually transfer the greenbugs from the culture plants to the test plants. Three adult wingless greenbugs were transferred to each plant for a total of 30 greenbugs per pot. Each pot then was covered with a plastic cage. The greenbugs on the test plants were killed 8 days after infestation by spraying with malathion insecticide. After killing the greenbugs, all pots were watered with 80 cc of a solution containing "Hyponex" fertilizer (7-6-19, N-P-K formulation(at the rate of 2 grams per liter.

Ten to 12 days after inoculation with P. recondita f. sp. tritici, the plants were evaluated for disease severity by using a system of 1% for flecking (no pustule formed) to 100% for maximum pustule development on the leaf area. Similarly, 8 days after infestation with the greenbugs, plants in each pot were evaluated for greenbug damage by rating them 0 for no injury to 9 for dead or dying plants.

Measurements of foliage and root growth of the plants were made at a different date for each experiment. The foliar portions were cut with scissors at a point immediately above the first node. Foliar portions of plants from each pot were placed separately in small paper bags, and weighed while still fresh. The pots then were removed from the greenhouse and soaked in tap water until the soil was saturated. The contents of each individual pot were washed by running a fine stream of tap water over the root mass until the soil was thoroughly washed away. The root portions of plants from each pot were

placed separately in small paper bags and weighed. Root volume for the total of all plants in each pot was obtained by placing the roots from each pot in 100 ml of water in a graduated cylinder and measuring the displaced water.

After weighing, the samples were placed in a drying oven at 38 C for 120 hours; after which, the oven-dry samples again were weighed.

Field Experiment

A study to investigate the effect of leaf rust in combination with greenbug on the grain yield of TMP-64, GBS-1, GBS-2, and GBS-3 was conducted at the Plant Pathology Farm, Oklahoma State University, Stillwater, Oklahoma. Each cultivar and line including the spreader (Triumph 64) was sown on October 19, 1978, at a seeding rate of 10 grams per 4.3 m row. The experimental design used for this study was a Latin square of four rows and four columns.

There were 16 plots in this experiment. Each plot consisted of four rows, 30.5 cm apart and 4.3 m in length. The plots were planted with a tractor mounted four-row planter. The two outside rows of each plot were left as borders. The two center rows were harvested for grain yield at maturity. Each side of the plot was surrounded by four rows of TMP-64 as a leaf rust spreader. The field lay-out can be seen more clearly in Figure 1.

No fertilizer was applied at planting, but nitrogen, in the form of urea, was applied as a top dressing over the plots at the rate of 45 pounds of actual N per acre on March 20, 1979.

Inoculum of P. recondita f. sp. tritici race 6B was produced on the cultivar Danne grown in 6.4 cm plastic cups. This inoculum was

S	S	S	S	S	S	S	S	S
S	A	S	B	S	D	S	C	S
S	B	S	D	S	C	S	A	S
S	D	S	C	S	A	S	B	S
S	C	S	A	S	B	S	D	S
S	S	S	S	S	S	S	S	S

Figure 1. Experimental Design of the Field Experiment. (A) = GBS-1, (B) = GBS-2, (C) = GBS-3, and (D) = TMP-64, and (S) = Borders and Spreaders.

applied to the test plants and spreader wheat in the field using the brush inoculation technique (3) at the rate of 8 cups per plot on the evening of November 4, 1978.

The greenbugs used to infest the field experiment were cultured similarly to those used in the greenhouse experiments. The center of the two rows to be harvested in each plot was marked with a 30 cm stake. The area around these stakes was infested with greenbugs from two pots on November 30, 1978, and again after the winter had passed, on March 15, 1979.

On May 7, 1979, the percent of leaf rust severity and the number of greenbugs/tiller were recorded. The center 3 m of each yield row of each plot was harvested on June 14, 1979, and the grain yield and test weight were measured.

CHAPTER IV

RESULTS

Greenhouse Experiments

Three different experiments were designed to observe the combined effect of leaf rust and greenbugs on growth of young wheat plants of TMP-64, GBS-1, GBS-2, and GBS-3. This effect was measured by percent leaf rust severity, a greenbug damage rating, the number of plants surviving on the harvest date, fresh and dry weights of forage, and the volume and dry weight of roots of each experimental unit of ten plants. The results of each experiment are presented under separate headings for simplicity and convenience.

Experiment 1

This experiment was designed to determine the effect of leaf rust when the plants were inoculated at five different ages and harvested 32 days after inoculation (Table II). Greenbugs were placed on the plants 2 days after each inoculation of the fungus. The leaf rust severity was recorded 10 days after the inoculation (Table V). Numerous sporulating pustules of leaf rust developed on TMP-64 and GBS-1 while only necrotic flecks with an occasional small pustule developed on GBS-2 and GBS-3 (Figure 2).

After the greenbugs were killed with malathion 8 days after infes-

TABLE V

PERCENT LEAF RUST SEVERITY IN GREENHOUSE EXPERIMENT 1

Cultivar or line[1]	Treatment[2] 1	2	3	4	5
TMP-64	80	75	65	80	65
GBS-1	70	75	65	60	50
GBS-2	1	1	1	1	1
GBS-3	1.25	2	1	1.5	1.25

