EPIDEMIOLOGY OF RUST AND LEAF SPOTS DISEASES OF GROUNDNUT (*Arachis hypogaea* L.)

Thesis submitted to the Andhra Pradesh Agricultural University in part fulfilment of the requirements for the award of the Degree of Doctor of Philosophy

by

A. Sudhakara Rao M.Sc.,(Ag.)

Department of Plant Pathology
College of Agriculture
Andhra Pradesh Agricultural University
Rajendranagar, Hyderabad 500030

September 1986

इन्द्रियाणि पराण्याहुरिन्द्रियेभ्यः परं मनः ।
मनसस्तु परा बुद्धिर्यो बुद्धेः परतस्तु सः ॥४२॥

The senses are said to be greater than the body; but greater than the senses is the mind. Greater than the mind is the intellect; and what is greater than the intellect is he (the Self).

BHAGAVADGITA 3:42

DEDICATED

ANILA
(Daughter)

LAKSHAMMA
(Mother)

CERTIFICATE

Sri A. Sudhakara Rao has satisfactorily prosecuted the course of research and that the thesis entitled "Epidemiology of rust and leaf spots diseases of groundnut (*Arachis hypogaea* L.)" submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. We also certify that the thesis or part thereof has not been previously submitted by him for a degree of any university.

(K. RAMACHANDRA REDDY)
CHAIRMAN

(D. MACDONALD)
CO-CHAIRMAN

CERTIFICATE

This is to certify that the thesis entitled "Epidemiology of rust and leaf spots diseases of groundnut (*Arachis hypogaea* L.)" submitted in partial fulfilment of the requirements for the degree of "Doctor of Philosophy" in Agriculture in the major field of Plant Pathology of the Andhra Pradesh Agricultural University, Hyderabad is a record of the bonafide research work carried out by Sri A. Sudhakara Rao under our guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee.

No part of the thesis has been submitted for any other degree or diploma or has been published. All the assistance and help received during the course of investigations have been duly acknowledged by him.

(K. RAMACHANDRA REDDY)
CHAIRMAN

(D. McDONALD)
CO-CHAIRMAN

Thesis approved by Student Advisory Committee

CHAIRMAN	(K. RAMACHANDRA REDDY) .....
CO-CHAIRMAN	(D. McDONALD) .....
MEMBER	(D.V.R. REDDY) .....
MEMBER	(C.A. JAGADISH) .....
MEMBER	(C.S. REDDY).....

CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

ACKNOWLEDGEMENTS

I feel immense pleasure in expressing my sincere thanks and deep sense of gratitude to Drs K. Ramachandra Reddy and D. McDonald, Professor and Head, Department of Plant Pathology, Agricultural College, Tirupati, and Principal Plant Pathologist, Groundnut Pathology, ICRISAT, Patancheru, respectively for suggesting the problem and their encouragement and guidance throughout the investigation and in preparation of the manuscript.

I am highly thankful to Dr D.V.R. Reddy, Principal Virologist, Groundnut Pathology, ICRISAT for his valuble suggestions and help rendered during the course of investigation and for acting as a Member of the Advisory Committee. I am equally thankful to Dr P. Subrahmanyam, Groundnut Pathologist for his guidance, valuable suggestions and constant encouragement throughout the investigation and in preparation of the manuscript.

I am grateful to Dr D.L. Oswalt, Principal Training Officer, ICRISAT for his encouragement and providing critical comments throughout this investigation.

I extend my thanks and gratitude to Prof C.A. Jagadish, Departemnt of Genetics and Plant Breeding, College of Agriculture for his excellent encouragement and critically going through the manuscript and acting as a Member of the Advisory Committee. I am also thankful to Dr C.S. Reddy, Associate Professor, Department of Genetics and Plant Breeding, College of Agriculture for criti-

cally going through the manuscript and for acting as a Member of the Advisory Committee. I am also thankful to Dr Murari Singh, Statistician for his help in statistical analysis.

I am highly thankful to Prof A.H. Bunting, Retd. Professor for Agricultural Development Overseas, University of Reading, England for his constnat encouragement and valuable suggestions during the course of this investigation. Thanks also due to Dr V.T. John, Principal Plant Pathologist, IITA, Nigeria, Prof P. Ramachar, Dept. of Botany, Nizam College, Hyderabad, and Dr K.V.Seshu Reddy, Principal Entomologist, ICIPE, Kenya for their moral encouragement throughout the course of this investigation.

I am also thankful to Prof K.A. Balasubrahmaniam, Principal, Agricultural College, Bapatla for his valuable suggestions throughout the course of this investigation.

I am thankful to Mr P.M. Reddy, Research Associate II and Mr P.V. Subba Rao Research Associate I (on study leave) Groundnut Pathology, and Mr M.R. Sudharshana, Research Associate I, Agronomy (Legumes) for their consant and sincere help during the course of this investigation and also helping in the statistical analysis of the data. I am also grateful to all the staff of the Groudnut Pathology especially to Mr D. Yohan, field attendant for their constant and sincere help during the course of this investigation. Thanks also due to Drs S. Sithanantham, J.

Kanniyan, M. Natarajan, and Mr Y.V.R. Reddy, and Mr C.Rajagopala Reddy for their constant encouragement and moral support.

I specially thank my wife Smt Vasantha and daughter Madhusmita for their cooperation and inspiration during my Ph.D program.

Thanks are due to ICAR for providing the Senior Fellowship for carrying out this investigation. I thank A.P.Agricultural University for granting study leave.

I wish to express my appreciation to Mr Sai Ranga Rao, typist, Groundnut Pathology, and Mr P. Chenchaiah, senior typist, Mrs Jagatha Seetharman, secretary, Training Program for typing the manuscript.

September 30, 1986

A. SUDHAKARA RAO

ABSTRACT

Author	: A. Sudhakara Rao
Title of the thesis	: Epidemiology of rust and leaf spots diseases of groundnut (*Arachis hypogaea* L.)
Degree	: Ph.D.
Faculty	: Plant Pathology
Chairman and Co-Chairman	: Dr K. Ramachandra Reddy Dr D. McDonald
University	: Andhra Pradesh Agricultural University
Year of submission	: 1986

Rust and leaf spots diseases of groundnut were studied over two years from 1983 to 1985 at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Hyderabad.

Temperature was an important factor in determining the longevity of rust and leaf spots pathogens. Spores of rust and late leaf spot pathogens retained germinability and infectivity for longer periods (>160 days) at lower temperatures (-17 and 10°C) than when stored at higher temperatures (30 and 40 °C). In rust-susceptible genotypes, the spores survived for 30 days when the infected debris was kept on the field surface and at 5 and 10 cm depth in the soil after the harvest of the 1983 rainy season crop. They lost viability more rapidly (15 days) after the harvest of the 1983-84 postrainy season crop. However, they survived for 45 days when kept indoors in both seasons of harvest. The late leaf spot fungus survived in crop debris for 60 days after harvest of the 1983 rainy season crop and for 30

days after harvest of the 1983 postrainy season crop when stored on the soil surface. It could survive for 30 days when the debris was buried at 5 and 10 cm depth in the soil. The viability was retained for over a year when crop debris was stored indoors. However, in debris from the rust and late leaf spot-resistant genotypes, viability was lost very rapidly. The rust and leaf spots pathogens survived for 30 days in the soil.

Rust, early and late leaf spots fungi were observed on ground-keepers and volunteer groundnut plants from October 1984 (end of the 1984 rainy season) to June 1985 (beginning of the 1985 rainy season). No collateral hosts for the three pathogens were found although many leguminous crop and weed plants were artifically inoculated.

Groundnut pods and seeds surface-contaminated with viable spores of rust, early and late leaf spots pathogens gave rise to disease-free seedlings.

Rust and late leaf spot-resistant genotypes had increased incubation periods, decreased infection frequencies and leaf area damage, and reduced lesion diameters and sporulation indexes. Rust and late leaf spot diseases development was optimum at temperatures of 20-30 ^{o}C and was in agreement with the studies on *in vitro* spore germination. Early leaf spot development was favoured by temperatures in the range of 20-30 ^{o}C.

Two genotypes with resistance to rust and late leaf spot diseases and two with moderate resistance to these diseases were

grown in two rainy (1983 and 1984) and two postrainy (1983-84 and 1984-85) seasons together with two susceptible genotypes. Rust and late leaf spot diseases attacks appeared early and were severe (higher area under the disease progress curve (AUDPC)) in the inoculated plots than in the uninoculated plots. There was a strong varietal interaction on rust and late leaf spot development. The diseases were more severe on all genotypes in the rainy seasons than in the postrainy seasons. The apparent infection rates (r-values) for rust and late leaf spot diseases were higher for susceptible genotypes than for resistant ones except in the 1983 rainy season. The initial Δt (delay in time to disease onset) for rust was high in susceptible genotypes in both rainy seasons, but it was variable for late leaf spot. The initial Δt for both the diseases was zero for all the genotypes in the postrainy season. The final Δt for rust and late leaf spot was variable in both rainy and postrainy seasons.

INTRODUCTION

CHAPTER 1

INTRODUCTION

India is the world's largest producer of groundnut (*Arachis hypogaea* L.) and in 1983/84 some 7.64 million hectares were planted and 7.28 million tonnes of dried pods were harvested (ASI, 1984). The states of Gujarat, Andhra Pradesh, Tamil Nadu, Karnataka and Maharashtra contribute approximately 85% of the country's production. About 90% of the crop is produced in the rainy season (*kharif*) and the remainder in the postrainy season (*rabi*) (Subrahmanyam and McDonald, 1982). In India, groundnut is grown almost entirely by small farmers, and yields are low, around 900 kg ha^{-1}, compared with approximately 2500 kg ha^{-1} in the developed world. The major constraints of groundnut production in India are diseases, pests, and unreliable rainfall patterns (Gibbons, 1980).

A number of diseases caused by fungi, viruses and nematodes have been reported on groundnut in India. Some are widely distributed and cause considerable yield losses, while others are restricted in distribution and are not considered to be economically important on a national basis.

Among the fungal diseases of groundnut, rust caused by *Puccinia arachidis* Speg., early leaf spot caused by *Cercospora arachidicola* Hori, and late leaf spot caused by *Phaeoisariopsis personata* (Berk. & Curt.) v.Arx are commonly present wherever groundnut is grown in India. Rust and late leaf

spot are the most serious and economically important groundnut diseases in India. Individually, each of these diseases can reduce yields by more than 50%; when they occur together losses can be as high as 70% (Subrahmanyam *et al.*, 1980). The magnitude of yield losses caused by these diseases has attracted the attention of agricultural research workers in India who have appreciated the need for collaborative research efforts at regional and national level to manage these diseases effectively.

The distribution of rust and leaf spots diseases in India has been largely determined, and the yield losses caused by these diseases in various groundnut growing areas have been estimated. Research on chemical control of rust and leaf spots has been extensively carried out and management recommendations have been made to the farmers on a regional basis. Breeding for resistance to rust and leaf spots has gained momentum in recent years and efforts are being made in India to develop high-yielding groundnut genotypes with resistance to these diseases (Gibbons, 1980). However, the research on epidemiology of groundnut rust and leaf spots has not received adequate emphasis in India. In recent years, there have been some research publications on perpetuation and carry-over of groundnut rust in India, and on the effects of various climatic factors on rust development on susceptible groundnut cultivars in the field. Information on perpetuation, carry-over and spread of leaf spot pathogens in India is scanty. Information on host X pathogen X

environment interactions is not available. These data are essential to develop integrated disease management strategies.

The major objectives of the present investigation are to study the survival of rust and leaf spots pathogens in infected crop debris under both field and laboratory conditions; to study the effect of temperature on survival of spores of rust and leaf spots pathogens; to investigate the possible carry-over and spread of rust and leaf spots pathogens on seed; to search for collateral hosts and determine the role of ground-keepers and volunteer groundnut plants on perpetuation and carry-over of rust and leaf spots pathogens; to study the effect of temperature on rust and leaf spots development on resistant and susceptible genotypes under monocyclic infection in the laboratory, and to investigate host X pathogen X environment interactions in respect of rust and leaf spots diseases and resistant and susceptible groundnut genotypes in rainy and postrainy seasons at ICRISAT Center, Patancheru, Andhra Pradesh.

REVIEW OF LITERATURE

CHAPTER-II

REVIEW OF LITERATURE

Information on geographical distribution of rust and leaf spots, their economic importance, symptoms, description of causal organisms, and disease management including cultural, biological, chemical and genetical methods, is briefly reviewed, and the relevent literature on epidemiology is reviewed in detail in this chapter.

2.1. Rust:

2.1.1. Geographical distribution: Prior to 1969, groundnut rust was largely confined to south and central America with occasional outbreaks in the southeastern USA (Bromfield, 1971). The disease was also recorded in the USSR (Jaczewski, 1910), Mauritius (Stockdale, 1914) and the People's Republic of China (Tai, 1937), but did not become permanently established in these countries (Subrahmanyam and McDonald, 1983). Hammons (1977) pointed out that rust was not considered a serious problem in the USA. In recent years, rust of groundnut has spread to many countries in Asia, Australasia and Oceania including Australia, Brunei, Fiji, India, Indonesia, Japan, Korea, Malaysia, Papua New Guinea, the People's Republic of China, the Philippines, the Solomon Islands, Taiwan, Thailand and Tonga (QDPI, 1973; Bromfield, 1974; Mayee *et al.*, 1977; Subrahmanyam *et al.*, 1979; Subrahmanyam and McDonald, 1983; Vilsoni, 1980; Firman 1981). Rust has also been reported since 1974 from several African countries including Botswana, Ethiopia, Ghana, Kenya,

Mauritius, Mozambique, Malawi, Zimbabwe, Tanzania, Zambia, Somalia, Benin, Republic of South Africa, Senegal, Sudan, Uganda, Burkina Faso, and Nigeria (Reddy, 1975; Rothwell, 1975; Keswani and Ondieki, 1976; Raemaekers and Preston 1977; Castellani *et al.*, 1977; McDonald and Emechebe, 1978; Subrahmanyam and McDonald, 1983; Subrahmanyam *et al.*, 1985).

In India, rust was first observed in July, 1969, in the telial stage in the glasshouse at Punjab Agricultural University, Ludhiana, by Chahal and Chohan (1971). It was simultaneously reported from the east-coast region in 1971 in the uredinial stage (Bhama, 1972; Ramakrishna and Subbayya, 1973; Shanmugam *et al.*, 1972; Sharma and Mukherji, 1972). Subsequently, rust has been reported in many other groundnut growing areas of the country (Mayee *et al.*, 1977; Subrahmanyam *et al.*, 1979). The disease has become particularly important in southern India, where groundnuts are grown for most of the year and where conditions favour development and spread of the pathogen (Subrahmanyam and McDonald, 1982).

2.1.2. Economic importance: Rust was considered to be endemic to the West Indies and has hindered the commercial production of groundnut in these islands (Hammons, 1977). In Australia, it is now considered a serious problem. The early establishment of the disease is known to advance harvesting by 28 days which results in poor pod filling (O'Brien, 1977). Felix and Ricaud (1977) from Mauritius, reported losses amounting to 70% in some cases. Subrahmanyam *et al.*

(1980) from India, reported 70% losses in susceptible genotypes from combined attack of rust and leaf spots, while rust alone was responsible for 52% reduction in pod yield, and yield losses are more substantial in the rainy season than in the postrainy season. Zhou *et al.* (1980) recorded a loss of 20.4% for spring groundnut and 17.3% for autumn groundnut in Guangdong Province of the People's Republic of China. They further estimated losses following artificial inoculation at different growth stages, and showed that losses were greater when the rust attack developed early. Yield losses were 49% when rust appeared at the flowering stage, 41% at pegging stage, 31% at pod initiation, and 18% at middle pod forming period. Ghuge *et al.* (1981) estimated that rust caused a loss of 50% pod yield and lowered the 100-grain weight to the extent of 19% in India. Kenjale *et al.* (1981) from India, reported a loss of 35% in pod yield. Harrison (1972) noted that losses due to rust at two locations in Texas were 50% and 70%.

2.1.3 Symptoms: Rust can be readily recognised when the orange-coloured pustules (uredinia) appear on the abaxial (lower) surfaces of the leaves. The pustules later rupture to expose masses of reddish-brown urediniospores. Uredinia appear first on the abaxial surface. The original sorus may later be surrounded by colonies of secondary sori. Uredinia may also develop later on the adaxial (upper) surface opposite those on the abaxial surface. The uredinia, which develop on all aerial plant parts except flowers, are usually circular and

range from 0.3 to 1.0 mm in diameter. In contrast to the rapid defoliation associated with leaf spots, rust-damaged leaves tend to remain attached to the plant (Subrahmanyam and McDonald, 1983). Zhou *et al.* (1980) reported that pegs and shells also show infection of rust, the uredinia on pegs are elliptic and 1-2 mm in diameter; uredinia on shells are round to irregular and 1-2 mm in diameter.

2.1.4. *Causal organism*: Spegazzini (1884) described the rust on groundnut as *Puccinia arachidis* Spegazzini. Other names were subsequently proposed, but later Arthur (1934) accepted the nomenclature given by Spegazzini.

Puccinia arachidis Spegazzini

= *Uredo arachidis* Lagerheim. 1894. Tromso, Mus; Aarsh. 17:106;

= *Uromyces arachidis* P.Henning. 1896. Hedwigia 35:224; and

= *Bullaria* (?) *arachidis* (Speg.) Arthur & Mains. 1972. North American Flora 7(7):484.

Garren and Wilson (1951) noted that the telial stage was rarely reported, but Higgins (1956) stated that Guarch in Uruguay reported abundant telia on certain specimens of groundnut. Chahal and Chohan (1971) observed the teliospores on rust-infected plants in Punjab, India. However, there have been no similar reports of the occurrence of telia in India. Recently, Hennen *et al.* (1976) reported the occurrence of teliospores on the cultivated groundnut from Brazil. They stated that the teliospores developed within uredinia on inoculated plants grown in the greenhouse.

The rust fungus has been described by Arthur (1934), Jackson and Bell (1969), and Hennen *et al.*(1976) Cummins (1978) as follows:

Stage 0 = Spermogonia not known.

Stage I = Aecia not known.

Stage II = Uredinia mostly hypophyllous, scattered or irregularly grouped, round, ellipsoid, or oblong and dark cinnamon-brown when mature. Ruptured epidermis is conspicuous. Urediniospores (16-22 x 23-29 μm) are broadly ellipsoid or obovoid and brown-walled. Walls are 1-2.2 μm thick, and finely echinulate. They have usually two but occasionally three to four germpores, which are nearly equatorial, often in flattened areas.

Stage III. Telia chiefly occurring on the adaxial surface of leaves, are 0.2-0.3 mm in diameter, scattered, prominent, naked, and chestnut or cinnamon-brown, becoming gray or almost black with maturation. Teliospores are predominantly two-celled, rarely three to four-celled, oblong, obovate, ellipsoidal, or ovate, with a round to acute and thickened apex. They are constricted in the middle, tapering gradually at the base or tapered and rounded at both ends, smooth-walled, and light-yellow or golden-yellow or chestnut-brown, 38-42 x 14-16 μm, spore walls 0.7-0.8 μm thick at the sides and 2.5-4.0 μm thick at the top. The apical thick area is almost hyaline. The thin-walled, hyaline pedicels are 35-65 μm long, often collapse laterally, but, are usually detached at the spore base. Teliospores germinate at maturity without dormancy.

Stage IV. Metabasidia and basidiospores not known.

Cook (1972) from Jamaica, indicated that the rust fungus exists in more than one racial form. Five isolates of the fungus collected from different parts of India and maintained on a susceptible groundnut cultivar SB-IX revealed that urediniospore morphology did not vary significantly, however, the thermosensitivities of some isolates differed (Munde and Mayee, 1979). Mayee (1982) believed that "ecological races" of groundnut rust pathogen exist in India.

2.1.5. Epidemiology:

Bromfield (1971) emphasized the lack of information on the epidemiology of groundnut rust. Before 1975, there were only few reports on the epidemiology of groundnut rust. However, the recent spread of the disease to almost all major groundnut growing areas in the world has triggered research on perpetuation and carry-over of the pathogen and factors influencing the disease development.

2.1.5.1: Perpetuation, carry-over and spread of groundnut rust: Groundnut rust is known almost exclusively by its uredinial stage. There are a few records of the occurrence of the telial stage on cultivated groundnut in South America (Hennen et al., 1976) and on wild Arachis species (Bromfield, 1971). There has been no authentic report of the occurrence of teliospores of groundnut rust from India. It is not known if the fungus can

produce pycnia and aecia or if any alternate host is involved in the life cycle. It would appear that urediniospores are the main, if not the only, means of dissemination of groundnut rust (Subrahmanyam and McDonald, 1982).

2.1.5.1.1: *Infected crop debris*: The importance of infected crop debris in perpetuation of rust disease has been stressed by several workers (Rothwell, 1975; Lingaraju *et al.*, 1979; Zhou *et al.*, 1980; Subrahmanyam and McDonald, 1982). Lingaraju *et al.* (1979) studied the survival of urediniospores over three seasons in Dharwad, India by preserving infected leaves at room temperature and exposing them to atmospheric temperatures by placing them in plastic boxes that were then placed in a cage. They found that rust spores survived for 43-51 days in the rainy season (June-September), for 39-41 days in winter (October-December), and for 34-49 days in summer (January-May) under natural and room temperature conditions. Mallaiah and Rao (1979b) reported that in their studies involving monthly collection of spores from infected debris over a year, spores did not remain viable for more than four weeks. They further stated that in winter in the absence of the crop, the fungus survived for four weeks in the infected crop debris. The urediniospores on the harvested plants of the rainy season crop (July-October) could provide the primary source of inoculum for the postrainy season (November-March) crop. However, similar survival of urediniospores was not likely in the summer crop (February-May) because of the high temperatures. They suggested that spores

from the postrainy season crop might infect the summer crop and infection could then remain dormant until the return of favourable conditions with monsoon rains, when uredinia would be produced to provide spores to infect the rainy season crop. Zhou *et al.* (1980) found that the rust fungus in the debris of the 1973 and 1974 season crops in the People's Republic of China retained its infectivity after storage for 120-150 days and 132 days respectively, with 8.3 to 100% plants infected. However, they did not mention where they had stored the infected debris. Subrahmanyam and McDonald (1982) reported that the urediniospores exposed to weather after the rainy season harvest at ICRISAT Center, India, survived for only 22 days after rainy season harvest and for 14 days after postrainy season harvest. Mayee (1982) recorded that under field conditions in Parbhani, India, the urediniospores lost viability within 20 days. Subrahmanyam *et al.*(1984) commented that urediniospores were short-lived in the infected crop debris. Therefore, the fungus was unlikely to perpetuate from season to season under post-harvest conditions that included a break of four weeks between crop seasons.

2.1.5.1.2:Ground-keepers and volunteer groundnut plants: Over-wintering of the rust fungus on volunteer plants was stressed by many research workers as a possible carry-over mechanism (Castellani, 1959; Rothwell, 1975; McDonald *et al.*, 1980; Mayee, 1982; Subrahmanyam and McDonald, 1983; Subrahmanyam *et al.*, 1984). Harrison (1972) surveyed many fields for volunteer

groundnut plants in Frio county, Texas, USA in September 1971 and found rust on them, however, groundnut rust was not believed to over-winter on volunteer plants in the USA. Mallaiah and Rao (1979b) suggested that the urediniospores could survive on ground-keepers of the rainy season crop and so provide the primary source of inoculum for the winter crop. Lingaraju *et al.* (1979) from Dharwad, also indicated that rust in the rainy season survives on volunteer plants and this forms the primary source of inoculum for the postrainy season crop in Dharwad region of Karnataka. O'Brien (1977) reported that the rust problem in the Atherton Tableland of Australia was more serious because the disease carried over on volunteer plants. He also stressed that further spread to Kingaroy in 1976 was probably from undetected, rust-infected, volunteer plants from the 1975 season crop. Zhou *et al.* (1980) in the People's Republic of China proved the importance of survival of rust on volunteer plants. During a survey in 1975-76 they found that rust on volunteer plants appeared in December and could be found until early April of the next year with 1 to 66 % infection. The number of volunteer plants per moh (1 moh = 0.2 ha) varied from 300 to 500, with 3-5 uredinia on a leaflet. They further stated that in the spring, rusted volunteer plants could make up 15-42% of the crop thus serving as inoculum for the autumn crop.

2.1.5.1.3: Collateral hosts: There is no authenticated report of rust being spread by germplasm exchange. Groundnut rust is known to attack several other members of the

genus *Arachis*, but because of this limited geographic distribution they can hardly be involved in the perpetuation of groundnut rust outside their native South America (Subrahmanyam and McDonald, 1982). However, Feakin (1973) cautioned that the susceptible wild *Arachis* species could act as sources of primary inoculum if they were growing near to a crop of groundnut. Subrahmanyam and McDonald (1982) inoculated over fifty-two leguminous crop plants, leguminous weed plants, and non-leguminous weed plants; none of them became infected with the rust fungus.

2.1.5.1.4: *Through seed*: West (1931) stated that the groundnut rust fungus was believed to have been introduced from Brazil to the USA in the seeds or pods of the two species *Arachis nambyquarae* and *A. prostrata*. Dissemination on seed was also indicated by Garren and Wilson (1951). Peregrine (1971) reported that the introduction of rust to Brunei was through seed. The seeds brought from China for consumption were planted in the Agricultural Farm and gave rise to rust infection of the seedlings. Feakin (1973) had the same opinion, and suggested that phytosanitation was very important, groundnut pods imported as animal or human food stuffs should never be planted as they may carry the rust spores. Chohan (1974) from Punjab, India, suspected that rust was seed-borne and advocated seed treatment. Shaw and Layton (1975) stated that seed surreptitiously imported remained a possible cause of the spread of groundnut rust into Papua New Guinea. Arokoyo *et al.* (1977) pointed out that steps

should be taken to avoid spread of disease on seed from the sites where the disease was found in Nigeria. Seed for distribution from diseased crops should be treated with fungicidal seed dressings before despatch. Seif (1979) suspected that rust was seed-borne and recommended restriction of the movement of groundnut seeds from coastal to inland areas in Kenya. Zhou et al. (1980) reported that the primary source of inoculum of spring groundnut in Guangdong province may be spore-bearing pods of the previous season's crop. On the other hand, it has been said that the rust was not apparently carried from season to season on pods or seeds and there was little chance of rust being spread on seed samples, especially if the seed was stored at normal room temperatures for 2 months (ICRISAT, 1978; Subrahmanyam and McDonald, 1982). Kolte and Awasthi (1979) from Uttar Pradesh, India, reported that the seedlings that grew from the seeds of heavily infected plants did not show symptoms of rust under controlled conditions. Vilsoni (1980) from Fiji, also considered that rust was not seed-borne. Subrahmanyam and McDonald (1982) proved that groundnut rust was not internally seed-borne. In their experiments, groundnut seeds artifically contaminated with urediniospores gave rise to rust-free seedlings when grown in isolation plant propagators. Subrahmanyam and McDonald (1983) indicated that if groundnut seeds are treated with a fungicide, or are stored for 4 weeks or longer at room temperature, there should be no chance of rust disease being carried either in or on them.

2.1.5.1.5: Long distance spread: Higgins (1956) reported that the fungus apparently does not over-winter in the USA, but blows in on winds from subtropical regions. Wells (1962) also felt that rust did not over-winter in North Carolina, USA, since it did not survive on dead groundnut haulms or in the soil. Also, no other host of this pathogen was known. Consequently, the only source of infection was from spores blown from the subtropical areas where groundnuts are grown in the winter. Van Arsdel and Harrison (1972) were also of this opinion as to the annual transport of urediniospores to the USA from distant regions. They caught spores in rain water during July-August, 1970, and observed the rust in the field close to the place of trapping after 10-15 days. At that time the rust was abundant in the Mexican region, which was 1290 km away from the place of their observation. Meteorological observations were in concurrence with their calculation that a wind speed of 9 km sec^{-1} for 40 hours was required for transport of spores and rainfall was required to wash them down onto the crop. Hammons (1977) was of the same opinion that the rust fungus does not over-winter in the USA, but the inoculum is blown in from sub-tropical areas. Mayee *et al.* (1977) noted that on the rainy season crop the disease appeared in July-August in southern India, in September in central India and in October in northern India. Subrahmanyam and McDonald (1982) also supported the above statement based on their observations on cropping patterns in southern India. They stated that groundnut was grown only in the rainy season in northern India, but the crop was grown

throughout the year in southern India, presenting an excellent opportunity for survival of rust. Based on the cropping pattern in India they hypothesised that groundnut crops in southern India might act as a reservoir of the rust disease from which spores are carried by the monsoon winds to infect the crop in northern India. McDonald *et al.* (1980) suggested that in Nigeria, the rust survived the dry season in the south and was spread in the rainy season to the main groundnut growing areas of the north by means of wind-borne urediniospores. Rain-bearing south-west winds affect much of West Africa and a similar situation with regard to rust survival and distribution could well occur in other West African countries. Subrahmanyam *et al.* (1984) were of the opinion that the practice of continous cultivation of groundnut without any break appears to be an important factor in perpetuation of rust in India and the People's Republic of China.

The rust fungus may also be spread by man and machines (Feakin, 1973).

2.1.5.2. *Effect of environmental factors on rust disease development:*

2.1.5.2.1: *Effect of temperature on urediniospore viability and germination:* Castellani (1959) reported that urediniospores were viable for 3 months when stored at laboratory temperature. Veeranjaneyulu (1973) from Andhra Pradesh, India, observed that urediniospores were viable for nine weeks in infected leaves preserved at room-temperature (33 - 37 ^{o}C), 13 weeks when buried

in unsterilised soil, 15 weeks at 15 °C, and over 33 weeks at 5 °C. Mallaiah and Rao (1979b) found that urediniospores remained viable for up to 4 weeks when temperatures were below 30 °C, but when temperatures were above 35 °C no germination was observed even after two weeks. Zhou *et al.* (1980) studied the viability of urediniospores at different temperatures and in different seasons. They found that spores lost viability rapidly when subjected to high temperature (40.5 °C). Spores were viable for 16-29 days in summer season's room-temperatures, 9-11 days at 40 °C, and 7-9 days at 45 °C. However, spores survived for 120-150 days in winter and spring seasons temperatures, for 3-6 months at -24 °C, and for nearly one year at 5 °C (Zhou *et al.*, 1980). Subrahmanyam and McDonald (1982) studying urediniospores stored at temperatures of -16, 6, 25, and 40 °C, and at room temperature, noted that spores kept at 40 °C lost viability within 5 days; spores kept at 25 °C survived for up to 40 days, and those stored at room-temperature (on stored seed) survived for 45 days. Spores stored at 6 °C were viable for 60 days and those stored at - 16 °C were viable for over 120 days.

Foudin and Macko (1974) from Georgia, USA, observed that the optimum temperature for urediniospore germination was around 18 °C. Kono (1977) from Japan stated that the spores germinated on groundnut leaves at 12-31 °C with optimum germination at 21-22 °C, and that most infection developed at 20-26 °C. Fang (1977, 1982) from Taiwan found that the

urediniospores germinated at 15-30 °C with an optimum temperature range of 20-25 °C, and urediniospores were produced 3-4 days after formation of uredinia at 15-30 °C. Mallaiah and Rao (1979a) from Andhra Pradesh, reported that the optimum temperature for germination was around 20 °C. Zhou *et al.* (1980) from the People's Republic of China established the optimum temperature for spore germination as 24.5-28.0 °C. The germination was low at temperatures higher than 28 °C and very few spores germinated at 11 and 31 °C. No germination occurred at under 8 °C. They further stated that the thermal death point was 50 °C for 10 minutes.

2.1.5.2.2: *Effect of temperature and relative humidity on rust disease development*: Castellani (1959) in the Dominican Republic inoculated groundnut plants with urediniospores, then held them for four days in the laboratory at 80-90% relative humidity and 28-32 °C temperature. Plants were then placed in the open (minimum temperature 26 °C). Symptoms appeared 12-14 days after inoculation. McVey (1965) in Puerto Rico maintained temperatures of 22-25 °C at night and 30-43 °C during the day, in his successful inoculation experiments. Bromfield and Cevario (1970) in the USA successfully used a broad temperature range with night temperatures of 20-25 and day temperatures of 30-40 °C for infection. The temperature range of 25-30 °C and relative humidity above 80% were found to be favourable for rust infection (ICRISAT, 1977). Munde and Mayee (1980) in Maharashtra, India, found that once the infection had occurred, rust development continued to be good at 30 °C

temperature and 80% relative humidity.

Mallaiah and Rao (1982) from Andhra Pradesh, India, found that rust developed rapidly when temperatures were between 28 and 34 °C and relative humidity between 55 and 85%. Mallaiah (1976) noted that plants grown in shade developed rust pustules 1-2 days earlier than plants grown under direct sunlight. He also recorded that the incubation period during summer months (May and June) was 18 days, while in winter months (December and January) it was only 7 days. Fang (1977) stated that the incubation period varied from 7-18 days and was greatly influenced by environmental factors. Mallaiah and Rao (1979a) showed that rust development occurred under a broad range of temperatures, 20 to 35 °C, with an optimum of 25 °C. Incubation period was only 7 days at 25 °C, while it was 14 days at 35 °C. Munde and Mayee (1979) stated that the incubation period was prolonged at high temperatures. They found that at 23 °C, the incubation period varied from 6-9 days for rust isolates from Akola, Coimbatore and Parbhani. At 27 °C it increased to 8-10 days and at 30 °C it was from 11 to 14 days. Isolates from Coimbatore and Akola failed to develop at 33 °C and above, while the Parbhani isolate failed to develop above 39 °C. Their results accounted for the observed longer incubation period during summer months. Munde and Mayee (1980) found that when inoculated plants were incubated at 27 °C and 100% relative humidity for 120 hours, under a cycle of 12 hr fluorescent light followed by 12 hr darkness, rust infection reached a maximum with an early

appearance of pustules. Zhou *et al.* (1980) pointed out that the incubation period of rust varies under different temperatures. It has an incubation period of 18 days at 18 °C, 10-14 days at 24 °C, 6-8 days at 24.5 - 26 °C and 9 days at 29 °C. Subrahmanyam *et al.* (1984) stated that temperature in the 20-30 °C range, free water on the leaf surface, and high relative humidity, favoured infection and subsequent rust disease development. Mallaiah and Rao (1979a) stated that the urediniospores did not germinate when the relative humidity was below 100%. Even at 100% relative humidity only 7.4% of spores germinated only in water droplets that condensed on the slides. Relative humidity of over 80% supported higher germination when spores were placed on a thin film of water on slides. Subrahmanyam *et al.* (1980) stated that the urediniospores require the presence of a water drop for germination. Zhou *et al.* (1980) kept inoculated plants in moist chambers for 4, 6, 8 and 24 hours at 25.5-26.0 °C; infection occurred within 4 hrs, but severity was low. When the plants were held in the moist chambers for over 6 hr, the infection reached 100%. They also reported that urediniospores germinated only when in contact with water droplets, and otherwise could not germinate even when under saturated moisture conditions.

Krishna Prasad *et al.* (1979) from Dharwad, India, found that for disease initiation the optimum temperature was 23-24 °C, with intermittent rain resulting in mean relative humidity above 87% for a few days. Under these

conditions, there was good infection and initial symptoms were noted within 10-12 days. Siddaramaiah *et al.* (1980) from Dharwad, India, noted that continous dry periods with temperatures above 26 °C and relative humidity below 70% delayed rust occurrence and severity. Intermittent rain, high relative humidity, and temperatures in the range of 20-26 °C favoured disease development. Rust development was extremely slow when temperatures were above 35 °C as was evidenced in the summer-sown crop in Maharashtra, India (Munde and Mayee, 1979).

2.1.6. Disease management

The term "plant disease control" is popularly used to denote methods for reducing losses due to plant disease. Of late, 'disease management' is the preferred term as 'management' conveys the concept of a continous process rather than a specific treatment. It is based on the principles of maintaining the damage or losses below an economic injury level. The various methods reported in the literature for managing groundnut rust are briefly reviewed below:

2.1.6.1. Cultural: Chohan (1974) and Seif (1979) recommended removal of infected crop debris from the field for reducing rust. Chohan (1974), O'Brien (1977), Seif (1979), and Subrahmanyam *et al.* (1984) suggested eradication of volunteer plants before sowing. Peregrine (1971) and Seif (1979) emphasised the importance of plant quarantine to

control further spread of the pathogen through seed. Siddaramaiah *et al.* (1980) suggested sowing in the first fortnight of June to reduce rust severity in the Dharwad region of India. Subrahmanyam *et al.* (1984) suggested that time of planting could be adjusted to avoid infection from outside sources and to avoid environmental conditions conducive to rust build-up. Rust-susceptible wild *Arachis* species should not be grown near groundnut fields as they may act as collateral hosts of the rust fungus (Feakin, 1973).

2.1.6.2. *Biological*: The possibility of biological control of rust has been reported. Mycoparasites, *Verticillium lacani* (Zimmerm.) Viegas, *Penicillium islandicum* Sopp., *Eudarluca caricis* (Fr.) O. Ericks, *Acremonium persicinum* (Nicot) W.Gams, *Darluca filum* (Biv.) and *Tuberculina costaricana* Syd., have been observed to parasitise *P. arachidis* (Bhama, 1972; Sharma *et al.*, 1977; Raemaekers and Preston, 1977; Rothwell, 1975; Misra and Misra, 1975; Subrahmanyam, McDonald and Reddy, personal communication). Mycophagous insects feeding on uredinia of *P.arachidis* have also been reported (Shanmugam *et al.*, 1975; Vaishnav and Kapadia, 1982). However, no serious attempts have been made to use any of these organisms in biological control of groundnut rust.

2.1.6.3. *Chemical*: Extensive work on chemical control of rust has been done in India and elsewhere. Perhaps, Robson (1914) from Barbados was the first to attempt to control rust with Bordeaux mixture in Montserrat, West Indies. Later, Nowell (1915) tried the same fungicide to control rust in Barbados.

Subsequently, many reports ~~appeared on chemical~~ control of groundnut rust. Castellani and Anglesio (1964) in the Dominican Republic found that zineb-sulphur-DDT-talc dust (6:8:5:9) was more effective than copper oxychloride-sulphur-DDT-Talc (10:75:5:10). Sulphur fungicide was extensively used for rust control (Patil and Kalekar, 1974; Durairaj and Mohan, 1978). Arneson (1970) in Honduras observed that dithiocarbamate (Dithane M-45) gave fairly good control of rust besides controlling leaf spots. Subsequently, many reports have appeared on the use of dithiocarbamates (Harrison, 1971, QDPI, 1973; Felix and Ricaud, 1977; Raemaekers and Preston, 1977; Siddaramaiah *et al.*, 1977b; Schiller and Samoapol, 1981). Nickel chloride was used by Seshadri (1975) and Barve (1980). Chlorothalonil was also extensively used (Harrison, 1973; Raemaekers and Preston, 1977; Subrahmanyam *et al.*, 1980; Zhou *et al.*, 1980). Tridemorph was also found to be effective against groundnut rust (Mayee *et al.*, 1979; Ghuge *et al.*, 1980; Prasad and Vyas, 1981; Subrahmanyam *et al.*,1983b). Patil and Kalekar (1974) and Siddaramaiah *et al.* (1977b) reported that carboxin and oxycarboxin compounds were effective against rust.

