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# Evaluation of hydraulic spraying parameters for applying foliar fungicides in snap beans

Donley J. Canary

To the Graduate Council:

I am submitting herewith a thesis written by Donley J. Canary entitled "Evaluation of hydraulic spraying parameters for applying foliar fungicides in snap beans." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering.

Fred D. Tompkins, Major Professor

We have read this thesis and recommend its acceptance:

Charles Mullins, J. W. Hilty

Accepted for the Council:
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(Original signatures are on file with official student records.)

To the Graduate Council:

I am submitting herewith a thesis written by Donley J. Canary entitled "Evaluation of Hydraulic Spraying Parameters for Applying Foliar Fungicides in Snap Beans." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Mechanization.

Fred D. Tompkins, Major Professor

We have read this thesis
and recommend its acceptance:

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James W. Hilty

Accepted for the Council:

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# EVALUATION OF HYDRAULIC SPRAYING PARAMETERS FOR APPLYING FOLIAR FUNGICIDES IN SNAP BEANS

A Thesis

Presented for the

Master of Science

Degree

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Donley J. Canary

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ABSTRACT

A medium-volume, two-row hydraulic sprayer was used in the application of various treatments of a foliar fungicide solution and fluorescent particle suspension to snap bean foliage. The treatments consisted of 20, 40, or 60 gallons of solution per acre applied at either 50 or 100 psi using 1, 2, or 3 nozzles per row.

Trifoliate bean leaves were randomly selected from the treated rows and evaluated for rust control efficiency and completeness of bean leaf surface coverage. Data evaluation in these two areas was based upon visual subjective observation.

Rust rating data indicated that fungicide applications of 20 gallons per acre applied using 1 nozzle at 50 psi were just as effective in controlling bean rust as higher application rates applied with 2 or 3 nozzles per row at 50 or 100 psi. Also, pod curvature and yield were not appreciably affected by the various fungicide parameters.

Evaluation of coverage data showed that as the application rate increased, increases in the percentage of both top and bottom leaf surface coverage occurred. However, even at the highest application rate, only about 60 percent of the total leaf surface received spray coverage.

Increasing sprayer pressure from 50 to 100 psi was found to slightly increase coverage of both top and bottom leaf surfaces. As the number of nozzles per row was increased, leaf coverage was found to also increase. Data indicated that bottom leaf surface coverage was

more markedly influenced by increasing the number of nozzles than top leaf surface coverage.

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# CHAPTER I

# INTRODUCTION

## I. BACKGROUND AND PROBLEM DEFINITION

Bean rust is one of the most severe foliage diseases affecting the yield and quality of snap beans grown in Tennessee, particularly in the Cumberland Plateau Region. The disease, which has developed annually in epidemic proportions since 1973, is known to affect most common commercial varieties of snap beans planted in late July or August in Tennessee. Bean rust has drastically increased in economic importance as the acreage of snap beans grown in the state for commercial use has risen from 12,700 acres in 1970 to the 1978 level of 16,800 acres (U.S.D.A., 1979). The adverse effect on yield and quality of snap beans by rust makes it imperative that the disease be effectively controlled so that this multimillion dollar industry can thrive in the state.

Snap bean rust is caused by the fungus *Uromyces phaseoli typica* Arth., which develops only on bean plants of the genus *Phaseolus*. The disease in its early stages may be almost impossible for the human eye to detect, first appearing as small, white, slightly raised spots on the underneath portion of the bean leaf. Next, the raised spots enlarge and spread to the top portion of the leaf. At this time the raised spots develop into rust pustules where the brown or rust-colored uredospores characteristic of the fungus first appear. This particular spore form is the most common of the five types of spores which might develop during the autoecious life cycle of the fungus. These spores are disseminated by wind and splashing water to healthy bean plants, thus spreading infection. Later in the growing season the fungus produces a second spore. This is the black-colored teliospore. The teliospore overwinters in bean plant residue and serves as a means of initiating infection the next year. Following the production of the teliospores the fungus is capable of producing pycniospores, basidiospores, and aeciospores; but their production is rare.

Any spore landing on the bean leaf surface has the capability of producing a pustule. Each pustule may contain several thousand spores. Therefore, the disease can rapidly develop into epidemic proportions if effective control methods are not adopted and practiced.

Current recommendations for the control of snap bean rust favor the use of foliar fungicides. Hilty and Mullins (1975) tested the effectiveness of four foliar fungicides for the control of bean rust. Their results showed that foliar fungicides such as Bravo, Manzate D, and combinations of the two had a significant effect in controlling development of the pathogen. However, their work gave rise to questions as to the most effective and efficient way to apply these foliar fungicides to snap beans. In response to these questions, a study was initiated at The University of Tennessee Plateau Experiment Station near Crossville using a medium-volume hydraulic sprayer for application of a foliar fungicide to snap beans.

## II. OBJECTIVES

The purpose of this study was to evaluate the efficiency of foliar fungicide applications on snap beans using a hydraulic sprayer. Specifically, the main objectives were to determine the optimum number of nozzles per row, rate of application, and operating pressure by which the foliar fungicide should be applied to effectively control the bean rust pathogen, *Uromyces phaseoli typica*, as it occurs on varieties of *Phaseolus vulgaris L*.

# CHAPTER II

## REVIEW OF LITERATURE

### I. BEAN RUST

#### History and Scope

The bean rust fungus, *Uromyces phaseoli typica*, was first reported in 1795 by Persoon as recorded in Arthur's (1934) *Manual of the Rusts in United States and Canada*. This account, though the first recorded, was surely not the beginning of the bean rust pathogen. The fungus had probably prevailed for as long as the genus *Phaseolus* existed, but simply had not been brought to man's attention until beans were grown on a commercial level.

Proper identification and naming of the bean rust pathogen originally resulted in much confusion. Arthur (1934) provided the early names and the years of recognition of the fungi. They were as follows:

*Uredo appendiculata* Pers. (1795)

*Uredo appendiculata phaseoli* Pers. (1795)

*Puccinia phaseoli* Rebent. (1804)

*Aecidium phaseoli* Funck (1814)

*Uromyces appendiculatus* Fries (1849)

*Uromyces phaseoli*

*Uromyces vignae* Barclay (1891)

*Nigredo appendiculata* Arth. (1906).

After much discussion Arthur suggested that perhaps *Uromyces phaseoli* typica was the most appropriate name, and this was adopted by most plant pathologists during the 1930's. Research done prior to the 1930's with the bean rust pathogen used extensively the name Uromyces appendiculatus adopted from Fries in 1849. In their studies Littlefield and Heath (1979) warned readers of the many different names of the rust pathogen which might be encountered in early literature concerning work with the fungus. However, for all practical purposes, the fungus causing bean rust is now universally recognized by plant pathologists as being properly named Uromyces phaseoli typica.

The disease has been observed to occur on a worldwide basis wherever beans are grown. Arthur (1934) reported the disease occurring on four of the seven continents, Asia, Europe, North and South America. Bean rust has also been noted to be prevalent in tropical areas such as the West Indies, Hawaiian Islands, and Puerto Rico. Here in the United States the disease ranges from Maine southward down the Atlantic Coast to Florida and westward to California and Oregon. The disease is extensive in bean growing areas of the Upper Midwest. Fisher (1952) recorded cases of bean rust occurring in isolated areas of Colorado, Montana, and Wyoming.

## Organism and Life Cycle

The rust fungus, Uromyces phaseoli typica, is a member of the Family Pucciniaceae, Order Uredinales, Subclass Heterobasidiomycetidae, and Class Basidiomycete (Kenaga, 1974). The pathogen is placed in the fungal class Basidiomycete due to the presence of a conspicuous club-like structure, a basidium, which is distinct in the reproductive cycle of fungi belonging to the class Basidiomycete.

The species phaseoli of the bean rust pathogen can be separated into many different physiological races. Studies involving physiological races and their interactions with Phaseolus vulgaris provided information concerning host reactions against infection. Wei (1937) first noted the varying reactions encountered between host and supposed differing physiological races of the pathogen. Similarly, Harter and Zaumeyer (1941) determined from their research that different races of the pathogen resulted in different symptom expressions or reactions from the host. These reactions, though similar for the entire group, were distinct for a particular race on Phaseolus vulgaris.

Much research has been conducted to determine the exact number of physiological races residing in the United States. Early work by Dundas and Scott (1939) identified four physiological races of the pathogen. They identified them as 1, 2, W (Washington), and F (Florida). From this work Harter and Zaumeyer (1941) added 16 new races to the existing list, bringing the total to 20. Fisher (1952) identified 10 more new races in 1952, raising the mark to 30. The list grew slowly from that point, with the addition of a single race by Sappenfield (1954), Zaumeyer (1960), and Hikida (1961), bringing the total number of identified races to 33. Plant pathologists believe that new races will be discovered in the future and added to this list of identified physiological races of Uromyces phaseoli typica in the United States.

Uromyces phaseoli typica is an autoecious rust completing its life cycle on one host the bean plant. The pathogen is macrocyclic in nature but not all races will produce all spore forms. The pathogen enters the bean field in the form of a uredospore. Arthur (1934) described the uredospore as being globoid or ellipsoid in shape, golden-brown in color, and possessing two equatorial pores. The uredospores are transported to the bean leaf surface by wind or some other means. Here under proper environmental conditions of light, relative humidity, and temperature, the spores germinate and a germ tube grows into the epidermis, either by direct penetration or through stomata. Schein and Snow (1963) proposed that host susceptibility to germ tube penetration paralleled that of stomata development. Although germ tubes would not penetrate a stomatal primordia, they would penetrate at about the time of the final division of the primordium. The ability of the germ tube to penetrate was related to the breaking of the cuticle, exposing the middle lamella between juvenile guard cells. Autolysis of this layer resulted in the stomatal pore and the ultimate infection site.

Proper environmental conditions are necessary for successful uredospore germination and germ tube penetration. Early tests by Bell and Daly (1962) revealed uredospore germination was greatest between 15 and 24°C with a decided drop in germination when the temperature exceeded 24°C. Shands and Schein (1962) stated that the optimum temperature for uredospore germination ranged between 12.5 and 18°C. At this particular temperature interval a 70 percent germination rate could be expected of the uredospores. If the temperature exceeded 24°C, a sharp drop in germination could be expected. Further studies by Shand and Schein (1962) revealed that germ tube elongation was greatest between 12.5 and 15°C, but infectivity was greatest between 18 and 21°C.

The environmental factors of light and relative humidity also play a significant role in uredospore germination and germ tube penetration. Yarwood (1953) concluded that uredospore germination was greater at high relative humidity than at low relative humidity. Subsequent tests by Yarwood (1961) determined that an incubation period of at least 8 hours was necessary for successful germination and penetration with low light and 95 percent relative humidity. Studies conducted by Curtis (1966) expressed the idea that there was no marked difference between the effect of light and darkness on uredospore germination when temperature was nearly equal. However, thermal effects resulting from high light intensity could severely impede spore germination.