LSD .01 = 24.75

LSD .05 = 18.55

[1]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

[2]Means of 4 replications of 10 plants

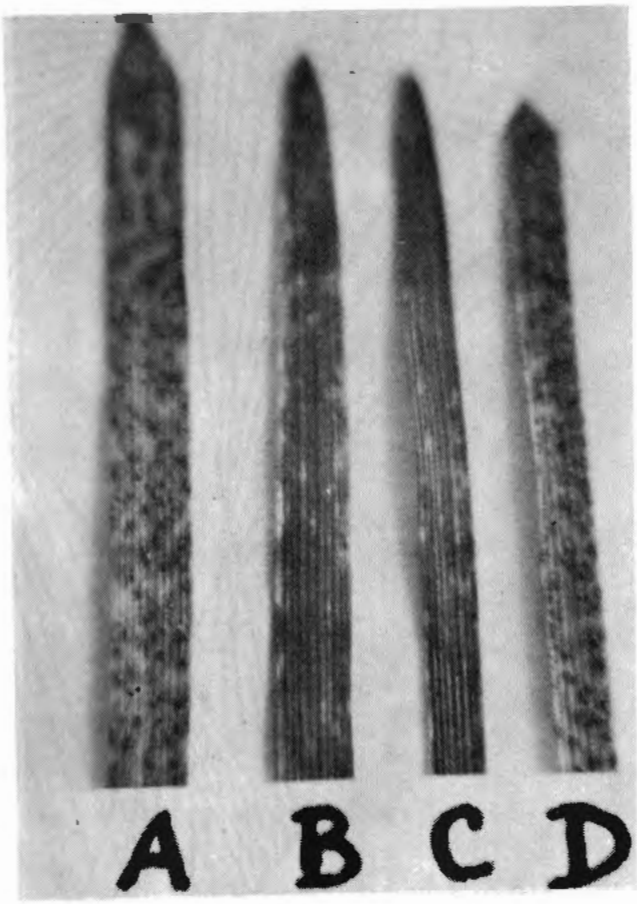

Figure 2. A Comparison of Leaf Rust Development on Resistant and Susceptible Leaves; (A) = GBS-1, (B) = GBS-2, (C) = GBS-3, and (D) = TMP-64.

tation, the damage they had caused was scored on a scale of 0 to 9. Means of the data are shown in Table VI. Greenbug injury on TMP-64 and GBS-3 was much more severe than GBS-1 and GBS-2 in all treatments.

At early stages of growth (treatments 1 and 2), TMP-64 and GBS-3 were very susceptible to the greenbug. The damage on this cultivar and line averaged more than 7 on the 0 to 9 scale. When TMP-64 and GBS-3 were infested in more advanced growth stages, the damage was less severe, averaging between 4.5 and 6.3 (treatments 3, 4, and 5). The lines GBS-1 and GBS-2 were resistant to the greenbug regardless of age at infestation.

The number of living plants on the harvest date indicated that leaf rust in combination with greenbugs killed 67.5, 22.5, and 15% of TMP-64 plants in treatments 1, 2, and 3, respectively (Table VII). In GBS-3, the line resistant to leaf rust but susceptible to greenbugs, 25, 10, and 5% of the plants were killed in treatments 1, 2, and 3, respectively. All plants in lines GBS-1 and GBS-2 survived the combined attack of the fungus and insect.

Cultivar, lines, leaf rust infection, and greenbug infestation significantly affected fresh and dry weights of the foliage. TMP-64, (susceptible to both leaf rust and greenbug) produced lower fresh and dry weights of foliage than GBS-1, GBS-2, or GBS-3 in every treatment, except that in treatments 1 and 2 it did not differ from GBS-3 (Table VIII and IX).

A highly significant decrease in foliage production was obtained on GBS-3 (resistant to leaf rust but susceptible to the greenbug) when compared with GBS-1 and GBS-2 in each treatment and with TMP-64 in

TABLE VI

GREENBUG DAMAGE RATING IN GREENHOUSE EXPERIMENT 1[1]

Cultivar or line[3]	Treatment[2]				
	1	2	3	4	5
TMP-64	8.0	7.8	6.3	5.3	5.75
GBS-1	1.0	1.0	1.5	2.0	1.5
GBS-2	1.3	1.0	1.3	1.3	1.3
GBS-3	7.5	7.8	5.8	4.8	4.5

LSD .01 - 1.3

LSD .05 = 1.0

[1]Rating scale: 0 = No damage, 9 = Dead plant

[2]Means of 4 replications of 10 plants

[3]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

TABLE VII

NUMBER OF PLANTS THAT SURVIVED ON HARVEST DATE IN EXPERIMENT 1

Cultivar or line[1]	Treatment[2] 1	2	3	4	5
TMP-64	3.3	7.8	8.5	10.0	10.0
GBS-1	10.0	10.0	10.0	10.0	10.0
GBS-2	10.0	10.0	10.0	10.0	10.0
GBS-3	7.5	9.0	9.5	10.0	10.0

LSD .01 = 0.7

LSD .05 = 0.5

[1]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

[2]Means of 4 replications of 10 plants

TABLE VIII

EFFECT ON LEAF RUST AND GREENBUGS ON FRESH WEIGHT IN GRAMS OF FOLIAR PORTIONS OF WHEAT SEEDLINGS IN EXPERIMENT 1

Cultivar or line[1]	Treatment[2] 1	2	3	4	5
TMP-64	1.04	1.89	3.38	3.51	3.68
GBS-1	3.83	4.46	7.62	8.48	8.49
GBS-2	4.58	5.72	10.43	11.58	12.63
GBS-3	1.47	2.47	5.33	6.51	6.65

LSD .01 = 1.40

LSD .05 = 1.05

[1]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

[2]Means of 4 replications of 10 plants

TABLE IX

EFFECT OF LEAF RUST AND GREENBUGS ON DRY WEIGHT IN GRAMS OF FOLIAR PORTIONS OF WHEAT SEEDLINGS IN EXPERIMENT 1

Cultivar or line[1]	Treatment[2] 1	2	3	4	5
TMP-64	0.17	0.32	0.56	0.58	0.60
GBS-1	0.64	0.75	1.25	1.41	1.42
GBS-2	0.76	0.95	1.74	1.93	2.10
GBS-3	0.25	0.41	0.89	1.08	1.11

LSD .01 = 0.23

LSD .05 = 0.17

[1]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

[2]Means of 4 replications of 10 plants

treatments 3, 4, and 5. A comparison between the two greenbug resistant lines, GBS-1 and GBS-2, indicated leaf rust did significantly reduce foliar growth of the leaf rust susceptible GBS-1 in the late growth stages (treatments 1 and 2) (Table VIII). In this experiment, the superiority in growth of GBS-2, which has a specific type of resistance to both pests, was clearly evident.

