INTEGRATED DISEASE MANAGEMENT OF WILT (*Fusarium udum* Butler) OF PIGEONPEA (*Cajanus cajan* (L.) Millsp.)

By

M. BHARATHI
M.Sc. (Ag)

THESIS SUBMITTED TO THE
ACHARYA N.G.RANGA AGRICULTURAL UNIVERSITY
IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE OF
DOCTOR OF PHILOSOPHY IN AGRICULTURE

DEPARTMENT OF PLANT PATHOLOGY
COLLEGE OF AGRICULTURE
ACHARYA N.G.RANGA AGRICULTURAL UNIVERSITY
RAJENDRANAGAR, HYDERABAD-500030

MAY, 2000

2

CERTIFICATE

This is to certify that the thesis entitled "**INTEGRATED DISEASE MANAGEMENT OF WILT (*Fusarium udum* Butler) OF PIGEONPEA (*Cajanus cajan* (L.) Millsp.)**" submitted in partial fulfilment of the requirements for the degree of '**DOCTOR OF PHILOSOPHY IN AGRICULTURE**' of the Acharya N.G.Ranga Agricultural University, Hyderabad, is a record of the bonafide research work carried out by **Mrs. M. BHARATHI** under my 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. The published part has been fully acknowledged. All assistance and help received during the course of investigations have been duly acknowledged by the author of the thesis.

(Dr. K. CHANDRASEKHAR RAO)
Chairman of the Advisory Committee

Thesis approved by the Student's Advisory Committee

Chairman : **(Dr. K. CHANDRASEKHAR RAO)**
Professor & Head
Department of Plant Pathology
College of Agriculture, ANGRAU
Rajendranagar, Hyderabad 500 030.

Co-Chairman : **(Dr. M.V. REDDY)**
Principal Scientist (Pulses)
Regional Agricultural Research Station
LAM Farm, Guntur-522 034.

Member : **(Dr. K.B. SAXENA)**
Senior Scientist (Pigeonpea Breeding)
Genetic Resources Enhancement Program
ICRISAT Centre, Patancheru
Hyderabad - 502 324.

Member : **(Dr. S.P. WANI)**
Senior Scientist (Soil Microbiology)
Program Liaison
Natural Resources Management Program
ICRISAT Centre, Patancheru
Hyderabad - 502 324.

Member : **(Dr. K.RAMANNA CHOWDARY)**
Professor & Head
Department of Agricultural Economics
College of Agriculture, ANGRAU
Rajendranagar, Hyderabad-500 030.

CERTIFICATE

Mrs. **M. BHARATHI** has satisfactorily prosecuted the course of research and that the thesis entitled **INTEGRATED DISEASE MANAGEMENT OF WILT (*Fusarium udum* Butler) OF PIGEONPEA (*Cajanus cajan* (L.) Millsp.)** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part thereof has not been previously submitted by her for a degree of any university.

15.5.2000

Date: 15.5.2000

(DR. K. CHANDRASEKHAR RAO)
Major Advisor

DECLARATION

I, **M. BHARATHI,** hereby declare that the thesis entitled **"INTEGRATED DISEASE MANAGEMENT OF WILT (*Fusarium udum* Butler) OF PIGEONPEA (*Cajanus cajan* (L.) Millsp.)"** is a result of the original research work done by me. It is further declared that the thesis or any part thereof has not published earlier in any manner.

Bharathi

Date: 15.5.2000 M. BHARATHI

LIST OF CONTENTS

LIST OF TABLES

Contd..

Contd..

Contd..

Contd..

Contd..

LIST OF ILLUSTRATIONS

Contd..

Contd..

Contd..

Contd..

Contd..

Contd..

LIST OF PLATES

Contd..

Contd..

Contd..

Contd..

LIST OF APPENDICES

LIST OF ABBREVIATIONS

cfu	:	Colony forming units
FYM	:	Farm yard manure
GM	:	Green manure
SD	:	Seed dressing
IDM	:	Integrated disease management
ANOVA	:	Analysis of variance
CD	:	Critical difference
cm	:	centimeter
g	:	gram(s)
ha	:	hectare
kg	:	kilogram
SE	:	Standard error
ml	:	milliliters
PDA	:	Potato dextrose agar
PDB	:	Potato dextrose broth
CSA	:	Competitive saprophytic ability
mts	:	meters
%	:	Per cent
mg	:	milligram
m^2	:	square meter
viz.	:	namely
µm	:	micrometer
i.e.	:	that is
@	:	at the rate of
kg/ha	:	kilogram per hectare
g/pot	:	gram per pot
g/plant	:	gram per plant
P (0.05)	:	CD at 5% level

ACKNOWLEDGEMENTS

*I have no words to express my profound gratitude to **Dr.K.Chandrasekhar Rao**, Professor and Head, Department of Plant Pathology for his perspicacity, indefatigable interest and meticulous guidance on the work. I take this oppurtunity to thank him for the interest he has taken to give me the right perspective of research.*

*My special thanks are due to **Dr.M.V.Reddy,** Principal Scientist, Lamfarm for his close monitoring, timely suggestions and expert guidance throughout my research work.*

*I am also thankful to **Dr.K.B.Saxena** Senior Scientist, Pigeonpca breeding, GREP, ICRISAT for the help rendered by him in completing the objectives of this project.*

*I am highly indebted to **Dr.S.P.Wani,** Senior Scientist, Program Liaison, NRMP, ICRISAT for his critical observation and comments which helped to improve this piece of work.*

*I express my sincere thanks to **Dr.K.R.Chowdhary** for his guidance and encouragement shown during the course of my experiment.*

I am greateful to the Staff of Department of Plant Pathology, College of Agriculture, ANGRAU, Rajendranagar, Hyderabad for their unstinted cooperation.

I appreciate the assistance and cooperation extended to me by all the staff of (Ex) Legumes Pathology unit and Pigeonpea breeding throughout my research work at ICRISAT.

I deem it my privilege to thank Dr. B. Diwakar, Ex program leader and staff of Training and Fellowships Program, ICRISAT for permitting me to avail the research facilities at ICRISAT.

I am highly indebted to Sri S.S. Navi, K. Reddy Scientific Officer, GREP, ICRISAT and Dr S L Chowdhary for their help and encouragement through out my research work.

Finally, I take this opportunity to express my sincere regard and deep love to my parents and family members for their patience, affection and encouragement given to me during the course of study.

Diction is not enough to express my unboundable gratitude to my beloved husband Mr. V.Ravindranath Reddy for his help, moral support, cooperation and encouragement during the course of my study.

I am very much indebted to my In-laws, children and other family members for their patience , endurance, understanding and encouragement that made possible the completion of this work.

My special thanks to the College of Agriculture, Acharya N.G. Ranga Agricultural University, Rajendranagar for providing financial support during the course. I am also greateful to ICRISAT center for providing all the facilities required for the research work.

My warmest thanks to Mr. Sagar for his patience and excellent type work carried out in getting the thesis its present shape.

(BHARATHI)

Name of the student	:	**M. BHARATHI**
Title of the thesis	:	**INTEGRATED DISEASE MANAGEMENT OF WILT (*Fusarium udum* Butler) OF PIGEONPEA (*Cajanus cajan*)**
Degree to which it is submitted	:	**DOCTOR OF PHILOSOPHY**
Faculty	:	**AGRICULTURE**
Department	:	**PLANT PATHOLOGY**
Major Advisor	:	**Dr. K. CHANDRASEKHAR RAO**
University	:	**ACHARYA N.G. RANGA AGRICULTURAL UNIVERSITY**
Year of submission	:	**2000**

ABSTRACT

The present investigations on "Integrated disease management of wilt (*Fusarium udum* Butler) of pigeonpea (*Cajanus cajan*)" were undertaken at International Crops Research Institute for Semi-arid Tropics (ICRISAT) Centre, Patancheru and in the predominant pigeonpea growing areas of Andhra Pradesh during 1996-98.

Studies on the effect of cropping systems and nitrogen (N) sources and N levels through KNO_3 and FYM and N levels on pigeonpea wilt revealed low levels of *Fusarium udum* population in all the cropping systems investigated compared to sole cropping of pigeonpea. However, intercropping of sunflower with soyabean was observed to be superior, in terms of reduced pigeonpea wilt pathogen and enhanced antagonistic fungal populations. Further, the application of N through inorganic sources (KNO_3) and their combination with organic amendment sources (FYM+KNO_3) were found to be superior to sole application of N through organic amendments (FYM) with regards to promotion of antogonistic fungi and inhibition of *Fusarium* wilt pathogen. Application of 40 kg N ha^{-1} as KNO_3 was however, observed to be uniformly superior, in all the cropping systems investigated.

Investigations on the effect of pre-dominant pigeonpea intercropping systems of Andhra Pradesh on pigeonpea wilt incidence were carried out in farmers fields and glass house conditions. The results revealed the effectiveness of intercropping systems in the management of pigeonpea wilt under both Alfisols and Vertisols. Intercropping of pigeonpea with groundnut in Alfisols and with cotton and greengram in Vertisols was found to be most effective in pigeonpea wilt management. *Fusarium udum* population was higher in Vertisols than Alfisols. *Aspergillus* sp. population was high in pigeonpea/ cotton system in Vertisols and pigeonpea/groundnut in Alfisols. Same was the case with

Penicillium and with regard to *Trichoderma*, it was higher in pigeonpea/maize in Alfisols and pigeonpea/cotton in Vertisols.

Studies on wilt control in Alfisols had revealed the superiority of integrated disease management (IDM) involving tolerant cultivar (C11), organic amendments (GM and FYM) and seed dressing with Bavistin, Thiram and *Trichoderma* talc based formulation under both sole and intercropping systems of pigeonpea with groundnut (TMV2) compared to individual treatments. Yield and biomass of pigeonpea were also relatively higher in the IDM treatment. However, application of organic amendments, such as green manure and farm yard manure were also observed to be effective in pigeonpea wilt management, under both sole and intercropped systems compared to control.

Investigations on wilt control in Vertisols had also revealed the superiority of integrated disease management in different cropping systems investigated. Further, adoption of integrated disease management strategy (GM+FYM+$ZnSO_4$+SD) under both sole and intercropping system of resistant pigeonpea (ICP 8863) and tolerant pigeonpea varieties (C11) with hybrid sorghum (CSH 9) was found to be most effective for wilt management. However, the yields and biomass of pigeonpea were relatively lower in the intercropping system compared to sole cropping of pigeonpea.

Studies on the effects of different crop root exudates on conidial germination and radial growth of *Fusanum udum* revealed highly inhibitory effect of groundnut, castor, soybean, sunflower, maize, greengram, hybrid sorghum and resistant pigeonpea root exudates, compared to control. However, stimulatory effects of these crop root exudates were observed on the antagonistic fungi. In contrast, root exudates from susceptible pigeonpea and local sorghum varieties had promoted germination and radial growth of the wilt pathogen, while inhibiting the antogonistic fungi, explaining the variations in disease incidence levels observed in different pigeonpea based cropping systems. However, more detailed investigations are essential for a thorough understanding of the role of cropping systems and production practices in pigeonpea wilt management, under varied soil conditions.

Economic analysis of different wilt management treatments for pigeonpea revealed IDM treatment in Vertisols and Alfisols yield the highest gross returns with highest benefit-cost ratio. Seed dressing treatment gave the highest gross returns both in sole crop and intercropped pigeonpea in Vertisols. Green manuring treatment alone and in combination with zinc sulphate which again is a component of IDM gave the highest net returns under both systems in Alfisols and Vertisols, respectively. Economics of intercrops such as groundnut in Alfisols and sorghum in Vertisols yielded the highest gross returns and net returns without affecting the benefit cost ratio. Tolerant variety in combination with IDM, Zn+GM and Zn in Vertisols, and GM and IDM in Alfisols was found beneficial in increasing the gross and net returns for sorghum and groundnut, respectively. However, the IDM package appears to be ideal to the farmers taking into consideration the economic factors of inputs such as Farm yard manure and green manure etc., are non monetory inputs which influence the decision making of the farmer.

INTRODUCTION

CHAPTER I
INTRODUCTION

Pigeonpea (*Cajanus cajan* (L.) Millspaugh) is one of the major pulse crops of the tropics and subtropics. It is widely grown in the Indian subcontinent, which accounts for almost 90 per cent of the world's pigeonpea area (Nene and Sheila, 1990). In India, it is grown in almost all states, but the major concentration is in the states of Uttar Pradesh, Gujarat and Maharashtra in western India, Madhya Pradesh in central India, Andhra Pradesh, Karnataka and Tamilnadu in southern India (Fig.1). In India the crop is grown over an area of 3.61 M ha with an annual production of 2.7 M tonnes with an average yield of 747 kg ha^{-1}. It is cultivated in Andhra Pradesh in an area of 0.36 M ha with an annual production of 0.14 M tonnes with an average yield of 383 kg ha^{-1} (Agricultural statistics, 1998). It is widely used as a pulse, green vegetable, fodder and for a variety of other purposes (Nene and Sheila, 1990). The seed protein content of pigeonpea (21%) compares well with that of other important grain legumes. The average yields of the crop are however, very low (750 kg ha^{-1}). High sensitivity of the crop to the attack of insect-pests and diseases appears to be the main reason for such low yields.

The crop is attacked by more than 100 pathogens (Nene *et al.*, 1996) including fungi, bacteria, viruses, phytoplasma like organisms and nematodes. However, only a few of them cause economic losses (Kannaiyan *et al.*, 1984). The diseases of considerable economic importance at present are sterility mosaic (SM), *Fusarium* wilt, *Phytophthora* blight (PB), *Macrophomina* root rot, stem canker and Alternaria blight.

Fusarium wilt is the most important disease of pigeonpea in India resulting in yield losses upto 67 per cent at maturity and cent per cent in case of infection at pre-pod stage (Kannaiyan and Nene, 1981). An annual loss of US$36 millions was estimated due to the disease in India alone (Kannaiyan *et al.*, 1984). The fusarium wilt in pigeonpea was first reported from Bihar by Butler (1910). However, of late, it has posed a serious threat to the successful cultivation of pigeonpea in several parts and is present in all major pigeonpea producing states of the country. Surveys conducted for the disease (Fig.2) by Kannaiyan *et al.* (1984) have indicated it to be a major problem in the states of Bihar and Maharashtra (Reddy *et al.*, 1990).

Fusarium wilt characterised by wilting of the affected plants and characteristic internal browning or blackening of the xylem vessels extending from root system to stems. Partial wilting of the plants (Upadhyay and Rai, 1992) and patches of dead plants (Reddy *et al.*, 1993b) was reported to be common in the fields during advanced stages of plant growth.

Fusarium udum Butler, the causal organism of pigeonpea wilt is soil borne and is capable of saprophytic survival on crop residues in the soil for upto eight years (Nene, 1980). Chemical control of the disease is therefore difficult, impractical and uneconomical, as the large scale soil application of chemicals required is expensive, hazardous and disturbs the biological balance (Songa, 1990). Hence efforts have to be made to curtail pathogen activity and restricting losses below economic threshold level by choosing alternative methods. Of late biocontrol methods involving manipulation of antagonistic rhizosphere microflora either by adding mycoparasites such as *Trichoderma*, or by incorporating green manure, farm yard manure, plant residues, oil cakes or animal residues in the soil which increases antagonistic microflora are being extensively employed against soil borne plant pathogens.

Pigeonpea is commonly grown in association with cereals, oilseeds, short season pulses or cotton in traditional cropping systems, with an objective to obtain higher yield per unit area, to minimize pest and disease incidence and to improve soil fertility and stability in production. However, little work has been done on these aspects in intercropped pigeonpea compared with sole cropped pigeonpea. Reductions in wilt incidence was also observed when pigeonpea was grown mixed or intercropped with sorghum (Natarajan *et al.*, 1985) or *Crotoloaria medicaginea* (Upadhyay and Rai, 1981a). Several workers reported importance of intercropping systems in the management of *Fusarium* wilt of pigeonpea (Naik, 1993; and Bhatnagar, 1995).

Plant root exudates are known to affect survival, reproduction and development of various micro organisms in soil through extremely complex phenomena (Snyder, 1960). They affect the pathogens directly by inducing their germination, contributing to their nutritional status prior to penetration or by inhibiting their saprophytic and pathogenic activities indirectly by competition and antibiosis by the root microflora whose activities are mediated by exudates (Schroth *et al.*, 1963). Gaur and Sharma (1991) established an apparent correlation between wilt incidence, magnitude of *Fusarium udum* and population of antagonists in the rhizosphere soil of resistant pigeonpea cultivar SP-15. Promotion of *Trichoderma viride* and inhibition of *Fusarium udum* conidial germination was also reported with root exudate of sorghum, maize groundnut and castor (Bhatnagar, 1995). However, studies on the role of different other crop root exudates on pigeonpea wilt mangement are limited.

Cultivation of resistant varieties, an effective method of reducing crop losses, (Stakman and Harrar, 1957) was reported to lowered inoculum levels of the pathogen (Wensley and McKeen, 1966; and Naik, 1993), coupled with an increase in the antagnoistic fungal populations (Agnihothrudu, 1955; Goswamy and Battacharya, 1988; Arun aryan and Mathew, 1993; and Naik, 1993).

Cultural practices, such as application of green manure (McRae, 1928; Upadhyay and Rai, 1981a), farm yard manure (Bhatnagar, 1995), inorganic fertilizers (Rai and Upadhyay, 1983; Deb and Dutta, 1992; Bhatnagar, 1995) and seed dressing (Kotasthane *et al.*, 1987; Mukhopadhyay *et al.*, 1992) also reported that cultural practices to greatly influence wilt incidence as well as the pathogenic and antagonistic fungal population in the soil. However, the effect was reported to vary with soil type (Chand and Thakur, 1969; Shukla, 1975; Upadhyay, 1979; Nene *et al.*, 1979; and 1981; Naik, 1993; Bhatnagar, 1995). Further, none of the measures are usually effective individually, at the field level (Chattopadhyay and Sen, 1996) and hence an integrated approach, involving several measures is essential.

Of late, integrated disease management (IDM) a relatively new approach is gaining very much importance which involves blending of compatible systems of control for effective management of the disease from profitability to food safety and the environment (Jacksen and Backman, 1993). Although, there are some reports of integrated control of *Fusarium* wilt in other crops (Srivastava and Saksena, 1968; Locke *et al.*, 1985; Chattopadhyay and Sen, 1996), there is little information regarding the effect of integrated measures on the disease, pathogen and its antagonistic fungi in pigeonpea.

In view of the multiple damages, the scientists in the Agricultural Research stations have developed a package of integrated management technologies which are based on natural balancing forces in ecological systems. IDM package for pigeonpea has been developed at ICRISAT, Patancheru and it was found to be practically feasible and econoically viable. The economics of various productions practices with pigeonpea, as a base crop, groundnut and sorghum as intercrops in both Alfisols and Vertisols, respectively were carried out.

The present investigation was therefore undertaken with the following objectives:

1. To study the effect of N sources and levels and cropping systems on the pathogen population and antagonistic fungi in experimental field trial at ICRISAT.

2. To study the influence of predominant pigeonpea based cropping systems followed in Andhra Pradesh on incidence of pigeonpea wilt and population of *Fusarium udum* and its antagonistic fungi both in on-farm and under glasshouse conditions.

3. To analyze the effect of soil type both Alfisol and Vertisol on occurrence of wilt incidence, *Fusarium udum* population and its antagonistic fungi.

4. Identification and efficacy of various cultural, chemical and biological components of integrated disease management for effective control of *Fusarium* wilt of pigeonpea both in Alfisols and Vertisols under pot conditions.

5. Identification and efficacy of various cultural, chemical and biological components of integrated disease management for effective control of *Fusarium* wilt of pigeonpea both in Alfisols and Vertisols under field conditions.

6. To study the effect of root exudates of different crops on *Fusarium udum* and its antagonistic fungi viz., *Aspergillus, Penicillium* and *Trichoderma* spp.

7. To determine the economics of various IDM packages of field experiment.

—

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

A brief review of literature on "Integrated disease management of pigeonapea wilt" is presented hereunder.

2.1 GEOGRAPHICAL DISTRUBUTION

Fusarium wilt is an important soil borne disease of pigeonpea and has been reported from Bangladesh, Ghana, Canada, India, Indonesia, Uganda and Venezuela (Nene *et al.*, 1989 a). Hovever, it is a major problem in India, particularly in the states of Bihar and Maharashtra. Prevalence of pigeonpea wilt is also been reported in the states of Uttar Pradesh, Madhya Pradesh, Rajasthan, Gujarat, West Bengal, Orissa, Karnataka, Tamil Nadu and Andhra Pradesh. Average incidence of the disease in India varied from 0.1 per cent in Rajasthan to 22.6 per cent in Maharashtra (Kannaiyan *et al.*, 1981).

2.2 ECONOMIC IMPORTANCE

Yield losses due to *Fusarium* wilt have been depends on the stage, at which the plants are infected wilt. Cent per cent yield losses have been reported in case of wilting at the pre-pod stage, while 67 per cent of yield losses was noticed in case of wilting at maturity. However, the yield losses of 30 per cent was reported in case of wilting at the pre-harvest stages (Kannaiyan and Nene, 1981). Annual crop losses due to pigeonpea wilt in India were estimated at US $ 36 millions (Kannaiyan *et al.*, 1984).

2.3 SYMPTOMATOLOGY

The symptoms of disease have been described in detail by several workers (Butler, 1910 and 1918; Satyanarayana and Kalyansundaram, 1952; Subramanian, 1963; Chaube, 1968; Amin *et al.*, 1976; Upadhyay and Rai, 1989 ; Nene *et al.*, 1979). The disease was reported to be systemic (Upadhyay and Rai, 1992), occurring through fine lateral roots by the germ tube produced from conidia, chlamydospores (Singh, 1975) or ascospores (Rai and Upadhyay, 1982). The pathogen, from infection court enters vascular system of the host plant and blocks the xylem vessels by mycelial clumps resulting in characteristic browning or blackening of the vascular tissues, visible when the main stem and primary branches are split open. Pinkish mycelial growth of the fungus were also observed under humid weather conditions on basal portions of the wilted plants.

Initial visible symptoms of the disease include loss of leaf turgidity, inter-veinal clearing and chlorosis of leaves. Appearance of brown to dark purple bands on the stem surface, extending upwards from the base form the most characteristic feature of the disease. The other characteristic symptom of wilt is browning of the stem tissue in the region of the purple band. Partial wilting of the plants was also reported to be common (Upadhyay and Rai, 1992) in the fields during advanced stages of plant growth. The typical symptoms of the disease appear in plants as gradual or sudden withering and drying of green parts exactly as if they were suffering from drought, even though there may be plenty of water in the soil. Further, wilt affected fields were usually reported to be characterized by patches of dead plants, that increased in size on successive cropping of pigeonpea in the same field (Reddy *et al.*, 1993 b).

2.4 CAUSAL ORGANISM

The causal organism of pigeonpea wilt (*Fusarium udum* Butler) is a soil borne facultative parasite, specific to the crop (Upadhyay and Rai, 1989a) and was first described by Butler (1910). A detailed description of the pathogen has also been provided by several other workers (Wollenwebber, 1931); Wollenwebber and Reinkings, 1935 a and b; Subramanian, 1955; Booth (1971); Booth *et al.*, 1978; Gerlach and Nirenberg, 1982; Upadhyay and Rai, 1989). Padwick (1940) studied the cultural characteristics of *Fusarium udum* and proposed the name *Fusarium udum* Butl. var. *Cajani*. However, the name of *Fusarium udum* is commonly accepted as the macroconidia of *Fusarium udum* are distinguished by a prominent hook (Booth, 1971).

Mycelium of the fungus was reported to be either parasitic within the roots of the host plant or saprophytic. The mycelium is hyaline, slender, much branched and usually with little aerial growth, while microconidia are of *Cephalosporium* type, produced successively on the tips of short simple or clustered conidiophores. These conidiophores bear branched monophialides, on the ultimate tips of which conidia are produced. Under a stereo-binocular microscope they appear as dry, white powdery (false) heads. The phialides (microconidiophores) are subcylindrical to almost doliiform, with a distinct collarette, and measure 8-15 x 2.5-3.5 µm. Microconidia are single or bicelled, hyaline, reniform, mostly curved, ovoid to fusoid, scattered, hyaline singly and salmon pink in mass. Occassionally they develop from the surface of minute spherical stromata and then they are of the Tubercularia type, 5.15 x 2.4 µm in diameter, white to salmon-pink and orange red (ever green or purple) in colour. Sporodochia contain masses of variable macroconidia which are hyaline, thin walled, falcate with a distinct foot cell, and as apical cell that decreases in width towards the tip. These are produced on macroconidiophores. The most important characteristic features of on the macroconidia are their strongly curved or hooked apices. They are 3 septate, less frequently 4-5 septate, very rarely 7-septate, and measure 13-50 x 2-4 um. Chlamydospores of the fungus are round or oval, rather thick - walled, hyaline and are sometimes seen in short chains, 5 to 10 um in diameter. Perfect state of the fungus was observed by Rai and Upadhyay (1979) on wilted pigeonpea plants near Varanasi, Uttar Pradesh, India. They identified it as a new species of *Gibberella*, namely, *G. indica*. The fungus is heterothallic and its perithecia are formed on exposed root and collar region of pigeonpea plants. Perithecia are globose to sub-globose, sessile and smooth walled (Upadhyay and Rai, 1992). Disease development by *G. indica* is also through germ tube or conidia produced from ascospores. More work on the perfect state of the pathogen is in progress at ICRISAT and Varnasi.

2.5 DISEASE CYCLE

pigeonpea wilt pathogen survives in the soil and diseased plant debris for several years (Butler, 1918; Mcrae and Shaw, 1933; Agnihothrudu, 1954; Mundkur, 1967; Nene and Reddy, 1981) either in the imperfect or perfect state which helps in the development of disease (Nene *et al.*, 1979). Upadhyay and Rai (1983a) also reported that disease cycle of wilt may occur through both imperfect (*Fusarium udum*) and perfect (*G. indica*) states of the pathogen. Chlamydospores of the fungus are also formed, both in parasitic and saprophytic phases, from the hyphae and conidial cells (Singh, 1975) depending on environmental conditions. These chlamydospores serve as resting spores during prolonged absence of the host. On return of favorable conditions, these resting spores germinate to cause infection. Sometimes ascospores, under unfavourable conditions produce somatic hyphae, which on germination either cause infection in the host roots or produce conidia (*Fusarium udum*) which in turn may cause infection. Spread of the pathogen occurs mostly through rainwater, irrigation, termites (Upadhyay and Rai, 1983 a), seed (Dwivedi and Tandon, 1975), infected plant debris or contact of infected roots with the healthy ones.

2.6 EPIDEMIOLOGY

The disease is both seed borne and soil borne. Untreated seed showed 13-19 per cent of internal infection with *F. udum*. Infected seed may be the primary means of spread of the pathogen over long distances and to new areas (Haware and Kannaiyan, 1992). The fungus can survive on infected plant debris in the soil for about 3 years. Disease incidence is more severe on Vertisols than on Alfisols and ratooning predisposes the plant to wilt (Reddy *et al.*1990). Slightly acidic to alkaline soils containing 50 per cent or more sand particles were reported to favour disease in susceptible cultivars (Upadhyay , 1979 and Upadhyay and Rai, 1989). Shukla (1975) noted that a higher proportion of sand in the soil favours occurrence of wilt. Nene and Reddy (1981) studied the behaviour of *F. udum* in two soil types ie., Vertisols and Alfisols having different physico chemical properties and observed that Alfisols (sand 59.6%; silt 7.2% and 33.2% with pH 5.9) supported the survival of wilt pathogen six months longer than Vertisols (sand 38.8%; silt 2% and clay 41.2% with pH 7.85), resulting in greater wilt incidence. However, Latham and Watson (1967) reported suppression of the pathogen levels in cultivated soils to be of microbial origin, influenced more by cropping and management practices than by soil type.

Soil temperature and moisture levels were also reported to play a significant role in occurrence of the wilt disease. Mitra (1924) and McRae (1926) reported wilt incidence to be influenced by the retentive nature of the soil, and not directly by its water content. Upadhyay (1979) reported temperature between 20-29°C was most suitable for the disease development at moisture levels of 6-16 per cent, while Singh and Bhargava (1981) found the fungal population to be highest at 30 per cent soil water holding capacity and soil temperature between 20 and 30°C. However, Mundkur (1935) had earlier reported a temperature range of 12-29°C to be favourable for the disease. The initial inoculum levels in soil was found to be the major factor influencing final wilt incidence compared to soil moisture and temperature. Upadhyay and Rai (1981b) correlated the soil physico-chemical properties with fungistasis and the wilt of pigeonpea and concluded that less incidence of the wilt in soils of southern states of India, as observed by Kannaiyan *et al.* (1984) might be due to a higher level of soil fungistasis against the pathogen. Indian soils have been classified into three categories (Upadhyay and Rai, 1981b and 1989) based on the disease incidence as follows: (a) conducive soils that support the growth of *Fusarium udum* and promote wilting, (b) suppressive soils that do not favour the growth of *Fusarium udum* and suppress the incidence of wilt and (c) intermediate soils that moderately suppress *Fusarium udum* and the disease. The cause of suppression was noticed to be due to antagonistic microorganisms like *Aspergillus niger, Aspergillus flavus, Penicilliumcitrinum, Trichoderma viride* and *Streptomyces griseus,* which were effective in preventing root colonization by the pathogen. Agnihothrudu (1955) also reported the occurrence of some microorganisms with fungistatic properties in the rhizosphere of pigeonpea. Microorganisms displaying high fungistatic activity were able to reduce wilt incidence to a significant level.

Incidence of wilt in a particular soil was reported to depend mainly on the saprophytic activity and survival of *Fusarium udum* in soil which are favoured by continued presence of the host substrate and also type or cultivar used (Upadhyay and Rai, 1992). Reddy *et al.* (1980) reported low levels of wilt in short duration types compared to long duration types of pigeonpea. The disease was more severe when susceptible varïeties of pigeonpea were grown in infested soils successively (Nene *et al.*, 1979; Upadhyay, 1987a; and Upadhyay and Rai, 1989). Severity of the disease and size of infection patches were also observed to increase markedly under such conditions in the field. Though infection may occur in seedling stage, maximum expression of the disease is however at flowering and podding (Reddy *et al.*, 1990). Recent work at ICRISAT revealed that apperance of wilt starts with the colonization and infection of the basal portions of the plant which takes appropriately 3-4 months (Reddy *et al.*, 1993a).

2.7 DISEASE MANAGEMENT

Successful control of pigeonpea wilt has been reported to be difficult mainly because of soil-borne nature of the pathogen (Kotasthane *et al.*, 1987). Further, the wilt pathogen invades the host much earlier to appearance of symptoms and becomes systemic due to which it enjoys protection against competitions by other saprophytes. in addition, the roots of pigeonpea are quite tough and are not easily decomposed till the next cropping season (Upadhyay and Rai, 1982) giving an opportunity to the pathogen to grow profusely and survive for many years. An integrated approach involving a combination of cultural, chemical, host plant resistance and biological control methods is thereforee necessary for effective management of the disease. Relevant literature on these aspects is presented hereunder.

2.7.1 Cultural practices

These refer to the mainpulation of crop environment in order to make it less favorable for the pathogen, through the adoption of measures such as adjusting planting time, plant spacing, season, irrigation, green manuring, crop rotation and crop combination either alone or in combination with other techniques. The effect of different cropping systems which vary in cropping pattern, crop combinations, soil type, fertilization, irrigation and crop rotation on plant diseases and pathogen population have been reported by serveral workers (Rotem and Palti, 1969; Sumner *et al.*, 1981; Natarajan *et al.*, 1985; Singh *et al.*, 1990; Trenbath, 1993; Brust and King, 1994). Cultivar and cropping histories have also been reported to influence fungal and bacterial diseases (Mueller *et al.*, 1985).

The practice of crop rotation (Brust and King, 1994), intercropping (Trenbath, 1993) and multiple cropping (Thurston, 1992) have long been regarded as successful means of reducing diseases and pathogen populations. Although many farmers have successfully managed plant diseases using cultural practices for thousands of years, their role in modern disease management strategies is barely emphasized. The role of cultural practices in disease management should not be undermined as it is essential for long term disease management and sustainable agriculture (Bhatnagar, 1995).

2.7.1.1 Intercropping

Intercropping is a long-established practice, which still predominates in many tropical and subtropical regions (Potts, 1990). Perrin (1977) reported higher and more dependable returns in intercropping, compared to monocropping in capital-scarce, labour intensive, high pest and disease prone agriculture systems. The mixing of crops or cultivars of a single crop species in the intercrop allows for the possible exploitation of diversity so as to optimize beneficial effects. Such effects include the influence of intercropping on the spatial separation of above-or below-ground plant parts, the imposition of a physical barrier between plants, modification of the microclimate and influence on colour, smell and insect vision, all of which may effect pest or disease development or that of natural enemies. Intercropping also influences the disease spread rate and if used judiciously may reduce disease spread, so that a critical level is not attained, or is attained only late in the season, when its effects are usually minimized (Potts, 1990).

Pigeonpea is traditionally intercropped with a variety of other crops, such as sorghum, pearl millet, groundnut, soybean and cotton in the semi-arid tropics of India. Intercropping with sorghum was reported to result in lowered pigeonpea wilt incidence (Dey, 1947a; Kannaiyan *et al.*, 1981; Natarajan *et al.*, 1985; Sharma *et al.*, 1987; Bhatnagar, 1995; Naik *et al.*, 1997). Natarajan *et al.* (1985) reported 24 per cent wilt in pigeonpea intercropped with sorghum, compared to 85 per cent wilt in the sole crop. These results were observed to be consistent across 14 susceptible genotypes raised in sick plots. Sharma *et al.* (1987) also reported a similar reduction in wilt incidence upon intercropping of pigeonpea variety H-102, with the sorghum hybrid, CSH-5. However, no reduction in the disease incidence was observed upon intercropping with either the sorghum cultivar, 72-44 or the local varieties of soybean, indicating a variation in disease incidence with cultivar of the intercrop. Naik *et al.* (1997) also reported a significant reduction in wilt incidence of pigeonpea, when intercropped with sorghum cultivar CSH-9, compared to sole pigeonpea. However, the reduction was noticed only at high inoculum densities (1725-4960 cfu/g soil), and not at lower densities (220-1070) cfu/g soil). A significant reduction in the pigeonpea wilt pathogen and disease incidence was also reported upon intercropping of pigeonpea with castor (ICRISAT, 1994; Bhatnagar, 1995). Low levels of pigeonpea wilt (<10%) in cotton/pigeonpea intercropping system were reported by Bhatnagar (1995), in spite of high levels of *Fusarium sp.* population in the soil, due to high levels of antagonistic fungal populations.