2.1.6.4. Genetical: Several reports on the identification of rust resistance have appeared from the western hemisphere where rust has occurred for a long time. KenKnight (1941) in Texas made the earliest attempt at screening of genotypes for their reaction to rust and found that all the 50 cultivars he tested were susceptible to rust. Mazzani and Hinojosa (1961) in

Venezuela, tested 254 varieties for resistance under field conditions, and an entry from Peru, 'Tarapoto', was found to be highly resistant. Bromfield and Cevario (1970) found two of the 173 accessions they tested to be resistant to rust. Cook (1972) reported that of the seven groundnut germplasm accessions she tested, five showed marked resistance and of the 31 named cultivars and breeding lines tested only one, the breeding line NC 13, was markedly resistant to rust. Hammons (1977) from Georgia, USA, found the following have resistance to two or more isolates of rust viz., Tarapoto (P.I. 259747; 341879, 350680, 381622 and 405132); Israel line 136 (PI 298115 and 315608), a selection from a USA introduction to Israel, and DHT-200 (PI 314817) collected from Peru. Screening of over 10,000 germplasm lines for resistance to rust was carried out at ICRISAT Center and several sources of resistance have been identified (Subrahmanyam *et al.*, 1983b; 1985).

Exploitation of resistance in wild *Arachis* spp. started in the early 1970s. Bromfield and Cevario (1970) reported that five accessions of *A. glabrata* were immune to groundnut rust. Jayaramaiah *et al.* (1979), from Dharwad, India, reported that *A. monticola*, *A. villosa* and *A. prostrata* were resistant to rust. Subrahmanyam *et al.* (1983a) tested 61 accessions of wild species representing five sections of the genus *Arachis* under field and laboratory conditions against rust and found that most were immune and six were highly resistant.

2.2. Leaf spots

Leaf spots caused by *Cercospora arachidicola* Hori ('early leaf spot') and *Phaeoisariopsis personata* (Berk.& Curt.) v. Arx ('late leaf spot') are probably the most serious diseases of groundnut on a world wide scale (Jackson and Bell, 1969; Feakin, 1973; McDonald *et al.*, 1985). These diseases have also been referred to as Mycosphaerella leaf spots, Cercospora leaf spots, peanut cercosporosis, tikka, viruela, brown spot and black spot (Jackson and Bell, 1969).

2.2.1. *Geographical distribution*: Both leaf spots are commonly present wherever groundnut is grown (Feakin, 1973; McDonald *et al.*, 1985). The incidence and extent of damage caused by each disease can differ markedly between localities and seasons. In the USA, most reports have listed *C. arachidicola* as the predominant species (Woodroof, 1933; Jenkins, 1938; Miller, 1953; Smith, 1984). It is usually found early in the season, whereas *P. personata* appears later and is less abundant. Frezzi (1960) from Argentina, noted that the occurrence of the two species was more closely related to host differences than to the period of the growing season. *C. arachidicola* was more frequent on common varieties of *Arachis hypogaea*, while *P. personata* was found more commonly on wild species in plant collections. Corbett (1965) from Malawi, suggested that variation in climate may be a cause of variation in distribution of the two species. In India, late leaf spot is currently predominant (Nath and Kulakarni, 1967; Subrahmanyam *et al.*, 1980).

2.2.2. Economic importance: Leaf spots are generally accepted to be the most serious diseases of groundnut world wide. Losses in yield from leaf spots vary from place to place and between seasons. Mallamaire (1931) reported from West Africa that leaf spots caused losses of up to 20%. Bolhuis (1955) stated that the two leaf spots reduce groundnut yield by 15% in Indonesia. Losses in yield of kernels of around 10% have been estimated for the southern USA, where fungicide application is normally practiced, while over much of the semi-arid tropics where chemical control of leaf spots is very rarely practiced, losses in excess of 50% are commonplace (Jackson and Bell, 1969; Garren and Jackson, 1973). McDonald and Fowler (1977) reported from Nigeria, that haulm losses from leaf spots were also high, generally exceeding kernel losses, and this is important in areas where groundnut hay is valued as a live-stock food. McDonald (1980) suggested that the losses attributed to leaf spots in the People's Republic of China were around 10% in pod yield.

In India, Mehta and Mathur (1954) estimated a reduction in yield of groundnut from 20-50% due to leaf spots in severe cases, particularly in late-maturing cultivars. According to Vasudeva (1961) leaf spots alone were responsible for more than half of the total loss caused by diseases to this crop in India. Sulaiman (1965) recorded a reduction in groundnut yield of 40% due to leaf spots in Maharashtra. Sundaram (1965) in his inoculation trials under severe disease pressure recorded up to 22% loss in yield compared to plots

receiving fungicide sprays. Siddaramaiah *et al.* (1977a) stated that losses of more than 50% were caused by leaf spots in Karanataka. In India, leaf spots and rust normally occur together and yield losses as high as 70% have been attributed to their combined attack in the rainy season. Leaf spots alone were responsible for 59% loss in pod yield (Subrahmanyam *et al.*, 1980).

2.2.3. *Symptoms*: Woodroof (1933) designated the disease caused by *C. arachidicola* as early leaf spot, and that by *P. personata* as late leaf spot, based on the relative time of their appearance on groundnut in the USA. Earlier workers (Butler, 1918; Woodroof, 1933; Jenkins, 1938) placed considerable emphasis for diagnosis on the shape and size of the lesions and the presence or absence of a halo around them. Early leaf spots are sub-circular, 1 to over 10 mm in diameter and dark brown on the adaxial leaflet surface where most sporulation occurs. A yellow halo is often less conspicuous in, or absent from, late leaf spot lesions, but its presence and its intensity are not reliable for distinguishing between early and late leaf spots (Subrahmanyam *et al.*, 1982). Sporulation of the early leaf spot fungus usually occurs on the adaxial leaf surface, whereas sporulation of the late leaf spot fungus is mainly on the abaxial surface. Although visual symptoms are useful diagnostic features, positive identification of early and late leaf spot requires microscopic examination of conidia. Lesions caused by both fungi develop on petioles, stipules, stems, pegs, and pods in the later stages of an epidemic.

2.2.4. Causal organisms: The teleomorphs of Cercospora arachidicola and P. personata were described by Jenkins (1938) as Mycosphaerella arachidicola W.A.Jenkins and M. berkeleyii W.A.Jenkins, respectively. Deighton (1967) changed the specific epithet to M. arachidis Deighton. The teleomorphs are rarely observed. The anamorphs are most commonly seen during the development of the disease in the field.

Early leaf spot:

Cercospora arachidicola Hori. Annual Report of Nishigahara Agricultural Experiment Station, Tokyo, 1917, 26 (anamorph);
= Mycospaerlla arachidicola W.A. Jenkins. Journal of Agricultural Research 56, 324, 1938.
Mycospaerella arachidis Deighton. Transactions of the British Mycological Society 50, 328, 1967 (teleomorph).

The anamorph of the fungus was described by Jenkins (1939) and Chupp (1953) as follows:
Fruiting body is amphigenous, conidia form primarily on the upper surface. Stromata are dark brown, 25-100 µm in diameter. Conidiophores (15-45 x 3-6 µm) pale olivaceous or yellowish-brown, form in dense fasicles of five to many. They are darker at the base, mostly once-geniculate, unbranched and septate. Conidia (35-110 x 3- 6 µm) are subhyaline, olivaceous, obclavate, and mildly too much curved, up to 12 septate, base truncate, and tip subacute.

Late leaf spot:

Phaeoisariopsis personata (Berk.& Curt.) v. Arx. Proceedings of the Koninklijk Nederlands Akademie 86(1),15-54, 1983 (anamorph);
= Cercosporidium personatum (Berk.& Curt.) Deighton. Mycological Papers 112, 71, 1967.
= Cladosporium personata Berk.& Curt. Grevillea 3,106, 1875.,
= Cercospora personata (Berk.& Curt.) Ellis & Everhart. Journal of Mycology 1, 63, 1885.,
= Septogloeum arachidis Racib. Zeitschrift fuer Pflanzen - (R) krankheiten und Pflanzenschutz 8, 66, 1898.,
= Cercospora arachidis P. Hennings. Hedwigia 41, 18, 1902.,
= Passalora personata (Berk.& Curt.) Khan & Kamal. Pakistan Journal of Science, 13(4), 188, 1961.
Mycosphaerella berkeleyii W.A. Jenkins. Journal of Agricultural Research 56, 330, 1938. (teleomorph).

The anamorph of the late leaf spot fungus is described as follows:
The fruiting bodies are present on both surfaces of the leaf, but are more common on the lower surface. Dense pseudoparenchymatous stromata are up to 130 µm in diameter. Conidiophores (10 - 100 x 3 - 6.5 µm) pale to olivaceous-brown, smooth, geniculate, and continuous or sparingly septate, commonly form dense fasicles in concentric rings; conidial scars, 2-3 µm wide, conspicous, prominent, and thickened. Conidia (20-70 x 4-9 µm) are medium-olivaceous, usually of the same colour as the conidiophores, cylindrical, obclavate, usually straight or slightly curved, with a finely roughened wall that is

rounded at the apex. The base is shortly tapered with a conspicuous hilum. Conidia are often 1-9 sepetate but usually 3-4 septate.

Cultural races varying in colour, growth rate, and colony type were isolated from groundnut from various localities of the USA in 1946-47. The greenhouse tests revealed significant differences in pathogenicity between several of the isolates in both pathogens. Blackish leaf lesions with sharp margins were characteristic of one biotype of *C. arachidicola* on the spanish cultivar No.146, while the same cultivar, inoculated with another isolate of this species, developed light-brown lesions with small yellow borders (Miller, 1949). Sulaiman and Hande (1969) from Maharashtra, India, also reported cultural races in both pathogens. They further stated that leaf spots caused by different isolates varied in colour, size and shape of the spots. There was also variation in incubation period and optimum temperatures for infection. Littrell (1974) collected several isolates of *C. arachidicola* from fields in six locations in four counties in Georgia, USA. He found that a few isolates grew well in a medium supplemented with benomyl. Clark *et al.* (1974) and Smith *et al.* (1978) isolated benomyl-tolerant strains of both pathogens from groundnut crops in the USA. Katan (1980) found benomyl-tolerant strains of the late leaf spot fungus in Israel.

2.2.5. Epidemiology

2.2.5.1. Perpetuation, carry-over and spread of leaf spots fungi:

2.2.5.1.1. Infected crop debris: There is general agreement in many reports that leaf spots are more serious in monocultures where groundnut follows groundnut. In these situations early infection is common and the source of inoculum is probably from conidia or ascospores produced in or on infected crop debris in the field (Jackson and Bell, 1969). Jenkins (1938) and Frezzi (1960) considered that ascospores formed in persisting litter were a source of early season inoculum. Feakin (1973) described from earlier literature, the perfect stages of both fungi which are said to play an important role in the survival of the fungus and in establishing primary infection in the North American crop, but are not found in other groundnut growing regions of the world.

Butler (1918) from India, reviewed the previous literature and stated that the late leaf spot conidia can be viable for six months. He further stressed that spores could remain viable in the soil long enough to infect the succeeding groundnut crop. Roldan and Querijero (1939) from the Philippines, showed that the leaf spot pathogens persist in the soil from one season to the next as stroma in the debris of the diseased groundnut which may be covered with a protective layer of soil. The stroma could produce fresh conidia as conditions became more favourable and these conidia caused the primary infection. They further proved that infection in the field is due to spores carried by wind, from the soil, or

from the infected leaves of diseased plants. Over-wintering of sclerotic tissue is also reported to lead to production of conidia in the next spring season (Research and Farming, 1943). Miller (1953) from the USA, suggested that the leaf spot fungi produce chlamydospores. Hemingway (1954) from Tanzania, and Shanta (1960) from Madras, India, stated that the leaf spot fungi survive in mycelial form in the soil as well as in plant debris from the previous season. Shanta (1960) found that P. personata survived for 22 weeks in infected leaves preserved in soil at 40 % and 60% moisture. Frezzi (1960) from Argentina, demonstrated that conidia have sufficient longevity to carry over from one crop to another. Feakin (1973) stated that both the fungi overwinter in infected crop debris on the soil surface. Karunakaran and Raj (1973) from Kerala, India, studied the survival of P. personata on diseased leaves, (a) buried in the soil at a depth of 10 cm, (b) buried in the soil at a depth of 10 cm after covering the leaves with a wire mesh, and (c) kept exposed on the surface of the soil. They found that the pathogen survived for 6 weeks when leaves were buried in soil 10 cm deep and up to 17 weeks when placed on the soil surface.

The secondary spread of these pathogens has been reported to be by wind, insects, water currents from flooded rows, rain, and machinery (Research and Farming, 1943; Higgins, 1956; Feakin, 1973).

2.2.5.1.2.Ground-keepers and volunteer groundnut plants: Hemingway (1954) from Tanzania, observed that volunteer groundnut plants persisted through the dry season. Volunteers

germinated after the first rains and on them the disease build-up was very rapid, and subsequently spread to the later crop. Fowler (1970) suggested that the leaf spot fungi survived during the off-season on volunteer plants and recommended destruction of volunteer plants as a control measure in Nigeria. Feakin (1973) also mentioned that both fungi over-winter on volunteer plants in the field.

2.2.5.1.3. Collateral hosts: Mercer (1977) from Malawi, found that groundbean (Voandzeia subterranea) was a host of C. arachidicola. Pyzner (1980) from the USA, observed natural infection of Stylosanthes biflora by C. arachidicola. Subrahmanyam et al. (1983b) from India, inoculated 23 leguminous weeds and crop plants but no case of infection was recorded on any of the plant species examined.

2.2.5.1.4. Through seed: Singh (1948) from India, isolated P. personata from groundnut seeds using the Ulster method. Vasudeva (1961) noted that seed treatment with fungicides gave a clean crop, indicating that seed-borne inoculum might be playing an important role. Feakin (1973) stated that over-wintering of both fungi was possibly on seed. Butler (1918) from India, found that seed disinfection could not control the leaf spots diseases. Roldan and Querijero (1939) from the Philippines, showed that when plants were raised from seeds of late leaf spot infected plants were disease-free, therefore late leaf spot was not seed-borne. They emphasised that seed treatment did not satisfactorily control the disease. Prasad

(1968) from India, and Mulder and Holliday (1974) from England, felt that seed transmission of leaf spots pathogens was unimportant.

2.2.5.2. Effect of environmental factors on leaf spots diseases development:

Maublanc (1925) from Senegal and KenKnight (1941) from the USA, attributed the rapid spread and severity of leaf spots to heavy rainfall in August-September and in spring in their respective countries. The leaf spots diseases were found relatively more in damp, warm weather and periods of heavy dew in North Carolina, USA (Research and Farming, 1943). Das (1951) from Texas, USA, reported that *P. personata* had cardinal temperatures of 23, 27 and 35 °C. Chevaugeon (1952) reported that the infection was favoured when temparatures showed no marked day and night variation (monthly average 26.6 to 31.0 °C) and by high average relative humidity with saturation over long periods. Miller (1953) found that in culture, three isolates of *C. arachidicola* grew at 2 to 35 °C (optimum 25-32 °C) and three isolates of *P. personata* grew at 4-34 °C (optimum 25-30 °C); germination occurred only in humid conditions. Tarr (1954) observed that leaf spots were most prevalent in wet areas of Sudan with annual rainfall exceeding 500-620 mm.

Lyle (1964) from Alabama, USA, found that greater numbers of conidia were detected over groundnut crops during periods of abundant rainfall and high minimal (22 °C) and high maximal (35 °C) temparatures. The infection was

correlated directly with inoculum production during this period. Jensen and Boyle (1965) from Georgia, USA, stated that explosive increases in leaf spot disease in 1963 and 1964 were correlated with periods of high relative humidity, when temperatures were usually around 70 °F. Rains were frequent and probably helpful in conidial dispersal and in producing suitable leaf wetness conditions. They also found that if the groundnut foliage remained wet for a period greater than or equal to 10 hr, and minimum temperature was 21 °C or higher for two consecutive days or nights, conditions were ideal for rapid epidemic progress. Sulaiman and Agashe (1965) recorded that minimum predisposing factors to disease development were: an average rainfall of 240.8 mm, an average maximum temperature of 29.3 °C, an average minimum temperature of 23.0 °C, and an average relative humidity of 81.8%. Ramakrishna and Appa Rao (1968) from Hyderabad, India, reported that a 72 hr period of high humidity was ideal for infection and further development of leaf spots diseases. The early leaf spot fungus could grow well at an optimum temparature of 24-28 °C, and two isolates of the late leaf spot fungus grew well at 26-28 and 24-28 °C, respectively. The thermal death points of the fungi were between 50 and 52 °C (Sulaiman and Hande, 1969).

Kao and Wu (1970) from Taiwan, found that C. arachidicola infection was well established at high relative humidity and 25 °C. Cardinal temperatures for growth of the fungus were 12, 25, 28 and 31 °C. Oso (1972) reported that C. arachidicola conidia required a saturated or near saturated atmosphere

to germinate with optimum temperature of 20 - 30 °C. Chohan and Singh (1973) from Punjab, India, recorded that enough precipitation (rainfall and dew) ensuring free water on the surface of leaves, relative humidity of 90-93%, and a temperature of around 20 °C for 6-7 days during any month of the growing period, ensured that epiphytotics of leaf spots would occur. Wangikar and Shukla (1976) determined that August was the most favourable month for leaf spots infection in Maharashtra, India with a relative humidity of 75-85% and temprature of 25-26 °C. Blamey *et al.* (1977) stated that *C. arachidicola* infection was severe when temperatures were above 21 °C with high relative humidity. They related these factors to the study of increase of disease during January to March 1976, when rainfall was low and poorly distributed in the USA. The leaf spot outbreak would be serious when the maximum temperature was 31-35 °C, minimum temperature 18-23 °C, and mean monthly rainfall at least 60 mm. (Venkataraman and Kazi, 1979). Young *et al.* (1980) reported that the leaf spots diseases were favoured by warm and moist conditions. Melouk (1982) found that when one-month-old plants were inoculated with *C. arachidicola* and placed in polyethylene chambers at 30 °C (day) and 20 °C (night) temperatures and relative humidity of 90- 95%, severe disease developed. Subrahmanyam *et al.* (1984) stated that long periods of leaf wetness at temperatures ranging from 25-30 °C, led to lesions developing within 10-14 days of inoculation.

2.2.6. Disease management

2.2.6.1. Cultural: From the comments on the sources of primary inoculum of leaf spots pathogens, crop rotation appears to be of prime importance and has been suggested by many workers (Clinton, 1962; Fowler, 1970; McDonald et al., 1985). Mazzani and Allievi (1971) reported that fallowing the fields for 6 years reduced the leaf spots incidence by 50%. Crop rotation with soybean or maize reduced the incidence by 88-93% (Kucharek, 1975). McDonald (1980) stated that rotation with rice and improved drainage were useful in controlling leaf spots in China. Destruction of volunteer plants reduces the leaf spots incidence. Early planting was suggested as a control measure by many workers (Bailey, 1966; Gibbons, 1966; Nath and Kulakarni, 1967). Shokes et al., (1982) from the USA reported that late planting reduced the disease incidence in Florida.

2.2.6.2. Biological: Krishna and Singh (1979) and Siddaramaiah et al., (1981) from India, found a fungus Dicyma pulvinata (Berk.& Curt.) v. Arx (=Hansfordia pulvinata (Berk.& Curt.) Hughes) on lesions of leaf spots. The fungus Verticillum lecani was also found parasitising leaf spot fungi of groundnut in the greenhouse (Subrahmanyam, McDonald, and Reddy, personal communication). Spurr and Bailey (1983) from the USA, found that two bacteria, Bacillus thuringiensis and Pseudomonas cepacia, controlled both the leaf spots in the laboratory and in small scale field tests. However, to date no attempt has been made to use these hyperparasites to control leaf spots under field conditions.

2.2.6.3. Chemical: Chemicals have been widely used and constitute an established practice for leaf spots management, especially in developed countries (Smith and Littrell, 1980). Sulphur has perhaps been the most widely used chemical (Higgins, 1940; Woodroof, 1942; McCallan, 1946; Cooper, 1961; Farrell *et al.*, 1968). Copper and its combinations were also widely used in the control of leaf spots pathogens (Miller, 1939; Botany, 1945; Mehta *et al.*, 1953). Tin compounds like Du-Ter and Brestan have also been used (Ter Horst, 1961; Plant Pathology, 1965). The use of dithiocarbomates commenced in the 1960s (Cooper, 1961; Tandon and Singh, 1968; Sidhu and Chohan, 1972; Kolte *et al.*, 1978; Mehan and Chohan 1981). After the introduction of systemic fungicides such as benomyl and carbendazim in the late 1960s many workers advocated their use for control of the leaf spots (Prasartsee and Brown, 1971; Miller *et al.*, 1971; Chahal and Aulakh, 1972; Mercer, 1976; Ghuge *et al.*, 1980; Natarajan and Subramanian 1983). Chlorothalonil is also extensively used to control the leaf spots (Mercer, 1973; Kolte and Sinha, 1976; Smith and Littrell, 1980; Ponnaiah *et al.*, 1982).

2.2.6.4 Genetical: The most economical and effective method of leaf spots control would be to identify and use agronomically acceptable cultivars resistant to these diseases. But such cultivars are not presently available for the majority of groundnut growing areas. Breeding of cultivars resistant to leaf spots diseases was initiated in the 1930s. Higgins (1935) from Georgia, USA, stated that

resistance to the two leaf spots appeared to be inherited independently, selections very resistant to one fungus often being highly susceptible to the other, and *vice versa*. Subsequently, many reports have come from various countries. Nandi (1941) from Assam, India, found that "Shan" (Magura), Cawnpore No. 23, and M 30/38 were resistant to *P. personata*. Gregory (1956) in the USA, demonstrated the possibility of the production of radiation-induced mutants of groundnut with the aid of D-rays. He reported that some groundnut mutants had resistance to leaf spots. Rothwell (1962) from Zimbabwe, reported that late-maturing cultivars like Virginia and Mt. Makulu Red were more resistant than early-maturing ones. Muhammad and Dorairaj (1968) from Madras, India, tested 206 bunch cultivars and found 2.4% were highly resistant, whereas from among 44 semi-spreading cultivars tested 43.2% were highly resistant to both leaf spots. Aulakh *et al.* (1972) from India, screened over 1100 cultivars, but found none resistant to both leaf spots. Sowell *et al.* (1976) found that genotypes PIs 109839, 162857, 350680, 259639 259679, 259747 and 270806 were resistant to *C. arachidicola*. Moraes and Salgado (1979) from Brazil, evaluated seven genotypes against *C. arachidicola*; SO.905 (PI 109839) was most resistant. Subrahmanyam *et al.* (1983b), Hyderabad, India, screened over 10,000 genotypes and found the genotypes NC Ac 17133 (RF), EC 76446 (292), PI 259747 and PI 350680 showed good resistance to both rust and late leaf spot. Genotypes RMP 91 and NC Ac 15989 showed greater resistance to late leaf spot than to rust.

Exploring the possibilities of utilizing leaf spots resistance in the wild *Arachis* species commenced in the 1950s. *Arachis diogoi* from Brazil, appeared to be immune to both leaf spots (GAES, 1951). Gibbons and Bailey (1967) from Malawi, tested 8 wild *Arachis* spp. against *C. arachidicola* and found that *A. repens*, *A. glabrata* and *A. hagenbeckii* developed no lesions but the rest showed a gradation in susceptibility. Abdou (1967), and Abdou *et al.* (1974) from the USA, reported that *A. cardenasii* was susceptible to *C.arachidicola* but immune to *C. personatum*, *A.chacoense* was highly resistant to *C. arachidicola* but susceptible to *P. personata*. Prasad *et al.* (1979) from India, found *A. prostata* and *A. villosa* were resistant to leaf spots diseases. Company *et al.* (1982) from the USA, found inter-specific hybrids between NC 2 and NC 5 groundnut, and *A. cardenasii* and *A. chacoense* were highly resistant to *C. arachidicola*.

Little work has been carried out on the mechanisms of resistance. Gibbons and Bailey (1967) attributed resistance in wild species to the small stomatal apertures on their leaves. Resistance to *P. personata* was due to fewer stomata per unit area. Dark green foliage and long season growth period also seem associated with resistance (MANN, 1957). Hemingway (1957) concluded that thickness of palisade tissue and dark green colour were well linked with resistance to leaf spots. Mazzani *et al.* (1972) attributed the resistance to stomatal size. Abdou *et al.* (1974) found that resistance was associated with formation of a barrier in

advance and around the infection site, and pectic substances were deposited on the cell walls and intercellular spaces.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

The information on materials and methods used in several experiments throughout this investigation are described in general section (3.1). Details pertinent to other experiments are outlined under separate heads (3.2 to 3.5).

3.1. General

3.1.1. Plant material: Seeds of six groundnut (*Arachis hypogaea* L.) genotypes with varied degrees of resistance to rust (*Puccinia arachidis* Speg.), early (*Cercospora arachidicola* Hori) and late (*Phaeoisariopsis personata* ((Berk. & Curt.) v. Arx) leaf spots diseases were obtained from groundnut pathology laboratory at ICRISAT Center, Patancheru, Andhra Pradesh, India. The description of each genotype together with their reactions to rust, early and late leafspots diseases at ICRISAT Center are presented in Table 1.

3.1.2. The pathogens: Single-lesion isolates of rust , early and late leaf spots pathogens of groundnut available in the groundnut pathology laboratory at ICRISAT Center were used in this investigation. The isolates were multiplied on the susceptible groundnut genotype TMV 2 either on detached leaves in the laboratory or on potted plants in the greenhouse as described in the following pages.

Table 1: Description of groundnut genotypes used in the investigation.

Genotype		Botanical variety	Growth habit	Season length at ICRISAT Center (days)		Disease reaction		
ICG[1] No.	Other identity			Rainy season	Post-rainy season	Rust[2]	Early[3] leaf spot	Late leaf spot[2]
221	TMV 2	vulgaris	Erect bunch	100	125	9.0	9.0	9.0
779	Robut 33-1	hypogaea	Spreading bunch	115	135	9.0	9.0	9.0
1703	NC Ac 17127	fastigiata	Erect bunch	115	135	4.7	9.0	4.4
1704	NC Ac 17129	fastigiata	Erect bunch	115	135	4.0	9.0	4.6
2716	EC 76446 (292)	fastigiata	Erect bunch	115	135	2.9	7.7	3.1
6340	PI 350680	fastigiata	Erect bunch	115	135	3.0	7.0	3.1

1 = ICRISAT Groundnut Accession Number

2 = Scored on a 9-point scale at ICRISAT Center over several seasons (Subrahmanyam et al., 1983b)

3 = Scored on a 9-point scale at ICRISAT Center during the 1983 rainy season

3.1.2.1. Inoculum: Leaves infected with rust and leaf spots pathogens were collected from the greenhouse and incubated in plastic trays lined with moist filter paper for 48 hr in plant growth chambers (Percival Co., Boone, Iowa, USA) at 25 ^{o}C and 12 hr photoperiod (4,000 lux). The spores were collected from the lesions using a cyclone spore collector (ERI Instrument Shop, Iowa State University, Ames, Iowa, USA) at 120 mm mercury vacuum for rust and 160-180 mm mercury vacuum for leaf spots into Kimex glass vials (7.5 cm long x 2.0 cm diameter). The spores were suspended in distilled water to which a few drops (10 drops 1000 ml^{-1}) of Tween-80 (polyoxyethylene sorbitan monooleate) were added (Melouk and Banks, 1978). The spore suspension was stirred well using a magnetic stirrer (Model 213, Fisher Scientific Co., USA) to make it uniform and adjusted to a concentration of approximately 50,000 spores $milliliter^{-1}$ using a hemacytometer. The inoculum thus prepared was used for inoculating either detached leaves or on potted plants.

3.1.2.2. Detached leaf technique (DLT): Mature, undamaged, apparently healthy leaves of greenhouse-grown groundnut plants were excised through the pulvinus base from the middle portions of the mainstem and placed in polyethylene bags containing water in such a way that the petioles were immersed in water to retain turgidity. The leaves were brought to the laboratory, thoroughly washed in distilled water, and the leaf surfaces were blotted using a tissue paper.

The leaves were arranged in plastic trays (55 cm long x 27.5 cm wide x 5 cm deep) with their petioles buried in a layer (1.0 - 2.5 cm) of steam sterilised (15 lbs for 30 min) river sand. There were 5-6 leaves per row with a total of 6-7 rows per tray. Hoagland's nutrient solution (Hoagland and Arnon, 1950) was applied to the sand throughout the experimental period to maintain sufficient moisture and to provide mineral nutrients to the leaves. Trays were covered with clear polyethylene bags (62 x 38 cm), the open ends of which were partially sealed with cellophane tape to maintain high relative humidity. The leaves were stabilised for 24 hr in plant growth chambers at 25 ^{o} C and 12 hr photoperiod (4,000 lux) before inoculation. Trays were removed from the growth chambers and leaves were sprayed on both surfaces with spore suspensions using a plastic atomiser until incipient run-off. The trays were then returned to the growth chambers and incubated at 25 ^{o}C with 12 hr photoperiod.

3.1.2.3. Potted plants: Plants were grown in plastic pots (15 cm diameter) containing a mixture of red sandy soil and farmyard manure (4:1 v/v) in the greenhouse. Three seeds were sown in each pot, and the seedlings were later thinned to two per pot.

Thirty-day-old plants were used for inoculation. All the leaves were inoculated with spore suspensions with a plastic atomiser until incipient run-off. The inoculated plants were arranged in polyethylene chambers (152 cm long x 75 cm width x 76 cm height) and misted with water by running humidifiers (Defensor 3001, Atkiengesellschaft, Zurich,

Switzerland) for 24 hr for rust and 48 hr for leaf spots pathogens. Plants were returned to the greenhouse benches and observed for disease development. When watering, care was taken to avoid wetting the foliage. Air temperature and relative humidity in the greenhouse ranged from 20-30 ^{o} C and 75-95% respectively, during the experimental period.

3.2. Perpetuation of rust and leaf spots pathogens:

3.2.1. Survival of rust and late leaf spot pathogensin infected plant debris:

3.2.1.1. Under natural environmental conditions:

3.2.1.1.1. On soil surface: Dried leaves and stems of genotypes TMV 2 and PI 350680 infected with rust and late leaf spot pathogens were collected from the field on the day of harvest in the 1983 rainy season. However, in the 1983-84 postrainy season because of low disease development on PI 350680, only leaves of TMV 2 infected with rust and late leaf spot were collected.

The dried infected leaves and stem pieces (10 cm long) were spread on the soil surface in a 2 sq.m area of 2 cm deep layer and exposed to natural climatic conditions in a protected area near Manmool, ICRISAT Center. Air temperature, relative humidity and rainfall near the experimental site were recorded at 07.17 and 14.17 hr every day during the experimental period. Viability of rust and late leaf spot pathogens was determined as follows:

At 15-day intervals, approximately 5 g of infected leaves and 5 g of stems were brought to the laboratory and incubated for 24 hr in plastic trays (22 sq. cm) lined with moist filter paper and covered with a polyethylene bag to maintain high humidity.

The infected material was soaked for 15 min in 50 ml of sterile distilled water in a beaker and crushed to make a suspension. Mature, undamaged leaves of genotype TMV 2 were collected from 15-day old potted plants raised in the greenhouse (3.1.2) and inoculated by dipping them in the suspension. The leaves were incubated in plant growth chambers as described under the DLT (3.1.2). Ten leaves were used for inoculation at each sampling time. Five leaves were maintained as uninoculated controls.

3.2.1.1.2. At different depths in the soil: Seventy-five sq. cm area pits were dug with either 5 or 10 cm depths in a protected area near Manmool, ICRISAT Center. Leaves infected with rust and late leaf spot were collected from the field in December 1984. Leaves were spread uniformly in shallow layers over the bottom of the pits and the soil replaced. The soil temperature at different depths was recorded at 08.30 and 14.30 hr every day. Per cent soil moisture was estimated at 15-day intervals during the experimental period using the gravimetric method (Hanks and Ashcroft, 1980).

At 15-day intervals, the soil was carefully removed from above a part of the buried leaves and 5 g of leaves removed and

the viability of rust and late leaf spot pathogens estimated as described above.

3.2.1.1.3. Under puddled conditions in paddy fields (late leaf spot only): The experiment was conducted in the paddy fields of the Directorate of Rice Research located at ICRISAT Center. Dried groundnut leaves infected with late leaf spot were collected from the field in May 1984. The leaves were placed in nylon net bags (20 x 10 cm), and buried under puddled conditions in a rice field at 15 and 30 cm depths two days after transplantation of paddy.

At 30-day intervals, a sample of crop debris was taken from each treatment (depth) thoroughly washed with distilled water, ground in a mortar and suspended in sterile distilled water. The viability of the late leaf spot pathogen was determined as described in 3.2.1. The remaining portion of the infected leaves was surface sterilised in an 0.1% aqueous solution of mercuric chloride for 1 min, then washed in several changes in sterile distilled water, and then incubated in Petri plates lined with moist filter paper. After incubation for fifteen days the infected leaves were examined under a light microscope for sporulation.

3.2.1.2. Under greenhouse conditions: Dried leaves and stems of genotypes TMV 2 and PI 350680 infected with rust and late leaf spot were collected from groundnut fields on the day of harvest in the 1983 rainy season. However, in the 1983-84 postrainy season because of low disease pressure, only leaves of TMV 2

infected with rust and late leaf spot were collected. The dried infected leaves and stems (10 cm long) were stored in cardboard boxes (57 cm long x 30 cm wide x 13 cm height) containing red sandy soil (5 cm deep) collected from an uncultivated Alfisol field at ICRISAT Center. The boxes were placed on benches in an asbestos shed at Manmool, ICRISAT Center. Air temperature in the cardboard box was recorded at 15-day intervals at 14.30 hr during the experimental period. Viability of rust and late leaf spot pathogens was determined at 15-day intervals as described earlier (3.2.1).

3.2.2. Survival of rust and leaf spots pathogens in field soil: Top soil (2.5 cm deep) was collected from a field planted with rust- and leaf spots-susceptible genotypes TMV 2 and Robut 33-1 on the day of harvest of the 1983 rainy and 1983-84 postrainy season crops. The soil was spread in a thin layer in plastic trays (55 x 27.5 x 5 cm). The trays were placed in an asbestos shed at Manmool, ICRISAT Center. Air temperature was recorded at 10-day intervals at 08.30 and 14.30 hr during the experimental period.

At 15-day intervals, 20 g of soil was brought to the laboratory and suspended in 100 ml of sterile distilled water. Viability of rust and leaf spots pathogens was examined using detached leaves as described earlier (3.2.1).

3.2.3. Perpetuation of rust and leaf spots pathogens on ground-keepers and volunteer groundnut plants: About 100 ground-keepers (left over plants after harvest in the field) and volunteer

groundnut plants (self-sown plants in the field) (cultivars unknown) present in and around groundnut fields were labelled at ICRISAT Center after the harvest of the 1984 rainy season crop. The plants were examined at 30-day interval until June 1985 for the presence of rust and leaf spots. On each sampling day, 5 infected leaves were brought to the laboratory, examined under a steriomicroscope (X 70) and the extent of sporulation was scored on a 5-point scale (1 = no sporulation and 5 = extensive sporulation) (Subrahmanyam *et al.*,1983b). Leaves, on which lesions were present but not sporulating were incubated in Petri plates lined with moist filter paper for 24 hr and then re-examined for sporulation.

3.2.4. *Search for collateral hosts of rust and leaf spots pathogens*: Seeds of eleven leguminous weeds growing in and around groundnut fields at ICRISAT Center and eleven cultivated leguminous crops were collected and sown in plastic pots (15 cm dia.) in the greenhouse. Thirty days after sowing, five plants of each species were inoculated with either rust or leaf spots fungi (100,000 spores ml^{-1}) using a plastic atomizer. Following inoculation, plants were placed in a polyethylene chamber (152 x 75 x 76 cm), and misted with water for 48 hr. They were then returned to the greenhouse and observed for disease development until 30 days after inoculation. Similarly inoculated groundnut (cv. TMV 2) plants served as controls.

3.3. Possible means of spread of rust and leaf spots pathogens:

3.3.1. Pod contamination: Mature, undamaged, groundnut pods (cv. TMV 2) were surface sterilized by immersion in a 0.1% aqueous solution of mercuric chloride for 2 min, then washed in several changes in sterile distilled water. The pods were dusted with spores (100 mg of spores 100 g^{-1} of pods) of either rust or leaf spots fungi by agitating in sterile conical flask. The inoculated pods were sown in Isolation Plant Propagators (IPP) (Burkard manufacturing Co. Ltd., England) (Subrahmanyam *et al.*, 1983b). Uninoculated pods served as control. Three pods were sown in each plastic pot and ten pots were kept for each pathogen. The resulting plants were observed regularly for rust and leaf spots development until 45 days after sowing.

3.3.2. Seed contamination: Healthy, undamaged, mature groundnut (cv. TMV 2) seeds were surface sterilised with mercuric chloride solution and dusted with spores (50 mg spores 100 g^{-1} of seeds) of either rust or leaf spots pathogens by agitating in sterile conical flasks and sown in IPP as described earlier for pods.

In another experiment, seeds were soaked in sterile distilled water for 15 min. Testae were removed carefully with sterile forceps and the cotyledons were dusted with spores (50 mg spores 100 g^{-1} of seeds) either rust or leaf spots pathogens and the seeds sown in IPP as described earlier.

3.3.3. Shell contamination (rust only): Fifty grams of groundnut shells were surface sterilised with mercuric chloride solution as previously described (3.3.1) and oven dried at 30 ^{o}C for 6 hr.

The shells were then dusted with 50 mg of rust urediniospores by agitating in a sterile conical flask. The shells were scattered over 20-day-old groundnut plants (cv. TMV 2) grown in the IPP so that the spores carried on the shells could land on the leaves. The pots were again covered and the plants were observed for rust development until 15 days after inoculation. Uninoculated plants served as control. Ten pots were inoculated. Each pot held four plants.

3.3.4. Clothes contamination (rust only): Twenty-days-old potted groundnut (cv. TMV 2) plants were arranged in two rows in the greenhouse with an access space of approximately one meter between the rows. Twenty milligrams of rust urediniospores freshly collected from infected leaves were dusted onto the shirt sleeves of the researcher who then walked between the rows so that his sleeves brushed against the foliage of the plants enabling the attached rust spores to land on the leaves. The plants were then transferred to polyethylene chambers, misted with water for 24 hr, and then placed in the greenhouse for observation of disease development. A control treatment was used in which the researcher walked between plants wearing a shirt that had not been covered with spores.

3.4. Effect of temperature on rust and leaf spots pathogens:

3.4.1. Effect of temperature on rust and late leaf spot spore viability:

Groundnut (cv. TMV 2) leaves infected with rust and late leaf spot were collected from the greenhouse, washed in running

tap water, and incubated for 72 hr in plastic trays (55 x 27.5 x 5 cm) lined with moist filter paper. The trays were covered with polyethylene sheets. Spores were then collected in Kimex glass vials using a cyclone spore collector as described earlier (3.1.2), and their percentage viability was estimated by standard slide germination tests before storage.

Approximately, 2 mg of spores were placed in glass vials (2.5 cm long x 0.5 cm dia.). The vials were fitted with cork stoppers and sealed with paraffin wax. The vials were stored in the dark at temperatures of -17, 10, 20, 30 and 40 °C. Sixty vials of containing spores were placed in each temperature.