It was interesting, however, that when the ages of wheat plants at harvest increased from 53 to 67 days (treatments 3 to 5), the fresh and dry foliage weights of TMP-64 and GBS-1 did not increase significantly as did lines GBS-2 and GBS-3. This could be attributed to the leaf rust susceptibility of this cultivar and line.

Root growth was markedly reduced by leaf rust and greenbugs in this study. The root weight and root volume measurements are shown in Tables X and XI. Root growth of TMP-64 and GBS-3 was severely reduced in every treatment compared to that of GBS-1 and GBS-2. The average oven-dry weights of TMP-64 showed a reduction of 68, 59, 54, 60, and 61% less than the resistant GBS-2 in treatments 1 to 5, respectively. Also, root weights of greenbug susceptible GBS-3 were more than 40% less than GBS-2 in all treatments.

The effect of leaf rust on greenbug resistant lines was significantly pronounced on GBS-1 in treatments 4 and 5. GBS-1 produced 19 and 24% less root weight than leaf rust resistant GBS-2 in treatments 4 and 5. Root volume followed the same trend with almost identical percentages of reduced growth.

Statistically, highly significant interactions between the tested wheats X treatments were obtained for all variables in this experiment, except that no interaction was indicated for only leaf rust

TABLE X

EFFECT OF LEAF RUST AND GREENBUGS ON ROOT GROWTH OF WHEAT SEEDLINGS AS MEASURED BY DRY WEIGHT IN GREENHOUSE EXPERIMENT 1

Cultivar or line[1]	Oven-Dry Weight in gms[2]				
	1	2	3	4	5
TMP-64	0.15	0.23	0.36	0.45	0.52
GBS-1	0.46	0.47	0.76	0.92	1.02
GBS-2	0.47	0.56	0.79	1.13	1.34
GBS-3	0.22	0.26	0.43	0.67	0.74

LSD .01 = 0.14

LSD .05 = 0.10

[1]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

[2]Means of 4 replications of 10 plants

TABLE XI

EFFECT OF LEAF RUST AND GREENBUGS ON ROOT VOLUME OF WHEAT SEEDLINGS IN GREENHOUSE EXPERIMENT 1

Cultivar or line[1]	Volume in ml[2]				
	Treatment				
	1	2	3	4	5
TMP-64	1.05	1.44	2.81	3.56	4.13
GBS-1	3.78	3.82	6.19	7.13	7.19
GBS-2	3.83	4.38	6.20	9.13	10.94
GBS-3	1.30	1.88	3.25	5.63	5.81

LSD .01 = 0.90

LSD .05 = 0.67

[1]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

[2]Means of 4 replications of 10 plants

damage. The interactions derived from the specific response of each cultivar or line varied depending upon the treatment.

Experiment 2

Leaf rust inoculum was applied to 10 day old wheat seedlings in every treatment. Greenbugs were applied 35 days before the harvest date except in treatment 1 where no greenbugs were used. Thus, this experiment was designed to observe the effect of leaf rust inoculum applied to 10 day old plants in combination with the effect of greenbug infestation at different stages of growth.

A high percentage of leaf rust infection developed on leaves of susceptible plants (TMP-64 and GBS-1) while only light damage occurred on the resistant lines (GBS-2 and GBS-3). The means of leaf rust severity are shown in Table XII.

Greenbugs produced results similar to those of the previous experiment. The means of greenbug damage in Table XIII indicated that GBS-1 and GBS-2 have a high level of greenbug resistance in every stage of growth. When the plants were infested 12 days after planting (treatment 2), TMP-64 and GBS-3 were very susceptible to the insect toxin.

The number of plants that survived infection by leaf rust and infestation by greenbugs were counted on the harvest date (Table XIV). Due to these pests, the number of plants of TMP-64 were reduced 62.5, 22.5, and 7.5%, in treatments 2, 3, and 4, respectively. Also, in GBS-3, the number of plants were reduced as much as 20% (treatment 2). All plants of the greenbug resistant lines (GBS-1 and GBS-2) survived.

Leaf rust alone did not produce as great an effect on foliar growth of tested wheats (treatment 1) as did other treatments in which

TABLE XII

PERCENT LEAF RUST SEVERITY IN GREENHOUSE EXPERIMENT 2

Cultivar or line[1]	Treatment[2] 1	2	3	4	5	6
TMP-64	75.0	75.0	80.0	75.0	70.0	75.0
GBS-1	60.0	75.0	75.0	65.0	80.0	70.0
GBS-2	1.0	1.0	1.3	1.5	1.0	1.3
GBS-3	1.5	1.5	1.8	1.0	1.3	1.3

LSD .01 = 17.0

LSD .05 = 12.8

[1]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

[2]Means of 4 replications of 10 plants

TABLE XIII

GREENBUG DAMAGE RATING IN GREENHOUSE EXPERIMENT 2[1]

Cultivar or line[3]	Treatment[2] 1	2	3	4	5	6
TMP-64	0	7.5	6.8	6.0	5.3	5.8
GBS-1	0	1.3	1.5	1.5	1.8	1.5
GBS-2	0	1.0	1.3	1.3	1.0	1.3
GBS-3	0	7.3	5.8	5.5	4.8	4.0