A variation in disease intensity with the intercrop was reported by Kloos *et al.* (1987) in their studies on potato wilt, caused by *Pseudomonas solanacearum*. They observed a reduction in wilt incidence upon intercropping with maize or cowpea, due to prevention of root to root contact of the host crop, while intercropping with sweet potato, mungbean or mustard did not result in any significant reduction in the disease incidence. Similar results were observed by Midmore (1988) in potatoes intercropped with maize. Raymond (1983) also reported a decrease in root damage caused by *Meloidogyne incognita* when intercropped with maize or onion, due to the barrier effct, since there was no reduction upon intercropping with the susceptible *Phaseolus* beans or tomatoes.

The effect of intercropping on soil-borne diseases was also reported in subsequent cropping seasons by Dey (1947 a). Similar results were observed in the studies of Autrique and Potts (1990), wherein intercropping of potatoes with beans or maize reduced the bacterial wilt incidence by 37 and 39 per cent respectively, in the following season, compared to crops grown in a pure stand at the same density.

2.7.1.2 Soil amendments

Soil amendments have been reported to be effective for biocontrol of diseases. Amendments in the form of plant debris, green manure, farm yard manure, compost, oilcakes, fertilizers,etc., are known to improve crop productivity by improving nutrient status and soil tilth. Further, these materials can either increase or decrease plant pathogen levels and thereby disease intensity (Sivaprakasam, 1990). Several reviews have covered the role of soil amendments in management of plant diseases (Baker and Cook, 1974; Papavizas and Lumsden, 1980; Cook and Baker, 1983; Hoitink and Fahy, 1986). Amendements may reduce pathogens and diseases either independently or together by (i) a reduction in number of fungal propagules through germination stimulation followed by lysis (ii) a temporary or permanent inactivation of fungal propagules in soil (iii) immobilization of nutrients which favour competition at the expense of the pathogen (iv) inhibition of germling growth analysis of hyphae; and (v) an increase in production of antibiotics, toxins and volatiles (Papavizas and Lumsden, 1980). Both organic and inorganic amendments have been shown to exert profound influence on the soil microbes and thereby disease intensity (Garret, 1960; Alexander, 1971). Various amendments have been employed in different forms by the earlier workers (Mitchel and Alaxender, 1961; Reddy and Rao, 1966; BhagyaRaj and Rangaswamy, 1967; Adams *et al.*1968; Huber and Watson, 1970; Khanna and Singh, 1974; Dhirendra

Table 1 Use of various organic amendments suggested for control of *Fusarium* wilts in different crops

Organic amendment	Crop	References
Cowdung	Chickpea	Satyaprasad and Ramarao (1983)
Compost	Tomato	Kato *et al.* (1981)
Composted larch bark	Yam	Sekiguch (1977)
Farm yard manure	Pigeonpea	Raghuchander *et al.* (1992)
	Tomato	Mayakrishnan and Subbaraja (1995)
Green manure (*Crotolaria medicaginea*)	Pigeonpea	Upadhyay and Rai (1981a)
(*Crotolaria juncea*)	Pigeonpea	McRae (1923)
Azadiracta indica	Pigeonpea	
Eucalyptus globulus	Pigeonpea	Upadhyay and Rai (1981a)
Clerodendrum aculeatum *Clerodendrum fragrens*	Pigeonpea	Verma and Singh (1998)
Plant tissues	Bean	Lewis and Papavizas (1975)
Oat straw	Pigeonpea	Kotasthane and Gupta (1986)
Sawdust	Pigeonpea	Singh (1974); Singh and Singh (1982)
	Tomato	Kato *et al.* (1981)
Castor cake	Pigeonpea	Singh (1974)
Mahua cake Mustard cake	Pigeonpea	Singh and Singh (1970b); Dasgupta and Gupta (1989); Mukhopadhyay and Sengupta (1991); Rai and Singh (1995)
Linseed cake Sesamum cake	Coriander	Srivastava and Sinha (1971)
Groundnut cake	Sorghum	Hundekar *et al.* (1998)
	Coriander	Srivastava and Sinha (1971)
Mahua cake	Tomato	Mayakrishnan and Subbaraja (1995)
Margosa cake	Pigeonpea	Singh and Singh (1982)
Neem cake	Pigeonpea	Khanna and Singh (1974); Dasgupta and Gupta (1989); Raghuchander *et al.* (1992); Rai and Singh (1995)
	Sorghum	Hundekar *et al.* (1998)
	Crossandra	Lakshmi and Jayarajan (1987)
Mustard cake Cauliflower residue	Cumin	Sharma *et al.* (1989)
Farm yard manure Neem cake Pongania fresh leaves	Tomato	Padmodaya and Reddy (1999)
Neem cake compost	Musk melon	Chakrabarti and Sen (1991)

Prakash *et al.*, 1976; Goyal and Mehrotra, 1979; Chattopadhyaya and Mustafee, 1980; Singh and singh, 1980; Sudhir chandra *et al.*, 1981; Singh and Singh, 1982) to find out the quantitative and qüalitative changes in mycoflora of amended and unamended soils besides evolving a suitable control method for soil borne diseases.

2.7.1.2.1 Organic amendments

Organic amendments were reported to be quite helpful in reducing crop diseases caused by soil borne pathogens (Stova, 1962; Latham and Watson, 1967; Wajidkhan *et al.*, 1974; Mehrotra, 1994). The suppressive effect of organic amendments on *Fusarium* species has been demonstrated by many workers in serveral crops (Table 1). An effective control of pigeonpea wilt by organic amendment of the soil has also been reported by McRae and Shaw (1933), Mahmood (1964), and Vasudeva *et al.*(1962). Further, green manuring was also reported to reduce the disease appreciably (McRae, 1924, 1926, 1928 and 1930).

The effect of soil amendments with decomposable organic matter on *Fusarium*sp. was studied by Baker and Nash (1965) and Singh and Singh (1970b). Katznelson (1946) had suggested that addition of organic matter to soil may exert an indirect rhizosphere effect by influencing the rate of plant growth. Soil amendments that suppressed root pathogens increased soil microflora but decreased rhizosphere flora (Katznelson, 1965). Antagonism (competition, antibiosis including lysis and exploitation) has also been considered as one of the main causes of suppression of plant pathogens in

Table 2: Effect of organic amendments on population levels of soil microflora

Crop	Amendments	Increase in population	References
Pigeonpea	Neem and castor cakes	Fungi, bacteria and actinomycetes	Khanna and Singh (1974)
	Groundnut cake, Molasses and Sweet clover roots	*Bacillus subtilis*	Vasudeva *et al.* (1962)
	Margosa cake, Rice husk and Sawdust	Fungi, bacteria and actinomycetes	Singh and Singh (1981)
	Chitin	Actinomycetes	Buxton *et al.* (1965)
	Neem leaves	Fungi, bacteria and actinomycetes	Arun Aryan and Mathew (1993)
Sorghum	Neem and Groundnut cakes	Fungi, bacteria and actinomycetes	Hundekar *et al.* (1998)
Tomato	Neem cake, groundnut cake	Fungi	Goswami and Bhattacharya (1989)
Tomato	Farm yard manure and Mahua cake	Bacteria	Mayakrishnan and Subbaraja (1995)
Coriander	Groundnut and Neem cakes	Fungi	Nishat khals and Manoharachary (1985)
Tobacco	Green manure (sunhemp)	Total fungi	Patel and Patel (1998)
Cumin	Mustard cake Cruciferous residues (Cauliflower) Compost	Actinomycetes	Sharma *et al.* (1989)

soil (Park, 1960; Snyder, 1960; Baker and Cook, 1974). An increase in the population levels of the native antagonists, upon application of organic amendments to the soil has also been reported earlier (Table 2). Organic amendments were in general reported to influence severity of soil borne diseases by (i) increasing the biological buffering capacity of soil (ii) reducing pathogen numbers during anaerobic decomposition of organic matter, and (iii) affecting nitrification which influences the form of nitrogen predominating in the soil (Huber and Watson, 1970).

2.7.1.2.2 Inorganic amendments

Inorganic soil amendments have been reported to influence the microorganisms in soil (Waksman, 1922) and increase (Sivaprakasam and Rajagopalan, 1974; Punja *et al.*, 1986) or decrease (Thakur and Mukhopadhyay, 1972) the disease severity. Soils with added nitrogen, phosporous and potassium could stimulate genera of fungi normally dormant without affecting other soil inhabitants (Waksman, 1922). Guillemat and Mantegut (1958) and Dutta and Isaac (1979) reported an increase in the fungal population, in soils receiving unbalanced fertilizers of PK,NK and NP, compared with plots which had received no fertilizers. The effects of mineral fertilizers (NPK) and soil reactions, on total numbers and types of soil fungi in the field and laboratoty was determined by Kaufman and Williams (1964) and Mahmood and Rama Rao (1992)reported that nitrogen fertilization had the greatest effect on composition fungal population in soil, followed by phosphorus and potassium, respectively. Soil amendments rich in nitrogen were also consistently effective in bringing about a substantial reduction in the inoculum potential of *Verticillium alboatrum* in soil, the reduction being approximately proportional to the nitrogen content of the amendments. Isaac (1957) showed that the incidence of antirrhinum wilt induced by *Verticillium dahliae* and *Verticillium nigrescens* was reduced by increasing sulphate of potash or ammonium sulphate. The addition of nitrogenous fertilizers to potato crops infected with *Verticillium*, also appeared to have a good effect, a high fertilizer level delaying symptom expression and reducing disease severity (Whilhelm, 1951; Robinson *et al.*, 1957; Harrison, 1968).

Soil amendment with urea @ 0.1 per cent also induced the suppression of *Phytophthora cinnamomi* and *Phytophthora parasitica* in non-sterile avocado or citrus soils. The suppression of pathogens by urea was inferred to result from inhibition by ammonia, nitrous acid or other toxic metabolites or by-products of microbial decomposition (Tso and Zentmeyer, 1979). Further sandy soils infested with *Pythium ultimum, Macrophomina phaseolina* and *Thielaviopsis basicola,* when amended with urea at 0.1, o.25, o.5 and 1.0 per cent (W/W) in field microplots resulted in a decrease in the population which was attributed to the formation of ammonia, through the degradation of urea by soil microorganisms (Chun and Lockwood, 1985). Application of nitrogen through neem coated urea was also reported to reduce the incidence of rice sheath rot (Alagarsamy *et al.*, 1987a). The effect of different forms of nitrogenous fertilizers on *Fusarium* wilt incidence in pigeonpea was reported by Raghuchander *et al.*,(1993). Ammonium sulphate at 30 kg/ha showed the least wilt incidence and produced higher grain yield.

Zinc was also reported to retard the colonization of pigeonpea substrates by *F. udum* in the soil (Sarojini, 1950). Similarly, Deb and Dutta (1992) reported significant reduction in the disease caused by *Sclerotium rolfsii* of soybean upon application of $ZnSo_4$ (10kg/ha). Liming of soil infested with *F. oxysporum* f. sp. *oxysporium* in the field or green house to pH 7.0-7.5 was also reported to greatly limit the availability of micronutrient and consistently decrease wilt in naturally low pH soils. High soil pH caused the unavailability of micronutrient which in turn limited the growth, sporulation and virulence of the pathogen. However, when soil with a high pH was further amended with lignosulfonate metal complexes of Zn, Mn or Fe, the beneficial effect of pH elevation was reversed according to Jones and Woltz (1972).

Among the plant nutrients, potassium has significant role in governing resistance to plant diseases. There are several reports of potassium imparting resistance to various diseases in different crops. Several workers reported control of cotton wilt through potassium fertilization (Tisdale and Dick, 1939; and McNew, 1953).

Use of potassium containing fertilizers resulted in decreased severity of wilt of cotton (Young et al., 1935) and muskmelon (Wensley and Mckeen, 1965; and Kannaiyan and Prasad, 1974). Application of potash to brinjal crop was also reported to confer resistance to *Verticillium* wilt disease (Sivaprakasham and Rajgopalan, 1971). Survival and saprophytic activity of *Rhizoctonia solani,* causing seedling infection of rice was also reduced by the application of K and PK (Kannaiyan and Prasad, 1981). Application of

P and K also reduced the incidence of root rot of sunflower, caused by *Macrophomina phaseolina* (Sivaprakasham *et al.*, 1975). High level of nitrogen and potassium reduced the susceptibility of pepper to culture filtrate and fusaric acid produced by *F. oxysporum f. sp. redolens*(Sarhan and Hegazi, 1988). A fertilizer dose of 30 kg N + 20 kg P + 30 kg K per hactare resulted in lowest incidence of cumin wilt. Further, lower doses resulted in higher wilt incidence (Champawat and Pathak, 1988).

Application of inorganic soil amendments also influenced population levels of antagonistic microflora in the soil. Increased bacterial population in wheat rhizosphere following urea application to foliage has been reported by Vrany *et al.* (1962). Dutta and Isaac (1979) reported that inorganic soil amendments (NPK) affected the rhizosphere microorganisms of the antirrhinum plants. Addition of ammonium sulphate (0.25%), calcium nitrate (0.25 and 0.5%) and combined NPK (0.25%) to soil caused considerable reduction in disease severity. It was reported that the reduction was caused by antagonistic environment for pathogen in the rhizosphere, which was boosted when calcium nitrate was added as soil amendment. Reduction in the disease severity in soil amended with combined NPK, was due to the fact that antagonistic actinomycete population was boosted in the rhizosphere. Ammonium sulphate, potassium sulphate, superphosphate and NPK also increased *Trichoderma* population, while calcium nitriate boosted the *Penicillium* sp. vigorously.

Deb and Dutta (1992) reported that amendments also increased selective genera of fungi in the rhizosphere. Rock phosphate (o.25%W/W) and urea (0.5% W/W) boosted *aspergilli* while zinc sulphate (0.5% W/W) and ammonium nitrate (0.25% W/W) increased *Fusarium* spp. in the rhizosphere. *Penicillium* spp. were found to be present in all the treatments with comparatively higher population in zinc sulphate treatment.*Trichoderma* spp. were also found to be present following soil amendments with zinc sulphate (0.25%), calcium carbonate (0.25%) andcalcium nitrate (0.1%). Stimulation of *Penicillia* following zinc sulphate amendment has also been reported by Dutta and Deb (1986).

2.7.2 Chemical control

Fungicides have been frequently used to control the wilt disease (Sinha, 1975; Ghosh, 1975; Ghosh and Sinha, 1981; Upadhyay and Rai, 1981a) These have been studied both under laboratory and field conditions. The effect of systemic fungicides on *Fusarium udum* was studied by Ghosh and Sinha (1981). Spore germination of *Fusarium udum* was completely inhibited by Benlate and Campogram-M at 50 ppm. Bavistin and BAS 38601F were also highly effective in checking the mycelial growth of *Fusarium udum*and these fungicides were most effective as seed treatments. Effectiveness of pigeonpea seed treatment with Benlate and Thiram (Kotasthane *et al.*, 1987), and Benomyl and Thiram (Haware and Kannaiyan, 1992) mixtures was also reported. Seed treatment with bavistin and thiram (0.5 and 2.0 g/kg seed) reported to be promising in pulses (Jalal et al., 1980).

Sinha (1975) reported that Bavistin applied as a soil drench at 2000 ppm, 10 days before inoculation of pigeonpea plants with *Fusarium udum* controlled the wilt. Upadhyay and Rai (1981a) studied the effect of eight chemicals including urea and four fungicides on wilt incidence under field conditions. Out of which Phygon XL was reported to effectively reduce the wilt incidence in pigeonpea, Dithane Z-78 and Zincop were also found to be effective. However, during later stages of plant growth the effect became insignificant. Amongst other chemicals, calcium carbonate and orthophosphoric acid reduced the incidence of the disease, but only in early stages of plant growth.

Rai and Upadhyay (1983) also reported a reduction in the competitive saprophytic colonization of *Fusarium udum* in the soil-sand inoculum mixture amended with Bavistin,Dithane Z-78 and Difolatan fungicides. Further, Sinha and Upadhyay (1990) conducted experiments with eleven compounds for control of *Fusarium udum*. The results revealed an inhibition of the pathogen growth by Emisan-6 (Methl ethyl mercuric chloride) and sulfex (80%) at all concentrations, while Dithane M-45 (mancozeb) and Thiram were relatively less effective. Sumitha and Gaikwad (1995a) also evaluated few systemic and non-systemic fungicides against the pathogen *in vitro* and the results revealed a complete inhibition in the fungal linear growth by Bavistin (0.1%), Topsin M-70 (0.1%), Thiram (0.1%), Captan (0.15%) and Dithane Z-78 (0.3%). An evaluation of these fungicides *in vivo* as seed treatment, soil drenching and in combination (seed treatment+soil drenching), however, revealed the effectiveness of Thiram, compared to other fungicides. Griseofulvin and bulbiformin, two antibiotics, were also found very effective against *Fusarium udum* (Vasudeva *et al.*, 1958 and Chakrabarti and Nandi, 1969).

Table 3: Pigeonpea lines/cultivars reported resistant to *Fusarium* wilt in India

Location	Resistant lines	Reference
Andhra Pradesh	ST1 (C11), ST2 (C28), ST3 (C36)	Vaheeduddin and Nanjundiah (1956)
Hyderabad	ICP 8867, ICP 9174, PR 5149 and ICPL 227	Reddy and Raju (1998)
	C11, C26	Bhaskaran (1954)
	ICP 1641, 3753, 3782, 4769, 5097, 6831, 7118, 7273, 7182, 7198, 7201, 7273, 7336, 7867, 8858 to 8869, C. Nos. 74342, 74360, and 74363, AWR 74/15, Bandapalerasel., Purple 1 sel., Bori 1 sel.	Nene and Kanniayan (1982)
	ICPL 25, ICPL 31, ICPL 108	Kannaiyan *et al.* (1983)
Bihar	ICP 8863	Haque *et al.* (1984)
	Kanke 9, Kanke 3	Bhargava (1975)
Pusa	Type A2 (WR), Type A4	McRae (1932)
	Type 80, 16, 41, 50, 51, 82	McRae and Shaw (1933)
	11-80, 18-41, C 38, C 15, A 126-4-1	Mundkur (1946)
Delhi	IP 80, IP 41, Hybrid 5 (D 419-2-4)	Dastur (1946)
	NP 41, C 38-1-2, D 419-2-4	IARI (1953)
Delhi	C 15 (WE), P3, P8, S 55	Vasudeva *et al.* (1958)
	NP (WR) 15, NP 41, NP 51, NP 80 (A2)	Deshpande *et al.* (1963)
	NP(WR) 15, NP(WR) 16, NP(WR) 42	Chaube (1968)
Gujarat	BDN2	Zaveri *et al.* (1986)
	GAUT 82-9, 82-74, 82-127, 83-23	Patel *et al.* (1988)
Karnataka	Maruthi (ICP 8863)	Konda *et al.* (1986); Parameswarappa *et al.* (1986)
	ICPL 270	Parameswarappa *et al.* (1987)

Contd.. Table 3

Location	Resistant lines	Reference
Maharashtra	BDN 15-3-3, ICP 7336, ICP 8862, AWR 74/15	Zote *et al.* (1987)
	ICP 7182, 7336, 8863, 8869, BDN 1	Zote *et al.* (1983)
	Osmanbad, NP(WR) 19, NP 69, S 103, Balapur 10, P 1005, Washmi 4, Chandrikapur 1, Paras 5, Jarud	Patil and Sable (1973)
Parbhani	Bori 11, Tuljapur 455, Latur 466-1, Latur 476-11, DT 230, Mu x K 132	Raut and Bhombe (1971)
Tamilnadu	Co2	Veeraswamy *et al.* (1975)
	Co3, S18	Sheriff *et al.* (1977)
Uttar Pradesh	NP 80	Dey (1947b)
	Bori 192-12-5-2; Bori 192-15-2-2-11-42	Singh and Mishra (1976)
West Bengal	ICP 8863, ICP 10957,ICP 10958, ICP 11290, ICP 11292, ICP 11294	Gupta and Sen Gupta (1988)

2.7.3 Host plant resistance

Host plant resistance is the main stay of integrated disease management in any crop, as it is a cheap and safe method of disease control (Songa, 1990). The search for sources of resistance to wilt in pigeonpea began as early as 1905 at Poona in India (Butler, 1908 and 1910). Subsequently, a large number of germplasm lines and cultivars have been evaluated against *Fusarium udum* under both natural and artificial conditions at several locations in India. Multilocational testing by Nene *et al.*, (1989 b) in India and eastern Africa had helped in the identification of several lines with broad based resistance (ICP 4769, 7118, 7182, 8863, 9168, 10958, 11299). The lines reported resistant or promising, at different locations, by different workers in India are listed in Table 3.

2.7.3.1 Resistant verses susceptible

Quantitative changes in rhizosphere microflora of crop plants alters to a great extent the infection and development of soil borne plant pathogens. Krishna Rao et al. (1987) reported that rhizosphere soil supported more microbial population than that of nonrhizosphere soil at all the the three stages of plant growth in both resistant and susceptible cultivars of pigeonpea due to the secretion of root exudates which influenced the development of high microbial population in rhizosphere soil. Soil saprophytes and antagonists such as *T. viride* and *A. niger* were among the mycoflora of the wilt resistant cultivar ICP 8858, while the mycoflora of the

Table 4: Microorganisms exhibiting antagonistic activity against *Fusarium udum*

Organism	Reference
Aspergillus flavus	Upadhyay and Rai (1987)
Aspergillus fumigatus	Upadhyay (1992)
Aspergillus niger	Upadhyay and Rai (1987); Naik (1993)
Aspergillus nidulans	Rai and Upadhyay (1983); Upadhyay (1987a)
Aspergillus terreus	Upadhyay and Rai (1987)
Cephalosporium roseo-griseum	Upadhyay (1992)
Cladosporium cladosporioides	Upadhyay (1992)
Gliocladium sp.	Naik (1993)
Micromonospora globosa	Upadhyay and Rai (1978); Upadhyay and Rai (1987)
Papulaspora sp.	Upadhyay (1992)
Penicillium citrinum	Baker (1981); Gessler and Kuc (1982); Ogawa and Komada (1984); Upadhyay and Rai (1987)
Penicillium decumbens	Upadhyay (1986); Upadhyay (1992)
Penicillium granulatum	Baker (1981); Gessler and Kuc (1982); Ogawa and Komada (1984)
Penicillium pinophillum	Baker (1981); Gessler and Kuc (1982); Ogawa and Komada (1984); Naik (1993)
Streptomyces griseolus	Upadhyay (1991)
Streptomyces sp.	Gaur and Sharma (1991)
Trichoderma viride	Rai and Upadhyay (1983); Naik (1993); Bhatnagar (1995 and 1996)
Trichoderma harzianum	Upadhyay (1992); Sumitha and Gaikwad (1995b); Mehata *et al.* (1995); Bhatnagar (1996); Somasekhara et al. (1996)
Trichoderma koningii	Bhatnagar (1996); Somasekhara et al. (1996)
Bacillus subtilis	Vasudeva et al. (1962); Podile et al. (1985); Upadhyay (1992); Sumitha and Gaikwad (1995b)
Bacillus sp.	Gaur and Sharma (1992); Naik (1993)

susceptible cultivar ICP 8518 showed a predominance of *F. udum* during all the stages of plant growth (Shaik Imamand Nusrath, 1987).

Guar and Sharma (1991) stated that the rhizosphere soil of resistant SP-15 of pigeonpea supported fungi such as *A. niger*, *Streptomyces* sp., *Penicillium* sp. and *Bacillus* sp. An apparent correlation existed between the wilt disease incidence and magnitude of population of *F. udum*/g soil and antagonists.

2.7.4 Biological control

Biological control remains an attractive possibility for many soil borne plant pathogens. It has been found at least partially successful for many wilt causing *fusaria* (Baker and Cook, 1974; Cook and Baker, 1983). There have been several attempts to identify antagonists of *Fusarium udum* (Table 4). In early studies, *Bacillus subtillis* was identified as a potential antagonist (IARI, 1950; Vasudeva and Roy, 1950; Vasudeva *et al.*, 1962 and 1963). Singh and Singh (1980, 1981 and 1983) also observed antagonism of *Bacillus subtilis* against *Fusarium udum* in soil amended with organic matter. Further, Cook and Baker (1983) reported *Bacillus subtilis* to have good potential for biological control of several plant pathogens.

Another antagonist reported for *Fusarium udum* is *Micromonospora globosa* (Upadhyay and Rai,(1978) which acts as a destructive parasite. An important feature of the antagonist is that chlamydospores, when formed in large numbers as a consequence of parasitism, are also attacked by the

Table 5: Summary of literature on seed treatment with antagonists against *Fusarium* wilt

Bioagent	Crop	Reference
Penicillium citrinum	Chickpea	Gowily *et al.* (1995)
Trichoderma harzianum	Pigeonpea	Sumitha and Gaikwad (1995b); Somasekhara *et al.* (1996)
	Chickpea	Gowily *et al.* (1995); De *et al.* (1996)
	Cotton, wheat and muskmelon	Sivan and Chet (1986)
	Cotton and melon	Sivan and Chet (1987)
	Tomato	Sivan *et al.* (1987)
Trichoderma pseudokoningii	Soybean	Wu (1982)
	Tomato	Sivan *et al.* (1987)
Trichoderma viride	Pigeonpea	Somasekhara *et al.* (1996)
	Chickpea	Gowily *et al.* (1995); De *et al.* (1996)
	Tomato	Padmodaya and Reddy (1998); Yeshia *et al.* (1981)
Gliocladium virens	Chickpea	Mukhopadhyay and Mukharjee (1991)
Bacillus subtilis	Pigeonpea	Sumitha and Gaikwad (1995b); Singh *et al.* (1965)
	Maize	Chang and Kommedahl (1968)
	Chickpea	Gowily *et al.* (1995)
Streptomyces griseus	Tomato	Yeshia *et al.* (1981)

antagonist. Several other potential antagonists for *Fusarium udum* have been screened by Upadhyay (1991), by taking various parameters of antagonism into consideration. *Aspergillus flavus, Aspergillus niger, Aspergillus terreus, Micromonospora globosa, Penicillium citrinum, Streptomyces griseus and Trichoderma viride* have been identified as potent antagonists of *Fusarium udum* , both *in vivo* and *in vivo*. These antagonists suppress or prevent *Fusarium udum* from colonizing the roots of pigeonpea which suppress the wilt disease (Upadhyay and Rai, 1985). *Aspergillus nidulans* has also been indentified as a possible biocontrol agent in slightly acidic to alkaline soil at higher temperatures (Upadhyay, 1987b). *Penicillium pinophilum,* isolated from solarized soils also shows great promise as an antagonist for biological control of the wilt disease.

Introduction of the antagonist along with planting material has been reported to be more economical and effective method of biological control (Cook and Baker, 1983). A summary of earlier work on seed treatment of different antagonists against *Fusarium* wilts is presented in Table 5. Spore suspension as well as dry powder of the fungal antagonists have been used to coat crop seeds (Harman *et al.*, 1980; Hader *et al.*, 1984; Mukhopadhyay and Mukharjee, 1991). Antagonists when applied to seeds were found to colonize the rhizosphere and offer protection against several soil borne pathogens (Chao *et al.*, 1986; Turner and Backman, 1991; Harman, 1991). Seed treatment with *Cheatomium, Penicillium, Trichoderma* and *Aspergillus sp.* also reduced the *Fusarium* wilt incidence significantly in pea, corn, soybean and melons under both glasshouse and field conditions (Harman *et al.*, 1980; Kommedahl *et al.*, 1981; Windeb and Kommedahl, 1982; Naik, 1989; Sharma, 1989). Further, bacterization of pigeonpea seeds with *Bacillus subtilis* mixed with molasses and groundnut cake reduced pigeonpea wilt incidence caused by *Fusarium udum* (Singh *et al.*, 1965). Seed dressing of maize with *Bacillus subtilis* was also reported to be effective against wilt, caused by *Fusarium roseum* f. sp. *ciceris* (Chang and Kommedahl, 1968). Sharma and Jain (1978) also reported a successful reduction in the infection of ginger rot of rhizomes, caused by *Fusarium oxysporum* f. sp. *zingeberi,* from 58.7 per cent in the untreated control to 8.3 per cent in the treatment with *Bacillus subtilis.*

Significant reduction in wilt disease was also obtained in cotton, melon and wheat crops with seed treatment of *Trichoderma harzianum* (Sivan and Chet, 1986). Seed treatment with *Trichoderma* also afforded better protection against crown rot of tomatoes, in fields naturally infested with *Fusarium oxysporum* f.sp. *lycopersici* (Sivan *et al.*, 1987). Similarly Gowily *et al.* (1995) reported an effective control of *Fusarium* root rot of chickpea with seed coating of *Trichoderma viride.* Seed treatment of pigeonpea with *Trichoderma viride* (H) isolate also reduced *Fusarium udum* propagules in soil from 19.4 x 10^2 to 2.5 x 10^2 cfu g^{-1} of soil, under greenhouse conditions (Somasekhara *et al.*, 1996).

2.7.5 Integrated disease management

Integrated control is a flexible, multidimensional approach to disease control utilizing a range of control components such as biological, cultural and chemical strategies needed to hold diseases below damaging economic thresholds without damaging the agro-ecosystem (Papavizas and Lewis, 1988).

Integrated disease management has been reported to be quite effective for control of soil-borne plant pathogens (Upadhyay and Rai, 1989), including *Fusarium* wilt (Srivastava and Saksena, 1968; Locke *et al.*, 1985). Amending soil with oat meal, wheat straw and saw dust and use of antagonistic species of *Trichoderma, Streptomyces* and *Pseudomonas* controlled the *Fusarium* wilt of potato (Srivastava and Saksena, 1968). Integration of benomyl with *Trichoderma harzianum* and *T. viride* controlled fusarium wilts of carnation (Mirkova, 1983) and *Chrysanthemum* (Locke *et al.*, 1985).

Studies on use of host resistance, antagonists (*Trichoderma*) and fungicides to control peas from *Fusarium solani* f. sp. *pisi* and *Pythium ultimum* by Kraft and Papavizas (1983) revealed that the integration of above three components resulted in higher yields of pea. Integration of biocontrol agent with fungicides was observed to improve the prospects of *Fusarium* wilt control in chickpea (Lifshitz *et al.*, 1985; Papavizas, 1985; Upadhyay and Mukhopadhyay, 1986). Seed coating with different bioagents (*Bacillus subtilis, Gliocadium virens, Trichoderma harzianum, Trichoderma viride)* and carboxin (vitavax) significantly controlled the wilt of chickpea by 30.0-45.8 per cent over control (Rajib *et al.*, 1996). Kotasthane *et al.* (1987) also reported a considerable reduction in pigeonpea wilt incidence upon fungicidal seed treatment with benlate and thiram (1:3) in combination with soil amendment of oat crop residues.

Kaur and Mukhopadhyay (1992) found that integration of seed treatment of chickpea with vitavax - 200 and Ziram with soil application of *T. harzianum* resulted in reduction of chickpea wilt complex upto 63.3%.

Use of resistant varieties together with soil drench on 0.3 per cent Bavistin (Carbendazim) 45 days after planting and three times at 10 days intervals thereafter was suggested to control *Fusarium* wilt of gladiolus (Kaur *et al.*, 1989).

Naik and Sen (1991) recommended crop rotation with garlic, onion and radish, mixed cropping with bhendi and onion, avoiding cultivation of symptomless carriers like cowpea and tomato, use of resistant cultivars Smokylee and Colhoun Gray and biocontrol agent *A. niger* in integrated disease management of Fusarium wilt of watemelon.

Further, Silbernagel and Mills (1990) reported the effectiveness of deep sub soiling, narrow row spacing and the use of resistant cultivars in increasing seed yields of snap beans (*Phaseolus vulgaris)* grown in fields infested with *F. solani* f. sp.*phaseoli,* the pathogenic agent of root rot.

Chattopadhyay and Sen (1996) studied the IDM strategies of Fusarium wilt of Muskmelon caused by *Fusarium oxysporum* and concluded that integration of *T. viride* isolate T_4 and Bavistin 0.1% seed treatment with soil application of KCL was the most effective treatment in reducing muskmelon wilt with PDR 74.14%.

Bidari and Gundappagol (1997) reported the combined use of *Trichoderma viride* as a seed treatment with other recommended practices in reducing wilt incidence of pigeonpea by 27.6% in comparison with control. However, suseptible cultivar GS - 1 showed a reduction of 29.2% and resistant cultivar with 23.6% wilt reduction against control (12.1% wilt) in a wilt sick field.

2.8 ROLE OF ROOT EXUDATES IN DISEASE CONTROL

The relation of plant exudates to increased microbial activity around roots has been recognized for years. The concept that the host may stimulate or influence a pathogen in the soil is not new. In 1723,the ingenious Micheli observed that seeds of the phanerogamic parasite, *Orobanche*, germinated only in the presence of host roots. The first direct reference to the possibility that root exudates affect a pathogen may have been made by who, in his discussion on the occurrence of *Orobanche* only when tobacco was grown, stated that the tobacco plants must be yielding some secretion fitted to stimulate into active operation the latent vitality of the pathogen seed. In 1888, Halsted observed that the root tip of clover was the breeding place for large number of bacteria representing many groups. He reported that this occurred because of the exudation of substances from exfoliated cells from the root. Subsequently, beginning with Hiltner's introduction of the term, "rhizosphere", in 1904 to describe this type of phenomenon, there have been innumerable reports describing the activities of bacteria, fungi, nematodes and phanerogamic parasites in association with plant roots. Comprehensive accounts of studies of rhizosphere and rhizoplane microflora have been provided by several workers (Schroth and Hilderbrand, 1964). These discussions have been complemented by the reviews of ther workers (Borner, 1960; Grodzinsky, 1962; and Woods, 1960) on the sources and nature of plant exudates.

The plant root exudates are known to affect survival, reproduction and development of various microorganisms in soil through extremely complex phenomena (Snyder, 1960). Schroth and Hilderbrand (1964) explained that plant exudates affect the pathogens directly by inducing their germination, contributing to their nutritional status prior to penetration, or by inhibiting their saprophytic and pathogenic activities, and indirectly by competition and antibiosis by the root microflora whose activities also are mediated by exudates.

