STUDIES ON THE FOOT AND ROOT ROT DISEASES OF IRRIGATED WHEAT IN THE NORTHERN STATES OF NIGERIA WITH EMPHASIS ON PATHOGENICITY AND SAPROPHYTIC BEHAVIOUR OF CAUSAL FUNGI

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D E C L A R A T I O N

I hereby declare that the whole of the work now submitted as a Thesis for the Master of Science degree in Crop Protection of Ahmadu Bello University is the result of my investigation (except where reference is made to published literature and where assistance is acknowledged) and has not been part of any presentation for any other qualification.

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I. INTRODUCTION

Wheat (Triticum aestivum L.) has been traditionally cultivated in the Sahel and Sudan areas in the northern States of Nigeria for an unknown length of time. Andrews (1968) reported that it was generally grown as a minor crop during the dry season in irrigated gardens on bunds between beds and on the edges of irrigation channels where such existed. Production, however, had been very small and the grains were used for purposes other than bread flour production.

Major interest in local wheat production started in 1959 when the Government of Nigeria decided to develop irrigation schemes in the far North of the country (between latitudes 12° - 14°N) for the cultivation of wheat suitable for bread flour production (Andrews, 1968). Four areas (Fig. 1) were selected: (i) The Rima River Valley near Sokoto - the main location being Wurno,

(ii) Hadejia on the River Hadejia,

(iii) The Yo area near Lake Chad on the Komadugu Yobe River,

(iv) Gambaru, to the South West of Lake Chad on the Ebedji River.

In 1976, the Federal Government gave further boost to wheat production in Northern Nigeria by creating three River Basins, viz: the Chad Basin Development Authority, the Hadejia Jema'are River Basin Development Authority and the Sokoto Rima Basin Development Authority.

At present most of the wheat consumed in the country is imported. Nigeria's current annual wheat needs are in excess of 350,000 tons and the

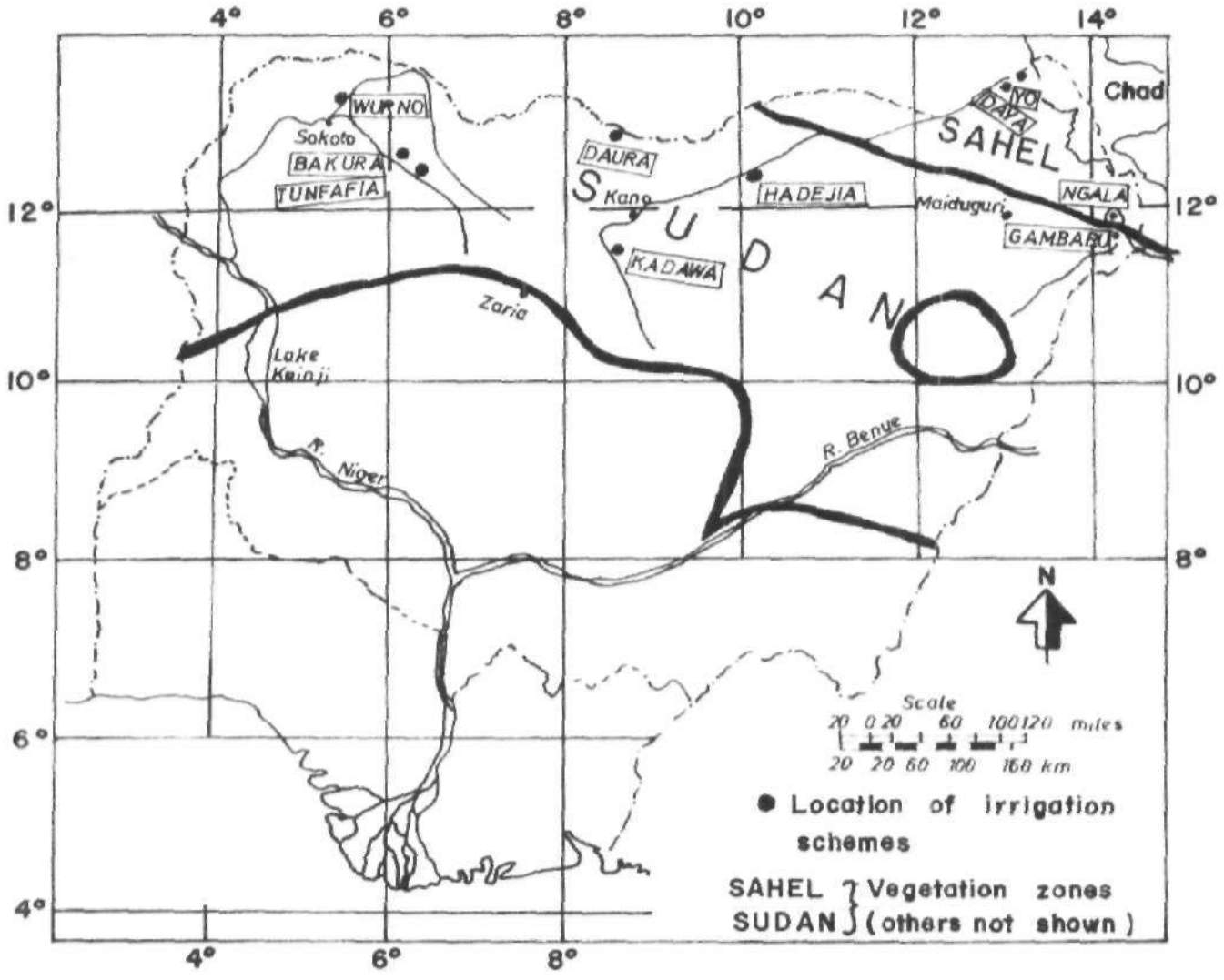


Fig. 1. Map of Nigeria showing locations of irrigation schemes in the northern part of the country.

cost of wheat importation with the growing demand for it, justify the need for increasing domestic production (Abalu, 1977). Estimated total production of wheat in Nigeria in 1978 was 8,000 tons from an area of about 4,000 ha, corresponding to a yield of about 2,000 kg/ha. It is, however, expected that by 1984, wheat production will reach up to 0.23 million tons per annum (Soribe, 1978).

Wheat suffers from many diseases in different parts of the world but in Nigeria, few diseases have been reported on this crop. Those reported include: rusts (Andrews, 1968; Giha, 1976), loose smut, foot and root rots and Alternaria and Helminthosporium leaf spots (Giha, 1976). At present, the crop is either free or suffers little from these diseases. The importance of foot and root rot diseases has, however, been emphasized by Giha (1976). In a recent paper, he has reported that all the Drechslera and Fusarium species found associated with foot and root rots of irrigated wheat in Nigeria are pathogenic to wheat (Giha, 1978). However, the two most important species associated with these diseases are Drechslera rostrata (Drechsler) Richardson and Fraser, and Fusarium equiseti (Corda) Sacc. These pathogens can cause considerable reduction in grain yield when artificially inoculated into wheat (Giha, 1978).

In view of the importance of wheat crop in Nigeria, studies were initiated on some aspects of foot and root rot diseases. Particular attention was given to investigations on pathogenicity and saprophytic behaviour of D. rostrata and F. equiseti, the principal pathogens involved in foot and root rots.

II. REVIEW OF LITERATURE

Over the years, much attention has been devoted to the study of foot and root rot diseases of wheat and other cereals. The work on these diseases has been reviewed by several authors, for example, Bennett (1935), Simmonds (1941, 1953a), Butler (1961), and Sallans (1965).

1. Causal Fungi

(a) Drechslera rostrata

This fungus was first described by Drechsler in 1923 and named as Helminthosporium rostratum. Its current valid name is Drechslera rostrata (Subramanian and Jain, 1966; Richardson and Fraser, 1968).

Drechslera spp. are well known for their cultural and morphological variability. In culture, D. rostrata is made up of several forms, varying from each other in such characters as amount of superficial mycelium, coloration, zonation, and growth rate of colonies (Giha, 1977). The existence of physiologic races had earlier been reported in India (Misra and Mishra, 1971).

The fungus sporulates profusely when infected plant material is incubated in humid chambers but sporulation on artificial media is generally poor (Giha, 1977). Two types of conidia are produced by D. rostrata: the short and elliptical and the long and rostrate. But there appears to be no consistency in the sizes of conidia because long conidia may produce cultures with short conidia and vice versa. Such variations in conidial morphology have been observed by Reddy and Bilgrami (1969) and Chidambaram et al (1973).

(b) Fusarium equiseti

F. equiseti is known to be common in warm temperate, sub-tropical, and tropical areas of the world. The Nigerian isolates are similar in many respects to those from other parts of the world (Giha, 1977). They vary from one another in such characters as amount of aerial mycelium, mycelial organization, chlamydospore formation and sporulation.

2. Symptoms

Giha (1976) reported that in foot and root rot diseases of wheat prevalent in Nigeria, basal stems appear brown and necrotic while the roots are decayed and shed. The crop stand is generally poor and diseased plants are stunted and yellowed, with some dry and dead. D. rostrata and F. equiseti are the main organisms associated with the disease. The former is mainly isolated from basal stems while the latter can be isolated from stems and roots. On the other hand, the main pathogen associated with foot and root rot complex in other parts of the world is D. sorokiniana (Helminthosporium sativum). In many ways, the disease in Nigeria seems to resemble the 'Helminthosporium - Fusarium' foot and root rot disease complex (generally designated as 'Common root rot') known in other parts of the world.

Infection by D. sorokiniana may occur at any stage of development of the wheat plant and variously results in grain rots, pre - and post-emergence seedling blights and root, crown, and foot rot conditions of older plants. In the post-heading phase of crop growth, premature bleaching of the ears and straw, with the resultant production of shrivelled grains is a conspicuous and common symptom of foot and root rots (Simmonds, 1953a); Sallans, 1965). Recently, Giha(1978) has reported that foot and root rot

fungi prevalent in Nigeria may cause considerable reduction in grain yield when artificially inoculated into wheat.

3. Host Range

(a) D. rostrata

Drechsler (1923) isolated this pathogen from the leaf spot of Eragrostis major. Bunting (1927, 1928) reported a similar fungus on maize in Ghana. It has also been found on maize and some graminiaceous hosts in India (Young et al., 1947). Various other reports indicate that it is a common leaf-spotting fungus on a variety of hosts such as rice and wheat (Chattopadhyay and Das Gupta, 1959), maize (Whitehead and Calvert, 1959), millet (Misra and Singh, 1970), sugarcane (Nolia, 1970), sorghum (Misra and Mishra, 1971), and several grasses (Misra et al., 1971). However, there are only two reports which show that D. rostrata can also cause foot rot of wheat (Putterill, 1954; Giha, 1976). These workers isolated D. rostrata along with other fungi from foot-rotted wheat in South Africa and Northern Nigeria, respectively.

(b) F. equiseti

This fungus has been isolated from several crops: mung bean (Nath, Mathur and Neergaard, 1970), curcubits (Joffe and Palti, 1971; Tuvardzhieva, 1974), piper (Singh and Joshi, 1972), citrus (Joffe, 1972), cycas (Subramanyam, Prabhakar and Rao, 1974) and maize (Mensah and Zwatz, 1975).

It is considered as non-pathogenic or weakly pathogenic to wheat roots and stems (Bennett, 1935; Johnston and Greaney, 1942; Oswald, 1949; Zakharova, 1971). However, Joffe and Palti (1967) are of the opinion that

the pathogenic potential of F. equiseti is greatly underestimated. According to them, this fungus is prominently associated with seed infections, wilts and rots of various crops. This view has also been shared by Giha (1976). Joffe (1973) concluded that the pathogenicity of F. equiseti is non-specific.

4. Pathogenicity Testing

While many workers have standardized different techniques to test the pathogenicity of D. sorokiniana and Fusarium spp. on wheat and other cereals, Giha (1978) for the first time developed methods to test the pathogenicity of D. rostrata and F. equiseti on wheat.

Inoculation of seeds or seedlings with heavy spore suspension and fragments of mycelium was used by Johnston and Greaney (1942), Oswald (1949), Ludwig et al (1956) and Giha (1978). Johnston and Greaney (1942) inoculated the seedlings by dipping the entire root system in water suspension of the spores and mycelial fragments of the test fungus. The seedlings were then transplanted into potted soil.

For testing the pathogenicity of D. rostrata Giha (1978) inoculated wheat seeds with dry spores and mycelium of the fungus before sowing them on moist filter papers in petri dishes. In the case of F. equiseti, seeds were inoculated with spore suspension. Infected 12-day-old seedlings were then transplanted into pots filled with sterilized soil. The plants were grown to maturity and assessment made for the loss in grain yield.

In many studies, instead of seeds or seedlings, the soil was infested with inoculum. For this purpose, inoculum was multiplied on a suitable medium. Greaney and Machacek (1938), Johnston and Greaney (1942), and Oswald (1949) grew the test fungi on finely ground oat hull medium. Butler (1953a),

Lucas (1955), Macer (1961) and Deacon (1973) multiplied the test fungi on sand-maizemeal medium while Whittle (1977) incorporated chopped wheat straw into this medium. The rates of application of inoculum to the soil show considerable variation according to the investigator (Johnston and Greaney, 1942; Butler, 1953a; Whittle, 1977).

There is considerable evidence to indicate that infection by root rotting organisms is facilitated by prior injury to the root system of the host (Simmonds, 1953b). Thus wounding or damage of the tissues is necessary for infection by F. equiseti (Iren and Soren, 1973). Injury caused by the application of 2, 4-D, insecticides, fungicides or seed damage, winter injury and wounds produced by insects facilitate infection (Bruehl, 1967). Giha (1976) observed association of termites with wheat plants suffering from foot and root rots. These plants invariably yielded Fusarium spp.

5. Varietal Resistance

No information on varietal resistance in wheat to the two pathogens, D. rostrata and F. equiseti, in Nigeria or elsewhere is available. However, work has been done in various countries with other pathogens such as D. sorokiniana and Fusarium spp. involved in common root rot complex.

Bruehl (1967) reported that work done on development of wheat cultivars resistant to foot and root rots has not been notably successful. All the varieties tested by Butler (1961) were susceptible to most of the Helminthosporium and Fusarium spp. associated with foot and root rot of wheat in Australia. Tests conducted under artificial conditions of infection with D. sorokiniana showed that few cultivars of wheat were tolerant while most were susceptible (Sharp, 1962). Bruehl (1967) reported

that very few cultivars have been found to be resistant to foot and root rot pathogens in the Mediterranean countries and in the steppes of Russia. Also, out of 403 lines assessed in East Germany, only 6 were relatively resistant to root rots caused by Fusarium and Helminthosporium spp. (Pukhal'skil et al.;1977). However, differential susceptibility to common root rot among durum wheat cultivars was reported by McMullen and Stack (1978).

6. Production of Toxic Metabolites and their Relation to Disease

Metabolites of Drechslera spp. implicated in disease include toxins produced by D. victoriae (Luke and Wheeler, 1955); D. oryzae (Orsenigo, 1956); D. sorokiniana (Ludwig, 1957); D. maydis (Lim and Hooker, 1972); and D. apathernae (Deshpande and Gajewar, 1976).

There is no published report of the production of toxic metabolites by D. rostrata but D. sorokiniana, which also causes foot and root rots of wheat is known to produce toxins. Canadian workers (DeMayo et al.,1961, 1962; Spencer et al.,1963) isolated the toxin helminthosporal (C_{15} H_{22} O_2) from the culture filtrate of D. sorokiniana. According to Tamura et al (1963), the Japanese strains of the pathogen did not produce helminthosporal, but only the partially reduced compound helminthosporol (C_{15} H_{24} O_2). This toxin is capable of reducing the shoot and root growth of wheat. Using crude culture filtrate of D. sorokiniana, similar results were reported by Tyagi (1963), and Fit and Hornby (1978). Tyagi (1963) also speculated on the production of a growth factor by the pathogen.

Various species of Fusarium are known to produce phytotoxins (Wood, 1967). Brian et al (1961) isolated several phytotoxic substances from the culture filtrates of F. equiseti, the most phytotoxic being "diacetoxyscirpenol'

Though highly phytotoxic this compound stimulated elongation of cress root at 0.01-0.5ug/ml. Jauch et al (1975) reported that this compound caused yellowing and necrosis of fodder crops. These workers confirmed the presence of a diacetoxy alcohol in the culture filtrates of F. equiseti which they suggested was diacetoxyscirpenol. Both groups of workers observed that root development in cress and fodder crops was reduced when the plants were treated either with the culture filtrate or the toxic substance extracted from it.

7. Saprophytic Behaviour of Causal Fungi

In the life history of root disease fungus, the saprophytic phase is quite important because it affects the recurrence of the disease (Garrett, 1956). Garrett (1956, 1963) discussed in detail the concepts of competitive saprophytic ability. A highly specialized pathogen often showed a low degree of saprophytic ability (Garrett,1956; Rao, 1959; Wastie, 1961). However, D. sorokiniana appeared to have a very low saprophytic ability though it cannot be called a specialized pathogen (Butler, 1953a, 1953c).

Garrett (1963) compared competitive saprophytic ability to pathogenicity in that both imply intrinsic behaviour with respect to a particular specified substrate. Saprophytism, he suggested, should be considered with respect to the dead material of the natural host. However, competitive saprophytic colonization, he stressed, is controlled not solely by the nature of the substrate and the intrinsic competitive saprophytic ability of the fungus, but the environment is also very important. Burgess and Griffin (1967) also emphasized the importance of controlled soil environment. It is only under such conditions that the results of saprophytic colonization experiments

would be meaningful.

Garrett (1956) defined competitive saprophytic ability as the summation of the physiological characteristics that make for success in the competitive colonization of dead organic substrates. The cellulolytic approach for explaining competitive saprophytic ability (Garrett, 1975, 1976) placed emphasis on the adequacy of the cellulolytic rate for making soluble carbohydrates available for the metabolism of the test fungus in the presence of other soil micro-organisms. The differing responses to nitrogen by some root rot fungi for saprophytic survival might be connected with their cellulolytic abilities (Garrett, 1970).

(a) Competitive saprophytic colonization

Pathogenic root-infecting fungi are potentially capable of competing with obligate saprophytes and with some other root-infecting fungi for colonization of dead plant tissue lying in or on the soil (Butler, 1953a, 1953c; Garrett, 1956, 1963, 1970, 1975). Garrett (1970) pointed out that the degree of success in such competitive saprophytic colonization attained by a particular fungus at a given locus in the soil depends upon:

(i) the competitive saprophytic ability of the fungus species for colonization of the particular substrate;

(ii) its inoculum potential at the surface of the substrate; and

(iii) the total soil environment including the microbial population.

Garrett (1963, 1970) stressed that just as pathogenicity is host specific for most specialized parasites, competitive saprophytic ability for saprophytic colonization is also substrate specific.

A quantitative method for assessment of success in competitive saprophytic

colonization of wheat straw by cereal foot rot fungi was developed by Butler (1953a) and Lucas (1955). This method was subsequently employed at Cambridge by Macer (1961) and Deacon (1973). This method, now called the "Cambridge Method", has also been used by Burgess and Griffin (1967) and Gerlagh (1968).