At 10-day intervals, three vials were taken at random from each temperature. The spores in each vial were suspended in a few millilitres of distilled water containing traces of Tween-80 and the vial was shaken well for 1-2 min on Vortex-Genie mixer (Model K-550-GE, Scientific Industries Inc., New York, USA). One or two drops of this suspension were added to a glass slide which was then placed in a Petri plate lined with moist filter paper. Two slides were kept in each Petri plate. Subsequently, the plates were incubated in the laboratory (in the dark for rust and in the light for late leaf spot) for 15 hr. A drop of 0.1% mercuric chloride solution was then added to each slide to arrest further germination (Melouk and Banks, 1978; Subrahmanyam *et al.*, 1983b) and the slides were observed under the microscope for spore germination. A total of 200 spores were counted for each replication (vial) and percentage germination was estimated.

3.4.2. Viability and infectivity of spores stored at different temperatures: Spores of rust and late leaf spot pathogens were collected as described above (3.1.2) and distributed into screw capped glass vials (5 mg per vial). The vials were stored at temperatures of -17, 10, 20 and 30 ^{o}C as described earlier (3.4.1). Three replications were maintained, each replication consisting of 5 vials. The spores were tested for germinability and infectivity at 10, 20, 40, 80 and 160 days after storage. One vial was taken from each replication and spores were suspended in sterile distilled water. The spore concentration was adjusted to 50,000 spores ml^{-1} as described earlier (3.1.2). One or two drops of the suspension from each replication was placed on a glass slide and germinability was determined as described earlier (3.4.1).

Five detached leaves used in each replication to determine the infectivity. A total of 15 leaves were inoculated for each treatment. Untreated leaves served as controls. The percentage of leaves infected was determined.

3.4.3. Survival of leaf spots pathogens in infected leaves at 45^{o}C: Leaves of the genotype TMV 2 infected with early and late leaf spots were collected separately from the greenhouse and all conidia were washed from the lesion surfaces using a cyclone spore collector (3.1.2). The leaves were then surface disinfected with 0.1% mercuric chloride solution, then washed in several changes in sterile distilled water and oven dried at 30 ^{o}C for 6 hr. Leaves were placed in card board boxes (20 x 8

cm) with a layer of sterilized sand at the bottom and incubated in the dark at 45 °C. Leaves treated similarly but incubated at laboratory temperature (25-30 °C) served as controls. There were two replications for each treatment.

At 30-day intervals, two leaves were removed from each replication and incubated in Petri plates filled with moist sand for 24 hr. Later, infected portions of leaves were scraped off with a sterile blade and placed on glass slides and incubated in Petri plates lined with moist filter paper for about 10 days and then examined for sporulation. This experiment was conducted for four months.

3.4.4. Effect of temperature on rust and late leaf spot spore germination: Spore suspensions (50,000 spores ml^{-1}) of rust and late leaf spot pathogens were prepared as described above (3.1.2). One or two drops of the suspension were placed on glass slides and incubated in Petri plates lined with moist filter paper. The Petri plates were incubated in the dark for rust and in the light for late leaf spot at -17, 5, 10, 15, 20, 25, 30 and 35 °C. Percentage germination was determined at 12 and 24 hours after incubation. There was one slide per Petri plate and three replications were maintained for each treatment.

3.4.5. Effect of temperature on rust and leaf spots development: The effects of temperature on rust, early and late leaf spots development on three groundnut genotypes TMV 2, NC Ac 17129, and PI 350680, with varying levels of resistance to these diseases, were studied.

Thirty-days-old plants of genotypes TMV 2, NC Ac 17129 and PI 350680 were raised in the greenhouse as described earlier (3.1.2). Leaves from the middle portions of the main stem were excised through the pulvinous base. Ten leaves of each genotype were taken, and leaf areas were determined using a leaf area meter (Li-COR Inc., Model 3100, Lincoln, Nebraska, USA). The leaves were then arranged in plastic trays and used for inoculation as described for the detached leaf technique (3.1.2).

Following inoculation with rust, early and late leaf spots pathogens, the trays were placed in a plant growth chamber at 25 ^{o}C for 24 and 48 hr for rust and leaf spots respectively. Then the trays were transferred to various temperatures viz., 10, 15, 20, 25, 30 and 35 ^{o}C in plant growth chambers. In a preliminary experiment it was found that the temperature was 2 ^{o}C more inside the tray than outside. Hence, the temperatures in the plant growth chambers were adjusted in such a way that the required temperature was maintained inside each tray. The experiment was repeated two times.

From 7 days after inoculation, the leaves were examined daily and the numbers of lesions appearing were recorded. When daily increase in number ceased, the following parameters were recorded.

Incubation period - the number of days between inoculations and appearance of 50% of the lesions.

Infection frequency - final number of lesions per cm^2 of leaf area.

Percentage leaf area damaged - the leaf area damaged by rust, early and late leaf spots was estimated by comparison with diagrams (Appendix 1) depicting leaf areas with known percentages of their areas affected (Subrahmanyam et al., 1983b).

Lesion diameter - the diameters of ten randomly selected lesions of rust and leaf spots were measured using an ocular micrometer and millimeter scale, respectively.

Sporulation - The extent of sporulation of rust and leaf spot lesions was scored on ten randomly selected lesions on a 1-5 scale (Subrahmanyam et al., 1983b) using a stereomicroscope (X 70).

Percentage defoliation - the percentage defoliation was calculated by counting the total number of leaflets and the number of abscised leaflets on each leaf.

3.5. Seasonal variation on rust and leaf spots development in the field.

3.5.1. Field condition:

3.5.1.1. Location of field plots and climate: The field experiments were conducted at ICRISAT Center. The farm is situated at a latitude of 17.27 N, longitude of 78.28 ^{o} E and at 545 MSL. The rainy season, also known as monsoon or kharif, usually begins in June and extends into October. More than 80% of the 800 mm average annual rainfall from the south-west monsoon occurs during these months. The postrainy season of November through April, also known as post-monsoon or

rabi, is dry cool winter (November-January) and hot dry summer (February-April). The crop grown in this season requires irrigation.

3.5.1.2. Soil type: The field experiments were conducted at ICRISAT Center on Alfisols (red soils) consisting of clay 33%, sand 60% and silt 7%, with pH 5.9.

3.5.1.3. Fertilizer application: Approximately 40 kg P_2O_5 ha^{-1}. was broadcasted as a basal dressing prior to planting.

3.5.1.4. Plant protection: Insecticide sprays were applied to control insect pests.

3.5.1.5. Seasons: Field trials were conducted in the rainy seasons of 1983 and 1984, and in the postrainy seasons of 1983-84 and 1984-85.

3.5.1.6. Planting method and treatments: Seed of six genotypes (Table 1) were treated with a thiram - based seed protectant fungicide (Thiram 50 W.P.) at the rate of 3 g kg^{-1} of seed. Four rows were sown singly on 9 m long ridges with 75 cm apart from ridge to ridge with 10 cm spacing between seed to seed for each genotype. Two blocks in each of three locations were considered. Two blocks were kept 100 m apart according to the wind direction, so that all the untreated were up of the inoculated blocks. For providing the initial source of inoculum, potted plants heavily infected with rust and late leaf spot diseases were systematically arranged in the second and third rows of each plot about 15 days after sowing. However, no inoculum source was provided for early leaf spot.

3.5.1.7. Disease assessment: The severity of rust, early and late leafspots diseases was recorded every 10 days from 40 days after sowing until harvest. Five plants were selected randomly in the second and third rows of each plot, labelled, and assessment of rust and leaf spots development was carried out on them throughout the experimental period. The parameters evaluated were:

a) Percentage defoliation: The total number of leaflets on the mainstem and the number of abscised leaflets were counted on each plant and percentage defoliation was calculated.
b) Percentage leaf area damaged: The leaf area damaged by rust, early and late leaf spots were estimated separately for all remaining leaves of the mainstem as described earlier (3.4.4).

3.5.1.8. Analysis of the data: The data on visible disease (XV), including the percentage leaf area damaged from rust, early and late leaf spots, and defoliation (d) were used to calculate the total disease (Xt) on each genotype by the equation:

$$Xt = [(1-d) * XV1+XV2+XV3+d]$$

where XV1 = leaf area damaged by rust disease, XV2 = leaf area damaged by early leaf spot, and XV3 = leaf area damaged by late leaf spot (Plaut and Berger, 1980).

The values XV, d and Xt were logistically transformed with the equation:

$$f(X) = \log e\ (X/1-X)$$ (Van der Plank, 1963; Zadoks and Schein, 1979).

The logistic transformations were made for percentage leaf area damaged by three pathogens and defoliation. The function (f) is called the logit of X. The apparent infection rate (r) sensu Van der Plank (1963) is the slope of the linear regression line, often termed the logit line, and was determined by plotting logit (X) against time (t) using the equation:

$$r = 1/(t2-t1) * [\text{logit } (X2) - \text{Logit } (X1)]$$

where t=time; X2=XV1, XV2, XV3, d, or Xt at time 2; and X1=XV1, XV2, XV3, d, or Xt at time 1, was used to calculate the apparant infection rate for logit (XV1), (XV2), (XV3), logit (d), and logit (Xt), respectively (Van der Plank, 1963; Zadoks and Schein, 1979).

The delay in time (Δt) represents the time needed in a uninoculated plot to reach a given severity compared to the time in inoculated plot was calculated using the equation:

$$\Delta t = 1/r \quad (\text{logit } (XI) - \text{logit } (XU))$$

where;

r=apparant infection rate,

XU (uninoculated)=XV1, XV2, XV3, d or Xt under uninoculated conditions, and

XI (inoculated)=XV1, XV2, XV3, d or Xt under inoculated conditions.

Area under disease progress curve (AUDPC) was calculated for rust, leaf spots, defoliation and total disease by using the formula:

$$A = \sum_{i=1}^{k} 1/2\ (Si+Si-1)$$

where;

Si= disease severity at the end of week i,

k= number of successive evaluations (Wilcoxson et al., 1975; Nagarajan, 1983).

3.5.1.9. Meteorological data: The meteorological data on minimum and maximum temperatures, relative humidity, rainfall, sunshine, solar radiation, and evaporation during the experimental period were taken from the meteorological laboratory, ICRISAT Center (Appendix 2). The data on weather parameters were divided into the following components:

1. Mean maximum temperature.
2. Mean minimum temperature.
3. Number of days with maximum temperature between 20-25 °C.
4. Number of days with maximum temperature between 25-30 °C.
5. Number of days with maximum temperature between 30-35 °C.
6. Number of days with maximum temperature above 35 °C.
7. Number of days with minimum temperature less than 20 °C.
8. Number of days with minimum temperature between 20-25 °C.
9. Mean relative humidity at 0717 hr.
10. Mean relative humidity at 1417 hr.
11. Number of days with relative humidity less than 50% at 0717 hr.
12. Number of days with relative humidity between 50-75% at 0717 hr.

13. Number of days with relative humidity above 75% at 0717 hr.
14. Number of days with relative humidity less than 50% at 1417 hr.
15. Number of days with relative humidity between 50-75% at 1417 hr.
16. Number of days with relative humidity above 75% at 1417 hr.
17. Total rainfall.
18. Number of rainy days.
19. Number of days with 0.1-5.0 mm rain.
20. Number of days with 5-10 mm rain.
21. Number of days with 10-20 mm rain.
22. Number of days with rain above 20 mm.
23. Number of days with 0 hr sunshine.
24. Number of days with 1-5 hr sunshine.
25. Number of days with 5-12 hr sunshine.
26. Mean evaporation.
27. Number of days with 100-200 solar radiation.
28. Number of days with 201-300 solar radiation.
29. Number of days with 301-400 solar radiation.
30. Number of days with 401-500 solar radiation.
31. Number of days with 501-600 solar radiation.

Each of these weather components were regressed against the AUDPC of rust, leaf spots, defoliation and total disease to study their effects on disease development.

RESULTS

CHAPTER IV

RESULTS

4.1. Perpetuation of rust and leaf spots pathogens:

4.1.1. Survival of rust and late leaf spot pathogens in infected plant debris: Survival of rust and late leaf spot pathogens in infected leaves and stems of two groundnut genotypes, TMV 2 and PI 350680, was examined following the harvest of the 1983 rainy season crop. In the 1983-84 postrainy season, only leaves of TMV 2 were used since the disease severity on PI 350680 and stems of TMV 2 was low.

4.1.1.1. Under natural environmental conditions:

4.1.1.1.1. On soil surface: The results of survival of rust and late leaf spot pathogens in infected leaves and stems preserved on the soil surface are presented in Tables 2 and 3.

Rust was viable for 30 and 15 days in infected leaves of TMV 2 collected in the 1983 rainy and in the 1983-84 post-rainy seasons, respectively (Table 2). Rust was viable for only 15 days in infected stems of TMV 2 in the 1983 rainy season. Viability was short (15 days) in infected leaves and stems of PI 350680 (Table 2).

A perusal of Table 3 indicates that the late leaf spot pathogen was viable in the infected leaves of TMV 2 for 60 and 30 days in the 1983 rainy and 1983-84 postrainy seasons, respectively. Late leaf spot was viable for 30 days in infected leaves of PI 350680. The period of survival was much shorter (15 days) in the stems of both genotypes in the 1983

Table 2: Survival of groundnut rust in infected leaves and stems of two groundnut genotypes after harvest in the 1983 rainy and 1983-84 postrainy seasons at ICRISAT Center.

Genotype	Infected plant part	Period of exposure (days)	Number of leaves infected with rust	
			1983 rainy season	1983-84 post-rainy season
			x/10	x/10
TMV 2	Leaves	15	5	2
		30	3	0
		45	0	0
		60	0	0
	Stems	15	2	NE[1]
		30	0	NE
		45	0	NE
PI 350680	Leaves	15	2	NE
		30	0	NE
		45	0	NE
	Stems	15	2	NE
		30	0	NE
		45	0	NE

1. Not examined

Table 3: Survival of groundnut late leaf spot pathogen in infected leaves and stems of two groundnut genotypes after harvest in the 1983 rainy and 1983-84 postrainy seasons at ICRISAT Center.

Genotype	Infected plant part	Period of exposure (days)	Number of leaves infected with late leaf spot	
			1983 rainy season	1983-84 postrainy season
			(x/10)	(x/10)
TMV 2	Leaves	15	10	5
		30	6	7
		45	9	0
		60	1	0
		75	0	NE[1]
		90	0	NE
	Stems	15	1	NE
		30	0	NE
		45	0	NE
PI 350680	Leaves	15	6	NE
		30	2	NE
		45	0	NE
		60	0	NE
	Stems	15	1	NE
		30	0	NE
		45	0	NE

1. Not examined

rainy season.

Weather conditions recorded at the experimental site are presented in Table 4. Temperatures were lower and relative humidities higher during October to December 1983 (following the rainy season) than during April to May 1984 (following the postrainy season)(Table 4). There were two rainy days in November 1983 and one rainy day in May 1984.

4.1.1.1.2. At different depths in the soil: Survival of rust and late leaf spot pathogens in infected leaves buried at 5 and 10 cm depths was determined. Data (Table 5) indicated that rust and late leaf spot pathogens remained viable for 30 days at 5 and 10 cm depths. There were no marked differences in per cent soil moisture and temperature between 5 and 10 cm depths (Table 6).

4.1.1.1.3. Under puddled conditions in paddy fields (late leaf spot only): Survival of the late leaf spot pathogen in infected leaf debris buried at different depths under puddled conditions in paddy fields was studied.

There was no sporulation of the pathogen on lesion surfaces after 15 days of incubation in humid chambers. Inoculation tests on healthy groundnut leaves were also negative, indicating that the fungus was short lived (less than 30 days) under puddled conditions (Table 7).

4.1.1.2. Under greenhouse conditions: The results of survival of rust and late leaf spot pathogens in infected leaves and stems under greenhouse conditions are presented in Tables 8 and 9.

Table 4: Weather conditions during the experimental period.

Period of exposure	Temperature (°C) range		Relative humidity (%) range		Rainfall (mm)
	Minimum	Maximum	Hr 07.17	Hr 14.17	
Following rainy season (20-10-1983 to 20-12-1983	10.0-21.0	26.2-30.4	61-99	29-83	0.2 and 15 (only 2 days)
Following postrainy season (26-4-1984 to 26-5-1984)	21.7-30.2	36.8-43.2	19-65	9-33	0.5 (only 1 day)

Table 5: Survival of groundnut rust and late leaf spot pathogens in infected leaves of groundnut (TMV 2) buried at different depths in soil after harvest in the 1984 rainy season crop at ICRISAT Center.

Depth (cm)	Period of exposure (days)	Number of leaves infected with	
		Rust	Late leaf spot
		(x/10)	(x/10)
5	15	5	10
	30	6	8
	45	0	0
	60	0	0
10	15	4	6
	30	3	3
	45	0	0
	60	0	0

Table 6: Soil temperature and per cent soil moisture in different depths during the experimental period (23 December 1984 to 23 January 1985).

Depth (cm)	Soil temperature (^{O}C)		Soil moisture (%)
	Minimum	Maximum	
5	20-21	26-30	0.56 - 1.4
10	21-25	27-29	0.74 - 1.6

Table 7: Survival of groundnut late leaf spot in infected leaves buried at different depths under puddled conditions in paddy fields after harvest in the 1984-85 postrainy season at ICRISAT Center.

Period of storage (days)	Number of leaves infected with late leaf spot		Number of sporulating lesions	
	15 cm	30 cm	15 cm	30 cm
	(x/10)	(x/10)	(x/5)	(x/5)
30	0	0	0	0
60	0	0	0	0
90	0	0	0	0
120	0	0	0	0
150	0	0	0	0
180	0	0	0	0

The rust pathogen was viable for 45 days in TMV 2 leaves collected in the 1983 rainy and the 1983-84 post-rainy seasons. However, in the rainy season in stems of TMV 2 and in the leaves of PI 350680 it was viable for only 30 days and in stems of genotypes PI 350680 for 15 days (Table 8).

The data in Table 9 indicate that the late leaf spot pathogen survived for over 390 days in infected leaves of TMV 2 collected in the 1983 rainy season and for 285 days in the 1983-84 postrainy season. However, the pathogen was viable for only 135 days in leaves of PI 350680 collected from the 1983 rainy season.

The pathogen survived in stems of genotype TMV 2 for 30 days, whereas it was viable for only 15 days in stems of genotype PI 350680 (Table 9).

The air temperatures ranged from 20-30 ^{o}C throughout the experimental period.

4.1.2. *Survival of rust and leaf spots pathogens in field soil*: Rust and late leaf spot pathogens were viable in the soil for 30 days in rainy and postrainy seasons (Table 10). The early leaf spot survived for 30 days in the 1983 rainy season. These results indicate that all three pathogens are short lived in the soil after the harvest of the crop.

Air temperatures following the rainy season (20-10-1983 to 20-11-1983) ranged from 15-30 ^{o}C and 20-40 ^{o}C follow-

Table 8: Survival of groundnut rust in infected leaves and stems of two groundnut genotypes preserved in the greenhouse after harvest in the 1983 rainy and 1983-84 postrainy seasons at ICRISAT Center.

Genotype	Infected plant part	Period of exposure (days)	Number of leaves infected with rust	
			1983 rainy season	1983-84 postrainy season
			(x/10)	(x/10)
TMV 2	Leaves	15	8	8
		30	2	6
		45	3	3
		60	0	0
		75	0	0
	Stems	15	5	NE[1]
		30	1	NE
		45	0	NE
		60	0	NE
PI 350680	Leaves	15	5	NE
		30	1	NE
		45	0	NE
		60	0	NE
	Stems	15	6	NE
		30	0	NE
		45	0	NE

1. Not examined

Table 9: Survival of late leaf spot in infected leaves and stems of two groundnut genotypes preserved in the greenhouse after harvest in the 1983 rainy and 1983-84 postrainy seasons at ICRISAT Center.

Genotype	Infected plant part	Period of exposure (days)[1]	Number of leaves infected with late leaf spot	
			1983 rainy season	1983-84 post-rainy season
			(x/10)	(x/10)
TMV 2	Leaves	15	10	5
		30	6	10
		45	10	6
		285	3	1
		300	2	0
		315	3	0
		390	1	
	Stems	15	2	NE[2]
		30	1	NE
		45	0	NE
		60	0	NE
PI 350680	Leaves	15	7	NE
		30	4	NE
		45	2	NE
		135	1	NE
		150	0	NE
		165	0	NE
	Stems	15	1	NE
		30	0	NE
		45	0	NE

1. Selected sample dates only
2. Not examined

Table10:Survival of rust,early,and late leaf spots pathogens in field soil collected after harvest in the 1983 rainy and 1983-84 postrainy seasons at ICRISAT Center.

Period of exposure (days)	Number of leaves showing rust and leaf spots symptoms					
	1983 rainy season			1983-84 postrainy season		
	Rust	Early leaf spot	Late leaf spot	Rust	Early leaf spot	Late leaf spot
	(x/10)	(x/10)	(x/10)	(x/10)		(x/10)
15	2	4	3	3	NE[1]	6
30	1	2	3	2	NE	2
45	0	0	0	0	NE	0
60	0	0	0	0	NE	0

1. Not examined

ing the postrainy season (1.5.1984 to 1.6.1984).

4.1.3. *Perpetuation of rust and leaf spots pathogens on ground-keepers and volunteer groundnut plants*: Ground-keepers and volunteer groundnut plants present in and around the fields after the harvest of the 1984 rainy season crop in October 1984 were observed for the presence of rust and leaf spots pathogens at monthly intervals until June 1985 (Table 11).

Lesions of rust, early and late leaf spots were observed on labelled ground-keepers and volunteer groundnut plants during the experimental period (October 1984 to June 1985). However, the number of lesions per plant were extremely low. Leaves collected in October 1984 and March, April, and June 1985 showed profusely sporulating lesions of rust and leaf spots. In November 1984 to February 1985 and in May 1985 the lesions showed no sporulation. However, the lesions which were not sporulating in the field, showed profuse sporulation after incubation for 24 hr in humid chambers in the laboratory indicating that all three pathogens were viable and could perpetuate on volunteer groundnut plants when the crop was not present in the field (Table 11).

4.1.4. *Search for collateral hosts of rust and leaf spots pathogens*: Eleven leguminous weed plants and eleven leguminous crop plants (Table 12) were inoculated with rust and leaf spots pathogens in the greenhouse. None of the pathogens infected any of the leguminous plants tested, while the susceptible groundnut genotype TMV 2 inoculated and incubated under similar conditions developed severe rust and leaf spots.

Table 11: Occurrence of rust and leaf spots on ground-keepers and volunteer groundnut plants in and around groundnut fields at ICRISAT Center during October 1984 to June 1985.

Plants examined on	Diseases observed			Extent of sporulation		
	Rust	Early leaf spot	Late leaf spot	Rust	Early leaf spot	Late leaf spot[2]
1st Oct. '84	x[1]	x	x	4.0	4.0	4.5
1st Nov. '84	x	x	x	2.5	1.0	1.0
3rd Dec. '84	x	x	x	2.0	1.0	1.0
2nd Jan. '85	x	x	x	2.5	1.0	1.0
1st Feb. '85	x	x	x	3.0	1.0	1.0
1st Mar. '85	x	x	x	4.0	4.5	4.5
1st April '85	x	x	x	4.0	4.5	4.5
1st May '85	x	x	x	2.5	1.0	1.0
3rd June '85	x	x	x	4.0	4.0	4.0

1. Presence of disease
2. Extent of sporulation scored on a 1-5 scale (Subrahmanyam et al., 1983b)

Table 12: Leguminous plant species examined as possible collateral hosts of *Puccinia arachidis*, *Cercospora arachidicola*, and *Phaeoisariopsis personata* in the greenhouse inoculation tests.

Crop plants	Weed plants
Cajanus cajan (L.) Millsp.	*Aeschynomene indica* L.
Cicer arietinum L.	*Alysicarpus longifolius* W. & A.
Crotalaria juncea L.	*A. monilifera* (L.) DC.
Cyamopsis tetragonaloba (L.) Taub.	*Cassia occidentalis* L.
Glycine max (L.) Merr.	*C. tora* L.
Lablab purpurens (L.) Sweet	*Desmodium dichotomum* (Willd.) DC.
Phaseolus lunatus L.	*Indigofera glandulosa* Willd.
P. vulgaris L.	*I. cordifolia* Heyne ex Roth.
Vicia faba L.	*Rhynchosia minima* (L.) DC
Vigna mungo (L.) Hepper	*Sesbania bispinosa* (Jacq) W.F. Wight
V. radiata (L.) Wilez	*Tephrosia hirta* Ham.

4.2. Possible means of spread of rust and leaf spots pathogens:

4.2.1. Pod and seed contamination: The possible spread of rust and leaf spots pathogens on pods and seeds was examined. The pods and seeds artificially contaminated by dusting with the spores of rust and leaf spots and sown in isolation plant propagators gave rise to disease-free seedlings. No diseases had developed even after 45 days from sowing.

4.2.2. Shell contamination (rust only): The possible means of spread of groundnut rust through urediniospore-contaminated shells was examined. Groundnut plants were raised in isolation plant propagators and artificially contaminated shells were "thrown on to" the plants so that the spores carried on the shells could land on the leaf surface. This resulted in severe rust development in all test plants within 15 days after this treatment.

4.2.3. Clothes contamination (rust only): The possible spread of groundnut rust through clothes of research workers was considered. The movement of research workers in the greenhouse with clothes artificially contaminated with urediniospores gave rise to severe rust development on test plants.

4.3. Effect of temperature on rust and leaf spots pathogens:

4.3.1: Effect of temperature on spore viability: The spores of rust and late leaf spot pathogens were collected from infected leaves, distributed in glass vials, and stored in the dark at -17, 10, 20, 30 and 40 ^{o}C. Viabilities of spores were

determined at 10-day intervals.

4.3.1.1. Rust: The results on effect of temperature on viability of rust urediniospores are presented in Table 13. The initial viability of rust urediniospores before storage was 87.4%. At -17 and 10 °C the urediniospores remained viable for over 200 days of storage. However, there was significant variation in percentage germination between sampling times at -17 and 10 °C. At 20 °C, there was 47.3% germination at 10 days after storage, however, the viability decreased rapidly with increase in storage time (30 days). At 30 °C, there was no viability even at 10 days of storage. At 40 °C, the percentage viability at 10 days of storage was 7.6. However, in subsequent samplings there was no viability at 40 °C. At 20, 30 and 40 °C, although there was no viability for some period of storage, very low percentage (0.2 to 0.3) of spores showed viability at various periods of storage (Table 13).

4.3.1.2. Late leaf spot: The initial viability of conidia of late leaf spot pathogen before storage was 91.8%. At -17, 10, and 20 °C, the conidia remained viable for over 200 days of storage (Table 14). However, at 20 °C the viability was very low. At 30 °C, the viability was only 6% after 10 days of storage. There was no viability in subsequent samplings, however, after 60 and 140 days of storage, very low percentage of spores germinated. At 40 °C, there was a depletion in viability with increase in period of storage (40days) (Table 14).

4.3.2. Viability and infectivity of rust and late leaf spot

Table 13: Effect of temperature on viability of urediniospores of Puccinia arachidis.

Days after storage	Percentage germination at different temperatures (° C)[1]				
	40	30	20	10	-17
10	7.6 (14.2)[2]	0.0 (0.0)	47.3 (43.5)	31.2 (33.7)	16.5 (20.6)
20	0.0 (0.0)	0.0 (0.0)	22.3 (28.0)	61.3 (52.1)	14.8 (20.9)
30	0.0 (0.0)	0.0 (0.0)	1.3 (5.2)	48.5 (44.1)	29.2 (32.5)
40	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	42.3 (38.6)	54.0 (47.3)
50	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	15.0 (20.2)	17.2 (19.7)
60	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	29.5 (32.4)	23.3 (24.2)
70	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	7.3 (14.2)	1.3 (5.0)
80	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	57.2 (49.2)	18.9 (24.5)
90	0.0 (0.0)	0.0 (0.0)	0.2 (1.4)	41.5 (40.1)	26.3 (30.5)
100	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	40.5 (39.5)	25.5 (28.4)
110	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	28.2 (31.3)	4.3 (9.6)
120	0.0 (0.0)	0.2 (1.4)	0.0 (0.0)	46.2 (42.8)	17.0 (23.0)
130	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	37.0 (37.3)	5.2 (12.6)
140	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	23.3 (28.2)	5.5 (12.8)
150	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	31.8 (34.3)	16.0 (23.4)
160	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	32.8 (34.9)	21.7 (25.5)
170	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	13.0 (17.5)	7.2 (15.3)
180	0.2 (1.4)	0.0 (0.0)	0.2 (1.4)	21.0 (27.1)	13.7 (21.0)
190	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	21.2 (27.3)	5.8 (13.9)
200	0.3 (1.9)	0.0 (0.0)	0.0 (0.0)	23.7 (29.1)	20.0 (24.9)
SE	±4.84				
CV (%)	78.1				

1. Average of three replications
2. Angular transformation values are presented in parenthesis

Table 14: Effect of temperature on viability of conidia of Phaeoisariopsis personata.

Days after storage	Percentage germination at different temperatures (°C)[1]				
	40	30	20	10	-17
10	49.7 (49.8)[2]	6.0 (13.4)	24.7 (27.3)	2.2 (8.3)	1.2 (5.0)
20	15.0 (22.4)	0.0 (0.0)	25.5 (30.3)	85.8 (69.4)	19.8 (24.5)
30	1.8 (5.7)	0.0 (0.0)	7.8 (16.2)	69.0 (56.4)	43.2 (40.8)
40	1.0 (4.6)	0.0 (0.0)	0.0 (0.0)	86.8 (69.0)	3.8 (10.4)
50	0.0 (0.0)	0.0 (0.0)	2.0 (7.5)	26.5 (27.8)	25.3 (24.7)
60	0.0 (0.0)	0.8 (4.3)	0.0 (0.0)	12.3 (15.7)	27.7 (28.4)
70	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	40.5 (39.5)	13.3 (19.1)
80	0.2 (1.4)	0.0 (0.0)	1.7 (7.4)	62.8 (52.5)	55.2 (48.5)
90	0.0 (0.0)	0.0 (0.0)	3.5 (10.3)	62.0 (52.0)	46.2 (42.8)
100	0.0 (0.0)	0.0 (0.0)	0.3 (1.9)	47.2 (43.3)	37.7 (36.9)
110	0.0 (0.0)	0.0 (0.0)	1.0 (4.7)	42.7 (40.7)	16.8 (24.0)
120	0.0 (0.0)	0.0 (0.0)	1.0 (4.7)	38.8 (38.5)	27.0 (31.3)
130	0.0 (0.0)	0.0 (0.0)	1.2 (6.2)	52.5 (46.5)	24.2 (29.4)
140	0.0 (0.0)	0.2 (1.4)	1.2 (6.2)	50.5 (49.3)	38.3 (38.1)
150	0.0 (0.0)	0.0 (0.0)	1.3 (6.6)	32.8 (34.9)	27.7 (31.7)
160	0.0 (0.0)	0.0 (0.0)	0.3 (1.9)	32.8 (34.9)	16.2 (23.4)
170	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	38.0 (37.9)	33.0 (35.0)
180	0.0 (0.0)	0.0 (0.0)	0.2 (1.4)	47.2 (43.4)	24.3 (29.5)
190	0.0 (0.0)	0.0 (0.0)	0.3 (1.9)	46.2 (42.8)	27.8 (31.8)
200	0.0 (0.0)	0.0 (0.0)	0.5 (3.3)	49.5 (44.7)	28.7 (32.1)
SE	±5.2				
CV(%)	56.2				

1. Average of three replications

2. Angular transformation values are presented in Parenthesis

spores at different temperatures: Spores of rust and late leaf spot pathogens were stored in the dark at -17, 10, 20, and 30 °C in screw-capped glass vials and their viability and infectivity was determined after 10, 20, 40, 80 and 160 days of storage.

4.3.2.1. Rust: The initial percentage germination of urediniospores before storage was 87.4, and they caused infection on all inoculated leaves.

The percentage germination of urediniospores decreased with increase in period of storage at 20 and 30 °C (Table 15).

The percentage germination was 1.7 at 10 days of storage at 30 °C but infectivity was 100%. Though there was no germination after 10 days of storage at 30 °C, the infectivity was shown at 40 and 160 days of storage. At 20 °C, the viability lost after 20 days of storage, but a few spores germinated after 40 days of storage. However, even though there was no germination, infectivity was shown at all times of testing. At 10 and -17 °C, there was viability and infectivity at all times of testing. It is interesting to note that although the spores did not germinate on glass slides, they caused infection on groundnut leaves at 30 and 20 °C (Table 15).

4.3.2.2. Late leaf spot: The initial percentage germination of late leaf spot spores was 91.8%, and they caused infection on all test leaves as in the case of rust. Although, the spores were viable for over 160 days at -17 and 10 °C, the percentage viability at each sampling time was lesser at -17 than at 10 °C. However, the percentages of leaves infected

Table 15: Effect of temperature on viability and infectivity of urediniospores of Puccinia arachidis.

Days after storage	Percentage germination and infection of urediniospores stored at different temperatures (°C)[1]							
	30		20		10		-17	
	Per cent germination	Per cent leaves infected	Per cent germination	Per cent leaves infected	Per cent germination	Per cent leaves infected	Per cent germination	Per cent leaves infected
10	1.7 (7.3)[2]	100.0 (90.0)	41.7 (40.0)	93.3 (81.1)	51.7	100.0 (90.0)	9.7 (17.9)	100.0 (90.0)
20	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	93.3 (81.1)	68.0	40.0 (38.9)	2.2 (6.9)	46.7 (43.1)
40	0.0 (0.0)	13.3 (17.7)	4.5 (11.6)	100.0 (90.0)	81.3	100.0 (90.0)	54.2 (47.4)	100.0 (90.0)
80	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	13.30 (17.7)	68.5	100.0 (90.0)	2.8 (9.5)	26.7 (30.8)
160	0.0 (0.0)	13.3 (17.7)	0.0 (0.0)	6.70 (8.9)	58.8	100.0 (90.0)	2.3 (8.7)	33.3 (35.0)
SE	±3.00	±5.15						
CV (%)	23.4	15.2						

1. Average of three replications

2. Angular transformation values are presented in parenthesis

with spores stored at -17 and 10 °C were more or less similar. Some spores were viable after 160 days at 20 °C, however, the percentage viability decreased with increase in period of storage (Table 16). Although there was no germination of spores on glass slides after 40 days of storage at 20 °C, about 47% of leaves inoculated with the same batch of spores developed late leaf spot lesions. There was an opposite trend at 160 days of storage. Although, there was a small percentage of spores viable, no infection was observed on detached leaves. At 30 °C, there was a drop in spore viability with increase in period of storage. There was no viability after 20 days of storage. Although, the percentage spore germination as measured on glass slides was zero at 20 days of storage, over 50% of leaves inoculated with the spores developed late leaf spot lesions (Table 16).

4.3.3. *Survival of leaf spots pathogens in infected leaves at 45°C:*

The results on survival of early and late leaf spots pathogens in infected leaves as vegetative mycelium or stroma incubated at 45 °C and at the laboratory temperature (20-30 °C) are presented in Table 17. Survival of the pathogens was determined at 30-day intervals until 120 days. At each sampling time the infected leaves were incubated at high relative humidity and the lesions were examined for sporulation. Almost all lesions produced fresh conidia. These results clearly show that both early and late leaf spots pathogens can survive

Table 16: Effect of temperature on viability and infectivity of conidia of Phaeoisariopsis personata.

Days after storage	Percentage germination and infection of conidia stored at different temperatures (°C)[1]							
	30		20		10		-17	
	Per cent germination	Per cent leaves infected	Per cent germination	Per cent leaves infected	Per cent germination	Per cent leaves infected	Per cent germination	Per cent leaves infected
10	6.0 (13.4)[2]	93.3 (81.1)	32.2 (34.4)	93.3 (81.1)	3.2 (10.2)	100.0 (90.0)	3.2 (10.2)	100.0 (90.0)
20	0.0 (0.0)	53.3 (46.9)	30.8 (33.7)	60.0 (56.2)	75.8 (60.7)	80.0 (73.1)	19.8 (26.1)	100.0 (90.0)
40	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	46.7 (38.9)	86.8 (69.0)	100.0 (90.0)	3.8 (10.4)	100.0 (90.0)
80	0.0 (0.0)	0.0 (0.0)	3.3 (10.4)	46.7 (38.9)	56.2 (48.6)	100.0 (90.0)	38.7 (38.4)	100.0 (90.0)
160	0.0 (0.0)	0.0 (0.0)	0.3 (1.9)	0.0 (0.0)	22.7 (28.3)	93.3 (81.1)	12.8 (20.8)	93.3 (81.1)
SE	±2.08	±8.56						
CV (%)	17.4	21.9						

1. Average of three replications

2. Angular transformation value are presented in parenthesis

Table 17: Survival of early and late leaf spotspathogens in lesions of infected leaves at 45 °C.

Days after storage	Number of leaflets on which conidia were produced after storage			
	In the laboratory (20-30 °C)		At 45 °C	
	Early leaf spot	Late leaf spot	Early leaf spot	Late leaf spot
	(x/4)	(x/4)	(x/4)	(x/4)
30	4	4	4	4
60	4	4	4	4
90	4	4	4	4
120	4	4	4	4

in infected leaves for over 120 days, even at 45 °C.

4.3.4. Effect of temperature on spore germination: Spore suspensions of rust and late leaf spot pathogens were placed on glass slides and incubated at different temperatures. Percentage germination was determined after 12 and 24 hr after incubation.

4.3.4.1. Rust: There were statistically significant differences in percentage urediniospore germination at the different temperatures (Table 18). There was no germination at -17 °C and only very low percentages of spores germinated at 5, 10, 15 and 35 °C after both 12 and 24 hr of incubation. Temperatures in the range of 20-30 °C were favourable for urediniospore germination, the optimum being 25 °C. No significant differences in percentage germination were observed between 12 and 24 hr of incubation (Table 18).

4.3.4.2. Late leaf spot: The percentage germination was high at temperatures in the range of 15 to 30 °C. There was no germination at -17 °C, and very low percentage germination occurred at 5, 10, and 35 °C at both 12 and 24 hr of incubation. In general, the percentage germination was significantly higher after 24 hr than after 12 hr of incubation (Table 19).

4.3.5. Effect of temperature on rust and leaf spots development: The effect of temperature on rust, early and late leaf spots development on detached leaves of three groundnut genotypes TMV 2, NC Ac 17129 and PI 350680 with varying levels of resistance to these diseases was studied in the laboratory. The parameters

Table 18: Effect of temperature on germination of urediniospores of Puccinia arachidis.

Incubation time (hours)	Percentage of germination urediniospores at different temperatures (^{0} C)[1]							
	35	30	25	20	15	10	5	-17
12	0.6 (4.2)[2]	87.0 (68.9)	94.6 (76.6)	93.3 (75.2)	12.6 (20.8)	2.2 (8.5)	2.5 (9.1)	0.0 (0.0)
24	1.2 (6.4)	88.4 (70.2)	94.0 (76.3)	91.5 (73.6)	14.2 (22.0)	8.8 (17.0)	5.5 (13.5)	0.0 (0.0)
SE	±1.41							
CV (%)	5.8							

1. Average of three replications

2. Angular transformation values are presented in parenthesis

Table 19: Effect of temperature on germination of conidia of Phaeoisariopsis personata.

Incubation time (hours)	Percentage germination of conidia at different temperatures (^{0}C)[1]							
	35	30	25	20	15	10	5	-17
12	3.9 (11.4)[2]	87.9 (69.7)	87.7 (69.7)	85.6 (67.9)	83.1 (66.0)	11.7 (19.9)	2.4 (8.7)	0.0 (0.0)
24	4.3 (11.9)	90.2 (70.3)	92.7 (74.6)	93.6 (75.5)	86.6 (68.8)	13.4 (21.3)	3.8 (11.0)	0.0 (0.0)
SE	±2.29							
CV (%)	7.4							

1. Average of three replications

2. Angular transformation values are presented in parenthesis

measured were incubation period, infection frequency, lesion diameter, leaf area damaged, defoliation, and sporulation index.