The indirect effect of root exudates on *Fusarium* spp. through their influence on the rihizosphere microflora was reported by Rangaswamy and Balasubramanian 1963), in their studies on root exudates of sorghum. Root exudates of the crop had inhibited *Fusarium* spp. in the soil, while promoting the bacterial populations. However, no significant effects were observed on the numbers of actinomycetes. Gaur and Sharma (1991) stated that the rhizosphere soil of resistant pigeonpea cv. SP-15 supported fungal and bacterial spp. such as *Aspergillus niger, Streptomyces sp.* and *Bacillus sp.* They also observed an apparent correlation between wilt incidence, magnitude of *Fusarium udum* and population of these antagonists in the soil. Bhatnagar (1995) had also reported an inhibition of pigeonpea wilt pathogen and promotion of *Trichoderma viride* conidial germination with root exudates of sorghum, maize, groundnut and castor.

Hillocks *et al.* (1997) reported that cyanide content of root exudate solution of sorghum and millet were found inhibitory to Chlamydospore germination of *Fusarium udum* in pigeonpea and *F. oxysporum* f. sp. *Vasinfectum* in cotton, respectively.

The root exudates are reported to be generally composed of commonly occurring substances like amino acids (Odunfa, 1978), sugars (Schroth and Snyder, 1961), phenols (Naik, 1993) and organic acids (Bhatnagar, 1995). These compounds affect the chemical environment of rhizosphere which in turn affects the rhizosphere microflora (Bolten *et al.*, 1993). Schroth *et al.* (1963) reported chlamydospore germination of *Fusarium solani* f.sp. *phaseoli* to be dependent on the balance between the amount of fungitoxins and availability of nutrients provided by plant exudates. Naik (1993) also concluded that inhibition of conidial germination of *Fusarium udum* observed with the resistant cultivars of pigeonpea was due to low levels of carbon and nitrogen, reported to be required for germination of fungal spores (Cook and Schroth, 1965), in addition to the high levels of inhibitor phenols present in root exudates of these cultivars. Inhibition of fungal populations of *Fusarium* spp. by root exudates of sorghum was also reported to be due to volatile compounds (Rangaswamy and Balasubramanian, 1963) and cyanide (Natarajan *et al.*, 1985; Sharma *et al.*, 1987) present in the crop root exudates. Stevenson *et al.* (1995), however, reported presence of ethylacetate fractions in root exudates of resistant chickpea cultivars to be responsible for inhibition of *Fusarium oxysporium* f. sp. *ciceri.*

Genotypes of the host were also reported to govern the magnitude and composition of rhizosphere microbial populations (Schroth and Hilderbrand, 1964) with surprising specificity, presumably through the control of quantity or quality of root exudates (Atkinson *et al.*, 1975). Afifi (1976) observed that the susceptible variety of *Hibiscus esculentus* stimulated conidial germination of three *Fusarium* spp., while the resistant ones inhibited their germination. A greater germination of chlamydospores of *Fusarium oxysporum* f. sp. *cicerii* in the root exudates of susceptible cultivars of chickpea was also demonstrated by Satyaprasad and Rama Rao (1983) and Haware and Nene (1984).

Spore germination of *F. udum* was found to be highest (91.6%) in root extracts of susceptible cultivar ICP 6997, while it was 8, 8.18, 14 and 4.28% in resistant cultivars C11, 15-3-3, BDN-1 and Banda, respectively as earlier reported by Kotasthane *et al.* (1985).

Naik (1993) had also reported a variation in the effect of root exudates of different pigeonpea cultivars with regards to inhibition of *Fusarium udum.* The inhibition of conidial germination was 72 per cent in root exudates of resistant genotypes, compared to 15 - 18 per cent in the root exudates of susceptible and moderately susceptible genotypes. The effect also varied with the plant species (Rovira, 1969). Root exudates of cotton and pigeonpea were observed to stimulate conidial germination of pigeonpea, while root exudates of groundnut, castor, greengram, maize and hybrid sorghum inhibited the conidial germination (Bhatnagar, 1995).

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

The present investigations on integrated disease management of pigeonpea wilt were undertaken at ICRISAT Center, Patancheru, India during 1996-1998. Details of the experimental materials and methods adopted are presented hereunder.

3.1 PIGEONPEA WILT PATHOGEN (*Fusarium udum* Butler)

The causal organism of pigeonpea wilt, *Fusarium udum* Butler, was isolated on potato dextrose agar (PDA) from wilted pigeonpea plants at ICRISAT, Patancheru. The culture thus obtained was purified by single hyphal tip method. Further, its identity was confirmed by pathogenicity test on young pigeonpea seedlings, adopting root dip inoculation and transplantation technique as suggested by Nene *et al.*(1981).

Seeds of three pigeonpea cultivars namely, ICP 2376, C11 and ICP 8863 were surface sterilized for 2 minutes in 2.5 per cent chlorax solution and then sown in sterilized sand filled in polythene bags. These were then kept in glasshouse at 25-30^{0}c and wateredwith sterilized water. The pathogen was also multiplied undertaken simultaneously in potato dextrose broth (PDB) from the inoculum maintained on PDA slants (at 28$\pm$2^{0}c, by periodic transfers). The 250 ml conical flasks containing 100 ml sterilized PDB per flask were inoculated with the pathogen and incubated at 25-30^{0}c in an orbital shaker for three days, for the production of fungal conidia.

One week old seedlings were inoculated by pruning the tip of root system of about 3 mm, after uprooting the seedlings from the sterilised sand bags and thorough washing of the root system with running tap water. The pruned seedlings were dipped in one week old *Fusarium udum* conidial suspension (1×10^1 conidia/ml) for one minute and then transplanted into 6" diameter plastic pots filled with sterilized soil. Each cultivar was replicated four times, with one pot consisting of five plants representing one replication. Wilt incidence was recorded on these plants at 15 and 30 days after transplantation.

3.2 FIELD, GLASS-HOUSE AND LABORATORY STUDIES

Investigations on the effect of cropping systems and production practices on pigeonpea wilt incidence and population levels of *Fusarium udum* and its antagonistic fungi, in addition to studies on the effect of crop root exudates on conidial germination of *Fusarium udum* pathogen and its antagonistic fungi were carried out in field, glasshouse and laboratory during *kharif* 1996-97 and *Kharif* 1997-98.

3.2.1 Effect of cropping systems and N sources and levels on pigeonpea wilt

The effect of four cropping systems and six production practices on wilt and population levels of *Fusarium udum* and its antagonistic fungi viz., *Aspergillus, Penicillium and Trichoderma* spp. was studied in Soil biology experimental trial in BW_3 field at ICRISAT Center, Patancheru, Andhra

Pradesh. The experiments were conducted during *kharif* 1996-97 in a split-plot design with three replications. N sources and levels viz., FYM and KNO_3 were used @ 40 and 20 kg N ha^{-1} through farm yard manure (FYM), 20 and 40 kg N ha^{-1} through KNO_3 and 20 kg N ha^{-1} through FYM in combination with 20 kg N ha^{-1} through KNO_3 (20:20 Fert:FYM), and in addition to control (unamended) constituted the main treatments. While cropping systems namely, sole cropping of soybean and pigeonpea and intercropping of soybean with sunflower and sorghum with pigeonpea constituted the sub-treatments. Plantings were taken up on broad bed furrows. Sole pigeonpea and soybean was sown two rows per bed while intercropping of soybean (PK#472) with sunflower (Morden) was taken up in 4:1 (5 rows) and sorghum (CSH-9) with pigeonpea (ICPL 87119) in 2:1 (3 rows) crop row ratios, respectively. Application of both FYM and KNO_3 were undertaken before planting. The crops were raised following recommended package of practices and observations on populations levels of the wilt pathogen (***Fusarium udum***) and its antagonistic fungi were recorded after harvest, following standard procedures.

3.2.2 Effect of predominant pigeonpea intercropping systems of Andhra Pradesh on wilt, *F. udum* and its antagonistic fungi

The effect of predominant pigeonpea intercropping systems of Andhra Pradesh on population levels of *Fusarium udum* and its antagonistic fungi, in addition to pigeonpea wilt incidence was investigated in both on-farm trials and glasshouse studies during 1996-98. On-farm studies were conducted during *Kharif* 1996-97 in four districts of Andhra Pradesh, at six

Studies on predominant pigeonpea based intercropping systems on wilt incidence (ICRISAT Soils)

Plate 1. Sole pigeonpea – Vertisols

Plate 2. Sole pigeonpea – Alfisols

Plate 3. Pigeonpea/Sorghum - Vertisols

Plate 4. Pigeonpea/Groundnut – Alfisols

locations, each with a distinct pigeonpea based intercropping system. Ten individual fields were studied at each location, the details of which are presented below.

District	Location	Cropping systems	Soil type
Ranga Reddy	Pati	Pigeonpea/Sorghum	Vertisols
Ranga Reddy	Tandur	Pigeonpea/Greengram	Vertisols
Medak	Siddipet	Pigeonpea/Cotton	Vertisols
Medak	Basawapur	Pigeonpea/Maize	Alfisols
Nalgonda	Mall	Pigeonpea/Castor	Alfisols
Kurnool	Dhone	Pigeonpea/Groundnut	Alfisols

The effect of these cropping systems in comparison to sole and intercropped pigeonpea (with groundnut and sorghum) was also studied at ICRISAT Center, Patancheru. Pot culture experiments were conducted with wilt sick Alfisols and Vertisols using randomized block design with four replications (Plates 1-4). Each pot represented a single replication of a treatment. These studies were undertaken during two consecutive *Kharif* seasons of 1996-97 and 1997-98 in glasshouses. Details of the treatments are as follows:

Studies on predominant pigeonpea based intercropping systems on wilt incidence (Farmers fields soils)

Plate 5. Pigeonpea/Groundnut – Dhone (Anantapur)

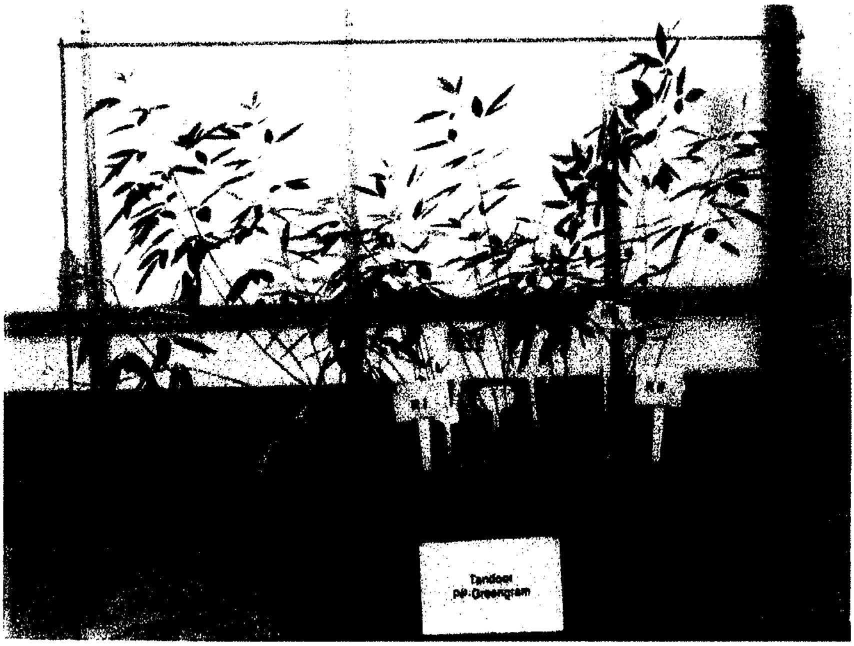


Plate 6. Pigeonpea/Green gram – Tandur (Rangareddy)

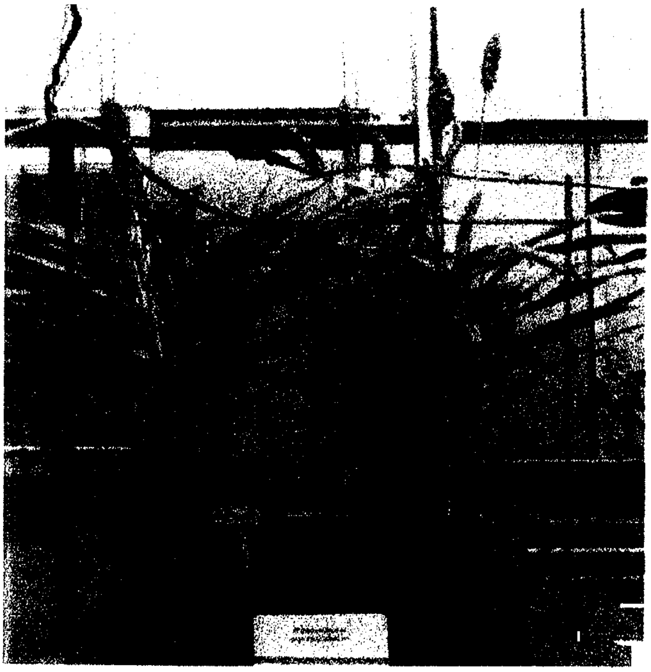


Plate 7. Pigeonpea/Sorghum – Patancheru - Pati (Medak)

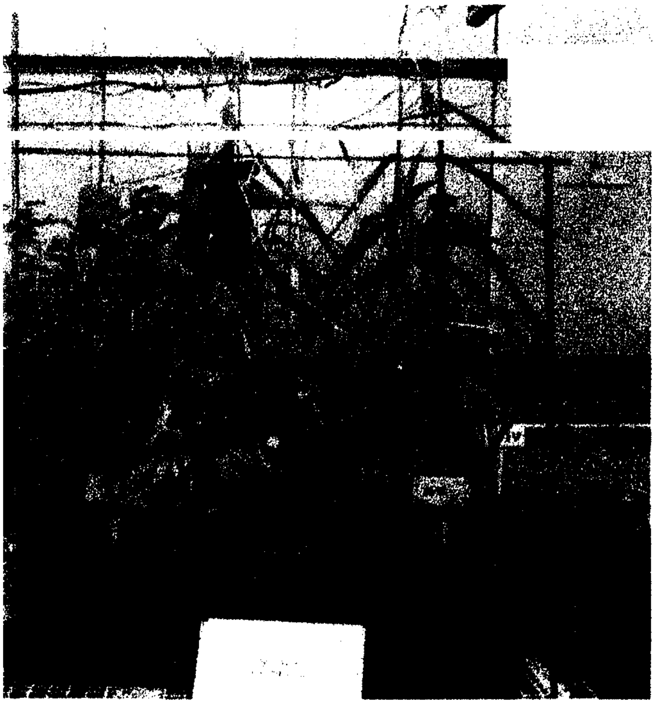


Plate 8. Pigeonpea/Maize – Basawapur (Medak)

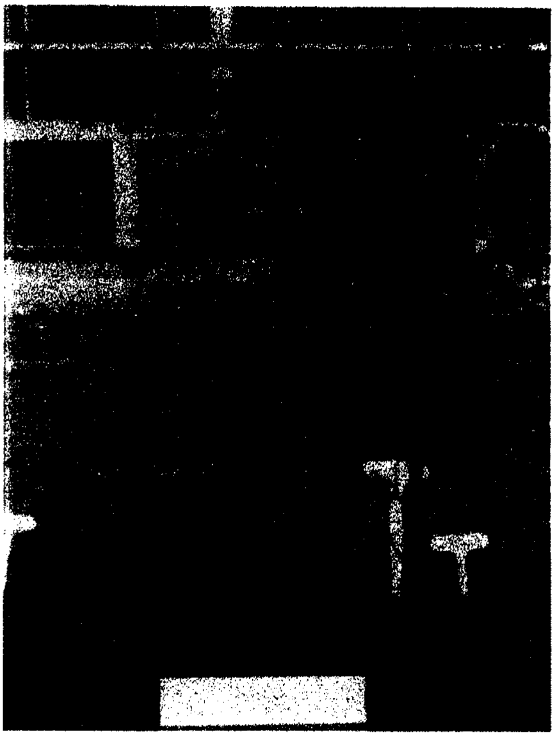


Plate 9. Pigeonpea/Castor – Mall (Nalgonda)

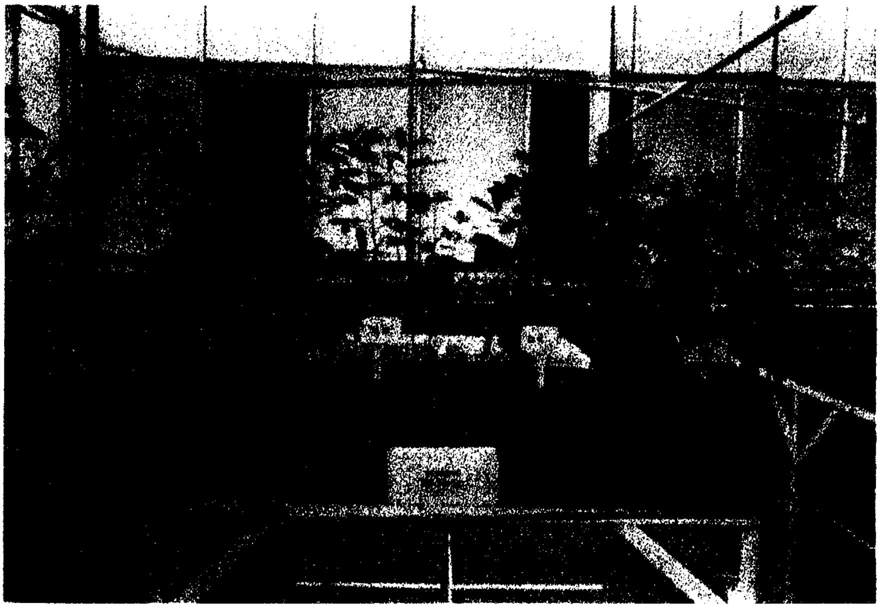


Plate 10. Pigeonpea/Cotton – Siddipet (Medak)

District	Location	Cropping system	Soil type
ICRISAT fields			
Medak	BIL 2B	Pigeonpea/Sorghum	Vertisol
Medak	BIL 2B	Pigeonpea	Vertisol
Medak	RM 8E	Pigeonpea	Alfisol
Medak	RM 8E	Pigeonpea/Groundnut	Alfisol
Farmer's fields			
Ranga Reddy	Pati	Pigeonpea/Sorghum	Vertisol
Ranga Reddy	Tandur	Pigeonpea/Greengram	Vertisol
Medak	Siddipet	Pigeonpea/Cotton	Vertisol
Medak	Basawapur	Pigeonpea/Maize	Alfisol
Nalgonda	Mall	Pigeonpea/Castor	Alfisol
Kurnool	Dhone	Pigeonpea/Groundnut	Alfisol

The experiments during *Kharif* 1997-98 were repeated utilizing the same pots and soil of *Kharif* 1996-97. Each location/cropping system was represented by four 12" diameter plastic pots, filled with soil obtained from the respective locations (Plates 5-10). These pots were sown with crops similar to the cropping systems observed at the respective locations. A single row of intercrop, comprising of four plants was planted between two pigeonpea rows comprising of three plants with a spacing of 8 cms in each row. Sole cropping of pigeonpea was also planted in three rows withfour plants in the central row and three plants on either side of central row. Sowings of both pigeonpea and the intercrop were taken up simultaneously.

Details regarding different crop varieties used in glasshouse studies are as follows:

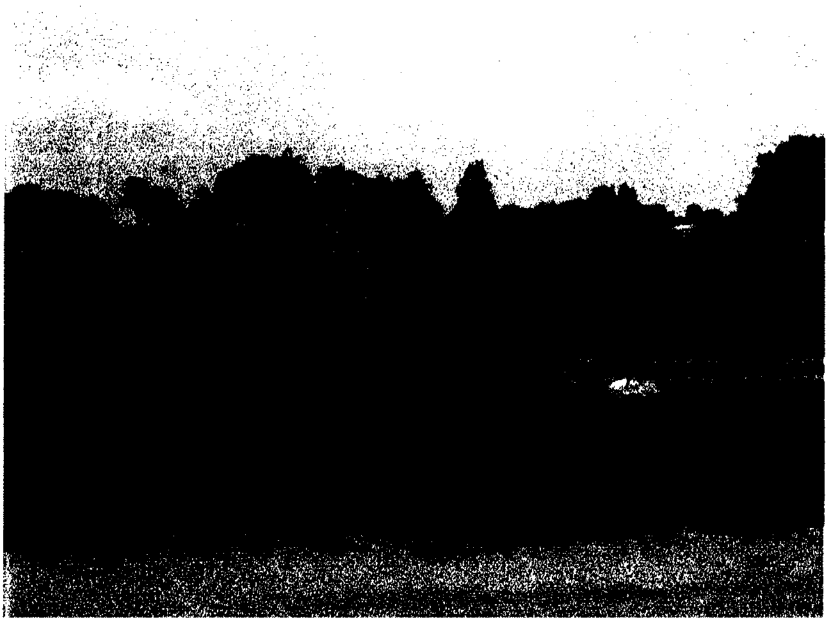
Crop	Variety
Pigeonpea	ICPL 332 (Susceptible variety)
Sorghum	CSH 9
Groundnut	TMV 2
Maize	DHM 103
Greengram	PS 16
Cotton	MNH 44

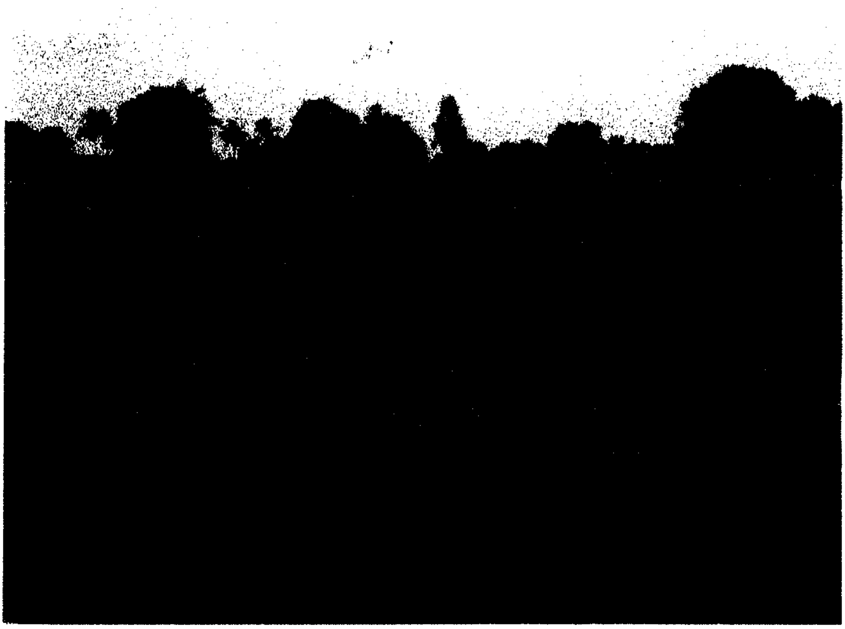
The plants were raised in pots with 24 kgs and 28 kgs of Vertisol and Alfisols respectively. They are watered in alternate days with a rose can. Temperature of 28-30°C and relative humidity of 60-70% was maintained in glasshouse. Spraying of endosulfan @ 2 ml per litre was taken up at pod formation stage. Further, standard procedures were adopted for observations on wilt incidence and population levels of the pathogen and its antagonistic fungi in the different treatments.

3.2.3 Studies on integrated disease management of pigeonpea wilt

Integrated management of pigeonpea wilt was studied in both Alfisol and Vertisol conditions during two consecutive *Kharif* seasons of 1996-97 and 1997-98, under both glasshouse and field conditions. Glasshouse experiments were conducted in 12" diameter plastic pots, with each pot representing one treatment of a replication. Further, the glasshouse experiments

Plate 11. Field view of integrated disease management of pigeonpea wilt trial in Alfisols





during *Kharif* 1997-98 were undertaken utilizing the same pots and soil used in *Kharif* 1996-97. Glasshouse investigations during the two consecutive seasons were also undertaken with the soil from the respective treatment plots in Vertisol and Alfisol sick fields. The meteorological data is presented in Appendix (G) i.e., from June 1996-March, 1998.

3.2.3.1 Integrated disease management trial in Alfisols

The IDM trial was laid in a randomized block design with eight treatments and three replications, under field (Fig.3) and glasshouse conditions (Plate 11 and 13). The field studies were conducted in RM 8E field of ICRISAT Center, Patancheru, Andhra Pradesh, while glasshouse experiment was undertaken outside at ICRISAT glasshouse Center. Details of the treatments are as follows:

S.No.	Treatments
1.	Sole cropping of pigeonpea (sole PP)
2.	Sole cropping of pigeonpea with incorporation of *Crotolaria juncea* green manure (GM) @ 5 tons ha^{-1}
3.	Sole cropping of pigeonpea with incorporation of farm yard manure (FYM) @ 5 tons ha^{-1}
4.	Sole cropping of pigeonpea with adoption of integrated disease management (IDM) technique (1/2 GM+1/2 FYM+SD)
5.	Intercropping of pigeonpea with groundnut (PP/Gnut)
6.	Intercropping of pigeonpea with groundnut in addition to incorporation of *Crotolaria juncea* green manure (PP/Gnut+GM) @ 2.5 tons ha^{-1}
7.	Intercropping of pigeonpea with groundnut in addition to farm yard manure (PP/Gnut+FYM) @ 2.5 tons ha^{-1}
8.	Intercropping of pigeonpea with groundnut in addition to adoption of IDM (PP/Gnut+IDM) (1/2 dose of each component)

Note: SD = Bavistin + Thiram + Trichoderma

Fig. 3: Layout of IDM of pigeonpea wilt trial in RM 8E field of ICRISAT Center, Patancheru, Andhra Pradesh (*Kharif*, 1996 and 97) (Alfisols)

Replication I	PP/Gnut Control	PP Control
	PP IDM	PP/Gnut IDM
	PP FYM	PP/Gnut FYM
	PP GM	PP/Gnut GM
Replication II	PP/Gnut Control	PP Control
	PP/Gnut GM	PP GM
	PP/Gnut IDM	PP IDM
	PP/Gnut FYM	PP FYM
Replication III	PP IDM	PP/Gnut IDM
	PP FYM	PP/Gnut FYM
	PP/Gnut GM	PP Control
	PP Control	PP/Gnut Control

PP - Pigeonpea; PP/Gnut - Pigeonpea/Groundnut; GM - Green manure; FYM - Farm yard manure; IDM - Integrated disease management

Wilt tolerant pigeonpea cv. C11 and TMV 2 variety of groundnut were used in the present studies. These were planted in field on ridges, 60 cm apart with a plant to plant distance of 20 cm for pigeonpea and 15 cm for groundnut. Intercropping of pigeonpea with groundnut was undertaken adopting 1:2 (1 row pigeonpea and 2 rows groundnut) planting row ratio.

A uniform basal application of DAP @ 100 kg ha^{-1} was applied for all treatments, in all replications, prior to planting. Green manure and farm yard manure were also applied as basal, before planting at the time of field preparation. Green manure and farm yard manure were applied @ 5 tons ha^{-1}. Green manure was applied on dry weight basis @ 31 kgs per plot (82 kg fresh weight). Farm yard manure was applied @ 31 kg per plot (45 kgs fresh weight). Integrated disease management (IDM) treatment involving seed dressing with fungicides and *Trichoderma* (1.5 g of talc based *Trichoderma* formulation coupled with 1.5 g of Bavistin and Thiram, mixed in 1:1 proportion) per kg seed, in addition to basal application of farm yard manure and green manure @ 2.5 tons ha^{-1}, prior to planting. Each treatment was sown in a plot of 13 x 4.8 m^2 area. In glasshouse study, a single 12" diameter pot representing one treatment/plot of a field in a replication. The crop was raised following recommended package of practices such as seed rate @ 12 kg/ha field preparation and sowings. Further, observations on wilt incidence, population levels of the pathogen and its antagonistic fungi, in addition to yield and biomass of pigeonpea were recorded following standard procedures of Natarajan *et al.* (1985), Raghu Chander *et al.* (1992) and Bhatnagar (1995).

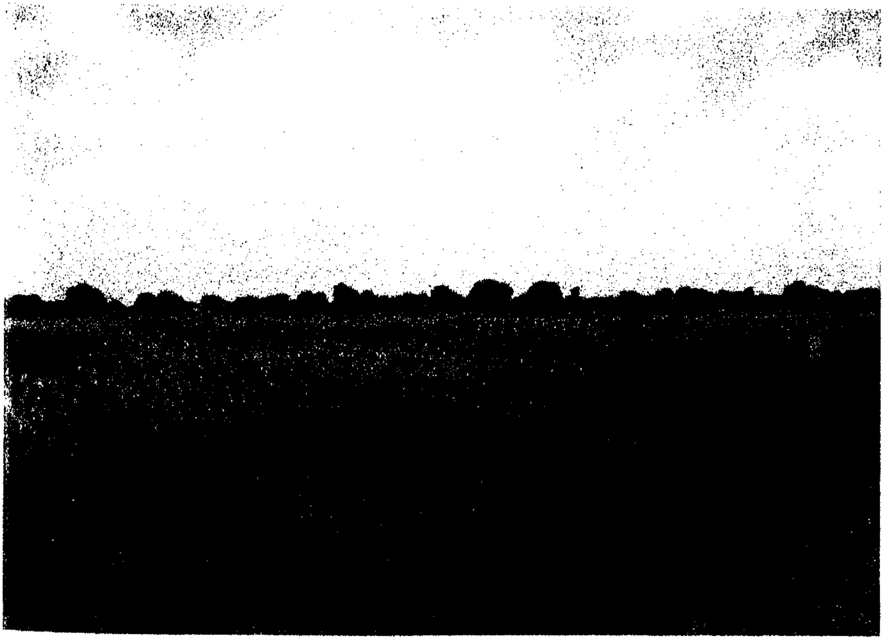
Fig. 4: Layout of IDM of pigeonpea wilt trial in BIL 2B field of ICRISAT Center, Patancheru, Andhra Pradesh, **Kharif (1996 & 97) (Vertisols)**

Replication I				Replication II				Replication III			
C11/Sor SD	Sole C11 SD	Sole 8863 SD	8863/Sor SD	Sole 8863 FYM	8863/Sor FYM	C11/Sor FYM	Sole C11 FYM	Sole C11 Zn+GM	Sole 8863 Zn+GM	C11/Sor Zn+GM	8863/Sor Zn+GM
C11/Sor IDM	Sole 8863 IDM	8863/Sor IDM	Sole C11 IDM	Sole 8863 FYM+GM	Sole C11 FYM+GM	C11/Sor FYM+GM	8863/Sor FYM+GM	C11/Sor Control	Sole C11 Control	8863/Sor Control	Sole 8863 Control
8863 Sole FYM	C11 Sole FYM	8863/Sor FYM	C11/Sor FYM	C11/Sor GM	Sole 8863 GM	8863/Sor GM	Sole C11 GM	Sole 8863 GM	Sole C11 GM	C11/Sor GM	8863/Sor GM
C11/Sor Zn+FYM	Sole 8863 Zn+FYM	8863/Sor Zn+FYM	Sole C11 Zn+FYM	C11/Sor IDM	Sole C11 IDM	8863/Sor IDM	Sole 8863 IDM	Sole C11 Zn	8863/Sor Zn	Sole 8863 Zn	C11/Sor Zn
C11/Sor Control	8863/Sor Control	Sole C11 Control	Sole 8863 Control	Sole 8863 Zn+FYM	C11/Sor Zn+FYM	Sole C11 Zn+FYM	8863/Sor Zn+FYM	8863/Sor IDM	C11/Sor IDM	Sole C11 IDM	Sole 8863 IDM
C11/Sor FYM+GM	8863/Sor FYM+GM	Sole C11 FYM+GM	Sole 8863 FYM+GM	Sole C11 Control	8863/Sor Control	C11/Sor Control	Sole 8863 Control	C11/Sor FYM+GM	8863/Sor FYM+GM	Sole 8863 FYM+GM	Sole C11 FYM+GM
Sole 8863 Zn+GM	C11/Sor Zn+GM	Sole C11 Zn+GM	8863/Sor Zn+GM	Sole 8863 SD	Sole C11 SD	C11/Sor SD	8863/Sor SD	8863/Sor Zn+FYM	Sole C11 Zn+FYM	Sole 8863 Zn+FYM	C11/Sor Zn+FYM
8863/Sor GM	C11/Sor GM	Sole C11 GM	Sole 8863 GM	8863/Sor Zn	Sole 8863 Zn	C11/Sor Zn	Sole C11 Zn	C11/Sor FYM	Sole C11 FYM	8863/Sor FYM	Sole 8863 FYM
8863/Sor Zn	Sole C11 Zn	Sole 8863 Zn	C11/Sor Zn	8863/Sor Zn+GM	Sole 8863 Zn+GM	C11/Sor Zn+GM	Sole C11 Zn+GM	8863/Sor SD	Sole C11 SD	C11/Sor SD	Sole 8863 SD

Main treatments: Control; Zn- $ZnSO_4$; GM- Green manure; FYM- Farm yard manure; Zn+GM- Zinc+Green manure; Zn+FYM- Zinc+Farm yard manure; FYM+GM- Farm yard manure+Green manure; SD- Seed dressing (Bavistin+Thiram+*Trichoderma*); IDM-Integrated disease management (Combination of all above components).