This quantitative method facilitates the work of comparing the competitive saprophytic abilities of several fungi involved in the root rot complex. Garrett (1975) showed that generally, the percentage of substrate units that are colonized, decreases progressively with decrease in inoculum density of the fungus down the dilution series.

Ghurde (1966) tested D. sorokiniana (Helminthosporium sativum), D. rostrata (H. rostratum), D. bicolor (H. bicolor) for their saprophytic ability in colonizing wheat straw in unsterilized soil by direct observation method. He observed that although all the three species spread and sporulated well on straw in contact with soil, D. rostrata displayed a restricted spread in soil. He also observed that aeration favours colonization by all the three fungi and thus under field conditions species of Drechslera probably multiply on stubble on the surface of the soil.

(b) Saprophytic survival

Lying between competitive saprophytic colonization and dormancy is a state termed saprophytic survival (Garrett, 1970). Griffin (1972) distinguished it from dormancy by stressing that it exists at a low level of exogenous respiration, and from saprophytic colonization by its failure to colonize new independent areas of tissue. Garrett (1970) suggested that it is examplified particularly by a parasite surviving in tissues that were

III. MATERIALS AND METHODS

A. COLLECTION OF SAMPLES, ISOLATION OF THE PATHOGENS AND PREPARATION OF INOCULUM

1. Collection of Samples

The two pathogens used in the present investigations were isolated from foot-and root-rotted wheat plants collected from the various irrigation sites in the Northern States of Nigeria. Each sample consisted of a number of wheat plants which were dug up with roots, shoots and ears and transferred to the laboratory in polyethylene bags.

Most of the samples were collected in February and March 1978 when the plants were about two to three months old. Relatively more specimens were collected from water-logged areas (Plates 1 and 2) because the disease incidence was apparently higher in water-logged than in well drained soil.

2. Isolation of the Pathogens

Collected diseased plants were washed clean of soil. Necrotic pieces, each about 3 cm long, were cut from the basal parts of the stem and from roots, surface sterilized with0.5%sodium hypochlorite solution and plated on potato dextrose agar plus streptomycin (PDAS). In addition, some surface sterilized pieces were plated on moistened filter papers in petri dishes.

The two fungi used in this study, D. rostrata (Plates 3a and 3b), and F. equiseti (Plate 4) were brought into pure culture by single spore multiplication. Except F. culmorum, the other fungi isolated from diseased tissues were not studied further. The identity of each fungus isolated was



Plate 1. A typical water-logged area from where some samples of wheat plants affected by foot and root rots were collected.



Plate 2. A wheat field showing an irrigation channel and a water-logged area (far right) caused by water seepage from the channel.

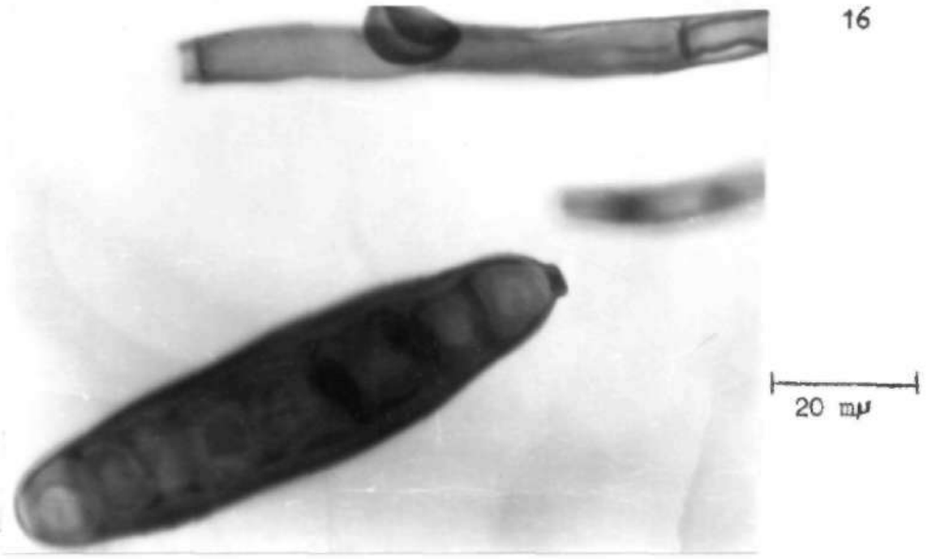


Plate 3a: A spore and hyphae of D. rostrata

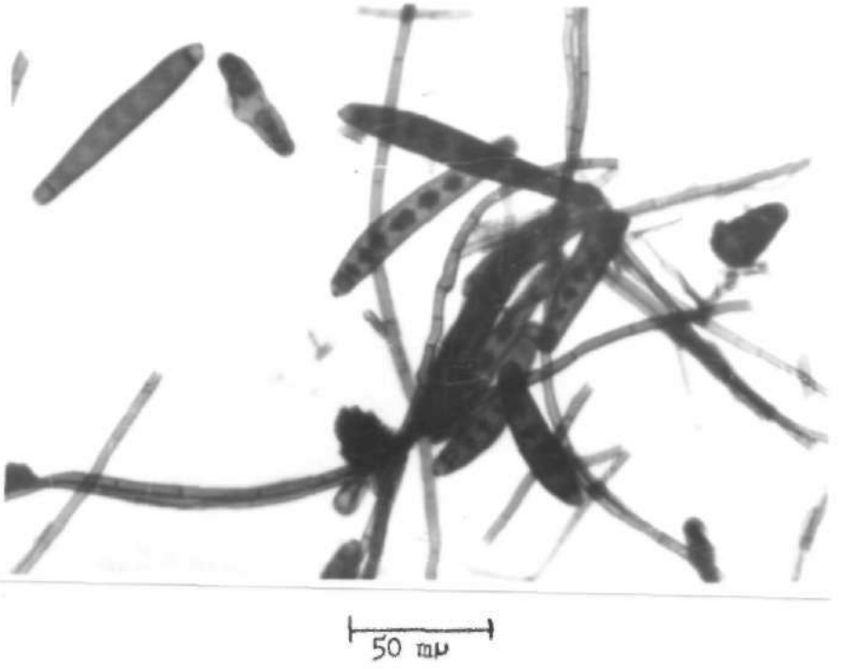


Plate 3b: Spores and mycelium from 14-day-old cultures of D. rostrata on PDAS.



10 mμ

Plate 4: Spores of F. equiseti from 21-day-old culture on PDAS.



10 mμ

Plate 4: Spores of F. equiseti from 21-day-old culture on PDAS.



10 mμ

Plate 4: Spores of F. equiseti from 21-day-old culture on PDAS.

confirmed by comparison with similar cultures in the stock collections of the Plant Pathology Section of the Institute for Agricultural Research (I.A.R.). Those collections include only cultures that have been identified by the Commonwealth Mycological Institute.

The pathogens were maintained in each of the following media from which they were readily recovered when needed:

(a) Under mineral oil

Sporulating agar slant cultures of the different isolates of each pathogen were covered with liquid paraffin and stored at room temperatures.

(b) Autoclaved wheat straw

About 5g of wheat straw pieces, each approximately 3cm long, were mixed with about 150ml of water in 500ml flasks. The flasks were autoclaved twice at 15lb/square inch for 15 minutes. The sterilized wheat straws were then inoculated with two 8mm agar disks of the test fungus. Each fungus grew very rapidly and profusely sporulated. After about three weeks, both the fungus and the straw became dry and the flasks were stored at room temperatures (23° - 32°C).

3. Preparation of Inoculum

The following media were used for the mass multiplication of the pathogens:

(a) Sand-maize meal medium

The sand-maize meal medium (Butler, 1953a) comprised:

100 parts sand, 3 parts ground maize meal and 13 parts water

(weight basis). Each 500ml flask, half filled with medium, was autoclaved at 15lb/square inch for 30 minutes and inoculated with two 8mm agar disks of the test fungus. The medium was stirred with sterile glass rod after two weeks, otherwise the flasks remained undisturbed during the four weeks incubation at room temperatures (23 - 32°C).

(b) Sand-maize meal-chopped wheat straw medium

The sand-maize meal-chopped wheat straw medium (Whittle, 1977) is similar to the sand-maize meal medium (Butler, 1953a) except that 1 part (by weight) of chopped wheat straw was added to the mixture before autoclaving.

(c) Chopped-wheat straw medium

Chopped wheat straws mixed with water were autoclaved and inoculated with the test fungus using the method described earlier in sub-section 2 (b) on p. 18. After 4 weeks of incubation at room temperatures (23° - 32°C), the inoculum was used for soil contamination.

B. PATHOGENICITY TESTS

1. Pathogenicity of *D. rostrata* and *F. equiseti* on 14 Cultivars of Wheat

14 cultivars of wheat obtained from the Plant Breeding Section of I.A.R., were tested for their resistance to foot and root rot diseases. Virulent isolates of the test fungi, KD/4 (*D. rostrata*) and KD/7 (*F. equiseti*), were used. Pathogenicity tests were conducted with plants grown in both petri dishes placed in a glass chamber, and in potted soil.

(a) Petri dish experiment

In the case of D. rostrata dry spores and fragments of mycelium were used as inoculum. This inoculum was obtained by allowing the fungus to grow until the culture medium had dried up. The spores and fragments of mycelium were scrapped off from the surface.

The inoculum of F. equiseti consisted of a spore suspension produced by adding a little sterile distilled water to sporulating cultures which were not completely dry. Each petri dish was gently rotated and the water stirred to release the spores.

Wheat seeds of each variety were surface sterilized with 5% sodium hypochlorite solution and washed in several changes of sterile distilled water. While still wet, seeds of each variety were mixed thoroughly with the inoculum. This ensured a high load of inoculum on seeds. Twenty seeds were plated on moistened sterilized filter paper in each petri dish which constituted a replicate. There were four replicates for each variety or cultivar. In the control, also replicated four times, the seeds were not inoculated. The dishes were arranged in a completely randomized design.

Sterile distilled water was added whenever necessary to each of the petri dishes to keep the filter paper moist. After 12 days, the seedlings were scored for foot and root rots.

(b) Pot experiment

Twenty parts of inoculum, multiplied on sand-maize meal medium, was mixed with 80 parts of unsterilized soil (w/w basis). Ten seeds of each cultivar were then sown in each potted soil. Each pot (12 x 10cm) represented a replicate and there were three replicates for each cultivar. Uninoculated controls were also provided for each cultivar.

All the pots were arranged in a completely randomized design and kept outside the laboratory. Watering was done at regular intervals but water-logging was avoided. After four weeks, the seedlings were dug out, the roots were washed gently with tap water and then scored for the diseases.

2. Pathogenicity of Different Isolates of D. rostrata and F. equiseti on Wheat Cultivar Pitic 62.

Cultures used were derived from pure single spore cultures of both fungi. The pathogenicity of each isolate on wheat cultivar Pitic 62 was tested both in the petri dish and in potted soil. In each case, the method of inoculation and experimental design were identical to those described in sub-section 1a and 1b above (pp. 20-21). Cultivar Pitic 62 was used in this study because of its high susceptibility to foot and root rots.

3. The Relationship Between Inoculum Density and Severity of Foot and Root Rot Diseases caused by D. rostrata and F. equiseti

The purpose of this study was to determine the minimum quantity of the inoculum of each pathogen necessary for successful infection of the host plant. The relationship between inoculum density and disease incidence and/

or severity would serve as a basis of comparing the relative pathogenicities of the two pathogens on wheat. It will also establish the optimum inoculum density needed in future studies.

Each pathogen was multiplied using each of the media described under section A.3 (a - c) on pp. 18-19 . Unsterilized field soil was used to dilute each inoculum in order to produce inoculum : soil ratios of 5:95, 10:90, 30:70, 50:50, and 70:30. Isolates DY/2 of D. rostrata and NG/8 of F. equiseti were used because they were previously found to be the most pathogenic of all the isolates. The plants were inoculated by the following two methods:

(a) Planting seeds in infested soil

Ten seeds of the wheat variety Indus 66 were sown in each of the inoculum-soil mixtures in a plastic pot (12 x 10cm). Each treatment had four replications.

Four weeks after sowing, the seedlings were dug out and the roots were washed free of adhering soil. Shoot and root lengths were recorded and each seedling scored for foot and root rots.

(b) Transplanting seedlings into infested soil

The purpose of transplanting the seedlings was to ensure that the root system was wounded because results of work reported later have shown that such wounds facilitated infection. In this experiment, only inoculum grown on sand-maize meal and sand-maize meal-chopped wheat straw media were used.

The seedlings used were grown on moist filter paper for 10 days, and were approximately of the same height. Five seedlings were transplanted into each pot. All the treatments had four

replications and immediately after transplanting, the soil was well irrigated. Thereafter, watering was done whenever necessary.

The seedlings were dug out four weeks after transplanting and assessed for the diseases.

4. Some Factors Affecting Pathogenicity

(a) The effect of soil sterilization

The experiment was carried out in 12 x 10cm plastic pots. The treatments consisted of flame-sterilized and unsterilized soil. Ten-day-old seedlings of the wheat cultivar Indus 66 grown in sterilized moist sand in a tray, were transplanted to pots containing flame sterilized or unsterilized soil contaminated with the test fungus. Both the sterilized and the unsterilized soil were also used for control in which the soil was not inoculated.

All the treatments had four replications and the pots were arranged in a completely randomized design. Four weeks after transplanting the seedlings were dug out, and scored for the diseases.

(b) The effect of method of inoculation

Plants were inoculated by the following three methods:

(i) Contaminated seeds

Seeds of the cultivar Indus 66 were inoculated as in section B1 (a) on p. 20 and then sown in unsterilized soil. The control consisted of non-inoculated seeds. Each treatment had four replications and the pots were arranged in a completely randomized design. After 4 weeks, the seedlings were dug out and scored for foot and root rots.

(ii) Injury to roots and crowns

Seeds of the cultivar Indus 66 were raised in unsterilized potted soil until they were two weeks old; a 2cm deep furrow was made around the foot of each seedling and filled up with inoculum grown on sand-maize meal-chopped wheat straw medium. Before filling up the furrows, the exposed parts of the crown and stem bases were lightly injured with a flame sterilized needle. Controls were similarly treated except that instead of inoculum, soil was used to fill the furrows. The seedlings were then grown for four weeks and then dug out and scored for the diseases.

In a similar experiment, plants were grown up to maturity and grain weights were recorded.

(iii) Inoculation of seedlings without injury to roots and crowns

This experiment was similar in all respects with the one described in sub-section b(ii) above except that injury was not given to the roots and crowns of the seedlings. Some plants were also grown up to maturity to obtain grain weights.

c. The effect of soil moisture

The inoculum for this experiment was grown on sand-maize meal-chopped wheat straw medium. In the first experiment with each pathogen, seeds of the wheat cultivar Indus 66 were sown in 30:70 (w/w) mixture of inoculum: soil in 12 x 10cm plastic pots. Plants in four pots inoculated with each pathogen were watered twice a day by adding water on the soil surface, while

another four were watered from below by standing each pot in a metal tray containing water.

The pots were arranged in a completely randomized design. The seedlings were dug out after six weeks and scored for foot and root rots.

In the second experiment, 10-day-old seedlings of the same cultivar, raised in moist sterile sand, were transplanted into inoculum-soil mixture similar to that of the first experiment. Plants were also watered by the two methods used in the first experiment. The seedlings were dug out five weeks after transplanting and scored for foot and root rots.

In the third experiment similar to the second, plants were grown up to maturity to facilitate assessment of the loss in grain yield due to each of the pathogens.

d. The effect of soil type

Four types of soil, viz sandy, sandy loam, loam and clay obtained from the Soil Science Section of the I.A.R. were used in this experiment. Seedlings were raised in infested and non-infested soils following the methods described in sub-section 3(a) on p. 22 . Plants were scored for diseases after five weeks.

e. The effect of combined inoculum of D. rostrata and F. equiseti

Isolates KD/2 of D. rostrata and NG/8 of F. equiseti were cultured on sand-maize meal medium. Thereafter, equal proportions of inoculum of the two pathogens were mixed. This mixture was then used for inoculating the soil (30:70 parts by weight of inoculum to soil). Two other treatments consisted of similar inoculum-soil mixture except that pure inoculum of D. rostrata or F. equiseti was used in place of mixed inoculum. Ten seeds

of the cultivar Indus 66 were sown in each of the pots which were then arranged in a completely randomized design. The plants were scored for foot and root rots six weeks after sowing.

5. Production of Toxic Metabolites

Investigations were carried out to determine the effect of cell-free culture filtrate of each pathogen on young seedlings of wheat. Each fungus was grown for the various tests in either Czapek-Dox or Potato Dextrose liquid media.

For the first two tests reported in sub-sections 'a' and 'b' below, each fungus was grown in 80ml of Czapek-Dox liquid medium in 500ml flasks. The flasks were incubated at room temperatures (23° - 32°C) for 10 days. To obtain a cell-free extract, the cultures were passed through Whatman No. 3 filter paper. The crude extract was then centrifuged (2,000 rpm) for 15 minutes and the cell-free supernatant was collected in a beaker. That the supernatant was cell-free was confirmed by the absence of fungal growth when the sample of each supernatant was streaked on PDAS.

(a) The effect of cell-free culture filtrate and/or dry ground mycelial mat on wheat

Twenty surface sterilized seeds of the variety Indus 66 were incubated in each petri dish containing 3-4 filter papers moistened with the cell-free culture filtrate of the test fungus.

In the second treatment, the cell-free filtrate and the dry mycelial mat ground with small quantity of moist sterilized sand were thoroughly mixed and then used to contaminate the seeds before plating on filter papers.

In the third treatment dry ground mycelial mat was used for

contaminating the seeds before plating on filter papers moistened with sterile distilled water. Controls consisted of seeds plated on filter papers, moistened with autoclaved Czapek-Dox liquid medium or sterile distilled water.

All the treatments had four replicates. After 12 days, observations were recorded on seed germination and root length.

(b) The effect of different concentrations of culture filtrate

The cell-free filtrates from still and shake cultures of each fungus were diluted with sterile distilled water to obtain solutions containing the following percentages of crude culture filtrate: 20, 40, 60, 80 and 100. Similarly diluted autoclaved Czapek-Dox liquid medium and sterile distilled water served as controls. The culture filtrate and the controls were changed every 24 hours. After 10 days seed germination, shoot length and root lengths were recorded.

(c) The effect of autoclaving filtrate obtained from still cultures

Each test fungus was grown for 7 days in liquid potato dextrose medium at room temperatures (23 - 32°C). A portion of the cell-free culture filtrate for each pathogen was autoclaved. The effect of autoclaved and non-autoclaved culture filtrate on wheat was tested. In each case 20 surface sterilized seeds of the cultivar Indus 66 were plated on filter paper moistened with one of the following: autoclaved culture filtrate, non-autoclaved culture filtrate, autoclaved potato dextrose liquid medium, and sterile distilled water. Each of these liquids was changed every

24 hours. Data on seed germination, and root length were taken after 72 hours.

6. Disease Assessment

In the present study, the following scale was used for disease assessment:

0 - Healthy vigorous seedlings with no discoloration of stem bases or roots.