4.3.5.1. Rust: There were statistically significant differences in incubation period, infection frequency, lesion diameter, percentage leaf area damaged, and sporulation index between the genotypes at all temperatures studied (Table 20). In general, incubation period was high and infection frequency, lesion diameter, percentage leaf area damaged and sporulation index were lower for resistant (PI 350680) and moderately resistant (NC Ac 17129) genotypes than for the susceptible genotype (TMV 2).

There were statistically significant differences in incubation period between 15, 20, and 25 ^{o}C, but the differences were not statistically significant between 25 and 30 ^{o}C. However, there were no differences between temperatures in infection frequency, lesion diameter or sporulation index. In general, the percentage leaf area damaged by rust was more or less same at 15, 20, and 25 than 30 ^{o}C.

No disease was observed at 10 and 35 ^{o}C even at 45 days after inoculation.

4.3.5.2. Early leaf spot: Although, there were no statistically significant differences in incubation period, infection frequency, lesion diameter, percentage leaf area damaged or sporulation index between the genotypes, the magnitude of difference between the genotypes at all

Table 20: Effect of temperature on rust disease development on three groundnut genotypes under monocyclic infection in the laboratory.

Temperature (°C)	Genotype	Parameters studied									
		Incubation period (days)		Infection frequency (lesions/cm²)		Lesion diameter (mm) (%)		Leaf area damage (%)		Sporulation index	
		I[1]	II[2]	I	II	I	II	I	II	I	II
15	TMV 2	33.3	32.5	2.9	3.9	0.51	0.53	2.4	3.2	5.0	4.6
	NC Ac 17129	36.2	35.7	2.1	3.2	0.43	0.44	2.2	3.4	4.4	4.4
	PI 350680	39.0	37.3	0.6	2.0	0.38	0.38	0.8	1.9	3.3	3.4
20	TMV 2	18.4	17.8	3.1	3.3	0.61	0.60	2.7	6.4	5.0	5.0
	NC Ac 17129	21.5	20.5	2.3	3.0	0.45	0.47	2.4	3.7	4.3	4.3
	PI 350680	24.0	23.3	0.8	1.9	0.40	0.40	0.6	3.2	3.6	2.9
25	TMV 2	10.2	10.2	3.4	3.8	0.63	0.63	2.8	3.9	4.8	4.9
	NC Ac 17129	12.7	12.5	1.8	1.7	0.47	0.45	2.5	3.4	4.2	4.0
	PI 350680	15.0	15.3	0.9	1.1	0.38	0.41	1.5	1.9	1.8	1.7
30	TMV 2	10.4	10.3	3.3	3.6	0.62	0.60	4.8	7.6	4.8	5.0
	NC Ac 17129	12.3	13.3	3.8	2.3	0.50	0.47	3.4	4.4	3.8	4.3
	PI 350680	14.3	14.3	0.8	0.9	0.40	0.39	1.2	1.3	2.4	2.0
SE		±1.45	±1.50	±0.86	±0.94	±0.067	±0.053	±1.60	±2.28	±0.46	±0.35
CV (%)		7.1	7.6	40.0	37.0	14.0	11.0	19.5	21.6	11.8	9.0

1. Average of ten replications in experiment 1

2. Average of ten replications in experiment 2

temperatures was small since all the three genotypes were susceptible to early leaf spot in the field.

There were no differences in lesion diameter at all temperatures. In general, there were no differences in infection frequency at 15, 20, and 25 ^{o}C. The percentage leaf area damaged and defoliation were highest at 25 ^{o}C and were least at 30 ^{o}C (Table 21).

No early leaf spot development was recorded at 10 and 35 ^{o}C even at 45 days after inoculations.

4.3.5.3. Late leaf spot: There were statistically significant differences in incubation period, infection frequency, lesion diameter, percentage leaf area damaged, percentage defoliation and sporulation index between genotypes at all temperatures (Table 22). In general, the resistant (PI 350680) and moderately resistant (NC Ac 17129) genotypes had longer incubation periods, reduced infection frequencies, lesion diameters, percentage leaf area damaged, percentage defoliation and sporulation index than the susceptible TMV 2.

The incubation period was longer at 15 and 20 than at 25 and 30 ^{o}C for all genotypes. The infection frequency was higher at 15, 20, and 25 than at 30 ^{o}C. There were no differences in lesion diameter between 15, 25 and 30 ^{o}C. The percentage leaf area damaged was highest at 25 followed by 15, 30 and 20 ^{o}C. The percentage defoliation was highest at 25 followed by 30, 20, and 15 ^{o}C. There were no differences in the sporulation index between temperatures (Table 22).

Table 21. Effect of temperature on early leaf spot disease development on three groundnut genotypes under monocyclic infection in the laboratory.

Temperature (°C)	Genotype	Parameters studied											
		Incubation period (days)		Infection frequency (lesions/cm²)		Lesion diameter (mm)		Leaf area damaged (%)		Defoliation (%)		Sporulation index	
		I[1]	II[2]	I	II	I	II	I	II	I	II	I	II
15	TMV 2	23.6	22.0	2.0	2.8	3.5	3.6	7.2	8.8	20.0	12.5	3.9	3.7
	NC Ac 17129	24.8	25.9	2.1	3.5	2.9	2.3	10.7	6.7	10.0	7.5	3.3	3.5
	PI 350680	24.8	23.3	1.5	2.6	2.9	2.7	3.9	9.2	12.5	15.0	3.3	3.4
20	TMV 2	21.0	20.1	1.5	2.7	3.8	3.6	14.0	9.3	17.5	12.5	4.3	4.7
	NC Ac 17129	23.0	21.2	1.9	2.6	3.2	3.1	12.6	9.4	12.5	15.0	3.9	4.3
	PI 350680	21.6	19.5	1.4	2.2	3.2	3.0	3.9	9.0	15.0	22.5	3.6	3.4
25	TMV 2	14.0	13.8	2.3	2.4	3.5	3.3	20.9	15.3	20.0	22.5	4.2	4.7
	NC Ac 17129	15.0	14.6	2.3	2.0	2.5	2.9	13.4	12.4	12.5	17.5	3.8	4.2
	PI 350680	13.8	14.6	1.4	1.7	2.6	2.9	14.2	12.5	12.5	22.5	4.0	4.0
30	TMV 2	14.1	13.8	2.4	1.4	3.6	3.2	8.3	7.3	12.5	12.5	4.0	4.8
	NC Ac 17129	15.4	14.5	2.3	1.4	2.2	2.9	3.7	9.1	12.5	12.5	3.6	4.1
	PI 350680	13.9	13.6	1.2	1.2	2.3	3.1	3.4	8.8	10.0	12.5	3.7	4.1
	SE	±1.71	±1.32	±1.0	±0.76	±0.78	±0.65	±5.94	±4.63	±16.97	±17.13	±0.43	±0.32
	CV (%)	9.1	7.3	54.1	34.2	25.8	21.0	35.2	26.20	107.7	100.0	11.4	7.8

1. Average of ten replications in experiment 1.

2. Average of ten replications in experiment 2.

Table 22. Effect of temperature on late leaf spot disease development on three groundnut genotypes under monocyclic infection in the laboratory.

Temperature (°C)	Genotype	Parameters studied											
		Incubation period (days)		Infection frequency (lesions/cm²)		Lesion diameter (mm) (%)		Leaf area damaged (%)		Defoliation (%)		Sporulation index	
		I[1]	II[2]	I	II	I	II	I	II	I	II	I	II
15	TMV 2	24.0	24.7	4.0	3.1	2.2	2.6	17.3	12.0	15.0	10.0	4.5	4.8
	NC Ac 17129	25.4	25.8	2.4	2.0	2.0	2.2	11.0	6.0	10.0	15.0	4.0	3.7
	PI 350680	30.7	30.7	2.2	2.4	0.9	1.3	6.8	4.4	7.5	7.5	3.3	2.2
20	TMV 2	17.3	18.2	3.1	2.7	2.9	3.1	15.0	13.6	15.0	12.5	5.0	4.9
	NC Ac 17129	21.1	22.0	3.8	2.2	2.0	2.1	9.4	6.2	7.5	12.5	3.9	3.3
	PI 350680	24.5	23.0	2.3	2.8	1.1	1.1	7.1	5.8	10.0	12.0	3.3	2.4
25	TMV 2	12.4	12.8	4.8	2.6	2.5	2.3	18.5	16.5	25.0	22.5	4.9	4.7
	NC Ac 17129	14.5	14.9	2.7	1.7	1.3	1.9	11.1	9.2	15.0	15.0	3.8	3.5
	PI 350680	17.5	16.1	2.2	2.9	1.1	1.0	7.4	6.7	10.0	10.0	3.2	2.6
30	TMV 2	11.3	12.3	3.0	2.3	2.6	3.1	12.2	10.3	12.5	15.0	4.8	4.9
	NC Ac 17129	13.5	14.2	1.4	1.7	1.6	1.5	10.1	8.1	15.0	15.0	3.9	3.4
	PI 350680	16.6	16.0	1.5	1.3	0.9	0.9	6.0	2.9	10.0	7.0	3.2	1.5
	SE	±1.41	±1.57	±1.06	±0.69	±0.41	±0.49	±4.95	±4.09	±16.00	±16.60	±0.37	±0.38
	CV(%)	7.4	8.2	39.1	29.9	23.4	25.4	26.5	25.3	109.4	115.6	9.3	10.9

1. Average of ten replications in experiment 1.

2. Average of ten replications in experiment 2.

No late leaf spot development was observed at 10 and 35 °C even at 45 days after inoculation.

4.4. Development of rust and leaf spots diseases at ICRISAT Center:

The progress of rust and leaf spots development was monitored on six groundnut genotypes in field plots with and without inoculation in the 1983 and 1984 rainy seasons and in the 1983-84 and 1984-85 postrainy seasons at ICRISAT Center. Disease development was measured in terms of percentage leaf area damaged from rust and leaf spots pathogens and percentage defoliation at 10-day interval. The data on percentage leaf area damaged from rust and leaf spots and percentage defoliation were combined to calculate the percentage total disease.

1983 rainy season: At the final time of observation the percentage leaf area damaged from rust, late leaf spot, defoliation and total disease were markedly higher in inoculated plots than uninoculated plots of all genotypes (Tables 23, 24, 25 and 26 and Figs.1 to 4). The area under the disease progress curve (AUDPC) was consistantly higher for rust, late leaf spot, defoliation and total disease in inoculated than in uninoculated plots for all genotypes (Tables 23 to 26).

There was a strong varietal interaction on the onset of rust and late leaf spot development. Both the diseases appeared at 40 days after sowing (DAS) in susceptible genotypes. There was a delay of at least 20 days in rust and late leaf spot

Table 23. Percentage leaf area damaged by rust in the 1983 rainy season.

Genotype	Percentage leaf area damaged by rust													
	40 DAS[1]		50 DAS		60 DAS		70 DAS		80 DAS		90 DAS		AUDPC[2]	
	I[3]	UI[4]	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI
PI 350680	0.00	0.00	0.05	0.00	0.16	0.02	0.77	0.13	2.21	0.64	1.85	1.12	4.12	1.35
EC 76446(292)	0.00	0.00	0.04	0.00	0.25	0.06	0.78	0.15	2.30	0.66	1.68	1.53	4.22	1.64
NC Ac 17127	0.28	0.00	0.96	0.10	3.97	0.47	4.81	1.59	8.77	3.94	4.87	5.86	21.09	9.04
NC Ac 17129	0.29	0.00	1.08	0.07	4.02	0.59	4.43	1.76	8.61	4.10	4.86	5.70	20.71	9.38
TMV 2	0.65	0.09	2.86	0.92	12.93	2.36	7.90	4.28	3.35	7.75	2.48	3.44	28.61	17.05
Robut 33-1	0.65	0.09	2.70	0.97	14.03	2.14	8.31	3.95	4.42	8.87	2.72	3.86	31.42	17.91
SE	±0.02		±0.18		±0.48		±0.46		±0.57		±0.45		±1.20	
CV(%)	18.9		37.7		24.3		24.4		21.4		23.3		15.0	

1. Days after sowing
2. Area Under Disease Progress Curve
3. Inoculated
4. Uninoculated

Table 24. Percentage leaf area damaged by late leaf spot in the 1983 rainy season.

Genotype	Percentage leaf area damaged by late leaf spot													
	40 DAS[1]		50 DAS		60 DAS		70 DAS		80 DAS		90 DAS		AUDPC[2]	
	I[3]	UI[4]	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI
PI 350680	0.00	0.00	0.06	0.00	0.45	0.12	1.77	0.27	3.06	1.90	1.19	1.08	5.95	2.84
EC 76446(292)	0.00	0.00	0.05	0.00	0.52	0.11	2.00	0.33	3.05	1.82	1.16	1.03	6.20	2.80
NC Ac 17127	0.08	0.00	0.29	0.07	1.91	0.56	4.06	0.96	5.10	3.44	2.34	0.81	12.57	5.44
NC Ac 17129	0.07	0.00	0.24	0.05	2.12	0.40	4.14	1.09	5.29	3.57	2.29	0.86	12.99	5.55
TMV 2	0.25	0.06	1.53	0.36	6.27	3.05	10.34	7.12	5.49	10.65	2.60	2.60	25.06	22.51
Robut 33-1	0.25	0.05	1.60	0.28	5.76	2.51	8.92	6.87	5.70	9.53	2.76	2.09	23.48	20.26
SE	±0.02		±0.15		±0.39		±0.59		±0.45		±0.31		±0.63	
CV(%)	43.7		68.9		34.5		25.5		16.0		30.8		9.0	

1. Days after sowing
2. Area Under Disease Progress Curve
3. Inoculated
4. Uninoculated

appearance in resistant genotypes and a delay of 10 days in moderately resistant genotypes in uninoculated plots. The onset of both diseases was also delayed in inoculated plots of resistant genotypes (Tables 23 and 24).

The defoliation started earlier in inoculated plots than in uninoculated plots of resistant and moderately resistant genotypes. However, defoliation started at the same time in all genotypes in inoculated plots. Percentage defoliation was much higher in susceptible genotypes than in resistant and moderately resistant genotypes. These differences in percentage defoliation between inoculation treatments and genotypes were consistant throughout the experimental period. The AUDPC for defoliation was greater in inoculated plots. The resistant and moderately resistant genotypes showed lower AUDPC values than susceptible genotypes (Table 26).

The percentage total disease was significantly lower in resistant and moderately resistant genotypes than in susceptible genotypes. Significant differences were also recorded between the two treatments. Inoculated plots showed more total disease than uninoculated plots (Table 27).

The early leaf spot development was severe in the 1983 rainy season (Table 25). There were no consistant varietal differences in severity of early leaf spot since all the test genotypes are susceptible to the disease.

Table 25. Percentage leaf area damaged by early leaf spot in the 1983 rainy season.

Genotype	Percentage leaf area damaged by early leaf spot													
	40 DAS[1]		50 DAS		60 DAS		70 DAS		80 DAS		90 DAS		AUDPC[2]	
	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI
PI 350680	0.08	0.08	0.76	0.77	2.90	2.65	3.32	3.12	3.14	3.85	2.20	1.97	11.3	11.5
EC 76446(292)	0.06	0.12	0.69	0.36	3.41	1.86	3.88	2.77	4.96	5.50	1.28	1.90	13.7	11.6
NC Ac 17127	0.15	0.10	1.55	0.34	3.29	1.96	3.58	2.37	3.47	3.25	2.35	2.10	13.2	9.1
NC Ac 17129	0.14	0.14	0.78	1.12	3.39	2.57	4.24	3.12	4.23	3.66	2.55	1.61	14.1	11.4
TMV 2	0.20	0.26	0.82	1.02	3.64	4.06	6.69	7.73	1.91	3.47	0.94	1.76	13.7	17.4
Robut 33-1	0.14	0.16	1.25	1.05	3.70	2.21	4.46	3.03	5.62	4.60	1.57	1.90	15.9	12.0
SE	±0.03		±0.18		±0.21		±0.42		±0.34		±0.38		±3.82	
CV(%)	40.5		35.7		12.2		18.1		14.6		35.7		4.8	

1. Days after sowing
2. Area Under Disease Progress Curve
3. Inoculated
4. Uninoculated

Table 26. Percentage defoliation in the 1983 rainy season.

Genotype	Percentage defoliation													
	40 DAS[1]		50 DAS		60 DAS		70 DAS		80 DAS		90 DAS		AUDPC[2]	
	I[3]	UI[4]	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI
PI 350680	0.00	0.00	1.32	0.00	22.39	11.23	41.19	23.40	56.75	46.45	75.09	70.05	159.3	116.1
EC 76446(292)	0.00	0.00	1.81	0.00	24.47	11.73	43.87	23.68	59.31	48.36	75.68	70.72	167.4	119.2
NC Ac 17127	0.00	0.00	4.80	0.00	23.97	17.59	43.62	31.67	65.62	49.54	83.61	73.20	179.9	135.5
NC Ac 17129	0.00	0.00	4.21	0.00	25.90	17.98	43.56	31.59	64.61	49.51	80.83	73.45	178.8	135.9
TMV 2	0.00	0.00	8.73	4.76	34.42	31.55	59.75	43.72	78.91	66.23	92.67	87.71	228.2	190.1
Robut 33-1	0.00	0.00	7.51	4.24	33.90	30.75	57.79	43.25	76.96	65.55	90.81	86.13	221.6	186.7
SE			±1.06		±2.14		±2.70		±3.04		±2.22		±4.21	
CV(%)			58.8		15.5		11.7		8.7		4.8		4.3	

1. Days after sowing
2. Area Under Disease Progress Curve
3. Inoculated
4. Uninoculated

Table 27. Percentage total disease in the 1983 rainy season.

Genotype	Percentage total disease													
	40 DAS[1]		50 DAS		60 DAS		70 DAS		80 DAS		90 DAS		AUDPC[2]	
	I[3]	UI[4]	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI
PI 350680	0.08	0.08	2.19	0.78	25.11	13.67	44.65	26.10	60.34	49.84	76.42	71.23	170.6	126.1
EC 76446(292)	0.06	0.12	2.58	0.38	27.59	13.53	47.60	26.16	63.52	52.49	76.70	72.01	179.7	128.7
NC Ac 17127	0.52	0.12	7.47	0.52	30.93	20.26	50.62	35.04	71.55	54.93	85.19	75.55	203.5	148.4
NC Ac 17129	0.51	0.14	6.23	1.24	32.92	20.90	50.73	35.69	71.03	55.24	82.66	75.65	202.6	151.4
TMV 2	1.09	0.42	13.48	6.68	49.33	38.04	69.85	59.40	81.19	80.61	93.11	88.70	261.0	217.5
Robut 33-1	1.05	0.30	12.64	6.44	49.62	35.47	66.95	51.18	73.54	73.48	91.46	87.19	256.1	210.4
SE	±0.03		±1.17		±1.97		±2.55		±2.72		±2.11		±3.88	
CV(%)	16.1		40.0		11.4		9.5		7.2		4.5		3.6	

1. Days after sowing
2. Area Under Disease Progress Curve
3. Inoculated
4. Uninoculated

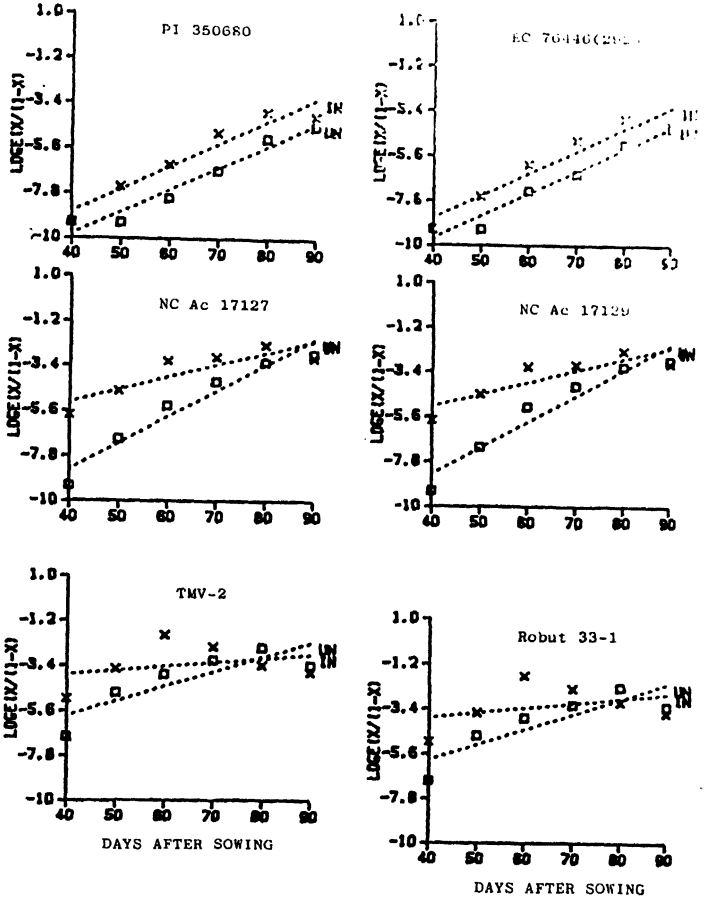


Fig. 1 : Rust development on six groundnut genotypes in inoculated and uninoculated plots during the 1983 rainy season at ICRISAT Center (See Table 29 for linear equations and correlation coefficients).

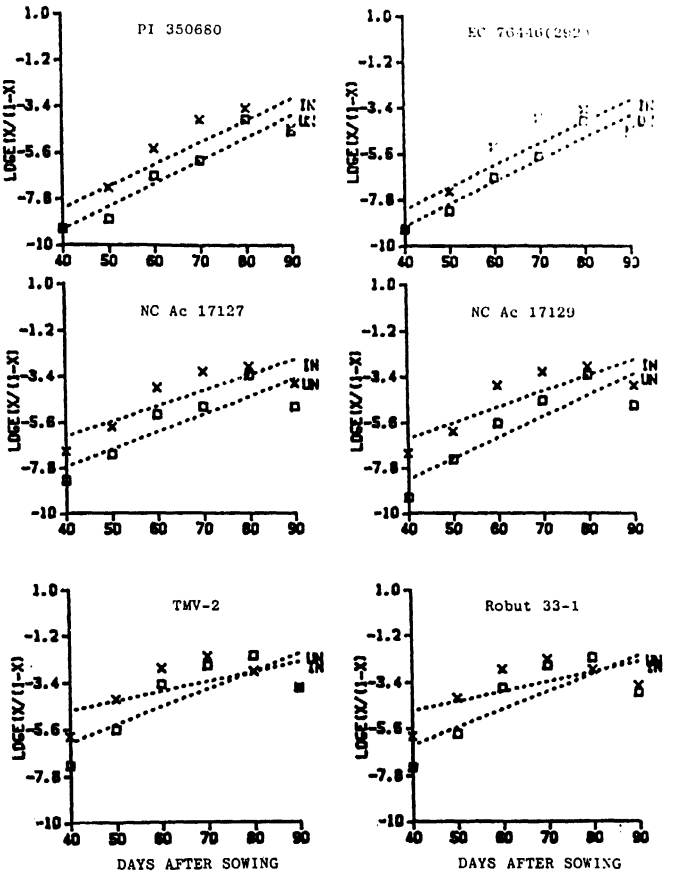


Fig. 2 : Late leaf spot development on six groundnut genotypes in inoculated and uninoculated plots during the 1983 rainy season at ICRISAT Center (See Table 29 for linear equations and correlation coefficients).

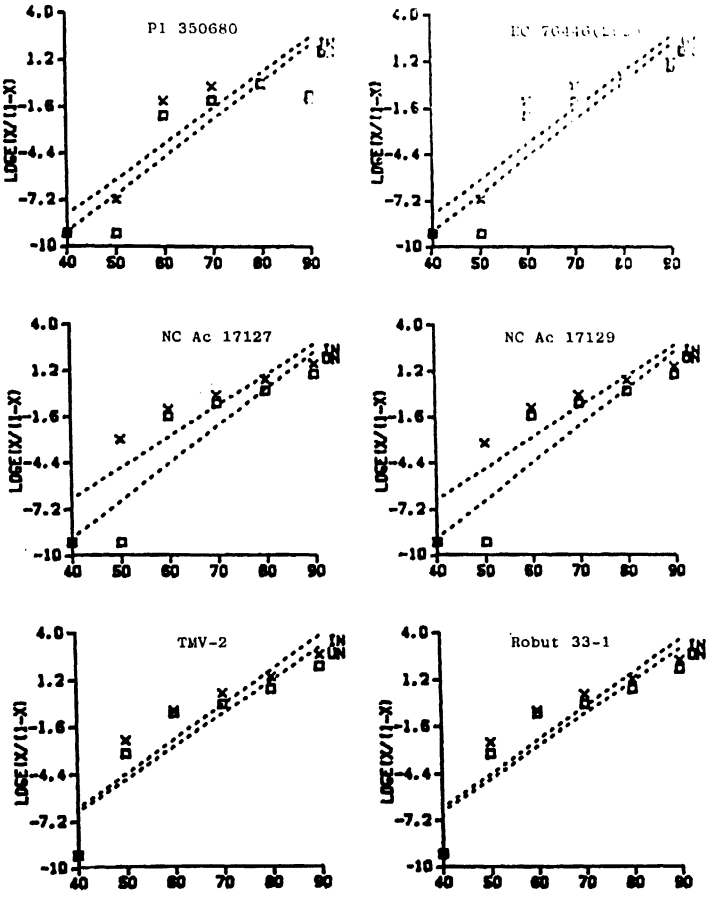


Fig. 3 : Defoliation due to foliar diseases on six groundnut genotypes in inoculated and uninoculated plots during the 1983 rainy season at ICRISAT Center (See Table 29 for linear equations and correlation coefficients).

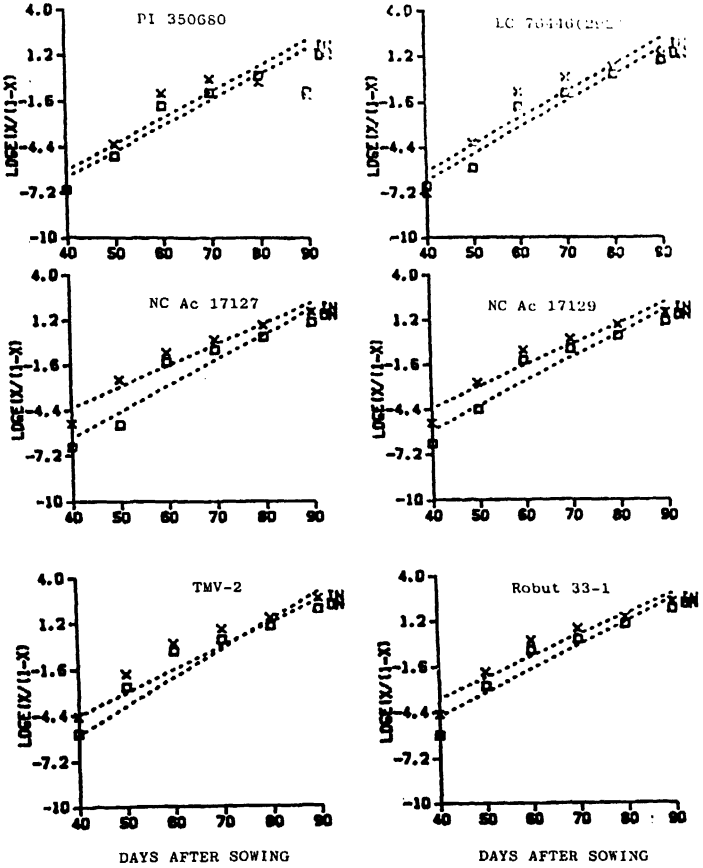


Fig. 4 : Total disease (rust, early leaf spot, late leaf spot and defoliation) development on six groundnut genotypes in inoculated and uninoculated plots during the 1983 rainy season at ICRISAT Center (See Table 29 for linear equations and correlation coefficients).

The apparent infection rate (r) was calculated between 40 and 90 DAS. The rate of rust development was higher in uninoculated plots of susceptible and moderately resistant genotypes than in inoculated plots (Table 28). However, there were no differences in the rate of rust development between inoculated and uninoculated plots of resistant genotypes (Table 28). Rust disease development was more rapid in resistant and moderately resistant than susceptible genotypes. In general, there were no marked differences in the rates of late leaf spot development, defoliation, and total disease, between inoculated and uninoculated plots (Table 28). The rate of late leaf spot development was higher in resistant genotypes than in moderately resistant and susceptible genotypes. There were no consistant varietal differences in the rate of defoliation and total disease development (Table 28).

There were significant varietal differences in delay in time (Δt) of rust and late leaf spot development between inoculated and uninoculated plots. There were no differences in Δt of all disease components between inoculated and uninoculated plots of resistant genotypes when measured at 40 DAS. However, at 90 DAS there were some differences in Δt between inoculated and uninoculated plots. The differences in Δt of rust and late leaf spot at 40 DAS were markedly higher in moderately resistant and susceptible genotypes. There were no differences in Δt of defoliation at 40 DAS. The delay in time of total disease was markedly higher at 40 DAS than at 90

Table 28: Apparent infection rates (r) of leaf area damage by rust, late leaf spot, defoliation and total disease in inoculated and uninoculated field plots in the 1983 rainy season at ICRISAT Center.

Genotype	Parameter	Apparent infection rate (r)	
		Inoculated	Uninoculated
PI 350680	% Rust	0.10	0.10
	% Late leaf spot	0.10	0.09
	% Defoliation	0.21	0.20
	% Total disease	0.16	0.16
Ec 76446(292)	% Rust	0.10	0.10
	% Late leaf spot	0.10	0.09
	% Defoliation	0.21	0.20
	% Total disease	0.17	0.15
NC Ac 17127	% Rust	0.06	0.13
	% Late leaf spot	0.07	0.07
	% Defoliation	0.22	0.20
	% Total disease	0.14	0.16
NC Ac 17129	% Rust	0.06	0.13
	% Late leaf spot	0.07	0.08
	% Defoliation	0.22	0.20
	% Total disease	0.14	0.15
TMV 2	% Rust	0.03	0.07
	% Late leaf spot	0.05	0.07
	% Defoliation	0.24	0.22
	% Total disease	0.15	0.15
Robut 33-1	% Rust	0.03	0.07
	% Late leaf spot	0.05	0.07
	% Defoliation	0.23	0.22
	% Total disease	0.14	0.15

Table 29: The linear equations and correlation coefficients of five disease components measured in inoculated and uninoculated field plots in the 1983 rainy season at ICRISAT Center.

Genotype	Disease component	Linear equation ($Y = r X + b$)[2]	Correlation coefficient (R)
PI 350680	% Rust		
	Inoculated	Y = .11 X - 13.13	.96**
	Uninoculated	Y = .10 X - 14.06	.97**
	% Early leaf spot		
	Inoculated	Y = .06 X - 8.16	.70
	Uninoculated	Y = .06 X - 8.15	.69
	% Late leaf spot		
	Inoculated	Y = .10 X - 12.45	.86*
	Uninoculated	Y = .10 X - 13.64	.93**
	% Defoliation		
	Inoculated	Y = .21 X - 16.19	.91*
	Uninoculated	Y = .22 X - 18.07	.90*
	% Total disease		
	Inoculated	Y = .16 X - 12.20	.93**
	Uninoculated	Y = .16 X - 12.56	.96**
EC 76446(292)	% Rust		
	Inoculated	Y = .11 X - 13.03	.95**
	Uninoculated	Y = .11 X - 14.05	.98**
	% Early leaf spot		
	Inoculated	Y = .06 X - 8.16	.58
	Uninoculated	Y = .06 X - 8.70	.79
	% Late leaf spot		
	Inoculated	Y = .10 X - 12.50	.85*
	Uninoculated	Y = .10 X - 13.34	.95**
	% Defoliation		
	Inoculated	Y = .21 X - 16.65	.90*
	Uninoculated	Y = .22 X - 18.10	.90*
	% Total disease		
	Inoculated	Y = .16 X - 12.38	.92**
	Uninoculated	Y = .16 X - 12.90	.96**

NC Ac 17127	% Rust		
	Inoculated	Y = .06 X - 7.60	.84*
	Uninoculated	Y = .13 X - 13.56	.96**
	% Early leaf spot		
	Inoculated	Y = .04 X - 7.03	.61
	Uninoculated	Y = .06 X - 8.57	.81
	% Late leaf spot		
	Inoculated	Y = .07 X - 9.23	.80
	Uninoculated	Y = .08 X - 11.12	.83*
	% Defoliation		
	Inoculated	Y = .19 X - 14.16	.87*
	Uninoculated	Y = .23 X - 18.05	.89*
	% Total disease		
	Inoculated	Y = .13 X - 9.54	.96**
	Uninoculated	Y = .16 X - 12.55	.94**
Nc Ac 17129	% Rust		
	Inoculated	Y = .06 X - 7.46	.84*
	Uninoculated	Y = .13 X - 13.56	.96**
	% Early leaf spot		
	Inoculated	Y = .05 X - 7.83	.72
	Uninoculated	Y = .04 X - 7.24	.61
	% Late leaf spot		
	Inoculated	Y = .07 X - 9.41	.79
	Uninoculated	Y = .10 X - 12.41	.85*
	% Defoliation		
	Inoculated	Y = .19 X - 14.19	.87*
	Uninoculated	Y = .23 X - 18.5	.89*
	% Total disease		
	Inoculated	Y = .13 X - 9.62	.95**
	Uninoculated	Y = .15 X - 11.76	.95**
TMV 2	% Rust		
	Inoculated	Y = .01 X = 4.59	=1
	Uninoculated	Y = .07 X - 8.67	.81
	% Early leaf spot		
	Inoculated	Y = .03 X - 6.40	.18
	Uninoculated	Y = .04 X - 6.58	.45
	% Late leaf spot		
	Inoculated	Y = .04 X - 6.61	.51
	Uninoculated	Y = .08 X - 9.60	.75
	% Defoliation		
	Inoculated	Y = .20 x - 14.62	.88*
	Uninoculated	Y = .19 x - 14.41	.88*

	% Total disease		
	Inoculated	Y = .13 X - 9.00	.96**
	Uninoculated	Y = .14 X - 10.10	.95**
Robut 33-1	% Rust		
	Inoculated	Y = .02 X - 4.75	-
	Uninoculated	Y = .07 X - 8.84	.82
	% Early leaf spot		
	Inoculated	Y = .04 X - 7.13	.51
	Uninoculated	Y = .05 X - 7.53	.72
	% Late leaf spot		
	Inoculated	Y = .04 X - 6.68	.55
	Uninoculated	Y = .08 X - 9.78	.74
	% defoliation		
	Inoculated	Y = .20 X - 14.41	.87*
	Uninoculated	Y = .19 X - 14.35	.88*
	% Total disease		
	Inoculated	Y = .13 x - 8.78	.95**
	Uninoculated	Y = .14 X - 10.42	.95**

1. Residual varience exceeded varience of Y-variate

2. r = Van der Plank's term for the slope of the linear regression line

Table 46: Delay in disease onset (Δt) between inoculated and uninoculated plots in the 1983 and 1984 rainy and 1983-84 and 1984-85 postrainy seasons at ICRISAT Center.

Genotype		Rainy season								Postrainy season							
		1983				1984				1983-84				1984-85			
		R[3]	LLS[4]	DEF[5]	TD[6]	R	LLS	DEF	TD	R	LLS	DEF	TD	R	LLS	DEF	TD
PI 350680	Initial[1]	0	0	0	0	0	40	0	32	0	0	0	0	0	0	0	0
	Final[2]	5	1	1	2	15	19	0	17	21	23	0	23	9	10	0	9
EC 76446(292)	Initial	0	0	0	3	0	41	0	33	0	0	0	0	0	0	0	0
	Final	1	1	1	2	13	16	0	14	42	28	0	37	35	17	0	21
NC Ac 17127	Initial	57	19	0	10	28	48	0	48	0	0	0	0	0	0	0	0
	Final	3	15	3	5	29	18	0	26	10	7	0	7	14	22	0	19
NC Ac 17129	Initial	57	20	0	9	27	51	0	49	0	0	0	0	0	0	0	0
	Final	3	13	2	4	29	19	0	26	8	5	0	6	19	28	0	24
TMV 2	Initial	61	27	0	7	45	29	0	31	0	0	0	0	0	0	0	0
	Final	11	1	3	4	16	21	62	23	11	6	0	9	24	20	0	18
Robut 33-1	Initial	63	29	0	9	44	30	0	32	0	0	0	0	0	0	0	0
	Final	11	1	3	4	16	21	62	23	11	11	0	11	23	14	0	12

1. Δt estimated at 40 days after inoculation
2. Δt estimated at 90 and 120 days after inoculation
3. Rust
4. Late leaf spot
5. Defoliation
6. Total disease

DAS for moderately resistant and susceptible genotypes (Table 46).

1983-84 Postrainy season: At the final time of observation there were statistically significant differences in disease developmental between the uninoculated and inoculated plots and among the genotypes (Tables 30,31 and 32 and Figs.5 to 7). The AUDPC for rust, late leaf spot, and total disease, were consistantly higher in inoculated than in uninoculated plots. There was no defoliation in any treatment during the 1983-84 postrainy season (Tables 30 to 32).

There was a strong varietal interaction on the onset of rust and late leaf spot diseases. The rust and late leaf spot diseases appeared at 50 and 60 DAS in inoculated plots of both susceptible genotypes. There was a 20-day delay in the onset of rust and a 10-day delay in the onset of late leaf spot in uninoculated plots of susceptible genotypes. There were delays of over 30 and over 60 days in the onset of rust on moderately resistant and resistant genotypes in inoculated plots. The delay was about 40 and 60 days in the case of late leaf spot in inoculated plots of moderately resistant and resistant genotypes (Tables 30 and 31).

The percentage total disease was significantly lower in resistant and moderately resistant genotypes than in susceptible genotypes. Inoculated plots showed more total disease than uninoculated plots (Table 32).

The apparent infection rate (r) was calculated between 40

Table 30: Percentage leaf area damaged by rust in the 1983-84 postrainy season.

Genotype	Percentage leaf area damaged by rust																					
	40 DAS[1]		50 DAS		60 DAS		70 DAS		80 DAS		90 DAS		100 DAS		110 DAS		120 DAS		AUDPC[2]	
	I[3]	UI[4]	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI
PI 350680	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.04	0.00	0.15	0.06	0.11	0.03
EC 76446(292)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.13	0.00	0.23	0.04	0.32	0.02
NC Ac 17127	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.13	0.00	0.24	0.08	0.38	0.12	1.01	0.38	1.69	0.95	2.67	1.06
NC Ac 17129	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.12	0.00	0.19	0.05	0.30	0.09	0.99	0.45	1.66	1.06	2.49	1.13
TMV 2	0.00	0.00	0.05	0.00	0.15	0.00	0.29	0.00	0.47	0.07	1.92	1.20	1.90	0.52	3.84	1.05	5.26	2.31	10.28	3.01
Robut 33-1	0.00	0.00	0.06	0.00	0.16	0.00	0.30	0.00	0.50	0.08	1.01	0.20	1.87	0.48	3.90	0.98	5.26	2.33	10.44	2.91
SE			±0.003		±0.01		±0.01		±0.02		±0.03		±0.09		±0.12		±0.18		±0.29	
CV(%)			63.2		59.7		33.6		30.8		22.0		32.5		21.0		17.9		16.4	

1. Days after sowing
2. Area Under Disease Progress Curve
3. Inoculated
4. Uninoculated

Table 31: Percentage leaf area damaged by late leaf spot in the 1983-84 postrainy season.