LSD .01 = 1.3

LSD .05 = 0.9

[1]Rating scale: 0 = No damage, 9 = Dead plant

[2]Means of 4 replications of 10 plants

[3]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

TABLE XIV

NUMBER OF PLANTS THAT SURVIVED ON HARVEST DATE IN EXPERIMENT 2

Cultivar or line[1]	Treatment[2] 1	2	3	4	5	6
TMP-64	10	3.8	7.8	9.3	10	10
GBS-1	10	10	10	10	10	10
GBS-2	10	10	10	10	10	10
GBS-3	10	8	9.8	10	10	10

LSD .01 = 0.5

LSD .05 = 0.4

[1]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

[2]Means of 4 replications of 10 plants

both leaf rust and greenbug were used (Table XV and XVI). However, TMP-64 produced significantly less foliage than GBS-1 and GBS-2 in treatment 1. Calculations indicated that TMP-64 produced 28% less dry foliage weight than GBS-2 (Table XVI).

TMP-64, susceptible to both leaf rust and greenbugs, showed a tremendous reduction in foliage growth in treatments 2 through 6. In treatment 2, the aphids were put on the plants 12 days after planting. At this stage of growth the plants were very susceptible to both fungus and insects. For instance, TMP-64 produced 56% less dry foliage weight than the leaf rust and greenbug resistant line, GBS-2 (Table XVI). When the greenbugs were fed on the plants 38 days after planting (treatment 6), TMP-64 produced 37% less foliage than GBS-2. This indicates that age is an important factor in the degree of susceptibility of plants to the greenbug. Line GBS-2 produced more foliage than any of the other wheats in this experiment. GBS-1, which was susceptible only to leaf rust, ranked second, followed by GBS-3, susceptible only to the greenbug.

Root growth was measured immediately after harvesting. Oven dry root weight and root volume measurements are given in Tables XVII and XVIII, respectively. The difference in root growth for the leaf rust susceptible (TMP-64) and resistant (GBS-2) plants was significant for oven dry weight (treatment 1). This result was similar to those found by other leaf rust workers (17). However, no difference was observed between GBS-1 (leaf rust susceptible) and GBS-2 for root weights and root volume in treatment 1.

Greenbug susceptible wheats (TMP-64 and GBS-3) were inferior in root growth compared to the resistant ones (GBS-1 and GBS-2). TMP-

TABLE XV

EFFECT OF LEAF RUST AND GREENBUGS ON FRESH WEIGHT IN GRAMS OF FOLIAR PORTIONS OF WHEAT SEEDLINGS IN EXPERIMENT 2

Cultivar or line[1]	Treatment[2] 1	2	3	4	5	6
TMP-64	7.19	1.13	3.25	5.23	6.65	7.05
GBS-1	9.44	7.09	8.53	9.88	10.09	10.30
GBS-2	10.16	8.63	9.09	10.58	11.55	11.79
GBS-3	8.25	5.11	6.50	6.74	7.52	8.33

LSD .01 = 2.13

LSD .05 = 1.60

[1]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

[2]Means of 4 replications of 10 plants

TABLE XVI

EFFECT OF LEAF RUST AND GREENBUGS ON DRY WEIGHT IN GRAMS OF FOLIAR PORTIONS OF WHEAT SEEDLINGS IN EXPERIMENT 2

Cultivar or line[1]	Treatment[2] 1	2	3	4	5	6
TMP-64	1.21	0.19	0.58	0.81	1.25	1.43
GBS-1	1.59	1.37	1.42	1.65	1.68	1.96
GBS-2	1.68	1.44	1.51	1.80	1.93	2.27
GBS-3	1.37	0.43	1.08	1.12	1.32	1.42

LSD .01 = 0.36

LSD .05 = 0.27

[1]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

[2]Means of 4 replications of 10 plants

TABLE XVII

EFFECT OF LEAF RUST AND GREENBUGS ON ROOT GROWTH OF WHEAT SEEDLINGS AS MEASURED BY DRY WEIGHT IN GREENHOUSE EXPERIMENT 2

Cultivar or line[1]	Oven-Dry Weight in gms[2]					
	1	2	3	4	5	6
TMP-64	0.56	0.15	0.49	0.60	0.75	0.80
GBS-1	0.92	0.90	0.97	1.11	1.22	1.34
GBS-2	0.86	0.96	1.14	1.22	1.21	1.33
GBS-3	0.70	0.48	0.69	0.77	0.80	0.94

LSD .01 - 0.40

LSD .05 - 0.30

[1]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

[2]Means of 4 replications of 10 plants

TABLE XVIII

EFFECT OF LEAF RUST AND GREENBUGS ON ROOT VOLUME OF WHEAT SEEDLINGS IN GREENHOUSE EXPERIMENT 2

	Volume in ml[2]					
	Treatment					
Cultivar or line[1]	1	2	3	4	5	6
TMP-64	6.03	0.98	3.00	5.50	5.58	6.00
GBS-1	7.70	6.10	7.25	8.25	8.57	9.93
GBS-2	7.20	7.35	8.08	8.98	9.10	9.40
GBS-3	6.88	2.18	5.53	5.68	6.40	7.00

LSD .01 = 1.81

LSD .05 = 1.36

[1]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

[2]Means of 4 replications of 10 plants

64 produced significantly less root growth (dry weight) than either GBS-1 or GBS-2 in all treatments. But when TMP-64 was compared with GBS-3, the difference in root growth was significant only in treatment 2.

As in experiment 1, interactions occurred between cultivar or line X treatments for all variables except leaf rust damage.