1 - Seedlings apparently healthy but with definite brown lesions on the roots; lesions only on leaf sheath, not penetrating through to the culm

2 - Seedlings stunted with severe rotting and discoloration of basal leaf sheath.

3 - Seedlings definitely stunted and containing a severe rotting of the roots and crown.

4 - Seedlings barely emerged and dead or nearly so at the time of scoring.

5 - Seedlings killed prior to emergence.

A mean disease rating was calculated for each replicate by multiplying the number of plants of each class by the class index number, summing the products and dividing by the total number of plants assessed.

C. SAPROPHYTIC BEHAVIOUR

1. Saprophytic Colonization

Two methods were used to study the ability of the test fungi to colonize dead wheat straw.

(a) Cambridge Method. (Butler, 1953a; Lucas, 1955; Macer, 1961; Deacon, 1973).

(i) Preparation of wheat straw and inoculum-soil mixtures

Mature wheat stems were cut into 3.5cm pieces, each piece consisting of a node at the lower end. Cultures grown on sand-maize meal medium were used to prepare inoculum-soil mixtures in which a pure culture of each test fungus was diluted with unsterilized soil to produce media containing the following percentages of inoculum: 100, 95, 90, 70, 50, 30, 10, 5 and 0%.

(ii) The effect of pre-treatment of straw pieces with 2% sodium nitrate + 2% dextrose, 2% dextrose, or distilled water (control), on colonization was studied. Such pre-treatment involved thorough soaking of over 450 straw pieces in each of these solutions for 24 hours before autoclaving.

In the second experiment, the straw pieces were similarly treated except that soaking was done in one of the following 2% ammonium nitrate, 2% urea, 2% sodium nitrate, or distilled water (control).

Twenty-five autoclaved straw pieces were buried in about 200ml of each inoculum-soil mixture in a 9 x 7cm plastic pot. The percentage of straws colonized by each test fungus was assessed after 4 weeks incubation at room temperatures.

(b) Direct observation (Ghurde, 1966).

Sterilized straw pieces (5cm long) were placed in a thin layer of moist unsterilized sand in petri dishes. To ensure adequate

aeration, the surface of each straw piece was partially covered with a thin layer of sand so that some portions of the straw could still be seen.

Inoculum in the form of bars cut from the agar colonies of each fungus was put at one end of each set of 5 straw pieces in each plate. Four such replications were made for each fungus.

All the plates were arranged in a completely randomized design on the laboratory table at room temperatures (23° - 32°C). The colonization of the straw pieces was observed daily with a binocular microscope (x 30). After 10 days, the percentage of straw colonized by each fungus was assessed. F. culmorum was included in this study because Walker (1941) assessed it as a strong saprophyte. The saprophytic ability of each test fungus was then assessed by comparison with that of F. culmorum in this experiment.

- Assessment of saprophytic colonization

  (i) Agar-plate method (Butler, 1953a; Burgess and Griffin, 1967)

  The straw pieces were surface sterilized in 5% sodium hypochlorite solution for 3 minutes and rinsed in several changes of sterile distilled water. They were plated on PDAS at the rate of 5 straw pieces per petri dish and incubated at room temperatures for 7 days.

  Mixed fungal colonies developed from most straw pieces and as a result of this, the total fungal growth was divided into 4 sectors (Rao, 1959). For each straw piece, the test fungus was

assigned a rating of 1, $\frac{3}{4}$, $\frac{1}{2}$, $\frac{1}{4}$ or 0 according to the proportion of the total fungus colony that occupied it. The ratings of the test fungus for each set of straw pieces (with the same treatment) were then summed up and the percentage of straw colonized was calculated.

(ii) Sand-plate method (Butler, 1953a; Rao, 1959; Macer, 1961)

Straw pieces were surface sterilized as in the Agar-plate method and then plated in petri dishes containing moist sterile sand. The plates were then incubated at room temperatures for 15 days and the percentage of straws yielding the test fungus was also recorded as in the Agar-plate method described above.

2. Saprophytic Survival of *D. rostrata* and *F. equiseti* in Wheat Straw Buried in Soil

The same type and length of straw pieces described in sub-section 1(a) on p. 29 were used. They were thoroughly soaked in distilled water for 12 hours and then 500 of such straw pieces were autoclaved in a 1,000ml flask. Five of such flasks were used for each test fungus. Each flask containing straw pieces was inoculated with two 8mm agar disks of the test fungus and incubated for 3 weeks at room temperatures.

At the end of the 3 weeks, 200 straw pieces each were buried in unsterilized soil contained in each 12 x 10cm plastic pot, and incubated at room temperatures for 40 weeks. The soil was kept moist but not waterlogged throughout this period; there was however no special device for moisture control.

A similar experiment was set up, but in this case the soil was enriched with nitrogen (sodium nitrate) at the rate of 2.0g/kg of soil.

Assessment of saprophytic survival

The percentage of each test fungus surviving in the straw pieces was assessed by the Agar plate method described in sub-section C(i) on pp. 30-31.

For each treatment, 10 straw pieces each from any two pots were removed at each sampling. Samples were taken every 4 weeks starting from the end of the 1st week to the 40th when the experiment was terminated.

IV. RESULTS

A. PATHOGENICITY TESTS

1. Pathogenicity of D. rostrata and F. equiseti on 14 Cultivars of Wheat

The germination percentages of seeds of 14 wheat cultivars inoculated with D. rostrata in petri dish experiment were not significantly different (P=0.05) from one another. Analysis of variance shows that for the same cultivars inoculated with D. rostrata, that shoot lengths (Appendix 1b) and the disease intensities (Appendix 1c) are significantly different (P=0.05) from one another. Mean separations by Duncan's Multiple Range test are shown on Table 1. Except for a few cultivars (e.g., Super X and Pitic 62) the suppression in shoot growth was not directly related to disease rating.

By contrast, germination percentages of seeds of the 14 cultivars inoculated with F. equiseti were significantly different (P=0.01) from one another (Appendix 2a). There were also significant differences (P=0.01) between shoot lengths (Appendix 2b) and disease ratings (Appendix 2c). Mean separations by Duncan's Multiple Range test for all these parameters are shown on Table 2 which shows that for most cultivars, there is no consistent relationship between suppression of seed germination, retardation of shoot length and disease intensity. As in the case of D. rostrata, seed inoculation of Super X and Pitic 62 with F. equiseti resulted in both decreased germination and retarded shoot growth which were directly related to disease intensity.

Brown necrosis of the stem bases, crowns and roots on most diseased seedlings was more severe on seedlings grown from seeds inoculated with D. rostrata than on those grown from seeds inoculated with F. equiseti.

Table 1: Pathogenicity of D. rostrata on 14 cultivars of wheat in petri dishe

Cultivar/Line	Disease rating	Germination (% of control)	Shoot length (% of control
Indus 66	1.35^{abc}	83.95^{a}	92.17^{bcdef}
UQ 105	1.07^{a}	80.78^{a}	97.09^{f}
369(354 X Y54)5667	1.80^{cde}	78.06^{a}	95.57^{def}
No. 055	1.26^{ab}	83.11^{a}	89.87^{abcd}
Florence Aurore 8193	1.57^{abcd}	76.92^{a}	96.47^{ef}
Pitic 62	2.7^{f}	76.44^{a}	84.92^{a}
((LeeX10-B)(B55))GB56	1.77^{cde}	72.17^{a}	94.99^{cdef}
Sonora 63	1.75^{bcde}	84.43^{a}	91.95^{bcdef}
301XSon 64-Pi 62	1.12^{b}	78.63^{a}	93.56^{cdef}
Siete Cerros	2.05^{de}	80.52^{a}	90.02^{abcde}
Anza	1.87^{de}	78.45^{a}	86.16^{ab}
067,12300 X LR-8156	2.50^{f}	81.53^{a}	93.83^{cdef}
Tousson	1.97^{de}	78.29^{a}	90.50^{abcdef}
Super X	2.20^{ef}	77.07^{a}	88.48^{abc}

Using Duncan's Multiple Range test, means in each column with the same superscript are not significantly different (P=0.05).

Table 2: Pathogenicity of *F. equiseti* on 14 cultivars of wheat in petri dishe

Cultivar/Line	Disease rating	Germination (% of control)	Shoot length (% of control)
Indus 66	1.29^{de}	87.66^{bcdefg}	97.12^{f}
UQ 105	1.12^{bc}	90.75^{defgh}	95.11^{ef}
369(354XY54)5667	1.56^{gh}	86.03^{bcde}	97.04^{f}
NO. 055	0.91^{a}	$88.15^{bcdefgh}$	94.35^{def}
Florence Aurore 8193	1.39^{de}	88.32^{cdefgh}	97.00^{f}
Pitic 62	1.68^{h}	81.52^{ab}	86.37^{ab}
(LeeX10-B)(B55))GB56	1.29^{de}	92.55^{efgh}	88.19^{abc}
Sonora 63	1.25^{cde}	94.40^{h}	95.00^{ef}
301XSon64-Pi 62	1.04^{ab}	93.76^{gh}	91.90^{cde}
Siete Cerros	0.92^{a}	93.35^{fgh}	90.64^{bcd}
Anza	1.38^{de}	87.03^{bcdef}	85.17^{a}
067,12300XLR-8156	1.36^{de}	85.69^{bcd}	91.31^{cde}
Tousson	1.21^{cd}	83.23^{bc}	91.23^{cde}
Super X	1.52^{fg}	75.37^{a}	95.21^{ef}

Using Duncan's Multiple Range test, means in each column with the same superscript are not significantly different (P=0.05).

In potted soil experiment (Table 3) seedling reactions were similar to those observed in the above petri dish experiments except that the severit of diseases was higher on plants inoculated with F. equiseti than on those inoculated with D. rostrata.

On the basis of disease rating, some cultivars, e.g. 067,12300XLR-8156, Super X and Pitic 62 were very susceptible to both pathogens while the other cultivars such as 369(354XY54)5667 and No. 055 appeared to be resistant. On the other hand, Indus 66, and Sonora 63 were relatively more susceptible to F. equiseti than to D. rostrata.

However both pathogens were successfully isolated from lesions on both apparently susceptible and resistant seedlings in both petri dish and potted soil experiments.

2. Pathogenicity of Different Isolates of D. rostrata and F. equiseti on Wheat Cultivar Pitic 62

In petri dish experiment, observed differences in seed germination percentages of the cultivar Pitic 62, inoculated with different isolates of any of the pathogens (Tables 4a and 4b) were not significant (P=0.05). These tables, however, show that there were significant differences (P=0.01) in shoot length of the same cultivar inoculated with different isolates of either D. rostrata or F. equiseti (Appendices 4b and 5b). Disease intensities caused by the same isolates were also significantly different (P=0.01) from each other. Contrary to expectation, disease ratings obtained in this experiment were much lower than those reported in a previous similar

Table 3: Pathogenicity of D. rostrata and F. equiseti on 14 cultivars of wheat in potted soil

Cultivar/Line	Disease rating	
	D. rostrata	F. equiseti
Indus 66	0.93^{a}	1.60^{abc}
UQ 105	1.47^{bc}	1.67^{bc}
369(354XY54)5667	1.20^{abc}	1.47^{ab}
NO. 055	1.13^{ab}	1.20^{a}
Florence Aurore 8193	1.33^{abc}	1.73^{bc}
Pitic 62	1.73^{c}	2.40^{de}
((LeeX10-B)(B55))GB56	1.33^{abc}	1.93^{c}
Sonora 63	0.93^{a}	2.07^{d}
301XSon64-Pi 62	1.27^{abc}	1.87^{bc}
Siete Cerros	1.60^{bc}	1.93^{c}
Anza	1.07^{ab}	2.00^{cd}
067,12300XLR-8156	1.73^{c}	2.67^{e}
Tcusson	1.33^{abc}	1.60^{abc}
Super X	1.67^{c}	1.80^{bc}

Using Duncan's Multiple Range test, means in each column with the same superscript are not significantly different (P=0.05).

Table 4a: Pathogenicity of different isolates of D. rostrata on wheat cultivar Pitic 62 in petri dishes

Isolate	Disease rating	Seed Germination (%)	Shoot length (cm)
KD/1	0.26	57.98	10.59
DY/2	1.26	50.88	10.23
DY/3	0.84	52.97	11.77
KD/4	1.14	51.90	12.04
KD/5	1.04	51.92	12.45
KD/6	0.54	54.78	14.70
Control	0.04	59.00	14.20
$LSD_{(0.05)}$	0.49	12.04	2.21
S.E.	0.16	3.96	0.73

Table 4b: Pathogenicity of different isolates of F. equiseti on wheat cultivar Pitic 62 in petri dishes

Isolate	Disease rating	Seed Germination (%)	Shoot length (cm)
KD/7	0.94	54.83	12.02
NG/8	1.26	53.76	10.20
NG/9	0.66	50.84	12.91
KD/10	0.44	48.88	13.32
NG/11	0.76	54.83	13.86
KD/12	0.70	57.88	13.42
Control	0.04	59.00	14.20
$LSD_{(0.05)}$	0.43	7.67	1.35
S.E.	0.14	2.53	0.44

experiment (Tables 1 and 2) on the same cultivar. This apparent loss of virulence may be due to long storage under mineral oil and/or subsequent subculturing done to multiply inoculum.

Results obtained with seedlings grown in inoculated potted soil (Tables 5a and 5b) were similar to those in Tables 4a and 4b. Although all the isolates of D. rostrata and F. equiseti were pathogenic on Pitic 62 (Tables 4a, 4b, 5a and 5b) the intensities of foot and root rots caused by them varied. In both experiments, isolates DY/2 of D. rostrata and NG/8 of F. equiseti were consistently the most pathogenic of all the isolates.

3. Relationship Between Inoculum Density and Severity of Foot and Root Rot Diseases caused by D. rostrata and F. equiseti

In general, for each pathogen (irrespective of the method of inoculation and the media on which inoculum was produced), the higher the amount of inoculum in the infested soil, the higher the severity of foot and root rots (Tables 6 and 7). However, higher proportions of chopped straw (50-70%) as a source of inoculum in the inoculum : soil mixtures tended to decrease disease severity on plants grown from seeds sown in infested soil. The reason for this is difficult to explain and consequently the medium was not used in the second experiment in which seedlings were transplanted into infested soil.

For each pathogen, severities of foot and root rots on plants whose seedlings were transplanted into soil infested with the respective

Table 5a: Pathogenicity of different isolates of D. rostrata on wheat cultivar Pitic 62 in potted soil

Isolate	Disease rating	Shoot length (cm)
KD/1	1.12	21.00
DY/2	2.35	16.12
DY/3	1.60	19.97
KD/4	1.15	20.55
KD/5	1.15	20.32
KD/6	0.32	21.45
Control	0.05	22.92
$LSD_{(0.05)}$	0.76	2.43
S.E.	0.25	0.82

Table 5b: Pathogenicity of different isolates of F. equiseti on wheat cultivar Pitic 62 in potted soil

Isolate	Disease rating	Shoot length (cm)
KD/7	0.10	21.67
NG/8	1.95	18.70
NG/9	0.30	21.42
KD/10	0.92	20.97
NG/11	0.25	21.72
KD/12	0.45	21.22
Control	0.05	22.92
$LSD_{(0.05)}$	0.43	1.80
S.E.	0.14	0.61

Table 6a: Relationship between inoculum density of D. rostrata and severity of foot and root rots on plants grown from seeds sown in infested soil

% Inoculum	Disease rating		
	M1	M2	M3
0 (control)	0.12	0.08	0.01
5	0.80	0.08	0.72
10	1.30	0.63	1.02
30	1.42	0.78	2.65
50	1.70	0.43	2.90
70	2.12	0.50	1.30
$LSD_{(0.05)}$	0.39	0.30	0.48
S.E.	0.13	0.10	0.16

M1 = Sand-maize meal-chopped straw media.

M2 = Sand-maize meal media.

M3 = Chopped straw media.

Table 6b: Relationship between inoculum density of F. equiseti and severity of foot and root rots on plants grown from seeds sown in infested soil

% Inoculum	Disease rating		
	M1	M2	M3
0 (control)	0.12	0.08	0.01
5	0.15	0.30	0.37
10	0.25	0.33	0.50
30	1.10	1.18	2.52
50	1.85	0.88	0.42
70	2.12	0.88	0.37
$LSD_{(0.05)}$	0.50	0.37	0.56
S.E.	0.16	0.12	0.19

M1 = Sand-maize meal-chopped straw media.

M2 = Sand-maize meal media.

M3 = Chopped straw media.

Table 7a: Relationship between inoculum density of D. rostrata and severity of foot and root rots on plants whose seedlings were transplanted into infested soil

% Inoculum	Disease rating	
	M1	M2
0 (control)	0.15	0.15
5	2.82	1.77
10	3.07	3.30
30	3.10	3.17
50	3.15	3.15
70	3.61	2.82
$LSD_{(0.05)}$	0.45	0.45
S.E.	0.15	0.16

M1 = Sand-maize meal-chopped straw media.

M2 = Sand-maize meal media.

Table 7b: Relationship between inoculum density of F. equiseti and severity of foot and root rots on plants whose seedlings were transplanted into infested soil

% Inoculum	Disease rating	
	M1	M2
0 (control)	0.15	0.15
5	1.02	2.12
10	2.17	3.22
30	2.67	3.02
50	2.67	3.12
70	2.82	3.20
$LSD_{(0.05)}$	0.50	0.28
S.D.	0.16	0.09

M1 = Sand-maize meal-chopped straw media.

M2 = Sand-maize meal media.

pathogen (Tables 7a and 7b) were invariably higher than those on plants grown from seeds sown in similarly infested soil (Tables 6a and 6b).

4. Some Factors Affecting the Pathogenicity of D. rostrata and F. equiseti

(a) The effect of soil sterilization

Analysis of variance (Appendix 11a) showed that the shoot length (Table 8a) of plants grown in flame sterilized soil infested with D. rostrata was significantly (P=0.01) greater than those of plants grown in unsterilized soil infested with the same pathogen. Also the fresh weights (Appendix 11b) of plants grown in sterilized soil infested with this pathogen were significantly higher than those of plants grown in similarly infested non-sterilized soil. However, the disease intensities on plants grown in sterilized and non-sterilized soil infested with the fungus were not significantly different from each other.

Similar results were obtained with plants grown in sterilized and non-sterilized soil infested with F. equiseti (Table 8b). Although sterilized compared to non-sterilized soil did not influence the intensities of foot and root rots of wheat caused by any of the pathogens, Tables 8a and 8b show clearly that plant growth was much better in sterilized than in non-sterilized soil.