Genotype	Percentage leaf area damaged by late leaf spot																			
	40 DAS[1]		50 DAS		60 DAS		70 DAS		80 DAS		90 DAS		100 DAS		110 DAS		120 DAS		AUDPC[2]	
	I[3]	UI[4]	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI
PI 350680	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.03	0.00	0.05	0.02	0.16	0.06	0.18	0.05
EC 76446(292)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.08	0.01	0.16	0.05	0.19	0.04
NC Ac 17127	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.05	0.03	0.10	0.08	0.29	0.25	0.64	0.46	0.80	0.59
NC Ac 17129	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.06	0.04	0.12	0.08	0.27	0.22	0.63	0.47	0.80	0.58
TMV 2	0.00	0.00	0.00	0.00	0.03	0.00	0.07	0.00	0.12	0.04	0.23	0.11	0.54	0.22	1.19	0.59	2.21	1.54	3.30	1.74
Robut 33-1	0.00	0.00	0.00	0.00	0.03	0.00	0.06	0.00	0.12	0.05	0.22	0.10	0.54	0.21	1.09	0.53	2.34	1.07	3.23	1.42
SE					±0.001		±0.002		±0.01		±0.02		±0.02		±0.05		±0.12		±0.08	
CV(%)					63.2		61.6		45.1		38.6		23.2		22.9		25.0		13.5	

1. Days after sowing
2. Area Under Disease Progress Curve
3. Inoculated
4. Uninoculated

Table 32: Percentage total disease in the 1983-84 postrainy season.

Genotype	Percentage total disease																					
	40 DAS[1]		50 DAS		60 DAS		70 DAS		80 DAS		90 DAS		100 DAS		110 DAS		120 DAS		AUDPC[2]	
	I[3]	UI[4]	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI
PI 350680	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.04	0.00	0.09	0.02	0.32	0.12	0.29	0.08
EC 76446(292)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.22	0.01	0.40	0.09	0.50	0.05
NC Ac 17127	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.30	0.11	0.48	0.20	1.30	0.63	2.33	1.40	3.47	1.66
NC Ac 17129	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.26	0.09	0.43	0.17	1.26	0.67	2.29	1.53	3.29	1.70
TMV 2	0.00	0.00	0.05	0.00	0.18	0.00	0.36	0.00	0.60	0.13	1.16	0.31	2.45	0.75	5.04	1.64	7.47	3.85	13.58	4.75
Robut 33-1	0.00	0.00	0.06	0.00	0.18	0.00	0.36	0.00	0.63	0.13	1.23	0.30	2.41	0.70	4.99	1.51	7.60	3.40	13.67	4.33
SE	±0.003				±0.01		±0.01		±0.03		±0.04		±0.10		±0.14		±0.17		±0.28	
CV(%)	63.2				42.9		29.5		30.3		23.1		25.8		16.1		11.6		12.3	

1. Days after sowing
2. Area Under Disease Progress Curve
3. Inoculated
4. Uninoculated

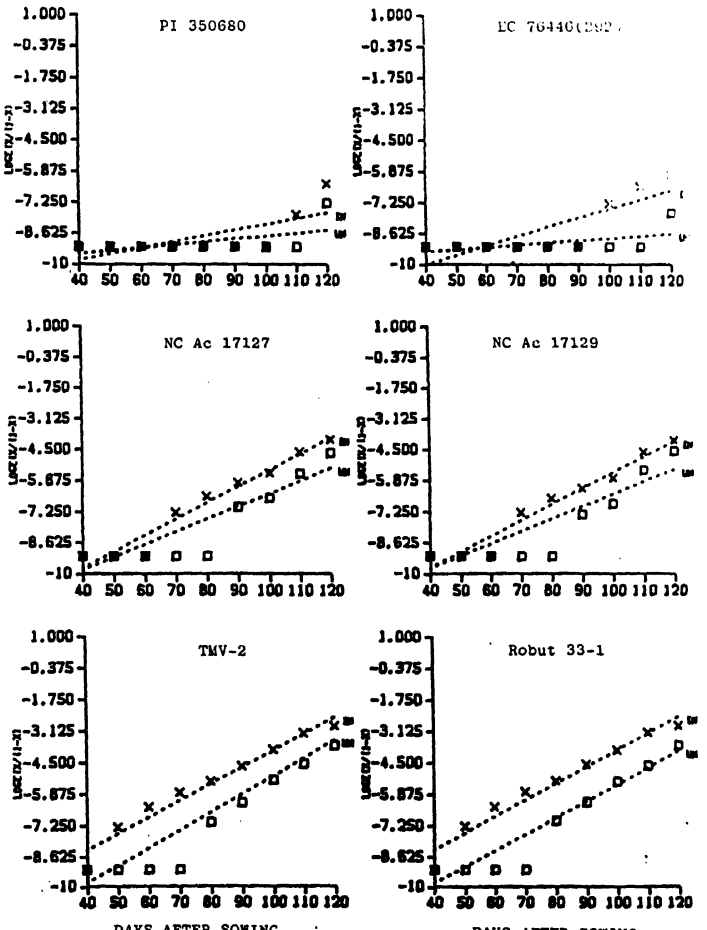


Fig. 5 : Rust development on six groundnut genotypes in inoculated and uninoculated plots during the 1983-84 postrainy season at ICRISAT Center (See Table 34 for linear equations and correlation coefficients).

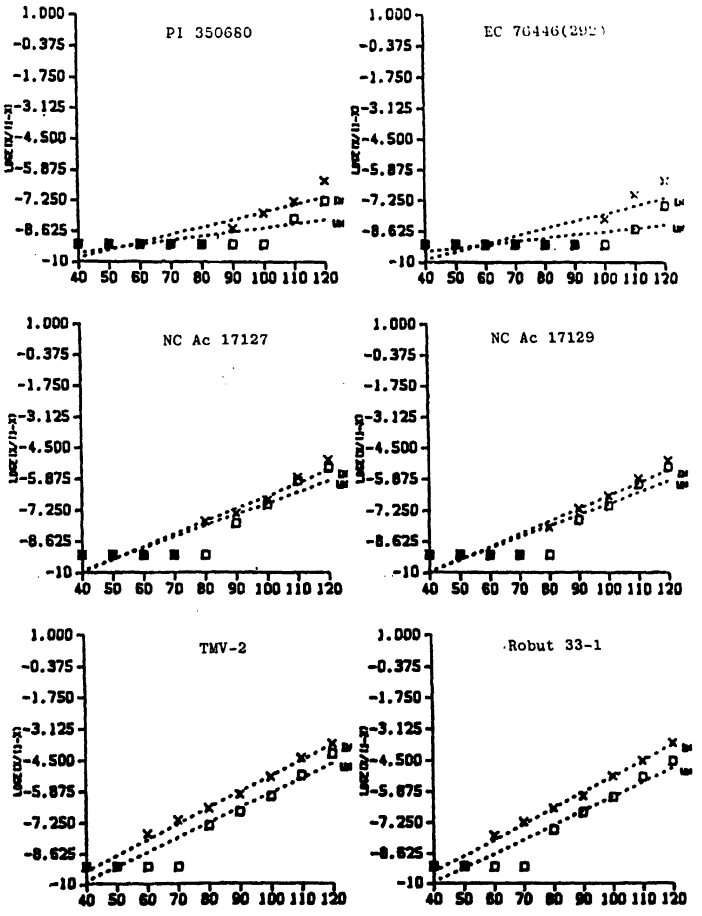


Fig. 6 : Late leaf spot development on six groundnut genotypes in inoculated and uninoculated plots during the 1983-84 post-rainy season at ICRISAT Center (See Table 34 for linear equations and correlation coefficients).

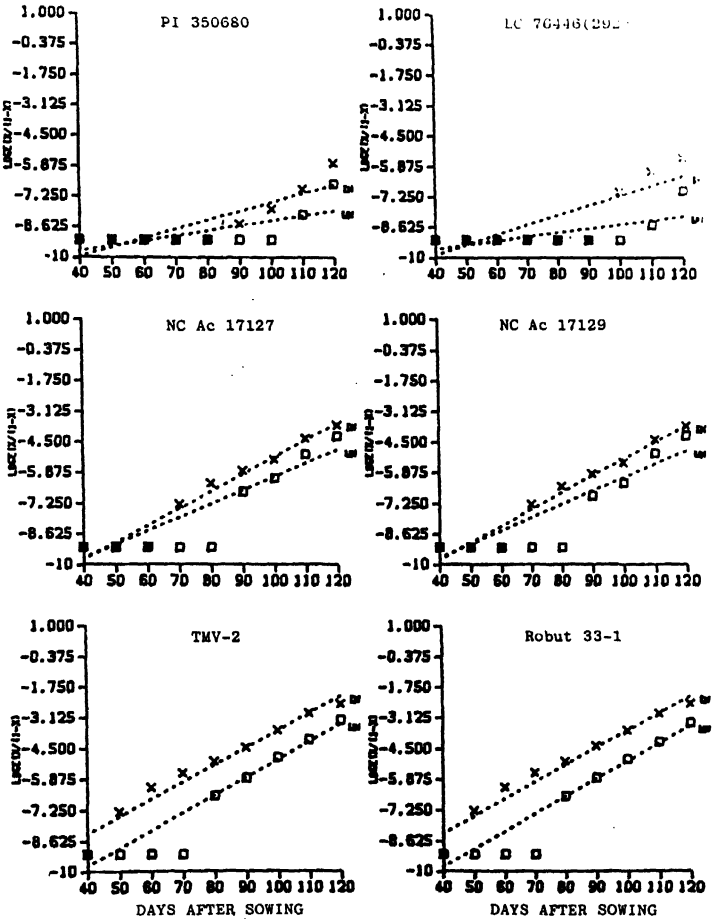


Fig. 7 : Total disease (rust and late leaf spot) development on six groundnut genotypes in inoculated and uninoculated plots during the 1983-84 postrainy season at ICRISAT Center (See Table 34 for linear equations and correlation coefficients).

and 120 DAS. It was usually greater in susceptible genotypes, followed by moderately resistant and resistant genotypes. There were no differences in r-values between the inoculated and uninoculated plots of susceptible and moderately resistant genotypes. The r-values of all disease components were higher in inoculated plots of resistant genotypes than in uninoculated plots. No marked differences were observed in the apparent infection rate (r) in rust, late leaf spot and total disease between inoculated and uninoculated plots (Table 33).

The delay in time (Δt) was initially zero for all genotypes and for rust, late leaf spot and total disease. The final Δt was more to resistant genotypes and was almost similar in moderately resistant and susceptible genotypes. The same trend has been observed for late leaf spot and total disease (Table 46).

1984 rainy season: At the final time of observation, statistically significant differences were observed in rust and late leaf spot development, defoliation and total disease between the inoculated and uninoculated plots (Tables 35,36,37 and 38 and Figs.8 to 11). The AUDPC for rust, late leaf spot, defoliation, and total disease were markedly higher in inoculated plots than in uninoculated plots for all genotypes (Tables 35 to 38).

The rust and late leaf spot diseases appeared at 40 DAS in susceptible and moderately resistant genotypes in

Table 33: Apparent infection rates (r) of leaf area damaged by rust, late leaf spot, and total disease in inoculated and uninoculated field plots in the 1983-84 postrainy season at ICRISAT Center.

Genotype	Parameter	Apparent infection rate (r)	
		Inoculated	Uninoculated
PI 350680	% Rust damage	0.04	0.02
	% Late leaf spot damage	0.04	0.02
	% Total disease	0.04	0.03
EC 76446(292)	% Rust damage	0.04	0.02
	% Late leaf spot damage	0.04	0.02
	% Total disease	0.04	0.03
NC Ac 17127	% Rust damage	0.06	0.06
	% Late leaf spot damage	0.05	0.05
	% Total disease	0.07	0.06
NC Ac 17129	% Rust damage	0.06	0.06
	% Late leaf spot damage	0.05	0.05
	% Total disease	0.07	0.06
TMV 2	% Rust damage	0.08	0.07
	% Late leaf spot damage	0.07	0.06
	% Total disease	0.08	0.07
Robut 33-1	% Rust damage	0.08	0.07
	% Late leaf spot damage	0.07	0.06
	% Total disease	0.08	0.07

Table 34: The linear equations and correlation coefficients of three disease components measured in inoculated and uninoculated field plots in the 1983-84 postrainy season at ICRISAT Center.

Genotype	Disease component	Linear equation (Y=rx+b)[1]	Correlation coefficient (R)
PI 350680	% Rust		
	Inoculated	Y = .03 X - 10.79	.66
	Uninoculated	Y = .01 X - 10.03	.45
	% Late leaf spot		
	Inoculated	Y = .03 X - 11.18	.88**
	Uninoculated	Y = .02 X - 10.35	.67*
	% Total disease		
	Inoculated	Y = .04 X - 11.57	.85**
	Uninoculated	Y = .02 X - 10.61	.65
EC 76446(292)	%Rust		
	Inoculated	Y = .04 X - 11.63	.82**
	Uninoculated	Y = .01 X - 9.85	.45
	% Late leaf spot		
	Inoculated	Y = .03 X - 11.23	.80**
	Uninoculated	Y = .01 X - 10.14	.63
	% Total disease		
	Inoculated	Y = .05 X - 12.02	.81**
	Uninoculated	Y = .02 X - 10.36	.61
NC Ac 17127	% Rust		
	Inoculated	Y = .07 X - 12.60	.97**
	Uninoculated	Y = .06 X - 12.65	.89**
	% Late leaf spot		
	Inoculated	Y = .06 X - 12.21	.94**
	Uninoculated	Y = .05 X - 12.15	.89**
	% Total disease		
	Inoculated	Y = .08 X - 12.83	.97**
	Uninoculated	Y = .07 X - 13.04	.90**
NC Ac 17129	% Rust		
	Inoculated	Y = .07 X - 12.55	.97**
	Uninoculated	Y = .06 X - 12.69	.89**
	% Late leaf spot		
	Inoculated	Y = .06 X - 12.25	.95**
	Uninoculated	Y = .05 X - 12.13	.89**

	% Total disease		
	Inoculated	Y = .08 X - 12.80	.98**
	Uninoculated	Y = .07 X - 13.06	.89**
TMV-2	% Rust		
	Inoculated	Y = .07 X - 11.25	.98**
	Uninoculated	Y = .08 X - 13.31	.95**
	% Late leaf spot		
	Inoculated	Y = .07 X - 12.24	.99**
	Uninoculated	Y = .07 X - 12.84	.95**
	% Total disease		
	Inoculated	Y = .08 X - 11.39	.98**
	Uninoculated	Y = .08 X - 13.68	.95**
Robut 33-1	% Rust		
	Inoculated	Y = .07 X - 11.23	.98**
	Uninoculated	Y = .08 X - 13.27	.95**
	% Late leaf spot		
	Inoculated	Y = .07 X - 12.29	.99**
	Uninoculated	Y = .07 X - 12.69	.95**
	% Total disease		
	Inoculated	Y = .08 X - 11.37	.98**
	Uninoculated	Y = .08 X - 13.59	.95**

1. r = Van der Plank's term for the slope of the linear regression line.

inoculated plots. There was a 10-day delay in the onset of late leaf spot in inoculated plots and over 30 and 40 day delay in rust in susceptible and moderately resistant genotypes in uninoculated plots. The onset of rust on resistant genotypes was delayed by 20 days in uninoculated plots. In uninoculated plots the rust and late leaf spot diseases were delayed by 50 and 20 days in resistant genotypes, respectively (Tables 35 and 36).

There was no defoliation in resistant and moderately resistant genotypes. Defoliation was recorded only in inoculated plots of susceptible genotypes (Table 37).

The percentage total disease was lower in uninoculated plots than in inoculated plots of all genotypes. It was greater in susceptible genotypes than in resistant and moderately resistant genotypes (Table 38).

Early leaf spot severity was negligible in this season, hence no data were collected.

The apparent infection rate (r) was calculated between 40 and 100 DAS. The rate of rust development was higher in uninoculated plots (0.10) than in inoculated plots (0.07) of susceptible genotypes. There was no marked difference in rate of rust development between resistant, moderately resistant and susceptible genotypes in inoculated plots (Table 39). However, in uninoculated plots the rate of rust development was markedly higher in susceptible genotypes

Table 35 : Percentage leaf area damaged by rust in the 1984 rainy season.

Genotypes	Percentage leaf area damaged by rust													
	40 DAS[1]		50 DAS		60 DAS		70 DAS		80 DAS		90 DAS		100 DAS		AUDPC[2]	
	I[3]	UI[4]	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI
PI 350680	0.00	0.00	0.01	0.00	0.04	0.00	0.07	0.00	0.15	0.00	0.25	0.05	0.34	0.13	0.71	0.12
EC 76446(292)	0.00	0.00	0.02	0.00	0.06	0.00	0.09	0.00	0.14	0.01	0.27	0.09	0.40	0.19	0.79	0.20
NC Ac 17127	0.06	0.00	0.13	0.00	0.19	0.00	0.39	0.00	0.53	0.03	1.22	0.15	3.80	0.50	4.40	0.43
NC Ac 17129	0.06	0.00	0.11	0.00	0.20	0.00	0.34	0.00	0.65	0.03	1.82	0.22	3.90	0.52	5.12	0.51
TMV 2	0.22	0.00	0.45	0.00	0.66	0.00	1.15	0.03	2.41	0.09	10.58	2.18	13.77	4.82	22.27	4.72
Robut 33-1	0.20	0.00	0.41	0.00	0.62	0.00	1.14	0.02	2.48	0.11	9.63	2.21	12.71	4.51	20.76	4.62
SE	±0.01		±0.02		±0.02		±0.07		±0.21		±0.47		±0.62		±1.01	
CV (%)	44.8		37.9		28.0		48.8		57.4		37.1		31.1		32.6	

1. Days after sowing
2. Area Under Disease Progress Curve
3. Inoculated
4. Uninoculated

Table 36: Percentage leaf area damaged by late leaf spot in 1984 rainy season.

Genotypes	Percentage leaf area damaged by late leaf spot																	
	40 DAS[1]		50 DAS		60 DAS		70 DAS		80 DAS		90 DAS		100 DAS		AUDPC[2]	
	I[3]	UI[4]	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI
PI 350680	0.00	0.00	0.10	0.00	0.11	0.06	0.16	0.10	0.21	0.12	0.33	0.14	0.54	0.26	1.22	0.59
EC 76446(292)	0.00	0.00	0.12	0.00	0.14	0.05	0.19	0.09	0.23	0.11	0.33	0.15	0.62	0.33	1.35	0.61
NC Ac 17129	0.10	0.00	0.23	0.04	0.27	0.07	0.35	0.13	0.63	0.21	0.95	0.26	2.11	0.84	3.55	1.14
NC Ac 17129	0.12	0.00	0.23	0.04	0.30	0.08	0.35	0.15	0.51	0.20	1.04	0.33	2.43	0.93	3.73	1.29
TMV 2	0.19	0.00	0.34	0.09	0.44	0.20	0.83	0.28	1.14	0.35	2.63	0.58	4.34	1.50	7.66	2.29
Robut 33-1	0.17	0.00	0.32	0.09	0.46	0.19	0.65	0.23	1.07	0.34	2.53	0.54	4.21	1.44	7.28	2.14
SE	±0.01		±0.03		±0.05		±0.06		±0.18		±0.22		±0.21		±0.35	
CV (%)	25.6		35.0		22.6		24.2		34.5		11.0		21.1		22.1	

1. Days after sowing
2. Area Under Disease Progress Curve
3. Inoculated
4. Uninoculated

Table 37: Percentage defoliation in 1984 rainy season.

Genotypes	Percentage defoliation															
	40 DAS[1]		50 DAS		60 DAS		70 DAS		80 DAS		90 DAS		100 DAS		AUDPC[2]	
	I[3]	UI[4]	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI
PI 350680	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EC 76446(292)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC Ac 17127	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC Ac 17129	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TMV 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.99	0.00	4.46	0.00	13.81	0.00	13.36	0.00
Robut 33-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.17	0.00	5.71	0.00	5.02	0.00
SE									±0.03		±0.24		±0.49		±0.52	
CV(%)									28.0		77.8		55.7		58.7	

1. Days after sowing
2. Area Under Disease Progress Curve
3. Inoculated
4. Uninoculated

Table 38: Percentage total disease in 1984 rainy season.

Genotypes	Percentage total disease															
	40 DAS[1]		50 DAS		60 DAS		70 DAS		80 DAS		90 DAS		100 DAS		AUDPC[2]	
	I[3]	UI[4]	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI
PI 350680	0.00	0.00	0.11	0.00	0.16	0.06	0.24	0.10	0.37	0.12	0.58	0.20	0.88	0.39	1.93	0.70
EC 76446(292)	0.00	0.00	0.14	0.00	0.20	0.05	0.28	0.09	0.37	0.11	0.60	0.25	1.03	0.52	2.13	9.81
NC Ac 17127	0.16	0.00	0.36	0.04	0.47	0.07	0.74	0.13	1.16	0.24	2.18	0.41	5.91	1.34	7.96	1.57
NC Ac 17129	0.18	0.00	0.35	0.04	0.51	0.08	0.70	0.15	1.17	0.23	2.86	0.56	6.33	1.45	8.85	1.80
TMV 2	0.41	0.03	0.79	0.09	1.11	0.20	1.98	0.31	5.48	0.45	17.08	2.76	29.39	6.32	41.35	7.01
Robut 33-1	0.38	0.03	0.74	0.09	1.08	0.19	1.79	0.26	3.56	0.45	14.11	2.76	21.63	5.99	32.31	6.76
SE	±0.02		±0.04		±0.04		±0.09		±0.23		±0.69		±1.00		±1.46	
CV(%)	28.8		27.4		19.1		27.0		31.5		34.5		27.4		26.9	

1. Days after sowing
2. Area Under Disease Progress Curve
3. Inoculated
4. Uninoculated

Table 39: Apparent infection rates (r) of leaf area damaged by rust, late leaf spot, defoliation and total disease in inoculated and uninoculated field plots in the 1984 rainy season at ICRISAT Center.

Genotype	Parameter	Apparent infection rate (r)	
		Inoculated	Uninoculated
PI 350680	% Rust damage	0.06	0.05
	% Late leaf spot damage	0.04	0.05
	% Defoliation	0.00	0.00
	% Total disease	0.05	0.06
EC 76446(292)	% Rust damage	0.06	0.05
	% Late leaf spot damage	0.04	0.06
	% Defoliation	0.00	0.00
	% Total disease	0.05	0.06
NC Ac 17127	% Rust damage	0.07	0.07
	% Late leaf spot damage	0.05	0.07
	% Defoliation	0.00	0.00
	% Total disease	0.06	0.08
NC Ac 17129	% Rust damage	0.07	0.07
	% Late leaf spot damage	0.05	0.07
	% Defoliation	0.00	0.00
	% Total disease	0.06	0.08
TMV 2	% Rust damage	0.07	0.10
	% Late leaf spot damage	0.05	0.06
	% Defoliation	0.12	0.00
	% Total disease	0.08	0.09
Robut 33-1	% Rust damage	0.07	0.10
	% Late leaf spot damage	0.05	0.06
	% Defoliation	0.10	0.00
	% Total disease	0.07	0.08

Table 40: The linear equations and correlation coefficients of four disease components measured in inoculated and uninoculated field plots in the 1984 rainy season at ICRISAT Center.

Genotype	Disease component	Linear equation (Y= r x + b)[1]	Correlation coefficient (R)
PI 350680	% Rust		
	Inoculated	Y = .06 X - 11.32	.98**
	Uninoculated	Y = .04 X - 11.44	.75
	% Late leaf spot		
	Inoculated	Y = .04 X - 8.87	.98**
	Uninoculated	Y = .05 X - 10.52	.93**
	% Total disease		
	Inoculated	Y = .04 X - 9.17	.98**
	Uninoculated	Y = .05 X - 10.87	.96**
EC 76446(292)	% Rust		
	Inoculated	Y = .06 X - 11.20	.98**
	Uninoculated	Y = .05 X - 11.92	.84*
	% Late leaf spot		
	Inoculated	Y = .03 X - 8.71	.96**
	Uninoculated	Y = .05 X - 10.90	.96**
	% Total disease		
	Inoculated	Y = .04 X - 8.99	.97**
	Uninoculated	Y = .06 X - 11.34	.98**
NC Ac 17127	% Rust		
	Inoculated	Y = .06 X - 9.82	.98**
	Uninoculated	Y = .06 X - 12.73	.86*
	% Late leaf spot		
	Inoculated	Y = .04 X - 8.54	.98**
	Uninoculated	Y = .06 X - 11.10	.95**
	% Total disease		
	Inoculated	Y = .05 X - 8.53	.98**
	Uninoculated	Y = .07 X - 11.57	.97**
Nc Ac 17129	% Rust		
	Inoculated	Y = .07 X - 10.13	.99**
	Uninoculated	Y = .07 X - 12.89	.86*
	% Late leaf spot		
	Inoculated	Y = .04 X - 8.40	.96**
	Uninoculated	Y = .06 X - 11.18	.96**

	% Total disease		
	Inoculated	Y= .05 X - 8.63	.98**
	Uninoculated	Y = .07 X - 11.66	.97**
TMV 2	% Rust		
	Inoculated	Y = .07 X - 9.22	.97**
	Uninoculated	Y = .11 X - 14.97	.92**
	% Late leaf spot		
	Inoculated	Y = .05 X - 8.37	.99**
	Uninoculated	Y = .05 X - 9.76	.97**
	% Defoliation		
	Inoculated	Y = .14 x - 16.32	.88
	% Total disease		
	Inoculated	Y = .08 X - 8.91	.98**
	Uninoculated	Y = .08 X - 11.22	.97**
Robut 33-1	% Rust		
	Inoculated	Y = .07 X - 9.24	.98**
	Uninoculated	Y = .11 X - 14.98	.91**
	% Late leaf spot		
	Inoculated	Y = .05 X - 8.43	.99**
	Uninoculated	Y = .05 X - 9.67	.98**
	% defoliation		
	Inoculated	Y = .10 X - 14.95	.75
	% Total disease		
	Inoculated	Y = .07 x - 8.63	.97**
	Uninoculated	Y = .08 X - 11.15	.97**

1. r = Van der Plank's term for the slope of the linear regression line.

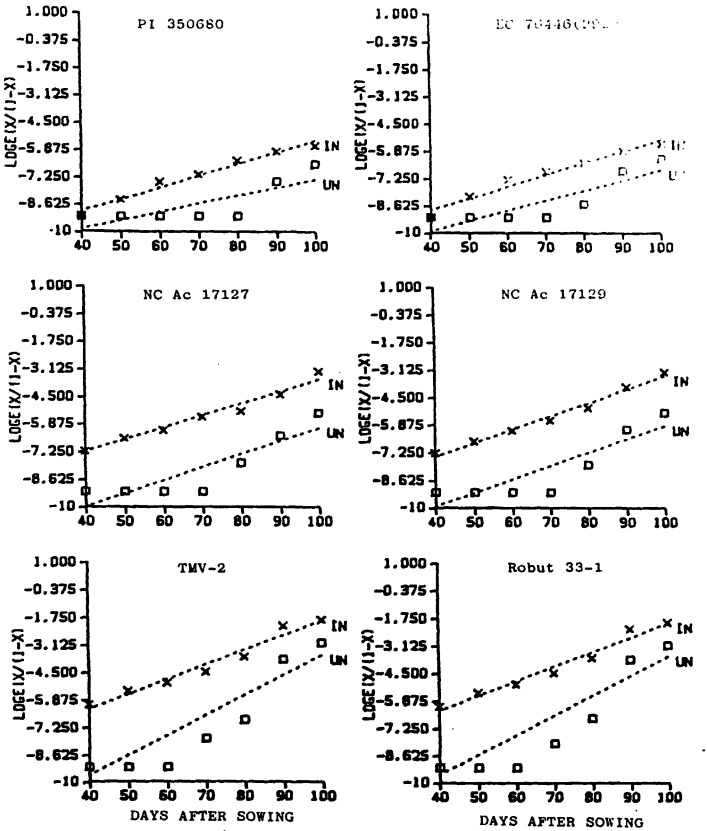


Fig. 8 : Rust development on six groundnut genotypes in inoculated and uninoculated plots during the 1984 rainy season at ICRISAT Center (See Table 40 for linear equations and correlation coefficients).

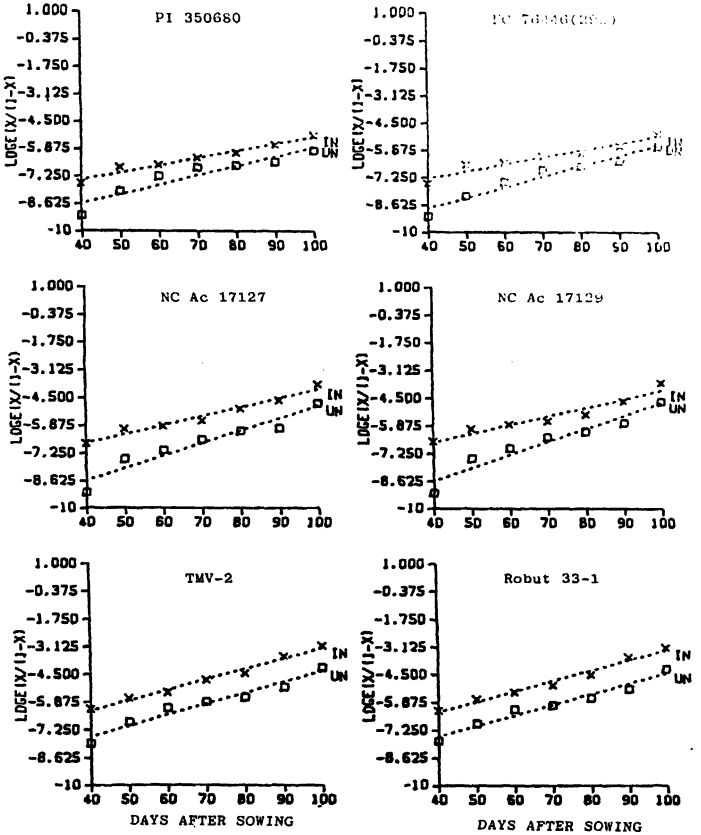


Fig. 9 : Late leaf spot development on six groundnut genotypes in inoculated and uninoculated plots during the 1984 rainy season at ICRISAT Center (See Table 40 for linear equations and correlation coefficients).

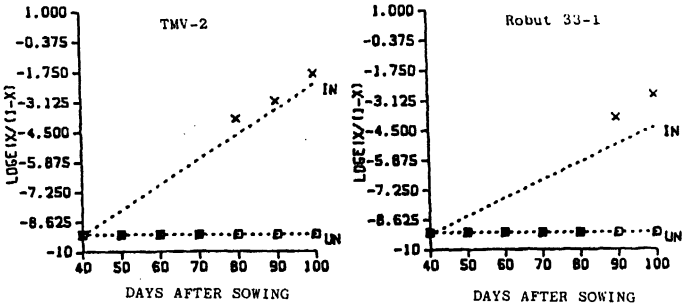


Fig. 10 : Defoliation due to foliar diseases on two groundnut genotypes in inoculated and uninoculated plots during the 1984 rainy season at ICRISAT Center (See Table 40 for linear equations and correlation coefficients).

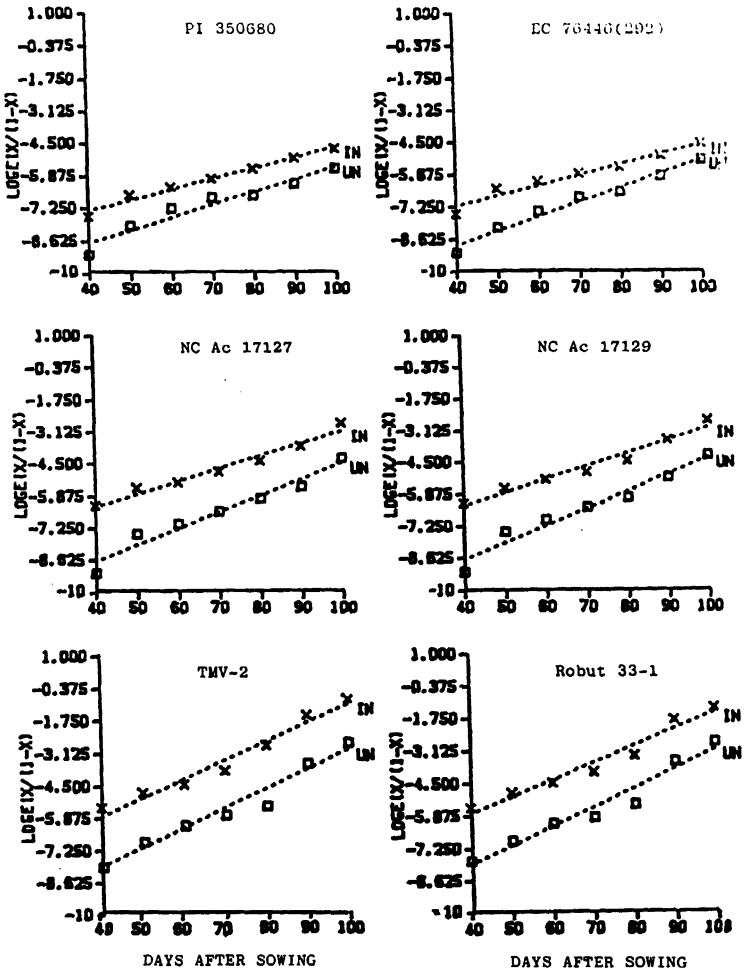


Fig. 11 : Total disease (rust, late leaf spot and defoliation) development on six groundnut genotypes in inoculated and uninoculated plots during the 1984 rainy season at ICRISAT Center (See Table 40 for linear equations and correlation coefficients).

than in moderately resistant and resistant genotypes. The rate of late leaf spot and total disease development was slightly more in uninoculated plots than in inoculated plots of all genotypes. However, the differences in rate of late leaf spot and total disease development were not consistant between the genotypes.

The delay in time (Δt) initially was zero for resistant genotypes in the case of rust the initial Δt in susceptible was more than in moderately resistant genotypes. The final Δt was almost the same in resistant and susceptible genotypes. The initial Δt for late leaf spot was greater in moderately resistant genotypes followed by resistant and susceptible genotypes. There was over 3-7 days variation in the final Δt between resistant, moderately resistant and susceptible genotypes. The final Δt for defoliation was highest for susceptible genotypes. In general, the initial delay in time (Δt) for total disease was usually more in moderately resistant genotypes than in resistant and susceptible genotypes. The final Δt was less in resistant genotypes and more or less same in moderately resistant and susceptible genotypes (Table 46).

1984-85 Postrainy Season: At the final time of observation, the percentage leaf area damaged from rust, late leaf spot, and total disease were higher in inoculated plots than in uninoculated plots (Tables 41,42 and 43 and Figs. 12 to 14). The AUDPC for rust, late leaf spot, and total disease was consistantly higher in inoculated plots than in uninoculated plots for all the genotypes (Tables 41,42 and 43). There

was no defoliation in any of the treatments.

The rust and late leaf spot diseases appeared at 80 DAS in inoculated plots in susceptible genotypes. There was about 20 days delay in the onset of both the diseases in uninoculated plots of susceptible genotypes. The rust and late leaf spot diseases appeared at 90 and 100 DAS in inoculated plots of moderately resistant and resistant genotypes, respectively. The onset of these diseases were at 110 and 120 DAS in uninoculated plots (Tables 41 and 42).

There were differences in total disease between the inoculated and uninoculated plots for all genotypes (Table 43).

In general, the apparant infection rates of rust, late leaf spot and total disease were slightly more in the inoculated plots than in the uninoculated plots. The rate of development of rust, late leaf spot total disease and were more rapid in susceptible genotypes than in resistant and moderately resistant genotypes (Table 44).

The delay in time (Δt) initially was zero for rust, late leaf spot and total disease for all the genotypes. The final delay in time (Δt) for rust was highest in EC 76446(292) lowest in PI 350680 and were greater in susceptible genotypes than in moderately resistant genotypes. In the case of late leaf spot, Δt for total disease was greater in moderately resistant genotypes, followed by susceptible and resistant genotypes. The Δt was more or less the same in moderately resistant genotypes

Table 41: Percentage leaf area damaged by rust in the 1984-85 postrainy season.

Genotype	Percentage leaf area damaged by rust																					
	40 DAS[1]		50 DAS		60 DAS		70 DAS		80 DAS		90 DAS		100 DAS		110 DAS		120 DAS		AUDPC[2]	
	I[3]	UI[4]	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI
PI 350688	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.05	0.04	0.04	0.02
EC 76446(292)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.05	0.02	0.04	0.01
NC Ac 17127	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.04	0.00	0.07	0.04	0.15	0.08	0.20	0.08
NC Ac 17129	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.05	0.00	0.08	0.02	0.16	0.07	0.22	0.06
TMV 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.05	0.00	0.19	0.03	0.35	0.08	0.57	0.17	0.90	0.20
Robut 33-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.09	0.00	0.22	0.04	0.42	0.07	0.60	0.18	1.07	0.20

1. Days after sowing
2. Area Under Disease Progress Curve
3. Inoculated
4. Uninoculated

Table 42: Percentage leaf area damaged by late leaf spot in the 1984-85 postrainy season.

Genotype	Percentage leaf area damaged by late leaf spot																			
	40 DAS[1]		50 DAS		60 DAS		70 DAS		80 DAS		90 DAS		100 DAS		110 DAS		120 DAS		AUDPC[2]	
	I[3]	UI[4]	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI
PI 350680	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.03	0.00	0.07	0.05	0.08	0.03
EC 76446(292)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.04	0.00	0.07	0.04	0.09	0.02
NC Ac 17127	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.04	0.00	0.08	0.03	0.18	0.07	0.23	0.07
NC Ac 17129	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.03	0.00	0.09	0.01	0.20	0.06	0.24	0.04
TMV 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.07	0.00	0.20	0.05	0.47	0.12	0.65	0.23	1.08	0.29
Robut 33-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.08	0.00	0.19	0.03	0.39	0.12	0.58	0.28	0.97	0.29

1. Days after sowing
2. Area Under Disease Progress Curve
3. Inoculated
4. Uninoculated

Table 43: Percentage total disease in the 1984-85 postrainy season.

Genotype	Percentage total disease																					
	40 DAS[1]		50 DAS		60 DAS		70 DAS		80 DAS		90 DAS		100 DAS		110 DAS		120 DAS		AUDPC[2]	
	I[3]	UI[4]	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI	I	UI
PI 350680	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.04	0.00	0.12	0.09	0.11	0.05
EC 76446(292)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.05	0.00	0.12	0.06	0.13	0.03
NC Ac 17127	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.08	0.00	0.15	0.07	0.33	0.15	0.43	0.15
NC Ac 17129	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.08	0.00	0.17	0.03	0.36	0.13	0.46	0.10
TMV 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.12	0.00	0.39	0.08	0.82	0.20	1.22	0.40	1.97	0.48
Robut 33-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.17	0.00	0.41	0.07	0.81	0.19	1.18	0.46	2.04	0.49

1. Days after sowing
2. Area Under Disease Progress Curve
3. Inoculated
4. Uninoculated

Table 44: Apparent infection rates (r) of leaf area damaged by rust, late leaf spot, and total disease in inoculated and uninoculated field plots in the 1984 rainy season at ICRISAT Center.