Sub treatments: Sole C11; Sole ICP 8863; C11/Sorghum (CSH 9); ICP 8863/Sorghum

Plate 12. Field view of integrated disease management of pigeonpea wilt trial in Vertisols



View of integrated disease management of pigeonpea wilt trial pot study

Plate 13. Integrated disease management of pigeonpea wilt trial in Alfisols under glass house conditions

Plate 14. Integrated disease management of pigeonpea wilt trial in Vertisols under glass house conditions

3.2.3.2 Integrated wilt management in Vertisols:

The studies were conducted in BIL 2B field (Fig.4); and in greenhouse of ICRISAT Center, Pantancheru, Andhra Pradesh, in a split-plot design (Plates 12 and 14) with three replications, comprising of nine production practices (including control) as main treatments, and four cropping systems as sub-treatment. Details of the treatments are as follows:

Main treatments (Production practices)

1. Application of $ZnSo_4$ @ 24 kg ha^{-1}
2. Application of FYM @ 5 tons ha^{-1}
3. Application of *Crotolaria juncea* as green manure @ 5 tons ha^{-1}
4. Application of $ZnSo_4$ @ 12.5 kg ha^{-1} and FYM @ 2.5 tons ha^{-1}
5. Application of $ZnSo_4$ @ 12.5 kg ha^{-1} and green manure @ 2.5 tons ha^{-1}
6. Application of green manure and FYM @ 2.5 tons ha^{-1} each
7. Seed dressing with 3 g mixture of Bavistin and Thiram, mixed in 1:1 proportion and 3 g of talc based *Trichoderma* product for every kg of seed.
8. Integrated disease management (IDM), involving seed dressing with fungicides and *Trichoderma* (1.5 g of talc based *Trichoderma* formulation coupled with 1.5 g of Bavistin anad Thiram, mixed in 1:1 proportion) and basal application of FYM, green manure each @ 1.25 tons ha^{-1} and $ZnSo_4$ @ 6.25 kg ha^{-1}.
9. Control (unamended)

Sub-treatments (Cropping systems)

1. Sole cropping of wilt tolerant pigeonpea (C11)
2. Sole cropping of wilt resistant pigeonpea (ICP 8863).
3. Intercropping of wilt tolerant pigeonpea (C11) with hybrid sorghum (CSH 9).
4. Intercropping of wilt resistant pigeonpea (ICP 8863) with hybrid sorghum (CSH 9)

A uniform basal aplication of DAP @ 100 kg ha^{-1} was taken up in all treatments prior to planting. Aplication of $ZnSo_4$, FYM and green manure was also undertaken as basal, before planting, at the time of field prearation. Green manure was applied on dry weight basis @ 24 kgs per plot (63 kg fresh weight) and Farm yard manure @ 24 kgs per plot (35 kgs fresh weight), respectively. Top dressing with urea @ 100 kg ha^{-1} was also applied for sorghum, 45 DAS. Field planting of pigeonpea and sorghum was done on ridges, 60 cm apart with a plant to plant distance of 20 cm for pigeonpea and 15 cm for sorghum. Intercropping of pigeonpea with sorghum was undertaken adopting 1:2 planting row ratio. Each treatment was sown in a plot of 8 x 6 m (48 m^2) area, in the field, while a single 12" diameter pot representing treatment/plot in a glasshouse study. The crop was raised following recommended package of practices. Observations on wilt incidence, population levels of the wilt pathogen *F. udum* and its antagonistic fungi, in addition to yield and biomass of pigeonpea were recorded following standard procedures.

3.3 EXPERIMENTAL TECHNIQUES

Various techniques followed in the integrated disease management of pigeonpea wilt in the present study are as follows:

3.3.1 Collection of soil sample:

Soil samples were collected to estimate population dynamics of the wilt pathogen and its antagonistic fungi namely, *Aspergillus*, *Penicillium* and *Trichoderma* spp. The samples were collected from 0-15 cm depth at ten random places in each plot of the experimental field, as per the procedure suggested by Ploetz *et al.* (1985), and each pot in case of glasshouse studies. Further, the soil samples were stored in cold storage room to prevent loss of biological activity. The chemical nature and status of the soils are presented in Appendix (C).

3.3.2 Estimation of *Fusarium, Aspergillus, Penicillium* and Trichoderma spp. populations

The fungal populations were estimated following soil plate method developed by Timonin (1941). Fusarium specific medium developed by Nash and Snyder (1962) subsequently modified using malachite green medium for estimation of *Fusarium udum* following the method of Sharma and Singh (1973). Martin's rose bengal agar medium (Martin, 1950) for *Aspergillus* and *Penicillium* spp., and *Trichoderma* selective medium for *Trichoderma* spp. (improved media) (Elad and Chet, 1983) (Appendices D-F). About 20 mg of air dried finely powdered soil was sprinkled on the surface of pre-poured medium in petriplates and incubated at 25±1 °C for *Fusarium udum* and at 28±2° for *Aspergillus, Penicillium* and *Trichoderma* spp., for two to three days in case of *Fusarium, Asperigillus* and *penicillum* and five days in case of *Trichoderma* spp., as standardised by Bhatnagar (1995). Fungal colonies produced on the media were then counted with Quebec colony counter. Four plates were used for one soil sample obtained from each plot or pot.

3.3.3 Estimation of wilt incidence

Observations on wilt incidence in all the replicates of each treatment in different studies were recorded and percentage wilt incidence was calculated as follows:

$$\text{Per cent wilt incidence} = \frac{\text{Total No. of plants - No of Wilted plants}}{\text{Total No. of plants}} \times 100$$

3.3.4 Yield and biomass

The yield and biomass of pigeonpea were recorded in all the experiments in Alfisol and Vertisol under both glasshouse and field conditions. Yield of pigeonpea in each plot, in the field and each pot in the glasshouse was recorded and expressed as Kg ha^{-1}. The biomass was obtained as weight of ten random plants in the field, in each plot and three random plants in the glasshouse, in each pot, and was expressed as g $plant^{-1}$.

3.4 LAB STUDIES

Studies on crop root exudates of nine crops namely, groundnut, castor, soybean, sunflower, maize green gram, cotton, sorghum and pigeonpea in comparison to control (water) were conducted in Legumes Pathology lab of Crop Protection Divison, ICRISAT Center, Patancheru, Andhra Pradesh during 1997-98 for their effects on conidial germination of *Fusarium udum* and its antagonistic fungi namely, *Aspergillus,* Penicillium and *Trichoderma* spp. Influence of crop root exudates was also studied for the local and hybrid cultivars of sorghum; and for susceptible and resistant cultivars of pigeonpea. Further, the effect of these root exudates was analyzed adopting completely randomized block design with three replications.

3.4.1 Collection of root exudates

Seeds of groundnut (TMV 2), castor (GAUCH 1), soybean (PK 472), sunflower (Morden), maize (DHM 103), greengram (PS 16), cotton (MNH 44), local sorghum, hybrid sorghum (CSH 9), wilt susceptible pigeonpea (ICP 2376) and resistant pigeonpea (ICP 8863) were surface sterilized with 2.5 per cent sodium hypochlorite solution for 10 minutes. They were then throughly rinsed with sterilized water and placed over sterilized moist blotting paper in petriplates for 72 h at 25±2 °C. The germinating seeds were then transferred on to holed styrofoam sheet cut to fit the size of 150 ml beaker containing 20 ml of sterilized distilled water. The young seedlings were placed in such a way that radicles of the germinating seeds (six per beaker), when passed

Equipment for root exudates experiment

late 15. Pigeonpea seedlings passed through holed styrofoam sheet for collection of root exudates

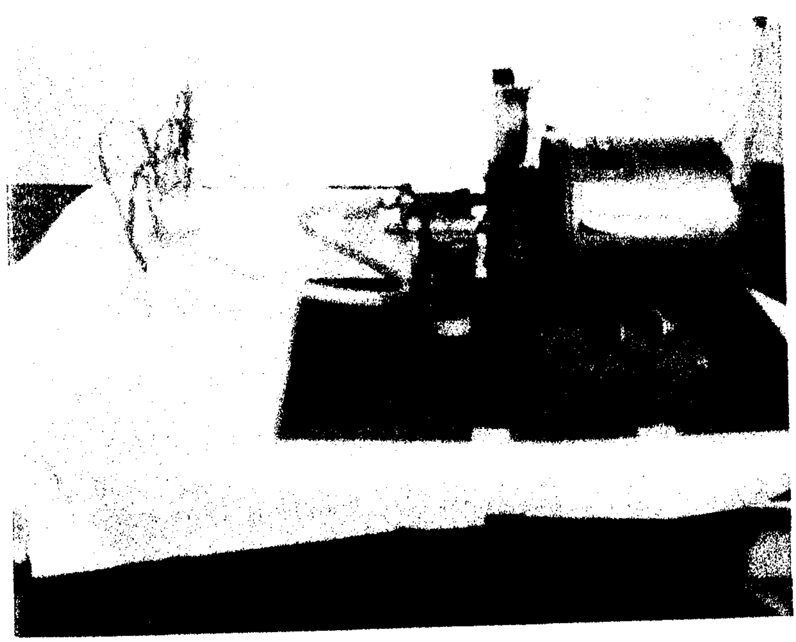


Plate 16 & 17. Collection of root exudates of Groundnut and Sorghum under vacuum using Nalgene millipore filters

through holes of the styrofoam sheet just dipped into the sterile water (Plate 15). The beakers along with young germinated seedlings were covered with black paper and incubated at 25±2°C for 15-20 days. Due care was taken to maintain the water level (20 ml) in each beaker. The root exudates collected in water after incubation, were passed through a nalgene millipore filter under vaccum (Plate 16 and 17) and the resultant filtrates were preserved at 10°C in a refrigerator for further use (Odunfa, 1978; Naik, 1993).

3.4.2 Conidial germination studies

Conidia of *Fusarium udum* and its antagonistic fungi were obtained by blending and filtration of one week old liquid growth cultures of the fungi in potato dextrose broth. Conidal concentration in the suspension was adjusted to 1000/ml conidial suspension of *Fusarium udum* or its antagonistic fungi, for study of the effect of root exudates on conidial germination. About 0.2 ml of exudate was used in the cavity slide and mixed with 0.2 ml of conidial suspension of Fusarium and other antagonists were incubated separately. The cavity slides were incubated at 25±2°C in a humid chamber for 24 hrs. A control set was also maintained by placing the conidial suspension in distilled water. Three slides were kept for each crop root exudate, each serving as replicate. The experiment was repeated three times.

3.4.3 Radial growth of the wilt pathogen

Ten ml of root exudates was thoroughly mixed with 10 ml of potato dextrose agar medium and 20 ml of such medium was poured into petriplates. PDA mixed with sterile water served as check. A mycelial discs of the wilt pathogen (*Fusarium udum)* and antagonistic fungi was cut from the periphery of 10 day old fungal cultures maintained on PDA in petriplates using a sterile 12 mm diameter cork borer. The discs were placed at the center of each petriplate, containing different crop root exudates and sterile water (control). The inoculated petriplates were then incubated at 25°C and observations on colony diameter were recorded at 4, 5, 8 and 10 days of incubation.

3.5 ECONOMIC ANALYSIS

The experimental data was used for economic analysis of IDM vis-a-vis control (Singh, 1978). Pigeonpea was chosen for the study. However, pigeonpea intercropping system with pigeonpea as a base crop and sorghum as an intercrop in Vertisols and pigeonpea as a base crop and groundnut as an intercrop in Alfisols were also used for the study. The various treatments followed in the experiments have already been explained.

All the specific inputs used and the outputs obtained are expressed in monetary terms. The methodology used in the economic analysis is "added costs and added returns". The benefit : cost ratio was also worked out for various treatments.

3.6 STATISTICAL ANALYSIS

Results of the various experiments were analyzed following appropriate statistical methods as per the procedures suggested by Panse and

Sukhatme (1978). Observations on per cent disease incidence and population counts of Fusarium and its antagonistic fungi recorded in the present investigations were however, suitably transformed using arc-sine transformation and square root transformations, respectively, prior to statistical analysis.

RESULTS

CHAPTER IV

RESULTS

The results of the present investigation on "Integrated disease management of pigeonpea wilt" are presented hereunder.

4.1 PIGEONPEA WILT PATHOGEN (*Fusarium udum* Butler)

4.1.1 Isolation of the pathogen

The causal agent was isolated from infected parts on PDA. The culture was further purified by single spore isolation technique and maintained. The characteristics of the fungal mycelium was observed under a stereo binocular microscope. Mycelium of the fungus is hyaline, branched and produce micro-conidia successively on the tips of short simple or clustered conidiophores. Under a microscope they appear as dry, white powdery (false) heads (Plate 18). Microconidiophores are subcylindrical with a distinct collaratte. Micro conidia are single or bicelled, hyaline, reniform mostly curved, ovoid to fusoid, scattered hyaline singly and salmon pink red in mass (Plate 19). Macro conidia are produced on macroconidiophores. The most characteristic of the macroconidia are their strongly curved or hooked apices (Plate 20). They are predominantly 3-4 septate. Chlamydospores of the fungus are oval, thick walled, hyaline in short chains (Plate 21).

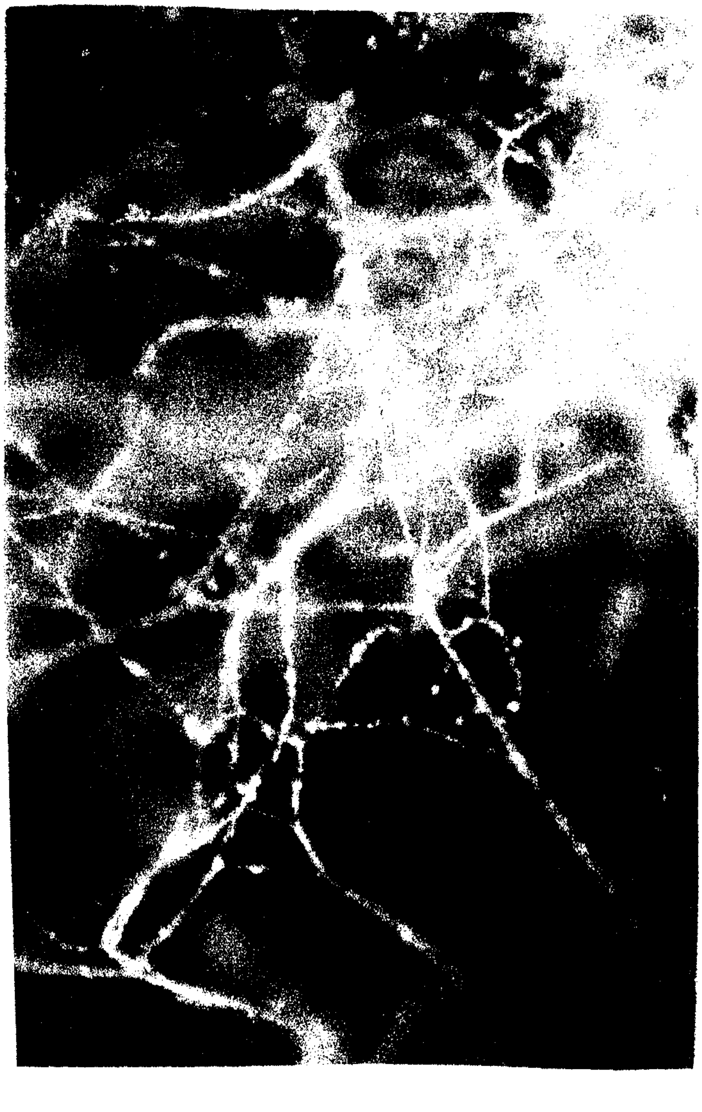


Plate 18: False heads (arrowed) produced on the mycelium of *Fusarium udum*

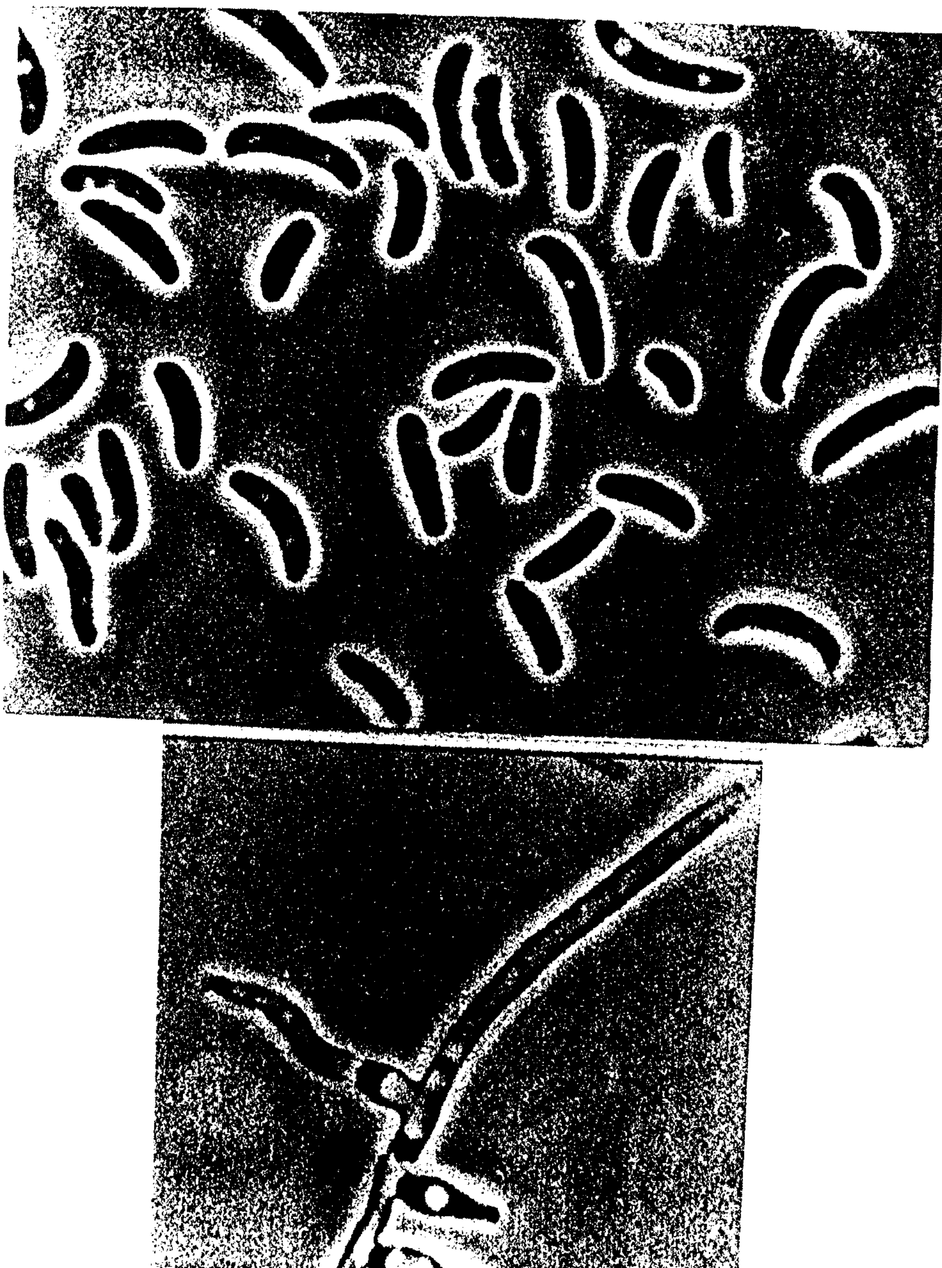


Plate 19: Microconidiophores with microconidia

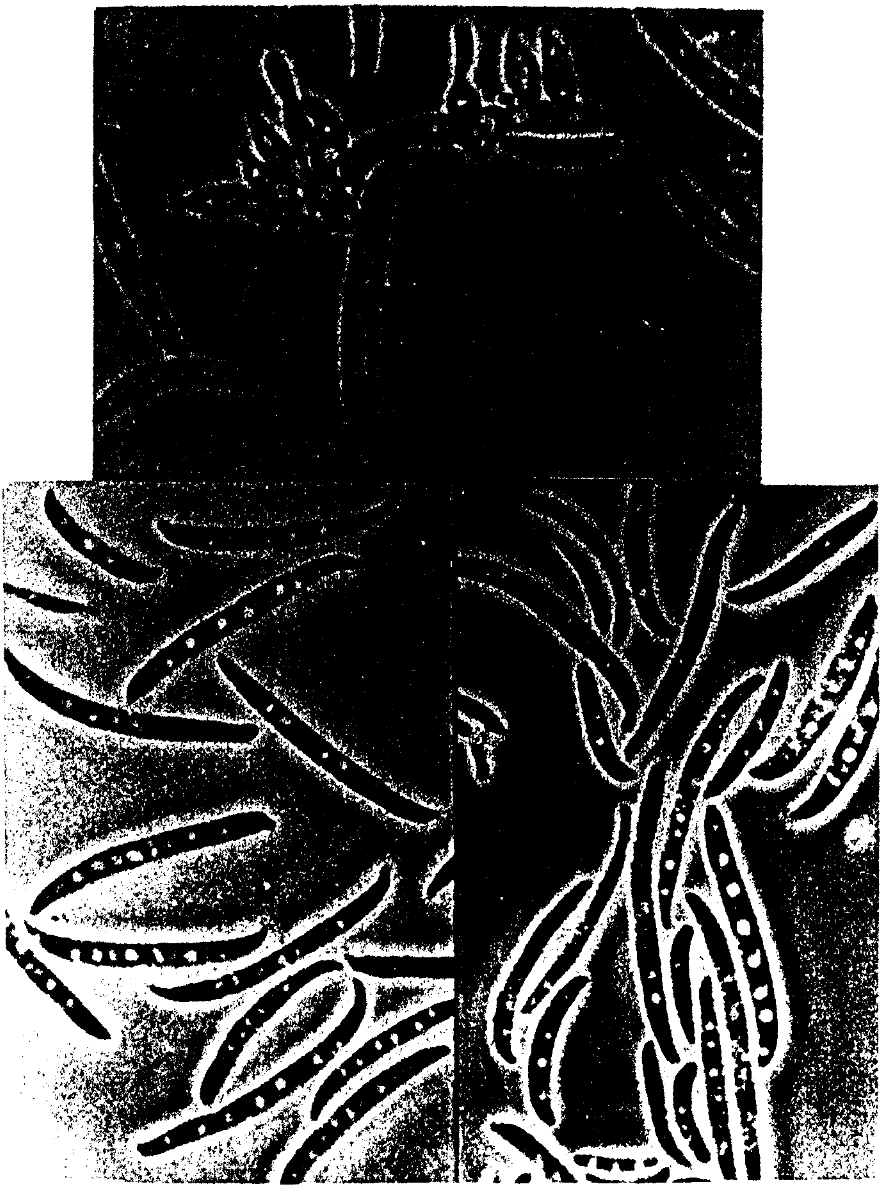


Plate 20. Macroconidiophores with macroconidia

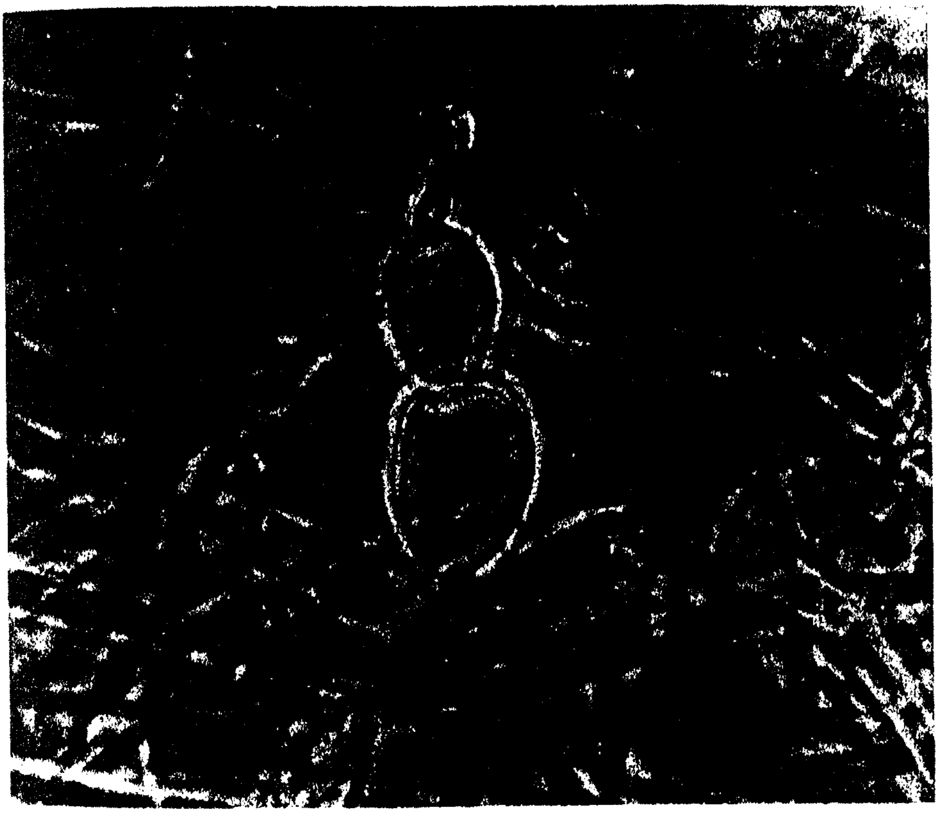


Plate 21: Chlamydospores of the fungus *Fusarium udum*

4.1.2 Pathogenicity test

Pathogenicity test was confirmed on young pigeonpea seedlings, adopting root dip inoculation and transplantation technique under glasshouse conditions in 6" diameter plastic pots. Symptoms were recorded on three cultivars of pigeonpea viz., ICP 2376 (susceptible), C11 (tolerant) and ICP 8863 (resistant varieties) respectively.

During early stages of plant growth it was observed that the wilt in ICP 2376 and C11 varieties was noticed upto 6 weeks age old inoculated plants beyond which there was no wilting. In the resistant variety (ICP 8863) the wilting was seen upto 2 week age old inoculated plants. Further, the wilting also varied with the variety. In the susceptible plants wilting in one week old plants was as higher 100 per cent whereas hardly 50 per cent could show wilting in 5 week age old inoculated plants. The wilt incidence was drastically reduced to 40 per cent in the ten week age old inoculated plants beyond which no wilting occured. High mortality (> 50%) due to wilt incidence was observed in ICP 2376 and (20-50%) mortality was found in C11 and 10% mortality in ICP 8863 varieties respectively. Young plants showed the following symptoms they usually do not show external banding but have obvious internal browning or blackening. Plants infected by the pathogen have exhibited loss of leaf turgidity, interveinal clearing and chlorosis before death (Plate 22).

ICP 8863 C 11 ICP 2376

Plate 22. Effect of wilt incidence on three varieties of pigeonpea viz., ICP 8863 (Resistant), C11 (Moderately susceptible) and ICP 2376 (Susceptible)

Symptomotology of Pigeonpea Wilt

Plate 23. Appearance of brown to dark purple bands on the stem surface

Plate 24. Browning of the stem tissue in the region of the purple band

Plate 25. Browning or blackening of the tissues visible, when the main stem is split open

Plate 26. Browning or blackening of the tissues visible, when the primary branch is split open

Plate 27. Clumps of mycelium in the xylem vessels

Plate 28. Pinkish mycelial growth of the fungus on bassal portions of the wilted plants

Plate 29. Gradual or sudden withering of green parts of the plant

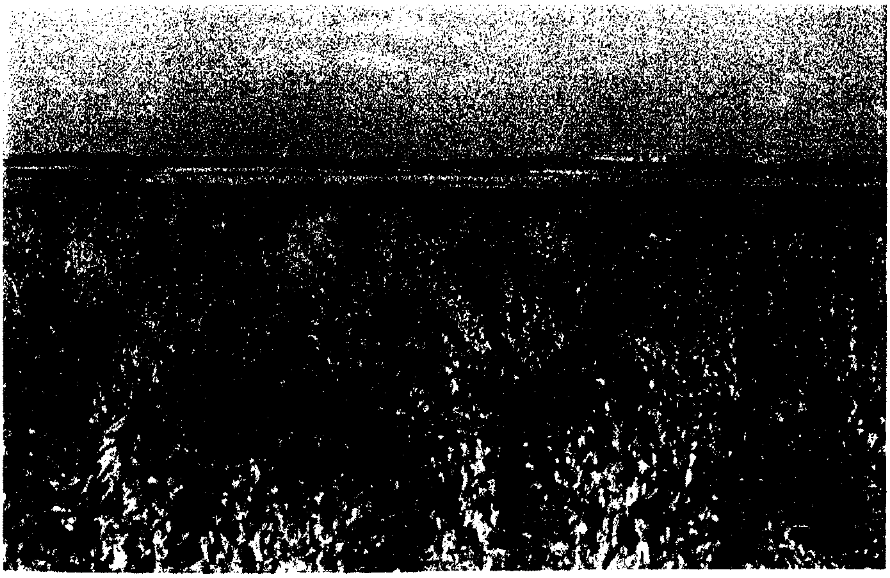


Plate 30. Patches of dead plants in the field

4.2 SYMPTOMATOLOGY

In the field the following symptoms of the disease were observed. Initial visible symptoms of the disease include loss of leaf turgidity, inter-veinal clearing and chlorosis of leaves. The most characteristic symptom of the disease is appearance of brown to dark purple bands on the stem surface (Plate 23), extending upwards from the base of the plant. The other characteristic symptom of wilt is browning of the stem tissue in the region of the purple band (Plate 24). The pathogen causes vascular wilt and block of the xylen vessels by mycelial clumps resulting in characteristic browning or blackening of the tissues visible when the main stem (Plate 25) and primary branches are split open (Plate 26). Fungus causes wilt due to clumps of mycelium in the xylem vessels (Plate 27) and pinkish mycelial growth of the fungus was also observed under humid weather conditions on basal portions of the wilted plants (Plate 28). The typical symptoms of the disease appear in plants as gradual or sudden withering and drying of green parts exactly as if they were suffering from drought (Plate 29). Patches of dead plants were observed in the field, usually when the crop is at flowering or podding (Plate 30).

4.3 EFFECT OF CROPPING SYSTEMS AND N SOURCES AND LEVELS ON *Fusarium udum* POPULATION AND ANTAGONISTIC FUNGI

The effect of four cropping systems and six N sources and levels on the population of *Fusarium udum* and antagonistic fungi namely,

Table 6: Effect of some cropping systems and N sources and levels on pigeonpea wilt pathogen *Fusarium udum* population in soil (cfu/g soil)

Cropping systems	N sources and levels						
	Control	20 FYM	40 FYM	20 KNO_3	40 KNO_3	20 FYM + 20 KNO_3	Mean
Soybean	950 (712)	866 (653)	829 (621)	662 (476)	708 (541)	733 (532)	791 (578)
Soybean/ Sunflower	545 (398)	800 (600)	691 (521)	741 (555)	291 (218)	750 (562)	636 (462)
Sorghum/ Pigeonpea (CSH-9)	1020 (748)	979 (723)	1112 (826)	529 (382)	854 (631)	508 (354)	834 (621)
Pigeonpea	1196 (868)	1044 (772)	987 (740)	933 (702)	900 (616)	916 (671)	996 (758)
Mean	928 (728)	922 (691)	905 (662)	716 (526)	688 (501)	727 (553)	814 (584)

	Production practices	Cropping system	Interaction A	Interaction B
S.Ed.	9.5	2.6	6.4	33.1
C.D.(0.05)	21.2	5.3	13.0	71.9
C.V.(%)	8.4			

Note:
A - For comparison of two sub-treatments at same level of main treatment;
B - For comparison of two main treatments at the same or different levels of sub-treatments.
Figures in parenthesis are transformation values.

Aspergillus sp., *Penicillium* sp. and *Trichoderma* sp. were studied in the field trial at ICRISAT Centre during 1996-97 and 1997-98. The results obtained are presented in Tables 6 to 10.

4.3.1 Effect on *F. udum* population

F. udum population in the soil as influenced by different cropping systems, each involving pigeonpea and soybean in comparison to sole pigeonpea and soybean at different N source and N levels. 40 and 20 kg N ha^{-1} through FYM, 40 and 20 kg N ha^{-1} through KNO_3 and 20 kg N ha^{-1} through KNO_3 + 20 kg N ha^{-1} through FYM (1:1) and control (unamended).

Perusal of the data in Table 6 indicated that population was influenced significantly by different N sources and levels studied, the wilt pathogen population ranged from 688 in the treatment consists of 40 kg N ha^{-1} as KNO_3 compared to 928 cfu/g soil in control. Application of 40 kg N through FYM (905 cfu/g soil), 20 kg N through KNO_3 (716 cfu/g soil) and 20 kg N through FYM + 20 kg N as KNO_3 (727 cfu/g soil) had recorded a significant reduction in CFU of *F. udum* compared to the CFU in case of control. The per cent reduction in *F. udum* population over control ranged from 3 with the application of 40 kg N ha^{-1} through FYM to 26 in case of application of 40 kg N ha^{-1} through KNO_3 ha^{-1}. Application of 20 kg N through FYM had no effect in terms of suppression of wilt pathogen population as that of control. Maximum inhibition was found in the plots with the application of 40 kg N ha^{-1} as KNO_3.

Among the different cropping systems studied, the pathogen population ranged from 636 in case of soybean and sunflower intercropping system compared to 996 cfu/g soil in sole pigeonpea (control). The different cropping systems studied in the present investigation had exhibited a significant reduction in the pathogen inoculum levels, compared to control (sole pigeonpea). The per cent reduction over control ranged from 16 in (sorghum/pigeonpea intercropping) to 36 in (soybean/sunflower intercropping). Intercropping of soybean with sunflower had exhibited lowest population (636 cfu/g soil).

Differences in interaction effects between the cropping systems and N sources and levels vary significantly. Application of 40 kg N through KNO_3 was found to be uniformly effective in the reduction of wilt pathogen population under various cropping systems studied in the present investigation and it ranged from 291 to 900 cfu/g soil. Soybean/sunflower cropping system with 40 kg N ha^{-1} through KNO_3 resulted in minimum population (291 cfu/g soil) as compared to other systems including control under sole pigeonpea at the same level of N as KNO_3 (708, 854 and 900 cfu/g soil). The per cent reduction of population was about 75 per cent over control (sole pigeonpea). Application of 20 kg N through KNO_3, 40 kg N through KNO_3 and 20 kg N ha^{-1} through FYM + 20 kg N ha^{-1} through KNO_3 were found to significantly reduce the population under sorghum/pigeonpea intercropping system. All N sources and N levels significantly reduced the population under sole pigeonpea and soybean cropping systems which were found to be ineffective individually (Table 6).

Table 7: Effect of some cropping systems and N sources and levels on *Aspergillus* sp. population (cfu/g soil) in soil

Cropping systems	N sources and levels						
	Control	20 FYM	40 FYM	20 KNO_3	40 KNO_3	20 FYM + 20 KNO_3	Mean
Soybean	425 (298)	499 (374)	620 (465)	591 (451)	485 (363)	616 (456)	539 (392)
Soybean/ Sunflower	486 (351)	620 (455)	583 (425)	641 (492)	755 (556)	534 (400)	603 (436)
Sorghum/ Pigeonpea	641 (386)	457 (342)	428 (314)	505 (378)	587 (450)	600 (468)	536 (402)
Pigeonpea	350 (262)	431 (331)	450 (337)	446 (321)	479 (391)	425 (322)	430 (334)
Mean	475 (333)	502 (362)	520 (385)	546 (409)	576 (431)	544 (394)	526 (394)

	Production practices	Cropping systems	Interaction A	Interaction B
S.Ed.	5.5	1.4	3.5	18.9
C.D.(0.05)	12.3	2.9	7.0	41.3
C.V. (%)	10.1			

Note:
A - For comparison of two sub-treatments at same level of main treatment;
B - For comparison of two main treatments at the same or different levels of sub-treatments.
Figures in parenthesis are transformation values.