(b) The effect of method of inoculation

The results are represented in Fig. 2, which shows that for both pathogens, the greatest disease intensities occurred

Table 8a: Effect of soil sterilization on intensity of foot and root rots of wheat caused by D. rostrata

Treatment	Disease rating	Shoot length (cm)	Fresh weight of seedlings (g)
Unsterilized soil infested with D. rostrata.	1.80	18.22	3.90
Unsterilized soil, not infested with D. rostrata.	0.22	23.07	5.60
Sterilized soil infested with D. rostrata.	1.85	22.52	6.77
Sterilized soil, not infested with D. rostrata.	0.1	28.42	7.62
$LSD_{(0.01)}$	0.69	2.92	0.61
S.E.	0.22	0.95	0.20

Table 8b: Effect of soil sterilization on intensity of foot and root rots of wheat caused by F. equiseti

Treatment	Disease rating	Shoot length (cm)	Fresh weight of seedlings (g)
Unsterilized soil infested with F. equiseti.	0.90	21.12	4.72
Unsterilized soil, not infested with F. equiseti	0.22	23.07	5.60
Sterilized soil infested with F. equiseti.	1.00	23.05	6.85
Sterilized soil, not infested with F. equiseti.	0.10	28.42	7.62
$LSD_{(0.05)}$	0.45	2.88	0.61
S.E.	0.14	0.94	0.20

Fig. 2. Effect of method of inoculation on intensities of foot and root rots of wheat caused by D. rostrata and F. equiseti

A. Disease rating on seedlings grown from artificially inoculated seeds.

B. Disease rating on seedlings whose roots and crowns were wounded at the time of inoculation.

C. Disease rating on seedlings whose roots and crowns were not wounded at the time of inoculation.

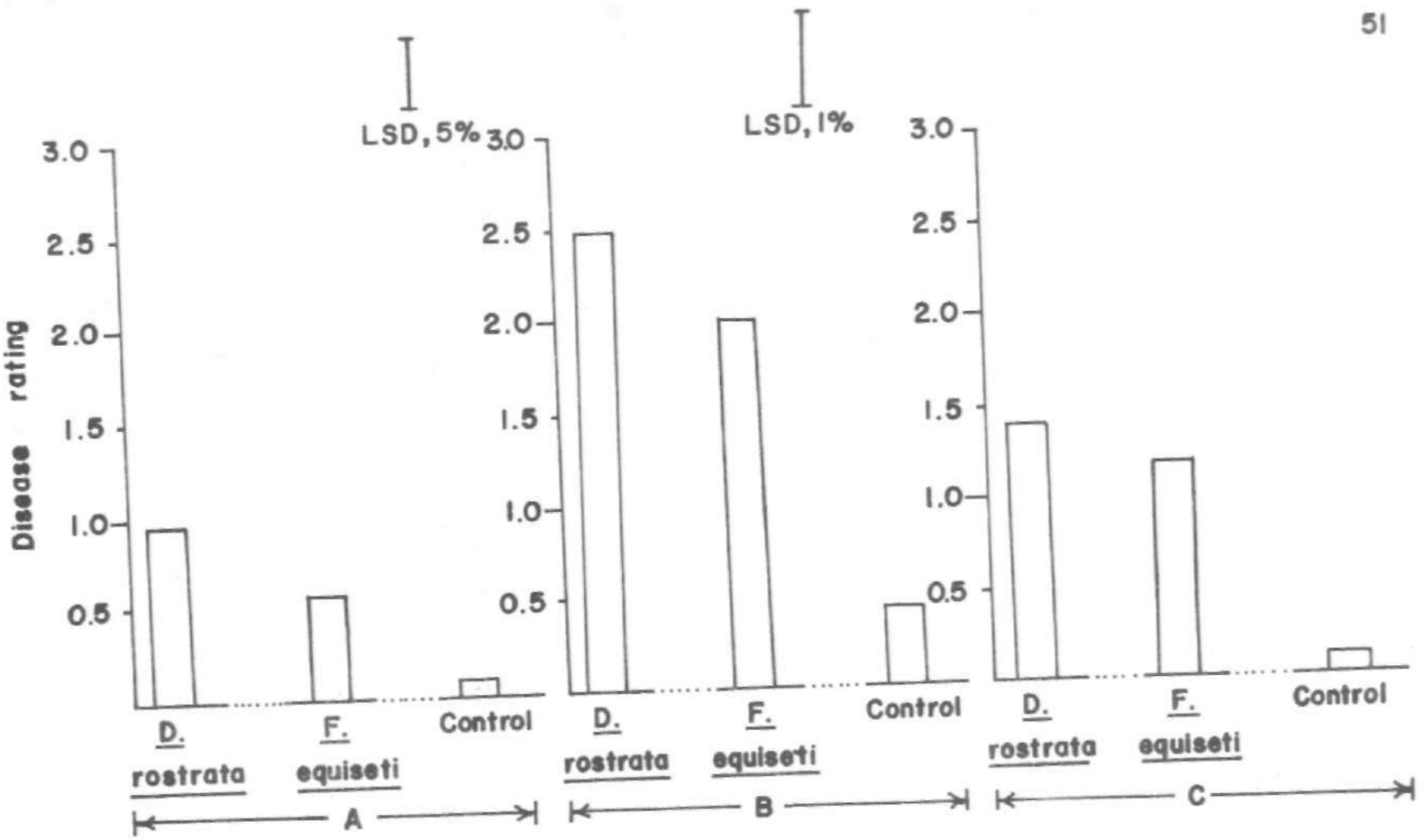


Fig. 2: Effect of method of inoculation on intensities of foot and root rots of wheat caused by D. rostrata and F. equiseti

in plants whose roots and crowns were wounded at the time of inoculation. Disease intensities in plants inoculated by this method were significantly higher (P=0.01) than those of plants whose roots and crowns were not wounded at the time of inoculation. It appears that wounding crowns and roots increased intensities of foot and root rots of wheat caused by D. rostrata and F. equiseti.

For any of the three inoculation methods, the intensities of diseases caused by D. rostrata were consistently, though not significantly (P=0.05), higher than those caused by F. equiseti. The relatively high disease rating in controls of plants whose roots and crowns were wounded at the time of inoculation is probably associated with invasion of wounds by other soil-borne pathogens.

Plate 5 shows that with both pathogens, injuries to the roots and crowns of seedlings at the time of inoculation, resulted in reduced ear size when compared with similarly injured but uninoculated controls. When the seedlings were inoculated without injury to the roots and crowns, reduction in ear size (Plate 6) was less when compared with the uninjured controls. Further, there was a higher loss in grain yield (Table 9) in plants whose roots and crowns were wounded at the time of inoculation than those whose roots and crowns were not wounded. Although in this experiment, inoculation with F. equiseti resulted in consistently lower disease rating than inoculation with D. rostrata, plants inoculated with the former sustained nearly the same loss in grain yield as those inoculated with D. rostrata, the method of inoculation notwithstanding.



Plate 5: Effect of inoculation of 2-week-old seedlings of wheat with D. rostrata and F. equiseti, after injury to roots and crowns, on ear size: 1 - D. rostrata; 2 - Control; 3 - F. equiseti.



Plate 6: Effect of inoculation of 2-week-old seedlings of wheat with D. rostrata and F. equiseti, without injuries to roots and crowns, on ear size: 1 - D. rostrata; 2 - Control; 3 - F. equiseti.



Plate 6: Effect of inoculation of 2-week-old seedlings of wheat with D. rostrata and F. equiseti, without injuries to roots and crowns, on ear size: 1 - D. rostrata; 2 - Control; 3 - F. equiseti.

Table 9: Yield of wheat inoculated with D. rostrata and F. equiseti with or without injuries to roots and crowns at the time of inoculation

Treatment	Total no. of ears	Total no. of grains	Total wt. of grains (g)	Yield as % of control yield
Inoculation with D. rostrata plus wounds to roots and crowns.	34	1,127	43.8	47.4
Inoculation with F. equiseti plus wounds to roots and crowns.	32	1,248	45.3	49.0
Wounds to roots and crowns without inoculation.	34	2,037	92.4	100.0
Inoculation with D. rostrata without wounding.	37	1,258	53.9	60.8
Inoculation with F. equiseti without wounding.	34	1,344	52.5	59.2
No wounds to roots and crowns and no inoculation.	36	1,875	88.6	100.0

c. The effect of soil moisture

Table 10a shows that plants grown by sowing seeds in soil infested with D. rostrata and watered by standing pots in water-containing trays were significantly (P=0.01) more severely diseased than those watered by applying water to the surface of the potted soil. By contrast, Table 10b shows that plants grown from seeds sown in soil infested with F. equiseti and watered by applying water to the surface of the potted soil were significantly (P=0.01) more severely diseased than those watered by standing pots in trays containing water. Also, plants inoculated by transplanting seedlings into soil infested with F. equiseti and watered by placing their pots in water contained in trays (Plate 7) produced more severe symptoms of foot and root rots than similarly treated plants inoculated with D. rostrata.

Generally, for each method of watering, plants grown by transplanting seedlings into infested soil were more severely diseased than those grown by sowing seeds in similarly treated soil. The root system of plants grown by transplanting seedlings into infested soil, watered by standing pots in water - containing trays (Plate 8) was smaller than that of plants grown from seeds sown in similarly watered and infested soil (Plate 9). Also for these two pathogens, plants grown by transplanting seedlings into infested soil and watered by standing pots in water contained in trays were more severely diseased than those watered by applying water to the soil surface (Tables 10a and 10b).

Table 10a: Effect of soil moisture on pathogenicity of D. rostrata on plants raised from seeds and those from seedlings transplanted into infested soil

Treatment	Disease rating	
	Direct sowing	Transplanting seedlings
Inoculated with D. rostrata; water applied on soil surface.	0.77	1.57
Inoculated with D. rostrata; pots stood in water in trays.	2.17	2.70
Uninoculated; water applied on soil surface.	0.07	0.25
Uninoculated; pots stood in water in trays.	0.35	0.45
	0.30	0.36
$LSD_{(0.01)}$	0.10	0.12
S.E.		

Table 10b: Effect of soil moisture on pathogenicity of F. equiseti on plants raised from seeds and those from seedlings transplanted into infested soil

Treatment	Disease rating	
	Direct sowing	Transplanting seedlings
Inoculated with F. equiseti; water applied on soil surface.	1.62	2.30
Inoculated with F. equiseti; pots stood in water in trays.	1.07	3.30
Uninoculated; water applied on soil surface	0.07	0.25
Uninoculated; pots stood in water in trays	0.35	0.45
$LSD_{(0.01)}$	0.33	0.42
S.E.	0.11	0.14



Plate 7: Effect of high soil moisture (created by standing potted soil in water-containing trays) on pathogenicity of D. rostrata (right) and F. equiseti (left) on plants grown from transplanted seedlings. The control is at the centre.



Plate 8: 28-day-old wheat plants grown by transplanting seedlings into potted soil and watered by placing pots in water-containing trays: F. equiseti (right), D. rostrata (left) and control (centre).



Plate 9: 28-day-old wheat plants grown by sowing seeds in infested potted soil and watered by placing pots in water-containing trays: F. equiseti (left), D. rostrata (right) and control (centre).

Table 11 shows yields of plants transplanted into soil infested with D. rostrata or F. equiseti and watered either by applying water on the soil surface or placing the potted soil in water-containing trays. It is clear that F. equiseti caused more reduction in seed size (Plate 10) and losses in yield (Table 11) than D. rostrata.

(d) The effect of soil type

Differences in disease rating on seedlings raised in the four soil types (Table 12a) infested with D. rostrata were not significant (P=0.05). On the other hand (Table 12b) disease rating on seedlings in sandy soil infested with F. equiseti was significantly less (P=0.05) than ratings on seedlings in clay and loamy soils infested with the same pathogen.

In addition, germination percentage of seeds sown in clay soil infested with F. equiseti was significantly less (P=0.05) than that of seeds sown in any of the other soil types infested with the same fungus. Thus for F. equiseti, the highest disease intensity on seedlings (which occurred in clay soil) was associated with the lowest percentage of seed germination, while the lowest disease intensity (which occurred in sandy soil) was associated with the highest seed germination percentage.

(e) The effect of the combined inoculum of D. rostrata and F. equiseti

There were no significant differences (P=0.05) in germination (Appendix 18a) between seeds sown in soil infested with a combined

Table 11: Grain yield of wheat plants grown by transplanting seedlings into soil infested with D. rostrata or F. equiseti and watered either by applying water on the soil surface or by standing potted soil in water-containing trays

Treatment	Total no. of ears	Total no. of grains	Total weight of grains (g)	Total grain wt as % of control	Average grain weight (mg)	Average grain wt as % of control
Inoculated with D. rostrata; water applied on soil surface	30	144	4.9	116.6	34.0	90.7
Inoculated with F. equiseti; water applied on soil surface	24	153	4.1	97.7	26.7	71.2
Uninoculated, water applied on soil surface.	28	112	4.2	100.0	37.5	100.0
Inoculated with D. rostrata; pots stood in water-containing trays.	21	84	2.7	71.1	32.1	90.5
Inoculated with F. equiseti, pots stood in water-containing trays.	18	97	2.4	63.2	24.7	69.6
Uninoculated; pots stood in water-containing trays.	26	107	3.8	100.0	35.5	100.0

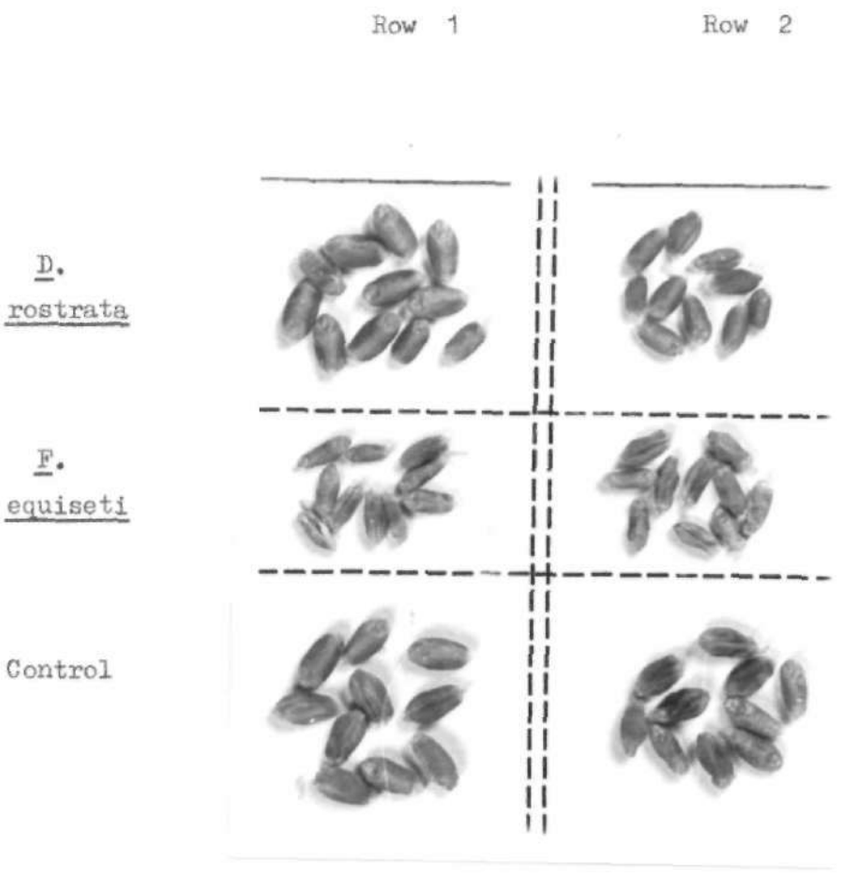


Plate 10: Seeds from wheat plants grown from seedlings transplanted into infested soil and watered by applying water on the surface of the potted soil (row 1), and by standing the pots in water-containing trays (row 2).

Table 12a: Effect of soil type on pathogenicity of D. rostrata

Treatment	Disease rating	Seed germination (% of control)
Clay soil infested with D. rostrata.	1.25	92.35
Loam soil infested with D. rostrata.	1.30	85.12
Sandy loam soil infested with D. rostrata.	1.30	92.20
Sandy soil infested with D. rostrata.	0.97	92.50
$LSD_{(0.05)}$	0.44	12.77
S.E.	0.14	4.14

Table 12b: Effect of soil type on pathogenicity of F. equiseti

Treatment	Disease rating	Seed germination (% of control)
Clay soil infested with F. equiseti	2.05	48.77
Loamy soil infested with F. equiseti	1.92	66.85
Sandy loam soil infested with F. equiseti	1.50	67.50
Sandy soil infested with F. equiseti	1.30	81.25
$LSD_{(0.05)}$	0.59	15.62
S.E.	0.19	5.07

inoculum of D. rostrata and F. equiseti and those sown in soil infested with only D. rostrata or F. equiseti (Table 13). In fact this table shows that the fresh weight of seedlings grown from the seeds sown in soil infested with both pathogens was more (though not significantly so at P=0.05) than that of seedlings grown in soil infested with any one of the fungi. Furthermore, the disease rating on seedlings grown in soil infested with F. equiseti was significantly higher (P=0.05) than that on seedlings grown in soil infested with either D. rostrata or with a combined inoculum of both pathogens.

Plate 11 shows differences in shoot and root growths of seedlings due to the different treatments.

5. Production of Toxic Metabolites

(a) The effect of culture filtrate and/or dry ground mycelial mat

The results are presented in Tables 14a and 14b. They show that cell-free culture filtrates of D. rostrata and F. equiseti had obvious adverse effects on seed germination and root growth compared to the control treatment which was either Czepeck-Dox liquid medium or sterile distilled water. These effects of culture filtrates compare quite favourably with those of mycelial mat inoculum of the respective fungi or those of mixture of the filtrate and the mycelial mat. It is concluded that in vitro, both pathogens produced substances which are toxic to wheat.

Table 13: The effect of combined inoculum of D. rostrata and F. equiseti on disease intensity

Treatment	Disease rating	Seed germination (%)	Fresh weight of seedlings (g)
D. rostrata + F. equiseti	0.80	67.50	8.70
D. rostrata	1.00	61.25	8.02
F. equiseti	2.30	65.00	7.90
Control (no inoculum)	0.07	72.50	13.07
$LSD_{(0.05)}$	0.36	15.20	0.82
S.E.	0.11	4.93	0.26



Plate 11: 28-day-old wheat seedlings grown by sowing seeds in potted soil infested with (from left to right): D. rostrata, the combined inoculum of D. rostrata and F. equiseti. Control is at the extreme right.

Table 14a: Effect of cell-free culture filtrate and/or dry ground mycelial mat of D. rostrata on seed germination and root growth of wheat

Treatment	Seed germination (% of germination in the control)		Root length (% of root length in the control)	
	Czapek-Dox as control	Sterile water as control	Czapek-Dox as control	Sterile water as control
Culture filtrate of D. rostrata	38.6	29.9	39.0	32.1
Culture filtrate + dry ground mycelial mat of D. rostrata.	25.1	19.4	41.9	35.6
Dry ground mycelial mat of D. rostrata.	45.4	35.4	41.7	34.1
Control	100.0	100.0	100.0	100.0
$LSD_{(0.05)}$	16.1	12.0	15.0	12.0
S.E.	4.6	3.4	4.3	3.4

Table 14b: Effect of cell-free culture filtrate and/or dry ground mycelial mat of F. equiseti on seed germination and root growth of wheat

Treatment	Seed germination (% of germination in the control)		Root length (% of root length in the control	
	Czapek-Dox as control	Sterile water as control	Czapek-Dox as control	Sterile water as control
Culture filtrate of F. equiseti	30.0	25.8	42.3	34.9
Culture filtrate + dry ground mycelial mat of F. equiseti	22.3	19.3	43.9	35.6
Dry ground mycelial mat of F. equiseti	33.2	25.9	34.5	28.0
Control	100.0	100.0	100.0	100.0
$LSD_{(0.05)}$	9.3	9.5	19.1	15.0
S.E.	2.7	2.7	5.5	4.3

(b) The effect of different concentrations of culture filtrate on seed germination and root growth

Tables 15a and 15b show that the germination of seeds was hardly affected by treatment with the different concentrations of culture filtrate of each fungus except that seed germination percentages in 100% crude filtrate of both shake and still cultures of D. rostrata was significantly less than those in any of the dilutions. By contrast, solutions containing 40-100% of the crude cell-free filtrates of both still and shake cultures of the two fungi caused significant (P=0.01) reduction in root growth of wheat when compared with root growth of control plants treated with sterile distilled water. Also from Fig. 3, it is apparent that relatively high concentrations of the culture filtrate in test solution are necessary to induce appreciable suppression of root growth.