Once uredospore germination and germ tube penetration has been accomplished, the pathogen begins to colonize the host plant. This process begins with the establishment of haustorial connections between the fungus and host. The haustoria penetrate the cells of the bean plant and absorb food from them. The food is used to nourish the growing pathogen. The fungus rapidly multiplies within the host's tissue; and the first visible signs of the disease, small white spots or flecks on the leaf surface, appear three or four days post inoculation. Four or five days after flecking first occurs, the flecks enlarge and develop into rust-colored pustules containing hundreds or possibly thousands of uredospores. Maturation of uredospores occurs approximately seven to eight days post inoculation. These spores are then released about two days after maturation (Yarwood, 1968).

When environmental conditions become unfavorable or nutrients unavailable to the pathogen, teliospore production is initiated. Arthur (1934) described the teliospore as black-brown, globoid or broadly ellipsoid, with a terminal pore covered by anhyaline papilla. The pathogen overwinters in colder climates as a teliospore while in milder climates the fungus overwinters in the uredospore stage of the life cycle (Harter et al., 1935). Infected bean straw or residue serve as sites for the overwintering spores. From here the spores will be disseminated in the spring to new host plants. In areas where winters are relatively mild, the teliospore portion of the life cycle will possibly never be reached. The pathogen will keep multiplying and producing a series of secondary cycles of uredospores.

In the spring uredospores or teliospores are disseminated to new bean plants and the life cycle resumes. If teliospores are spread, completion of the entire macrocyclic life cycle of the pathogen is possible. In completing the life cycle Groth and Mogen (1978) found that teliospores produce basidia which give rise to basidiospores. The basidiospores infect the bean leaf surface and result in pycnia formation. Pycnia are cup-shaped structures usually located in the top portion of the leaf surface. In the pycnia the pycniospores develop. A combination of the pyciniospores in the pycnia and subsequent movement of the mycelium downward through the leaf results in the formation of aecia on the bottom of the leaf surface. The aecia, upside down cup-shaped structures, serve as a site for aeciospore formation. The aeciospores reinfect the bean leaves and again result in uredospore production. The completion of the entire rust cycle is the exception rather than the rule in the life of Uromyces phaseoli typica.

Further research conducted by Groth and Mogen (1978) demonstrated two main problems in completing the pathogen's life cycle. Obtaining germination of the teliospores proved to be the main difficulty in obtaining a complete life cycle of the bean rust fungus. Secondly, the transfer of basidiospores to the leaf surface resulting in pcynia formation was extremely difficult to achieve. If these two obstacles were successfully overcome, Uromyces phaseoli typica had the opportunity to complete its entire life cycle.

Uredospore production is by far the most important portion of the pathogen's life cycle. This segment of the life cycle is often called the "repeating phase" due to its ability to reoccur and produce large numbers of infectious spores. Thus, the uredospore is usually responsible for the epidemic outbreaks of bean rust which occur.

## Symptoms

Symptom expression has been previously discussed in terms of outward appearance of the bean plant. However, no mention has been made of the inward condition of the host, especially the leaf, where symptom expression demonstrating the true destructive potential of Uromyces phaseoli typica is masked. Symptom expression is not a simple action but is the combined effect of several factors. The interaction between the host, the pathogen, and the environment determines the manner in which symptom expression will be displayed.

In terms of physiology, the healthy bean plant is not extremely active. The plant is involved in performing the metabolic processes necessary for maintaining life. However, when infection by the rust pathogen occurs, the plant, especially the leaf area, becomes very active.

Waters (1928) concluded that when the rust pathogen invaded a normal, healthy host under favorable environmental conditions for both, the pathogen was favored in their relationship as shown by massive uredospore production. Furthermore, when adverse conditions to the host decreased its vegetative vigor or nutrient-supplying ability, teliospore production was initiated. Waters' work demonstrated the importance of a defined environment when dealing with host symptom expression. He found that such factors as low light, reduced temperatures, and removal of host shoots acted in unison to change host reactions to symptom expression. Lending credence to Waters' work with symptom expression and environmental influence, Hart and Forbes (1935) determined that the severity of bean rust was drastically reduced by spore inoculation occurring during darkness or low light. Later, Schein (1961) explained that host symptom expression could be modified if, during the time of infection, bean plants were moved to a controlled environment of 32°C for a period of seven days. Dead leaf tissue resulted at the site of infection, thereby reducing disease severity and symptom expression.

Age of the host plant tissue has been shown to be an important factor in symptom expression. Research by Schein and Snow (1963) demonstrated that leaves of *Phaseolus vulgaris* were only slightly susceptible to infection by the rust pathogen when small (midrib length less than 2 cm). Susceptibility increased 6 times as the leaves expanded to a midrib length of 4 cm. Similar studies by Ikegami (1968) found that susceptibility of bean plants to rust gradually decreased as the plant aged beyond four weeks.

The plant part infected has been shown to be an important variable in symptom expression and disease development. Davison and Vaughan (1963) demonstrated that trifoliate and primary leaves differed slightly in their response to invasion by the pathogen. Yarwood (1954a) concluded that bean leaf pulvini was completely resistant to rust infection while the petioles and the laminae were susceptible.

Two of the vital metabolic processes in plant life, respiration and transpiration, have been shown to be affected in symptom expression. Daley et al. (1961) determined that the respiratory rate of both primary and trifoliate infected bean leaves were substantially greater than those of healthy ones. An interesting phenomenon concerning transpirational water loss as it paralleled disease development was noted by Duniway and Durbin (1968). They concluded that, at the time of flecking on the outer leaf surface, water loss was 10-40 percent less than that of healthy leaf tissue. By the time of sporulation, however, the water loss from infected leaves was 6.5 times greater than that of healthy ones.

Rust-infected bean leaves have been shown to contain abnormally high concentrations of carbon and starch. Zaki and Durbin (1965) found that increased concentrations of carbon in the form of carbon 14 existed in diseased leaves at the expense of the shoot apex and the roots. Lack of movement of the carbon 14 to these areas from the leaf resulted in decreased growth and yield on the part of the plant. Schipper and Mirocha (1969) discovered a gradual decrease in starch content around the site of spore inoculation on bean leaves lasting for about one day. This was followed by a tremendous increase in starch content within the next three days. They concluded that the initial starch depletion was the result of the leaf providing nutrients to the fungal pathogen. No satisfactory explanation was offered for the later starch accumulation.

Finally, another circumstance associated with symptom expression is inoculum density. Kenaga (1974) described inoculum density as the number of units of a pathogen capable of producing infection which are in the environment of a susceptible host. Yarwood (1968) found that, as inoculum density decreased from 200,000 spores per $cm^2$ to 4,000 spores per $cm^2$, minimum infection increased from 0 pustules per $cm^2$ to 20 pustules per $cm^2$ on the leaf surface. Earlier work by Davison and Vaughan (1963) noted a similar response between inoculum density and minimum infection.

## Control Measures

The control of the rust pathogen, Uromyces phaseoli typica, can be accomplished in one of four ways: exclusion, eradication, protection, or resistance. Concepts and recommendations concerning each of these control methods will be discussed.

Exclusion involves not allowing the pathogen to come in direct contact with the host. Frome (1924) concluded that exclusion practices could be incorporated into a overall bean rust control program by: (1) rotating crops and avoiding disease-infected crop refuse, (2) selecting clean seed, (3) preventing animals from straying into bean fields, and (4) working in bean fields only after dew and rain have been dried from the leaves. Today, practices of exclusion in bean rust control include not only Frome's ideas, but the strict enforcement of quarantine laws governing the transport of agricultural material which might be infected with the pathogen. However, due to the movement of rust spores by wind, these laws have had little effect on halting the pathogen's spread (Hilty, 1980).

Control by eradication occurs when the bean rust pathogen is already established, but an effort will be made to substantially reduce the population. Early attempts by Yarwood (1953) made use of pressure treatments to eliminate the fungus. He found that pressures between 10 and 240 pounds per square inch (psi) exerted on bean leaves killed many young infections of bean rust. The greater the pressure and the younger the leaf, the more successful was the therapy. However, host damage resulting from pressure treatments was often greater than that caused by the pathogen, thus rendering Yarwood's discovery useless in agricultural practice.

Heat therapy is sometimes used for the inactivation of fungi on living plants, but is rarely if ever used on the foliage of growing plants. Yarwood (1963) demonstrated that hot water treatments could successfully eradicate the rust pathogen from living bean foliage without resulting in severe host damage. Furthermore, he concluded that heat therapy would have the advantage of only being applied when the fungus built up to dangerous levels. Experimentation involving hot water treatments holds promise in the future for this method of eradication.

During the 1950's plant pathologists discovered the use of antibiotics in bean rust control. Pridham et al. (1956) demonstrated that the use of antibiotics derived from Streptomyces griseus were especially effective against the rust pathogen. Among these compounds were phytoactin, phytostreptin, streptomycin, and cycloheximide. Later, Zaumeyer (1957) made extensive use of the antibiotics oligomycin and anisomycin in bean rust eradication. Ark et al. (1958) found that the antibiotic GS1 displayed a high degree of activity against the uredospores of the fungus. Though effective, these antibiotics proved to be extremely costly to produce and difficult to apply. Therefore, the use of antibiotics in bean rust control is not practiced today.

Calpouzos et al. (1957) demonstrated that the hyperactive fungus, Darluca filum, could be successfully cultured and used in parasitizing Uromyces phaseoli typica. In further studies of this phenomenon, Littlefield and Heath (1979) found that the parasitic fungus penetrated the uredospores of the pathogen at random sites over the spore. This penetration appeared to be dependent upon the enzyme-producing capacity of the hyperparasite. This method of eradication holds promise for the future, but more research must be conducted in its use.

Bell (1969) observed the presence of substances in the wound sap of the bean plant which might be used in the control of rust infection. He determined that the substances, aldehydes and their derivatives, were extremely toxic and prevented the germination of uredospores. However, no practical method of application of these compounds to the bean plant has yet been discovered.

The area of fungicidal application was explored in bean rust eradication. Davis et al. (1959) observed that sydnones applied to bean foliage inhibited the development of established infections of the fungus. Whether the sydnones inhibited the disease as direct fungitoxicants or by some indirect mechanisms was not determined. However, Davis suggests that pathogen reduction is triggered by rendering host tissue unfavorable to the pathogen.

During the 1960's the discovery of systemic fungicides occurred. Oxycarboxin and carboxin were the most important of these new systemic fungicides in bean rust eradication. Schemling and Kulka (1966) reported that the application of oxycarboxin resulted in longer bean rust control than carboxin. However, carboxin was initially more fungitoxic than oxycarboxin. Later studies by Richmond and Pring (1978) demonstrated that the mode of action of these two systemic fungicides resulted in severe changes of the haustorial mitochondria. Disturbance of these mitochondria resulted in the pathogen's death.