Genotype	Parameter	Apparent infection rate (r)	
		Inoculated	Uninoculated
PI 350680	% Rust damage	0.02	0.02
	% Late leaf spot damage	0.03	0.02
	% Total disease	0.03	0.03
EC 76446(292)	% Rust damage	0.02	0.01
	% Late leaf spot damage	0.03	0.02
	% Total disease	0.03	0.02
NC Ac 17127	% Rust damage	0.04	0.03
	% Late leaf spot damage	0.04	0.02
	% Total disease	0.04	0.03
NC Ac 17129	% Rust damage	0.04	0.03
	% Late leaf spot damage	0.04	0.02
	% Total disease	0.04	0.03
TMV 2	% Rust damage	0.05	0.04
	% Late leaf spot damage	0.05	0.04
	% Total disease	0.06	0.05
Robut 33-1	% Rust damage	0.05	0.04
	% Late leaf spot damage	0.05	0.04
	% Total disease	0.06	0.05

Table 45: The linear equations and correlation coefficients of three disease components measured in inoculated and uninoculated field plots in the 1984-85 postrainy season at ICRISAT Center.

Genotype	Disease component	Linear equation (Y= r x + b)[1]	Correlation coefficient (R)
PI 350680	% Rust		
	Inoculated	Y = .01 X - 10.17	.63
	Uninoculated	Y = .01 X - 9.89	.44
	% Late leaf spot		
	Inoculated	Y = .02 X - 10.59	.79*
	Uninoculated	Y = .01 X - 9.97	.44
	% Total disease		
	Inoculated	Y = .02 X - 10.87	.77*
	Uninoculated	Y = .01 X - 10.18	.44
EC 76446(292)	% Rust		
	Inoculated	Y = .01 X - 10.17	.63
	Uninoculated	Y = .01 X - 9.67	.44
	% Late leaf spot		
	Inoculated	Y = .25 X - 10.72	.81**
	Uninoculated	Y = .01 X - 9.89	.44
	% Total disease		
	Inoculated	Y = .03 X - 10.98	.80**
	Uninoculated	Y = .01 X - 10.03	.44
NC Ac 17127	% Rust		
	Inoculated	Y = .03 X - 11.25	.88**
	Uninoculated	Y = .02 X - 10.60	.68*
	% Late leaf spot		
	Inoculated	Y = .04 X - 11.37	.89**
	Uninoculated	Y = .02 X - 10.49	.68*
	% Total disease		
	Inoculated	Y = .04 X - 11.87	.89**
	Uninoculated	Y = .03 X - 10.98	.68*
Nc Ac 17129	% Rust		
	Inoculated	Y = .04 X - 11.33	.88**
	Uninoculated	Y = .02 X - 10.41	.66
	% Late leaf spot		
	Inoculated	Y = .04 X - 11.40	.88**
	Uninoculated	Y = .02 X - 10.23	.62

	% Total disease		
	Inoculated	Y = .05 X - 11.94	.89**
	Uninoculated	Y = .02 X - 10.73	.66
TMV 2	% Rust		
	Inoculated	Y = .06 X - 12.35	.94**
	Uninoculated	Y = .03 X - 11.28	.81**
	% Late leaf spot		
	Inoculated	Y = .06 X - 12.54	.93**
	Uninoculated	Y = .04 X - 11.57	.81**
	% Total disease		
	Inoculated	Y = .07 X - 13.00	.94**
	Uninoculated	Y = .04 X - 12.00	.81**
Robut 33-1	% Rust		
	Inoculated	Y = .06 X - 12.40	.95**
	Uninoculated	Y = .03 X - 11.31	.81**
	% Late leaf spot		
	Inoculated	Y = .06 X - 12.39	.94**
	Uninoculated	Y = .04 X - 11.59	.80**
	% Total disease		
	Inoculated	Y = .07 x - 12.94	.95**
	Uninoculated	Y = .05 X - 12.02	.81**

1. r = Van der Plank's term for the slope of the linear regression line.

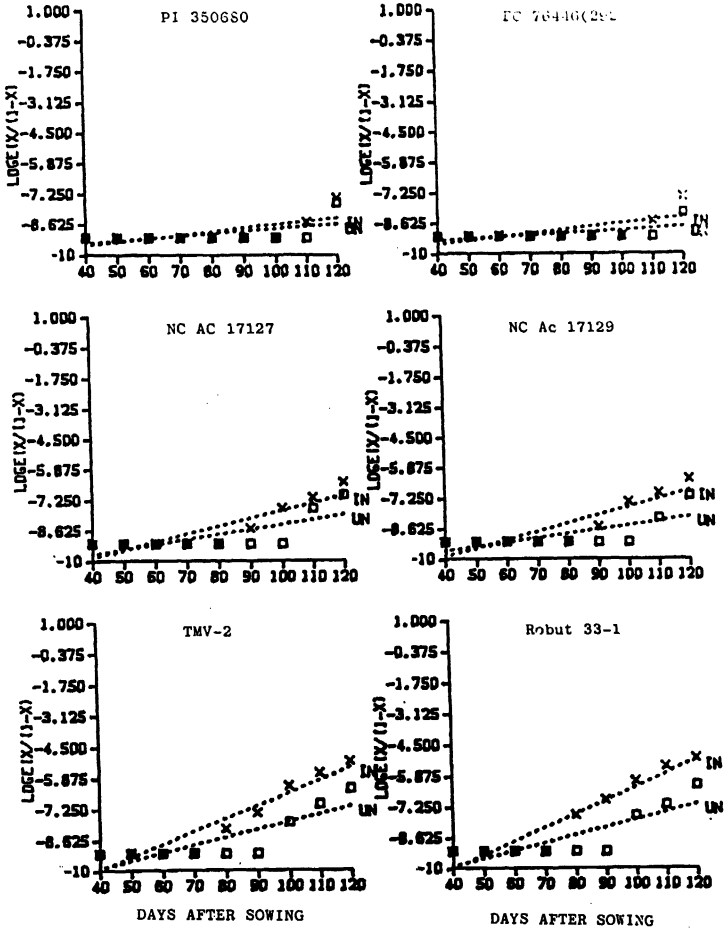


Fig. 12 : Rust development on six groundnut genotypes in inoculated and uninoculated plots during the 1984-85 postrainy season at ICRISAT Center (See Table 45 for linear equations and correlation coefficients).

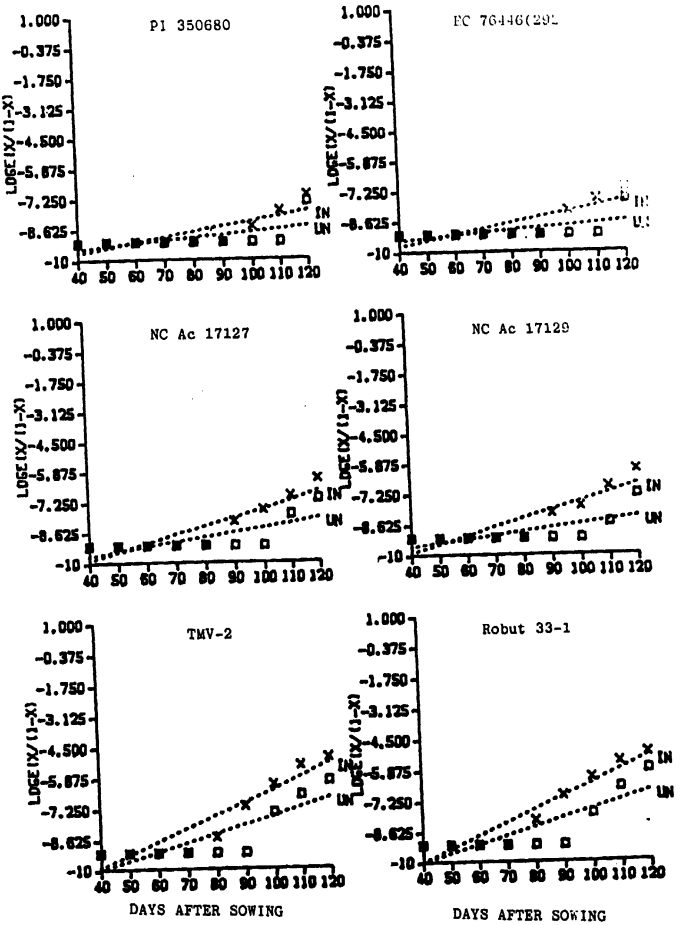


Fig. 13 : Late leaf spot development on six groundnut genotypes in inoculated and uninoculated plots during the 1984-85 post-rainy season at ICRISAT Center (See Table 45 for linear equations and correlation coefficients).

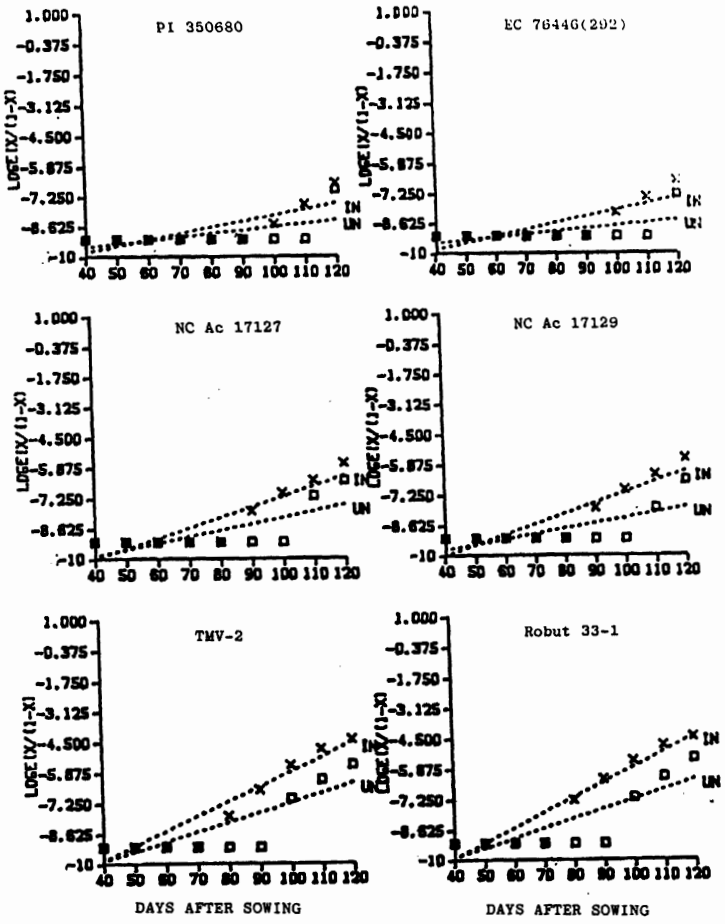


Fig. 14 : Total disease (rust and late leaf spot) development on six groundnut genotypes in inoculated and uninoculated plots during 1984-85 postrainy season at ICRISAT Center (See Table 45 for linear equations and correlation coefficients).

and EC 76446(292) followed by susceptible genotypes and PI 350680 (Table 46).

Effect of weather parameters on rust and late leaf spot development in the field:

The effects of weather factors on the AUDPC of rust, late leaf spot, defoliation and total disease were investigated on two susceptible genotypes, TMV 2 and Robut 33-1 in field plots at ICRISAT Center during 1983 and 1984 rainy seasons and 1983-84 and 1984-85 postrainy seasons.

There were no marked differences between the genotypes with regards to disease x environment interaction (Tables 47, 48). Statistically significant correlations were observed between rust development and weather parameters such as mean minimum temperature, number of days with relative humidity between 50-75% at 14.17 hr, total rain, number of days with 10-20 mm rain, number of days with above 20 mm rain, number of days with 0 hr sunshine and number of days with 201-300 solar radiation. Correlation (correlation coefficient above 0.90) was also observed between number of days with minimum temperature between 20-25 ^{o}C, number of rainy days, and number of days with 0.1-5.0 mm rain.

There was a statistically significant correlation between late leaf spot development and weather factors like mean relative humidity at 14.17 hr, total rain, number of rainy days and number of days with 0.1-5.0 mm rain. There was a correlation (correlation coefficient above 0.90) for mean maximum

Table 47: Effect of weather factors on the AUDPC of rust, late leaf spot, defoliation, and total disease on the c.

Weather parameter	Correlation coefficients (R)			
	Rust	LLS	Defol	TD
1. Mean maximum temperature	.30	.82	.90	.79
2. Mean minimum temperature.	.96*	.92	.83	.92
3. Number of days with maximum temperature between 20-25 C	.72	-	-	-
4. Number of days with maximum temperature between 25-30 C	-	-	-	-
5. Number of days with maximum temperature between 30-35 C	-	-	-	-
6. Number of days with maximum temperature 35 C	.30	-	.55	-
7. Number of days with minimum temperature less than 20 C	.39	.86	.85	.84
8. Number of days with minimum temperature between 20-25 C	.91	.89	.84	.84
9. Mean relative humidity at 0717 hr	.70	.94	.99**	.92
10. Mean relative humidity at 1417 hr	.84	.96*	.96*	.95*
11. Number of days with relative humidity less than 50% at 0717 hr	.66	.80	.95*	.75
12. Number of days with relative humidity between 50-75% at 0717 hr	.24	.80	.82	.79
13. Number of days with relative humidity abov 75% at 0717 hr	.57	.70	.90	.64
14. Number of days with relative humidity less than 50% at 1417 hr	.56	.90	.93	.89
15. Number of days with relative humidity between 50-75% at 1417 hr	.99**	.88	.70	.88
16. Number of days with relative humidity abov 75% at 1417 hr	.63	.81	.96*	.78
17. Total rain	.95*	.95*	.68	.96*
18. Number of rainy days	.92	.96*	.89	.95*
19. Number of days with 0.1-5.0 mm rain	.90	.95*	.90	.92
20. Number of days with 5.0-10.0 mm rain	.63	.81	.95*	.75
21. Number of days with 10.0-20.0 mm rain	.99**	.86	.60	.86
22. Number of days with above 20.0 mm rain	.99**	.90	.68	.90
23. Number of days with 0 hr sunshine	.99**	.78	.42	.76
24. Number of days with 1-5 hr sunshine	.88	.94	.93	.93
25. Number of days with 5-12 hr sunshine	.61	.91	.99**	.90
26. Mean evaporation	.64	.94	.97*	.92
27. Number of days with 100-200 solar radiation	.81	.75	.78	.69
28. Number of days with 201-300 solar radiation	.96*	.83	.46	.86
29. Number of days with 301-400 solar radiation	-	-	-	-
30. Number of days with 401-500 solar radiation	.61	.91	.72	.91
31. Number of days with 501-600 solar radiation	-	.58	.83	.51

1. Residual varience exceedes varience of Y- variate.

Table 48: Effect of weather factors on the AUDPC of rust, late leaf spot, defoliation, and total disease on Robut 33-1.

Weather parameter	Correlation coefficients (R)			
	Rust	LLS	Defol	TD
1. Mean maximum temperature	.34	.80	.92	.80
2. Mean minimum temperature.	.96*	.91	.80	.90
3. Number of days with maximum temperature between 20-25 C	.70	-	-	-
4. Number of days with maximum temperature between 25-30 C	-	-	-	-
5. Number of days with maximum temperature between 30-35 C	-	-	-	-
6. Number of days with maximum temperature 35 C	.28	-	.48	-
7. Number of days with minimum temperature less than 20 C	.42	.85	.88	.84
8. Number of days with minimum temperature between 20-25 C	.91	.89	.82	.84
9. Mean relative humidity at 0717 hr	.73	.93	.99**	.91
10. Mean relative humidity at 1417 hr	.86	.95*	.95*	.94*
11. Number of days with relative humidity less than 50% at 0717 hr	.66	.79	.96*	.72
12. Number of days with relative humidity between 50-75% at 0717 hr	.28	.78	.85	.81
13. Number of days with relative humidity abov 75% at 0717 hr	.57	.70	.90	.62
14. Number of days with relative humidity less than 50% at 1417 hr	.56	.91	.94	.89
15. Number of days with relative humidity between 50-75% at 1417 hr	.99**	.86	.69	.86
16. Number of days with relative humidity abov 75% at 1417 hr	.65	.81	.95*	.75
17. Total rain	.96*	.95*	.70	.96*
18. Number of rainy days	.92	.96*	.88	.93*
19. Number of days with 0.1-5.0 mm rain	.90	.96*	.90	.91
20. Number of days with 5.0-10.0 mm rain	.64	.80	.96*	.73
21. Number of days with 10.0-20.0 mm rain	.99**	.88	.58	.86
22. Number of days with above 20.0 mm rain	.99**	.91	.68	.88
23. Number of days with 0 hr sunshine	.99**	.81	.39	.75
24. Number of days with 1-5 hr sunshine	.88	.94	.91	.90
25. Number of days with 5-12 hr sunshine	.64	.91	.99**	.91
26. Mean evaporation	.68	.93	.98*	.92
27. Number of days with 100-200 solar radiation	.81	.75	.74	.67
28. Number of days with 201-300 solar radiation	.97*	.85	.46	.85
29. Number of days with 301-400 solar radiation	-	-	-	-
30. Number of days with 401-500 solar radiation	.66	.90	.76	.93
31. Number of days with 501-600 solar radiation	-	.54	.78	.52

1. Residual varience exceedes varience of Y- variate.

temperature, mean relative humidity at 07.17 hr, number of days with relative humidity less than 50% at 14.17 hr, number of days with above 20 mm rain, number of days with 1-5 hr and 5-12 hr sunshine, mean evaporation, and number of days with 401-500 solar radiation.

Statistically significant correlations were observed for the AUDPC of defoliation with mean relative humidity at 07.17 hr and 14.17 hr, number of days with relative humidity less than 50% at 07.17 hr, number of days with relative humidity above 75% at 14.17 hr, number of days with 5-10 mm rain, number of days with 5-12 hr sunshine and mean evaporation. There was a correlation (correlation coefficient above 0.90) between defoliation and weather factors such as mean maximum temperature, number of days with relative humidity above 75% at 07.17 hr, number of days with relative humidity less than 50% at 14.17 hr, number of days with 0.1-5.0 mm rain and number of days with 1-5 hr sunshine.

There was a statistically significant correlation for the AUDPC of total disease with weather parameters such as mean relative humidity at 14.17 hr, total rain and number of rainy days. Correlation (correlation coefficient above 0.90) was also observed between the AUDPC and mean minimum temperature, mean relative humidity at 07.17 hr, number of days with 0.1-5.0 mm rain, number of days with above 20 mm rain, number of days with 1-5 hr sunshine, number of days with 5-12 hr sunshine, mean evaporation, and number of days with 401-500 solar radiation (Tables 47 and 48).

In general, the percentage leaf area damaged by rust, late leaf spot, percentage defoliation and total disease were more in rainy seasons than in postrainy seasons under test. The weather factors that may promote high disease development in the rainy season were: minimum temperature more (21-22 ^{o}C) in the rainy season and less (15-18 ^{o}C) in the postrainy season, number of days with minimum temperature between 20-25 ^{o}C more (95-96) in the rainy season and less (15-32) in the postrainy season, the mean relative humidity at 07.17 hr more (86-92%) in the rainy season and less (77%) in the postrainy season. The mean relative humidity 14.17 hr was more (58-72%) in the rainy season and less in the postrainy season (28-36%), number of days with relative humidity above 75% at 07.17 hr were more (93-96) in the rainy season and less (73) in the postrainy season, number of days with relative humidity between 50-75% at 14.17 hr more (55-61) in the rainy season and less (4-21) in the postrainy season, number of days with relative humidity above 75% at 14.17 hr more (15-27) in the rainy season and nil in the postrainy season, total rain more (122-907 mm) in the rainy season and less (2.4-74 mm) in the postrainy season, number of rainy days more (40-71) in the rainy season and less (2-8) in the postrainy season, other rain parameters like number of days with 0.1-5.0 mm rain more (20-29) in the rainy season and less (2-5) in the postrainy season, 5-10 mm rain more (7-10) in rainy season and nil in the postrainy season, 10-20 mm rain more (7-17) in the rainy season and less (0-2) in the postrainy season, above 20 mm rain more (6-15)

in the rainy season and zero in the postrainy season, number of days with 0 hr sunshine higher (13) in the rainy season and lower (0-4) in the postrainy season, number of days with 1-5 hr sunshine more (33-49) in the rainy season and less (3-7) in the postrainy season respectively. The other parameters also contributed for more disease in the rainy seasons than in postrainy seasons viz., number of days with maximum temperature above 35 ^{o}C nil in the rainy season and more (27-32) in the postrainy season, number of days with minimum temperature less than 20 ^{o}C less (0-7) in the rainy season and more (89-106) in the postrainy season, number of days with relative humidity less than 50% at 07.17 hr nil in the rainy season and more (12-15) in the postrainy season, number of days with relative humidity at 07.17 hr less (0-7) in the rainy season and more (33-39) in the postrainy season, number of days with relative humidity less than 50% at 14.17 hr less (5-33) in the rainy season and more (102-117) in the postrainy season and number of days with 5-12 hr sunshine less (32-57) in the rainy season and more (112-118) in the postrainy season.

There was more severe rust and leaf spots development in the 1983 rainy season than in the 1984 rainy season. The reasons for severe disease buildup of rust and leaf spots diseases in the 1983 rainy season were: number of days with maximum temperature between 25-30 ^{o}C more (67) in the 1983 rainy season and less (45) in the 1984 rainy season. The number of days with maximum temperature between 30-35 ^{o}C less (23) in the 1983 rainy season and more (54) in the 1984 rainy season, mean

relative humidity at 07.17 hr more (93%) in the 1983 rainy season and less (87%) in the 1984 rainy season, mean relative humidity at 14.17 hr more (72%) in the 1983 rainy season and less (59%) in the 1984 rainy season, number of days with relative humidity less than 50% at 14.17 hr less (5) in the 1983 rainy season and more (33) in the 1984 rainy season, number of days with relative humidity above 75% at 14.17 hr more (27) in the 1983 rainy season and less (15) in the 1984 rainy season, total rain very high (907 mm) in 1983 rainy season and very low (122 mm) in the 1984 rainy season, number of rainy days more (71) in the 1983 rainy season and less (40) in the 1984 rainy season, number of days with 0.1-5.0 mm more (29) in the 1983 rainy season and less (20) in the 1984 rainy season, number of days with 10-20 mm rain more (17) in the 1983 rainy season and less (7) in the 1984 rainy season, number of days with above 20 mm rain more (15) in the 1983 rainy season and less (6) in the 1984 rainy season, number of days with 1-5 hr sunshine more (49) in the 1983 rainy season and less (33) in the 1984 rainy season, number of days with 5-12 hr sunshine less (32) in the 1983 rainy season and more (57) in the 1984 rainy season and number of days with 401-500 solar radiation less (19) in the 1983 rainy season and more (42) in the 1984 rainy season.

DISCUSSION AND CONCLUSIONS

CHAPTER-V

DISCUSSION AND CONCLUSIONS

I. Perpetuation, carry-over and spread of groundnut rust:

1. Survival of groundnut rust in infected crop debris:

Rust urediniospores in infected leaves of a rust-susceptible genotype (TMV 2) remained viable under field conditions at ICRISAT Center for 30 days after harvest of the 1983 rainy season crop and for 15 days after harvest of the 1983-84 postrainy season crop. Urediniospores remained viable for only 15 days in infected stems of a rust-susceptible genotype, and in infected leaves and stems of a rust-resistant genotype (PI 350680) after harvest of the 1983 rainy season crop. These results showed that urediniospores were short-lived in infected crop debris after harvest of the rainy and postrainy season crops. Urediniospore viability was shortest after harvest of the postrainy season crop, probably due to the high temperature (36-43 ^{o}C), low relative humidity (19-65%) and very high solar radiation (460-623 Ly/day) prevailing at that time of the year (April-May). Subrahmanyam and McDonald (1982) also observed that urediniospores in infected crop debris were short-lived and the extent of survival was shorter in postrainy seasons than in the rainy seasons at ICRISAT Center. Lingaraju *et al.* (1979), Mallaiah and Rao (1979b) and Mayee (1982), working in different locations in India, reported that groundnut rust urediniospores were short-lived (20-40 days) in infected leaf debris of susceptible genotypes under field conditions.

Urediniospores present on infected leaf debris buried in soil at 5 and 10 cm depths in the field lost viability within 30 days. These results indicated that the infected leaf debris buried in soil had similar survival of urediniospores to exposed debris.

Urediniospores in infected leaves of a rust-susceptible genotype collected on the day of harvest of the 1983 rainy and 1983-84 postrainy season crops and preserved in closed cardboard boxes in the glasshouse remained viable for 45 days. In infected stems, urediniospores were viable for only 30 days. However, in infected leaves and stems of a rust-resistant genotype, urediniospores remained viable for 30 and 15 days, respectively. These results indicated that urediniospores in infected crop debris remained viable for longer periods under glasshouse conditions than under field conditions. However, the period of survival under both field and glasshouse conditions was short i.e., less than 45 days, and was not likely to be useful in perpetuation of groundnut rust from one rainy season crop to the next. Lingaraju *et al.* (1979) also reported that urediniospores in infected leaf debris remained viable for longer periods (41 to 51 days) under glasshouse conditions than in the field (34 to 43 days). The results of this investigation also indicated that urediniospore viability was shorter in infected crop debris of a rust-resistant genotype than in that of a rust-susceptible genotype, probably because the urediniospores produced on

rust- resistant genotypes have intrinsically lower germinability than those produced on rust-susceptible genotypes (Subrahmanyam *et al.*, 1983c). But the differences in duration of urediniospore viability in rust-resistant and rust-susceptible genotypes were small (around 15 days) and may not have any practical implication in perpetuation of the pathogen.

It was concluded that urediniospores in infected crop debris were short-lived as reported by other workers in India (Mallaiah and Rao, 1979a; Lingaraju *et al.*, 1979; Subrahmanyam and McDonald, 1982; Mayee, 1982).

2. *Longevity of urediniospores stored in glass vials at different temperatures*:

Urediniospores of groundnut rust were collected from pustules on attached leaves of glasshouse-grown plants of the rust-susceptible genotype TMV2 and stored in glass vials at different temperatures. Viability was measured by germination tests in distilled water on slides, and by inoculation onto rooted detached leaves of the genotype TMV 2.

Urediniospores stored at -17 and 10 ^{o}C retained germinability and capability to infect TMV 2 leaves for over 160 days. When stored at 20 ^{o}C, they lost germinability after 30 days and when held at 30 ^{o}C they lost germinability within 10 days. Urediniospores stored at 20 and 30 ^{o}C for varying periods gave variable results when tested for germination *in vitro*, no uniform trends being evident, but when tested for ability to infect TMV 2 leaves the results were more uniform. In several

cases, no germination was recorded for a sample but infectivity was shown by production of pustules on inoculated TMV 2 leaves. The results from the *in vitro* germinability tests were in accord with those of Subrahmanyam and McDonald (1982) who did not carry out infectivity tests. Zhou (personal communication to D.McDonald) in the People's Republic of China also obtained similar data on effects of storage temperature on spore germinability. He also examined samples for ability to infect groundnut leaves and, as in the present study, found that infectivity could be demonstrated when no germination could be shown in the *in vitro* slide germination test. Germination of urediniospores on host leaf surfaces may be stimulated by chemical factors released by the leaves. However, this was not investigated in the present study.

3. *Perpetuation of groundnut rust on ground-keepers and volunteer groundnut plants:*

Rust was observed on ground-keepers and volunteer groundnut plants at ICRISAT Center from October 1984 (end of the 1984 rainy season crop) to June 1985 (beginning of the 1985 rainy season crop). However, the extent of sporulation varied in different months. For instance, the sporulation was low in November to February and in May, probably due to low temperatures during November to February and to high temperatures during May. The role of ground-keepers and volunteer groundnut plants in assisting the survival of groundnut rust has been stressed by many workers (Harrison, 1972; O'Brien,

1977; Mallaiah and Rao, 1979 b; Lingaraju *et al.*, 1979; Zhou *et al.*, 1980; Subrahmanyam and McDonald, 1982) and was likely to have been most important when the crop was grown only in the rainy season. In regions where groundnuts are grown continuously throughout the year (e.g., southern India), ground-keepers and volunteer groundnut plants are not needed to ensure the perpetuation of the rust pathogen.

4. *Perpetuation of groundnut rust on collateral hosts*: There was no record of the occurrence of any collateral hosts of groundnut rust outside the genus *Arachis*, and in India wild *Arachis* species occured only in research centers and can hardly be involved in perpetuation of the groundnut rust pathogen (Subrahmanyam and McDonald, 1982). In the present investigation, 22 leguminous weed and crop plants were examined as possible hosts of the groundnut rust pathogen, but no case of infection was recorded on any of them. These results are in agreement with those obtained earlier by Subrahmanyam and McDonald (1982).

5. *Spread of rust on pods and seeds*:
Pods and seeds of a rust-susceptible genotype TMV 2 surface-contaminated with viable urediniospores and sown in sterilised soil in isolation plant propagators gave rise to disease-free seedlings. This indicated that such contaminated pods or seeds were unlikely to be responsible for perpetuation or spread of the disease. This goes against the suggestion of several workers (West, 1931; Peregrine, 1971; Chohan, 1974; Shaw and Layton, 1975; Arokoyo *et al.*, 1977; Seif, 1979; Zhou

et al., 1980) but was supported by the findings of Subrahmanyam and McDonald (1982). No evidence has been provided to show that rust can be internally seed-borne (Kolte and Awasti, 1979; Vilsoni, 1980; Subrahmanyam and McDonald, 1982; Mayee, 1982). However, the presence of viable urediniospores on the surface of pods and seeds could pose a slight danger of rust spread if these spores were to come in contact with the foliage of a rust-susceptible groundnut genotype under environmental conditions favouring infection. Normal plant quarantine practices should prevent such a happening as indicated by Subrahmanyam and McDonald (1982).

6. On clothes of travellers:

The possibility of spread of viable urediniospores on the clothes of farmers, research workers etc., has been considered. Plant quarantine officials at international airports often question travellers as to whether or not they have recently been in farms and this could help in indicating possible danger of disease spread. The experiment in which viable urediniospores dusted on clothes gave rise to rust infection in glasshouse grown plants reinforces this point.

II. Perpetuation, carry-over and spread of groundnut leaf spots pathogens:

1. Survival of late leaf spot pathogen in infected crop debris:

Early and late leaf spots pathogens of groundnut were generally believed to remain viable in leaf debris from an infected crop through to the following season and produce

infection in the next crop (Jackson and Bell, 1969; Garren and Jackson, 1973; Porter *et al.*, 1982; McDonald *et al.*, 1985). However, in the present investigation the late leaf spot pathogen was viable for only 60 days in infected leaf debris of a late leaf spot-susceptible genotype kept in a shallow layer on the soil surface after harvest of the 1983 rainy season crop. The period of viability of the pathogen was still less (30 days) after harvest of the 1983-84 postrainy season crop. It was thought that the very high temperature (36-43 ^{o}C),low relative humidity (19-65%) and very high solar radiation (460-623 Ly/day) prevailing after harvest of the postrainy season crop at ICRISAT Center led to this rapid loss of viability. The pathogen was also found to be short-lived (30 days) in infected leaf debris buried at depths of 5 and 10 cm in an ICRISAT Alfisol or in a paddy field under puddled conditions. These results indicated that the late leaf spot pathogen looses viability within 60 days in infected crop debris under field conditions.

A period of viability of 60 days would be insufficient to ensure the carry-over of the late leaf spot pathogen from one rainy season to the next. However, from the prevalence of the disease in many groundnut-growing countries in the world, it was clear that the pathogen was able to perpetuate itself in some form or other in infected plant debris. In the present study, when the infected leaf debris was stored indoors in cardboard boxes the viability of the pathogen was retained for periods of over 12 months. It appears that environmental factors at ICRISAT Center were not conducive to survival of the

late leaf spot pathogen in infected crop debris in the field after harvest. The pathogen could survive in infected crop residues for a longer period when hay was stored in stacks or debris was left under shade. It is a common practice in many locations in India to stack groundnut haulms for feeding to cattle. These stackes may provide the late leaf spot inoculum to infect groundnut crops in the following season. Investigations are required to verify this hypothesis.

The period of viability of the pathogen was shorter in leaf debris of a late leaf spot-resistant genotype than in leaf debris of a late leaf spot-susceptible genotype. The differences in duration of viability of the pathogen in infected leaf debris of resistant and susceptible genotypes were small (30 days) under field conditions, but very large (255 days) when the infected debris were kept indoors. This may have important practical implications in perpetuation of the pathogen from season to season. The differences between genotypes operated in a favourable direction, and could be useful in combination with reduction of inoculum produced in a late leaf spot-resistant crop in comparison with a susceptible crop in reducing carry-over of the disease.

2. Longevity of conidia of the late leaf spot pathogen stored in glass vials at different temperatures:

Conidia of the late leaf spot pathogen were collected from lesions on glasshouse-grown plants of the late leaf spot-susceptible genotype TMV 2 and stored in glass vials at

different temperatures. Viability was determined by measuring germination of conidia in distilled water on slides, and by checking infectivity by applying a conidial suspension to detached leaves of the genotype TMV 2 in an incubator.

Conidia stored at -17, 10 and 20 °C retained viability and capability to infect TMV 2 leaves for over 160 days. When stored at 40 °C, the conidia remained viable for 40 days, but at 30 °C they lost viability within 10 days. This kind of response in longevity of conidia at 30 and 40 °C was unexpected. The short duration of survival of conidia of the late leaf spot pathogenat 30 °C was probably because of invasion of the conidia by a hyperparasite, *Verticillium lecani*. No such invasion of conidia by hyperparasites was observed at other storage temperatures.

3. *Perpetuation of early and late leaf spot pathogens of groundnut on ground-keepers and volunteer groundnut plants*:

Early and late leaf spots of groundnut were commonly observed on ground-keepers and volunteer groundnut plants at ICRISAT Center from October 1984 (end of the 1984 rainy season crop) to June 1985 (beginning of the 1985 rainy season crop). However, the extent of sporulation of the early and late leaf spot lesions varied in different months. Sporulation was limited in the period November 1984 to February 1985 and in May 1985, probably due to low temperatures during November to February and to high

temperatures during May. The importance of ground- keepers and volunteer groundnut plants in assisting the perpetuation of leaf spot pathogens has been stressed by many workers (Hemingway, 1954; Fowler, 1970; Feakin, 1973; McDonald *et al.*, 1985) and is likely to be most important when the crop was grown only in the rainy season. The role of ground-keepers and volunteer groundnut plants in perpetuation of leaf spots pathogens is not likely to be important in countries such as India and the People'sRepublic of China where groundnuts were grown in some regions throughout most of the year.

4. *Perpetuation of early and late leaf spots pathogens of groundnut on collateral hosts*:

Mercer (1977) reported that the Bambara groundnut (*Voandzeia subterranea*) was a collateral host of the early leaf spot pathogen in Malawi, and Pyzner (1980) made a similar claim for *Stylosanthes biflora* in the USA. However, these reports were not substantiated by further research. There was no authentic record of the occurrence of any collateral hosts of groundnut leaf spot pathogens outside the genus *Arachis*. In the present investigation, 22 leguminous weed and crop plants were examined as possible hosts of the leaf spots pathogens,but no case of infection was recorded on any of them. These results are in agreement with those obtained earlier by Subrahmanyam *et al.* (1983b). However, the above leguminous weeds (*V.subterranea* and *S. biflora*) were not tested in this investigation.

5. *Spread of early and late leaf spots pathogens onpods and seeds:*

Pods and seeds of the early and late leaf spots-susceptible genotype TMV 2 surface contaminated with viable conidia of early and late leaf spots pathogens and sown in sterilised soil in isolation plant propagators gave rise to disease-free seedlings. This indicates that contamination of pods and seeds with conidia is unlikely to be responsible for perpetuation or spread of the leafspots diseases, a view supported by the findings of Butler (1918), Roldan and Querijero (1939), Prasad (1968) and Moulder and Holliday (1974). There is no authenticated report of either early or late groundnut leaf spots pathogens being internally seed-borne (McDonald *et al.*, 1985).

III. *Effect of temperature on in vitro spore germination of rust and late leaf spot pathogens:*

1. *On germination of rust urediniospores:* Urediniospores of the rust pathogen were harvested from uredinia on a rust-susceptible groundnut genotype TMV 2 grown in the glasshouse and suspended in sterile distilled water to a concentration of 50,000 spores ml^{-1} and drops of the suspension were incubated at various temperatures on glass slides. No urediniospores germinated when incubated at -17 ^{o}C. Very low percentages of urediniospores germinated at 5,10,15 and 35 ^{o}C. Temperatures in the range of 20- 30 ^{o}C favoured germination. These results are in agreement with those obtained by Fang (1977, 1982), Kono (1977) Mallaiah and Rao (1979a), Zhou *et al.*

(1980), and Subrahmanyam *et al.* (1984). However, Foudin and Macko (1974) reported that the optimum temperature for urediniospore germination was around 18 °C.

2. *On germination of conidia of the late leaf spot pathogen:*

Freshly harvested conidia of the late leaf spot pathogen were suspended in sterile distilled water to a concentration of approximately 50,000 spores ml^{-1} and drops of the suspension were incubated on glass slides at various temperatures. No conidia germinated at -17 °C, and only very low percentages of conidia germinated at 5, 10, and 35 °C. Temperatures in the range of 15-30 °C favoured germination of conidia. The germination of rust urediniospores and late leaf spot conidia were similarly influenced by temperature; this was to be expected as the two diseases commonly occur together in India and in other groundnut- growing countries.

IV. *Effect of temperature on development of rust, early and late leaf spot diseases on three groundnut genotypes in the laboratory:*

Three genotypes were selected for study of the development of the three foliar diseases on detached leaves maintained at different temperatures. Genotype TMV 2 was susceptible to all the three pathogens, NC Ac 17129 was moderately resistant to rust and late leaf spot pathogens, but susceptible to early leaf spot pathogen, and PI 350680 was highly resistant to rust and late leaf spot pathogens but

susceptible to early leaf spot. Unfortunately, no genotype with resistance to early leaf spot was available. Incubation temperatures used were 10, 15, 20, 25, 30 and 35 °C. Disease development was assessed by measuring incubation period, infection frequency, lesion diameter, percentage leaf area damaged and sporulation index. Percentage defoliation was assessed only for leaf spots diseases.

1. Effect of temperature on rust disease:

Rust developed on leaves of all test genotypes incubated at 15, 20, 25 and 30 °C, but not at 10 and 35 °C, even after 45 days of incubation. The incubation period was longer at the lower temperatures (15 and 20 °C) than at the higher temperatures (25 and 30 °C) for all genotypes. Zhou *et al.* (1980) also reported that incubation period was long at low temperature (18 °C) and short at high temperature (24.5 to 26.0 °C). Infection frequency was highest at 25 °C for TMV 2 but lowest for NC Ac 17129, which had highest infection frequency at 30 °C. Temperatures between 15 and 30 °C did not significantly effect infection frequency or lesion diameter for PI 350680. Lesions were large at 20, 25 and 30 °C but small at 15 °C for TMV 2 and NC Ac 17129. Percentage leaf area damaged was highest at 30 °C for TMV 2 and NC Ac 17129. No significant differences were observed in sporulation index in TMV 2 and NC Ac 17129 plants maintained at temperatures in the 15-30 °C range. It was lowest at 25 °C for PI 350680. These results showed that there was a strong genotype x temperature interaction on rust development. In general, the temperature

range of 20-30 °C appears to be favourable for rust development on rooted detached leaves in the laboratory. Subrahmanyam and McDonald (1986) reported that temperatures in the 20-30 °C range favoured rust development in the laboratory. In the present investigation rust development was not observed at 10 and 35 °C, but Mallaiah and Rao (1979 a) recorded slight rust development at 35 °C. They also reported that the disease could be quiescent under high summer temperatures in Andhra Pradesh, but that infection was rapidly manifest when temperatures fell at the onset of the monsoon.