Experiment 3

Experiment 3 was designed to study the effect of leaf rust on wheat infected 10 days after planting, and infested with greenbugs at different ages when the plants were all harvested 50 days after planting.

The means of leaf rust severity are given in Table XIX. Results similar to those in the previous experiments were obtained. TMP-64 and GBS-1 were severely damaged by the leaf rust; whereas, the leaf rust resistant lines GBS-2 and GBS-3 sustained only slight damage.

In this experiment, greenbugs were placed on the plants in treatments 3 to 6. Assessments of damage are shown in Table XX. In treatments 3 and 4, TMP-64 was severely damaged by the greenbugs compared with the other three lines. Only in treatment 5, was the greenbug susceptible line GBS-3 damaged more severely than TMP-64. GBS-1 and GBS-2 were resistant to the greenbugs in every stage of growth.

The numbers of plants which survived until harvest are shown in Table XXI. The data from treatment 3 indicated that the damage caused by greenbug infestation is greatly influenced by plant age. When the greenbugs infested 17 day-old seedlings of TMP-64, 60% of the plants were killed. When 24 day old plants were infested, 20% of them were

TABLE XIX

PERCENT LEAF RUST SEVERITY IN GREENHOUSE EXPERIMENT 3

Cultivar or line[1]	Treatment[2] 1	2	3	4	5	6
TMP-64	0	80	75	70	75	70
GBS-1	0	75	75	75	75	75
GBS-2	0	1	1	1	1	1
GBS-3	0	1	1	1	1	1

LSD .01 = 11.86

LSD .05 = 8.91

[1]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

[2]Means of 4 replications of 10 plants

TABLE XX

GREENBUG DAMAGE RATING IN GREENHOUSE EXPERIMENT 3[1]

Cultivar or line[3]	Treatment[2] 1	2	3	4	5	6
TMP-64	0	0	8.0	7.3	6.5	7.8
GBS-1	0	0	1.0	1.3	1.0	2.0
GBS-2	0	0	2.0	1.0	2.0	2.5
GBS-3	0	0	6.8	6.5	7.5	7.5

LSD .01 = 0.7

LSD .05 = 0.6

[1]Damage rating: 0 = No damage, 9 = Dead plant

[2]Means of 4 replications of 10 plants

[3]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

TABLE XXI

NUMBER OF PLANTS THAT SURVIVED ON HARVEST DATE IN EXPERIMENT 3

Cultivar or line[1]	Treatment[2] 1	2	3	4	5	6
TMP-64	10	10	4	8	10	10
GBS-1	10	10	10	10	10	10
GBS-2	10	10	10	10	10	10
GBS-3	10	10	10	10	10	10

LSD .01 = 0.8

LSD .05 = 0.6

[1]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

[2]Means of 4 replications of 10 plants

killed, and no killing of TMP-64 plants occurred when infested at later growth stages. Damage to the susceptible line GBS-3 occurred only when the plants were infested at 17 days of age. All plants of GBS-1 and GBS-2 survived in all treatments.

The means of fresh and dry foliage weights are shown in Tables XXII and XXIII, respectively. In the control (treatment 1), GBS-3 produced lower fresh and dry weights than either GBS-1 or TMP-64. A statistically significant difference ($P = 0.05$) occurred among GBS-1, GBS-3 and TMP-64 in treatment 1. TMP-64 and each of the lines produced more foliage in treatment 1 than in the other 5 treatments. These differences were significant in all treatments except for line GBS-2, in which significance was not indicated for treatment 2, 3, and 4; and for line GBS-3 in which significance was not indicated for treatment 2.

Leaf rust alone significantly reduced foliage production of the susceptible TMP-64 and GBS-1, as indicated by the comparison of means of treatments 1 and 2. There were no differences for fresh soliage weights among TMP-64 and the lines in treatment 2.

GBS-2 was resistant to leaf rust and the greenbug, however, a highly significant reduction in fresh foliage weight was observed in treatments 5 and 6 (19 and 22%, respectively) when compared with treatment 1 (control).

In GBS-3, the most severe reduction in fresh foliage weight caused by leaf rust and greenbugs occurred in treatments 3 to 6. There were 41, 30, 51, and 66% reductions in fresh foliage in treatments 3, 4, 5 and 6, respectively, compared with the control. However, a non-significant reduction occurred in treatment 2 due to leaf rust alone.

TABLE XXII

EFFECT OF LEAF RUST AND GREENBUGS ON FRESH WEIGHT IN GRAMS OF FOLIAR PORTIONS OF WHEAT SEEDLINGS IN EXPERIMENT 3

Cultivar or line[1]	Treatment[2] 1	2	3	4	5	6
TMP-64	12.08	9.16	2.19	3.46	4.31	2.81
GBS-1	12.47	10.32	10.10	9.24	8.42	7.46
GBS-2	11.26	10.31	10.24	10.63	9.16	8.82
GBS-3	10.40	9.87	6.16	7.25	5.12	3.49

LSD .01 = 2.08

LSD .05 = 1.56

[1]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

[2]Means of 4 replications of 10 plants

TABLE XXIII

EFFECT OF LEAF RUST AND GREENBUGS ON DRY WEIGHT IN GRAMS OF FOLIAR PROTIONS OF WHEAT SEEDLINGS IN EXPERIMENT 3

Cultivar or line[1]	Treatment[2]					
	1	2	3	4	5	6
TMP-64	1.53	1.17	0.28	0.44	0.55	0.35
GBS-1	1.58	1.31	1.28	1.17	1.07	0.95
GBS-2	1.43	1.30	1.29	1.35	1.16	1.12
GBS-3	1.32	1.25	0.78	0.92	0.64	0.44

LSD .01 = 0.22

LSD .05 = 0.17

[1]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

[2]Means of 4 replications of 10 plants

As expected, leaf rust and the greenbug produced the most damage on foliar growth of TMP-64 (Figure 3). Considered singly, leaf rust caused a 24% decrease in fresh foliage weight in TMP-64 (treatment 2). But when both leaf rust and greenbugs parasitized TMP-64, the combination of pests caused 82, 71, 64, and 77% reduction in fresh foliage production in treatments 3, 4, 5, and 6, respectively, in contrast with the control.