(c) The effect of autoclaving filtrate from still cultures

Autoclaving the filtrate obtained from still cultures of each fungus did not seem to have much effect on seed germination when compared with non-autoclaved filtrate (Table 16). In addition, Table 16 shows that autoclaving the culture filtrate of F. equiseti did not have very obvious effect on root growth compared to that of non-autoclaved filtrate. However, root growth inhibition by non-autoclaved filtrate of D. rostrata was clearly higher than that by autoclaved filtrate. These observations suggest that heat probably impairs toxicity of culture filtrate of D. rostrata while the toxicity of the filtrate of F. equiseti appears

Table 15a: Effect of different concentrations of filtrates from still and shake cultures of D. rostrata on germination and root growth of wheat

Treatment	Seed germination (% germination in water as control)		Root length (% of root length in water as control)	
	Still culture	Shake culture	Still culture	Shake culture
Control (sterile distilled water)	100.0	100.0	100.0	100.0
20% culture filtrate of D. rostrata	98.2	98.4	64.8	97.6
40% culture filtrate of D. rostrata	98.0	89.5	52.0	61.3
60% culture filtrate of D. rostrata	94.8	88.3	36.7	52.7
80% culture filtrate of D. rostrata	91.0	85.0	38.0	33.9
100% culture filtrate of D. rostrata	83.9	69.5	29.6	19.1
$LSD_{(0.05)}$	7.0	7.4	17.0	13.0
S.E.	2.2	2.3	5.4	4.1

Table 15b: Effect of different concentrations of filtrates from still and shake cultures of F. equiseti on germination and root growth of wheat

Treatment	Seed germination (% germination in water as control)		Root length (% of root length in water as control)	
	Still culture	Shake culture	Still culture	Shake culture
Control (sterile distilled water)	100.0	100.0	100.0	100.0
20% culture filtrate of F. equiseti	94.7	96.4	73.7	83.8
40% culture filtrate of F. equiseti	95.0	93.0	68.8	56.1
60% culture filtrate of F. equiseti	96.4	88.0	74.2	50.1
80% culture filtrate of F. equiseti	96.6	89.3	52.1	46.5
100% culture filtrate of F. equiseti	89.2	91.1	40.3	18.9
$LSD_{(0.05)}$	10.8	8.6	20.5	15.9
S.E.	3.4	2.7	6.5	5.3

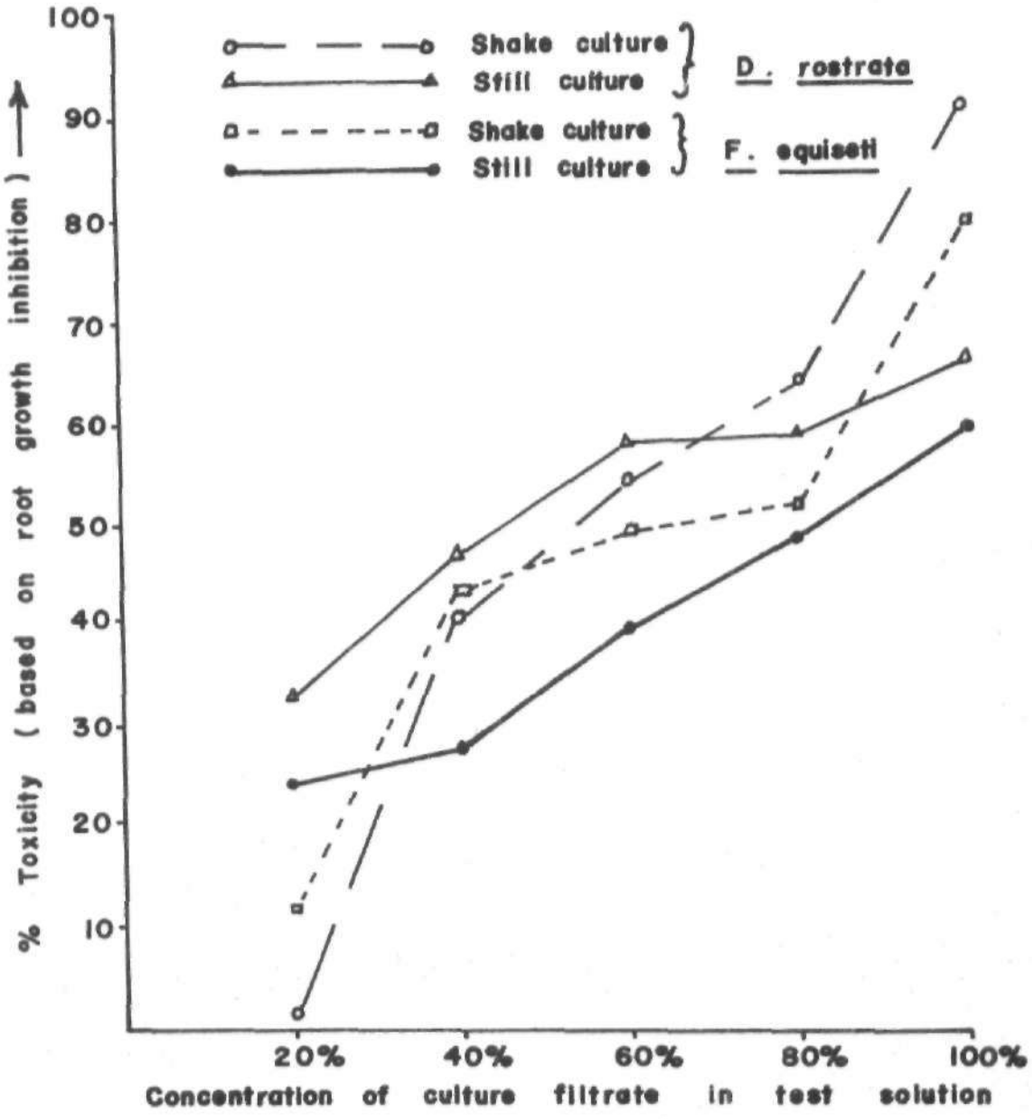


Fig. 3 : *Effect of different concentration of culture filtrate from still and shake cultures on root length of wheat seedlings at room temperature (23° – 32°C)*

Table 16: Effect of autoclaved filtrates obtained from still cultures of D. rostrata and F. equiseti on seed germination and root growth

Treatment	% germination	Root length (cm)
D. rostrata		
Autoclaved culture filtrate	66.2	3.5
Non-autoclaved culture filtrate	63.6	1.2
F. equiseti		
Autoclaved culture filtrate	58.0	1.8
Non-autoclaved culture filtrate	56.0	2.1
Sterile distilled water (control)	65.0	4.0
Autoclaved potato dextrose medium (control)	61.0	2.9

to be heat stable.

Neither in this experiment, nor in the experiments reported in sub-sections (a) and (b) of this section did the culture filtrate or its dilutions cause any of the characteristic necrotic lesions of foot and root rots of wheat caused by D. rostrata and F. equiseti.

B. SAPROPHYTIC BEHAVIOUR

1. Saprophytic Colonization

(a) Study of saprophytic colonizing abilities of D. rostrata and F. equiseti by Cambridge method

The results are presented in Figs. 4 to 7. In general, saprophytic colonization by any of the test fungi increased with increase in inoculum density. The general trend in colonization by D. rostrata of wheat straw treated with dextrose or dextrose plus sodium nitrate (Fig. 4) was remarkably similar to that by F. equiseti of similarly treated wheat straw (Fig. 5). For both fungi saprophytic colonization was higher in straws pretreated with water than in those pretreated with any of the above two nutrient solutions.

On the other hand, D. rostrata and F. equiseti colonized wheat straws pretreated with nitrogenous compounds (urea, ammonium nitrate, and sodium nitrate) better than straws pretreated with water (Figs. 6 and 7). Here again, the general trend in colonization by each of the two fungi was fairly similar. The observations suggest that compared to the control (presoaking in water), pretreatment of wheat straw with dextrose solution

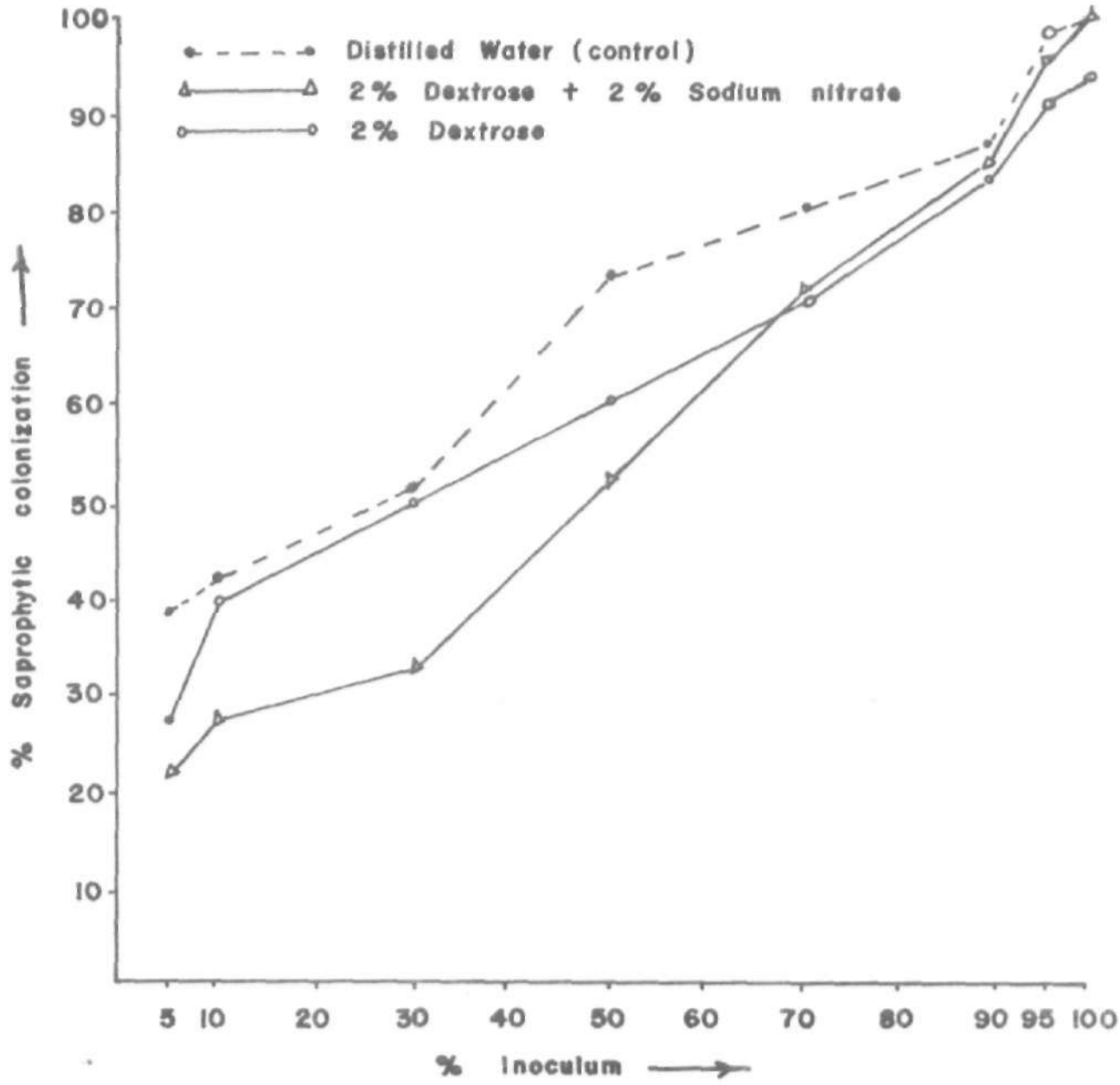


Fig. 4 : Saprophytic colonization of pre-treated wheat straw pieces by D. rostrata at different inoculum densities

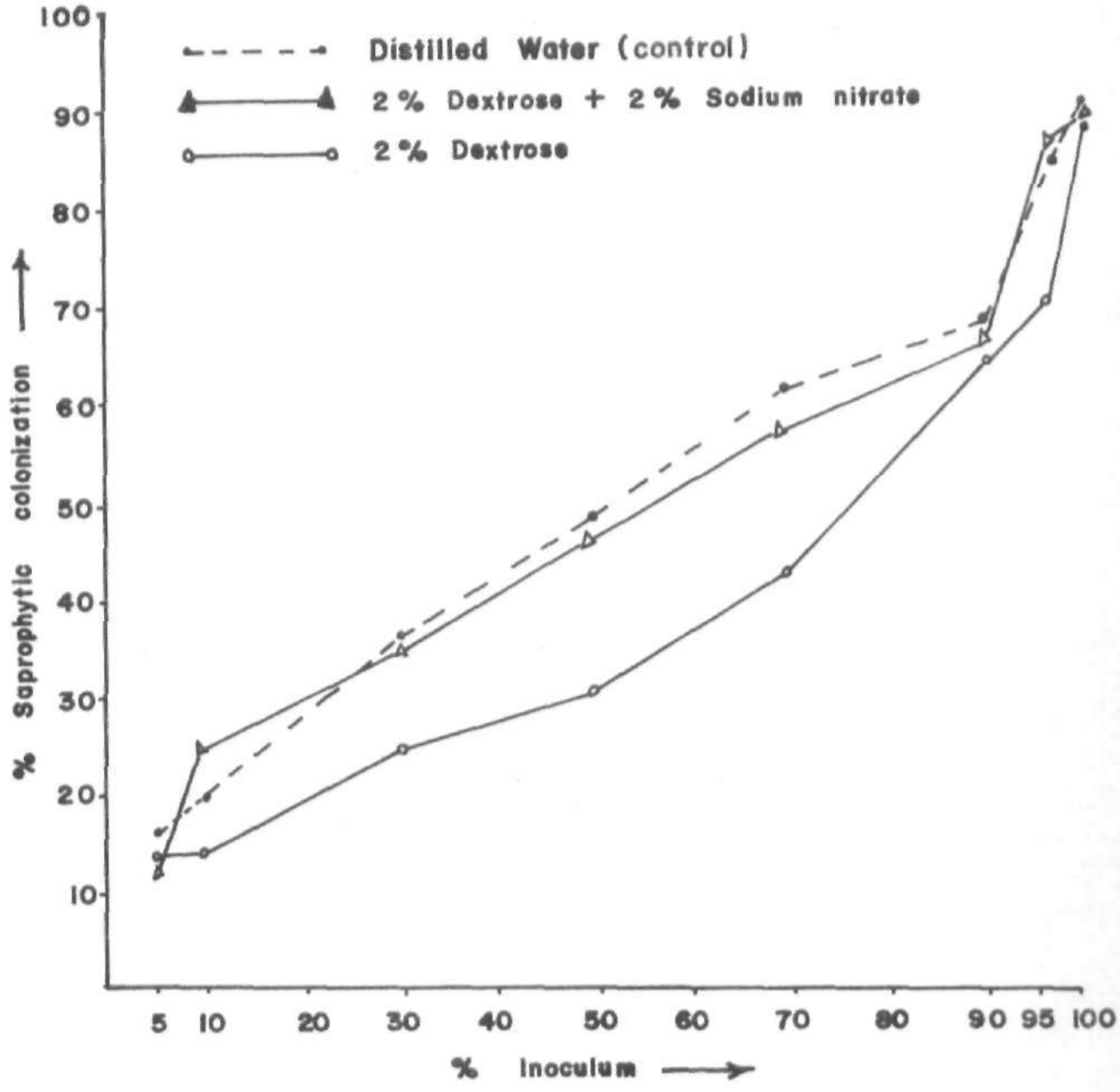


Fig. 5: Saprophytic colonization of pre – treated wheat straw pieces by *F. equiseti* at different inoculum densities

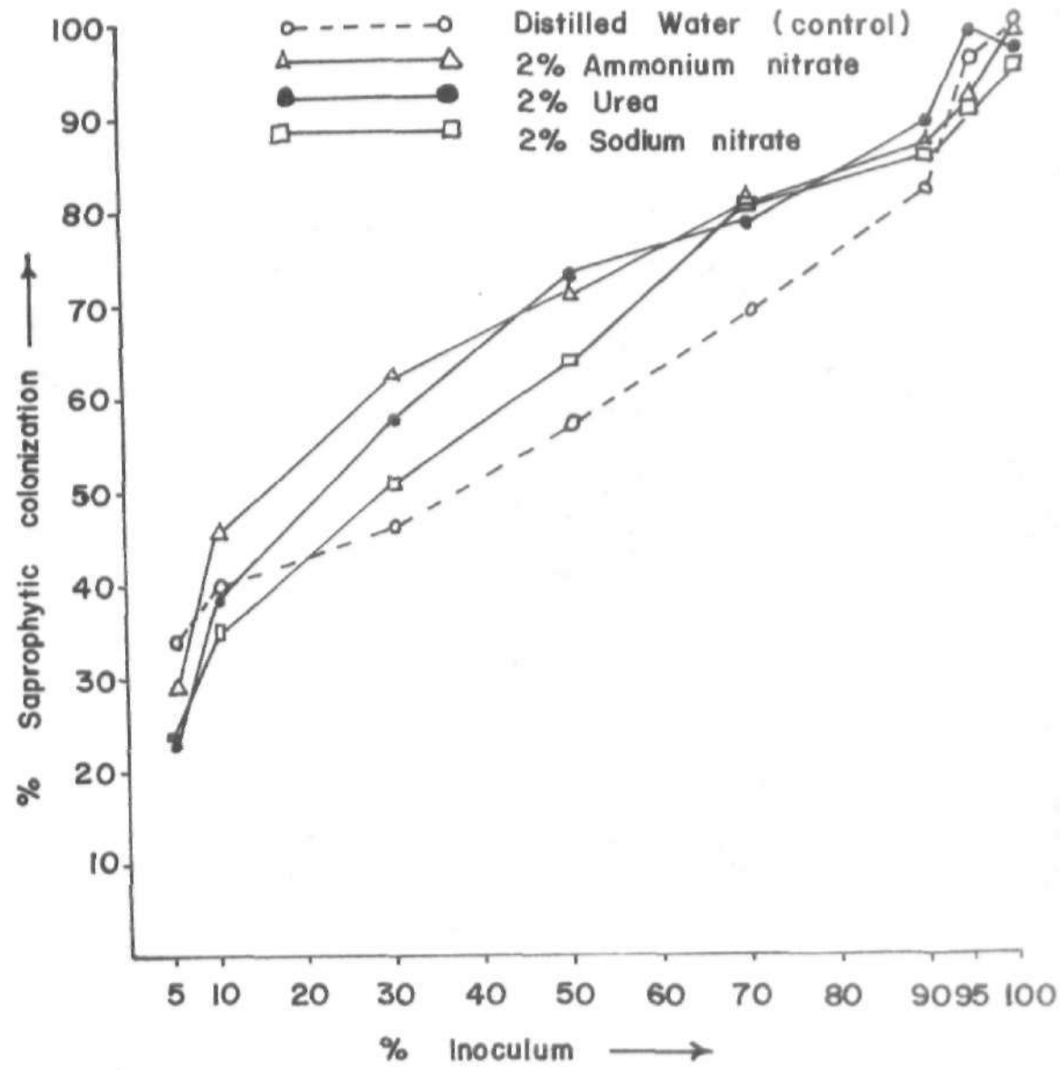


Fig. 6: Saprophytic colonization of pre-treated wheat straw pieces by D. rostrata. at different inoculum densities