Rust-resistant genotypes have increased incubation period, decreased infection frequency, leaf area damaged and reduced pustule size and spore production. These results were in agreement with those obtained by Lin (1981), Sokhi and Joohty (1982) and Subrahmanaym *et al.* (1983a, 1983c).

2. *Effect of temperature on early leaf spot disease:*

Early leaf spot developed on detached leaves of all test genotypes incubated at 15, 20, 25 and 30 °C but not at 10 and 35 °C even after 45 days of incubation. The incubation period was longer at lower temperatures (15 and 20 °C) and shorter at higher temperatures (25 and 30 °C) for all genotypes. The infection frequency was highest at 15 °C and lowest at 30 °C for all genotypes. No significant effects of temperature and genotype on lesion diameter were observed. Percentage leaf area damaged was largest at 25 °C for all genotypes, but low at 15, 20 and 30 °C. The genotypes PI

350680 and NC Ac 17129 showed low percentage leaf area damage at 25 °C. There was no consistant trend in genotype and temperature effects on defoliation. The results on defoliation were erratic and coefficient of variation exceeded 100%. The sporulation index was low at 15 and 30 °C and high at 20 and 25 °C for all genotypes.

Genotype NC Ac 17129 had the longest incubation period, the smallest lesions, the least percentage leaf area damage, and the lowest sporulation index. The genotype PI 350680 also had small lesions, low percentage leaf area damage and low sporulation index. Although the three genotypes used in this investigation were all susceptible to the early leaf spot pathogen in field screening trials at ICRISAT Center, the genotypes NC Ac 17129 and PI 350680 had smaller lesions and lower sporulation index than TMV 2. This indicates that if these genotypes are grown in larger areas, they might show a reduced apparent infection rate (r) because of low spore production. However, field trials are required to verify this hypothesis.

3. Effect of temperature on late leaf spot disease:

Late leaf spot developed on detached leaves of all test genotypes incubated at 15, 20, 25 and 30 °C but not at 10 and 35°C even after 45 days of incubation. The incubation period was longer at 15 and 20 °C and shorter at 25 and 30 °C for all genotypes. Infection frequencies were high at 15 and 25 °C and low at 15, 25 and 30 °C. Percentage leaf area damage

and percentage defoliation were higher at 25 °C than at the other temperatures for all genotypes. Within the range of 15-30°C there were no significant effects of temperature on sporulation index.

Late leaf spot-resistant genotypes have increased incubation period, and decreased infection frequency, leaf area damage, and defoliation, and reduced lesion size and spore production. These results were in agreement with those obtained by Nevill (1981), Subrahmanyam *et al.* (1982), and Walls and Wynne (1985).

It is concluded that the results of this investigation indicate that there was a strong genotype x temperature interaction on foliar diseases development. In general, temperatures in the 20-30 °C range favour rust, early and late leaf spot development on detached leaves in the laboratory. However, further trials are required to determine the optimum temperature requirements for each of these diseases. Surprisingly little information is available in the literature on the effects of temperature on development of rust, early and late leaf spots diseases. Rust and late leaf spot-resistant genotypes have an increased incubation period, decreased infection frequency, leaf area damaged, and reduced lesions and spore production. This type of reaction to diseases was similar to the "partial resistance" reported by various workers in several host-pathogen interaction studies (Hooker,1967; Parleveliet, 1975; MacKenzie, 1976; Berger, 1977; Shaner and Finney, 1980).

V. Development of rust and leaf spot diseases on groundnut crops at ICRISAT Center:

The progress of rust and leaf spots development was monitered on six groundnut genotypes in field plots, with and without inoculation, in the 1983 and 1984 rainy and the 1983-84 and 1984-85 postrainy seasons at ICRISAT Center. Genotypes PI 350680 and EC 76446 (292) were resistant to rust and late leaf spot; NC Ac 17127 and NC Ac 17129 were moderately resistant to rust and late leaf spot; and TMV 2 and Robut 33-1 were susceptible to rust and late leaf spot. All genotypes were susceptible to early leaf spot. Disease development was assessed by measuring the percentage leaf area damaged by rust and by leaf spots, and percentage defoliation, at 10-day intervals until harvest. The data on percentage leaf area damaged from rust and leaf spots and percentage defoliation were computed to calculate the percentage total disease.

1. Rust disease development:

Rust pustules appeared early on the 1983 and 1984 rainy season groundnut crops, but took much longer to appear on the 1983-84 and 1984-85 postrainy season crops. The area under the disease progress curve (AUDPC) for rust was higher in both rainy seasons than in the postrainy seasons. The weather was cool and wet during the rainy seasons thus providing favourable climatic conditions for rust infection and development. Most of the annual rainfall was received during the rainy season (June-October) when the main groundnut

crop was grown. In the postrainy seasons the number of rainy days and total rainfall were very low, and the weather was dry. In the postrainy seasons the temperatures were low during the early stages of crop development (November to February) and high during the later stages of crop development (March to May). Because of these climatic conditions the severity of rust was very low in the postrainy seasons. Siddaramaiah *et al.* (1980) reported that continuous dry periods with temperatures above 26 °Cand relative humidity below 70% delayed rust occurrence and disease severity. The disease severity was extremely low when temperatures were above 35 °C as evidenced in the postrainy seasons in Maharashtra (Munde and Mayee, 1980). The results of the present investigation showed that climatic conditions during the postrainy seasons are unfavourable for rust disease development.

There were marked differences in the time of first appearance of the rust pustules and the disease progress between the 1983 and 1984 rainy seasons. The pustules appeared early in the 1983 rainy season groundnut crops than in the 1984 rainy season groundnut crops. The AUDPC was also higher in the 1983 than in the 1984 rainy season. These differences in rust disease development between the 1983 and 1984 rainy seasons were probably due to difference in weather. The total rainfall (907 mm) and the number of rainy days (71) were more in the 1983 than in the 1984 rainy season. The climate was cool, wet and humid during the 1983 rainy season because of high rainfall, whereas 1984 was a drought year. It

appeared that the total rain and the number of rainy days during the crop season were important factors on epidemic build-up. Krishna Prasad *et al.* (1979) also reported that intermittent rainfall with mean relative humidity above 87% and optimum temperature at 23-24 ^{o}C for a few days were congenial for rust development in the field.

There were marked genotypic effects on rust disease development. Rust always appeared earlier on susceptible than on resistant genotypes in both rainy and postrainy seasons. This could be due to the short incubation periods in susceptible genotypes shown in the present investigation and reported by various investigators (Lin 1981; Sokhi and Jhooty, 1982; Subrahmanyam *et al.*, 1983a,1983c). These genotypic differences in the time of first appearance of the disease were especially marked in the uninoculated plots.

The apparent infection rate (r) of rust disease development was higher in rust-susceptible genotypes than in moderately resistant and resistant genotypes in the 1984 rainy, 1983-84 and 1984-85 postrainy seasons. These results indicated that the resistance to rust in groundnut genotypes was similar to the "partial resistance" described in various host-pathogen systems (Hooker, 1967; Parlevliet 1975; MacKenzie 1976; Berger, 1977; Shaner and Finney, 1980). However, in the 1983 rainy season a reverse trend was observed; the r-values were higher in resistant and moderately resistant genotypes than in suceptible genotypes in the 1983 rainy

season was probably due to severe leaf spot attack which resulted in premature defoliation.

In the present investigation, the r-values of groundnut rust development were in the range of 0.01 to 0.10 units and were very low compared to the r-values of cereal rusts (Van der Plank, 1963).

The delay in time (Δt) in rust disease severity was estimated at 40 days after sowing (initialΔt) and at harvest (finalΔt) for all genotypes in the 1983 and 1984 rainy, and 1983-84 and 1984-85 postrainy season. The initial Δt was high for susceptible genotypes in both rainy seasons. These differences in initial Δt were because of marked genotypic variation in rust disease severity at 40 DAS. Variation in rust disease severity between inoculated and uninoculated plots were higher in susceptible genotypes than in resistant ones. However, in the postrainy season the initial Δt was zero for all genotypes because there was no rust development in either inoculated or uninoculated plots at 40 DAS. There were no consistent genotypic differences in final Δt in any season because of compounding effects of leaf spots at crop maturity.

2. Leaf spots development:

Late leaf spot: Late leaf spot appeared early in the 1983 and 1984 rainy season groundnut crops, but delayed on the 1983-84 and 1984-85 postrainy season crops. The AUDPC for late leaf spot was higher in both rainy seasons than in postrainy seasons. The weather was cool and wet during the rainy seasons providing

favourable climatic condition for infection and development of the late leafspot pathogen. During the postrainy season the number of rainy days and total rainfall were very low, and the weather was dry. The temperatures were low during the early stages of the crop growth (November-February) and very high during the later stages of the crop development (March-May). Because of these climatic conditions the severity of late leaf spot was very low in the postrainy seasons. Sulaiman and Agashe (1965) recorded that minimum predisposing factors for late leaf spot development were:an average rainfall of 240.8 mm, average maximum temperature of 29.3 ^{o}C, average minimum temperature of 23 ^{o}C and average relative humidity of 81.8%. Wangikar and Shukla (1976) determined that August was most favourable month for leaf spot infection in Maharashtra State, India.

The AUDPC was higher in the 1983 than in the 1984 rainy season. These differences in late leaf spot development between the 1983 and 1984 rainy seasons were probably due to differences in weather conditions. The total rainfall (907 mm) and number of rainy days (71) were more in the 1983 rainy season than in the 1984 rainy season. The climate during the 1983 rainy season was cool and wet. It appeared that the total rainfall, the number of rainy days during the crop season were important factors in late leaf spot epidemic build-up. Maublanc (1925) in Senegal and KenKnight (1941) in the USA attributed that rapid spread and severity of leaf spots to heavy rainfall in August-September and spring, respectively.

Tarr (1954) reported that the leaf spots were more prevalent in wetter areas of Sudan with annual rainfall exceeding 500-620 mm. Chohan and Singh (1973) from Punjab, India, recorded that enough precipitation (rainfall and dewfall), high relative humidity (90-92%) and temperature around 20 ^{o}C for 6-7 days during the growth period ensured epiphytotics of leaf spots. Venkataraman and Kazi (1979) reported that leaf spots outbreak would occur when maximum temperature was in the range of 31-35 ^{o}C, minimum temperature in the range of 18-23 ^{o}C, and mean monthly rainfall at least 60 mm.

There were marked genotypic effects on late leaf spot disease development. Late leaf spots always appeared earlier on susceptible than on resistant genotypes to both rainy and postrainy seasons. This could be due to short incubation periods of the pathogen in susceptible genotypes as shown in the present investigation and as reported by various investigators (Nevill, 1981; Subrahmanyam *et al.*, 1982; Walls and Wynne, 1985). These genotypic differences in the time of first appearence of the disease were especially marked in uninoculated plots.

The r-values of late leaf spot disease development were higher in susceptible than in resistant genotypes in the 1984 rainy, 1983-84 and 1984-85 postrainy seasons. However, in the 1983 rainy season, a reverse trend was observed. The r-values were higher in resistant and moderately resistant genotypes than in susceptible genotypes, probably due to severe premature defoliation.

In the present investigation, the r-values of late leaf spot development were in the range of 0.02 to 0.10 units and are very low compared to the r-values of late leaf spot obtained by Plaut and Berger (1980) in Florida, USA.

The initial Δt was high in susceptible genotypes in the 1983 rainy season and in moderately resistant genotypes in the 1984 rainy seasons. However, a reverse trend was observed in the final Δt. In the postrainy seasons, the initial Δt was zero for all genotypes because there was no late leaf spot development in either inoculated or in uninoculated plots. There were no consistant differences in final Δt of all genotypes.

Early leaf spot: Early leaf spot development was very severe in the 1983 rainy season. The primary source of inoculum was not provided, hence there were no differences in the disease severity between the inoculated and uninoculated plots. No genotype interaction was observed, since all the test genotypes were susceptible. The severity of early leaf spot was not recorded in the 1984 rainy season and 1983-84 and 1984-85 postrainy seasons because the disease pressure was very low.

The probable reasons for severe early leaf spot development in the 1983 rainy season were high rainfall (907 mm) and more rainy days (71) during the crop season.

Defoliation: Defoliation was recorded in the 1983 and 1984 rainy season crops. No defoliation occurred in the 1983-84 and

1984-85 postrainy seasons. Defoliation was observed in moderately resistant and resistant genotypes in the 1984 rainy season. The AUDPC in susceptible genotypes was higher in the 1983 rainy season than in the 1984 rainy season. The differences in defoliation between the seasons were due to difference in weather factors between the seasons.

The r-values for defoliation were high in susceptible genotypes. In the present investigation the r-values were in the range of 0.10 to 0.24. The initial Δt was zero an the final Δt was almost same for all genotypes.

3. Total disease (rust, leaf spots and defoliation):

The AUDPC for total disease was higher in both rainy seasons than in the postrainy seasons probably because of the unfavourable climatic conditions during the postrainy seasons. The AUDPC was higher in the 1983 than in the 1984 rainy season.

There were marked genotypic effects on total disease. The total disease was always more in susceptible genotypes than in resistant genotypes in both rainy and postrainy seasons.

The r-values were higher in susceptible genotypes than in resistant genotypes in both rainy and postrainy seasons. The r-values were in the range of 0.03-0.16.

The initial and final Δt were higher in moderately rust and late leaf spot resistant genotypes than in susceptible genotypes in the 1983 and 1984 rainy seasons. The initial Δt was zero for

all genotypes in the 1983-84 and 1984-85 postrainy seasons. The final Δt varied with genotypes.

Very few studies on development of rust and leaf spots diseases have been reported in the literature and so there were only limited data for discussion. The influence of rainfall, temperature and humidity in encouraging or limiting initiation and development of epidemics has been fairly well established. Interaction of these factors with groundnut genotype differences has been less well worked out and such interactions could be important in establishing disease management strategies.

SUMMARY

CHAPTER VI

SUMMARY

Rust and leaf spots diseases of groundnut were studied for over two years from 1983 to 1985 at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) situated 25 km northwest of Hyderabad in Andhra Pradesh, India. The objective was to obtain a better understanding of factors influencing the development, spread and carry-over of the three major groundnut foliar diseases rust, early and late leaf spots. The interaction of the diseases with genetic resistance was included in the study for rust and late leaf spot, but no groundnut genotype was available with resistance to early leaf spot. Rust and late leaf spot epidemics were regular at ICRISAT Center in the 1983 and 1984 rainy seasons but early leaf spot was severe only in the 1983 rainy season. The data obtained on the epidemiology of early leaf spot disease were limited in comparison with the data for rust and late leaf spot. The foliar diseases were important in the rainy seasons but developed to only a very limited extent in the postrainy season irrigated crops.

Temperature was an important factor in determining the longevity of the three pathogens, both in terms of spores stored under controlled conditions in the laboratory, and of spores and mycelium in infected crop debris in the field or stored indoors.

Spores of rust stored in glass vials in the laboratory at low temperatures (-17 to 10 °C) retained germinability and capacity to infect groundnut foliage for lengthy periods (>160 days). When stored at 20 °C the rust spores lost viability within 30 days and when stored at 30 °C they lost viability even more rapidly. Conidia of the late leaf spot fungus could be stored for over 160 days without loss of germinability and infectivity at temperatures as high as 20 °C, but at 30 °C or above they also suffered rapid loss of viability. Bearing in mind the high ambient temperatures found during crop growth and after harvest in the semi-arid tropics, it is unlikely that spores of rust and late leaf spot fungi could survive for more than 30 days under such conditions. They might be able to cause infection of a neighbouring crop but could not carry over the disease to crops sown more than a few weeks later.

After harvest of rainy and postrainy season crops, debris from groundnut plants infected with rust and late leaf spot diseases was kept on the field surface, buried at 5 and 10 cm depths in the soil, and stored indoors. The pathogens rapidly lost viability when retained in the field (on and buried in the soil) and this was most rapid after the harvest of the postrainy season crop. When infected plant debris was stored indoors, the rust fungus survived for 30 days in debris from resistant genotypes and for 45 days in debris from susceptible genotypes. These periods of survival could help with disease perpetuation in a multiple cropping system where

groundnuts follow groundnuts with little or no break. They would not ensure carry-over from one rainy season to the next under temperatures commonly encountered in the tropics. In the case of late leaf spot disease, the fungus survived in debris from resistant genotypes for 135 days and in debris from susceptible genotype for over a year. These genotypic differences in survival of the late leaf spot pathogen may have practical implications in perpetuation of the pathogen from season to season.

Rust, early and late leaf spots were observed on groundkeepers and on volunteer groundnut plants at ICRISAT Center from October 1984 (end of the 1984 rainy season crop) to June 1985 (begining of the 1985 rainy season crop) indicating the likely role of these plants in carry-over of the three diseases.

No collateral hosts for rust, early or late leaf spot pathogens were found although many leguminous crop and weed plants were artificially inoculated with the pathogens.

Groundnut pods and seeds surface-contaminated with viable spores of rust, early and late leaf spot pathogens gave rise to disease-free seedlings. Such surface contaminated pods and seeds are therefore unlikely to be responsible for carry-over and spread of these diseases. However, the presence of viable spores on groundnut pods could be important if they were to come in contact with foliage of susceptible groundnut genotypes. Rust spores on clothes were shown to be

capable of being transported to foliage and to produce infection when the persons wearing them walked between rows of groundnut plants. Implications for plant quarantine are obvious.

Epidemiological studies under controlled conditions in the laboratory showed that rust and leaf spots diseases initiation and development were more rapid on susceptible than on resistant genotypes. Rust and late leaf spot-resistant genotypes had increased incubation periods, decreased infection frequencies and leaf area damage, and reduced lesion diameters and sporulation indexes. Humidity was maintained at a high level and temperatures were varied in the laboratory experiments. Rust and late leaf spot diseases development was optimum at temperatures of 20-30 ^{o}C. This agreed with conidia germination studies which showed the optimum temperature range for *in vitro* germination of rust urediniospores to be 20 to 30 ^{o}C and for late leaf spot conidia to be 15 to 30 ^{o}C. Early leaf spot development was favoured by temperatures in the 20-30 ^{o}C range. Although no resistant genotypes were available for early leaf spot pathogen, two field susceptible genotypes had smaller early leaf spot lesions and lower sporulation index es than the other genotype examined. None of the three diseases established at temperature below 10 ^{o}C or above 35 ^{o}C.

Two genotypes with resistance to rust and late leaf spot diseases and two with moderate resistance to these diseases were grown in replicated field trials in two rainy (1983 and

1984) and two postrainy (1983-84 and 1984-85) seasons together with two rust and late leaf spot susceptible genotypes. Effects of inoculation with rust and late leaf spot on disease development were studied. Measurements were made of percentage leaf area damaged from rust and late leaf spot, percentage defoliation, and the total disease (rust and late leaf spot). The area under the disease progress curve (AUDPC) was measured, and apparent infection rates (r- values) and the delay in time (Δt) were calculated for each treatment. Rust and late leaf spot diseases attacks appeared early and were severe (high AUDPC values) in inoculated plots in both rainy and postrainy seasons. There was a strong varietal interaction on rust and late leaf spot development. Development of these two diseases was delayed and they were less severe on resistant than on susceptible genotypes. However, on susceptible genotypes both diseases appeared early and were severe. Rust and late leaf spot diseases were much more severe on all genotypes in the rainy seasons than in the postrainy seasons. Levels of these diseases were higher in the 1983 rainy season than in the 1984 rainy season, reflecting the effects of high rainfall and relative humidity and low temperatures in 1983. Early leaf spot was severe only in the 1983 rainy season and all genotypes had similar levels of disease. The r-values for rust and late leaf spot diseases were higher for susceptible genotypes than for resistant ones except in the 1983 rainy season. This difference might have been caused by the severe defoliation observed in 1983 that could have been

due to the higher than normal levels of early leaf spot. Differences in rust and late leaf spot disease levels at the begining and end of the epidemic were compared by measuring the Δt. The initial Δt for rust was high in susceptible genotypes in both rainy seasons but the initial Δt for late leaf spot was variable. The initial Δt for rust and late leaf spot diseases in the postrainy season was zero for all genotypes. The final Δt for rust and late leaf spot was variable in both rainy and postrainy seasons.

The practical implications of these studies on groundnut foliar diseases are dependant to a considerable extent on the cropping system used and on climate. In a typical semi-arid tropics environment with groundnut grown as a rainy season crop and with a dry season break of 5 to 7 months there is no chance of rust spores lasting through the dry season in a viable state. For the disease to attack the second crop the spores have to come from an outside source, e.g., carried on wind currents, or the rust has to survive on ground-keepers and volunteer groundnut plants growing in swampy areas on associated with irrigated crops. Conidia and mycelia of the leaf spots fungi are more capable of remaining viable through a dry season break, particularly if infested crop residues or hay is protected from weathering.

In regions where temperatures are low during the dry season (winter) the spores of all three fungi may survive for longer periods.

Where crops are grown the year round there is always a source of inoculum of the pathogens to carry over the disease from crop to crop.

Use of resistant genotypes can greatly reduce rate of epidemic build-up for rust and late leaf spot diseases and considerably reduce yield losses. There is also likely to be less inoculum left after harvest for disease carry-over.

Under typical rainy season conditions build-up of rust and leaf spots can be rapid even if initial inoculum is limited.

LITERATURE CITED

Literature Cited

*Abdou, Y.A.M. 1967. The source and nature of resistance in Arachis L. to species, Mycosphaerella arachidicola Jenk. and Mycosphaerella berkeleyii Jenk., and factors influencing sporulation of these fungi. Diss. Abstr. 27B:1689. (Rev. Appl. Mycol. 46:2905).

Abdou, Y.A.M., Gregory, W.C., and Cooper, W.E. 1974. Sources and nature of resistance to Cercospora arachidicola Hori and Cercosporidium personatum (Berk. & Curt.) Dei. in Arachis species. Peanut Sci. 1:6-11.

Arneson, P.A. 1970. Chemical control of rust and Cercospora leaf spot of peanuts in Honduras and Nicaragua. Phytopathology 60:1539 (Abstract).

Arokoyo, J.O., Emechebe, A.M., Fowler, A.M., Gumerl, M.H., Harkness, C., and McDonald, D. 1977. Groundnut rust in Nigeria: Occurrence and preliminary survey. Samaru Miscellaneous Paper 68, Institute for Agrl. Res., Samaru, Nigeria, pp. 14.

Arthur, J.C., 1934. Manual of the Rusts in the United States and Canada. Purdue Res. Foundation, Lafayette, Indiana. pp. 438.

ASI, (Agricultural Situation in India). 1984. 39: 579-580.

Aulakh, K.S., Sandhu, R.S., and Sunar, M.S. 1972. Resistance to "tikka" leaf spot in groundnut germplasm. Indian J. Agric. Sci. 42:952-955.

*Bailey, B.E. 1966. Plant Pathology. Rep. Agric. Res. Coun. Cent. Africa, 1966:52-55. (Rev. Appl. Mycol. 46:1387a).

Barve, S.M., 1980. Bio-efficacy of nikel chloride against major foliar pathogens of groundnut. M.Sc., Thesis, M.A.U., Parbhani, India.

Berger, R.D. 1977. Application of epidemiological principles to achieve plant disease control. Ann. Rev. Phytopath. 15: 165-183.

Bhama, K.S. 1972. A rust on groundnut leaves near Madras. Curr. Sci. 41:188-189.

Blamey, F.P.C., Chapman, J., and Young, B.W. 1977. Epiphytology of Phoma web blotch and Cercospora leaf spot in Spanish groundnuts. Phytophylactica 9:63-64.

Bolhuis, G.G. 1955. La culture de l'Arachide en Indonesie, Oleagineux 10:157-160.

*Botany, 1945. Rep. Ga. Exp. Sta. 1944-45, pp. 48-58. (Rev. Appl. Mycol. 25:333).

Bromfield, K.R. 1971. Peanut rust: A review of literature. J. Amer. Peanut Res. Edu. Assoc. Inc. 3:111-121.

Bromfield, K.R. 1974. Current distribution of rust on groundnut and known sources of resistance. FAO Plant Prot. Bull. 22:29-31.

Bromfield, K.R., and Cevario, S.J. 1970. Greenhouse screening of peanut (Arachis hypogaea) for resistance to peanut rust (Puccinia arachidis). Plant Dis. Rep. 54:381-383.

Butler, E.J. 1918. Fungi and disease in plants. Thacker, Spink & Co., Calcutta. pp. 319-323.

Castellani, E. 1959. La ruggine de l' Arachide. (Peanut rust). Olearia 13:261-270.

Castellani, E., and Anglesio, P. 1964. (Control tests against groundnut rust in the Dominican Republic). Riv. Agric. Subtrop. 58:30-46.

*Castellani, E., Mohamed, I.M., and Jama, A.N. 1977. (Groundnut rust in Somalia). Sannadaalaha Waxbarashada Iyo Baarista Studi e Ricerche 1:57-68. (Rev. Pl. Path. 58:2041).

Chahal, A.S., and Aulakh, K.S. 1972. Control of tikka leaf spot (Cercospora personata and Cercospora arachidicola) of groundnut with benomyl. Plant Dis. Rep. 56:1099-1100.

Chahal, D.S., and Chohan, J.S. 1971. Puccinia rust on groundnut in India. FAO Plant Prot. Bull. 19:90.

*Chevaugeon, J. 1952. Recherches sur la Cercosporiose de l'Arachide en Moyenne Casamance. (Researches on cercosporiosis of groundnut in Middle Casamance). Ann. Inst. Nat. Rech. Agron., Ser. C. (Ann. Epiphyt), 3, 4:489-510. (Rev. Appl. Mycol. 32:661- 662.

Chohan, J.S. 1974. Recent Advances in diseases of groundnut in India. In: (Eds. S.P. Raychudhuri and J.P. Verma) Current Trends in Plant Pathology. Prof. S.N. Das Gupta birthday celebrations committee, Dept. of Botany, Univ. of Lucknow. pp. 171-184.

Chohan, J.S., and Singh, J. 1973. Cited in "Recent advances in diseases of groundnut in India". In: (Eds. S.P. Raychudhuri and J.P. Verma) Current Trends in Plant Pathology. Prof. S.N. Das Gupta birthday celebrations committee, Dept. of Botany, Univ. of Lucknow. pp. 171-184.

Chupp. C. 1953. A monograph of the fungus genus *Cercospora*. Published by Cornell University, Ithaca, N.Y. pp. 186.

Clark, E.M., Backman, P.A., and Rodriguez-Kabana, R. 1974. *Cercospora* and *Cercosporidium* tolerance to benomyl and related fungicides in Alabama peanut fields. Phytopathology 64:1476- 1477.

*Clinton, P.K.S. 1962. Causes of losses of yield in groundnuts in the Sudan Central Rainlands. The control of soil-borne pests and diseases of groundnuts in the Sudan Central Rainlands. Emp. J. Exp. Agric., 30:137-154. (Rev. Appl. Mycol. 41:690).

*Company, M., Stalker, H.T., and Wynne, J.C. 1982. Cytology and leaf spot resistance in *Arachis hypogaea* x Wild species hybrids. Euphytica 31:885-893.

Cook, M. 1972. Screening of peanut for resistance to peanut rust in the greenhouse and field. Plant Dis. Rep. 56:382-386.

Cooper, W.E. 1961. Control of peanut leaf spot (*Cercospora arachidicola* Hori) by fungicidal sprays. Plant Dis. Rep. 45:674- 676.

*Corbett, D.C.M. 1965. Annual Report of the Department of Agriculture, Malawi for the year 1962/63. Part II. pp. 157. (Rev. Appl. Mycol. 45:700b).

Cummins, G.R. 1978. Rust fungi on legumes and composites in North America. Tucson, Arizona, USA, University of Arizona Press.

*Das, G. 1951. Growth, spore germination and infection studies on a peanut leaf spot fungus. M.S. Thesis, Texas A & M Univ., College Station, USA. pp. 37.

Deighton, F.C. 1967. New names in *Mycosphaerella* (*M.arachidis* and *M.pruni-persicae*) and validation of *M.rosicola*. Tran. Br. Mycol. Soc. 50:328-329.

Durairaj, P., and Mohan, R. 1978. Evaluation of fungicides for control of groundnut rust. Madras Agric. J. 65:692.

Fang, H.C. 1977. (Studies on peanut rust in Taiwan). Plant Prot. Bulletin, Taiwan, 19:218-222.

Fang, H.C. 1982. (Occurrence of peanut rust and its control). In Tainan DAIS Scientific Meeting Report 1981. Tainan, Taiwan; Agric. Improvement Sta. pp. 105-112.

*Farrell, J.A.K., Bailey, B.E., and Mills, W.R. 1968. The effects of time of planting, spacing and fungicide on Cercospora leaf spots of groundnuts in Malawi. Rhodesia, Zamb., Malawi J. Agric. Res. 5:241-247. (Rev. Appl. Mycol. 47:2013).

Feakin, S.D. (Ed.) 1973. Pest control in groundnuts. PANS Manual No. 2. Centre for Overseas Pest Research, London, pp. 197.

Felix, S., and Ricaud, C. 1977. Occurrence and fungicidal control of groundnut rust in Mauritius. Revue Agricole et Sucriere de l'Ile Maurice. 56:110-114.

*Firman, I.D. (Compiler). 1981. Plant protection news. Information Circular South Pacific Commission. No. 88, pp. 12. (Rev. Pl. Path. 60:5641).

Foudin, A.S., and Macko, V. 1974. Identification of the self- inhibitor and some germination characteristics of peanut rust uredospores. Phytopathology 64:990-993.

Fowler, A.M. 1970. Epidemiology of Cercospora leaf spot disease of groundnuts. Samaru Agric. News letter No. 12:66-69.

Frezzi, M.J. 1960. Enfremedades Del mani en la Provincia de Cordoba (Argentina). Rev. Invest. Agr. 14:113-115.

*GAES, (Georg ia Agricultural Experimental Station), 1951. Sixty-second Annual Report, 1949-50. pp. 92 (Rev. Appl. Mycol. 31: 421).

Garren, K.H., and Jackson, C.R. 1973. Peanut disease. In Peanuts - Culture and Uses. APREA Stone Printing Co., Roanoke, VA. pp. 429-494.

Garren, K.H., and Wilson, C. 1951. "Peanut diseases". In "The peanut, the unpredictable legume". Natnl. Fertilizer Asson. Washington D.C. pp. 333.

Gibbons, R.W. 1966. Mycosphaerella leaf spots of groundnuts. FAO Plant Prot. Bull. 14:25-29.

Gibbons, R.W. 1980. The ICRISAT groundnut program. Proceedings of The International Workshop on groundnuts, 13-17 Oct. 1980. Patancheru, A.P. pp. 12-15.

Gibbons, R.W. and Bailey, B.E. 1967. Resistance to *Cercospora arachidicola* in some species of *Arachis*. Rhodesia, Zambia, Malawi J. Agric. 5:57-59.

Ghuge, S.S., Mayee, C.D., and Godbole, G.M. 1980. Development of rust and leaf spots of groundnut as influenced by foliar application of carbendazim and tridemorph. Pesticides 14:16-19.

Ghuge, S.S., Mayee, C.D., and Godbole, G.M. 1981. Assessment of losses in groundnut due to rust and tikka leaf spot. Indian Phytopath. 34:179-182.

*Gregory, W.C. 1956. Induction of useful mutation in peanut. Genetics in Plant Breeding, Report of Brookhaven Symposium in Biology. No. 9. Biology Dept. Boorkhaven, National Laboratory, Upton, New York.

Hammons, R.O. 1977. Groundnut rust in the United States and the Caribbean. PANS 23:300-304.

Hanks, R.J., and Ashcroft, G.L. 1980. Applied soil physics. Springer - Verlag, Berlin Heidelberg New York. pp. 155.

Harrison, A.L. 1971. Peanut leaf spot and rust control on peanuts. J. Amer. Peanut Res. Educ. Assoc. Inc. 3:96-101.

Harrison, A.L. 1972. Observations on the development and spread of peanut rust in South Texas in 1971. Plant Dis. Rep. 56:873- 874.

Harrison, A.L. 1973. Control of peanut leaf rust alone or in combination with Cercospora leaf spot. Phytopathology 63:668- 673.

*Hemingway, J.S. 1954. Cercospora leaf spot of groundnut in Tanganyika. E. Afr. agric. J. 19:263-271. (Rev. Appl. Mycol. 34:74).

*Hemingway, J.S. 1957. The resistance of groundnuts to Cercospora leaf spots. Emp. J. Exp. Agric. 25:60-68. (Rev. Appl. Mycol. 36:448).

Hennen, J.F., Figueiredo, M.B., Ribeiro, I.J.A., and Soave, J. 1976. The occurrence of teliospores of Puccina arachidis (Uredinales) on Arachis hypogaea in Sao Paulo State, Brazil, Summa Phytopathologica 2:44-46.

Higgins, B.B. 1935. Breeding peanuts for disease resistance. Phytopathology 25:971-972 (Abstract).

*Higgins, B.B. 1940. Botany. Rep. Ga. Agric. Exp. Sta. 1938-39, pp. 60-64. (Rev. Appl. Mycol. 20:450).

Higgins, B.B. 1956. Les maladies de l'Arachide aux Etats - Unis. Oleagineux 11:213-220.

Hoagland, D.R., and Arnon, D.I. 1950. The water culture method for growing plants without soil. Calif. Agric. Exp. Circ. 347.

Hooker, A.L. 1967. The genetics and expression of resistance in plants to rusts of the genus Puccinia. Ann. Rev. Phyopath. 5: 163-182.

ICRISAT, (International Crops Research for the Semi-Arid Tropics). 1977. Annual Report for 1976-77, Patancheru, India. pp. 121.

ICRISAT, (International Crops Research for the Semi-Arid Tropics). 1978. Annual Report for 1977-78, Patancheru, India, pp.154.

Jackson, C.R., and Bell, D.K. 1969. Diseases of peanut (groundnut) caused by fungi. Ga. Agric. Exp. Sta. Res. Bull. 56:156.

Jaczewski, A.A. 1910. Year book of information about diseases and injuries of cultivated and useful plants. 6:465.

Jayaramaiah, H., Siddaramaiah, A.L., and Prasad, K.S.K. 1979. Incidence of rust on some species/varieties of groundnut. Curr. Res. UAS, Bangalore 8:29-30.

Jenkins, W.A. 1938. Two fungi causing leaf spot of peanut. J. Agric. Res. 56:317-332.

Jenkins, W.A. 1939. The development of Mycosphaerella berkeleyii. J. Agric. Res. 58: 617-620.

Jensen, R.E., and Boyle, L.W. 1965. The effect of temperature, relative humidity and precipitation on peanut leaf spot. Plant Dis. Rep. 49:975-978.

*Kao, C.Y., and Wu, L.C. 1970. Cercospora leaf spots of peanut. I. Early leaf spot and the physiology of its causal organism, Cercospora arachidicola. Memoirs of the college of Agriculture. National Taiwan Univ. 11:90-100 (Rev Pl. Path. 53:747).

Karunakaran, P., and Raj, J.S. 1973. The survival of Cercospora personata (Berk. & Curt.) Ell. & Ev., Cercospora hibisci Tracy & Earle., and Cercospora henningsii Allesch. in the soil. Agric. Res. J. Kerala 11:162-163.

*Katan, T. 1980. Benomyl-resistant Cercosporidium personatum in peanut fields in the Sharon region of Israel. Phytoparasitica 8:213-215. (Rev. Pl. Path. 60:2889).

Kenjale, L.D., Shinde, P.A., and Utikar, P.G. 1981. Loss in groundnut yield due to rust. Indian Phytopath. 34:374-376.

KenKnight, G. 1941. Peanut diseases in certain Taxas counties in 1941, with notes on occurrence of peanut rust. Plant Dis. Rep. 25:587-588.

Keswani, C.L., and Ondieki, J.J. 1976. Groundnut rust in Kenya and Tanzania. FAO Plant Prot. Bull. 24:135-136.

Kolte, S.J., and Awasthi, R.P. 1979. Some observations on occurrence of groundnut rust in the Nainital Tarai region of Uttar Pradesh. Indian Phytopath. 32:155-156.

Kolte, S.J., and Shina, A.P. 1976. Influence of soil and seed application of certain systemic fungicides on the severity of Cercospora leaf spot of groundnut. Pesticides 10:31-32.

Kolte, S.J., Tewari, A.N. and Awasthi, R.P. 1978. Chemical control of Cercospora leaf spot of groundnut. Pesticides 12:21- 25.

Kono, A. 1977. On the uredospore germination of peanut leaf rust (Puccinia arachidis Speg.) on peanut leaves. Bull. Fac. Agric. Miyazaki Univ. 24:225-234.

Krishna, A., and Singh, R.A. 1979. Hansfordia pulvinata mycoparasitic on Cercospora species causing tikka disease of groundnut. Indian Phytopath. 32:318-320.

Krishna Prasad, K.S., Siddaramaiah, A.L., and Hegde, R.K. 1979. Development of peanut (groundnut) rust disease in Karnataka State, India. Plant Dis. Rep. 63:692-695.

Kucharek, T.A. 1975. Reduction of Cercospora leaf spots of peanut with crop rotation. Plant Dis. Rep. 59:822-823.

Lin, Y.S. 1981. Effects of inoculum concentrations on the resistance of peanuts of Puccinia arachidis Speg. J. Agric. Res. (China) 30: 324-331.

Lingaraju, S., Siddaramaiah, A.L., and Hegde, R.K. 1979. Viability and survival of uredospores of Puccinia arachidis Speg. in Dharwad. Curr. Res. UAS Bangalore 8:68-69.

Littrell, R.H. 1974. Tolerance to Cercospora arachidicola to benomyl and related fungicides. Phytopathology 64:1377-1378.

Lyle, J.A. 1964. Development of Cercospora leaf spot of peanut. J. Alabama Acad. Sci. 35:9.

MacKenzie, D.R. 1976. Application of two epidemiological models for the identification of slow rusting in wheat. Phytopathology 66: 55-59.

Mallaiah, K.V. 1976. A note on the seasonal changes in the incubation time of groundnut rust. Curr. Sci. 45:26.

Mallaiah, K.V., and Rao, A.S. 1979a. Groundnut rust: Factors influencing disease development, sporulation and germination of uredospores. Indian Phytopath. 32:382-388.

Mallaiah, K.V., and Rao, A.S. 1979b. Survival of groundnut rust in India. Indian J. Microbiology 19:209-213.

Mallaiah, K.V., and Rao, A.S. 1982. Aerial dissemination of urediniospores of groundnut rust. Trans. Br. Mycol. Soc. 78:21- 28.

*Mallamaire, A. 1931. L'extension de la maladie des taches brunes de l'Arachide en Afrique Occidentale Francaise et au Cameran. (The spread of the brown spot disease of groundnut in French West African and the Cameroon). Agron. Colon. 20:37-39. (Rev. Appl. Mycol. 11:279).

MANN, (Ministry of Agriculture, Northern Nigeria). 1957. Annual Report for 1956-57. pp. 144.

*Maublanc, A. 1925. La maladie des taches brunes de l'Arachide en Afrique occidentale. (The leaf spot disease of groundnut in West Africa). Agron. Colon. 13:126-127. (Rev. Appl. Mycol. 5:143).