Snel and Edington (1968) found that the systemic fungicides DCMO and DCMOD, derivates of oxycarboxin and carboxin, served as eradicants of bean rust. Foliar applications of the fungicides resulted in accumulation of the compounds at the tips and margins of the leaves. Both fungicides were found to be extremely fungitoxic to existing uredospores on the surface of the bean leaf.

Bean rust control by protection implies that the rust pathogen is not yet present but is expected to appear. However, in some instances the pathogen may already be present, but protection is provided against subsequent spore infection. This has long been the method of choice for control of bean rust in the field when resistant varieties are not available. This method of control usually involves dusting or spraying a fungitoxic protectant onto the plant foliage at regular intervals to kill germinating spores. Infection of the bean plant thus never occurs.

Several systemic fungicides were developed for protection against the bean rust pathogen, Uromyces phaseoli typica. Vaughan and Siemer (1967) demonstrated that the systemic fungicides F-461 and D-735, applied as seed treatments, were successful in preventing bean rust from developing. Story et al. (1970) reported the use of 4-amino-6-chloro-2-(methylthio) pyrimidine as an effective protectant systemic fungicide. When infection first developed, the fungicide was applied at the rate of 5 mg per plant as either a drench or dust. Results showed that protection from the rust pathogen occurred for approximately three to four weeks. At about this same time Baldwin (1970) noted that Plantvax, derived from oxycarboxin, could be applied at the rate of 1 pound active ingredient (A.I.) per acre. Use of this protectant foliar fungicide was implemented at either the two or three true-leaf stage of the plant.

When discussing protection, the term protection commonly refers to the non-systemic fungicides. The use of elemental sulfur is probably the oldest non-systemic protectant known. Harter et al. (1935) recommended the dusting of bean plants at the rate of 30 pounds per acre as a protective measure. Subsequent tests by Marcus (1952) confirmed the ability of sulfur to function as a protectant against bean rust invasion.

Yarwood (1948) discovered that lime sulfur or copper sulfate, applied as a foliar spray, was extremely beneficial in rust protection. Furthermore, he concluded that applications of dilute lime sulfur were effective up to eight days after inoculation against rust infection. He also found that cyanide gas was an efficient rust protectant, but was extremely phytotoxic.

In Maryland, Zaumeyer (1960) used the carbamates Maneb, maganese ethylenebisdithiocarbamate, and Zineb, zinc ethylenebisdithiocarbamate, as successful dust application protectants against bean rust. Today, these carbamate compounds exist not only as dusts, but in the forms amenadable to foliar spray applications.

Kantzes and Weaver (1967) tested the following non-systemic fungicides as bean rust protectants: Manzate D, Dithane M-45, Daconil 2787, Polyram, and Diflotan. Weekly applications of the fungicides at the rate of 3 pounds per acre were made. Results showed that plots sprayed with these fungicides were only 5, 10, 15, 15, and 10 percent rust-infected, respectively.

Hilty and Mullins (1975) experimented extensively with foliar applications of the fungicides Bravo, Manzate D, Polyram, Sulfur, and combinations of Bravo and Manzate D. When applied every 7 to 10 days at the beginning of infection, Bravo and Manzate D, used separately or in combination, provided significantly better bean rust protection than did either Polyram and Sulfur.

Another interesting method of protection against bean rust is cross-protection. Kenaga (1974) defined cross-protection as the condition whereby a normally susceptible host is infected with an avirulent pathogen (usually a virus), and thereby becomes resistant to infection by a virulent pathogen. Wilson (1958) observed this phenomenon of cross-protection between the bean rust pathogen, Uromyces phaseoli typica, and the tobacco mosaic virus (TMV). He found that bean leaf tissue showed resistance to rust infection after prior exposure to TMV. He concluded that this resistance was the result of leaf diffusates which inhibited uredospore germination. Earlier, Yarwood (1954b) suggested that this "acquired immunity" was due to the formation of antibodies. His original work with cross-protection gave some indication that rust resistance was the result of volatile toxic gases liberated from rust-infected tissue. However, Yarwood (1968) more recently reported evidence that the presence of water soluble nonvolatile materials were associated with cross-protection.

Littlefield and Heath (1979) expressed doubt about the role TMV played in cross-protection. Using the scanning electron microscope (SEM), they concluded that TMV particles did not penetrate the leaf tissue, but adhered only to the surface. Furthermore, they felt that additional studies in this area were needed before the true phenomenon of cross-protection could be completely understood.

Resistance is the inherent ability of a host plant to suppress, retard, or prevent entry or subsequent activity of a pathogen or other injurious factor (Kenaga, 1974). The use of resistant varieties of Phaseolus vulgaris is extremely important in the control of the bean rust pathogen.

Wingard (1935) worked extensively with the breeding strategy involved in the development of resistant varieties. His work found that crosses between susceptible and resistant varieties resulted in the first generation ($F_1$) offspring being resistant to rust infection. This result suggested that the genetic factor for resistance was dominant. Subsequent tests on the second generation ($F_2$) offspring demonstrated that the ratio of resistant to susceptible bean plants was 3 to 1. From this information Wingard concluded that a single factor, actually a gene, was responsible for bean rust resistance. Moreover, he proposed that the mode of inheritance of bean rust resistance was entirely comparable to Mendelian's genetics.

Dundas (1940) studied the $F_2$ offspring resulting from crosses between resistant Kentucky Wonder and a susceptible variety of snap beans. He found that host resistance to bean rust was controlled by three main independent dominant factors: A, B, and C. These factors, acting singularly or in combination, resulted in resistance to particular races of the rust pathogen. Each susceptible bean variety varied in the degree of resistance due to the presence or absence of the three factors.

Coyne and Schuster (1975) stated that snap bean varieties grown in many parts of the world are highly vulnerable to infection by *Uromyces phaseoli typica*. This was due to the presence of a very narrow genetic base and vertical resistance, which provided only temporary protection. They proposed altering bean breeding strategies to develop new varieties with a more permanent resistance to rust infection. This could be accomplished by gene manipulation involving multilines, multiplasm, horizontial resistance, gene pyramiding, and gene deployment.

Examination of the mechanism of host resistance to the pathogen's invasion was undertaken. In his early breeding work, Wingard (1935) recognized this mechanism as one of host hypersensitivity, or host response to the presence of the rust pathogen. This reaction resulted in the quick death of host cells around the pathogen and of the pathogen itself. Furthermore, he determined that this response triggered a sudden vegetative growth on the part of the host bean plant.

Using the SEM, Littlefield and Heath (1979) further explored this phenomenon of hypersensitivity in *Phaseolus vulgaris*. The level of response was found to vary with variety, depending upon the host's susceptibility and the race involved. However, in all varieties, several features appeared to be universally associated with hypersensitivity. First, the cytoplasm of both the invaded cell and the haustorium was completely disorganized. This cellular disorganization sometimes appeared in several adjoining cells. Secondly, depositing membraneous material on penetrating haustoria resulted in both cell and haustorium death. Littlefield and Heath concluded that further study was needed in different bean varieties to determine all facets of hypersensitivity.

## II. APPLICATION OF SPRAY MATERIAL

### Uniform Coverage

Uniform coverage in the application of non-systemic, protectant fungicides is necessary for the control of Uromyces phaseoli typica. Sharvell (1979) concluded that these fungicides, to be effective, must be uniformly applied to provide a blanket of protection against tissue penetration by fungus spores. The spores, which are minute in nature, required only a small area of unprotected leaf tissue to germinate and infect the bean plant. He determined that missed areas of spray coverage served as potential sites for spore germination and subsequent penetration.

Questions often arise as to the optimum quantity of protectant fungicide to apply in obtaining uniform coverage against bean rust infection. Sharvelle (1979) found that as excessive amounts of fungicide sprays were applied, runoff of the spray droplets occurred. This resulted in the loss of the protective residue and exposed unprotected leaf tissue. Therefore, the most effective fungicide applications are those of adequate volume, applied as fine mist sprays. Solutions such as this permit maximum particle deposition and coverage.

Since the bean rust pathogen can penetrate the host through both leaf surfaces, fungicide coverage of both upper and lower leaf tissues is necessary. The number of nozzles per row is very important in achieving this adequate spray coverage. The objective of disease protection with fungicide sprays is to sufficiently cover leaf surfaces with a uniform residue. Many applicators make the mistake of drenching bean plants with an unnecessarily large volume of spray material in the form of large spray droplets. Instead, they should strive for an optimum volume of smaller-sized droplets in uniform application. Himel (1969b) concluded that during normal agricultural pesticide application, sprayer pressure varied between 30 and 40 psi. Moreover, he found that increasing the sprayer pressure resulted in smaller-sized particles. These droplets were found to be more efficient in foliage penetration, thus resulting in more uniform coverage. However, Kepner et al. (1972) warned applicators that a reduction in droplet size resulted in decreasing spray coverage if droplets became too small. Problems associated with drift and impingement of small spray droplets on the plant surface were the cause of this reduced coverage. Therefore, necessary components for uniform spray coverage are an adequate number of nozzles, application rate, and spray droplet size.

Coverage Evaluation

Brittain et al. (1955) used the titrimetric technique in evaluating deposits of pesticides containing copper. The method was quick and easy to perform. A sample of leaves was placed in a wash solution to remove the pesticide. Following removal of the leaves, potassium iodide was added to the solution. The potassium iodide reacted to release available free iodine. A starch indicator was added, turning the solution dark blue. Finally, sodium thiosulfate was added until clearing occurred in the solution. This was due to the reaction of sodium thiosulfate with free iodine. The addition of sodium thiosulfate was directly proportional to the copper present in the solution. Unfortunately, titrimetric analysis can only be used with pesticides containing copper; and the procedure gave no information about the uniformity of leaf coverage.

Polarography was used by Ban and Carleton (1955) in the evaluation of dust deposits. Polarographic chemical analysis was based on the electrolysis of a solution of electrooxidizable or electroreducible substances by an electrolyte. One of the electrodes used in the electrolysis procedure consisted of mercury falling dropwise from a capillary tube. From this dropwise distribution, a unique current voltage could be plotted. Examination of this curve allowed the quality and quantity of all substances present to be determined. Using polargraphic analysis, Brazee (1963) concluded that the technique was extremely sensitive to the detection of minute concentrations of substances. Moreover, he found polarography to be a fast and accurate technique in evaluating deposition efficiency of organic or inorganic dusting and spraying materials.

Wilkes and Brazee (1963) discovered the use of activation analysis techniques in coverage evaluation. The procedure involved chemical analysis using atomic energy. The process began by the irradiation of a material with nuclear particles. Some of the atoms present in the material would interact with the nuclear particles and be converted into radioactive isotopes. Using a gamma ray spectrometer, quantitative measurements of the radioactive isotopes were made. The technique was fast and highly sensitive. Furthermore, they concluded that with further studies the procedure could be beneficial in determining uniformity of leaf coverage.