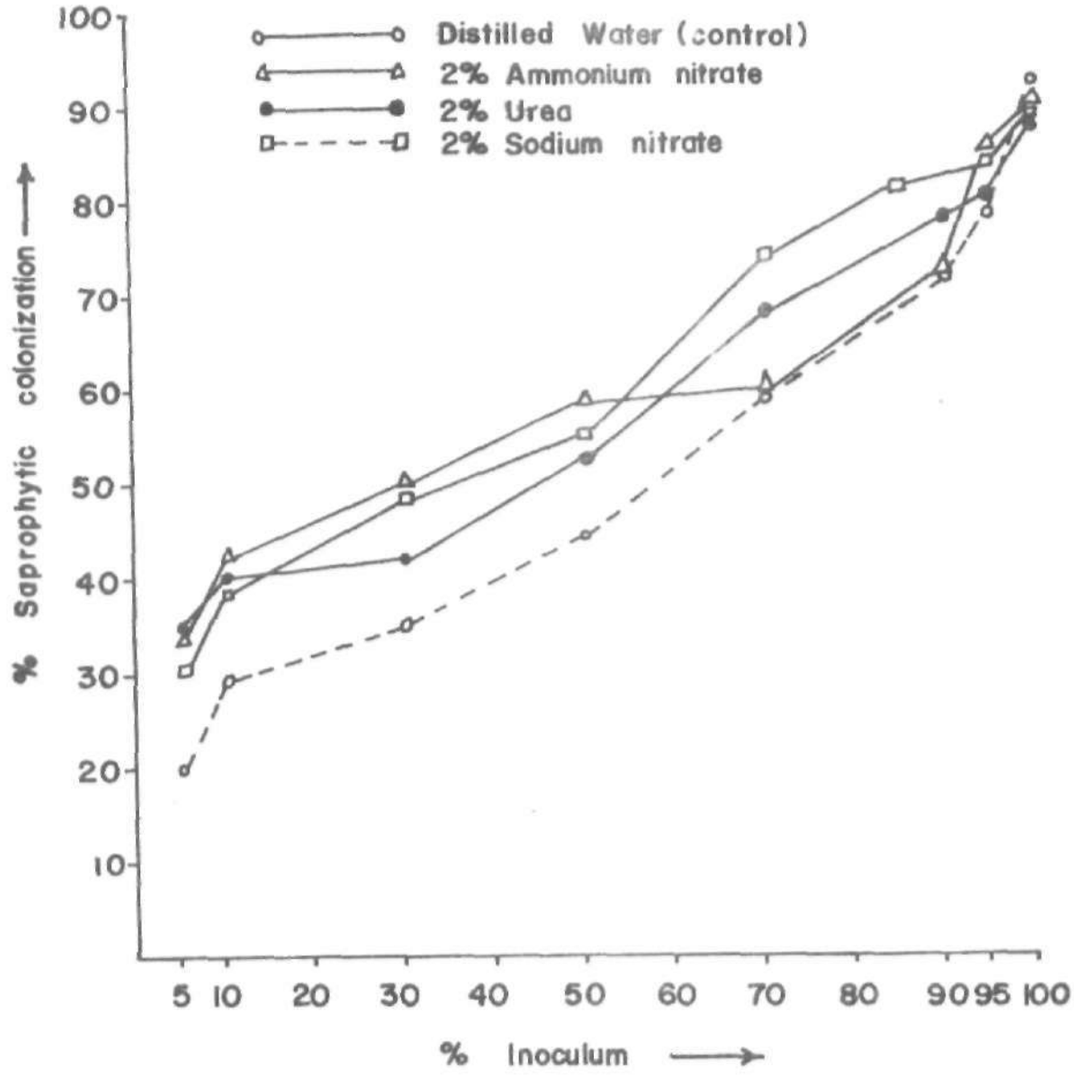


Fig. 7: Saprophytic colonization of pre-treated wheat straw pieces by F. equiseti. at different inoculum densities

suppressed saprophytic colonization by D. rostrata and F. equiseti while pretreatment with nitrogenous compounds enhanced saprophytic colonization by the same fungi.

(b) Study of saprophytic colonizing abilities of D. rostrata, F. equiseti and F. culmorum, by direct observation method

The percentage of straws colonized by D. rostrata was significantly higher (P=0.01) than that colonized by F. equiseti or F. culmorum (Fig. 8 and Appendix 23). But the percentage of straws colonized by F. equiseti did not differ significantly (P=0.01) from that of F. culmorum. These observations indicate that, by this method (Plate 12), D. rostrata has a higher saprophytic colonizing ability than F. equiseti and F. culmorum which appeared to have the same ability.

2. The Saprophytic Survival of D. rostrata and F. equiseti in Wheat Straw Pieces Buried in Soil

The percentage of each fungus surviving in wheat straw pieces both in nitrogen enriched and in unenriched soil (Figs. 9A and 9B) decreased with increase in time. D. rostrata survived better in straws buried in unenriched soil than in straws buried in nitrogen enriched soil (Fig. 9A).

On the other hand, F. equiseti survived better in nitrogen enriched soil than in soil not enriched with nitrogen (Fig. 9B).

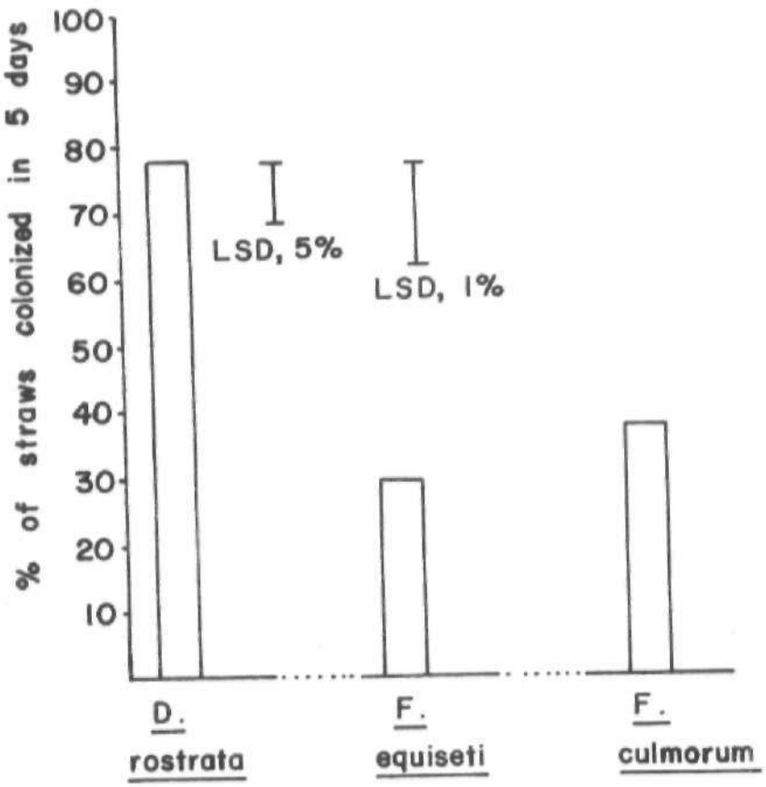


Fig. 8: Saprophytic colonization of sterilized wheat straw pieces by D. rostrata, F. equiseti and F. culmorum at room temperature (23° – 32° C), assessed by Direct observation.

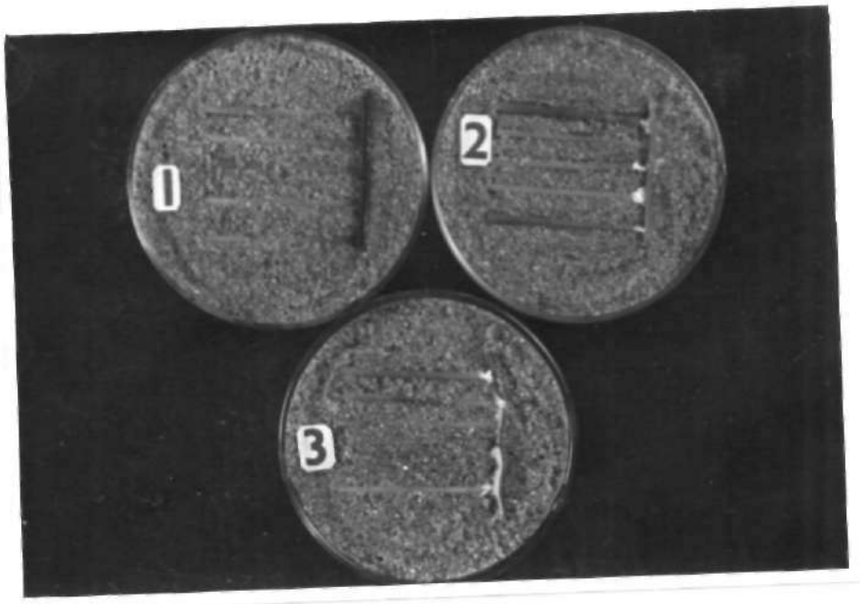


Plate 12: Saprophytic colonization of wheat straw pieces by: 1 - D. rostrata, 2 - F. equiseti, 3 - F. culmorum assessed by direct observation.

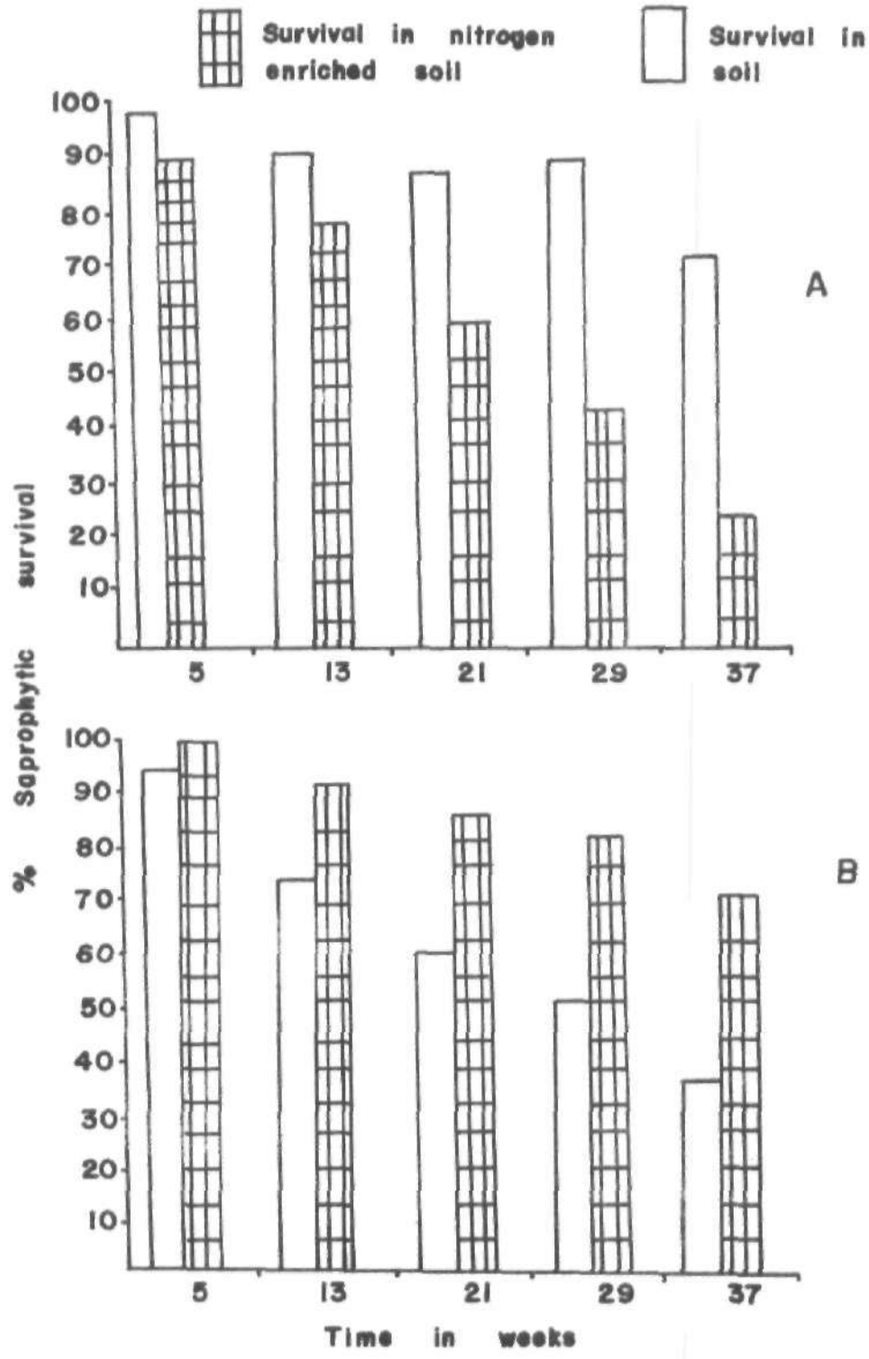


Fig. 9: Saprophytic survival of D rostrata (A) and F equiseti (B) in nitrogen ($NaNO_3$) enriched and unenriched potted soil incubated at room temperature (23°-32°C)

Making use of different inoculation methods as well as different inoculum densities, it has been shown that D. rostrata and F. equiseti are weak parasites. Firstly, each fungus was more pathogenic on plants whose roots and crowns were artificially wounded just before inoculation than on those that were not wounded (Fig. 2). Although the effects of any other soil microflora (fungi, bacteria, actinomycetes) were not studied, symptoms of the diseases observed in some uninoculated controls, suggest that they might have contributed to the high disease severity in plants wounded prior to inoculation. Garrett (1970), and Baker and Cook (1974) observed that in most diseases caused by soil-borne pathogens, the symptoms are often the combined effect of one or two main microflora (usually regarded as pathogens) and several minor ones (usually ignored in pathogenicity studies).

Secondly, it appears that relatively high inoculum densities are needed to produce appreciable amount of disease especially if seeds are sown in infested soil (Tables 6a and 6b). The importance of "unnaturally high inoculum levels" for infection of wheat plants by Drechslera and Fusarium spp. associated with foot and root rots of irrigated wheat in Nigeria was recognized by Giha (1978). In that investigation, however, he sowed artificially inoculated seeds in sterilized field soil. But in the present investigation, the amount of inoculum required to produce a certain disease intensity was comparatively lower, when seedlings were transplanted into infested soil (Tables 7a and 7b) than when seeds were sown in similarly treated soil. During transplanting some injury was automatically inflicted to the root system of seedlings and the results obtained appear

to confirm that D. rostrata and F. equiseti are wound pathogens. Giha (1976) isolated several Fusarium spp. from termite infested stem bases of wheat and barley plants. He suggested that termite injury facilitated infection by such fungi. However, Ohiagu (1979) pointed out that termites are generally prevalent in light soils in which they maintain a high population under relatively low moisture regimes. In the light of his findings, it is unlikely that termites play an important role in the infection of wheat plants by D. rostrata and F. equiseti because in Nigeria, foot and root rots caused by these fungi are generally confined to water-logged fields. However, such fields may harbour high population of parasitic and non-parasitic nematodes. The role of nematodes in the etiology of foot and root rots caused by D. rostrata and F. equiseti is worthy of investigation.

Thirdly, disease intensity caused by each pathogen was generally higher under high than under low soil moisture conditions (Tables 10a and 10b). Water-logging of the soil observed in the irrigated fields per se reduces vigour of most plants and thus encourages infection by weak pathogens (Garrett, 1963). In my investigation, water-logging created by watering the potted soil by placing it in water-containing trays generally favoured development of foot and root rots caused by D. rostrata and F. equiseti. Furthermore, these diseases were intensified, under water-logged conditions, on plants grown from transplanted seedlings than on those grown from seeds.

The type of soil did not affect the severity of foot and root rots caused by D. rostrata (Table 12a). Similar observation was made on foot and root rots of wheat caused by D. sorokiniana (Simmonds, 1953a). But

with F. equiseti, the severity of foot and root rots was significantly higher (P=0.05) in clay than in lighter textured soils. This agrees with reports from elsewhere which indicate that Fusarium spp. pathogenic on cereals generally do more damage in heavy (clay) than in light soils (Simmonds, 1953b; Mcknight, 1960; Sallans, 1965).

Plant growth was much better in sterilized than in non-sterilized soil. Since the disease intensity on plants grown in non-sterilized soil was not significantly different (P=0.01) from that of plants grown in sterilized soil (Tables 8a and 8b), the improvement of plant growth in sterilized soil was apparently not associated with lower intensity of foot and root rots. This type of improvement of plant growth in sterilized soil is quite common. Thus Baker and Roistacher (1957) suggested that the improved plant growth in heat treated soil may result from increased availability of nutrients, change from nitrate to ammonium nutrition or improved physical structure of the soil.

The severity of foot and root rots was less with the combined inoculum of the two pathogens compared to sole inoculum of each of the pathogens (Table 13). Probably the combined inoculum of the two pathogens suppressed the development of foot and root rots. At this stage, it is difficult to provide a satisfactory explanation for such results as the problem needs further investigation.

Microbial toxins have been found to produce at least a part of the disease syndrome in some fungal and bacterial diseases of plants (Wood, 1967). In the present investigation, the culture filtrates of D. rostrata

and F. equiseti inhibited root growth of the seedlings. This gives an indication of the production of some toxic metabolites by these pathogens. Further tests with autoclaved filtrates showed that D. rostrata produces thermolabile metabolites. On the other hand, the toxic substances produced by F. equiseti appear to be heat stable. However, a more detailed study would be needed to establish the identity of the toxic metabolites produced by each fungus and their roles in the foot and root rot syndrome of wheat.