4.3.2 *Aspergillus* sp. population

Aspergillus sp. population ranged from 476 (control) to 576 cfu/g soil (40 kg N ha^{-1} as KNO_3) in different N sources and levels. In cropping system effects, population ranged from 536 (sorghum/pigeonpea) to 603 cfu/g soil (soybean/sunflower) (Table 7). Application of N sources and levels and intercropping systems interaction study population ranged from 350 (control) under sole pigeonpea) to 755 cfu/g with the application of 40 kg N ha^{-1} KNO_3 in intercropping (soybean/sunflower).

Significant differences were found in *Aspergillus* sp. population with the adoption of different N sources and levels and different cropping systems and their combinations.

All N sources and levels studied in the present investigation exhibited a significant increase in the population over control (475 cfu/g soil). The application of 40 kg N ha^{-1} as KNO_3 resulted in the highest levels of Aspergillus sp. population (576 cfu/g soil) as compared to other sources and levels. The increase in the population ranged from 6.0 (20 kg N ha^{-1} as FYM) to 17 (40 kg N ha^{-1} as KNO_3) per cent over control.

The different cropping systems studied had a significant increase in the antagonist fungal population compared to sole pigeonpea. Cropping system of soybean/sunflower had resulted in significant increase in the population (603 cfu/g soil) than other cropping systems (536, 539 and 430 cfu/g soil).

Table 8: Effect of cropping systems and N sources and levels on *Penicillium* sp. population (cfu/g soil) in soil

Cropping systems	N sources and levels						
	Control	20 FYM	40 FYM	20 KNO_3	40 KNO_3	20 FYM + 20 KNO_3	Mean
Soybean	177 (128)	235 (176)	252 (181)	281 (240)	277 (201)	270 (192)	249 (199)
Soybean/ Sunflower	202 (151)	250 (185)	266 (199)	277 (218)	366 (268)	291 (218)	276 (217)
Sorghum/ Pigeonpea	118 (81)	170 (120)	168 (116)	222 (166)	275 (192)	231 (169)	197 (153)
Pigeonpea	92 (69)	109 (81)	123 (92)	205 (154)	242 (186)	202 (151)	162 (101)
Mean	148 (106)	192 (132)	203 (162)	247 (185)	278 (218)	249 (199)	219 (162)

	Production practices	Cropping systems	Interaction A	Interaction B
S.Ed.	4.2	1.1	2.6	14.4
C.D.(0.05)	9.4	2.2	5.3	31.4
C.V.(%)	7.1			

Note:
A - For comparison of two sub-treatments at same level of main treatment;
B - For comparison of two main treatments at the same or different levels of sub-treatments.
Figures in parenthesis are transformation values.

The study of interaction effects of cropping systems and N sources and levels revealed significantly higher levels of *Aspergillus* sp. population under intercropping of soybean with sunflower coupled with the application of 40 kg N ha^{-1} as KNO_3 than the other treatment combinations. The application of 20 kg N ha^{-1} through FYM, 40 kg N ha^{-1} as FYM, 20 kg N ha^{-1} through KNO_3 and 20 kg N ha^{-1} as KNO_3 + 20 kg N ha^{-1} as FYM also significantly increased population under sole soybean and soybean/sunflower intercropping systems. These treatments also recorded higher levels of the *Aspergillus* sp. population than the control under sorghum/pigeonpea cropping systems.

4.3.3 *Penicillium* sp. population

The results are presented in Table 8. *Penicillium* sp. population ranged from 148 (control) to 278 cfu/g soil (40 kg N ha^{-1} as KNO_3) for the different N sources and levels. In intercropping systems effects the population ranged from 148 (sole pigeonpea) to 278 cfu/g soil (soybean/ sunflower cropping system). Population ranged from 92 in (control under sole pigeonpea) to 366 cfu/g with application of 40 kg N ha^{-1} through KNO_3 under soybean/sunflower intercropping systems with different N sources and levels.

Perusal of the data in table 8 indicated that population was influenced significantly by different N sources and levels, cropping systems and their interactions. All N sources and levels had recorded a significant increase in the population. The population was maximum in the treated plot with 40 kg N ha^{-1} as KNO_3 (278) followed by 20 kg N ha^{-1} as FYM + 20 kg N ha^{-1} as KNO_3 (247 cfu/g soil). The per cent increase ranged from 29 (20 kg N ha^{-1} as FYM) to 88 (40 kg N ha^{-1} as KNO_3) over control.

The cropping systems studied had also recorded a significant increase in the fungal population compared to sole pigeonpea (148 cfu/g soil). Soybean/sunflower intercropping system recorded maximum population (276) followed by sole soybean (249) and sorghum/pigeonpea (197 cfu/g soil) systems. The per cent increase ranged from 22(sorghum/ pigeonpea) to 70 (soybean/sunflower). Intercropping of soybean with sunflower had resulted in significant increase of *Penicillium* sp. population compared to other cropping systems.

Studies on interaction effects of cropping systems and N sourcess and levels revealed significantly higher population of *Penicillium* sp. In intercropping system of soybean with sunflower coupled with application of 40 kg N ha^{-1} as KNO_3 (366 cfu/g soil) followed by 20 kg N ha^{-1} as FYM + 20 kg N ha^{-1} as KNO_3 under same system (291 cfu/g soil) than the other treatment combinations. The application of 20 kg N ha^{-1} as FYM, 40 kg N ha^{-1} as FYM, 20 kg N ha^{-1} as KNO_3, 40 kg N ha^{-1} as KNO_3 and 20 kg N ha^{-1} as FYM + 20 kg N ha^{-1} as KNO_3 resulted in significantly higher population under sole soybean, sole pigeonpea, soybean/sunflower and sorghum/pigeonpea cropping systems. However, with the application of 20 kg N ha^{-1} as FYM under sole pigeonpea cropping system which had recorded the population (109 cfu/g soil) on par with control (92 cfu/g soil).

Table 9: Effect of some cropping systems and N sources and levels on *Trichoderma* sp. population (cfu/g soil) in soil

Cropping systems	N sources and levels						
	Control	20 FYM	40 FYM	20 KNO_3	40 KNO_3	20 FYM + 20 KNO_3	Mean
Soybean	118 (84)	186 (132)	211 (146)	247 (185)	260 (199)	254 (196)	213 (148)
Soybean/ Sunflower	169 (126)	238 (178)	243 (171)	267 (192)	286 (224)	285 (223)	248 (179)
Sorghum/ Pigeonpea	130 (94)	122 (81)	129 (94)	179 (140)	190 (138)	179 (140)	155 (116)
Pigeonpea	104 (72)	111 (83)	111 (83)	145 (108)	173 (131)	155 (116)	133 (99)
Mean	131 (89)	165 (119)	174 (131)	210 (148)	228 (171)	219 (169)	188 (145)

	Production practices	Cropping systems	Interaction A	Interaction B
S.Ed.	3.8	1.3	3.1	14.2
C.D.(0.05)	8.6	2.6	6.3	30.6
C.V.(%)	11.8			

Note:
A - For comparison of two sub-treatments at same level of main treatment;
B - For comparison of two main treatments at the same or different levels of sub-treatments.
Figures in parenthesis are transformation values.

4.3.4 *Trichoderma* sp. population

The fungal population as influenced by different cropping systems, N sources and levels and their interaction effects are presented in Table 9.

Perusal of the data in Table 9 indicated that population ranged from 131 (control) to 228 cfu/g (40 kg N ha^{-1} as KNO_3 in different N levels and sources. In cropping systems it was ranged from 133 in case of sole pigeonpea to 248 cfu/g soil in case of soybean/sunflower intercropping (Table 9). In N sourcess and levels and cropping systems interaction study, population ranged from 104 in case of control under sole pigeonpea to 286 cfu/g soil in case of application of 40 kg N ha^{-1} as KNO_3 under intercropping of soybean with sunflower.

Significant differences were found for *Trichoderma* sp. population among the N sources and levels, cropping systems and their interactions. All N sources and levels resulted in a significant increase in the population over control (sole crop) (131 cfu/g soil). Application of 40 kg N ha^{-1} as KNO_3 recorded the highest level of population (228) followed by 20 kg N ha^{-1} as FYM + 20 kg N ha^{-1} as KNO_3 (219 cfu/g soil) compared to other N sources and levels. The per cent increase ranged from 26 (20 kg N ha^{-1} as FYM) to 74 (40 kg N ha^{-1} as FYM) over control.

The cropping systems studied had also resulted in significant increase in the population, compared to sole pigeonpea. The per cent increase ranged from 16 per cent in sorghum/pigeonpea to 86 in soybean/

Table 10: Effect of some cropping systems and N sources and levels on total antagonistic fungal population (cfu/g soil) in soil

Cropping systems	N sources and levels						
	Control	20 FYM	40 FYM	20 KNO_3	40 KNO_3	20 FYM + 20 KNO_3	Mean
Soybean	770 (550)	921 (678)	1085 (823)	1120 (840)	1023 (742)	1140 (838)	1002 (740)
Soybean/ Sunflower	858 (631)	1109 (831)	1093 (838)	1186 (911)	1407 (1041)	1110 (812)	1127 (825)
Sorghum/ Pigeonpea	890 (652)	750 (541)	725 (524)	907 (674)	1034 (775)	1010 (752)	886 (644)
Pigeonpea	546 (409)	653 (471)	685 (506)	797 (567)	831 (614)	784 (571)	716 (517)
Mean	753 (546)	858 (643)	897 (661)	1003 (752)	1074 (923)	1011 (758)	933 (684)

	Production practices	Cropping systems	Interaction A	Interaction B
S.Ed.	17.5	8.1	19.7	73.5
C.D. (0.05)	39.1	16.3	39.9	71.0
C.V. (%)	10.9			

Note:
A - For comparison of two sub-treatments at same level of main treatment;
B - For comparison of two main treatments at the same or different levels of sub-treatments.
Figures in parenthesis are transformation values.

sunflower intercropping. Intercropping of soybean/sunflower resulted in significantly higher population (248) followed by (213 cfu/g soil) in case of sole soybean than other cropping systems.

The study of interaction effects of cropping systems and N sources and levels revealed highest levels of *Trichoderma* sp. population under intercropping of soybean with sunflower coupled with application of 40 kg N ha^{-1} as KNO_3 (286) followed by 20 kg N ha^{-1} as FYM + 20 kg N ha^{-1} as KNO_3 (285 cfu/g soil) which were on par with each other. However, all other N sources and levels resulted in significantly higher fungal populations under soybean and soybean/sunflower intercropping system. Application of 20 kg N ha^{-1} as FYM and 40 kg N ha^{-1} as FYM recorded fungal population on par with control under sole pigeonpea and sorghum/pigeonpea cropping systems.

4.3.5 Total antagonistic population

The results are presented in table 10. Total antagonistic fungal population ranged from 753 in (control) to 1074 cfu/g soil (40 kg N ha^{-1} as KNO_3) for the different N sources and levels. In case of cropping systems it ranged from 716 in (sole pigeonpea) to 1127 cfu/g soil in (soybean/ sunflower intercropping).

Significant differences were noticed in total antagonistic population among different N sources and levels, cropping systems and their interactions. Application of 40 kg N ha^{-1} as KNO_3 recorded the highest levels of population (1074) followed by 20 kg N ha^{-1} as FYM + 20 kg N ha^{-1} as KNO_3 (1003 cfu/g soil). The per cent increase ranged from 13 (20 kg N ha^{-1} as FYM) to 42 (40 kg N ha^{-1} KNO_3).

The cropping systems resulted in a significant increase in the population, compared to sole pigeonpea. The per cent increase ranged from 23 in (sorghum/pigeonpea) to 57 in (soybean/sunflower) intercropping system. Intercropping of soybean with sunflower recorded the highest levels of population (1127) followed by sole soybean (1002) and sorghum/pigeonpea (886 cfu/g soil).

The study of interaction effects between cropping systems and N sources and levels revealed the highest levels of population in intercropping of soybean/sunflower in combination with 40 kg N ha^{-1} as KNO_3. The treatment consists of application of 20 kg N ha^{-1} as FYM, 40 kg N ha^{-1} through FYM, 20 kg N ha^{-1} as KNO_3 ha^{-1} and 20 kg N ha^{-1} as FYM + 20 kg N ha^{-1} as KNO_3 resulted in significant increase in total antagonistic population under soybean and soybean/sunflower cropping systems. However, the population was found to be on par with control in case of different N sources and levels under sorghum/pigeonpea except with the application of 40 kg N ha^{-1} as KNO_3. Application of 20 kg N ha^{-1} as KNO_3, 40 kg N ha^{-1} as KNO_3 and 20 kg N ha^{-1} through FYM + 20 kg N ha^{-1} through KNO_3 resulted significantly increase in population under sole pigeonpea cropping system.

4.4 STUDIES ON THE EFFECT OF PREDOMINANT PIGEONPEA INTERCROPPING SYSTEMS PREVALENT IN ANDHRA PRADESH ON *Fusarium udum* AND ITS ANTAGONISTIC FUNGI

The effect of six predominant pigeonpea based intercropping systems in Andhra Pradesh on population of *Fusarium udum* and its antagonistic fungi, in addition to pigeonpea wilt incidence was investigated in on-farm and glasshouse studies during 1996-98. The results obtained are presented in Tables 11-28.

4.4.1 On-farm studies

On-farm studies were conducted during *kharif* 1996-97 in four districts of Andhra Pradesh, at six locations, each with a distinct pigeonpea based intercropping system and the results obtained are presented in Tables 11-16.

4.4.1.1 Pigeonpea wilt incidence

The results are presented in Table 11. Wilt incidence was in general observed to be lower in Alfisols (16%) than Vertisols (26%). Further, the average wilt incidence was 20 per cent. Intercropping of pigeonpea and groundnut had recorded minimum wilt incidence (14%). Further, intercropping of pigeonpea with castor (16%) and maize (17%) had also resulted in wilt incidence below average. In contrast, intercropping of

Table 11: Pigeonpea wilt incidence (%) in farmers field in predominant pigeonpea intercropping systems in Andhra Pradesh (1996-97)

District	Location	Cropping system	No. of fields surveyed	Soil type	Wilt
Ranga Reddy	Pati	pp/sor(local)	10	V	35±4.05
Ranga Reddy	Tandur	pp/gg	10	V	21±1.97
Medak	Siddipet	pp/cotton	10	V	20±1.23
Medak	Basawapur	pp/maize	10	A	17±1.06
Nalgonda	Mall	pp/castor	10	A	16±1.73
Kurnool	Dhone	pp/gnut	10	A	14±1.57
Average					20.96
Alfisol (A)					16.06
Vertisol(V)					26.00

pp - pigeonpea; sor - sorghum; gg - greengram; gnut - groundnut;
V - Vertisol; A - Alfisol

Table 12: Pigeonpea wilt pathogen (*Fusarium udum*) population (cfu/g soil) in farmers field in predominant pigeonpea intercropping systems prevalent in Andhra Pradesh (1996-97)

District	Location	Cropping system	No. of fields surveyed	Soil type	*Fusarium udum* (cfu/g)
Ranga Reddy	Pati	pp/sor	10	V	1443±41
Ranga Reddy	Tandur	pp/gg	10	V	1051±130
Medak	Siddipet	pp/cotton	10	V	1575±87
Medak	Basawapur	pp/maize	10	A	436±10
Nalgonda	Mall	pp/castor	10	A	496±47
Kurnool	Dhone	pp/gnut	10	A	410±17
Average					902
Alfisol (A)					447
Vertisol(V)					1356

pp - pigeonpea; sor - sorghum; gg - greengram; gnut - groundnut;
V - Vertisol; A - Alfisol

pigeonpea with sorghum had recorded high wilt incidence (35%). The intercropping of pigeonpea with greengram (21%) and cotton (20%) had also resulted in wilt incidence above average.

4.4.1.2 *Fusarium udum* population

The results are presented in Table 12. In general, Alfisol fields (447 cfu/g soil) had recorded lower pathogen population than Vertisol fields (1356 cfu/g soil). The average pathogen population of both Vertisol and Alfisol fields was 902 cfu/g soil. Intercropping of pigeonpea with groundnut had recorded minimum pathogen population (410 cfu/g soil) among the various cropping systems studied. Further, intercropping with maize (436 cfu/g soil) and castor (496 cfu/g soil) had also resulted in relatively lower pathogen populations. However, intercropping with cotton had recorded maximum pathogen population (1575 cfu/g soil). The intercropping with greengram (1051 cfu/g soil) and sorghum (1443 cfu/g soil) had also resulted in relatively higher pathogen populations than the average.

4.4.1.3 *Aspergillus* sp. population

Alfisols had recorded higher levels of *Aspergillus* sp. population (551 cfu/g soil) than Vertisols (469 cfu/g soil). The average fungal population of both Vertisols and Alfisols was 510 cfu/g soil. Further, among the cropping systems, intercropping of pigeonpea with cotton in Vertisols had resulted in maximum fungal population (938 cfu/g soil), while intercropping with castor (673 cfu/g soil) and groundnut in Alfisols (811 cfu/g soil) was

Table 13: Antagonistic fungus *Aspergillus* sp. population (cfu/g soil) in predominant pigeonpea intercropping systems prevalent in Andhra Pradesh (1996-97)

District	Location	Cropping system	No. of fields surveyed	Soil type	*Aspergillus* sp.
Ranga Reddy	Pati	pp/sor	10	V	196±10
Ranga Reddy	Tandur	pp/gg	10	V	272±102
Medak	Siddipet	pp/cotton	10	V	938±147
Medak	Basawapur	pp/maize	10	A	168±36
Nalgonda	Mall	pp/castor	10	A	673±69
Kurnool	Dhone	pp/gnut	10	A	811±284
Average					510
Alfisol (A)					551
Vertisol (V)					469

pp - pigeonpea; sor - sorghum; gg - greengram; gnut - groundnut;
V - Vertisol; A - Alfisol

Table 14: Antagonistic fungus *Penicillium* sp. population (cfu/g soil) in predominant pigeonpea intercropping systems prevalent in Andhra Pradesh (1996-97)

District	Location	Cropping system	No. of fields surveyed	Soil type	*Penicillium* sp.
Ranga Reddy	Pati	pp/sor(local)	10	V	105±10
Ranga Reddy	Tandur	pp/gg	10	V	213±8
Medak	Siddipet	pp/cotton	10	V	245±19
Medak	Basawapur	pp/maize	10	A	120±9
Nalgonda	Mall	pp/castor	10	A	127±9
Kurnool	Dhone	pp/gnut	10	A	285±34
Average					183
Alfisol (A)					178
Vertisol(V)					189

pp - pigeonpea; sor - sorghum; gg - greengram; gnut - groundnut;
V - Vertisol; A - Alfisol

also found to result in relatively higher levels of the antagonistic fungi. However, intercropping with maize (168 cfu/g soil) had resulted in minimum levels of the fungi. Intercropping with sorghum (196 cfu/g soil) and greengram (272 cfu/g soil) had also recorded relatively lower levels of the antagonistic fungi, compared to the average (Table 13).

4.4.1.4 *Penicillium* sp. population

The results are presented in Table 14. In general, Alfisols had recorded lower fungal population (178 cfu/g soil) than Vertisols (189 cfu/g soil). The average fungal population of both Vertisols and Alfisols was 183 cfu/g soil. Intercropping of pigeonpea with groundnut had recorded maximum *Pencillium* population (285 cfu/g soil), among the various cropping systems studied. Further, intercropping with cotton (245 cfu/g soil) and greengram (213 cfu/g soil) had also resulted in relatively higher *Pencillium sp.* population in Vertisols. However, intercropping with castor had recorded minimum *Pencillium sp.* population (127 cfu/g soil). The intercropping with maize (120 cfu/g soil) and sorghum (105 cfu/g soil) had also resulted in relatively lower levels of *pencillium sp.* population than the average.

4.2.1.5 *Trichoderma sp.* population

Vertisols (224 cfu/g soil) had recorded higher levels of *Trichoderma sp.* population (Table 15) than Alfisol (135 cfu/g soil). The average fungal population of both Vertisols and Alfisols was 180 cfu/g soil. Intercropping

Table 15: Antagonistic fungus *Trichoderma* sp. population (cfu/g soil) in predominant pigeonpea intercropping systems prevalent in Andhra Pradesh (1996-97)

District	Location	Cropping system	No. of fields surveyed	Soil type	*Trichoderma* sp.
Ranga Reddy	Pati	pp/sor(local)	10	V	110±9
Ranga Reddy	Tandur	pp/gg	10	V	166±137
Medak	Siddipet	pp/cotton	10	V	397±127
Medak	Basawapur	pp/maize	10	A	226±79
Nalgonda	Mall	pp/castor	10	A	67±24
Kurnool	Dhone	pp/gnut	10	A	110±46
Average					180
Alfisol (A)					135
Vertisol(V)					225

pp - pigeonpea; sor - sorghum; gg - greengram; gnut - groundnut;
V - vertisol; A - alfisol

Table 16: Total antagonistic fungus population (cfu/g soil) in predominant pigeonpea intercropping systems prevalent in Andhra Pradesh (1996-97)

District	Location	Cropping system	No. of fields surveyed	Soil type	Total antagonistic fungal population
Ranga Reddy	Pati	pp/sor(local)	10	V	411±31
Ranga Reddy	Tandur	pp/gg	10	V	652±248
Medak	Siddipet	pp/cotton	10	V	1581±294
Medak	Basawapur	pp/maize	10	A	515±126
Nalgonda	Mall	pp/castor	10	A	869±103
Kurnool	Dhone	pp/gnut	10	A	1206±365
Average					873
Alfisol (A)					863
Vertisol(V)					882

pp - pigeonpea; sor - sorghum; gg - greengram; gnut - groundnut;
V - Vertisol; A - Alfisol

of pigeonpea with cotton had resulted in maximum fungal population (397 cfu/g soil), while intercropping with maize was also found to result in relatively higher levels of *Trichoderma sp.* population (226 cfu/g soil) than the average. Intercropping with castor had resulted in minimum levels of the fungi (67 cfu/g soil). Intercropping with greengram (166 cfu/g soil), sorghum (110 cfu/g soil) and groundnut (110 cfu/g soil) had also recorded relatively lower levels of *Trichoderma sp.* population than the average.

4.4.1.6 Total antagonistic fungal population

The results are presented in Table 16. In general, Vertisols had recorded higher levels of total antagonistic fungal population (882 cfu/g soil), than Alfisols (863 cfu/g soil). The average antagonistic fungal population of both Vertisols and Alfisols was 873 cfu/g. Intercropping of pigeonpea with sorghum had recorded minimum total antagonistic fungal population (411 cfu/g soil), among the various cropping systems studied. Further, intercropping with maize (515 cfu/g soil), greengram (652 cfu/g soil) and castor (869 cfu/g soil) had also resulted in relatively lower fungal populations than the average. However, intercropping of pigeonpea with cotton had recorded maximum antagonistic fungal population (1581 cfu/g soil). The intercropping of pigeonpea with groundnut (1206 cfu/g soil) had also resulted in relatively higher populations than the average.

4.4.2 Glass-house studies

The effect of predominant pigeonpea based cropping systems prevalent in Andhra Pradesh viz., pigeonpea/sorghum, pigeonpea/greengram,

:ffect of predominant pigeonpea based cropping systems on wilt incidence (ICRISAT soils)

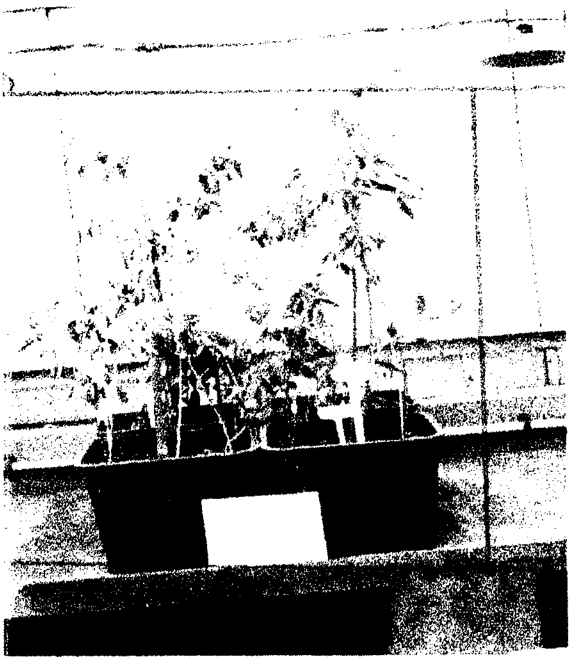


Plate 31. Sole pigeonpea - Vertisols

Plate 32. – Sole pigeonpea - Alfisols

High wilt incidence under sole cropped pigeonpea

Plate 33. Pigeonpea/Sorghum - Vertisols

Plate 34. Pigeonpea/Groundnut – Alfisols

Reduced wilt incidence under intercropped pigeonpea

pigeonpea/maize, pigeonpea/cotton, pigeonpea/castor, pigeonpea/groundnut and ICRISAT wilt sick Alfisols and Vertisols were investigated in pot experiment in glasshouse, simultaneously during two consecutive *kharif* seasons of 1996-97 and 1997-98. The effects of these cropping systems in comparison to sole and intercropped pigeonpea (with groundnut and sorghum) in both wilt sick Alfisol and Vertisols of ICRISAT was also studied. The results obtained are presented in Tables 17-22.

4.4.2.1 *Fusarium* wilt incidence

The results are presented in Table 17. The average wilt incidence was higher during 1997-98 (18%) than 1996-97 (15%). Further, Vertisols in general had recorded significantly higher wilt (18 and 16%) than Alfisols (11 and 14%) during both the seasons of 1996-97 and 1997-98. But greater wilt incidence was found in Alfisols and Vertisols of wilt sick soils of ICRISAT which were under mono cropping of pigeonpea for the past 20 years which were used as checks. The wilt incidence in ICRISAT field's was 26 and 33%) while in the farmer's fields it was 7 and 8%) during 1996-97 and 1997-98 seasons, respectively (Plates 31-32). Sick soils, intercropped pigeonpea with groundnut recorded significantly lower level of wilt incidence in Alfisols (16%) and with sorghum in Vertisols (25%) during 1996-98 than in sole cropped pigeonpea (Plates 33-34). Among the different intercropping systems studied during 1996-97, in Alfisols, intercropping of pigeonpea with groundnut (1%) and castor (2%) had recorded significantly lower levels of wilt incidence than intercropping with maize (4.17%). But in Vertisols, intercropping of pigeonpea with cotton recorded significantly

Reduced wilt incidence under intercropped systems of pigeonpea (farmers fields)

Plate 35. Pigeonpea/Groundnut – Dhone (Anantapur)

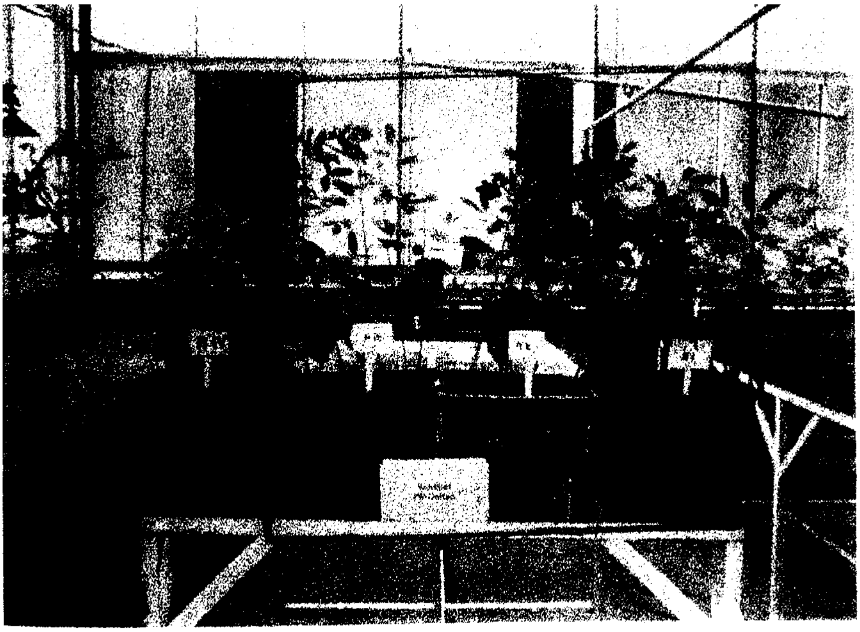


Plate 36. Pigeonpea/Cotton – Siddipet (Medak)

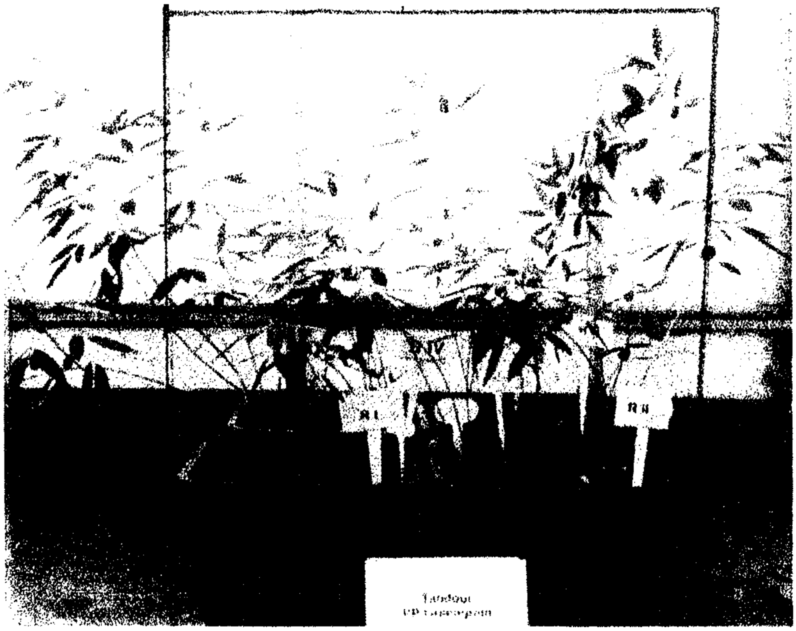


Plate 37. Pigeonpea/Green gram – Tandur (Rangareddy)

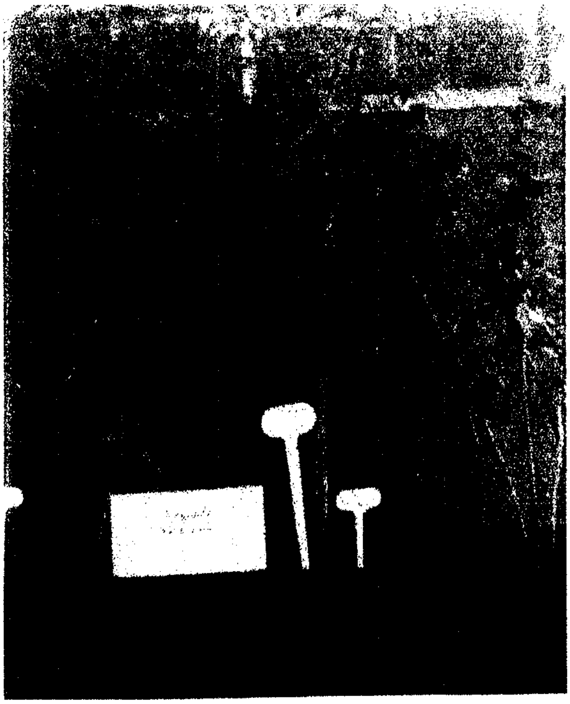


Plate 38. Pigeonpea/Castor – Mall (Nalgonda)

Plate 39. Pigeonpea/Sorghum – Patancheru – Pati (Medak)

Plate 40. Pigeonpea/Maize – Basawapur (Medak)

Table 17: Wilt incidence in soils of predominant pigeonpea intercropping systems prevalent at ICRISAT Center and farmer's fields in Andhra Pradesh during 1996-98 in glasshouse studies

District	Location	Cropping system	Soil type	Wilt (%)			
				1996-97		1997-98	
ICRISAT fields							
Medak	BIL 2B	pp/sor	V	25	(30)	15	(23)
Medak	BIL 2B	pp	V	29	(33)	40	(39)
Medak	RM 8E	pp	A	35	(36)	60	(50)
Medak	RM 8E	pp/gnut	A	16	(24)	6	(15)
Farmer's fields							
Ranga Reddy	Pati	pp/sor	V	11	(20)	7	(16)
Medak	Tandur	pp/gg	V	17	(24)	14	(22)
Medak	Siddipet	pp/cotton	V	6	(14)	2	(9)
Medak	Basawapur	pp/maize	A	4	(11)	3	(10)
Nalgonda	Mall	pp/castor	A	2	(8)	1	(4)
Kurnool	Dhone	pp/gnut	A	1	(4)	0	(0)
Mean				15	(22)	18	(25)
Soil type	Alfisol			11	(20)	14	(22)
	Vertisol			18	(25)	16	(23)
Location	IAC			26	(31)	33	(35)
	Farmer's fields			7	(15)	8	(17)
S.Ed.				1.4		0.5	
C.D. (0.05)				2.8		1.1	
C.V. (%)				13.1		10.9	

pp - pigeonpea; sor - sorghum; gg - greengram; gnut - groundnut; V - Vertisol; A - Alfisol

Note: Values in parenthesis are angular transformation values lower wilt incidence (6%) compared to intercropping with sorghum (11%) and greengram (17%) in farmers fields (Plates 35-40). A similar trend was also observed during the 1997-98 season.

4.4.2.2 *Fusarium udum* population

A decrease in *Fusarium udum* population (Table 18) was found during 1997-98 (1295 cfu/g soil), compared to 1996-97 (1384 cfu/g soil). Further, Vertisols recorded significantly greater levels of *Fusarium udum* (1798 and 1687 cfu/g soil), than Alfisols (970 and 903 cfu/g soil) during 1996-97 and 1997-98 seasons, respectively. *Fusarium udum* population was also found to be significantly higher in ICRISAT wilt sick fields (2071 and 2043 cfu/g soil), than farmer's fields (926 and 796 cfu/g soil) during 1996-97 and 1997-98 seasons, respectively. Further, in ICRISAT soils, intercropped pigeonpea had recorded significantly lower levels of *Fusarium udum* in both Alfisols (2103 cfu/g soil) and Vertisols (1803 cfu/g soil) during 1996-97 year. Among the different intercropping systems studied during 1996-97 in Alfisols brought from farmer's fields, intercropping with groundnut recorded significantly lower levels of pathogen population (181 cfu/g soil), than intercropping with castor (346 cfu/g soil) and maize (534 cfu/g soil). While, intercropping with greengram recorded significantly lower levels of the pathogen (1309 cfu/g soil), than intercropping with sorghum (1406.25 cfu/g soil) and cotton (1781 cfu/g soil) in Vertisols obtained from farmer's fields. A similar trend was also observed during the 1997-98 year.