During the late 1950's Staniland (1959) developed the fluorescent tracer technique for the study of spray and dust deposits. He classified the tracer materials into four categories: (1) luminescent powders, (2) fluorescent powders, (3) water-soluble dyes, and (4) oil-soluble dyes. Following tracer application, examination of leaf samples under an ultraviolet light source revealed droplet concentration and coverage. Staniland proposed that the fluorescent tracer technique would be beneficial in the following areas: (1) soil studies, (2) spraying hazards, and (3) experimental work with insectides.

At about the same time, Liljedahl and Strait (1959) examined another type of fluorescent tracer system. Spray containing fluorescent material was collected on a paper strip. The paper was passed under a scanning chamber which illuminated it with ultraviolet light. The fluorescence was then measured by a photocell. The photocell was amplified and recorded on a strip chart recorder. The recorder graphically traced the distribution of spray droplets collected on the paper. This technique proved to be extremely accurate and rapid in determining spray coverage.

Yates and Akesson (1963) used fluorescent tracers for quantitative microresidue residue. Applications of the fluorescent material, Brillant Sulpho Flavine, were applied in combination with the desired pesticide. Leaf samples were collected and subjected to analysis by the Turner Model 110 fluorometer. The fluorometer served to measure and record the amount of fluorescent material deposited upon the leaf surface. The technique was also useful in determining spray drift characteristics of a particular pesticide. Stafford et al. (1970) made similar use of the Turner fluorometer in evaluating spray coverage.

Himel (1969a) developed the fluorescent particle (FP) spray droplet tracer technique. The method was useful in identifying spray droplets by size and number. The FP technique was based on the uniform suspension of a known number of solid, insoluble, micron-size, fluorescent (Zn-Cd sulfide) particles in a known volume of non-volatile pesticide. During application, formation of spray droplets resulted in a certain number of FPs being contained in each droplet. When the sprayed droplet impinged on the leaf surface, the insoluble FP groupings were filtered out. Using an ultraviolet light, the FP groups could be examined to determine the number and size of droplets deposited.

## CHAPTER III

## PROCEDURES AND EXPERIMENTAL METHODS

### I. FIELD EQUIPMENT

A medium-volume, two-row hydraulic sprayer was designed and constructed in The University of Tennessee Agricultural Engineering Research Shop. The sprayer, shown in Figure 1, was used to apply various treatments of a fungicide solution and fluorescent particle suspension to snap bean foliage. Data obtained from sprayed bean leaf samples were utilized in evaluating the efficiency of foliar fungicide applications in controlling bean rust.

Sprayer construction began by fabricating a 25-inch by 30.5-inch rectangular steel frame. To the frame, a curved saddle (Century Model F10367) was welded. A 25-gallon polyvinyl tank (Century Model PT25-22D) was mounted on the saddle. An 8-foot boom constructed of 1.25-inch-square steel tubing was attached to the framework. The height of the boom could be manually adjusted by the removal and reinstallation of four bolts which connected the boom to the sprayer frame. Six nozzles were arranged along the boom to accommodate the spraying of 2 38-inch spaced rows in a single pass. This was done by placing a vari-spacing nozzle (TeeJet Type 112) directly over each row and a side-mounted single hose connection (TeeJet Type 6471A-400TD) on either side of the center nozzle as shown in Figure 2. Adjustment of the height and angle of each side-mounted nozzle was also possible.

Figure 1. Medium-volume, two-row hydraulic sprayer used in the application of the fungicide solution and fluorescent particle suspension.

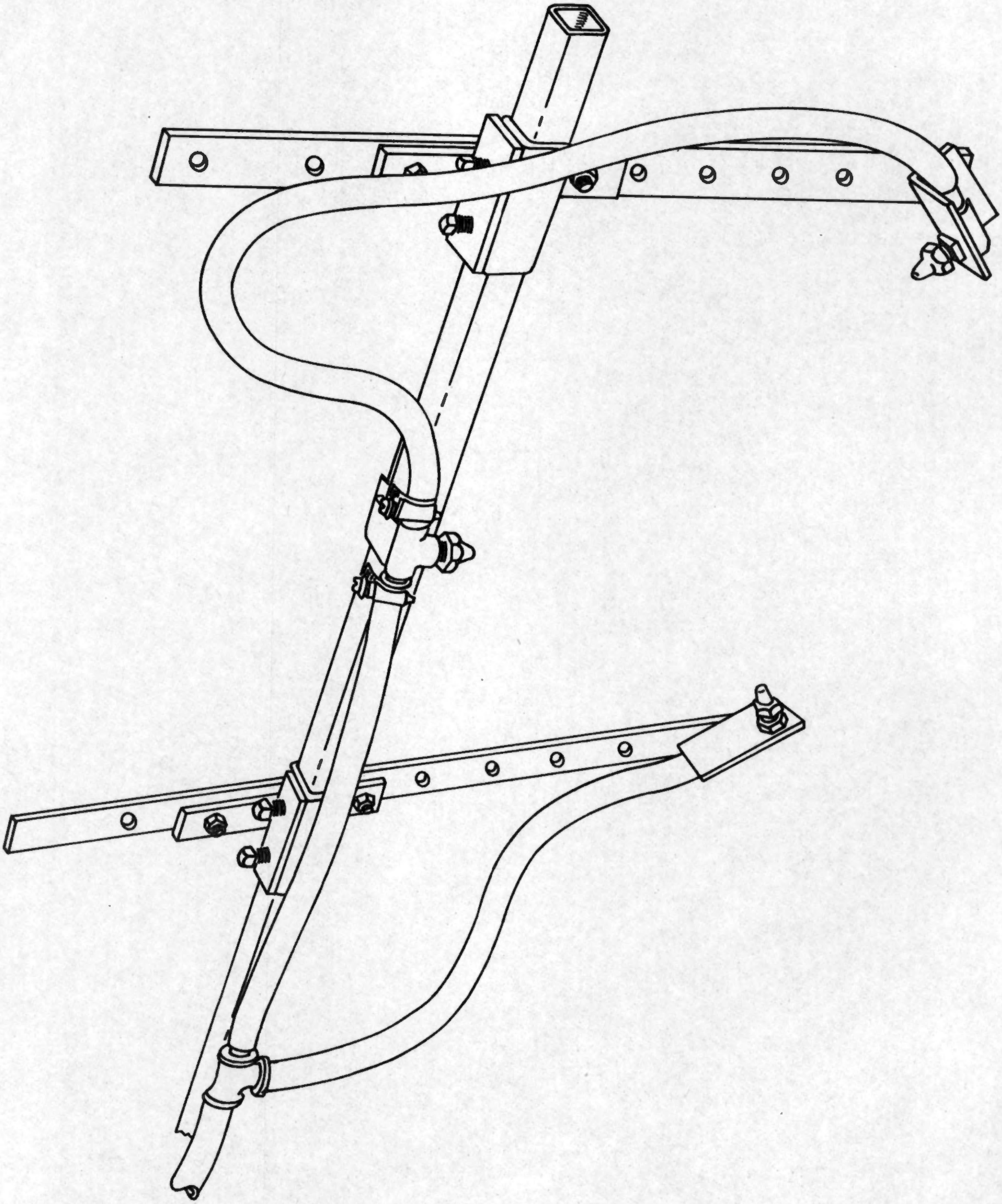

Figure 2. Diagram of nozzle arrangements in relationship to bean foliage.

This was accomplished by the removal and reinsertion of three bolts located along the flat steel bar supporting each nozzle.

The sprayer was equipped with a Hypro roller pump (Model N6500). The pump was driven by the PTO shaft of a John Deere 1020 tractor with a 540 revolution per minute standard power take off speed. Sufficient power was imparted to the pump from the PTO shaft for adequate distribution and agitation of the spray material. Flow paths and system controls are shown schematically in Figure 3.

Prior to the spraying of individual treatments, adjustments were made in the number of nozzles per row, application rate, and sprayer pressure. These adjustments were necessary to obtain the desired flow rate. Since various solution rates were required by different treatments, nozzle tips and cores were regularly changed to meet the needed application rates. Tractor speed necessary for each individual application was determined from earlier sprayer calibration tests using the appropriate treatment pressure.

## II. EXPERIMENTAL DESIGN

Treatments were arranged in a randomized complete block experimental design with a factorial arrangement of treatment combinations. Combinations consisted of 20, 40, or 60 gallons of solution per acre applied at either 50 or 100 psi using 1, 2, or 3 nozzles per row. A total of 18 treatments were possible, excluding a control where no fungicide was applied.

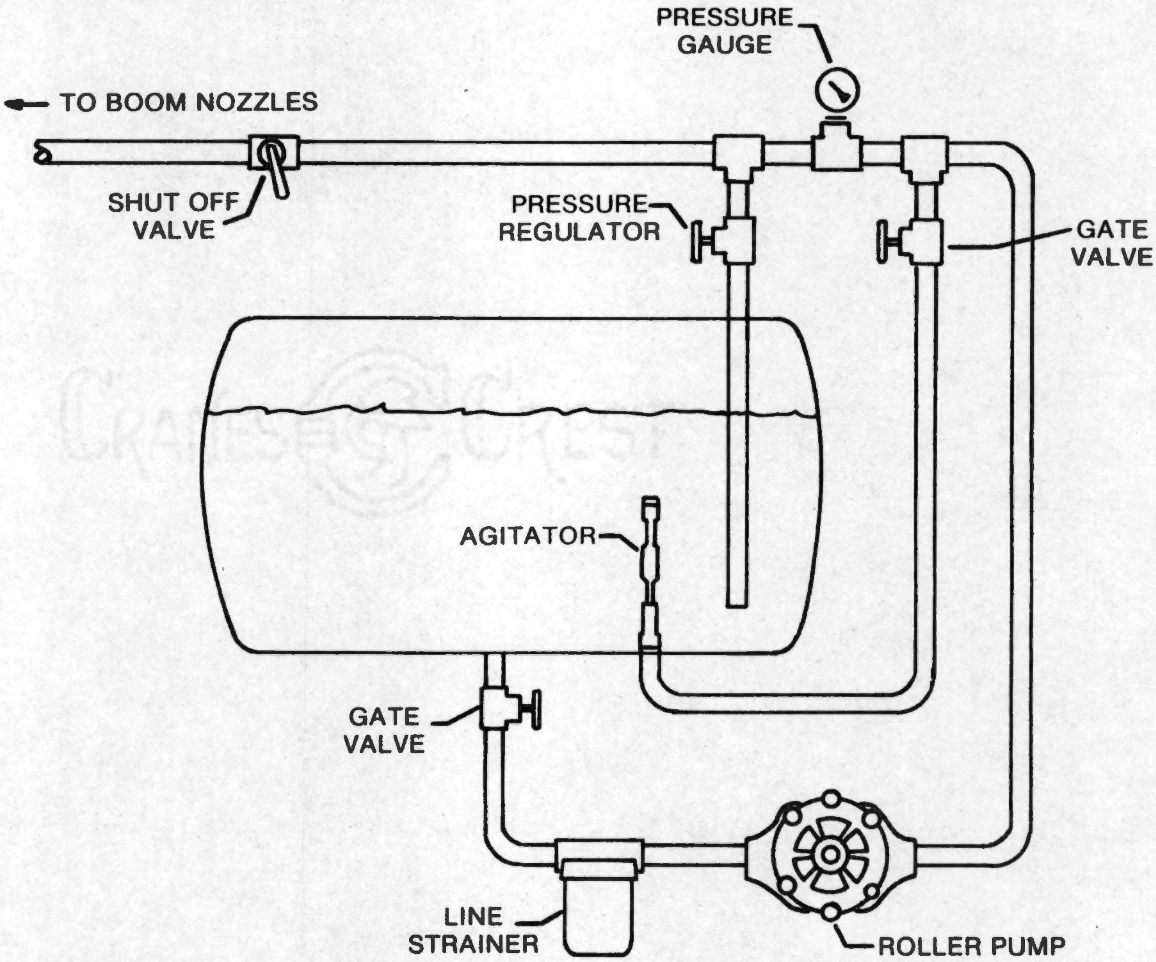


Figure 3. Schematic of the medium-volume, two-row hydraulic sprayer used to apply fungicide formulations.