In general, D. rostrata proved to be a more vigorous saprophytic colonizer than F. equiseti. Enrichment of the wheat straws with carbon source suppressed saprophytic colonization (Figs. 4 and 5), whereas enrichment with nitrogen sources enhanced the saprophytic colonization (Figs. 6 and 7). The $^{C}50$ values for each fungus, obtained from regression of percentage colonization on inoculum density are given in Tables 17 and 18. According to Garrett (1975) the $^{C}50$ value represents the highest percentage of unsterilized soil in an inoculum-soil mixture that still permits colonization by the inoculant fungus of 50 per cent of the total number of straws in a test sample.

The $^{C}50$ values given in Tables 17 and 18 reflect the competitive saprophytic ability of each test fungus. It is clear that the competitive saprophytic ability of D. rostrata is more than that of F. equiseti.

The importance of aeration in saprophytic colonization by Drechslera spp. was emphasized by Ghurde (1966). Using his technique, it has been established (Fig. 8) that under abundant aeration, D. rostrata is a better saprophytic colonizer than either F. equiseti or F. culmorum.

Table 17: C_{50} values for saprophytic colonization of wheat straws by D. rostrata and F. equiseti (straws pre-treated with distilled water, 2% dextrose or 2% dextrose + 2% sodium nitrate

Fungus	Pre-treatment	C_{50}
D. rostrata	Distilled water	76
	2% dextrose	67
	2% dextrose + 2% sodium nitrate	57
F. equiseti	Distilled water	49
	2% dextrose	38
	2% dextrose + 2% sodium nitrate	46

Table 18: C_{50} values for saprophytic colonization of wheat straw by D. rostrata and F. equiseti (straws pre-treated with distilled water, 2% ammonium nitrate, 2% urea or 2% sodium nitrate

Fungus	Pre-treatment	C_{50}
D. rostrata	Distilled water	68
	2% ammonium nitrate	78
	2% urea	73
	2% sodium nitrate	€1
F. equiseti	Distilled water	49
	2% ammonium nitrate	67
	2% urea	60
	2% sodium nitrate	69

The two test fungi responded differently to nitrogen in the longevity of their saprophytic survival in colonized wheat straw buried in soil (Fig. 9). In the case of D. rostrata, the saprophytic longevity was curtailed if the soil was enriched with nitrogen but with F. equiseti soil enrichment enhanced its saprophytic longevity. The S_{50} values read from Fig. 9 are shown in Table 19. S_{50} values represent the median period in weeks the test fungus survives in 50% of the straws sampled (Garrett, 1976).

Table 19: S_{50} values for D. rostrata and F. equiseti in nitrogen ($NaNo_3$) enriched and unenriched potted soil incubated at room temperatures ($23^{\circ}-32^{\circ}C$)

Fungus	Soil treatment	S_{50} (weeks)
D. rostrata	Nitrogen ($NaNo_3$) enriched soil	27
	Unenriched soil	60*
F. equiseti	Nitrogen ($NaNo_3$) enriched soil	60*
	Unenriched soil	33

* S_{50} was not reached in 40 weeks when the experiment was terminated; extrapolation of curve gave a value of about 60 in each case.

The S_{50} values given on Table 19 show clearly that the longevity of saprophytic survival of D. rostrata and F. equiseti on wheat straw depends on the nitrogen status of the soil. Butler (1953c) discovered that excess

soil nitrogen reduced the longevity of D. sorokiniana in wheat straw. It was suggested (Butler, 1953c; Wastie, 1961) that this effect of nitrogen in reducing the longevity of D. sorokiniana might be connected with its low tolerance of fungistatic growth products excreted by competing soil micro-organisms. However, according to Garrett (1967, 1970, 1976) these different responses to nitrogen could be explained in terms of variation in cellulolysis rate in relation to the general metabolic rate among different fungi. He expressed this ratio as Cellulolysis Adequacy Index (CAI) which he obtained by dividing cellulolysis rate by linear growth rate of the test fungus. Garrett (1976) showed that in soils of low fertility, i.e. low N status, the CAI value of the primary fungal colonizer is the chief determinant of its longevity of saprophytic survival. In infertile soil, therefore, longevity of saprophytic survival is dependent on CAI value. But in soils of high fertility, however, competition between the primary fungal colonizer and other soil micro-organisms is very intense. In such soils, the longevity of saprophytic survival would be determined by tolerance to microbial competition (Butler, 1953b; Garrett, 1976). Probably D. rostrata has a low tolerance to microbial competition as compared to F. equiseti and this may be the main cause of its negative response to nitrogen in its longevity of saprophytic survival.

Although D. rostrata and F. equiseti may be considered as moderately saprophytic, their survival for a period of 40 weeks in unsterilized soil was reasonably high. This is approximately the period between two successive wheat crops in Northern Nigeria. From this study, it is clear that the two fungi can survive in the soil as saprophytes on wheat residues until the next growing season.

At most of the irrigation sites in Northern Nigeria, some other crops are grown under rainfed conditions (between June and September). As D. rostrata and F. equiseti have been found to have wide host range (See pp. 6 - 7) they might live as mild pathogens in such crops. There is thus need to collect isolates of these pathogens from wheat and other crops and investigate their host range through cross inoculation tests.

Finally, although D. rostrata and F. equiseti have been shown to be weak parasites, their pathogenic variability (Giha, 1978) should be a cause of concern to pathologists and plant breeders working in Nigeria. As unspecialized parasites, their probable presence on other hosts in the absence of wheat, and their intrinsic ability to survive for long periods as saprophytes, are important aspects of their epidemiology. They may not pose a serious threat to wheat in Nigeria if the problems of water-logging. due to excessive irrigation and seepage from water channels, and injury to the crop through weeding operations, plant parasitic nematodes etc., are tackled properly.

VI. SUMMARY

Some aspects of pathogenicity and saprophytic behaviour of Drechslera rostrata and Fusarium equiseti were investigated. These fungi cause foot and root rots of wheat in Northern Nigeria. Pathogenicity studies were carried out both in petri dishes and artificially infested soil. Results showed that different isolates of both fungi varied in their pathogenicities on the most susceptible wheat cultivar, Pitic 62. In addition, 14 wheat cultivars varied in their susceptibilities to both D. rostrata and F. equiseti. In general, the cultivars were mildly to moderately susceptible.

Studies on factors that influence disease severity have shown that the severity of foot and root rot diseases caused by the two pathogens was generally higher in plants whose crowns and roots were wounded prior to inoculation than in those without wounds on their crowns and roots. Also high inoculum density of each fungus caused more severe disease than lower inoculum dosage. Water-logged conditions of soil resulted in higher disease severity than non water-logged conditions. These results suggest that both fungi are weak parasites. Furthermore, in most of the experiments, disease intensity was higher in plants whose seedlings were transplanted into infested soil than in those whose seeds were sown in similarly treated soil. With different inoculation methods, the pathogens caused nearly the same loss in grain yield but under water-logged conditions loss in grain yield due to F. equiseti was higher than that caused by D. rostrata. Both fungi produced toxic substances in liquid culture media. These toxic metabolites adversely affected seed germination and root growth.

The nature of these substances was not investigated in detail. However, D. rostrata seemed to produce some thermolabile substances while those produced by F. equiseti were apparently heat stable.

D. rostrata proved to be a stronger saprophyte than F. equiseti. Different nitrogen sources used enhanced saprophytic colonization of wheat straw by each fungus; on the other hand the carbon source (dextrose) suppressed saprophytic colonization. While the saprophytic survival of D. rostrata was shortened in nitrogen enriched soil, that of F. equiseti was longer in such a soil. The reasons for this are not very clear. What appears more important, however, is that both fungi survived in wheat straw in the soil for up to 40 weeks which is approximately the period between two crops of wheat in Northern Nigeria.

VII. BIBIOGRAPHY

Abalu, G.O.I. 1977. Problems of Wheat Marketing in Nigeria. NAFPP Sorghum, Millet and Wheat Workshop, Bagauda, Kano.

Andrews, D.J. 1968. Wheat Cultivation and Research in Nigeria. Niger. Agric. J. 5:67-72.

Baker, K.F., and R.J. Cock. 1974. Biological Control of Plant Pathogens. San Francisco. W.F. Freeman and Co.

Baker, K.F., and C.N. Roistacher. 1957. Heat treatment of soil. pp.123-137. In: K.F. Baker (ed), The U.C. System of producing healthy container-grown plants. Los Angeles, Univ. of California Press.

Bennett, F.I. 1935. Fusarium species on British cereals. Ann. appl. Biol. 22:479-507.

Brian, P.W., A.W. Dawkin, J.F. Grove, H.G. Hemming, D. Lowe, G.L.F. Norris. 1961. Phytotoxic substances produced by Fusarium equiseti. Journ. exper. Bot. 12:1-12.

Bruehl, G.W. 1967. Diseases other than Rust, Smut. and Viruses. In: K.S. Quisenberry and L.P. Reitz (ed.), Wheat and Wheat Improvement American Soc. of Agron. Madison. Wisconsin.

Bunting, R.H. 1927. Dept. Agric., Gold Coast Year Book. Bull. No. 7, pp. 25-27.

Bunting, R.H. 1928. Dept. Agric., Gold Coast Year Book. Bull. No. 10, pp. 19-20.

Burgess, L.W. and D.M. Griffin. 1967. Competitive saprophytic colonization of wheat straw. Ann. appl. Biol. 60:137-142.

Butler, F.C. 1953a. Saprophytic behaviour of some cereal root rot fungi. I - Saprophytic colonization of wheat straw. Ann. appl. Biol. 40:284-297.

Butler, F.C. 1953b. Saprophytic behaviour of some cereal root rot fungi. II - Factors influencing saprophytic colonization of wheat straw. Ann. appl. Biol. 40:298-304.

Butler, F.C. 1953c. Saprophytic behaviour of some cereal root rot fungi. III - Saprophytic survival in wheat straw buried in soil. Ann. appl. Biol. 40:305-311.

Butler, F.C. 1961. Foot and root rot diseases of wheat. Dept. Agric. N.S.W. Sci. Bull. 77, 98. (cited from Rev. appl. Mycol. 42:112-113).

Chattopadhyay, S.B., and C. Das Gupta. 1959. Helminthosporium rostratum Drechs. on rice in India. Pl. Dis. Reptr. 43:1124-1244.

Chidambaram, P., S.B. Mathur, and P. Neergaard. 1973. Identification of seed-borne Drechslera spp. Friesia. 10:165-207.

Deacon, J.W. 1973. Behaviour of Cercosporella herpotrichoides and Ophiobolus graminis on buried wheat plant tissue. Soil Biol. Biochem. 5:339-353.

DeMayo, P., E.K. Spencer, and R.W. White. 1961. Helminthosporal, toxin from Helminthosporium sativum. Can. J. Chem. 39:1602-1612.

DeMayo, P., E.K. Spencer, and R.W. White. 1962. The constitution of helminthosporal. J. Am. Chem. Soc. 84:494.

Deshpande, K.S., and D.M. Gajewar. 1976. Toxicity of Metabolites of Helminthosporium apathernae. Indian Phytopath. 29:281-286.

Drechslera, C. 1923. Some graminicolous species of Helminthosporium. Can. Journ. Agric. Res. 24:641-740.

Fitt, B.D., and D. Hornby. 1978. Effect of root-infecting fungi on wheat transport process and growth. Physiol. pl. Path. 13:335-346.

Garrett, S.D. 1956. Biology of Root-infecting Fungi. Cambridge University press.

Garrett, S.D. 1963. Soil fungi and soil fertility. Oxford: Pergamon press.

Garrett, S.D. 1967. Effect of Nitrogen level on survival of Ophiobolus graminis in pure culture on cellulose. Trans. Br. mycol. Soc. 50:519-524.

Garrett, S.D. 1970. Pathogenic Root-infecting Fungi. Cambridge University press.

Garrett, S.D. 1975. Cellulolysis rate and competitive saprophytic colonization of wheat straw by foot rot fungi. Soil Biol. Biochem. 7:323-327.

Garrett, S.D. 1976. Influence of nitrogen on cellulolysis rate and saprophytic survival in soil of some cereal foot rot fungi. Soil Biol. Biochem. 8:229-234.

Gerlagh, M. 1968. Introduction of Ophiobolus graminis into new polders and its decline. Meded. Lab. Phytopath. Wageningen No. 241.

Ghurde, V.R. 1966. Saprophytic ability of species of Helminthosporium. Trans. Br. mycol. Soc. 44:241-243.

Giha, O.H. 1976. Fungi associated with foot and root rot diseases of irrigated wheat in the northern states of Nigeria. PANS. 22:479-487.

Giha, O.H. 1977. A morphological study of the principal fungi associated with foot and root rot diseases of irrigated wheat in the northern states of Nigeria. Niger. J. Pl. Prot. 3:167-177.

Giha, O.H. 1978. The pathogenicity of fungi associated with foot and root rot diseases of irrigated wheat in Nigeria. PANS. 24:306-312.

Greaney, F.J. and J.E. Machacek. 1938. Studies on the control of foot and root rot diseases of cereals caused by Fusarium culmorum (W.G; S.M.) Sacc. and Helminthosporium sativum as influenced by Cephalothecium roseum Corda in green house pot tests. Sci. Agri. 15:377-386.

Griffin, D.M. 1972. Ecology of soil fungi Suffork. The Chaucer press.

Iren, S. and H. Soran. 1973. Studies on the identification and pathogenicity of the causal agents of melon fruit rot Fusarium equiseti (Corda) Sacc. Journal of Turkish Phytopathology 2:130-139.

Jauch C., H. Flesler, and W.E. Winter. 1975. Toxin production by Fusarium equiseti (Cda) Sacc. Fitopathologia. 10:109-116.

Joffe, A.Z. 1972. Fusarium isolated from avocado, banana, citrus fruits in Israel and their pathogenicity. Pl. Dis. Reptr. 56:963-966.

Joffe, A.Z. 1973. Fusarium species on groundnut kernel and on groundnut soil. Plant and Soil, 38:439-446.

Joffe, A.Z. and J. Palti. 1967. Fusarium equiseti (Corda) Sacc. in Israel. Israel Jour. of Bot. 16: 1-18.

Joffe, A.Z. and J. Palti. 1971. Causes of Fusarium wilts of curcubits in Israel and conditions favouring their development. Phytopathology 70:31-42.

Johnston, C.L. and F.J. Greaney. 1942. Studies on the pathogenicity of Fusarium spp. associated with root rot of wheat. Phytopathology 32:670-684.

Lim, S.M. and A.L. Hooker. 1972. Disease determinant of Helminthosporium maydis race T. Phytopathology. 62:968-971.

Lucas, R.L. 1955. A comparative study of Ophiobolus graminis and Fusarium culmorum in saprophytic colonization of wheat straw. Ann. appl. Biol. 43:134-143.

Ludwig, R.A., R.A. Clark, J.B. Julien, and D.B. Robinson. 1956. Studies on the seedling disease of barley caused by Helminthosporium sativum P.K. & B. Can J. Bot. 34:653-673.

Ludwig, R.A. 1957. Toxin production by Helminthosporium sativum P.K. & B and its significance in disease development. Can. J. Bot. 35:291-303.

Luke, H.H. and H.E. wheeler. 1955. Toxin production by Helminthosporium victoriae. Phytopathology 45:453-458.

Macer, R.C.F. 1961. Saprophytic colonization of wheat straw by Cercosporella herpotrichoides (Fron) and other fungi. Ann. appl. Biol. 49:152-164.

Mcknight, T. 1960. Survey of present incidence, importance and causes of cereal root rots in Australia. Proc. Conf. on Root Rots of Wheat, Wagga Wagga, N.S.W. pp. 1-12.

McMullen, M.V. and R.W. Stack. 1978. Differential susceptibility to common root rot among Durum wheat cultivars. Phytopathology News. 12:8.

Misra, A.P. and B. Mishra. 1971. Studies on the three isolates of Helminthosporium rostratum Drechsler, from sorghum in India. Indian Bot. Soc. 50:232-237.

Misra, A.P. and T.B. Singh. 1970. A new leaf spot disease of Pennisetum typhoides caused by Helminthosporium rostratum Drechs. in India. Indian Phytopath. 23:701-702.

Misra, A.P., R.A. Singh, and O. Prakash. 1971. New diseases of three graminaceous hosts caused by Helminthosporium rostratum in India. Indian Phytopath. 24:783-784.

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Mensah, R.A. and B.G. Zwatz. 1975. A study on stalk rot of maize Zea mays L. the disease complex with special reference to possibilities of artificial inoculation. Crops Res. Inst. 44:161-194.

Nath, R., S.B. Mathur, and P. Neergaard. 1970. Seedborne fungi of mungbean (Phaseolus aureus Roxb) from India and their significance. Proc. Inter. Seed Test. Assoc. 35:225-241.

Nolia, J.A.B. 1970. Helminthosporium rostratum in Puerto Rico. Phytopathology 60:1540.

Ohiagu, C.E. 1979. Termites as pests of crops and pastures in Northern Nigeria. A short review of the work of the Termite Research Project. Seminar delivered at I.A.R., A.B.U., Zaria.

Orsenigo, M. 1956. Produzione di tossine da prate di Helminthosporium oryzae. Breda de Hean. Parte I Ann. Sper. agri. N.S. 10:1745-1762 (cited from Rev. appl. Mycol. 36:422).

Oswald, J.W. 1949. Cultural variation, taxonomy and pathogenicity of Fusarium species associated with Fusarium root rots. Phytopathology 39:359-376.

Pisarev, V.E. and E.S. Malinovskaya. 1945. The breeding of spring wheats resistant to Fusarium. (cited from Rev. appl. Mycol. 24:184).

Pukhal'skil, A.V., T.D. Cheremisova, L.G. Gubanova, E.L. Kolbasina, M.F. Grigorev, M.V. Novikova. 1977. Winter wheat from German Democratic Republic and German Federal Republic as initial material for breeding in the non-czenozem zone of the Russian S.S.R. Trudy'po Prikladoni Botanike, Genetikei Selektsii. 60:5-23. (cited from Rev. Pl. Path. 58:226).

Putterill, K.M. 1954. Some graminicolous species of Helminthosporium and Curvularia occuring in South Africa. Bothalia. 6:347-378. (cited from Rev. appl. Mycol. 34:323).

Rao, A.S. 1959. A comparative study of competitive saprophytic ability of 12-infecting fungi by an agar-plate method. Trans. Br. mycol. Soc. 42:97-111.

Reddy, S.M. and K.S. Bilgrami. 1969. Studies on some species of Helminthosporium. Indian Phytopath. 22:429-437.

Richardson, M.J., and E.M. Fraser. 1968. New combinations in Drechslera. Trans. Br. Mycol. Soc. 51:147-148.

Sallans, B.J. 1965. Root rot of cereals III. Bot. Rev. 31:505-536.

Scott, P.R. 1969. Effect of nitrogen and glucose on saprophytic survival of Ophiobolus graminis in buried straw. Ann. appl. Biol. 63:27-36.

Sharp, E.L. 1962. Seedling reaction of wheat varieties to infection by several isolates of Helminthosporium sativum. Phytopathology. 52:364-365.

Simmonds, R.M. 1941. Root rot of cereals. Bot. Rev. 7:308-332.

Simmonds, P.M. 1953a. Root rot of cereals. Bot. Rev. 19:131-146.