It was noted that within a line, the fresh foliage weights between treatments 4 and 6 of GBS-1, GBS-2, and GBS-3 were significantly different from each other. This may be accounted for by the length of the recovery period from the time the greenbugs were killed until the date of harvest. In this experiment, the recovery time in treatment 4 was 18 days compared to only 4 days in treatment 6.

Variation within root weight and root volume existed in this experiment (Table XXIV and XXV). In treatment 2, dry root weights of TMP-64 and GBS-1 were decreased about 22% due to leaf rust alone. In treatment 3, leaf rust and greenbugs produced a marked effect on root growth on TMP-64 and GBS-3. The loss in root weights were 82% in TMP-64 and 48% in GBS-3 (Figure 4).

From treatments 3 to 6, variations in root growth occurred within TMP-64, GBS-1, and GBS-3 due to the differences in greenbug infestation dates.

Like the foliar portions, the root volumes and root weights of greenbug susceptible wheats were less than those of the greenbug resistant ones.

Interactions between cultivar or lines X treatments were indicated for all variables in this experiment.

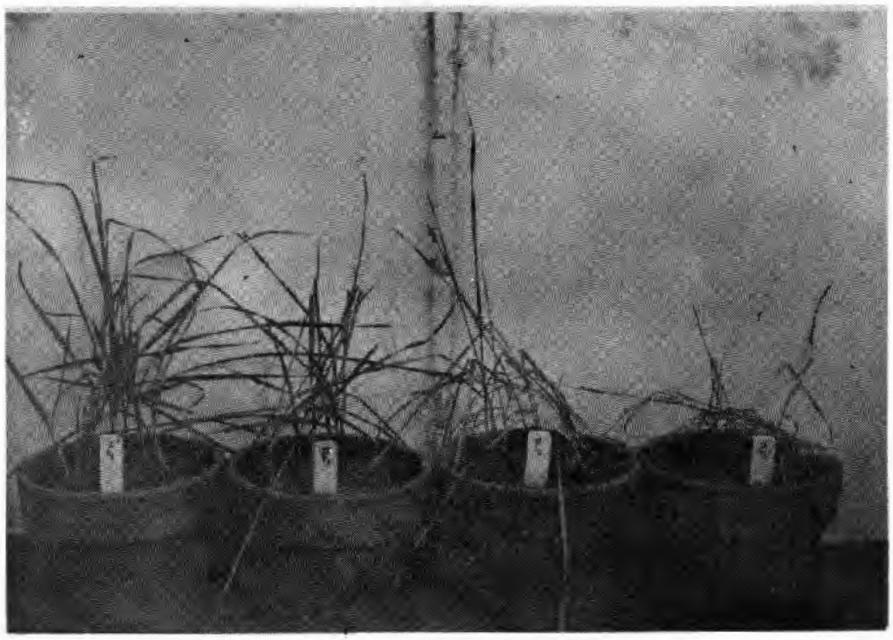

Figure 3. A Comparison of Wheat Plants Inoculated With Leaf Rust (Puccinia recondita f. sp. tritici) and Infested with Greenbugs (Schizaphis graminum (Rondani); (A) = GBS-1, (B) = GBS-2, (C) = GBS-3, and (D) = TMP-64.

TABLE XXIV

EFFECT OF LEAF RUST AND GREENBUGS ON ROOT GROWTH OF WHEAT SEEDLINGS AS MEASURED BY DRY WEIGHT IN GREENHOUSE EXPERIMENT 3

Cultivar or line[1]	Oven-Dry Weight in gms[2]					
	1	2	3	4	5	6
TMP-64	1.47	1.15	0.27	0.42	0.50	0.37
GBS-1	1.59	1.24	1.25	1.21	1.09	1.02
GBS-2	1.45	1.33	1.33	1.37	1.20	1.17
GBS-3	1.35	1.26	0.70	0.77	0.66	0.46

LSD .01 = 0.25

LSD .05 = 0.19

[1]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

[2]Means of 4 replications of 10 plants

TABLE XXV

EFFECT OF LEAF RUST AND GREENBUGS ON ROOT VOLUME OF WHEAT SEEDLINGS IN GREENHOUSE EXPERIMENT 3

Cultivar or line[1]	Volume in ml[2]					
	Treatment					
	1	2	3	4	5	6
TMP-64	9.88	7.60	1.80	2.83	3.44	2.48
GBS-1	10.46	8.60	8.20	7.74	6.94	6.55
GBS-2	9.44	8.60	8.68	9.00	7.94	8.13
GBS-3	8.81	8.34	5.00	5.94	4.30	2.98