During the first year of field study, the 18 treatments and a control treatment were replicated 4 times at each of 4 planting dates. Followup work conducted the second year utilized treatments consisting of only 20 or 60 gallons of solution per acre applied at 50 psi using 1, 2, or 3 nozzles per row. These six treatments and a control were replicated five times at three different planting dates.

The experimental unit consisted of four rows of snap beans. The middle two rows of each experimental unit were treated and evaluated for rust control efficiency and uniformity of spray coverage. Evaluation was based upon the observation of trifoliate leaves which were randomly selected from the treated rows. Data representing plant population, bean pod yield, and pod curvature were also obtained for each treatment.

Rust infection rating, percentage of top and bottom leaf surface covered with spray material, plant population, pod yield, and pod curvature were considered dependent variables in the experimental design. Using obtained data, an analysis of variance was conducted on each dependent variable to determine which of the independent variables (number of nozzles per row, pressure, application rate, or planting date) affected them. Number of nozzles per row, pressure, application rate, and planting date were considered fixed effects while replication was treated as a random effect. Means of a given independent variable were separated using Duncan's multiple range tests at the 95 percent level of significance.

## III. PLOT PREPARATION

Snap bean field research was conducted throughout the summers of 1979 and 1980 at The University of Tennessee Plateau Experiment Station near Crossville, Tennessee. During the summer of 1979, 4 plots measuring 240.7 feet by 125 feet were laid out. These plots consisted of 18 treatments and a control, each replicated 4 times. Plots used the following summer were 90.7 feet by 160 feet and contained 6 treatments plus a control, each replicated 5 times. Within each treatment, bean rows were 20 feet in length with a 15-foot work alley between replications.

Prior to planting, each plot received a broadcast application of granular fertilizer according to soil test recommendations. Residue from a winter wheat crop and the fertilizer application were incorporated into the soil by several diskings.

First year plots received EPTC, as a preplant incorporated herbicide applied at the rate of 3 pounds A.I. per acre. Next, a preemergence application of dinoseb was applied at the rate of 40 gallons of solution per acre containing 3 pounds A.I. Second year plots received only a preemergence tank mix application of dinoseb and pendimethalin applied at the rate of 40 gallons of solution per acre. This mixture contained 0.75 pounds of pendimethalin (A.I.) and 3 pounds of dinoseb (A.I.).

Early Gallatin, a snap bean cultivar highly susceptible to rust, was planted in each plot. First year plantings took place on June 20, July 2, July 18, and August 15, 1979. Second year seedings were on June 4, June 24, and July 29, 1980. The soil type was Hartsells fine sandy loam. Plantings were made with a two-row International Harvester plate-type planter with a full runner furrow opener. Row spacing was 38 inches. The snap bean seeds were treated with Orthocide 75, a seed protectant to control seed rotting diseases, and Lorsoban 25-SL, a wettable power insectide. In addition, Terrachlor, a soil fungicide for controlling root rot, was mixed with the seeds in the planter hopper. Plots were mechanically cultivated as needed for weed control.

## IV. TREATMENT APPLICATION

### Foliar Fungicide

Three weeks after snap beans were planted, foliar applications of the non-systemic, protectant fungicide chlorothalonil were initiated. Treatments were continued thereafter on a 7 to 10 day spray schedule until harvest. As shown in Table I, the treatments varied in number of nozzles per row, hydraulic pressure, and solution application rate.

Prior to each application, the hydarulic sprayer was thoroughly cleaned and inspected. Water was flushed through the system to remove any residue, and the strainers were checked for debris. Examination of line hoses and system controls was done to insure proper operation.

Treatment application rates of 20, 40, and 60 gallons of solution per acre were obtained by mixing 0.625 pints of chlorothalonil with an appropriate volume of water (2.9, 5.9, and 8.0 gallons,

TABLE I

OPERATING PARAMETERS ASSOCIATED WITH THE VARIOUS TREATMENTS UTILIZED IN THE APPLICATION OF THE FOLIAR FUNGICIDE

| Treatment Number | Number of Nozzles Per Row | Application Rate (gallons/acre) | Fluid Pressure (pounds/square inch) |
|---|---|---|---|
| 1 | 1 | 20 | 50 |
| 2 | 1 | 40 | 50 |
| 3 | 1 | 60 | 50 |
| 4 | 1 | 20 | 100 |
| 5 | 1 | 40 | 100 |
| 6 | 1 | 60 | 100 |
| 7 | 2 | 20 | 50 |
| 8 | 2 | 40 | 50 |
| 9 | 2 | 60 | 50 |
| 10 | 2 | 20 | 100 |
| 11 | 2 | 40 | 100 |
| 12 | 2 | 60 | 100 |
| 13 | 3 | 20 | 50 |
| 14 | 3 | 40 | 50 |
| 15 | 3 | 60 | 50 |
| 16 | 3 | 20 | 100 |
| 17 | 3 | 40 | 100 |
| 18 | 3 | 60 | 100 |
| Control | - | - | - |

respectively). Slight agitation of the chlorothalonil-water mixture was necessary to obtain the desired fungicide solution.

Sprays were directed onto the middle two rows of each four row experimental unit. Necessary adjustments were made in hydraulic pressure and number of nozzles per row for each application rate. Tractor speed to apply the different treatments had been determined from earlier sprayer calibration tests.

Following the completion of all spraying operations, the sprayer was cleaned and stored for later use. This fungicide application procedure was used during both summers of research.

Fluorescent Particle Tracer Suspension

When the snap beans of one planting reached bloom stage, Himel's (1969a) FP spray droplet tracer method was used to evaluate the coverage of the fungicide treatments obtained with each combination of application rate, pressure, and number of nozzles. Sprayings were identical to those utilized in the application of the fungicide solution with the exception of a FP suspension, being substituted for the chlorothalonil-water formulation.

The method was based upon a uniform suspension of a known number (2 x $10^{10}$ FPs per gram) of solid, insoluble, micron-sized, fluorescent (Zn-Cd sulfide) particles in a known volume of a non-volatile liquid (Himel, 1969a). As the spray droplets came in contact with the foliage, the carrier evaporated or was absorbed by the leaf, leaving the area of foliage covered with a number of FPs.

In the experiment, 189 grams of FPs were added to 378 grams of Arlacel 83 and 400 ml of dioctyl phthalate (DOP). Arlacel 83 served as a suspension stabilizer and dispersant for the fluorescent particles. The DOP served as the carrier portion of the suspension. The suspension was placed in a magnetic blender and slowly agitated for two days before spraying. This was necessary to insure proper dispersal of the FPs.

Prior to application, the sprayer was thoroughly cleaned and dried. Several gallons of kerosene were sprayed through the machine to remove any foreign material, especially water. Sprayer hoses were then disconnected and allowed to drain and dry thoroughly.

The FP suspension was divided into thirds with 133 ml set aside for each spraying application rate. Additional DOP was added to the tank to raise the volume to the necessary amount for each application rate. Special emphasis was given to agitation of the mixture during spraying operations.

The middle two rows of each four-row experimental unit were treated. Due to the limited quantity of DOP available, only three of four replications in the plot were sprayed.

After all treatments were applied, the sprayer was cleaned by flushing several gallons of kerosene through the applicator. The FP spray droplet tracer method was applied to the third planting in 1979.

# V. FIELD DATA ACQUISITION AND EVALUATION

## Rust Symptoms

When snap beans reached harvest maturity, trifoliate leaves from each treatment were inspected for rust symptoms. From each experimental unit, 10 trifoliate leaves were randomly selected from the middle 2 treated rows. The leaves were placed in paper bags which were coded by planting date, replication, and spray treatment.

Upon returning from the field, severity of disease on each leaf was estimated by visual observation of the number of rust pustules per trifoliate. Using a scheme similar to that described by Hilty and Mullins (1976), a rating scale of 1 (none or few pustules) to 5 (numerous pustules) was utilized to depict the severity of rust infection. For a given trifoliate from a particular treatment a rust rating was subjectively assigned and recorded on a data sheet.

In addition to the rust rating obtained for each treatment, plant population, pod yield, and pod curvature were also recorded. A yardstick was randomly placed alongside a section of the two treated rows in each four-row experimental unit. A 3-foot section was taken from each treated row. The number of plants in the designated sections were counted. Plants were then stripped of all bean pods. The pods were placed in a coded bag. Upon returning to the laboratory, the bags were weighed to determine the yield for a particular treatment. Finally, the pods harvested from each plot were evaluated for pod curvature. Twenty-five mature pods (sieve size 5) were randomly selected and examined for extreme curvature. The percentage of severely curved pods was determined.

Spray Coverage

After spraying the FP suspension, the foliage was allowed to dry. This process required approximately eight hours. From the treated rows 12 trifoliate leaves were randomly selected. The leaves were removed from the bean plant with special care to avoid disturbing the FPs deposited on the leaf surfaces. Each trifoliate was then placed in a separate paper bag. The bags were coded by planting date, replication, and treatment.

Laboratory analysis of the trifoliate leaves did not occur for several weeks. Therefore, upon being brought from the field, the leaves were pressed and stored in a cool area away from direct sunlight.

The analysis began by carefully removing the trifoliate from the paper bag. Determination of treatment coverage was accomplished by the use of two Spectroline (Model B-100) ultraviolet lamps. When placed side by side at 45° angles to the leaf surface, the lamps provided excellent illumination of the FPs on the leaf. For a given trifoliate, the percentage top and bottom leaf surface coverage was subjectively estimated by visual observation. These percentages were recorded with the corresponding treatment on a data sheet.