Table 18: *Fusarium udum* population (cfu/g soil) in soils of predominant pigeonpea intercropping systems prevalent at ICRISAT centre and farmer's fields in Andhra Pradesh during 1996-98 in Glasshouse studies

District	Location	Cropping system	Soil type	*Fusarium udum* (cfu/g) 1996-97	1997-98
ICRISAT fields					
Medak	BIL 2B	pp/sor	V	2103 (1575)	1737 (1318)
Medak	BIL 2B	pp	V	2393 (1782)	2928 (2212)
Medak	RM 8E	pp	A	1987 (1490)	2124 (1593)
Medak	RM 8E	pp/gnut	A	1803 (1341)	1409 (1032)
Farmer's fields					
Ranga Reddy	Pati	pp/sor	V	1406 (1062)	1325 (993)
Ranga Reddy	Tandur	pp/gg	V	1309 (981)	1015 (793)
Medak	Siddipet	pp/cotton	V	1781 (1356)	1456 (1108)
Medak	Basawapur	pp/maize	A	534 (392)	453 (366)
Nalgonda	Mall	pp/castor	A	346 (264)	318 (261)
Kurnool	Dhone	pp/gnut	A	181 (135)	211 (156)
Mean				1384 (1052)	1295 (981)
Soil type	Alfisol			970 (717)	903 (668)
	Vertisol			1798 (1356)	1687 (1281)
Location	IAC			2071 (1574)	2043 (1549)
	Farmer's fields			926 (674)	796 (537)
S.Ed.				52.4	50.5
C.D.(0.05)				107.4	103.5
C.V.(%)				18.2	15.1

Note: pp - pigeonpea; sor - sorghum; gg - greengram; gnut - groundnut;
V - Vertisol; A - Alfisol
Figures in parenthesis are transformation values.

Table 19: *Aspergillus* sp. population (cfu/g soil) in soils of predominant pigeonpea intercropping systems prevalent at ICRISAT centre and farmer's fields in Andhra Pradesh during 1996-98 in Glasshouse studies

District	Location	Cropping system	Soil type	*Aspergillus* sp. population 1996-97	1997-98
ICRISAT fields					
Medak	BIL 2B	pp/sor	V	300 (240)	1737 (1332)
Medak	BIL 2B	pp	V	275 (196)	480 (374)
Medak	RM 8E	pp	A	312 (248)	457 (342)
Medak	RM 8E	pp/gnut	A	340 (283)	1356 (827)
Farmer's fields					
R. Reddy	Pati	pp/sor	V	337 (241)	1706 (1282)
R. Reddy	Tandur	pp/gg	V	256 (184)	1459 (1082)
Medak	Siddipet	pp/cotton	V	606 (467)	2950 (2226)
Medak	Basawapur	pp/maize	A	306 (229)	1353 (995)
Nalgonda	Mall	pp/castor	A	356 (294)	1508 (1121)
Kurnool	Dhone	pp/gnut	A	428 (321)	2265 (1698)
Mean				345 (238)	1527 (1155)
Soil type	Alfisol			348 (248)	1388 (1036)
	Vertisol			355 (271)	1666 (1262)
Location	IAC			307 (216)	1007 (752)
	Farmer's fields			371 (292)	1873 (1404)
S.Ed.				10.5	47.6
C.D.(0.05)				21.5	97.6
C.V.(%)				6.1	9.7

Note: pp - pigeonpea; sor - sorghum; gg - greengram; gnut - groundnut;
V - Vertisol; A - Alfisol
Figures in parenthesis are transformation values.

4.4.2.3 *Aspergillus sp.*

The results are presented in Table 19. *Aspergillus sp.* population was found to be higher during 1997-98 (1527 cfu/g soil) compared to 1996-97 (345 cfu/g soil). Further, Vertisols recorded significantly higher levels of *Aspergillus sp.* population (355 and 1666 cfu/g soil) than Alfisols (348 and 1388 cfu/g soil) during 1996-97 and 1997-98 seasons, respectively. *Aspergillus sp.* population was also observed to be significantly higher in farmer's field soils (371 and 1873 cfu/g soil), than ICRISAT field soils (307 and 1007 cfu/g soil) during 1996-97 and 1997-98, respectively. Further, under ICRISAT soil conditions, intercropped pigeonpea had recorded significantly higher levels of *Aspergillus sp.* population in both Vertisols (300 cfu/g soil) and Alfisols (340 cfu/g soil) during 1996-97. Among the different intercropping systems studied during 1996-97 in Alfisols brought from farmer's fields, intercropping of pigeonpea with groundnut recorded significantly higher levels of *Aspergillus* sp. population (428 cfu/g soil) than intercropping of pigeonpea with castor (356 cfu/g soil) and maize (306 cfu/g soil). While, intercropping with greengram recorded significantly lower levels of *Aspergillus* sp. population (256 cfu/g soil), than intercropping with sorghum (337 cfu/g soil) and cotton (606 cfu/g soil) in Vertisols obtained from farmer's fields. A similar trend was also observed during the year 1997-98.

4.4.2.4 *Pencillium* sp.

An increase in *Pencillium* sp. population (Table 20) was found during 1997-98 (408 cfu/g soil), compared to 1996-97 (262 cfu/g soil).

Table 20: *Penicillium* sp. population (cfu/g soil) in soils of predominant pigeonpea intercropping systems prevalent at ICRISAT centre and farmer's fields in Andhra Pradesh during 1996-98 in Glasshouse studies

District	Location	Cropping system	Soil type	*Penicillium* sp. population 1996-97	1997-98
ICRISAT fields					
Medak	BIL 2B	pp/sor	V	225 (168)	444 (324)
Medak	BIL 2B	pp	V	184 (148)	272 (214)
Medak	RM 8E	pp	A	156 (117)	168 (129)
Medak	RM 8E	pp/gnut	A	181 (137)	455 (346)
Farmer's fields					
R. Reddy	Pati	pp/sor	V	218 (146)	456 (321)
R. Reddy	Tandur	pp/gg	V	278 (192)	470 (352)
Medak	Siddipet	pp/cotton	V	450 (349)	523 (383)
Medak	Basawapur	pp/maize	A	287 (226)	405 (309)
Nalgonda	Mall	pp/castor	A	237 (164)	412 (320)
Kurnool	Dhone	pp/gnut	A	408 (317)	473 (374)
Mean				262 (408)	408 (317)
Soil type	Alfisol			253 (176)	383 (287)
	Vertisol			271 (213)	433 (336)
Location	IAC			186 (139)	335 (242)
	Farmer's fields			312 (248)	456 (342)
S.Ed.				8.7	11.5
C.D. (0.05)				17.9	23.6
C.V. (%)				11.2	13.1

Note: pp - pigeonpea; sor - sorghum; gg - greengram; gnut - groundnut; V - Vertisol; A - Alfisol

Figures in parenthesis are transformation values.

Table 21: *Trichoderma* sp. population (cfu/g soil) in soils of predominant pigeonpea intercropping systems prevalent at ICRISAT centre and farmer's fields in Andhra Pradesh during 1996-98 in Glasshouse studies

District	Location	Cropping system	Soil type	*Trichoderma* sp. population 1996-97	1997-98
ICRISAT fields					
Medak	BIL 2B	pp/sor	V	262 (221)	450 (347)
Medak	BIL 2B	pp	V	237 (172)	296 (231)
Medak	RM 8E	pp	A	212 (156)	198 (148)
Medak	RM 8E	pp/gnut	A	240 (182)	437 (339)
Farmer's fields					
R. Reddy	Pati	pp/sor	V	131 (98)	382 (293)
R. Reddy	Tandur	pp/gg	V	270 (212)	462 (332)
Medak	Siddipet	pp/cotton	V	415 (301)	649 (472)
Medak	Basawapur	pp/maize	A	228 (163)	371 (274)
Nalgonda	Mall	pp/castor	A	237 (172)	388 (296)
Kurnool	Dhone	pp/gnut	A	281 (198)	413 (314)
Mean				251 (187)	405 (313)
Soil type	Alfisol			239 (177)	361 (270)
	Vertisol			263 (234)	448 (344)
Location	IAC			238 (181)	345 (248)
	Farmer's fields			260 (222)	444 (351)
S.Ed.				8.9	7.9
C.D.(0.05)				18.2	16.2
C.V.(%)				7.1	9.1

Note: pp - pigeonpea; sor - sorghum; gg - greengram; gnut - groundnut;
V - Vertisol; A - Alfisol
Figures in parenthesis are transformation values.

(260 and 444 cfu/g soil) than ICRISAT fields (238 and 345 cfu/g soil), during 1996-97 and 1997-98, respectively. Further, under ICRISAT soil conditions, intercropped pigeonpea had recorded significantly higher levels of *Trichoderma* sp. population in both Vertisols (262 cfu/g soil) and Alfisols (240 cfu/g soil) during 1996-97. Among the different intercropping systems studied during 1996-97 in Alfisols brought from farmers field, intercropped pigeonpea with groundnut recorded significantly higher levels of *Trichoderma* sp. population (281 cfu/g soil) than intercropped pigeonpea with castor (237 cfu/g soil) and maize (228 cfu/g soil). While, intercropping with sorghum recorded significantly lower levels of *Trichoderma* sp. population (131 cfu/g soil) than intercropping with greengram (270 cfu/g soil) and cotton (415 cfu/g soil) in Vertisols during the year 1996-97. A similar trend was also observed during the year 1997-98.

4.4.2.6 Total antagonistic fungal population

The total antagonistic fungal population (Table 22) was observed to be in general higher during 1997-98 (2340 cfu/g soil), than 1996-97 (871 cfu/g soil). Further, Vertisols recorded significantly greater levels of total antagonistic fungal population (889 and 2548 cfu/g soil) than Alfisols (853 and 2133 cfu/g soil) during 1996-97 and 1997-98, respectively. Antagonistic fungal population was also observed to be significantly higher in the farmers field soils (945 and 2775 cfu/g soil) than ICRISAT fields (731 and 1689 cfu/g soil) during 1996-97 and 1997-98, respectively. Further, under ICRISAT soil conditions, intercropped pigeonpea had recorded significantly higher levels of fungal population in both Vertisols (787 cfu/g

Table 22: Total antagonistic fungal population (cfu/g soil) in soils of predominant pigeonpea intercropping systems prevalent at ICRISAT centre and farmer's fields in Andhra Pradesh during 1996-98 in Glasshouse studies

District	Location	Cropping system	Soil type	Antagonistic fungal population 1996-97	Antagonistic fungal population 1997-98
ICRISAT fields					
Medak	BIL 2B	pp/sor	V	787 (581)	2632 (1986)
Medak	BIL 2B	pp	V	696 (522)	1049 (782)
Medak	RM 8E	pp	A	681 (500)	824 (628)
Medak	RM 8E	pp/gnut	A	761 (563)	2249 (1671)
Farmer's fields					
R. Reddy	Pati	pp/sor	V	687 (523)	2545 (1891)
R. Reddy	Tandur	pp/gg	V	805 (603)	2392 (1780)
Medak	Siddipet	pp/cotton	V	1471 (1115)	4123 (3092)
Medak	Basawapur	pp/maize	A	882 (676)	2129 (1586)
Nalgonda	Mall	pp/castor	A	831 (611)	2309 (1722)
Kurnool	Dhone	pp/gnut	A	1112 (834)	3152 (2348)
Mean				871 (643)	2340 (1751)
Soil type	Alfisol			853 (628)	2133 (1581)
	Vertisol			889 (666)	2548 (1924)
Location	IAC			731 (546)	1689 (1256)
	Farmer's fields			945 (728)	2775 (2095)
S.Ed.				10.3	25.7
C.D.(0.05)				21.2	52.8
C.V.(%)				8.1	12.1

Note: pp - pigeonpea; sor - sorghum; gg - greengram; gnut - groundnut;
V - Vertisol; A - Alfisol
Figures in parenthesis are transformation values.

soil) and Alfisols (761 cfu/g soil) during 1996-97. Among different intercropping systems studied during 1996-97 in Alfisols brought from farmers field, intercropping pigeonpea with groundnut recorded significantly higher levels of total antagonistic fungal population (1112 cfu/g soil) compared to intercropping with castor (831 cfu/g soil) and maize (822 cfu/g soil). But in Vertisols intercropping pigeonpea with sorghum recorded lower levels of fungal population (687 cfu/g soil) than intercropping with greengram (805 cfu/g soil) and cotton (1471 cfu/g soil) during the year 1996-97. A similar trend was in general observed for 1997-98. However, significantly lower levels of fungal population was found in pigeonpea-greengram intercropping system in Vertisols during the year 1997-98.

4.5 STUDIES ON INTEGRATED DISEASE MANAGEMENT OF PIGEONPEA WILT IN WILT SICK SOILS OF ICRISAT CENTER

Integrated disease management of pigeonpea wilt was studied under both Alfisols and Vertisols conditions during two consecutive kharif seasons of 1996-97 and 1997-98, under both glass house and field conditions at IAC and the results obtained are presented in Tables 23-44.

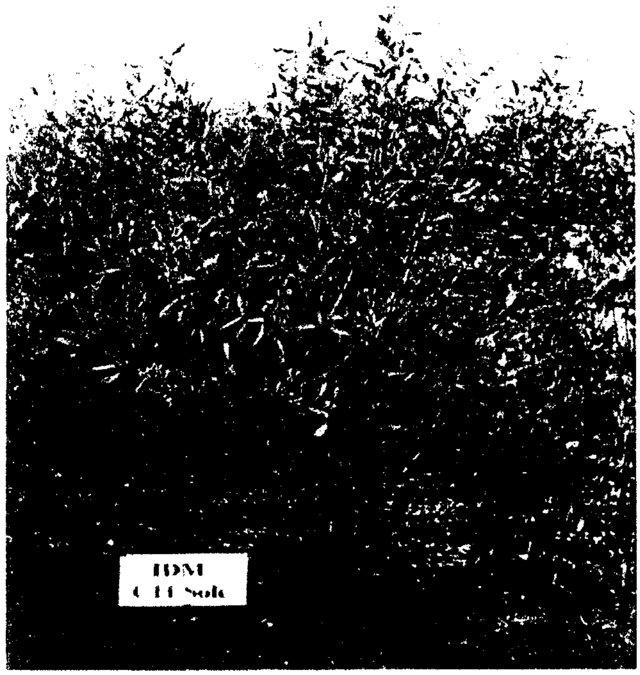
4.5.1 Integrated disease management of pigeonpea wilt in Alfisols

The experiment was conducted with eight treatments including a control under both field and glass house conditions during two consecutive kharif seasons of 1996-97 and 1997-98, and the results obtained are presented in Tables 23-28.

4.5.1.1 Wilt incidence

The results (Tables 23 & 24) revealed that wilt incidence was in general maximum in field (63 and 52%) compared to pots (28 and 26%) during 1996-97 and 1997-98 kharif seasons, respectively. Further, the wilt incidence was lower during 1997-98 (52 and 26) than 1996-97 (63 and 28%) in field and pots, respectively. The results also revealed significant differencess among the treatments for wilt incidence during both the years of study, under both field and pot conditions. Intercropping of pigeonpea with groundnut was found to record significantly less wilt incidence. Further, the decrease was higher (>30%) during 1997-98 than 1996-97 (<12%). Among the treatments applied to sole and intercropped pigeonpea during 1996-97 in field, IDM treatment comprising of seed dressing with fungicides and Trichoderma formulation, in addition to basal application of FYM and GM recorded significantly lower wilt incidence (Plate 41a). IDM treatment was found to be superior in reducing wilt incidence (40 and 28%) in intercropped pigeonpea and (56 and 35%) in sole pigeonpea during 1996-97 and 1997-98 years respectively when compared to other treatments and control (Plate 41b). The next best treatments FYM and GM under sole pigeonpea recorded less wilt incidence (62 and 49%) and (67 and 55%) compared to control (97 and 99%). In C11/groundnut cropping system GM and FYM were found to be on par with each other in reducing wilt incidence during 1996-97 and GM was found to be significantly superior over FYM during 1997-98 (Plate 41c and Plate 41d). Less wilt incidence was observed in pigeonpea/groundnut (86 and 69%) as against sole pigeonpea (97 and

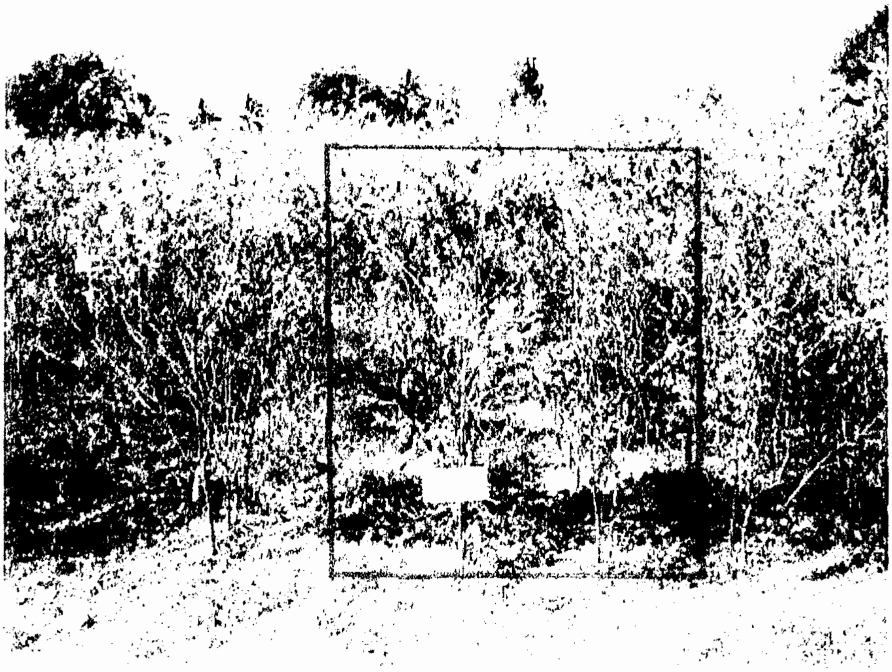
Plate 41 Integrated disease management of Pigeonpea wilt trial in Alfisols - Field study



(a) Effect of IDM treatment showing less wilt incidence in sole and intercropped Pigeonpea

Effect of individual treatment Green manure on wilt incidence in sole and intercropped pigeonpea

d) Effect of individual treatment Farm yard manure on wilt incidence in sole and intercropped pigeonpea



(b) Control plot showing high wilt incidence in sole and intercropped pigeonpea

Table 23: Effect of integrated disease management package in Alfisols on wilt incidence (%) and *Fusarium udum* population (cfu/g soil) during *kharif*, 1996-97 and 1997-98

Treatments	Wilt (%)		*Fusarium udum* population (cfu/g/soil)	
	1996-97	1997-98	1996-97	1997-98
C11	97 (80)	99 (85)	1941 (1455)	2251 (1692)
C11+GM	67 (54)	55 (48)	850 (644)	471 (318)
C11+FYM	62 (51)	49 (44)	941 (714)	485 (332)
C11+IDM	56 (48)	35 (42)	741 (534)	367 (275)
C11/Gnut	86 (68)	69 (56)	1408 (1033)	1148 (852)
C11/Gnut+GM	49 (44)	39 (38)	662 (472)	363 (252)
C11/Gnut+FYM	50 (45)	42 (40)	695 (512)	395 (312)
C11/Gnut+IDM	40 (39)	28 (34)	554 (431)	286 (198)
Mean	63 (52)	52 (46)	974 (726)	721 (540)
S.Ed.	1.0	0.7	12.0	8.9
C.D.(0.05)	2.1	1.6	25.8	19.2
C.V.(%)	6.0	8.3	12.1	13.1

Note: Figures in parenthesis indicate angular and square root transformation values;
GM - green manure; FYM - Farm yard manure;
IDM - Integrated disease management; Gnut - groundnut

Table 24: Effect of integrated disease management package in Alfisols in glasshouse on wilt incidence (%) and *Fusarium udum* population (cfu/g soil) during *kharif*, 1996-97 and 1997-98

Treatments	Wilt (%)		*Fusarium udum* population (cfu/g/soil)	
	1996-97	1997-98	1996-97	1997-98
C11	48 (44)	60 (50)	1875 (1392)	1989 (1511)
C11+GM	36 (37)	31 (34)	1434 (1062)	1292 (948)
C11+FYM	35 (36)	29 (32)	1475 (1126)	1347 (1001)
C11+IDM	20 (26)	15 (23)	1398 (1049)	1051 (763)
C11/Gnut	37 (37)	33 (35)	1529 (1132)	1401 (1021)
C11/Gnut+GM	26 (31)	15 (23)	1342 (1006)	1160 (876)
C11/Gnut+FYM	16 (23)	20 (26)	1350 (1022)	1190 (901)
C11/Gnut+IDM	10 (17)	6 (14)	1260 (925)	986 (722)
Mean	28 (33)	26 (30)	1457 (1064)	1302 (995)
S.Ed.	0.7	0.3	8.9	10.9
C.D.(0.05)	1.6	0.6	19.2	23.4
C.V. (%)	7.4	6.9	8.5	7.5

Note: Figures in parenthesis indicate angular and square root transformation values;
GM - green manure; FYM - Farm yard manure;
IDM - Integrated disease management; Gnut - groundnut

Integrated disease management of pigeonpea wilt trial in Alfisols pot study

S I

Plate 42a. Effect of IDM treatment showing less wilt incidence in sole and intercropped cropped pigeonpea

I S

Plate 42b. Control plot showing high wilt incidence in sole and intercropped pigeonpea

(c) Effect of individual treatment Green manure on wilt incidence in sole and intercropped pigeonpea

(d) Effect of individual treatment Farm yard manure on wilt incidence in sole and intercropped pigeonpea

99%) in control (unamended) during 1996-97 and 1997-98 years, respectively.

Similar results of reduced wilt incidence was found in IDM treatment with sole and intercropping system over GM and FYM in pot study (Plate 42a to Plate 42d).

4.5.1.2 *Fusarium udum* population

Population of *Fusarium udum* was in general observed to be lower in field (974 and 721 cfu/g soil) than pots (1457 and 1302 cfu/g soil) during 1996-97 and 1997-98 years, respectively (Table 23 and 24). Population was also lower during 1997-98 (721 and 1302 cfu/g soil) than 1996-97 (974 and 1457 cfu/g soil) in field and pots, respectively. The results also revealed significant differences among the treatments for the fungal population during both the years of study, under both field and pot conditions. Intercropping of pigeonpea with groundnut was found significantly reduce the pathogen population. Further, the reduction was noticed to be higher (>49%) during 1997-98 than 1996-97 (<27%). Among the treatments applied to sole and intercropped pigeonpea in fields, IDM treatment recorded significantly lower pathogen population (554 and 286 cfu/g soil) and 741 and 367 cft/g soil in C11/groundnut and sole C11 during 1996-97 and 1997-98 years, respectively. However, application of GM and FYM resulted in significantly lower population than the controls. Application of GM was the next best treatment in reducing the population (662 and 363 cfu/g soil) and (850 and 471 cfu/g soil) followed by IDM in intercropping and sole cropping during 1996-97 and 1997-98 years, respectively.

A similar trend was also found for the results obtained during 1996-97 and 1997-98 in pot study, with the exception of application of green manure to sole pigeonpea which had recorded pathogen population on par with IDM during 1996-97 year.

4.5.1.3 *Aspergillus* sp. population

Aspergillus sp. population was in general found to be higher in field (507 and 744 cfu/g soil) than in pots (268 and 326 cfu/g soil) during 1996-97 and 1997-98 kharif seasons, respectively (Table 25 and 26). Further, the fungal population was higher during 1997-98 (744 and 326 cfu/g soil) than 1996-97 (507 and 268 cfu/g soil) in field and pots, respectively. The results also revealed significant differences among the treatments for fungal population during both the years of study, under field and pot conditions. Intercropped pigeonpea with groundnut resulted in significant increase in the population. The increase was noticed to be relatively higher during 1997-98 than 1996-97. Among the treatments applied to sole and intercropped pigeonpea during 1996-97 annd 1997-98 in field, IDM treatment recorded significantly higher population (512 and 827 cfu/g soil) and (754 and 1305 cfu/g soil) during 1996-97 and 1997-98 years, respectively, than other treatments. However, application of green manure and farm yard manure resulted in significant increase in the fungal population than controls, for both sole and intercropped pigeonpea. However, in sole pigeonpea FYM (487 and 679 cfu/g soil) and in intercropped pigeonpea GM (654 and 1034 cfu/g soil) was found superior in increasing the population than control (284 and

Table 25: *Effect* of integrated disease management package in Alfisols on *Aspergillus*, *Penicillium*, *Trichoderma* spp. and total antagonistic fungal pupulation (cfu/g soil) during kharif, 1996-97 and 1997-98

Treatments	*Aspergillus* sp.		*Penicillium* sp.		*Trichoderma* sp.		Total antagonistic fungal population (cfu/g soil)	
	1996-97	1997-98	1996-97	1997-98	1996-97	1997-98	1996-97	1997-98
C11	284 (204)	270 (202)	212 (159)	193 (132)	220 (152)	201 (150)	717 (537)	664 (498)
C11+GM	437 (334)	609 (452)	240 (194)	311 (213)	366 (274)	419 (323)	1044 (75)	1339 (1004)
C11+FYM	487 (381)	679 (518)	341 (273)	411 (317)	316 (226)	382 (292)	1145 (864)	1473 (1104)
C11+IDM	512 (414)	827 (656)	400 (312)	598 (428)	400 (311)	472 (369)	1312 (996)	1897 (1422)
C11/Gnut	375 (274)	416 (306)	316 (202)	381 (293)	263 (187)	270 (210)	995 (727)	1072 (826)
C11/Gnut+GM	654 (502)	1034 (787)	454 (342)	641 (472)	466 (352)	612 (466)	1575 (1194)	2288 (1706)
C11/Gnut+FYM	554 (475)	817 (632)	375 (308)	559 (407)	433 (314)	530 (398)	1362 (1018)	1907 (1448)
C11/Gnut+IDM	754 (598)	1305 (986)	508 (412)	781 (582)	508 (394)	727 (561)	1770 (1338)	2814 (2122)
Mean	507 (394)	268 (211)	356 (267)	484 (371)	371 (289)	452 (339)	1235 (926)	1682 (1284)
S.Ed.	10.2	17.5	12.8	11.9	8.7	13.3	12.2	27.4
C.D.(0.05)	21.8	17.2	27.4	25.7	18.6	28.6	26.2	58.7
C.V (%)	8.4	13.1	13.1	16.1	14.1	16.2	18.3	16.2

Note: Figures in parenthesis indicate square root transformation values

GM - green manure; **FYM** - Farm yard manure;

IDM - Integrated disease management; Gnut - groundnut

Table 26: Effect of integrated disease management package in Alfisols in glasshouse on *Aspergillus*, *Penicillium*, *Trichoderma* spp. and total antagonistic fungal pupulation (cfu/g soil) during kharif, 1996-97 and 1997-98

Treatments	*Aspergillus* sp.		*Penicillium* sp.		*Trichoderma* sp.		Total antagonistic fungal population (cfu/g soil)	
	1996-97	1997-98	1996-97	1997-98	1996-97	1997-98	1996-97	1997-98
C11	195 (126)	182 (136)	100 (75)	110 (84)	101 (72)	97 (69)	397 (278)	390 (286)
C11+GM	233 (173)	278 (210)	145 (119)	145 (114)	116 (94)	177 (132)	495 (383)	602 (451)
C11+FYM	239 (188)	293 (227)	121 (90)	161 (120)	146 (111)	191 (149)	507 (399)	646 (508)
C11+IDM	304 (228)	398 (298)	159 (127)	181 (149)	194 (142)	250 (172)	657 (532)	829 (634)
C11/Gnut	237 (182)	250 (179)	114 (79)	139 (108)	121 (99)	152 (118)	473 (354)	543 (418)
C11/Gnut+GM	315 (236)	442 (312)	141 (122)	187 (148)	165 (126)	286 (231)	621 (478)	915 (672)
C11/Gnut+FYM	289 (221)	273 (228)	127 (95)	153 (120)	130 (118)	276 (204)	551 (432)	702 (539)
C11/Gnut+IDM	334 (274)	492 (373)	165 (138)	209 (158)	183 (168)	355 (276)	683 (545)	1058 (782)
Mean	268 (211)	326 (271)	149 (118)	178 (142)	144 (119)	233 (178)	548 (421)	711 (538)
S.Ed.	8.0	5.1	4.8	2.3	6.6	5.9	10.2	18.6
C.D.(0.05)	17.2	11.0	10.4	4.9	14.1	12.6	21.9	39.9
C.V (%)	6.2	7.1	6.1	8.7	6.2	7.8	7.6	10.2

Note: Figures in parenthesis indicate square root transformation values
GM - green manure; FYM - Farm yard manure;
IDM - Integrated disease management; Gnut - groundnut

270 cfu/g soil) during 1996-97 and 97-98 years respectively. A similar trend was also observed in pot study during both the years.

4.5.1.4 *Penicillium* sp. population

Penicillium sp. population was in general found to be maximum in field (356 and 484 cfu/g soil) than in pots (149 and 178 cfu/g soil) during 1996-97 and 1997-98 years, respectively (Tables 25 and 26). Fungal population was also found to be maximum during 1997-98 (484 and 178 cfu/g soil) than 1996-97 (356 and 149 cfu/g soil) in field and pots, respectively. The results also revealed significant differences among the treatments for fungal population during both the years of study, in field and pot conditions. Intercropping observed to result in a significant increase in the population. Further, the increase was noticed for to be higher during 1997-98 than 1996-97. Among the treatments applied to sole and intercropped pigeonpea, during 1996-98 in field IDM treatment was found superior (400 and 598 cfu/g soil and 508 and 781 cfu/g soil) in increasing the population. However, application of GM and FYM also resulted significant increase in the population compared to controls, for both systems. A similar trend was observed for the results obtained during both the years of study in pots.

4.5.1.5 *Trichoderma* sp. population

Trichoderma sp. population was in general higher in field (371 and 452 cfu/g soil) than pots (144 and 223 cfu/g soil) during 1996-97 and 1997-98 seasons respectively (Table 25 and 26). Further the population was higher during 1997-98 (452 and 223 cfu/g soil) in both and field and pots, respectively. The results revealed significant differences among the treatments for fungal population during both the years of study under both field and pot conditions. Intercropping resulted in significantly higher population, further the population was higher during 1997-98 than 1996-97. Among the treatments, IDM treatments had recorded higher population (400 and 472 cfu/g soil and 508 and 727 cfu/g soil) in sole and intercropped pigeonpea during 1996-97 and 1997-98 seasons respectively over all other treatments. However, application of GM and FYM showed significant increase in the population, compared to control both sole intercropped. Similar trend was observed during 1996-97 and 1997-98 under both sole and intercropped pigeonpea.

4.5.1.6 Total antagonistic fungal population

Total antagonistic fungal population was in general higher in field (1235 and 1682 cfu/g soil) than in pots (545 and 711 cfu/g soil) during 1996-97 and 1997-98 years respectively (Table 25 and 26). Fungal population was higher during 1997-98 (1682 and 711 cfu/g soil) than 1996-97 (1235 and 548 cfu/g soil) in both field and pots, respectively. The results also revealed significant differences among the treatments for the population during both the years of study under both field and pot conditions. IDM treatment recorded significantly higher population in intercropped pigeonpea with groundnut (1770 and 2814 cfu/g soil) and sole cropped pigeonpea (1312 and 1897 cfu/g soil). However, application of GM and FYM also showed significant increase in the fungal population than controls for both sole and intercropped pigeonpea. A similar trend was also observed for the results obtained during 1997-98 in field and both the years of study in pots. The next best treatment was GM in C11/groundnut cropping system (1575 and 2288 cfu/g soil) and FYM in sole C11 system (1145 and 1473 cfu/g soil) followed by IDM during 1996-97 and 1997-98 years, respectively. Intercropping had resulted in greater levels of population (955 and 1072 cfu/g soil) over sole pigeonpea (717 and 664 cfu/g soil) during 1996-97 and 1997-98 years, respectively.

4.5.1.7 Yield of pigeonpea

The results are presented in Tables 27 and 28. Yields in general were low due to *Helicoverpa* pest damage. Average yield was higher during 1997-98 (267 kg ha^{-1} and 35 g pot^{-1}), than 1996-97 (188 kg ha^{-1} and 27 g pot^{-1}) in field and pots, respectively. The results also revealed significant differences among the treatments for yield during both the years of study, under both field and pot conditions. Sole cropping of pigeonpea recorded significantly higher yield than intercropped pigeonpea. Further, the increase noticed was higher during 1997-98 than 1996-97. IDM treatment recorded maximum in yield of 247 and 341 kg ha^{-1} intercropped pigeonpea and 359 and 687 kg ha^{-1} in sole cropped pigeonpea during 1996-97 and 1997-98 years, respectively. However, application of green manure and farm yard manure also significantly increased yield compared to controls, for both sole and intercropped pigeonpea. A similar trend was also observed during both the years of study in pots.