LSD .01 = 1.79

LSD .05 = 1.34

[1]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

[2]Means of 4 replications of 10 plants

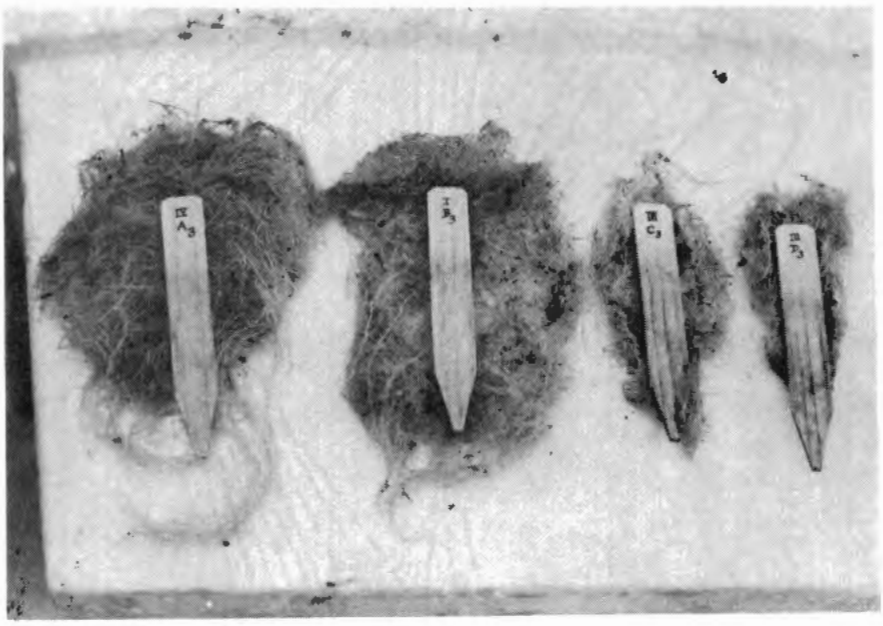

Figure 4. Root Mass of Wheat Inoculated with *Puccinia recondita* f. sp. *tritici* and Infested with Greenbugs (*Schizaphis graminum* (Rondani)) 50 Days After Planting. (A) = GBS-1, (B) = GBS-2, (C) = GBS-3, and (D) = TMP-64.

Field Experiment

A general view of the field experiment is shown in Figure 5. The percent leaf rust severity was recorded on May 7, 1979, and the means of rust severity are shown in Table XXVI. The differences observed were not significantly different, although the susceptible wheats TMP-64 and GBS-1 had the highest severities.

The number of greenbugs per tiller were counted on the same day that rust severity was recorded and the means are shown in Table XXVII. Again, the susceptible wheats TMP-64 and GBS-3 had the highest infestation, but the differences between the wheats were not significantly different.

At maturity, the yield of each cultivar and line was measured. These data are presented in Table XXVIII. Due to the low level of rust development and the small aphid population, the yields of tested wheats did not differ significantly.

It is interesting that soil borne mosaic was noted in one replication of GBS-1 and the yield of this line was less than of any of the other wheats tested.

Figure 5. General View of Field Experiment at Plant Pathology Farm, Oklahoma State University, Stillwater, Oklahoma.

TABLE XXVI

PERCENT LEAF RUST SEVERITY IN THE FIELD EXPERIMENT

TMP-64[1]	GBS-1	GBS-2	GBS-3
15.1[2]	13.75	9.35	4.65

[1]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

[2]Mean of 4 replications

TABLE XXVII

NUMBER OF GREENBUGS PER TILLER
IN FIELD EXPERIMENT

TMP-64[1]	GBS-1	GBS-2	GBS-3
24.1[2]	2.05	1.55	18.7

[1]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

[2]Mean of 4 replications, no significant differences between lines.

TABLE XXVIII

GRAIN YIELD IN GRAMS FOR TMP-64, GBS-1, GBS-2, and GBS-3 IN FIELD EXPERIMENT

TMP-64[1]	GBS-1	GBS-2	GBS-3
431.25[2]	323.75	420.25	450.75

[1]Abbreviations as follows: TMP-64 = Triumph 64

GBS-1 = Greenbug Selection Line 1

GBS-2 = Greenbug Selection Line 2

GBS-3 = Greenbug Selection Line 3

[2]Mean of 4 replications, no significant differences between lines.

CHAPTER V

DISCUSSION

A series of investigations in the greenhouse proved that leaf rust fungus and greenbugs seriously affected the foliar and root growth of young wheat seedlings. At early stages of growth, the combined effect of these pests killed many plants, especially those of the cultivar, TMP-64 and line GBS-3. TMP-64 was affected most because it was susceptible to both leaf rust and the greenbug whereas GBS-3 was susceptible only to the greenbug. When TMP-64 was infected with leaf rust and infested with greenbugs at an early age, 60% or more of the tested plants were killed. The line, GBS-3, susceptible only to the greenbug, was less affected than TMP-64 with 20 to 25% of the seedlings killed. Therefore, the age of the plants, leaf rust infection, greenbug infestation, and susceptibility of the plants all played a role in the survival of seedling plants.

The effect of greenbugs, particularly on foliar growth, of wheat plants has been reported by several authors (5, 8, 31, 35). This aphid injures the plants by injecting toxic saliva which alters the cell contents and eventually kills living tissues. Throughout these greenhouse experiments, where the aphids fed on the leaves, prominent yellow spots with necrotic centers appeared on the leaves of susceptible TMP-64 and GBS-3.

The effect of leaf rust alone was studied also in experiments 2 and 3. It was noted that roots of the rust-infected, susceptible cultivar or line were discolored and deteriorating compared to the resistant lines and to the rust-free control plants. Williams (45) and Vanitchayangkul (40) noted similar discoloration of the roots of inoculated plants, but it is a difficult characteristic to measure. Furthermore, leaf rust produced a considerable amount of damage to leaf cells which reduced the leaf area for photosynthesis. Rusted plants also required more water to produce the same amount of foliar growth as healthy plants. In experiment 3, TMP-64 and GBS-1 produced less foliage by as much as 24 and 17%, respectively, compared with the rust-free control plants. The growth of rust resistant lines (GBS-2 and GBS-3) was not affected by the fungus infection.