## CHAPTER IV

## RESULTS AND DISCUSSION

### I. PERCENTAGE OF LEAF COVERAGE

Mean percentages of top and bottom leaf surface coverage indicated by the FP technique are shown for the various treatments in Table II. Due to the limited amount of carrier (DOP) available, three treatments in two of the replications were not completed in the FP spraying operation. These treatments all involved the use of three nozzles per row in the application of the FP suspension. Inclusion of data from these partially treated plots resulted in biasing the mean values obtained. Therefore, the data from the three incomplete treatments were omitted from the analyses of variance and Table II.

As the application rate was increased from 20 to 60 gallons per acre, increases in the mean percentages of both top and bottom leaf surface coverage occurred. Top leaf surface coverage means were 63, 75, and 77 percent for the 20, 40 and 60 gallon per acre application rates, respectively. Bottom leaf surface coverage means were 29, 43, and 44 percent, respectively, for the same application rates. These increases in percentage surface coverage, though substantial, were not proportional to the fixed rate increases. Mean separation by Duncan's multiple range tests indicated that the 40 and 60 gallon per acre applications did not differ significantly on either the top or bottom leaf surfaces. However, the 20 gallon per

TABLE II

MEAN PERCENTAGE OF TOP AND BOTTOM LEAF SURFACE COVERAGE FOR THE FP APPLICATIONS

| Number of Nozzles Per Row | Fluid Pressure (pounds/square inch) | Application Rate (gallons/acre) | Coverage of the Top Leaf Surface (percentage of total surface) | Coverage of the Bottom Leaf Surface (percentage of total surface) |
|---|---|---|---|---|
| 1 | 50 | 20 | 48 | 12 |
| 1 | 50 | 40 | 54 | 19 |
| 1 | 50 | 60 | 67 | 17 |
| 1 | 100 | 20 | 58 | 19 |
| 1 | 100 | 40 | 74 | 12 |
| 1 | 100 | 60 | 74 | 29 |
| 2 | 50 | 20 | 80 | 34 |
| 2 | 50 | 40 | 78 | 60 |
| 2 | 50 | 60 | 84 | 60 |
| 2 | 100 | 20 | 68 | 49 |
| 2 | 100 | 40 | 83 | 48 |
| 2 | 100 | 60 | 75 | 46 |
| 3 | 50 | 40 | 72 | 53 |
| 3 | 100 | 40 | 86 | 61 |
| 3 | 100 | 60 | 84 | 61 |

acre application rate differed significantly from the other 2 application rates in both top and bottom leaf coverage. This result lends support to Sharvelle's (1979) findings regarding a possible fungicide runoff occurring at high application rates and affecting spray coverage. Even at the highest application rate (60 gallons per acre) only 60 percent of the total leaf surface was covered. This implies that little or no protection was offered against spore germination on 40 percent of the bean leaf surface for any given application. Therefore, the continual use of a protectant fungicide at regular intervals appears essential for controlling spore germination, thus preventing bean rust from developing.

The effect of sprayer pressure on treatment coverage was also investigated. Results showed that as sprayer pressure was increased from 50 to 100 psi, the mean percentage of leaf surface coverage increased. The mean percentage of top leaf surface coverage at 50 and 100 psi was 70 and 75, respectively. Similarly, the bottom leaf surface coverage means were 37 and 40 percent, respectively. F-test results indicated that bottom leaf coverage was not significantly affected by pressure. However, top leaf coverage did differ significantly for the two pressures. These results agreed with Himel's (1969b) findings which stated that as sprayer pressure increased, droplet size decreased, resulting in greater leaf coverage due to increased foliage penetration by the smaller spray droplets.

Another area of interest was the effect of the number of nozzles per row on leaf coverage. As the number of nozzles per row was increased, the mean percentage of both top and bottom leaf surface coverage increased. The mean percentage of top leaf surface coverage for the 1, 2, and 3 nozzles per row was 63, 78, and 81, respectively. The mean percentage of bottom leaf surface coverage was 18, 50, and 59 for the 1, 2, and 3 nozzles, respectively. Using Duncan's multiple range tests, the top leaf coverage for the two and three nozzles per row did not differ significantly from each other, but both differed significantly from the one nozzle per row arrangements. All nozzle arrangements differed significantly for bottom leaf coverage. This was due to the side-mounted sprayer nozzles in the two and three nozzles per row treatments. As the number of nozzles per row was increased, significant increases in spray coverage on the underneath portion of the leaf resulted.

## II. RUST RATING

Analyses of data were performed by planting data due to anticipated increasing rust infection later in the growing season. Therefore, each planting date was treated as a separate experiment for the statistical analysis. Rust rating means obtained for the 18 fungicide treatments and control for the various planting dates are shown in Tables III-VI.

For the first planting date, rust rating means were 1.2, 1.2, and 1.2 for the 1, 2, and 3 nozzles per row, respectively. Rust rating means for both 50 and 100 psi fungicide treatments were 1.2 and 1.2, respectively. The rust rating means for the 20, 40, and 60 gallon per

TABLE III

RUST RATING MEANS FOR SNAP BEANS SEEDED JUNE 20, 1979, THE FIRST PLANTING

| Number of Nozzles Per Row | Fluid Pressure (pounds/square inch) | Application Rate (gallons/acre) | Rust Rating |
|---|---|---|---|
| 1 | 50 | 20 | 1.4* |
| 1 | 50 | 40 | 1.2 |
| 1 | 50 | 60 | 1.1 |
| 1 | 100 | 20 | 1.8 |
| 1 | 100 | 40 | 1.3 |
| 1 | 100 | 60 | 1.3 |
| 2 | 50 | 20 | 1.2 |
| 2 | 50 | 40 | 1.3 |
| 2 | 50 | 60 | 1.1 |
| 2 | 100 | 20 | 1.3 |
| 2 | 100 | 40 | 1.2 |
| 2 | 100 | 60 | 1.3 |
| 3 | 50 | 20 | 1.1 |
| 3 | 50 | 40 | 1.3 |
| 3 | 50 | 60 | 1.3 |
| 3 | 100 | 20 | 1.3 |
| 3 | 100 | 40 | 1.2 |
| 3 | 100 | 60 | 1.1 |
| Control | - | - | 2.9 |

*Rust rating mean: 1 = no or few pustules, 5 = many pustules.

TABLE IV

RUST RATING MEANS FOR SNAP BEANS SEEDED JULY 2, 1979,
THE SECOND PLANTING

| Number of Nozzles Per Row | Fluid Pressure (pounds/square inch) | Application Rate (gallons/acre) | Rust Rating |
|---|---|---|---|
| 1 | 50 | 20 | 1.6* |
| 1 | 50 | 40 | 1.3 |
| 1 | 50 | 60 | 1.4 |
| 1 | 100 | 20 | 1.6 |
| 1 | 100 | 40 | 1.4 |
| 1 | 100 | 60 | 1.5 |
| 2 | 50 | 20 | 1.5 |
| 2 | 50 | 40 | 1.2 |
| 2 | 50 | 60 | 1.5 |
| 2 | 100 | 20 | 1.4 |
| 2 | 100 | 40 | 1.4 |
| 2 | 100 | 60 | 1.7 |
| 3 | 50 | 20 | 1.4 |
| 3 | 50 | 40 | 1.5 |
| 3 | 50 | 60 | 1.3 |
| 3 | 100 | 20 | 1.5 |
| 3 | 100 | 40 | 1.6 |
| 3 | 100 | 60 | 1.5 |
| Control | - | - | 2.5 |

*Rust rating mean: 1 = no or few pustules, 5 = many pustules.

TABLE V

RUST RATING MEANS FOR SNAP BEANS SEEDED JULY 18, 1979, THE THIRD PLANTING

| Number of Nozzles Per Row | Fluid Pressure (pounds/square inch) | Application Rate (gallons/acre) | Rust Rating |
|---|---|---|---|
| 1 | 50 | 20 | 1.7* |
| 1 | 50 | 40 | 1.7 |
| 1 | 50 | 60 | 2.2 |
| 1 | 100 | 20 | 1.4 |
| 1 | 100 | 40 | 1.6 |
| 1 | 100 | 60 | 1.8 |
| 2 | 50 | 20 | 1.4 |
| 2 | 50 | 40 | 1.4 |
| 2 | 50 | 60 | 1.5 |
| 2 | 100 | 20 | 1.9 |
| 2 | 100 | 40 | 1.9 |
| 2 | 100 | 60 | 1.6 |
| 3 | 50 | 20 | 1.3 |
| 3 | 50 | 40 | 1.5 |
| 3 | 50 | 60 | 1.7 |
| 3 | 100 | 20 | 1.6 |
| 3 | 100 | 40 | 1.9 |
| 3 | 100 | 60 | 1.4 |
| Control | - | - | 3.0 |

*Rust rating mean: 1 = no or few pustules, 5 = many pustules.

TABLE VI

RUST RATING MEANS FOR SNAP BEANS SEEDED AUGUST 15, 1979, THE FOURTH PLANTING

| Number of Nozzles Per Row | Fluid Pressure (pounds/square inch) | Application Rate (gallons/acre) | Rust Rating |
|---|---|---|---|
| 1 | 50 | 20 | 1.3* |
| 1 | 50 | 40 | 1.3 |
| 1 | 50 | 60 | 1.2 |
| 1 | 100 | 20 | 1.3 |
| 1 | 100 | 40 | 1.2 |
| 1 | 100 | 60 | 1.4 |
| 2 | 50 | 20 | 1.2 |
| 2 | 50 | 40 | 1.4 |
| 2 | 50 | 60 | 1.2 |
| 2 | 100 | 20 | 1.1 |
| 2 | 100 | 40 | 1.1 |
| 2 | 100 | 60 | 1.1 |
| 3 | 50 | 20 | 1.1 |
| 3 | 50 | 40 | 1.1 |
| 3 | 50 | 60 | 1.1 |
| 3 | 100 | 20 | 1.2 |
| 3 | 100 | 40 | 1.1 |
| 3 | 100 | 60 | 1.1 |
| Control | - | - | 3.4 |

*Rust rating mean: 1 = no or few pustules, 5 = many pustules.

acre application rates were 1.2, 1.2, and 1.2, respectively. F-test results and Duncan's multiple range tests indicated that all means for the dependent variable rust rating did not differ significantly from each other within number of nozzles per row, application rate, and pressure. However, all rust rating means for the various treatment parameters were significantly less than the rust rating in the control plot, which was about twice that of any treated plot.