Table 27: Effect of integrated disease management package in Alfisols on yield and biomass of pigeonpea during *Kharif* 1996-97 and 1997-98

Treatments	Yield (kg/ha)		Biomass (g/plant)	
	1996-97	1997-98	1996-97	1997-98
C11	84	78	90	80
C11+GM	264	318	130	138
C11+FYM	179	241	117	127
C11+IDM	359	687	147	154
C11/Gnut	72	102	78	64
C11/Gnut+GM	157	177	99	112
C11/Gnut+FYM	161	191	111	107
C11/Gnut+IDM	227	341	131	137
Mean	188	27	113	115
S.Ed.	2.9	17.5	6.1	3.7
C.D.(0.05)	6.2	37.5	13.2	7.9
C.V (%)	8.1	10.7	9.2	11.1

GM - green manure; FYM - Farm yard manure;
IDM - Integrated disease management; Gnut - groundnut

Table 28: Effect of integrated disease management package in Alfisols in glasshouse on yield and biomass of pigeonpea during *Kharif* 1996-97 and 1997-98

Treatments	Yield (kg/ha)		Biomass (g/plant)	
	1996-97	1997-98	1996-97	1997-98
C11	28	39	64	82
C11+GM	35	42	75	87
C11+FYM	36	42	79	89
C11+IDM	41	47	86	103
C11/Gnut	15	22	32	47
C11/Gnut+GM	19	28	48	59
C11/Gnut+FYM	21	28	57	61
C11/Gnut+IDM	25	32	61	74
Mean	27	35	63	75
S.Ed.	1.2	0.6	1.1	2.1
C.D.(0.05)	2.6	1.3	2.3	4.6
C.V (%)	5.1	6.4	6.3	8.5

GM - green manure; FYM - Farm yard manure;
IDM - Integrated disease management; Gnut - groundnut

4.5.1.8 Biomass

Biomass was in general found to be higher in field (113 and 115 g/plant) than in pots (63 and 75 g/plant) during 1996-97 and 1997-98 seasons, respectively (Tables 27 and 28). Further, average biomass was also maximum during 1997-98 (115 and 75 g/plant) than (113 and 63 g/plant) in field and pots, respectively. The results also revealed significant differences among the treatments for biomass. Intercropping of pigeonpea with groundnut resulted in a significant decrease in the biomass during both the years of study, under both field and pot conditions. Among the treatments applied to sole and intercropped pigeonpea, during 1996-97 in field, IDM treatment recorded significantly maximum biomass in intercropped pigeonpea (131 and 137 g/plant) and in sole pigeonpea (147 and 154 g/plant) compared to other treatments during 1996-97 and 1997-98 years, respectively. However, application of green manure and farm yard manure gave significantly higher biomass compared to controls, in both sole and intercropped pigeonpea. A similar trend was observed during both the years of study in pots.

4.5.2 Integrated disease management of pigeonpea wilt in Vertisols

The studies, comprising of nine production practices, including control as main treatments and four cropping systems were carried out during two consecutive kharif seasons of 1996-97 and 1997-98 years, both in field and pots and the results obtained are presented in Tables 29-44.

4.5.2.1 Wilt incidence

Wilt incidence of pigeonpea as influenced by different cropping systems, production practices in field and pots for the years 1996-97 are presented in tables 29-30. Wilt incidence was in general found to be maximum in field (32 and 27%) than in pots (21 and 19%) during 1996-97 and 1997-98 seasons, respectively. Further, the wilt incidence was lower during 1997-98 (27 and 19%) than 1996-97 (32 and 21%) in field and pots, respectively (Tables 29 and 30).

The results also revealed significant differences among production practices and cropping systems and their interaction effects for wilt incidence during both the years of study in field.

Perusal of the data in Table 29 during 1996-97 indicated that the wilt incidence was found to be significantly lower in intercropping system of ICP 8863 (30 and 22%) than with C11/sorghum cropping system (32 and 25%) than their respective sole pigeonpea cropping system of ICP 8863 (31 and 27%) and C11 (35 and 32%). Cultivation of resistant sole pigeonpea resulted in a significant reduction of wilt incidence (27%) compared to moderately susceptible pigeonpea C11 (32%) during 1997-98 year.

Among the production practices, studied in field during 1996-98, IDM treatment recorded significantly lower wilt incidence (12 and 9%) followed by seed dressing (15 and 11%) and $ZnSO_4$ in combination with green manuring (18 and 12%). However, all other production practices

Table 29: Effect of integrated disease management package in Vertisols on wilt incidence (%) in pigeonpea during *kharif* 1996-97 and 1997-98

Cropping systems	TREATMENTS									
	Control	Zn	GM	FYM	Zn+GM	Zn+FYM	FYM+GM	SD	IDM	Mean
1996-97										
C11	75	41	36	53	22	25	30	15	14	35
	(60)	(39)	(37)	(47)	(28)	(30)	(33)	(23)	(22)	(36)
ICP 8863	63	40	33	49	18	24	27	15	12	31
	(52)	(39)	(35)	(44)	(25)	(29)	(31)	(22)	(20)	(34)
C11/SOR	65	41	35	49	18	24	28	15	13	32
	(54)	(39)	(36)	(44)	(25)	(29)	(31)	(23)	(21)	(34)
ICP 8863/SOR	62	39	32	48	16	22	26	14	9	30
	(52)	(38)	(34)	(44)	(23)	(28)	(31)	(22)	(18)	(33)
Mean	66	40	34	50	18	24	27	15	12	32
	(54)	(39)	(36)	(45)	(25)	(29)	(31)	(22)	(19)	(34)
1997-98										
C11	87	37	33	43	13	20	25	12	10	32
	(69)	(37)	(35)	(41)	(21)	(27)	(30)	(20)	(18)	(34)
ICP 8863	71	35	31	39	12	18	20	11	8	27
	(57)	(36)	(34)	(38)	(20)	(25)	(26)	(19)	(17)	(31)
C11/SOR	48	36	32	39	12	16	22	11	9	25
	(44)	(37)	(34)	(38)	(20)	(23)	(28)	(20)	(17)	(30)
ICP 8863/SOR	43	32	29	37	11	13	18	10	8	22
	(41)	(34)	(33)	(37)	(19)	(21)	(25)	(19)	(16)	(28)
Mean	62	35	31	40	12	17	15	11	9	27
	(52)	(36)	(33)	(39)	(21)	(27)	(25)	(18)	(15)	(31)

	Production practices	Cropping systems	Interaction	
1996-97				
S.Ed.	1.0	0.2	0.8	3.7
CD (0.05)	2.1	0.5	1.5	0.7
CV (%)	13.5			
1997-98				
S.Ed.	0.9	0.2	0.7	1.7
CD (0.05)	1.9	0.4	1.4	1.7
CV (%)	11.2			

Note: **A** - For comparison of two sub-treatments at same level of main treatment
B - For comparison of two main treatments at the same or different levels of sub treatments
Figures in parenthesis are angular transformation values.

Table 30: Effect of integrated disease management package in Vertisols in glass house on wilt incidence (%) in pigeonpea during *kharif* 1996-97 to 1997-98

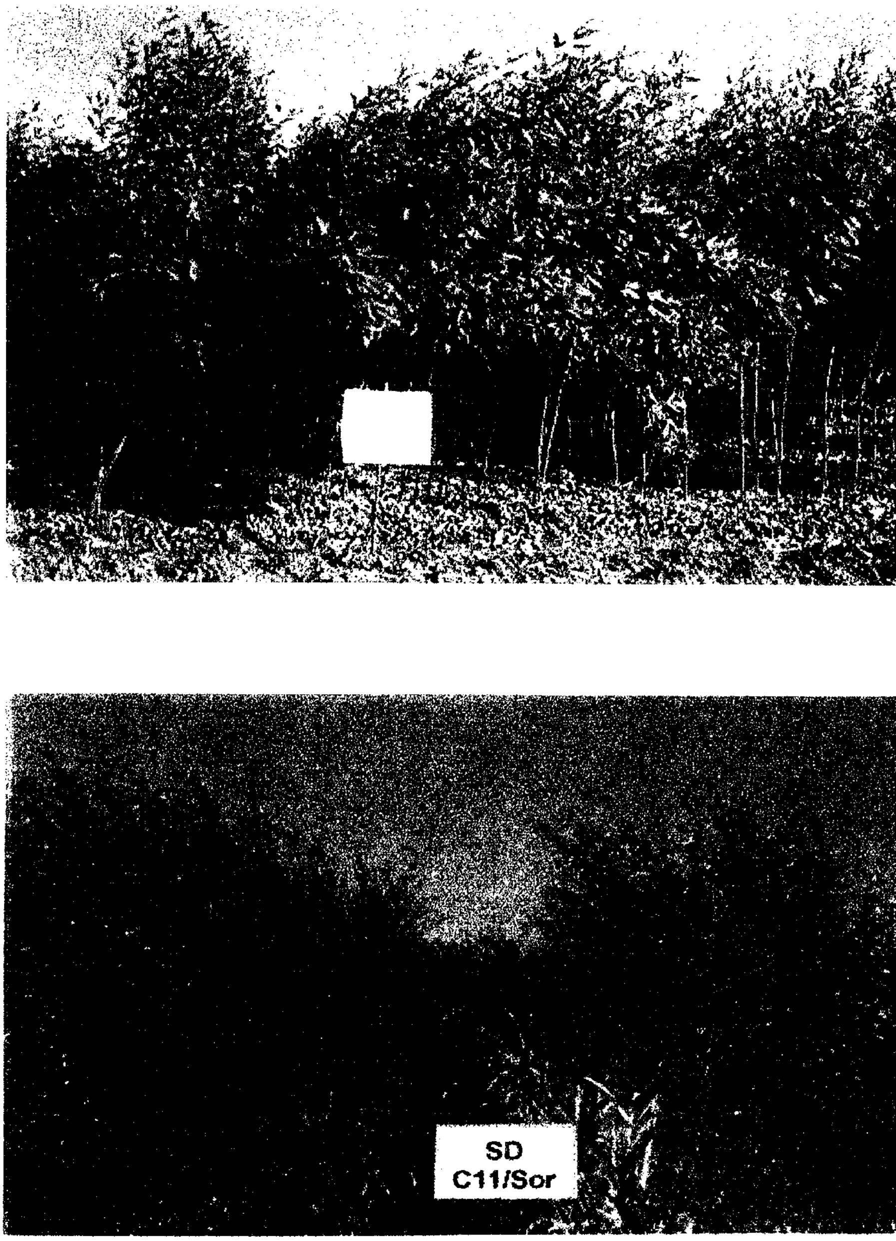
Cropping systems	TREATMENTS									
	Control	Zn	GM	FYM	Zn+GM	Zn+FYM	FYM+GM	SD	IDM	Mean
1996-97										
C11	45	30	27	31	11	16	20	12	10	22
	(42)	(33)	(31)	(34)	(20)	(23)	(26)	(20)	(18)	(28)
ICP 8863	39	26	24	31	11	14	17	9	9	20
	(58)	(30)	(29)	(34)	(19)	(22)	(24)	(18)	(17)	(26)
C11/SOR	39	29	25	31	11	15	18	10	9	21
	(39)	(33)	(30)	(34)	(19)	(22)	(25)	(18)	(17)	(27)
ICP 8863/SOR	39	28	22	29	10	12	17	8	7	19
	(38)	(32)	(28)	(32)	(19)	(20)	(24)	(17)	(16)	(26)
Mean	41	28	24	30	11	14	18	10	9	21
	(39)	(32)	(29)	(33)	(20)	(22)	(25)	(18)	(15)	(27)
1997-98										
C11	57	27	25	29	10	14	18	10	7	22
	(49)	(31)	(30)	(32)	(19)	(22)	(25)	(18)	(15)	(28)
ICP 8863	41	23	21	29	10	13	16	6	6	18
	(40)	(28)	(27)	(32)	(18)	(21)	(23)	(14)	(14)	(25)
C11/SOR	40	25	22	29	10	13	17	6	6	19
	(39)	(30)	(28)	(32)	(9)	(21)	(24)	(15)	(14)	(26)
ICP 8863/SOR	34	22	19	23	6	11	16	5	5	16
	(35)	(28)	(26)	(28)	(15)	(20)	(23)	(13)	(12)	(23)
Mean	43	24	22	27	9	13	17	9	6	19
	(41)	(29)	(28)	(31)	(18)	(21)	(24)	(15)	(12)	(25)

	Production practices	Cropping systems	Interaction	
1996-97				
S.Ed.	0.6	0.2	0.7	1.5
CD (0.05)	1.4	0.4	1.4	0.4
CV (%)	15.8			
1997-98				
S.Ed.	0.6	0.4	1.2	2.3
CD (0.05)	1.2	0.8	2.4	0.7
CV (%)	12.1			

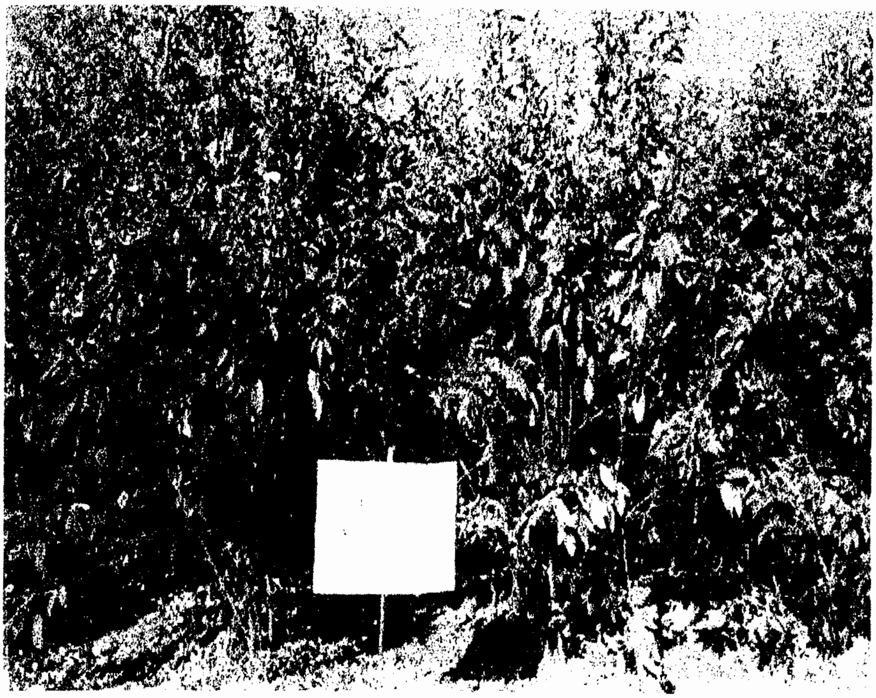
Note: Figures in parenthesis are angular transformation values
A - For comparison of two sub-treatments at same level of main treatment
B - For comparison of two main treatments at the same or different levels of sub treatments

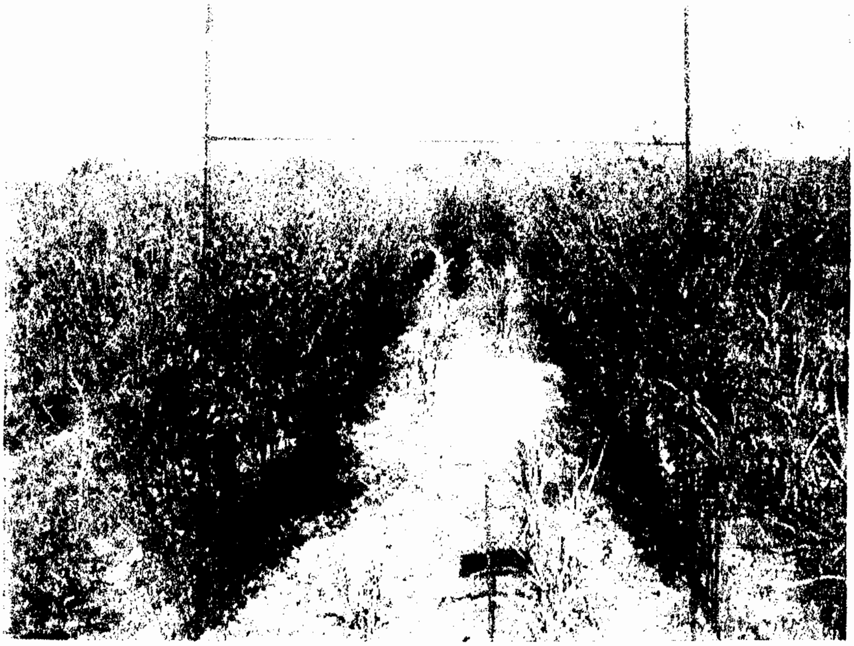
Plate 43. Integrated disease management of pigeonpea wilt trial in Vertisols – Field Study

(a) Effect of IDM treatment showing less wilt incidence in sole and intercropped pigeonpea

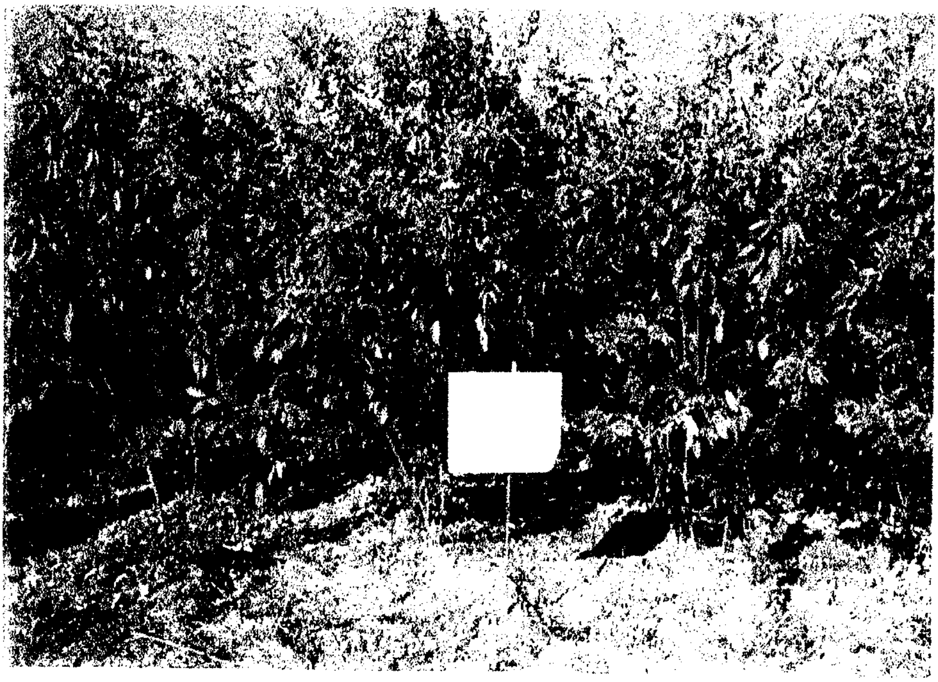


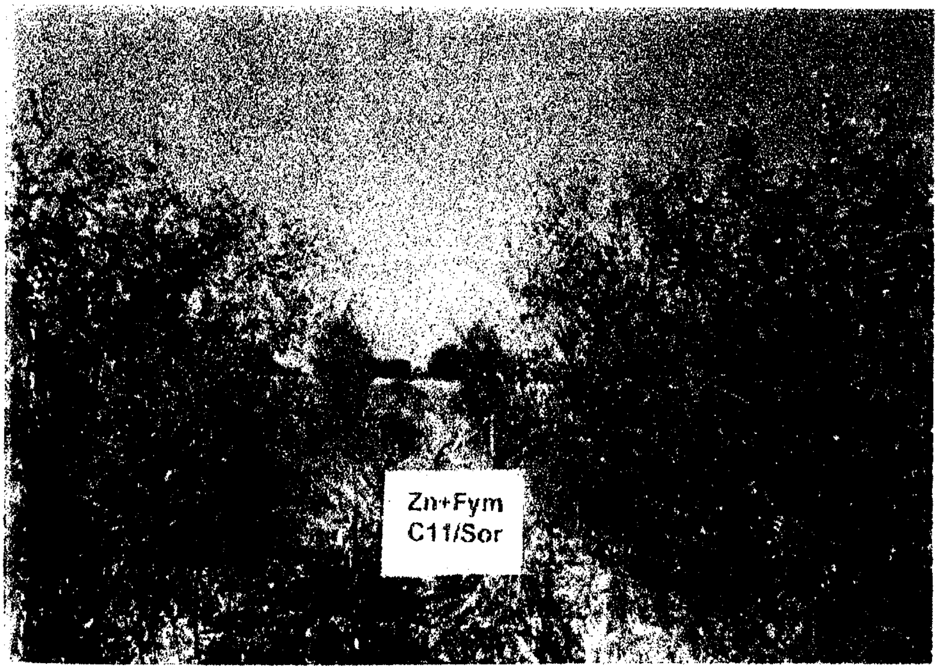
(b) Effect of seed dressing treatment on wilt incidence in sole and intercropped pigeonpea



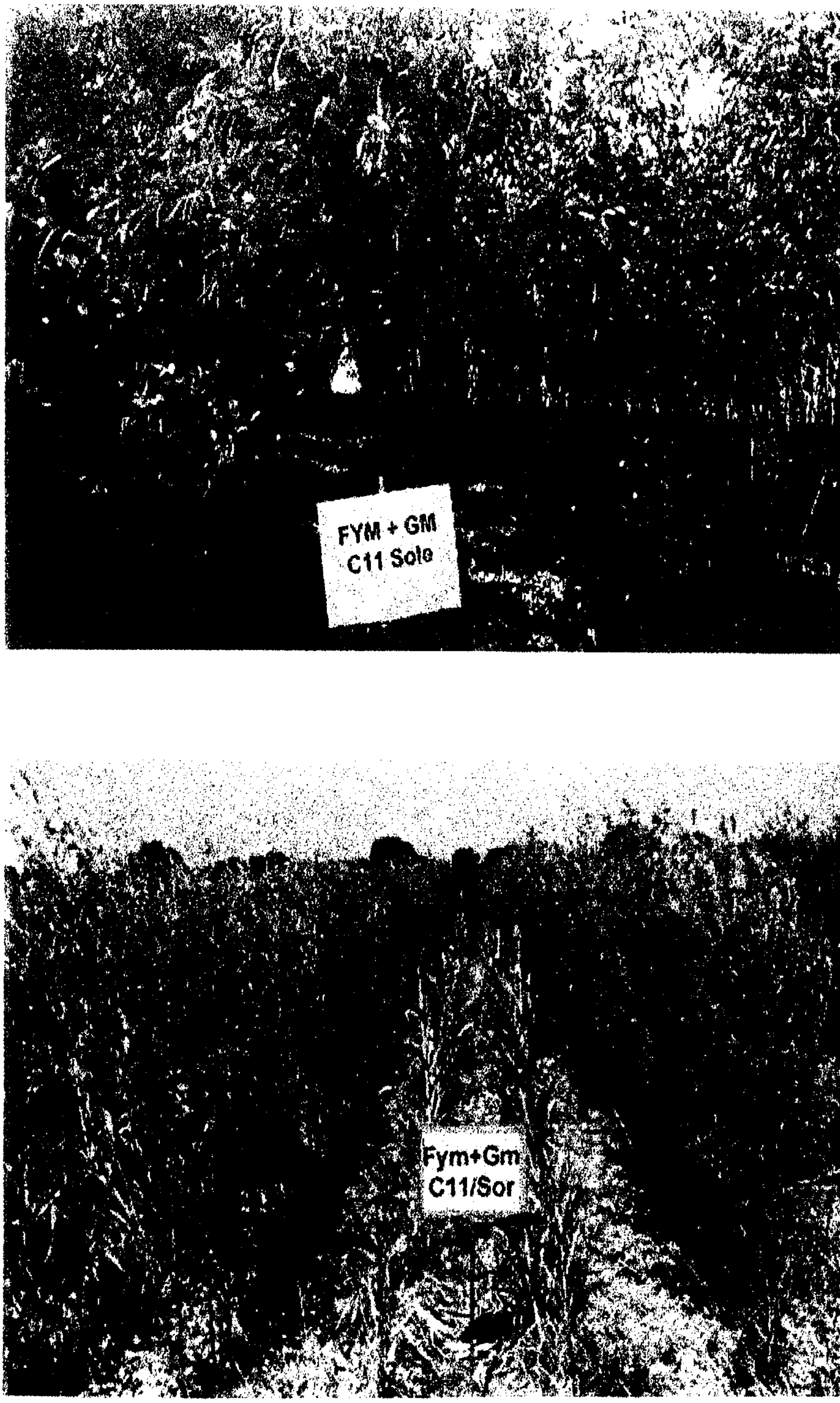


(c) Effect of Zinc + Green manure treatment on wilt incidence in sole and intercropped pigeonpea

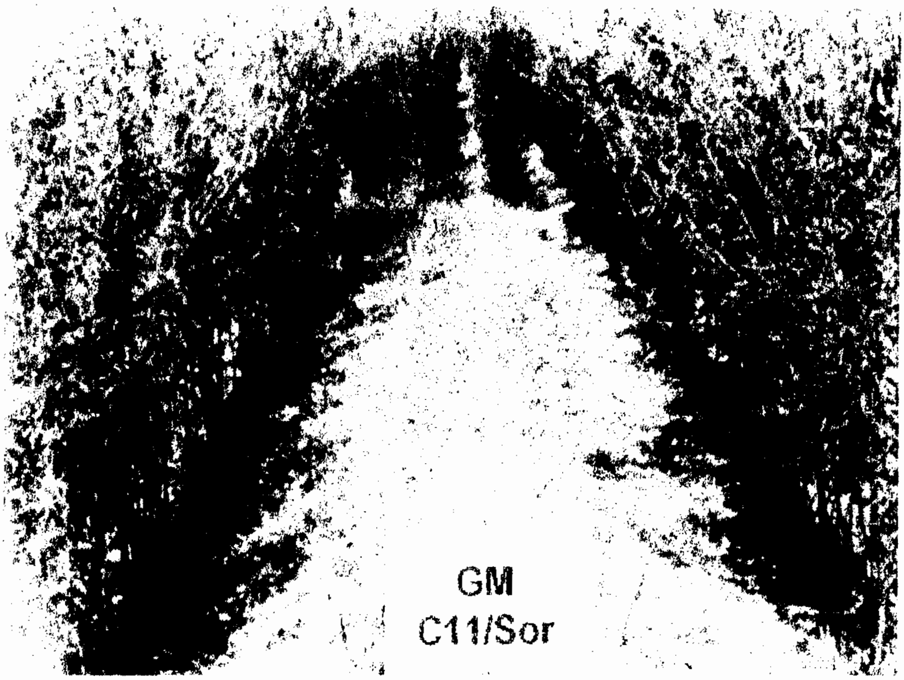




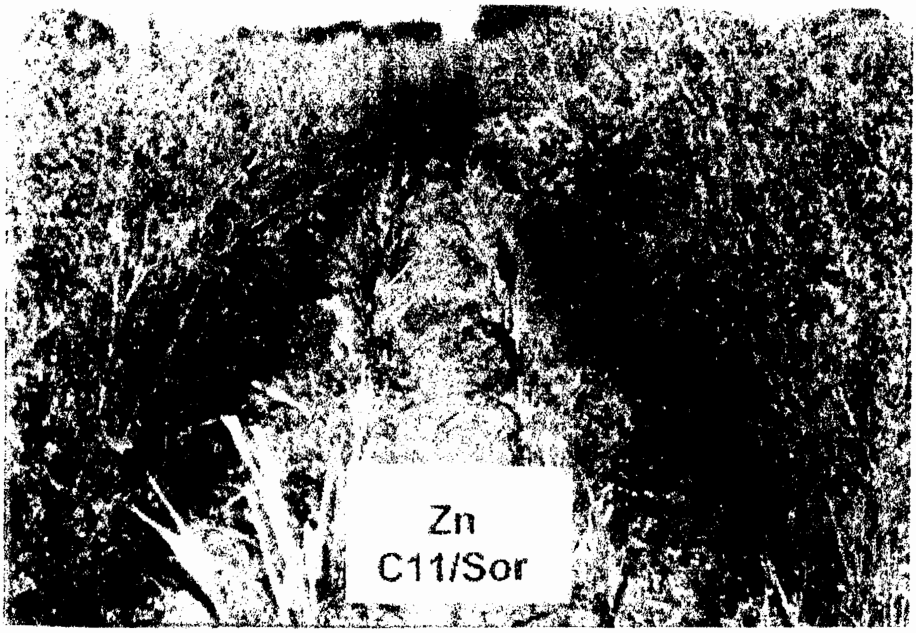
(d) Effect of Zinc + Farm yard manure on wilt incidence in sole and intercropped pigeonpea



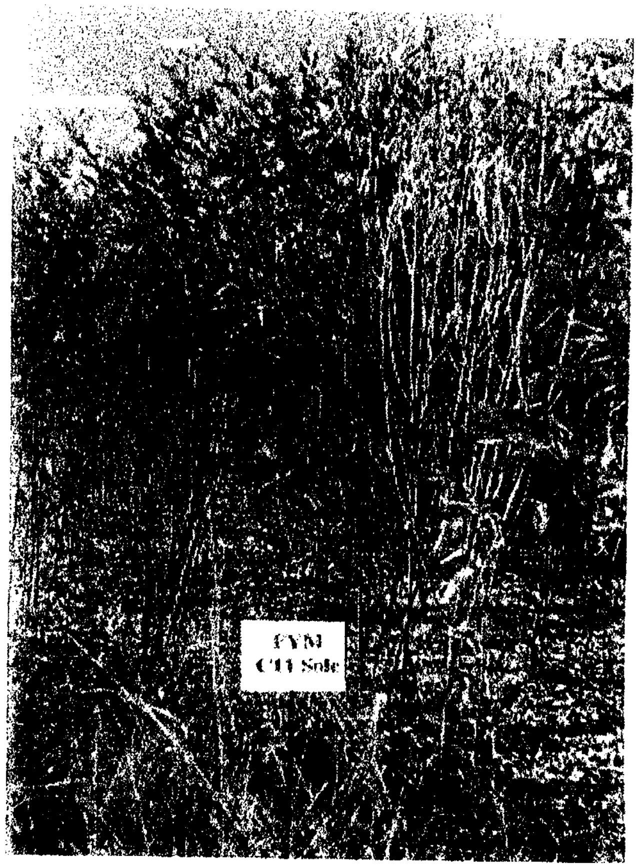
(e) Effect of Farm yard manure + Green manure on wilt incidence in sole and intercropped pigeonpea



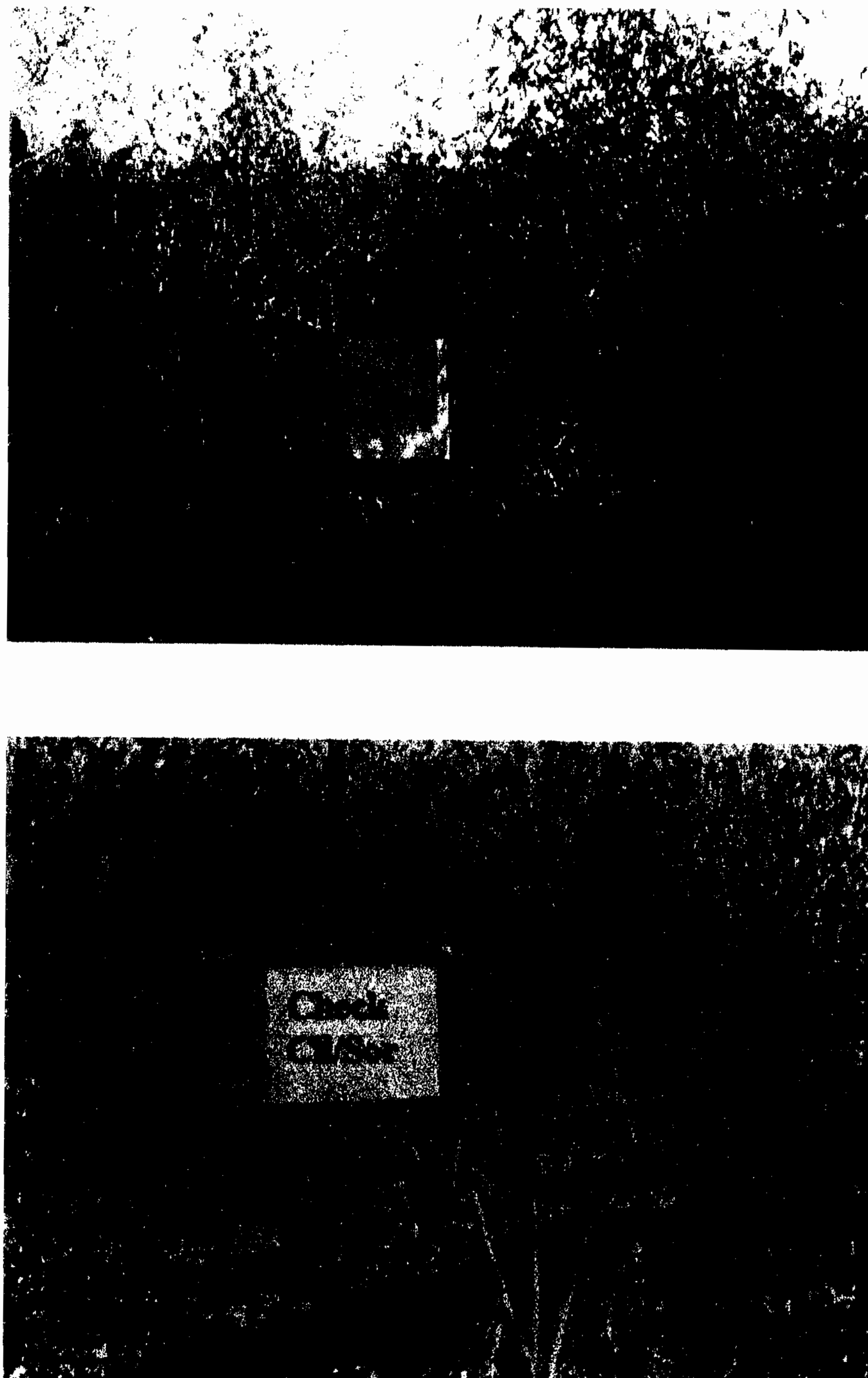
(f) Effect of individual treatment Green manure on wilt incidence in sole and intercropped pigeonpea



(g) Effect of individual treatment Zinc on wilt incidence in sole and intercropped pigeonpea



(h) Effect of individual treatment Farm yard manure on wilt incidence in sole and intercropped pigeonpea



(i) Control plot showing high wilt incidence in sole and intercropped pigeonpea studied had also recorded significantly lower wilt incidence than control (66% and 62%).

A study of interaction effects between cropping systems and production practices revealed reduced wilt incidence for all the production practices under both sole and intercropped pigeonpea compared to control (63-75%) and (71-87%) during 1996-97 and 1997-98 years, respectively. Application of IDM had uniformly resulted in minimum wilt incidence under all the cropping systems (9-14%) (Plate 43a). However, the next best treated plots were with SD (14-15%) (Plate 43b) and ZN + GM (16-22%) (Plate 43c). Zn + FYM and FYM + GM had recorded less wilt incidence i.e. (22-25%) (Plate 43d) and (26-30%) (Plate 43e), respectively when compared to control (62-75%). However, application of GM and Zn resulted in reduced wilt incidence under intercropping system (32-36%) (Plate 43f and 43g) compared to FYM (Plate 43h) and control (Plate 43i).