As expected, the leaf rust and greenbug resistant line, GBS-2, was superior in foliar and root growth to the susceptible cultivar and lines. In experiment 3, significant decreases in fresh foliage yields corresponded with later dates of greenbug infestation.

The combined effect of leaf rust and greenbug affected the growth of TMP-64 and GBS-3 in various ways. They caused reduction in foliar growth by damaging or even killing leaf tissue at early stages of plant growth. Consequently, they reduced root weight as much as 80%. Such losses to the root mass could cause the plants to be much more subject to moisture stress and winter injury than healthy plants.

Time of leaf rust inoculation caused an interesting effect on leaf rust susceptible line, GBS-1. For example, in experiment 1, when GBS-1 was inoculated with leaf rust at later dates, it produced significantly less fresh foliage than GBS-2, the resistant line. This was not true,

however, when both lines were inoculated at earlier dates. Also, this can be seen in a comparison of treatment 5 in experiments 1 and 2. In experiment 1, treatment 5 was inoculated 35 days after planting and GBS-1 was highly significantly different from GBS-2. GBS-1 produced 33% less foliage than GBS-2. In experiment 2 treatment 5 was inoculated 10 days after planting and GBS-1 produced only 13% less fresh foliage than GBS-2. This difference was not significant.

The amount of recovery time between removing the greenbugs from the test plants and the harvest date critically affected the amount of growth measured. In experiment 3, greenbugs were placed on plants at different growth stages and allowed to feed for 8 days. Consequently, the later infested plants had shorter recovery times. Under these conditions even the greenbug resistant lines produced successively smaller amounts of foliage as the length of the recovery time decreased.

Ortman and Painter (27) reported that the root systems and aboveground plant parts were approximately equally damaged by greenbugs. In my experiments, the combined effects of leaf rust and greenbugs caused almost the same proportional percentage damage to root systems and foliar parts. They also reported that dry root weight of four wheat varieties showed a maximum loss ranging from 32 to 55% compared with the control. However, in this study (experiment 3) the maximum loss in dry weights of susceptible TMP-64 and GBS-3 was 68% and 63%, respectively, when free of leaf rust; and 75% and 66%, respectively when both leaf rust and greenbugs were present.

The results of a field experiment to determine the effect of these pests on grain yield showed no significant differences among the variables measured. Maintaining a stable population of greenbugs on the test

plants was very difficult. Some of the greenbugs developed into winged females and these soon left the test plot. Due to dry soil conditions planting was delayed and the first greenbug infestation was initiated in the field in late November, 1978. By that time, the temperature was not optimum for survival or reproduction of the aphids. Pfadt (31) found that the optimum temperature for greenbugs to reproduce ranged from 21 to 24C (70 to 75 F). A second infestation at an even later date likewise did not become well established on the test plants.

Leaf rust severity in the field was very low even on susceptible TMP-64 and GBS-1, averaging 15.1 and 13.75% severity.

However, if a future field experiment were to be conducted, it is suggested that a location with a naturally high prevalence of greenbugs be selected in order to maintain a stable population. If artificial infestation is needed, it should be initiated early. For leaf rust inoculum, the spreader plants should be planted before the test plants and inoculation in the field should be done as early as above freezing temperature permit in the spring.

The principle objective of the study was to measure the combined effects of the leaf rust disease and greenbugs on various parameters of wheat growth. In every instance where comparison can be made from these experiments, the effects of these two pests were additive. For instance, in greenhouse experiment 1 none of the plants, of this line resistant to both pests were killed when both organisms were placed on the plants. Similarly, none of the plants of the line resistant only to the greenbug were killed. However, with the line susceptible only to the greenbug 28 percent of the plants were killed and with the cultivar susceptible to both pests 67 percent of the plants were killed.

The effect upon the foliage and root growth was almost identical. In greenhouse experiment 3 when these lines were not inoculated or infested with either organism their performance was almost equal. When they were inoculated with the leaf rust fungus only the rust susceptible line and cultivar were reduced slightly in growth parameters, but when both pests were used the cultivar susceptible to both pests was reduced 78 percent in foliar growth compared to a reduction of 1 percent for the line susceptible only to leaf rust and a reduction of 40 percent for the line susceptible only to greenbugs.

CHAPTER VI

SUMMARY

1. One cultivar (Triumph 64) and three leaf rust and greenbug selection lines (GBS-1, resistant to greenbugs and susceptible to leaf rust; GBS-2, resistant to both leaf rust and greenbugs; GBS-3, susceptible to greenbugs and resistant to leaf rust) of winter wheat were used to evaluate the combined effect of leaf rust and greenbug on growth of wheat seedlings in the greenhouse and on grain yield of wheat in a field experiment.
2. Severe infection of leaf rust and infestation of greenbugs at the earliest inoculation destroyed as much as 67.5% of the plants in the leaf rust and greenbug susceptible cultivar, Triumph 64.
3. In the leaf rust resistant and greenbug susceptible line (GBS-3), 25% was the highest number of plants killed by these pests when attacked at early age.
4. Leaf rust and greenbugs produced no death of plants in greenbug resistant lines, GBS-1 and GBS-2.
5. Growth of Triumph 64 and GBS-3, both susceptible to the greenbug, were more severely affected than the greenbug resistant lines, GBS-1 and GBS-2.
6. Leaf rust and greenbugs affected not only foliage growth but also produced a deleterious effect on the root systems. Foliar and root growth were reduced as much as 82% when compared with the control.

7. The age of wheat seedlings at the time of inoculation and infestation by the pests affected foliar and root growth significantly. Similarly, the harvest dates also affected the apparent damage to foliage production and root growth of wheat plants.
8. No differences in grain yield were observed among the wheat cultivar and lines in a field experiment due to the low levels of leaf rust severity and greenbug populations.

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