Mayee, C.D. 1982. Review of research on rust of groundnut. AGRESCO meeting, M.A.U., Parbhani, April, 1982.

Mayee, C.D., Godbole,G.M., and Patil, F.S. 1977. Appraisal of groundnut rust in India: problems and approach. PANS 23:162- 165.

Mayee, C.D., Patil, F.S., and Raut, K.G. 1979. Evaluation of groundnut cultivars for resistance to rust and possible existance of races. Indian Phytopath. 32:109-110.

*Mazzani, B., and Allievi, J. 1971. (Effect of crop rotation on the incidence of leaf spot due to Mycosphaerella on groundnut). Agronomia Trop. 21:329-332. (Rev. Appl. Mycol. 51:4552).

Mazzani, B., and Hinojosa, S. 1961. Diferencias varietales de susceptibilidad a la Roya del Mani en Venezuela. (Varietal differences in susceptibility to groundnut rust in Venezuela). Agron. Trop. Maracay 11:41-45.

*Mazzani, B., Allievi, J., and Bravo, P. 1972. (Relation between the incidence of leaf spots caused by *Cercospora* spp. and some varietal characteristics of groundnut). Agronomia Trop. 22:119-132. (Rev. Appl. Mycol.52:2080).

*McCallan, S.E.A. 1946. Outstanding diseases of agricultural crops and uses of fungicides in the United States. Contr. Boyce Thompson Inst. 14:105-115. (Rev. Appl. Mycol. 25:406).

McDonald, D., 1980. Report on a visit to People's Republic of China. ICRISAT, Patancheru, India pp. 62.

McDonald, D. and Emechebe, A.M. 1978. Occurrence and preliminary survey of peanut rust in Nigeria. Plant Dis. Rep. 62:5-8.

McDonald, D. and Fowler, A.M. 1977. Control of Cercospora leaf spot of groundnuts in Nigeria. Nigerian J. Plant Prot. 2:43-59.

McDonald, D., Fowler, A.M., Harkness, C., and Gumerl, M.H. 1980. Groundnut rust established in Nigeria: Observations on occurrence and effects on certain fungicides on control of the disease. Samaru Misc. Paper 58, Institute for Agrl. Res. Samaru, Nigeria, pp. 23.

McDonald, D., Subrahmanyam., Gibbons.R.W., and Smith, D.H. 1985. Early and late leaf spots of groundnut. Infor. Bull. No. 21. Patancheru, A.P. 502324, India: CRISAT, pp.19.

McVey, V.D. 1965. Inoculation and development of rust on Peanuts grown in the greenhouse. Plant Dis. Rep. 9:191-192.

Mehan, V.K., and Chohan, J.S. 1981. Effect of fungicides n leaf spot pathogens and phylloplane mycoflora of groundnut. Trans. Br. Mycol. Soc. 76:361-366.

*Mehta, P.R., and Mathur, S.C. 1954. Efficacy of various fungicides in controlling Cercospora leaf spots of groundnut (*Arachis hypogaea* L.). Agric. Anim. Husb., Uttar Pradesh 5:11- 12. (Rev. Appl. Mycol. 34:509).

*Mehta, P.R., Singh, B., and Mathur, S.C. 1953. Observations on known and new diseases of field crops in Uttar Pradesh during 1951-52. Plant Prot. Bull., New Delhi, 5:52-53. (Rev. Appl. Mycol. 34:697).

Melouk, H.A. 1982. Effect of early infection with Cercospora leaf spot on root mass, pegging and root nodulation of peanut plants. Protection Ecology 4:109-113.

Melouk, H.A., and Banks, D.J. 1978. A method of screening peanut genotypes for resistance to Cercospora leaf spot. Peanut Sci. 5:112-114.

Mercer, P.C. 1973. The control of Cercospora leaf spot on groundnuts in Malawi and its effect on the parameters of yield. PANS 19:201-207.

Mercer, P.C. 1976. Ultra - low volume spraying of fungicides for control of Cercospora leaf spot of groundnuts in Malawi. PANS 22:57-60.

Mercer, P.C. 1977. Pests and diseases of groundnuts in Malawi. I. Virus and foliar diseases. Oleagineaux 32:483-486.

*Miller, C.R., Kucharek, T.A., and Lipscomb, R.W. 1971. Chemical control of Cercospora leaf spots of peanuts. Proceedings, of Soil and Crop Science Society of Florida 30:371-376 (Rev. Pl. Path. 54:281).

Miller, L.I. 1939. Control of leaf spot of peanut with copper and sulphur fungicides. Plant Dis. Rep. 23:5-6. (Mimeographed).

Miller, L.I. 1949. Cultural and parasitic races of *Cercospora arachidicola* and *Cercospora personata*. Phytopathology 39:15 (Abstract).

*Miller, L.I. 1953. Studies of the parasitism of *Cercospora arachidiola* Hori and *C. personata* (B. & C.) Ell. & Ev. Diss. Abstr. 13:644-645. (Rev. Appl. Mycol. 33:463).

Misra, A.K., and Misra, A.P. 1975. Groundnut rust in Bihar - Varietal reaction. Indian Phytopath. 28:557-559.

Moraes, S.A., and Salgado, C.L. 1979. (Evaluation of the resistance of groundnut (*Arachis hypogaea* L.) to *Cercospora arachidicola*). Fitopatologia 14:65-72.

Muhammad, S.V., and Dorairaj, M.S. 1968. Note on the gradation of groundnut varieties to Cercospora resistance in Madras state. Indian J. Agric. Sci. 38:941-944.

Mulder, J.L., and Holliday, P. 1974. CMI descriptions of pathogenic fungi and bacteria No. 411 and 412. CMI, Kew, Surrey, England, Set 42 No. 411-420.

Munde, P.N., and Mayee, C.D. 1979. Effect of temperature on incubation period of three isolates of *Puccinia arachidis*. Res. Bull. Marathwada Agric. Univ. 3:62.

Munde, P.N., and Mayee, C.D. 1980. Factors influencing development of groundnut rust in detached leaf inoculation. Indian Phytopath. 33:444-449.

Nagarajan, S. 1983. Plant disease epidemiology. Oxford & IBH Publishing Co. New Delhi, Bombay, Calcutta. pp. 176.

*Nandi, H.K. 1941. Appendix II. Annual Report of the Economic Botanist, Assam, for the year 1939-40. pp. 55-138. (Rev. Appl. Mycol. 20:447).

Natarajan, S., and Subramanian, K.S. 1983. Fungicidal control of rust and leaf spots of groundnut. In Proceedings of the National seminar on management of diseases of oil seed crops, Madurai, TNAU, India, pp. 36-38.

Nath, V.R., and Kulakarni, L.G. 1967. Effect of different dates of sowing of groundnut on the development and intensity of leaf spot disease by Cercospora spp. Indian J. Agric. Sci. 37:362- 368.

Nevill, D.J. 1981. Components of resistance of Cercospora arachidicola and Cercosporidium personatum in groundnuts. Ann. appl. Biol. 99: 77-86.

Nowell, N. 1915. Spraying peanuts for leaf rust. The Agric. News (Barbados). 14:350.

O'Brien, R.G. 1977. Observations on the development of groundnut rust in Australia. PANS 23:297-299.

Oso, B.A. 1972. Conidial germination in Cercospora arachidicola Hori. Trans. Br. Mycol. Soc. 59: 169-172.

Parleveliet, J.E. 1975. Partial resistance of barley to leaf rust, Puccinia hordei. I. Effect of cultivar and development stage on latent period. Euphytica 24: 21-27.

Patil, B.P. and Kalekar, A.R. 1974. Effect of seven fungicides and antibiotics on the intensity of leaf rust of groundnut (Puccinia arachidis Speg.). Pesticides 8:23-25.

Peregrine, W.T.H. 1971. Groundnut rust (Puccinia arachidis) in Brunei. PANS 17:318-319.

*Plant Pathology, 1965. Rep. Dep. Agric. Mauritius 1963. pp. 59- 63. (Rev. Appl. Mycol. 44:3232d).

Plaut, J.L., and Berger, R.D. 1980. Development of Cercosporidium personatum in three peanut canopy layers. Peanut Sci. 7: 46-49.

Ponnaiah, S., Sachidhanantham, K., and Rao, S.M. 1982. Evaluation of fungicides against tikka and rust diseases of groudnut. Pesticides 16:27-28.

Porter, D.M., Smith, D.H., and Rodriguez - Kabana R. 1982. Peanut plant diseases In: Peanut Science and Technology. Eds. Pathee H.E. and Young, C.T., Amer. Peanut Res. Educ. Soc. Inc. Yoakum, Tx. USA, p. 326-340.

Prasad, K.S.K., Hegde, R.K., Siddaramaiah, A.L., and Jayaramaiah, H. 1979. Screening of groundnut varieties for tikka disease resistance. Curr. Res. UAS, Bangalore 8:104-105.

Prasad, K.V., and Vyas, S.C. 1981. Some high yielding varieties of groundnut resistant to rust and leaf spots. Seeds and Farms 7:19-20.

*Prasad, N. 1968. Proc. 1st summer Inst. Plant Disease Control. New Delhi. pp. 21. Cited in: (Eds. S.P. Raychudhuri and J.P. Verma) Current Trends in Plant Pathology. Prof. S.N. Das Gupta birthday celebrations committee, Dept. of Botany, Univ. of Lucknow. pp. 171-184.

*Prasartsee, C., and Brown, W.M. 1971. Systemic control of Cercospora leaf spot of peanuts under north east conditions. Thai J. Agric. Sci. 4:79-83. (Rev. Pl. Path. 51:4554).

Pyzner, J.R. 1980. Ph.D. Thesis, Oklahoma State Univ. — Stillwater, USA, pp. 91.

*QDPI, (Queensland Department of Primary Industries). 1973. Annual Report 1972-73, Brisbane, Australia, pp. 63. (Rev. Appl. Path. 54:653d).

Raemaekers, R., and Preston, G. 1977. Groundnut rust occurrence and foliar disease control in Zambia. PANS 23:166-170.

Ramakrishna, V., and Apparao, A. 1968. Studies on the tikka disease of groundnut. Indian Phytopath. 21:31-36.

Ramakrishna, V., and Subbayya, J. 1973. Occurrence of groundnut rust in India. Indian Phytopath. 26:574-575.

*Reddy, D.B., (Ed.) 1975. New records. Quarterly newsletter plant protection committee for South East Asia and Pacific region. 18:6-8. (Rev. Pl. Path. 55:985).

*Research and Farming 1943. Sixty-sixth Annual Report of the North Carolina Agricultural Experiment Station 1942-43. pp. 122. (Rev. Appl. Mycol.26:332).

Robson, W. 1914. Spraying of groundnuts for leaf rust. The Agric. News (Barbados). 13:380.

*Roldan, E.P., and Querijero, A.P. 1939. Black spot of peanut. Philipp. Agric. J. 27:669-682. (Rev. Appl. Mycol. 18:433).

Rothwell, A. 1962. Diseases of groundnuts in southren Rhodesia. Rhod. Agric. J. 59:199-120.

Rothwell, A. 1975. Peanut rust in Rhodesia. Plant Dis. Rep. 59:802-803.

Schiller, J.M., and Samoapol, R. 1981. Foliar diseases and their control in rainfed groundnut production in Thailand. Trop. Pest Management 27:13-23.

Seif, A.A. 1979. Peanut (Groundnut) rust in Kenya. Plant Dis. Rep. 63:591-593.

Seshadri, P. 1975. Control of groundnut rust disease with foliar application of nickel chloride. Farm Science 2:6-7.

Shaner, G., and Finney, R.E. 1980. New sources of slow leaf rusting resistance in wheat. Phytopathology 70: 1183-1186.

Shanmugam, N., Ranganathan, K., and Krishnamurthy, C.K. 1972. A new record of groundnut rust caused by Puccinia arachidis Speg. Madras Agric. J. 59:185.

Shanmugam, N., Thangavel, P., and David, B.V. 1975. Occurrence of a mycophagus thrips on the recently recorded groundnut rust. Sci. & Cult. 41:80.

Shanta, P. 1960. Studies on Cercospora leaf spot of groundnuts (Arachis hypogaea L.). I. Effect of environmental factors on disease incidence and on survival of the pathogen. J. Madras Univ. Sect. B. 39:167-177.

Sharma, B.D., and Mukherji, S.K. 1972. A new record of a rust on groundnut (Arachis hypogaea L.) in India. Curr. Sci. 41:229.

Sharma, N.D., Vyas, S.C., and Jain, A.C. 1977. Tuberculina costaricana Syd.: a new hyperparasite on groundnut rust (Puccinia arachidis Speg.). Curr. Sci. 46:311.

Shaw, E.D., and Layton, W.A. 1975. Occurrence of peanut rust and tobacco powdery mildew in Papua New Guinea. Dept. Agric. Stock & Fish., Port Moresby, Res. Bull. 32:13:27-32.

Shokes, F.M., Gorbet, D.W., and Sanden, G.E. 1982. Effect of planting date and spray initiation on control of peanut leaf spots in Florida. Plant Dis. 66:574-575.

Siddaramaiah, A.L., Desai, S.A., and Jayaramaiah, R. 1981. Occurrence and severity of a mycoparasite on "tikka" leaf spots of groundnut. Curr. Res. UAS, Bangalore 10:14-15.

Siddaramaiah, A.L., Hiremath, R.V., and Krishna, K.S. 1977a. Control of tikka disease of groundnut with Du-Ter. Indian J. Plant Prot. 5:193-194.

Siddaramaiah, A.L., Prasad, K.S.K., and Hegde, R.K. 1977b. Chemical control of groundnut rust. Pesticides 11:38-39.

Siddaramaiah, A.L., Desai, S.A., Hegde, R.K., and Jayaramaiah, H. 1980. Effect of different dates of sowing on rust development in Karnataka. Proc. Indian National Sci. Acad. B 46:389-392.

Sidhu, G.S., and Chohan, J.S. 1972. Field scale testing of different fungicides for the control of leaf spot (tikka) disease of groundnut in Punjab. J. Res. PAU 9:451-454.

Singh, U.B. 1948. Phytopathological examination of seeds by Ulster method. Curr. Sci. 17:266-267.

Smith, D.H. 1984. Early and late leaf spots. In: Compendium of peanut diseases. Eds. Porter, D.M., Smith, D.H., and Rodriguez-Kabana, R. Amer. Phytopath. Soc. St. Paul, MN, USA, p. 5-7.

Smith, D.H., and Littrell, R.H. 1980. Management of peanut foliar diseases with fungicides. Plant Dis. 64:356-361.

Smith, D.H., McGee, R.E., and Vesely, L.K. 1978. Isolation of benomyl tolerent strains of *Cercospora arachidicola* and *Cercosporidium personatum* at one location in Texas. Proc. Amer. Peanut Res. Ed. Assoc. Inc. 10:67.

Sokhi, S.S. ,and Joohty, J.S. 1982. Factors associated with resistance to *Puccina arachidis*. Peanut Sci. 9: 96-97.

Sowell, G. Jr., Smith, D.H., and Hammons, R.O. 1976. Resistance of peanut plant introductions to *Cercospora arachidicola*. Plant Dis. Rep. 60:494-498.

Spegazzini, C. 1884. Fungi guaranitici. Anales Sociedad Cientifica Argentina. 17:69-96, 119-134.

Spurr, H., and Bailey, J. 1983. Biological control of peanut leaf spot. Proc. Amer. Peanut Res. Edu. Soc. Inc. 15:93.

Stockdale, F.A. 1914. Annual Report of the Department of Agriculture, Mauritius. (Cited from Bromfield, 1971).

Subrahmanyam, P., and McDonald, D. 1982. Groundnut rust its survival and carry-over in India. Proc. Indian Acad. Sci. (Plant Sci.) 91:93-100.

Subrahmanyam, P., and McDonald, D. 1983. Rust disease of groundnut. Infor. Bull. No. 13, Patancheru, A.P. 502324, India: ICRISAT.

Subrahmanyam, P. and McDonald, D. 1986. Groundnut rust disease: Epidemiology and control. Proceedings of the International Group Discussion Meeting on Rust Disease of Groundnut, 24-28 Sept. 1984, ICRISAT, Patancheru P.O., A.P. 502 324, India (In Press).

Subrahmanyam, P., McDonald, D., and Hammons, R.O. 1984. Foliar diseases. In: Porter, D.M., D.H. Smith and R. Rodriguez - Kabana (Eds.) Compondium of Peanut diseases. The Ame. Phytopath. Soc. St. Paul. MN. pp. 73.

Subrahmanyam, P., Moss, J.P., and Rao, V.R. 1983a. Resistance to peanut rust in wild *Arachis species*. Plant Dis. 67:209-212.

Subrahmanyam, P., Mehan, V.K., Nevill, D.J., and McDonald, D. 1980. Research on fungal diseases of groundnut. In ICRISAT Proc. Int. Workshop on groundnut, 13-17, Oct. 1980, Patancheru, India. pp. 193-198.

Subrahmanyam, P., McDonald, D., Gibbons, R.W. and Subba Rao, P.V. 1983c. Componenets of resistance to *Puccinia arachidis* in peanuts. Phytopathology. 73: 253-256.

Subrahmanyam, P., McDonald, D., Reddy, P.M., and Subba Rao, P.V. 1983b. Investigations on rust and leaf spots of groundnut. Vol. 1 Groundnut Improvement Program, ICRISAT, Patancheru, India, pp. 362.

Subrahmanyam, P., Reddy, L.J., Gibbons, R.W., and McDonald, D. 1985. peanut rust: a major threat to peanut production in the semiarid tropics. Plant Dis. 69:813-819.

Subrahmanyam, P., McDonald, D., Gibbons, R.W., Nigam, S.N., and Nevill, D.J. 1982. Resistance to rust and late leaf spot diseases in some genotypes of *Arachis hypogaea*. Peanut Sci. 9:6- 10.

Subrahmanyam, P., Reddy, D.V.R., Gibbons, R.W., Rao, V.R., and Garren, K.H. 1979. Current distribution of groundnut rust in India. PANS 25:25-29.

*Sulaiman, M. 1965. Investigations on the control of tikka disease of groundnut in the Maharashtra State. Beitr. trop. subtrop. Landwirt Tropen veterinarmedizin 2:51-54. (Rev. Appl. Mycol. 45:305).

Sulaiman, M., and Agashe, N.G. 1965. Influence of climate on the incidence of tikka disease of groundnut. Indian Oil Seeds J. 9(3):176-177.

*Sulaiman, M., and Hande, J.K. 1969. Studies on cultural, morphological, physiological and pathogenic characters of one isolate of *Cercospora arachidicola* and two *C. personata*. Beitr. trop. and subtrop. Landwirt. Tropen Veterinarmedizin 6:103-115. (Rev. Appl. Mycol. 48:3767).

Sundaram, N.V. 1965. Notes on creation of tikka leaf spot of groundnut. Indian Oil seeds J. 9:98-101.

Tai, F.L. 1937. A list of fungi hitherto unknown from China. Science Report, Tsung - Mau University, series B, 2:191-639. (Cited from Bromfield, 1971).

Tandon, I.N., and Singh, B.K. 1968. Chemical control of leaf spot of groundnut. Indian Phytopath. 21:281-288.

*Tarr, S.A.J. 1954. Diseases of economic crops in the Sudan. II. Fibers, oil seeds, coffee and tobacco. FAO Plant Prot. Bull. 2:161-165. (Rev. Appl. Mycol. 34:137).

*Ter Horst, K. 1961. (Some experiments for the control of Mycosphaerella leaf spot on groundnut). Surinam Landb. 9:103- 117. (Rev. Appl. Mycol. 41:347).

Vaishnav, M.U., and Kapadia, M.N. 1982. Occurrance of mycophagous midge, *Mycodiplosis* sp. on groundnut rust in Gujarat. Pesticides 16:21.

Van Arsdel, E.P., and Harrison, A.L. 1972. Possible origin of peanut rust epidemics in Texas. Phytopathology 62: 794. (Abstract).

Van der Plank, J.E. 1963. Plant Diseases: Epidemics and Control. New York & London, Academic Press, 349 PP.

Vasudeva, R.S. 1961. Diseases of groundnut. In Groundnut (Ed. C.R. Seshadri), ICAR, New Delhi, pp. 229-240.

Veeranjaneyulu, M. 1973. Studies on rust disease of groundnut. M.Sc. (Ag) Thesis, A.P.A.U., Tirupati, pp. 74.

Venkataraman, S., and Kazi, S.K. 1979. A climatic disease calender for "tikka" of groundnut. J. Maharashtra Agric. Universities 4:91-94.

*Vilsoni, F. 1980. Peanut rust: Occurrence in Fiji. Fiji agric. J. 42: 45-46. (Rev. Pl. Path. 61:5371).

Walls, S.B. Wynne, J.C. 1985. Combining ability for resistance to *Cercosporidium personatum* for five late leaf spot resistant peanut germplasm lines. Oleagineux 40: 389-396.

Wangikar, P.D., and Shukla, V.N. 1976. Influence of prevailing temperatures and humidity on tikka disease of groundnut. J. Maharashtra Agric. Univ. 1 (Additional Number) :259-264.

Wells, J.C. 1962. Peanut rust in North Carolina. Plant Dis. Rep. 46:65.

West, E. 1931. Peanut rust. Plant Dis. Rep. 15:5-6.

Wilcoxson, R.D., Skovmand, B., and Atif, A.H. 1975. Evaluation of wheat cultivars for their ability to retard development of stem rust. Ann. Appl. Biol. 80: 275-81.

Woodroof, N.C. 1933. Two leaf spots of the peanut (Arachis hypogaea L.). Phytopathology 23:627-640.

*Woodroof, N.C. 1942. Increased yields of spanish peanuts obtained by dusting. Cir. Ga. Exp. Sta. 136:4. (Rev. Appl. Mycol. 21:402).

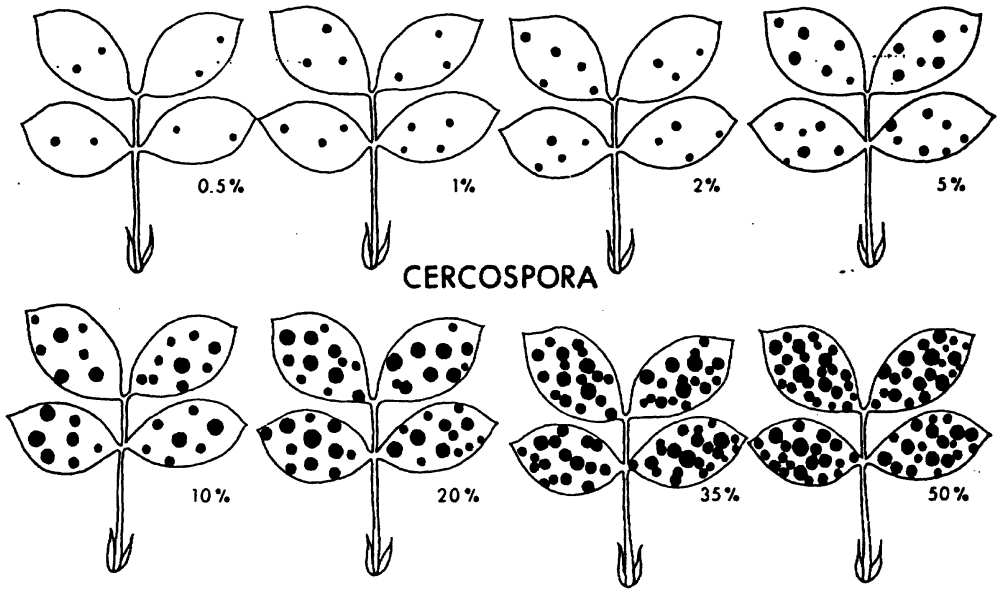
*Young, B.W., Blamey, F.P.C., and Chapman, J. 1980. Studies on the occurrence, epidemiology, and control of leaf and stem diseases of groundnuts. Technical communicaton, Dept. Agric. Tech. Ser., South Africa. No.166:22 (Rev. Pl.Path. 60:2888).

Zadoks, J.C., and Schein, R.O. 1979. Epidemiology and Plant Disease Management. Oxford University Press, New York, p. 427.

Zhou, L., Chaobin, H., Jingmei, L., and Zhiying, L. 1980. Studies on peanut rust in Guangdong Province (PRC). Acta Phytopatholacia Sinca 7:67-74.

* Original not seen.

agr. depecting by rust



Diagrams depecting leaf area damaged by leaf spots.

Appindex-2

Standard week weather data for the years 1983-1985 at ICRISAT Center, Patancheru, Andhra Pradesh.

PLEASE NOTE THAT RAINFALL AND EVAPORATION DATA ARE TOTALS NOT MEANS

STANDARD WEEK WEATHER DATA FROM WEEK NOS. 1 TO 52 FOR THE YEAR 1983

STD WEEK	RAIN MM	EVAP MM	MAX. TEM	MIN. TEM	R.HU 0717	R.HU 1417	WIND KPH	SUN SHINE	SOL.RADIATION (LY/DAY)
1	0.0	33.9	27.8	10.5	83.6	34.6	4.6	10.3	442
2	0.0	34.8	29.8	12.3	84.9	29.7	5.0	10.1	429
3	0.0	39.2	28.5	13.8	90.0	34.6	6.9	10.1	435
4	0.0	44.2	28.5	15.4	87.3	36.6	10.3	9.6	458
5	0.0	41.8	29.9	13.1	76.0	27.6	5.4	10.2	490
6	0.0	48.2	30.6	18.8	80.6	34.9	11.4	10.1	465
7	0.0	57.9	33.1	18.9	80.1	29.7	9.9	9.6	496
8	0.0	57.1	34.1	16.1	65.6	16.9	8.5	10.4	524
9	0.0	56.6	34.4	17.5	57.3	19.1	6.9	10.5	527
10	0.0	70.2	35.7	20.5	72.7	25.0	10.1	10.3	465
11	0.0	71.0	37.8	20.5	53.6	17.0	6.3	10.4	529
12	12.5	63.8	30.0	16.0	83.9	26.4	7.4	10.1	576
13	0.0	82.4	37.3	21.5	56.4	22.7	9.8	10.4	603
14	0.0	81.8	38.4	21.5	46.9	18.4	8.2	10.5	579
15	0.0	83.1	38.3	21.3	54.9	20.0	7.7	10.7	604
16	0.0	90.9	37.8	24.1	54.6	22.6	11.5	10.6	546
17	0.0	86.1	39.2	24.5	71.1	27.7	10.7	9.9	574
18	0.0	103.5	40.9	25.5	46.7	17.9	11.7	11.1	593
19	17.4	68.9	38.1	24.7	67.7	33.6	11.4	8.2	494
20	28.7	56.2	37.0	24.1	77.1	40.4	10.7	6.9	423
21	1.2	87.9	39.8	26.4	53.0	25.9	12.8	9.3	592
22	0.0	113.0	41.5	26.6	41.9	18.0	15.7	10.5	568
23	19.9	94.4	39.5	24.9	62.6	28.3	17.4	9.5	564
24	32.4	69.3	36.5	24.8	74.3	42.9	11.6	8.1	490
25	2.0	91.1	38.3	24.4	75.0	36.3	24.4	9.2	466
26	32.9	44.0	29.6	23.1	91.3	69.6	24.3	2.9	327
27	9.5	75.2	35.1	23.7	80.0	40.7	19.4	8.5	511
28	48.2	31.1	29.7	23.3	92.0	70.9	11.5	3.0	290
29	32.4	37.8	31.2	23.4	89.4	62.3	16.2	3.8	339
30	90.2	42.7	30.8	22.8	91.9	63.1	13.1	4.1	360
31	60.6	29.8	29.2	22.5	93.0	76.4	12.2	2.4	348
32	113.6	22.4	28.1	22.2	94.4	78.1	17.2	2.1	260
33	65.7	29.3	28.9	22.5	91.1	73.0	17.2	4.4	354
34	37.2	30.0	29.6	22.9	94.3	72.7	7.9	4.4	385
35	72.9	28.7	28.7	22.4	96.0	72.7	7.9	3.2	334
36	31.9	26.4	28.7	22.2	91.7	71.1	9.0	3.2	371
37	98.6	27.2	30.0	22.4	94.7	70.4	7.1	5.1	337
38	69.0	26.1	28.1	21.7	92.9	74.6	11.2	4.3	345
39	72.6	22.6	28.5	22.1	94.9	74.7	7.7	3.5	314
40	110.0	20.8	27.2	21.8	92.9	79.1	14.0	3.5	336
41	5.5	30.0	30.6	21.5	92.4	57.0	4.8	9.2	450
42	0.0	31.8	29.6	18.6	87.4	48.1	4.3	8.5	417
43	15.9	31.2	28.8	18.5	86.7	48.7	6.6	7.0	346
44	0.2	27.9	28.6	19.4	86.3	60.3	6.1	7.1	392
45	0.0	36.4	28.2	12.8	79.4	33.4	6.5	10.4	465
46	0.0	32.5	26.9	12.2	81.3	31.3	4.9	10.4	443
47	0.0	34.1	27.6	12.0	82.3	33.7	5.2	9.8	418
48	1.0	28.6	26.9	14.8	85.0	44.0	6.1	8.4	341
49	0.0	32.3	25.9	12.4	81.1	40.4	7.5	9.4	365
50	0.0	27.6	26.8	14.4	90.3	47.9	6.7	8.8	342
51	0.0	27.9	27.0	14.6	92.9	44.9	6.7	8.7	339
52	17.0	27.0	25.4	15.6	90.4	57.4	9.4	5.6	281

PLEASE NOTE THAT RAINFALL AND EVAPORATION DATA ARE TOTALS NOT MEANS

STANDARD WEEK WEATHER DATA FROM WEEK NOS. 1 TO 52 FOR THE YEAR 1984

STD WEEK	RAIN MM	EVAP MM	MAX. TEM	MIN. TEM	R.HU 0717	R.HU 1417	WIND KPH	SUN SHINE	SOL.RADIATION (LY/DAY)
1	4.8	26.4	26.7	17.9	93.1	59.6	12.4	6.6	284
2	0.0	31.1	27.0	15.2	95.9	48.6	9.8	8.4	371
3	0.0	33.4	29.6	15.5	84.3	35.1	7.1	9.3	387
4	0.0	41.3	30.0	14.8	85.4	30.9	9.1	10.3	427
5	0.0	42.0	29.5	16.8	91.3	35.9	10.3	9.9	421
6	0.0	39.8	28.8	18.3	86.4	47.3	10.5	7.9	357
7	0.0	43.8	28.7	18.2	89.7	44.9	12.2	8.2	387
8	1.4	48.7	31.5	19.7	72.4	41.9	9.2	9.0	392
9	0.0	70.2	30.8	13.6	50.0	19.1	8.5	10.2	487
10	15.8	53.1	32.9	20.7	56.9	25.9	7.4	4.8	365
11	4.8	54.9	34.7	18.8	78.3	26.3	6.4	10.2	516
12	0.0	62.4	30.4	19.5	56.3	15.0	6.4	10.3	509
13	0.0	64.2	30.8	21.6	63.6	19.0	7.4	9.3	485
14	29.4	63.1	30.8	22.9	70.4	28.4	9.5	9.5	515
15	0.7	66.8	35.4	22.5	67.1	26.1	9.3	9.7	532
16	0.0	81.1	38.9	24.3	54.4	17.1	9.8	10.6	534
17	0.5	77.1	37.3	23.0	56.9	25.9	12.4	9.6	549
18	0.0	81.7	39.6	22.9	43.0	12.9	8.4	10.5	560
19	0.0	84.9	40.9	26.1	53.3	16.1	9.6	10.5	573
20	0.0	99.1	41.4	26.8	33.6	15.4	10.3	11.4	579
21	0.0	110.7	42.5	27.5	23.7	12.4	12.4	11.4	590
22	0.0	100.7	39.5	28.0	45.0	22.3	15.5	6.1	408
23	1.4	76.5	30.4	25.4	69.9	36.9	18.9	5.0	422
24	85.3	47.8	31.7	22.8	86.6	55.4	19.0	2.2	322
25	2.4	72.3	34.4	23.5	76.9	40.0	25.2	6.0	485
26	3.8	62.1	32.8	23.5	76.1	45.4	20.2	4.3	358
27	21.6	46.4	31.8	23.1	82.3	57.1	20.0	3.7	348
28	36.8	43.5	31.5	23.0	84.7	55.4	10.0	4.8	370
29	68.1	27.6	28.0	21.4	91.6	73.6	14.6	2.9	312
30	25.2	30.7	28.2	21.9	91.3	77.0	11.0	3.0	332
31	149.6	22.9	26.5	21.4	93.0	77.3	12.9	3.3	304
32	14.0	40.4	29.5	21.7	88.0	60.6	14.9	5.3	389
33	0.3	46.3	29.8	22.0	82.1	54.6	14.0	5.1	384
34	0.0	45.2	30.9	22.6	79.1	50.7	9.9	7.1	442
35	3.2	48.4	30.6	22.3	79.6	52.9	12.1	5.3	371
36	0.0	50.5	31.1	21.8	76.7	42.7	9.8	5.5	442
37	73.5	27.9	28.5	20.9	90.9	69.4	7.2	5.0	367
38	13.4	33.9	30.7	22.1	92.3	55.4	4.6	7.3	450
39	12.3	34.3	31.1	21.3	92.1	58.1	4.5	7.9	439
40	0.0	40.1	31.6	21.0	84.3	44.4	6.9	8.7	488
41	73.0	33.0	28.8	20.6	89.7	62.3	6.8	5.5	350
42	0.0	36.3	30.4	18.7	82.9	33.9	4.7	9.3	475
43	7.4	33.0	30.7	19.1	86.4	48.1	4.3	9.4	433
44	6.4	35.9	29.8	18.4	86.3	41.6	5.6	9.4	426
45	0.0	39.1	29.5	14.9	85.1	39.0	5.6	9.8	455
46	0.0	42.6	28.5	14.7	73.3	31.0	6.4	6.9	385
47	0.0	39.6	27.7	10.9	76.4	23.6	6.0	10.5	430
48	0.0	39.8	26.3	10.9	79.3	30.4	7.7	9.2	382
49	0.0	31.2	29.8	17.3	88.4	44.1	5.5	8.1	350
50	0.0	36.3	29.9	12.3	79.7	24.6	4.2	10.5	404
51	0.0	34.7	28.6	10.9	84.3	24.9	4.7	10.3	389
52	0.0	36.9	28.7	14.0	83.4	34.5	5.8	9.8	331

PLEASE NOTE THAT RAINFALL AND EVAPORATION DATA ARE TOTALS NOT MEANS

STANDARD WEEK WEATHER DATA FROM WEEK NOS. 1 TO 52 FOR THE YEAR 1985

STD WEEK	RAIN MM	EVAP MM	MAX. TEM	MIN. TEM	R.HU 0717	R.HU 1417	WIND KPH	SUN SHINE	SOL.RADIATION (LY/DAY)
1	1.8	29.5	27.7	16.7	92.6	50.6	18.6	8.0	336
2	0.0	38.0	29.1	17.4	90.3	34.0	10.3	8.3	367
3	0.0	38.7	28.9	16.0	92.1	35.1	8.9	9.4	377
4	0.0	41.7	29.3	15.8	85.4	38.0	8.0	9.7	417
5	0.0	48.5	31.2	17.1	84.3	28.6	9.0	10.4	438
6	0.0	47.6	33.1	16.4	66.1	23.6	5.6	10.2	432
7	0.0	50.6	33.4	17.9	77.1	23.4	8.9	10.3	457
8	0.0	54.7	32.6	14.4	61.0	16.0	6.2	10.4	464
9	0.0	59.0	35.5	15.7	48.1	13.9	5.8	10.7	511
10	0.0	67.4	37.2	19.1	49.3	13.9	6.4	10.4	503
11	0.0	70.1	36.6	19.4	48.1	15.0	8.4	8.7	454
12	0.6	66.7	37.0	23.1	72.9	23.9	9.3	8.6	467
13	19.8	56.9	35.9	21.8	72.0	30.9	8.4	7.1	420
14	31.0	60.2	33.6	20.6	80.6	36.4	9.1	9.5	544
15	0.0	73.1	38.6	23.6	42.9	21.9	7.3	10.9	595
16	0.0	80.1	39.5	23.9	53.9	23.6	7.6	10.9	584
17	0.0	89.6	39.9	25.1	39.1	17.4	10.3	9.6	560
18	0.0	101.2	39.9	23.5	37.9	17.0	11.8	11.6	622
19	0.0	85.3	40.1	26.0	55.1	21.9	11.2	9.1	538
20	6.4	83.1	39.4	26.0	65.3	29.9	10.7	9.4	541
21	4.4	88.8	39.1	25.8	66.7	31.1	16.9	7.4	476
22	22.0	85.4	37.3	24.2	78.9	39.7	18.3	8.6	531
23	21.9	52.4	33.7	23.5	86.0	47.9	17.6	5.2	408
24	1.8	67.3	34.5	23.0	82.3	41.3	20.5	7.4	539
25	25.4	56.0	32.4	23.4	80.3	49.3	19.0	4.3	396
26	26.1	34.3	29.7	22.3	88.6	68.7	20.5	2.2	336
27	27.3	52.2	31.6	22.2	85.4	52.7	18.5	6.6	423
28	5.6	49.8	32.2	23.3	82.3	49.6	16.0	3.5	351
29	36.1	31.8	29.4	21.7	93.6	62.9	10.9	2.3	345
30	68.2	34.4	29.2	21.9	95.4	69.0	7.8	5.5	390
31	41.0	28.6	28.4	21.8	88.9	69.4	14.5	3.6	351
32	9.2	41.1	29.9	22.0	85.7	57.9	12.8	4.7	379
33	9.4	33.9	29.0	22.4	86.3	67.0	10.3	3.6	348
34	15.8	42.1	31.6	23.0	81.3	53.4	7.5	7.0	415
35	7.0	39.8	30.8	22.7	83.9	58.3	7.3	6.8	408
36	13.4	37.5	30.6	22.0	88.3	56.4	7.6	4.2	391
37	26.6	34.4	30.0	22.1	84.4	61.6	8.3	3.0	342
38	30.2	36.7	31.2	21.1	88.1	58.0	6.2	6.3	443
39	5.6	41.1	32.6	22.3	91.1	47.9	6.0	9.7	506
40	80.4	28.2	29.1	21.8	94.1	75.6	11.5	3.9	308
41	11.4	25.8	29.1	20.8	93.9	61.1	7.6	6.4	360
42	1.2	38.1	30.4	17.8	80.4	39.3	4.9	8.7	469
43	0.0	41.7	29.0	13.5	80.4	32.4	4.9	11.0	494
44	0.0	42.0	28.7	12.7	84.0	35.1	6.8	10.2	472
45	0.0	34.3	29.3	17.7	86.9	45.3	7.3	8.8	378
46	0.0	40.1	28.8	12.0	77.0	29.9	6.9	9.8	420
47	0.0	38.2	29.9	12.0	73.3	25.4	5.9	10.4	432
48	0.0	40.0	28.2	12.2	77.3	28.4	7.6	10.5	406
49	0.0	33.8	28.5	10.7	73.7	29.1	5.6	8.4	379
50	8.1	32.8	28.9	15.6	90.7	47.7	11.5	7.1	315
51	0.0	33.9	29.4	14.1	90.9	33.9	6.0	9.9	402
52	0.0	40.3	29.4	13.0	80.7	31.4	6.1	10.2	414

PLEASE NOTE THAT RAINFALL AND EVAPORATION DATA ARE TOTALS NOT MEANS