Simmonds, P.M. 1953b. Infection of crown and roots in relation to crown root injury. Phytopathology 43:484.

Singh, B.P., and L.K. Joshi. 1972. Studies on the diseases of Piper betle in Jabalpur (Madhya Pradesh). Four new world records of Fusaria. Sci. Cult. 38:285.

Soribe, F.I. 1978. River Basins development - the basis for agro-industries. New Nigerian 27th October. p.5.

Spencer, E.K., R.A. Ludwig, P. DeMayo, and R.W. White. 1963. Helminthosporal - the toxin associated with Helminthosporium sativum (Bipolaris sorokiniana) in disease development. 5th Inter. Pesticide Congr. London. 17-23 July 1963. (cited from Rev. appl. Mycol. 43: 169).

Subramanian, C.V., and B.L. Jain. 1966. A revision of some graminicolous Helminthosporia. Curr. Sc. 35:352-355.

Subramanyam, P., C.S. Prabhakar, A.S. Rao. 1974. Tuber rot of Cycas beddomi Dyer. caused by Fusarium equiseti (Corda) Sacc. Curr. Sci. 43:318-319.

Tamura, S., A. Sakurai, K. Kainuma and M. Takai. 1963. Isolation of helminthosporal as a natural plant growth regulator and its chemical structure. Agri. biol. Chem. 27:738-739.

Tuvardzhieva, L.V. 1974. Species composition of causal agents of Fusarium wilts of melon. Byelleteu Vsesoyuznogo Instituta Rastenrevodstva Imeni N.I. Vivalova. 41:72-73. (cited from Rev. pl. Path. 54:471).

Tyagi, P.D. 1963. Some effects of culture filtrates of Bipolaris spp. on wheat roots. Proc. Indian Acad. Sci. B. 57:106-116.

Walker, A. 1941. Colonization of buried wheat straw by soil fungi with special reference to Fusarium culmorum. Ann. appl. Biol. 28:333-350.

Wastie, R.L. 1961. *Factors affecting competitive saprophytic colonization of the agar plate by various root-infecting fungi.* Trans. Br. Mycol. Soc. 44:145-159.

Whitehead, M.D., and O.H. Calvert. 1959. Helminthosporium rostratum inciting ear rot of corn and leaf spot of 13 grass hosts. Phytopathology 49:817-820.

Whittle, A.M. 1977. Cochliobolus sativus on Barley in Scotland. Pl. Path. 26:67-74.

Wood, R.K.S. 1967. Physiological Plant Pathology. Oxford: Blackwell.

Young, G.Y., C.L. Lefebvre, and A.G. Johnson. 1947. Helminthosporium rostratum on corn, sorghum, and pearl millet. Phytopathology 47:180-183.

Zakharova, T.I. 1971. Role of Fusarium spp. in hollow ear formation of spring wheat. Trudy Vseoyunogo Nauchnoissledovatel-skogo Instituta Zashchity Raslenii 29: 92-99 (cited from Rev. pl. Path. 51:584).

VIII. APPENDIX

Appendix 1: Analysis of Variance for the pathogenicity of *D. rostrata* on 14 cultivars of wheat in petri dishes

(a) Seed germination

Source	D.F.	S.S.	M.S.	F
Cultivars	13	577.67632	44.436640	1.04^{NS}
Error	42	1801.2979	42.888045	
Total	55	2378.9742		

(b) Shoot length

Source	D.F.	S.S.	M.S.	F
Cultivars	13	707.31594	54.408918	2.37*
Error	42	964.09515	22.954646	
Total	55	1671.4111		

(c) Disease rating

Source	D.F.	S.S.	M.S.	F
Cultivars	13	12.930893	0.99468	7.71**
Error	42	5.41750	0.12899	
Total	55	18.348393		

NS = Not significant

* = Significant at 5%

** = Significant at 1%

Appendix 2: Analysis of Variance for pathogenicity of F. equiseti on 14 cultivars of wheat in petri dishes

(a) Seed germination

Source	D.F.	S.S.	M.S.	F
Cultivars	13	1462.8009	112.52314	4.98**
Error	42	949.36702	22.60379	
Total	55	2412.1679		

(b) Shoot length

Source	D.F.	S.S.	M.S.	F
Cultivars	13	810.63404	62.356464	6.75**
Error	42	387.83417	9.23415	
Total	55	1198.4682		

(c) Disease rating

Source	D.F.	S.S.	M.S.	F
Cultivars	13	17.697143	1.36132	18.093**
Error	42	3.16000	.07524	
Total	55	20.857143		

** = Significant at 1%

Appendix 3a: Analysis of Variance for disease rating of D. rostrata in potted soil experiment

Source	D.F.	S.S.	M.S.	F
Cultivars	13	2.91905	.22454	2.18*
Error	28	2.88000	.10286	
Total	41	5.79905		

* = Significant at 5%

Appendix 3b: Analysis of Variance for disease rating of F. equiseti in potted soil experiment

Source	D.F.	S.S.	M.S.	F
Cultivars	13	3.88286	.29868	5.06**
Errors	28	1.68333	.05905	
Total	41	5.53619		

** = Significant at 1%.

Appendix 4: Analysis of Variance of the pathogenicity of the different isolates of D. rostrata on wheat cultivar Pitic 62 in petri dishes

(a) Seed germination

Source	D.F.	S.S.	M.S.	F
Isolates	6	495.23810	82.539683	.62^{NS}
Error	14	1850.0000	132.14286	
Total	20	2345.2381		

(b) Shoot length

Source	D.F.	S.S.	M.S.	F
Isolates	6	50.673590	8.44560	5.24**
Error	14	22.551133	1.61080	
Total	20	73.224724		

(c) Disease rating

Source	D.F.	S.S.	M.S.	F
Isolates	6	3.87619	.64603	8.17**
Error	14	1.10667	.07905	
Total	20	4.98286		

NS = Not significant

** = Significant at 1%

Appendix 5: Analysis of Variance of the pathogenicity of the different isolates of F. equiseti on wheat cultivar Pitic 62 in petri dishes

(a) Seed germination

Source	D.F.	S.S.	M.S.	F
Isolates	6	630.95238	105.15873	2.01^{NS}
Error	14	733.33333	52.380952	
Total	20	1364.2857		

(b) Shoot length

Source	D.F.	S.S.	M.S.	F
Isolates	6	33.440114	5.57335	9.36**
Error	14	8.33687	.59549	
Total	20	41.776981		

(c) Disease rating

Source	D.F.	S.S.	M.S.	F
Isolates	6	2.68571	.44762	7.29**
Error	14	.86000	.06143	
Total	20	3.54571		

NS = Not significant

** = Significant at 1%

Appendix 6: Analysis of Variance of the pathogenicity of the different isolates of D. rostrata on wheat cultivar Pitic 62 in potted soil

(a) Shoot length

Source	D.F.	S.S.	M.S.	F
Isolates	6	105.17429	17.529048	6.39**
Error	21	57.590000	2.74238	
Total	27	162.76429		

(b) Disease rating

Source	D.F.	S.S.	M.S.	F
Isolates	6	14.083571	2.34726	8.64**
Error	21	5.675000	.27024	
Total	27	19.758571		

** Significant at 1%

Appendix 7: Analysis of Variance of relationship between inoculum density of D. rostrata and severity of foot and root rots on plants grown from seeds sown in infested soil

(a) Disease rating with sand-maize meal-chopped straw media

Source	D.F.	S.S.	M.S.	F
Inoculum densities	5	9.87708	1.97542	28.164**
Error	18	1.26250	.07014	
Total	23	11.139583		

(b) Disease rating with sand-maize meal media

Source	D.F.	S.S.	M.S.	F
Inoculum densities	5	3.35875	.67175	16.176**
Error	18	.74750	.04153	
Total	23	4.10625		

(c) Disease rating with chopped straw media

Source	D.F.	S.S.	M.S.	F
Inoculum densities	5	26.667083	5.33342	49.169**
Error	18	1.95250	.10847	
Total	23	28.619583		

** = Significant at 1%

Appendix 8: Analysis of Variance of relationship between inoculum density of F. equiseti and severity of foot and root rots on plants grown from seeds sown in infested soil

(a) Disease rating with sand-maize meal-chopped straw media

Source	D.F.	S.S.	M.S.	F
Inoculum densities	5	12.088333	2.41767	21.074**
Error	18	2.06500	.11472	
Total	23	14.153333		

(b) Disease rating with sand-maize meal media

Source	D.F.	S.S.	M.S.	F
Inoculum densities	5	3.69208	.73842	11.685**
Error	18	1.13750	.06319	
Total	23	4.82958		

(c) Disease rating with chopped straw media

Source	D.F.	S.S.	M.S.	F
Inoculum densities	5	22.018333	4.40367	30.254**
Error	18	2.62000	.14556	
Total	23	24.638333		

** = Significant at 1%

Appendix 9: Analysis of Variance of relationship between inoculum density of D. rostrata and severity of foot and root rots on plants whose seedlings were transplanted into infested soil

(a) Disease rating with sand-maize meal-chopped straw media

Source	D.F.	S.S.	M.S.	F
Inoculum densities	5	27.023750	5.40475	57.143**
Error	18	1.70250	.09458	
Total	23	28.726250		

(b) Disease rating with sand-maize meal media

Source	D.F.	S.S.	M.S.	F
Inoculum densities	5	30.427083	6.08542	58.812**
Error	18	1.86250	.10347	
Total	23	32.289583		

Appendix 10: Analysis of Variance of relationship between inoculum density of F. equiseti and severity of foot and root rots on plants whose seedlings were transplanted into infested soil

(a) Disease rating with sand-maize meal-chopped straw media

Source	D.F.	S.S.	M.S.	F
Inoculum densities	5	23.832083	4.76642	41.903**
Error	18	2.04750	.11375	
Total	23	25.879583		

(b) Disease rating with sand-maize meal media

Source	D.F.	S.S.	M.S.	F
Inoculum densities	5	29.365000	5.87300	155.46**
Error	18	.68000	.03778	
Total	23	30.045000		

** = Significant at 1%

Appendix 11: Analysis of Variance of effect of soil sterilization on intensity of foot and root rots of wheat caused by D. rostrata

(a) Shoot length

Source	D.F.	S.S.	M.S.	F
Treatments	3	209.9919	69.9973	38.28**
Error	12	21.9425	1.82854	
Total	15	321		

(b) Fresh weight of seedlings

Source	D.F.	S.S.	M.S.	F
Treatments	3	31.2350	10.41166	123.09**
Error	12	1.0150	.084583	
Total	15	32.2500		

(c) Disease rating

Source	D.F.	S.S.	M.S.	F
Treatments	3	11.0919	3.6975	35.85**
Error	12	1.2375	0.10312	
Total	15	12.3294		

** = Significant at 1%.

Appendix 12: Analysis of Variance of effect of soil sterilization on intensity of foot and root rots caused by F. equiseti

(a) Shoot length

Source	D.F.	S.S.	M.S.	F
Treatments	3	118.1400	39.3800	22.06**
Error	12	21.4200	1.7850	
Total	15	139.5600		

(b) Fresh weight of seedlings

Source	D.F.	S.S.	M.S.	F
Treatments	3	19.9560	6.65166	79.42**
Error	12	1.0050	.08375	
Total	15	20.9600		

(c) Disease rating

Source	D.F.	S.S.	M.S.	F
Treatments	3	2.53190	.843960	19.20**
Error	12	.52750	.043950	
Total	15	3.05940		

** = Significant at 1%.

Appendix 13: Analysis of Variance of effect of method of inoculation on intensity of foot and root rots caused by D. rostrata and F. equiseti

Source	D.F.	S.S.	M.S.	F
Treatments	9	20.9000	2.32220	31.77*
Error	26	1.9000	.07307	
Total	35	22.8000		

* = Significant at 1%.

Appendix 14: Analysis of Variance of effect of soil moisture on pathogenicity of D. rostrata

(a) Sowing seeds in infested soil

Source	D.F.	S.S.	M.S.	F
Treatments	3	10.44690	3.48230	165.50**
Error	12	.25250	.02104	
Total	15	10.6994		

(b) Transplanting seedlings into infested soil

Source	D.F.	S.S.	M.S.	F
Treatments	3	16.0569	5.3523	165.75**
Error	12	.3875	.03229	
Total	15	16.4444		

** = Significant at 1%.

Appendix 15: Analysis of Variance of effect of soil moisture on *pathogenicity of F. equiseti*

(a) Sowing seeds in infested soil

Source	D.F.	S.S.	M.S.	F
Treatments	3	5.9244	1.9748	74.04**
Error	12	.3200	.0266	
Total	15	6.2444		

(b) Transplanting seedlings into infested soil

Source	D.F.	S.S.	M.S.	F
Treatments	3	27.4900	9.16333	229.08**
Error	12	.4800	.04000	
Total	15	27.97		

** = Significant at 1%.

Appendix 16: Analysis of Variance of effect of soil type on pathogenicity of *D. rostrata*

(a) Seed germination

Source	D.F.	S.S.	M.S.	F
Soil type	3	156.78188	52.260625	.76^{NS}
Error	12	824.93750	68.744792	
Total	15	981.71937		

(b) Disease rating

Source	D.F.	S.S.	M.S.	F
Soil type	3	.29187	.09729	1.15^{NS}
Error	12	1.01750	.08479	
Total	15	1.30937		

NS = Not significant

Appendix 17: Analysis of Variance of effect of soil type on pathogenicity of *F. equiseti*

(a) Seed germination

Source	D.F.	S.S.	M.S.	F
Soil type	3	2128.8019	709.60062	6.90*
Error	12	1234.9675	102.91396	
Total	15	3363.7694		

(b) Disease rating

Source	D.F.	S.S.	M.S.	F
Soil type	3	1.49187	.49729	3.32^{NS}
Error	12	1.79750	.14979	
Total	15	3.28937		

NS = Not significant

* = Significant at 5%.

Appendix 18: Analysis of Variance of effect of combined inoculum of *D. rostrata* and *F. equiseti* on pathogenicity

(a) Seed germination

Source	D.F.	S.S.	M.S.	F
Pathogens	3	267.18750	89.06250	.91^{NS}
Error	12	1168.7500	97.395833	
Total	15	1435.93750		

(b) Fresh weight of seedling

Source	D.F.	S.S.	M.S.	F
Pathogens	3	42.995000	14.331667	50.067**
Error	12	3.43500	.28625	
		46.43000		

(c) Disease rating

Source	D.F.	S.S.	M.S.	F
Pathogens	3	10.311875	3.43729	59.996**
Error	12	.68750	.05729	
Total	15	10.999375		

** = Significant at 1%.

Appendix 19: Analysis of Variance of effect of culture filtrate and/or dry ground mycelial mat of D. rostrata on seed germination and root growth

(a) Seed germination (Czapek-Dox as control)

Source	D.F.	S.S.	M.S.	F
Treatments	2	640.13556	320.06778	4.87^{NS}
Error	6	394.03333	65.672222	
Total	8	1034.1689		

(b) Seed germination (Sterile distilled water as control)

Source	D.F.	S.S.	M.S.	F
Treatments	2	394.500000	198.25000	5.43*
Error	6	219.16000	36.526667	
Total	8	615.66000		

(c) Root length (Czapek-Dox as control)

Source	D.F.	S.S.	M.S.	F
Treatments	2	16.49556	8.24779	.15^{NS}
Error	6	338.25333	56.375556	
Total	8	354.74889		

(d) Root length (Sterile distilled water as control)

Source	D.F.	S.S.	M.S.	F
Treatments	2	18.835556	9.41778	.26^{NS}
Error	6	219.24000	36.540000	
Total	8	238.07556		

NS = Not significant
* = Significant at 5%.

Appendix 20: Analysis of Variance of effect of culture filtrate and/or dry ground mycelial mat of F. equiseti on seed germination and root growth

(a) Seed germination (Czapek-Dox as control)

Source	D.F.	S.S.	M.S.	F
Treatments	2	188.94889	94.474444	4.28^{NS}
Error	6	132.40667	22.067778	
Total	8	321.35556		

(b) Seed germination (Sterile distilled water as control)

Source	D.F.	S.S.	M.S.	F
Treatments	2	85.820000	42.910000	1.89^{NS}
Error	6	135.88000	22.646667	
Total	8	221.700000		

(c) Root length (Czapek-Dox as control)

Source	D.F.	S.S.	M.S.	F
Treatments	2	149.88667	74.943333	$.82^{NS}$
Error	6	551.57333	91.928889	
Total	8	701.46000		

(d) Root length (Sterile distilled water as control)

Source	D.F.	S.S.	M.S.	F
Treatments	2	105.86000	52.930000	$.93^{NS}$
Error	6	342.06000	57.010000	
Total	8	447.92000		

NS = Not significant.

Appendix 21: Analysis of Variance of effect of different concentrations of filtrates from still and shake cultures of D. rostrata on seed germination and root growth

(a) Seed germination in still cultures

Source	D.F.	S.S.	M.S.	F
Culture filtrate concentrations	4	424.04933	106.01233	6.99**
Error	10	151.62000	15.162000	
Total	14	575.66933		

(b) Seed germination in shake cultures

Source	D.F.	S.S.	M.S.	F
Culture filtrate concentrations	4	1316.1960	329.04900	19.469**
Error	10	169.01333	16.901333	
Total	14	1485.2093		

(c) Root length in still culture

Source	D.F.	S.S.	M.S.	F
Culture filtrate concentrations	4	2373.3067	593.32667	6.75**
Error	10	878.74667	87.874667	
Total	14	3252.0533		

(d) Root length in shake cultures

Source	D.F.	S.S.	M.S.	F
Culture filtrate concentration	4	10712.937	2678.2343	52.051**
Error	10	514.54000	51.454000	
Total	14	11227.477		

** = Significant at 1%.

Appendix 22: Analysis of Variance of effect of different concentrations of filtrates from still and shake cultures of F. equiseti on seed germination and root growth

(a) Seed germination in still cultures

Source	D.F.	S.S.	M.S.	F
Culture filtrate concentrations	4	108.08000	27.020000	.76^{NS}
Error	10	356.23333	35.62333	
Total	14	464.31333		

(b) Seed germination in shake cultures

Source	D.F.	S.S.	M.S.	F
Culture filtrate concentrations	4	130.83333	32.708333	1.43^{NS}
Error	10	228.48667	22.848667	
Total	14	359.32000		

(c) Root length in still cultures

Source	D.F.	S.S.	M.S.	F
Culture filtrate concentrations	4	2700.3000	675.07500	5.29*
Error	10	1275.5733	127.55733	
Total	14	3975.8733		

(d) Root length in shake cultures

Source	D.F.	S.S.	M.S.	F
Culture filtrate concentrations	4	6447.6173	1611.9043	20.862**
Error	10	772.64000	77.264000	
Total	14	7220.2573		

NS = Not significant
* = Significant at 5%
** = Significant at 1%.

Appendix 23: Analysis of Variance of saprophytic colonizing abilities of D. rostrata, F. equiseti and F. culmorum

Source		S.S.	M.S.	F
Fungi	2	3777.920	1888.9600	98.794**
Error	9	172.080	19.1200	
Total	11	3950.0000		

** = Significant at 1%.