During the second planting date, rust rating means obtained for the 1, 2, and 3 nozzles per row were 1.5, 1.4, and 1.4, respectively. Rust rating means for the 50 and 100 psi fungicide applications were 1.4 and 1.5, respectively. Rust rating means for the 20, 40, and 60 gallon per acre application rates were 1.5, 1.4, and 1.4, respectively. F-test results showed that the 50 and 100 psi rust ratings differed significantly from each other. However, Duncan's multiple range tests indicated that rust rating means within application rate and number of nozzles per row did not differ significantly. At this particular time variations in number of nozzles per row, pressure, and application rate did not appreciably differ in their ability to control bean rust. Nevertheless, rust rating means for the various treatment parameters were substantially less than those of the untreated control.

In the third planting date, the rust rating means for the 1, 2, and 3 nozzles per row had increased to 1.7, 1.6, and 1.6, respectively. The rust rating means for the 50 and 100 psi treatments were 1.6 and 1.7, respectively. Rust rating means for the 20, 40, and 60 gallon per acre application rates were 1.5, 1.7, and 1.7, respectively.

Significant differences were found to exist between the rust rating means using Duncan's multiple range tests and F-test results. First, the rust rating for the two and three nozzles per row differed significantly from the one nozzle per row applications. Next, the 50 and 100 psi fungicide application rates differed significantly from each other. Finally, the 20 gallon per acre application rates differed significantly from the 40 and 60 gallon per acre applications. The rust rating means for the various treatment parameters, though statistically and quantitatively different, are for all practical purposes the same in terms of rust control. Comparison of the rust rating means in the treated plots to those of the control indicated that the rust was markedly more prominent in the untreated plots.

Rust rating means for the fourth planting date, were 1.3, 1.2, and 1.1 for the 1, 2, and 3 nozzles per row, respectively. Rust rating means were 1.2 and 1.2 for the 50 and 100 psi spraying pressure, respectively. The rust rating means for the 20, 40, and 60 gallon per acre application rates were all 1.2, respectively. Duncan's multiple range test indicated that means for the number of nozzles per row all differed significantly from each other. However, F-test results and Duncan's multiple range test also showed that all other rust rating means for pressure and application rate did not differ significantly from each other. From these results the number of nozzles per row would appear to have a significant effect on the control of bean rust. These findings agreed in principle with those demonstrated in the FP spraying operation that as the number of nozzles per row was increased, greater leaf coverage was obtained. Thus, better rust control would be expected. As in the previous plantings, all rust rating means for the treated plots were significantly less than those of the untreated control.

F-test results for the second planting date indicated a significant two-way interaction between the fixed variables number of nozzles per row and application rate. Similarly, in the third planting number of nozzles per row and pressure interacted significantly. Possible human error in treatment applications or data evaluation might account for these significant interactions. However, no plausible explanation exists for these results. Since they did not occur consistently, they will be dismissed as unimportant.

Research conducted during the second year indicated a general absence of rust on bean foliage for two of three planting dates. The existence of rust pustules was found on only the last of the three plantings. Shown in Table VII are the rust rating means for the various treatment combinations in planting three.

Rust rating means for the 1, 2, and 3 nozzles per row were 1.0, 1.0, and 1.0, respectively. For the 20 and 60 gallon per acre application rates, the rust rating means were 1.0 and 1.0, respectively. Using Duncan's multiple range test and F-test results, the dependent variable rust rating did not differ significantly within number of nozzles per row and application rate. Examination of rust rating means seems to imply that rust infection, though existing, was not present in large quantities to allow valid conclusions to be drawn about treatment parameters.

TABLE VII

RUST RATING MEANS FOR SNAP BEANS SEEDED JULY 29, 1980,
THE THIRD PLANTING

| Number of Nozzles Per Row | Fluid Pressure (pounds/square inch) | Application Rate (gallons/acre) | Rust Rating |
|---|---|---|---|
| 1 | 50 | 20 | 1.0* |
| 1 | 50 | 60 | 1.0 |
| 2 | 50 | 20 | 1.0 |
| 2 | 50 | 60 | 1.0 |
| 3 | 50 | 20 | 1.0 |
| 3 | 50 | 60 | 1.0 |
| Control | - | - | 1.5 |

*Rust rating mean: 1 = no or few pustules, 5 = many pustules.

## III. PLANT POPULATION, BEAN POD YIELD, AND POD CURVATURE

For the 18 fungicide treatments and control, plant population, bean pod yield, and pod curvature were monitored and subjected to analyses of variance. Data collection was limited to the second and third plantings of 1979. Plant population, bean pod yield, and pod curvature means are shown in Table VIII and Table IX for the various treatment combinations in each planting.

Plant population, though not affected by bean rust, was recorded to insure that all experimental units had comparable plant stands. The overall population means for the second and third plantings were 35.5 and 33.0 plants per 6 linear feet of row, respectively. Analysis of variance indicated no significant differences between plant populations receiving the various treatment applications.

Yield was determined by stripping all bean pods from the plants within a total of 6 linear feet of row. The overall yield means for the second and third plantings were 1.6 and 2.2 tons per acre, respectively. Comparison of the appropriate overall yield mean to the individual treatment means within the planting indicated that none of the fungicide treatments had a definative effect upon yield.

The percentage of severely curved pods was rated for each treatment. The overall mean portion of severely curved pods for the second and third plantings were 16.4 and 18.6 percent, respectively. The slightly higher curvature mean for the third planting would be expected due to increasing rust pressure later in the growing season of 1979.

TABLE VIII

PLANT POPULATION, YIELD, AND POD CURVATURE MEANS ASSOCIATED WITH TREATMENT APPLICATIONS FOR THE JULY 2, 1979 SNAP BEAN PLANTING

| Number of Nozzles Per Row | Fluid Pressure (pounds/square inch) | Application Rate (gallons/acre) | | Plant Population (plants for 6 ft of row) | Pod Yield (tons/acre) | Curved Pods (percent) |
|---|---|---|---|---|---|---|
| 1 | 50 | 20 | | 35.5 | 1.4 | 15 |
| 1 | 50 | 40 | | 36.0 | 1.5 | 13 |
| 1 | 50 | 60 | | 35.5 | 1.8 | 16 |
| 1 | 100 | 20 | | 35.0 | 1.4 | 17 |
| 1 | 100 | 40 | | 34.5 | 1.3 | 18 |
| 1 | 100 | 60 | | 34.0 | 1.4 | 14 |
| 2 | 50 | 20 | | 37.5 | 1.7 | 17 |
| 2 | 50 | 40 | | 34.5 | 1.6 | 17 |
| 2 | 50 | 60 | | 34.0 | 1.6 | 20 |
| 2 | 100 | 20 | | 39.5 | 1.5 | 15 |
| 2 | 100 | 40 | | 36.5 | 1.8 | 22 |
| 2 | 100 | 60 | | 39.5 | 2.0 | 18 |
| 3 | 50 | 20 | | 34.5 | 1.6 | 10 |
| 3 | 50 | 40 | | 32.5 | 1.6 | 15 |
| 3 | 50 | 60 | | 32.5 | 1.4 | 17 |
| 3 | 100 | 20 | | 32.5 | 1.6 | 19 |
| 3 | 100 | 40 | | 42.5 | 2.1 | 19 |
| 3 | 100 | 60 | | 38.0 | 1.8 | 11 |
| Control | - | - | | 29.5 | 1.4 | 19 |
| | | | $\bar{X}$ = | 35.5 | 1.6 | 16.5 |

TABLE IX

PLANT POPULATION, YIELD, AND POD CURVATURE MEANS ASSOCIATED WITH TREATMENT APPLICATIONS FOR THE JULY 18, 1979 SNAP BEAN PLANTING

| Number of Nozzles Per Row | Fluid Pressure (pounds/square inch) | Application Rate (gallons/acre) | Plant Population (plants for 6 ft of row) | Pod Yield (tons/acre) | Curved Pods (percent) |
|---|---|---|---|---|---|
| 1 | 50 | 20 | 33.8 | 1.9 | 19 |
| 1 | 50 | 40 | 32.0 | 2.3 | 21 |
| 1 | 50 | 60 | 32.5 | 2.8 | 17 |
| 1 | 100 | 20 | 29.5 | 2.3 | 23 |
| 1 | 100 | 40 | 35.0 | 2.2 | 23 |
| 1 | 100 | 60 | 33.0 | 2.2 | 11 |
| 2 | 50 | 20 | 37.0 | 2.6 | 14 |
| 2 | 50 | 40 | 29.5 | 2.1 | 19 |
| 2 | 50 | 60 | 31.5 | 1.5 | 22 |
| 2 | 100 | 20 | 35.3 | 2.2 | 21 |
| 2 | 100 | 40 | 35.3 | 2.6 | 20 |
| 2 | 100 | 60 | 30.8 | 2.7 | 22 |
| 3 | 50 | 20 | 28.8 | 2.4 | 17 |
| 3 | 50 | 40 | 33.3 | 2.4 | 20 |
| 3 | 50 | 60 | 30.3 | 1.7 | 12 |
| 3 | 100 | 20 | 33.0 | 2.0 | 19 |
| 3 | 100 | 40 | 32.5 | 2.3 | 17 |
| 3 | 100 | 60 | 37.0 | 1.5 | 12 |
| Control | - | - | 37.3 | 1.8 | 24 |
| | | $\bar{X}$ = | 33.0 | 2.2 | 18.6 |

Comparison of the appropriate overall pod curvature mean to the individual treatment means within the planting date showed that none of the fungicide treatments significantly affected pod curvature.

CHAPTER V

# SUMMARY AND CONCLUSIONS

## I. SUMMARY

A medium-volume, two-row hydraulic sprayer was constructed and employed for application of various treatments of a fungicide solution and a FP suspension to snap bean foliage. First year treatments consisted of 20, 40, or 60 gallons of solution per acre applied at either 50 or 100 psi using 1, 2, or 3 nozzles per row. Treatments utilized during the second year's research included only the 20 and 60 gallon per acre application rates applied at 50 psi. Seven plantings in 1979 and 1980 were treated and evaluated for rust control efficiency and percentage of leaf surface coverage.

Fungicide applications were initiated 3 weeks after seedling emergence and were repeated thereafter on a 7 to 10 day schedule until pod harvest. Rust control efficiency was rated for 10 trifoliate leaves randomly selected from the treated rows. Using Hilty's and Mullins' (1976) rust rating system (1 - no or few pustules, 5 - many pustules), trifoliates receiving the various spray treatments were evaluated for the control of bean rust. Evaluation was based upon subjective visual observation of the trifoliates. To compliment the rust ratings, plant population, pod yield, and pod curvature data were also recorded for the various fungicide treatments.

A suspension containing fluorescent particles was applied when one planting was in the bloom stage. After allowing sufficient time for the FPs to dry on the foliage, 12 trifoliates leaves were randomly selected from the treated rows for the 18 treatment combinations. These trifoliates were placed under ultraviolet lamps which provided necessary light for coverage evaluation. The percentage of both top and bottom leaf surface coverage was visually estimated and recorded.

After all rust rating, leaf coverage, plant population, pod yield, and pod curvature data were recorded, they were subjected to analyses of variance using the Statistical Analysis System (SAS 79).

## II. CONCLUSIONS

The following conclusions were drawn from this study:

1. As the application rate was increased from 20 to 60 gallons per acre, increases in the percentage of both top and bottom leaf surface coverage occurred. These increases in surface coverage, though distinct, were not proportional to the fixed rate increases.
2. Even at the highest application rate, only about 60 percent of the total leaf surface received spray coverage. Therefore, repeated fungicide applications are necessary for the control of germinating bean rust spores.
3. Increasing sprayer pressure from 50 to 100 psi resulted in only slightly greater percentage of both top and bottom leaf surface coverage.

4. As the number of nozzles per row was increased from one to three, the percentage of both top and bottom leaf surface coverage increased. Bottom leaf surface coverage was more markedly influenced by increasing the number of nozzles per row than top leaf surface coverage.
5. In terms of rust control, 20 gallon per acre fungicide applications were just as effective as higher volume applications.
6. One nozzle spraying directly over the row was just as effective in controlling rust as two and three nozzles per row.
7. In terms of rust control, 50 psi fungicide applications were just as effective as 100 psi applications.
8. Yield and pod curvature were not appreciably affected by the various application parameters considered.
9. In all plantings rust rating means for the untreated plots were substantially greater than for any treated plot.

## LITERATURE CITED

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Ark, P. A., J. Dekker, and J. P. Thompson. 1959. Effectiveness of gsl, a new antibiotic. Phytopathology 49(2):112.

Arthur, J. C. 1934. Manual of the rusts in United States and Canada. Purdue Research Foundation, Lafayette, p. 938.

Baldwin, R. E. 1970. Control of snap bean rust with systemic and non-systemic fungicides. Phytopathology 60(7):1013.

Ban, N. J., and W. M. Carleton. 1955. Evaluation of dust deposits by polarography. Agricultural Engineering 36(12):803.

Bell, A. A. 1969. 4-hydroxybenzaldehyde and vanillin as toxins formed in leaf wound sap of phaseolus lunatus. Phytopathology 60(2):161-163.

Bell, A. A., and J. M. Daly. 1962. Assay and partial purification of self-inhibitors of germination from uredospores of the bean rust fungus. Phytopathology 60(3):261-266.

Brazee, R. D. 1963. Application of polarography to pesticide deposit analysis. Transactions of the ASAE 6(2):163.

Brittain, R. W., R. D. Brazee, and W. M. Carleton. 1955. Evaluating dusting and spraying efficiency. Agricultural Engineering 36(12):319.

Calpauzos, L., T. Theis, and C. M. Rivera. 1957. Culture of the rust parasite, darluca filum Phytopathology 47(2):108.

Coyne, D. P., and M. L. Schuster. 1975. Genetic and breeding strategy for resistance to rust in beans. Euphytica 24(3):795-803.

Curtis, C. T. 1966. Effect of light on the germination of uromyces phaseoli uredospores. Phytopathology 46(11):1316-1317.

Daly, J. M., A. A. Bell, and L. R. Krupka. 1961. Respiratory changes during development of rust diseases. Phytopathology 51(7):461-471.

Davis, D., H. J. Becker, and F. F. Rogers. 1959. Chemotherapy of wheat and bean rust diseases with sydnones. Phytopathology 49(12):821-823.

Davison, Arlen D., and E. K. Vaughan. 1963a. A simplified method for identification of races of uromyces phaseoli var. phaseoli. Phytopathology 53(4):456-459.

Davison, Arlen D., and E. K. Vaughan. 1963b. Effect of uredospore concentration on determination of races of rust fungi. Phytopathology 53(10):1138.

Dundas, B. 1940. A preliminary report on the inheritance of resistance to rust (uromyces appendoculatus) in beans (phaseolus vulgaris). Phytopathology 30(9):786.

Dundas, B., and G. W. Scott. 1939. Physiologic strains of bean rust. Phytopathology 29(9):820-821.

Duniway, J. M. and L. D. Durbin. 1968. Effect of uromyces phaseoli on the water relations of primary bean leaves. Phytopathology 58(8):1049.

Fisher, H. H. 1952. New physiologic races of bean rust (uromyces phaseoli typica). Plant Disease Reporter 36(3):103-105.

Frome, F. D. 1924. The rust of cowpeas. Phytopathology 14(2):67-79.

Groth, J. V., and B. D. Mogen. 1978. Completing the life cycle of uromyces phaseoli var. typica on bean plants. Phytopathology 68(11):1674-1677.

Hart, H., and I. L. Forbes. 1935. The effect of light on the initiation of rust infection. Phytopathology 25(7):715-725.

Harter, L. L., D. F. Andrus, and W. J. Zaumeyer. 1935. Studies on bean rust caused by uromyces phaseoli typica. Journal of Agricultural Research 50:737-759.

Harter, L. L., and W. J. Zaumeyer. 1941. Differentiation of physiologic races of uromyces phaseoli typica on bean. Journal of Agricultural Research 62:717-731.

Hikida, H. R. 1961. Race 33 of uromyces phaseoli var. typica arth., a distinct physiologic race of bean rust from origin. Plant Disease Reporter 45(5):388.

Hilty, J. W., and C. A. Mullins. 1975. Chemical control of snap bean rust. Tennessee Farm and Home Science 93:4-5.

Hilty, J. W., and C. A. Mullins. 1976. Snap bean rust - a continued threat. Tennessee Farm and Home Science 98:29.

Hilty, J. W. 1980. Personal interview.

Himel, C. M. 1969a. The fluorescent particle spray droplet tracer method. Journal of Economic Entomology 62(4):912-916.

Himel, C. M. 1969b. The optimum size for insectide spray droplets. Journal of Economic Entomology 62(4):919-925.

Ikegami, H. 1968. Heat-induced susceptibility of beans to rust. Phytopathology 58(6):773-775.

Kantzes, J. G., and L. O. Weaver. 1967. Chemical control of bean rust. Phytopathology 47(7):646.

Kenaga, C. B. 1974. Principles of phytopathology. Bolt Publishers, Lafayette, pp. 316-318, 362.

Kepner, R. A., R. Bainer, and E. Barger. 1972. Principles of farm machinery. AVI Publishing Company, Westport, p. 272.

Liljedahl, L. A., and J. Strait. 1959. Spray deposits measured rapidly. Agricultural Engineering 40(6):332.

Littlefield, L., and M. C. Heath. 1979. Ultrastructure of rust fungi. Academic Press, New York, pp. 208-241, 246-248.

Marcus, C. P., Jr. 1952. A new physiologic race of rust (uromyces phaseoli typica arthur) causing losses to beans in Maryland. Phytopathology 42(16):342.

Pridham, J. C., and et al. 1956. Antibiotics against plant disease. Phytopathology 47(10):568-574.

Richmond, D. V., and R. J. Pring. 1978. Some cytological effects of systemic fungicides on fungi and plants. Netherland Journal Plant Pathology 83(1):403-410.

Sappenfield, W. P. 1954. A new physiologic race of bean rust (uromyces phaseoli typica) from New Mexico. Plant Disease Reporter 38(4):282.

Schein, R. D. 1961. Temperature conversion of rust response of bean. Phytopathology 51(7):486-488.

Schein, R. D., and J. A. Snow. 1963. Stomata as infection courts. Phytopathology 53(3):352.

Schipper, A. L., and C. J. Mirocha. 1969. The histochemistry of starch depletion and accumulation in bean leaves at rust infection sites. Phytopathology 59(4):1416-1422.

Schmeling, B. V. and M. Kulka. 1966. Systemic fungicidal activity of 1,4-oxathiin derivatives. Phytopathology 66(8):659-660.

Shands, W. A., Jr. and R. D. Shein. 1962. Time-temperature interactions of uromyces phaseoli during spore germination and tube elongation. Phytopathology 58(10):1068.

Sharvelle, E. G. 1979. Plant disease control. AVI Publishing Company, Westport, pp. 39-45.

Snel, M. and L. V. Edington. 1968. Fungitoxicity, uptake, and translocation of two oxathiin systemic fungicides in beans. Phytopathology 58(6):1068.

Stafford, E. M., J. B. Byass, and N. B. Akesson. 1970. A fluorescent pigment to measure spray coverage. Journal of Economic Entomology 63(3):769.

Staniland, L. N. 1959. Fluorescent tracer techniques for the study of spray and dust deposits. Journal of Agricultural Engineering Research 4:110.

Story, G. E., J. C. Sharp, and M. W. Moon. 1970. A new systemic fungicide for the control of rusts. Phytopathology 60(9):1316.

U.S.D.A. 1979. Tennessee agricultural statistics. Tennessee Crop Reporting Service Bulletin T-16, p. 27.

Vaughan, E. K., and S. R. Siemer. 1967. Systemic chemical therapeutants for control of bean rust. Phytopathology 57(2):103.

Waters, C. W. 1928. The control of teliospore and uredospore formation by experimental methods. Phytopathology 18(9):157-213.

Wei, C. J. 1937. Rust resistance in the garden bean. Phytopathology 27(11):1090-1105.

Wilkes, L. H., and J. C. Brazee. 1963. Activation analysis techniques for pesticide tracers. Transactions of the ASAE 6(2):102.

Wilson, E. M. 1958. Rust-tmv cross protection and necrotic-ring reaction in beans. Phytopathology 48(4):228-231.

Wingard, S. A. 1935. Host-parasite relationship in bean rust. Phytopathology 25(1):39.

Yarwood, C. E. 1948. Therapeutic treatments for rusts. Phytopathology 38(7):542-551.

Yarwood, C. E. 1954a. Resistance of bean leaf pulvini to fungi and viruses. Phytopathology 44(2):64.

Yarwood, C. E. 1954b. Acquired immunity from bean rust. Phytopathology 44(9):511.

Yarwood, C. E. 1961. Uredospore production by <u>uromyces phaseoli</u>. Phytopathology 51(1):22-27.

Yarwood, C. E. 1963. Heat therapy of bean rust. Phytopathology 53(11):1313-1316.

Yarwood, C. E. 1968. Selective retention of uredospores by powdery mildews and rusts. Phytopathology 61(8):1325.

Yates, W. E., and N. B. Akesson. 1963. Fluorescent tracers for quantitative microresidue analysis. Transactions of the ASAE 6(2):104.

Zaki, A. I, and R. D. Durbin. 1965. The effect of bean rust on the translocation of phytosynthetic products from diseased leaves. Phytopathology 55(5):528-529.

Zaumeyer, W. J. 1957. Comparative protection of bean leaves from fungus infection by antibiotic treatments of lower and upper surfaces. Phytopathology 57(9):539.

Zaumeyer, W. J. 1960. A new race of bean rust in Maryland. Plant Disease Reporter 44(7):459-462.

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