The results from the Table 30 revealed significant differences among production practices, cropping systems and their interaction effects during both the years of study in pots. IDM treatment recorded significantly lower wilt incidence (9%) (Plate 44a) when compared to other treatments and control (Plate 44b). However, all other practices SD (10%) and Zn + GM (11%) and Zn + FYM had also recorded significantly lower wilt incidence than control (41%) (Plate 44c). In the interaction study, all production practices viz., GM, Zn and FYM (Plate 44d) under both sole and intercropped pigeonpea resulted in reduced wilt incidence compared to control. IDM treatment uniformly resulted in minimum wilt incidence (8-

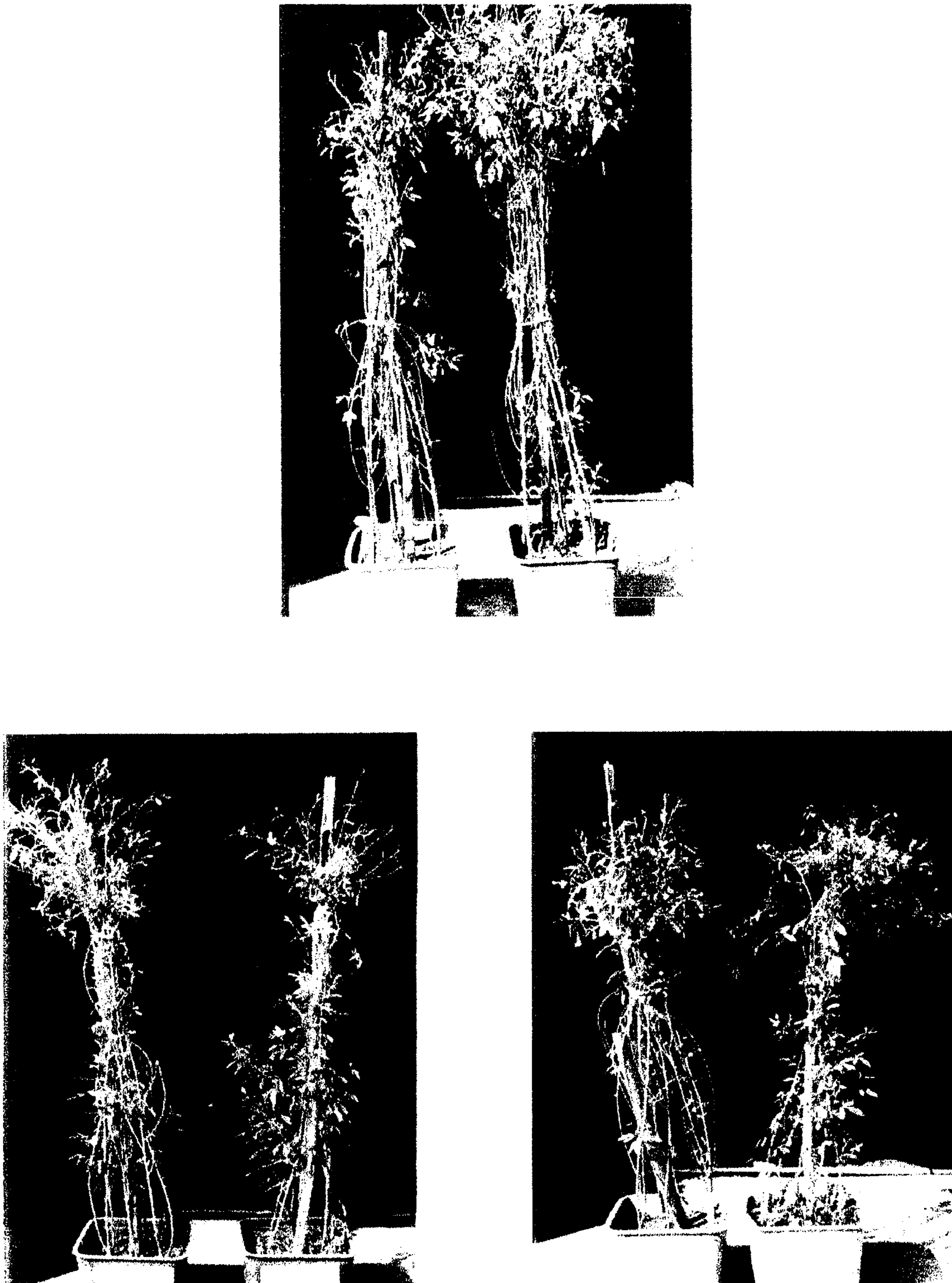
Plate 44. Integrated disease management of pigeonpea wilt in Vertisols – pot study

I S

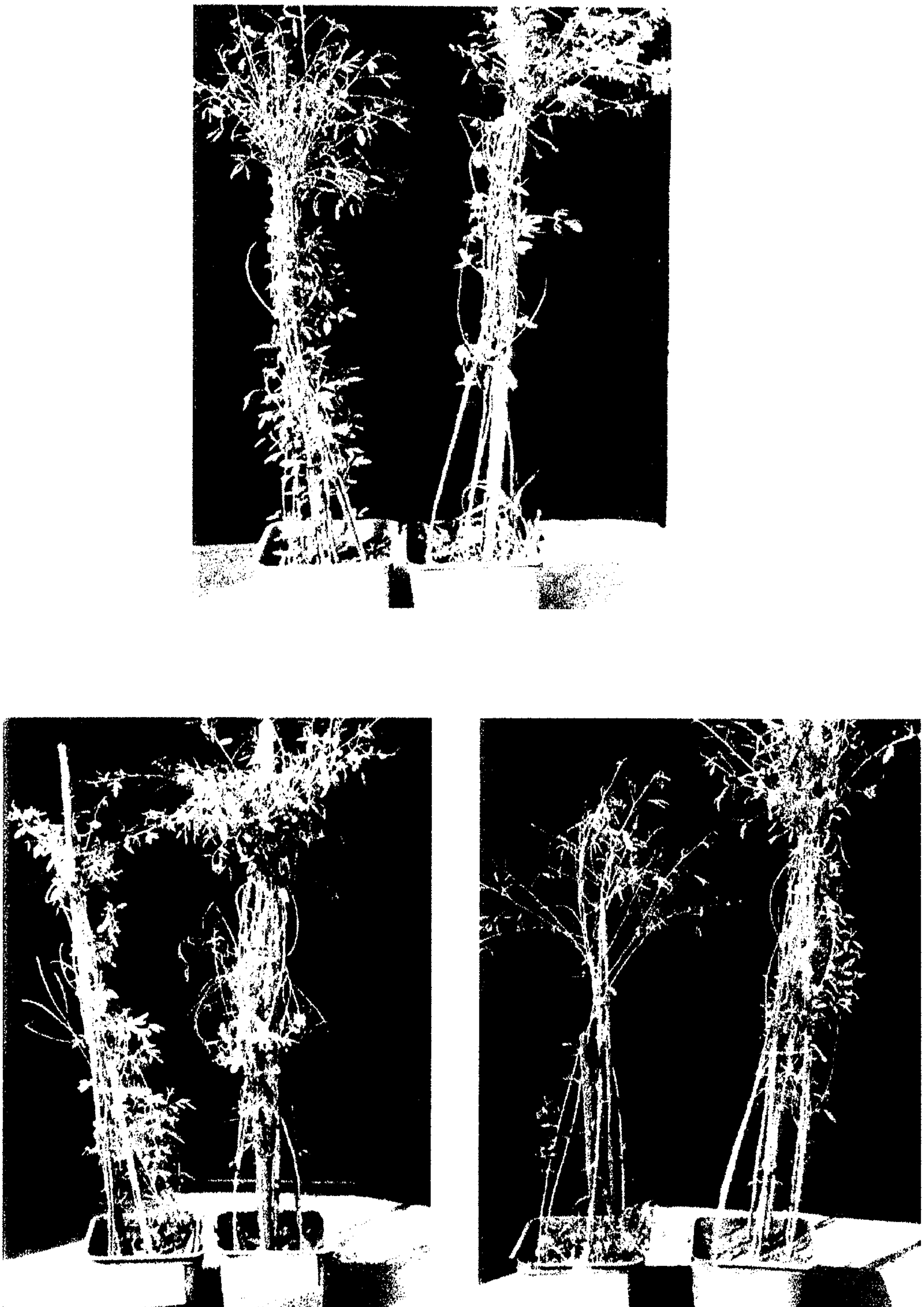
a. Effect of IDM treatment showing less wilt incidence in sole and intercropped pigeonpea

I S

b. Control plot showing high wilt incidence in sole, intercropped pigeonpea



(c) Effect of treatment combinations viz., Seed Dressing, Zinc+Farm Yard Manure, Zinc+Green Manure on wilt incidence in sole and intercropped pigeonpea



[illegible]) Effect of individual treatments viz., Green Manure, Farm yard manure and Zinc on wilt incidence in sole and intercropped pigeonpea

10%) under all the cropping systems. Application of SD and Zn + GM had recorded less wilt incidence followed by IDM treatment under the various cropping systems. Similar results were observed during 1997-98 year in pot study. However, application of GM and Zn recorded reduced wilt incidence (22% and 24%) in C11/sorghum cropping system than sole cropped C11 pigeonpea (25 and 27%), respectively during 1997-98. FYM treatment with C11/sorghum recorded wilt incidence on par with C11 sole crop (29%) (Plate 44d). Further, in unamended pot reduced wilt incidence was observed in intercropped pigeonpea than sole crop.

4.5.2.2 *Fusarium udum* population

Wilt pathogen population was found to be maximum in field (2320 and 1928 cfu/g soil) than in pots (1589 and 1191 cfu/g soil) during 1996-97 and 1997-98 seasons, respectively (Table 31-32). Further the fungal population was lower during 1997-98 (1928 and 1191 cfu/g soil) than 1996-97 (2320 and 1589 cfu/g soil) in field and pots, respectively.

The results revealed significant differences among production practices, cropping systems and their interaction effects for the pathogen population during both the years of study, under both field and pot conditions.

The results from the Table 31 revealed that among production practices, IDM treatment recorded significantly minimum pathogen population (1681 and 982 cfu/g soil). Seed dressing involving bavistin,

Table 31: Effect of integrated disease management package in vertisols on wilt pathogen (*Fusarium udum*) population (cfu/g soil) during *kharif* 1996-97 and 1997-98

Cropping systems	TREATMENTS									
	Control	Zn	GM	FYM	Zn+GM	Zn+FYM	FYM+GM	SD	IDM	Mean
1996-97										
C11	3217	2725	2366	2687	2762	2295	2379	1990	1858	2476
	(2431)	(2032)	(1761)	(2005)	(2064)	(1720)	(1724)	(1484)	(1342)	(1862)
ICP 8863	2945	2562	2397	2579	2579	2204	2266	1962	1737	2359
	(2224)	(1914)	(1784)	(1921)	(1927)	(1648)	(1691)	(1462)	(1284)	(1754)
C11/SOR	2920	2525	2291	2558	2316	2187	2237	1937	1633	2289
	(2201)	(1884)	(1712)	(1908)	(1718)	(1632)	(1671)	(1446)	(1204)	(1701)
ICP 8863/SOR	2533	2450	2179	2489	2366	1825	2125	1925	1495	2154
	(1878)	(1822)	(1634)	(1842)	(1746)	(1358)	(1582)	(1431)	(1112)	(1598)
Mean	2904	2565	2308	2578	2506	2128	2252	1954	1681	2320
	(2178)	(1923)	(1733)	(1912)	(1869)	(1584)	(1678)	(1454)	(1254)	(1752)
1997-98										
C11	3317	2300	2078	2468	2569	1670	1896	1445	1097	2093
	(2487)	(1725)	(1546)	(1842)	(1916)	(1246)	(1411)	(1112)	(830)	(1550)
ICP 8863	2941	2275	2032	2312	2229	1629	1754	1372	1017	1951
	(2205)	(1692)	(1512)	(1718)	(1658)	(1202)	(1306)	(991)	(734)	(1453)
C11/SOR	2885	2629	1906	2330	1960	1633	1671	1385	968	1930
	(2163)	(1962)	(1420)	(1732)	(1491)	(1220)	(1236)	(1026)	(711)	(1422)
ICP 8863/SOR	2575	2102	1768	2316	1971	1283	1564	1279	847	1738
	(1931)	(1561)	(1316)	(1706)	(1456)	(1955)	(1154)	(923)	(616)	(1285)
Mean	2915	2326	1946	2357	2182	1554	1721	1370	982	1928
	(2186)	(1714)	(1451)	(1755)	(1616)	(1165)	(1290)	(1011)	(726)	(1423)

	Production practices	Cropping systems	Interaction A	Interaction B
1996-97				
S.Ed.	5.0	1.7	6.0	13.1
CD (0.05)	10.4	3.5	12.5	27.5
CV (%)	18.2			
1997-98				
S.Ed.	27.4	14.0	41.9	78.4
CD (0.05)	58.2	28.0	83.8	160.2
CV (%)	15.3			

Note: A - For comparison of two sub-treatments at same level of main treatment
B - For comparison of two main treatments at the same or different levels of sub treatments
Figures in parenthesis are square root transformation values.

thiram and talc based *Trichoderma* powder was the next best treatment in resulting reduced population (1954 and 1370 cfu/g soil) during 1996-97 and 1997-98 years respectively. It was found that the reduction in CFU of *Fusarium* population over control was 42 and 65 per cent with the application of IDM treatment during 1996-97 and 1997-98 seasons, respectively.

Among the cropping systems, cultivation of resistant pigeonpea (CIP 8863) resulted in a significant reduction of population (2359 and 2476 cfu/g soil) when compared to C11 variety (1951 and 2093 cfu/g soil) under sole cropped pigeonpea. Population was found to be significantly lower in C11/sorghum (2289 and 1930) and ICP 8863/sorghum (2154 and 1738 cfu/g soil) cropping system than sole pigeonpea cropping systems of respective varieties.

A study of the interaction effects had also revealed reduced fungal population for all production practices under both sole and intercropped pigeonpea compared to control (unamended). Intercropping system of C11 and ICP 8863 with sorghum with IDM treatment resulted in reduced population levels (1633 and 1495 cfu/g soil) and (968 and 847 cfu/g soil) during 1996-97 and 1997-98 years, respectively. However, IDM treatment found significantly superior over all other treatments and control in reducing population. SD and Zn + FYM were the next best treatments in reducing population followed by IDM treatment. However, application of GM under C11/sorghum and ICP 8863/sorghum cropping system was found much better

Table 32: Effect of integrated disease management package in Vertisols in glasshouse on wilt pathogen (*Fusarium udum*) population (cfu/g soil) during 1996-97 and 1997-98

Cropping systems	TREATMENTS									
	Control	Zn	GM	FYM	Zn+GM	Zn+FYM	FYM+GM	SD	IDM	Mean
1996-97										
C11	2596	1916	1450	2008	1616	1287	1745	1237	1083	1660
	(1961)	(1437)	(1087)	(1548)	(1204)	(948)	(1308)	(912)	(803)	(1225)
ICP 8863	2475	1904	1433	2000	1591	1279	1708	1200	1062	1628
	(1864)	(1417)	(1074)	(1527)	(1166)	(948)	(1271)	(864)	(754)	(1212)
C11/SOR	2291	1800	1350	1991	1487	1270	1666	1100	1041	1555
	(1701)	(1350)	(1012)	(1483)	(1115)	(941)	(1249)	(856)	(708)	(1166)
ICP 8863/SOR	2220	1795	1295	1920	1454	1266	1637	1095	929	1512
	(1660)	(1381)	(1028)	(1465)	(1141)	(937)	(1248)	(848)	(658)	(1212)
Mean	2396	1854	1382	1980	1537	1276	1689	1158	1029	1589
	(1808)	(1381)	(1028)	(1465)	(1141)	(937)	(1248)	(848)	(761)	(1212)
1997-98										
C11	2642	1600	1013	1675	1207	767	1283	691	504	1265
	(1977)	(1192)	(754)	(1246)	(889)	(561)	(962)	(508)	(382)	(962)
ICP 8863	2420	1587	997	1667	1182	758	13621	654	483	1230
	(1805)	(1181)	(741)	(1242)	(845)	(542)	(1018)	(482)	(341)	(924)
C11/SOR	2237	1483	913	1658	1078	750	1279	554	462	1157
	(1690)	(1101)	(676)	(1228)	(792)	(523)	(959)	(419)	(313)	(887)
ICP 8863/SOR	2166	1479	859	1587	1045	746	1250	550	350	1114
	(1623)	(1082)	(632)	(1190)	(764)	(514)	(892)	(402)	(244)	(816)
Mean	2366	1537	945	1647	1128	755	1283	612	450	1191
	(1772)	(1138)	(698)	(1225)	(823)	(551)	(951)	(446)	(317)	(893)

	Production practices	Cropping systems	Interaction A	Interaction B
1996-97				
S.Ed.	11.8	7.6	22.7	52.1
CD (0.05)	25.1	15.2	45.5	104.2
CV (%)	17.1			
1997-98				
S.Ed.	18.3	7.7	32.8	54.4
CD (0.05)	38.7	15.4	65.6	104.9
CV (%)	14.3			

Note: A - For comparison of two sub-treatments at same level of main treatment
B - For comparison of two main treatments at the same or different levels of sub treatments
Figures in parenthesis are square root transformation values.

in reducing population (1768 and 1906 cfu/g soil) compared to Zn, FYM and control during 1997-98.

The results of the pot study revealed significant differences among production practices and cropping systems (Table 32). IDM treatment recorded significantly minimum pathogen population (1029 and 450 cfu/g soil) during 1996-97 and 1997-98 years, respectively. It was found that the reduction in CFU over control was 57 and 80 per cent in the treatment with IDM during 1996-97 and 1997-98 years, respectively. Among the cropping systems ICP 8863 exhibited significant reduction of CFU of *fusarium* (1628 and 1660 cfu/g soil) when compared to C11 (1230 and 1265 cfu/g soil) during 1996-97 and 1997-98 years, respectively. C11/sorghum and ICP 8863/sorghum recorded reduced population (1157 and 1114 cfu/g soil) compared to sole pigeonpea (1265 and 1230 cfu/g soil) during 1997-98 year.

Interaction study revealed application of IDM and SD had resulted uniformly in minimum pathogen population under all the cropping systems studied. However, all other treatments had also recorded reduced population levels when compared to control.

4.5.2.3 *Aspergillus* sp. population

Average *Aspergillus* sp. population was found to be higher in pots (435 and 573 cfu/g soil) than in field (410 and 536 cfu/g soil) during 1996-97 and 1997-98 seasons, respectively. Further, the population was higher during 1997-98 (536 and 573 cfu/g soil) than 1996-97 (410and 435 cfu/g soil) in field and pots, respectively (Tables 33-34).

Table 33: Effect of integrated disease management package in Vertisols on *Aspergillus* sp. population (cfu/g soil) during *kharif* 1996-97 and 1997-98

Cropping systems	TREATMENTS									
	Control	Zn	GM	FYM	Zn+GM	Zn+FYM	FYM+GM	SD	IDM	Mean
1996-97										
C11	220	356	405	295	514	331	297	298	403	346
	(152)	(267)	(301)	(221)	(382)	(248)	(218)	(220)	(276)	(263)
ICP 8863	300	465	503	486	554	422	406	403	424	440
	(212)	(348)	(377)	(364)	(530)	(312)	(306)	(298)	(371)	(358)
C11/SOR	282	454	375	401	514	343	390	429	416	400
	(201)	(340)	(281)	(300)	(381)	(257)	(294)	(316)	(322)	(312)
ICP 8863/SOR	299	489	415	352	613	499	384	495	542	454
	(216)	(366)	(311)	(264)	(459)	(364)	(281)	(351)	(426)	(378)
Mean	275	441	425	384	548	398	369	406	446	410
	(198)	(322)	(297)	(388)	(446)	(274)	(263)	(289)	(348)	(327)
1997-98										
C11	342	484	447	380	652	417	367	479	489	450
	(196)	(343)	(315)	(281)	(508)	(304)	(265)	(364)	(378)	(324)
ICP 8863	368	584	637	443	1032	449	415	507	729	574
	(256)	(418)	(482)	(321)	(789)	(348)	(301)	(398)	(562)	(441)
C11/SOR	358	586	566	443	722	491	385	555	634	527
	(268)	(429)	(442)	(321)	(556)	(379)	(286)	(416)	(486)	(401)
ICP 8863/SOR	442	588	558	475	1046	456	443	558	778	594
	(321)	(456)	(429)	(352)	(803)	(352)	(317)	(436)	(597)	(487)
Mean	377	560	552	435	863	453	402	525	657	536
	(270)	(433)	(416)	(325)	(662)	(341)	(311)	(402)	(512)	(429)

	Production practices	Cropping systems	Interaction A	Interaction B
1996-97				
S.Ed.	11.6	7.3	21.9	28.2
CD (0.05)	24.5	14.6	43.8	57.3
CV (%)	10.1			
1997-98				
S.Ed.	6.3	1.6	7.1	12.2
CD (0.05)	13.5	13.1	14.2	24.9
CV (%)	15.2			

Note: A - For comparison of two sub-treatments at same level of main treatment
B - For comparison of two main treatments at the same or different levels of sub treatments
Figures in parenthesis are square root transformation values.

Table 34: *Effect of integrated disease management package in Vertisols in glass house on Aspergillus sp. population (cfu/g) during kharif* 1996-97 and 1997-98

Cropping systems	TREATMENTS									
	Control	Zn	GM	FYM	Zn+GM	Zn+FYM	FYM+GM	SD	IDM	Mean
1996-97										
C11	347	426	447	389	471	404	373	422	429	412
	(252)	(319)	(335)	(291)	(358)	(303)	(279)	(306)	(334)	(309)
ICP 8863	363	465	524	404	549	412	389	439	481	447
	(275)	(348)	(393)	(303)	(401)	(309)	(291)	(329)	(354)	(326)
C11/SOR	358	456	454	397	485	412	387	430	460	427
	(288)	(342)	(340)	(297)	(358)	(309)	(290)	(312)	(342)	(314)
ICP 8863/SOR	426	471	454	464	542	416	389	439	471	452
	(324)	(353)	(340)	(348)	(416)	(312)	(291)	(329)	(372)	(328)
Mean	374	455	470	413	512	411	384	432	460	435
	(272)	(341)	(352)	(309)	(384)	(302)	(280)	(324)	(351)	(316)
1997-98										
C11	221	461	499	303	728	393	307	360	570	427
	(161)	(345)	(374)	(221)	(549)	(294)	(221)	(291)	(432)	(314)
ICP 8863	370	717	771	618	886	605	512	578	702	640
	(277)	(537)	(578)	(460)	(660)	(443)	(374)	(413)	(536)	(480)
C11/SOR	346	638	547	500	733	432	470	583	644	544
	(259)	(478)	(410)	(361)	(563)	(320)	(346)	(440)	(483)	(423)
ICP 8863/SOR	382	874	890	546	965	447	455	728	835	680
	(286)	(655)	(667)	(392)	(736)	(323)	(333)	(561)	(639)	(519)
Mean	330	672	677	492	828	469	436	562	688	573
	(240)	(484)	(507)	(354)	(604)	(351)	(328)	(446)	(536)	(448)

	Production practices	Cropping systems	Interaction A	Interaction B
1996-97				
S.Ed.	10.1	4.8	4.5	11.5
CD (0.05)	21.4	9.6	8.9	23.4
CV (%)	18.1			
1997-98				
S.Ed.	5.5	2.1	18.3	36.5
CD (0.05)	11.7	4.2	36.6	74.7
CV (%)	12.5			

Note: A - For comparison of two sub-treatments at same level of main treatment
B - For comparison of two main treatments at the same or different levels of sub treatments
Figures in parenthesis are square root transformation values.

Significant differences were noticed among production practices and cropping systems for fungal population during both the years of study, under both field and pot conditions. Perusal of the results in the Table 33 indicated that among the production practices, studied in the field during 1996-97, zinc sulphate in combination with green manure treatment recorded significantly higher fungal population (548 and 863 cfu/g soil) than other practices. The next best treatment was IDM treatment (446 and 657 cfu/g soil) followed by Zn + GM. However, all other treatments had also recorded greater population significantly over control (275 and 377 cfu/g soil) during 1996-97 and 1997-98 in field respectively.

Among the cropping systems, intercropping systems of C11/sorghum and ICP 8863/sorghum recorded higher populations (400 and 454 cfu/g soil) and (527 and 594 cfu/g soil) over the respective sole cropping system during 1996-97 and 1997-98 years respectively. Cultivation of resistant pigeonpea resulted in an increase in the population (440 and 574 cfu/g soil) over C11 (346 and 440 cfu/g soil) during 1996-97 and 1997-98 years, respectively.

A study of interaction effects had also revealed significantly higher population for all production practices under both sole and intercropped pigeonpea than control. The treatment consists of Zn + GM and IDM resulted in uniformly maximum population under both the cropping systems and significantly higher population over control. However, application of individual treatments such as $ZnSO_4$ and GM under the intercropping system had resulted in maximum population (586 and 588 cfu/g soil) and (566 and 558 cfu/g soil) in C11/sorghum and ICP 8863/sorghum, respectively during

1997-98. Further, Zn + FYM and FYM + GM were found to on par in increasing the population. The results of the pot study revealed higher population in the treatment with the application of Zn + GM treatment (512 and 828 cfu/g soil) followed by IDM treatment (460 and 688 cfu/g soil) (Table 33-34). Intercropping system of ICP 8863/sorghum had recorded maximum population (452 and 680 cfu/g soil) over C11 (427 and 544 cfu/g soil). Significant differences were recorded in combination of treatments under all the cropping systems than their individual application in their interaction effects during 1996-97 year. However, Zn + FYM and FYM + GM were found to be on par in their interaction effects during 1997-98 year. All other treatments significantly recorded higher population over control under all the cropping systems. Similar results were observed under pot study (Table 34).

4.5.2.4 *Penicillium* sp. population

Population of *Penicillium* sp. was found to be higher in pots (396 and 555 cfu/g soil), than in field (260 and 332 cfu/g soil) during 1996-97 and 1997-98 years, respectively (Table 35-36). The fungal population was higher during 1997-98 (332 and 555 cfu/g soil) than 1996-97 (260 and 396 cfu/g soil) in field and pots, respectively. The results also revealed significant differences among production practices and cropping systems and their interaction effects for fungal population during both the years of study under field and pots.

Table 35: Effect of integrated disease management package in Vertisols on *Penicillium* sp. population (cfu/g) during *kharif* 1996-97 and 1997-98

Cropping systems	TREATMENTS									
	Control	Zn	GM	FYM	Zn+GM	Zn+FYM	FYM+GM	SD	IDM	Mean
1996-97										
C11	144	205	232	201	280	263	222	211	235	222
	(94)	(154)	(212)	(151)	(222)	(186)	(161)	(158)	(172)	(158)
ICP 8863	150	243	216	209	328	200	260	287	275	241
	(112)	(171)	(162)	(148)	(268)	(150)	(187)	(201)	(218)	(174)
C11/SOR	197	246	267	288	367	354	284	284	335	291
	(139)	(162)	(192)	(204)	(294)	(261)	(213)	(206)	(258)	(206)
ICP 8863/SOR	185	303	286	273	415	293	279	244	305	287
	(128)	(217)	(214)	(201)	(311)	(206)	(191)	(186)	(249)	(221)
Mean	169	249	250	243	347	277	261	256	287	260
	(106)	(168)	(177)	(159)	(287)	(209)	(172)	(198)	(224)	(201)
1997-98										
C11	152	217	276	219	327	295	201	238	280	245
	(104)	(154)	(181)	(151)	(258)	(221)	(158)	(175)	(210)	(192)
ICP 8863	166	293	309	224	392	292	391	409	283	307
	(116)	(197)	(214)	(168)	(284)	(208)	(289)	(294)	(229)	(239)
C11/SOR	218	298	308	336	502	411	406	280	446	356
	(156)	(204)	(205)	(238)	(384)	(319)	(292)	(216)	(337)	(284)
ICP 8863/SOR	322	372	443	375	493	460	426	392	487	419
	(214)	(261)	(326)	(254)	(397)	(351)	(319)	(272)	(350)	(319)
Mean	214	295	334	289	429	365	356	330	374	332
	(152)	(216)	(235)	(201)	(362)	(279)	(247)	(262)	(298)	(254)

	Production practices	Cropping systems	Interaction A	Interaction B
Field 1996-97				
S.Ed.	5.8	5.9	12.2	23.5
CD (0.05)	12.2	11.8	24.5	48.1
CV (%)	10.3			
Field 1997-98				
S.Ed.	5.4	4.1	12.2	22.5
CD (0.05)	11.4	8.2	24.5	45.6
CV (%)	16.2			

A - For comparison of two sub-treatments at same level of main treatment
B - For comparison of two main treatments at the same or different levels of sub treatments
Figures in parenthesis are square root transformation values.

Table 36: Effect of integrated disease management components in Vertisols in glass house on *Penicillium* sp. population (cfu/g) during *kharif* 1996-97 and 1997-98

Cropping systems	TREATMENTS									
	Control	Zn	GM	FYM	Zn+GM	Zn+FYM	FYM+GM	SD	IDM	Mean
1996-97										
C11	176	289	385	224	520	429	408	370	466	363
	(121)	(204)	(246)	(161)	(396)	(301)	(289)	(268)	(337)	(264)
ICP 8863	249	350	422	325	591	397	412	400	475	402
	(164)	(242)	(316)	(238)	(452)	(297)	(309)	(304)	(368)	(298)
C11/SOR	210	350	458	304	533	433	408	391	496	398
	(142)	(251)	(313)	(208)	(404)	(342)	(302)	(314)	(360)	(288)
ICP 8863/SOR	254	366	458	329	624	433	420	404	540	425
	(172)	(244)	(313)	(246)	(464)	(342)	(305)	(292)	(419)	(302)
Mean	222	338	431	295	567	423	412	391	494	396
	(143)	(253)	(321)	(221)	(415)	(338)	(312)	(293)	(382)	(279)
1997-98										
C11	126	342	556	295	797	604	493	457	638	478
	(82)	(236)	(401)	(215)	(626)	(461)	(369)	(331)	(484)	(362)
ICP 8863	259	506	756	394	823	647	610	516	768	586
	(178)	(359)	(551)	(265)	(671)	(496)	(467)	(367)	(591)	(452)
C11/SOR	291	435	679	350	816	651	528	487	726	551
	(218)	(316)	(509)	(252)	(636)	(504)	(399)	(351)	(555)	(416)
ICP 8863/SOR	303	510	715	411	904	598	704	535	776	606
	(207)	(361)	(523)	(301)	(698)	(466)	(541)	(401)	(601)	(471)
Mean	244	448	679	362	835	625	583	498	727	555
	(171)	(316)	(491)	(262)	(656)	(462)	(432)	(364)	(549)	(429)

	Production practices	Cropping systems	Interaction A	Interaction B
1996-97				
S.Ed.	16.1	1.0	3.1	20.4
CD (0.05)	13.3	2.0	6.1	42.8
CV (%)	18.3			
1997-98				
S.Ed.	12.0	5.8	5.5	12.4
CD (0.05)	25.5	11.5	11.1	25.7
CV (%)	12.8			

Note: A - For comparison of two sub-treatments at same level of main treatment
B - For comparison of two main treatments at the same or different levels of sub treatments
Figures in parenthesis are square root transformation values.

Perusal of the data indicated that during 1996-97 in field (Table 35), application of Zn + GM had recorded significantly higher population (347 and 429 cfu/g soil) than other treatments and over control. The next best was IDM treatment (287 and 374 cfu/g soil) followed by Zn + GM. However, all other treatments recorded maximum population over control (169 and 214 cfu/g soil). Among the cropping systems, resistant pigeonpea had recorded maximum population (241 and 307 cfu/g soil) than C11 (222 and 245 cfu/g soil). ICP 8863/sorghum recorded maximum population (287 and 419 cfu/g soil) over C11 (291 and 356 cfu/g soil).

A study of interaction effects had also revealed significant increase in the population with all the treatments under all the cropping system over control. $ZnSO_4$ in combination with green manure had resulted in maximum population over all other treatments under all the croppings systems. Intercropping of pigeonpea with sorghum in both varieties in combination with Zn + GM resulted in higher population (502 and 493 cfu/g soil) during 1997-98. IDM and Zn + FYM followed by Zn + GM found better in increasing the population. Similar results were observed in pot study (Table 36) during 1996-97 and 1997-98 years, respectively. In interaction study, Zn + GM recorded maximum population under all the cropping systems. Intercropping of both varieties C11 and ICP 8863 recorded higher population count of 816 and 904 cfu/g soil. Adoption of other practices resulted in a significant increase in the population over control under all the cropping systems. Among the treatments the population levels were nonsignificant in the combination of treatments during 1996-97 and it was not found to exist during 1997-98 indicating their superiority over others.

4.5.2.5 Population of *Trichoderma* sp.

Population of Trichoderma sp. was found to be greater in pots (401 and 531 cfu/g soil) than in field (292 and 490 cfu/g soil) during 1996-97 and 1997-98 seasons, respectively (Table 37-38). The fungal population was higher during 1997-98 (490 and 531 cfu/g soil) than 1996-97 (290 and 401 cfu/g soil) in field and pots, respectively. The results also revealed significant differences among production practices and cropping systems and their interaction effects for fungal population during both years of study under field and pot conditions.

Among the production practices studied in field (Table 37) during 1996-97 and 1997-98, seed dressing treatment recorded significantly higher population (404 and 808 cfu/g soil) than other treatments. IDM treatment was found the next best in increasing population (324 and 726 cfu/g soil) followed by SD. However, adoption of all other practices resulted in significantly higher population over control (207 and 293 cfu/g soil).

Among the cropping systems studied, cultivation of resistant pigeonpea resulted in a significant increase in the population of *Trichoderma* sp. under sole pigeonpea. Population of *Trichoderma* was (298 and 269 cfu/g soil) and (472 and 415 cfu/g soil in ICP 8863 and C11 during 1996-97 and 1997-98 years, respectively. Further, ICP 8863/sorghum coppying system resulted in maximum population (313 and 597 cfu/g soil) than C11 (282 and 478 cfu/g soil).

Table 37: Effect of integrated disease management package in Vertisols on *Trichoderma* sp. population (cfu/g) during *kharif* 1996-97 and 1997-98

Cropping systems	TREATMENTS									
	Control	Zn	GM	FYM	Zn+GM	Zn+FYM	FYM+GM	SD	IDM	Mean
1996-97										
C11	195	284	226	249	289	287	274	345	269	269
	(118)	(162)	(124)	(146)	(230)	(206)	(194)	(286)	(224)	(201)
ICP 8863	210	305	284	257	299	278	295	425	332	298
	(142)	(204)	(198)	(191)	(213)	(215)	(206)	(310)	(254)	(229)
C11/SOR	208	273	231	233	299	296	293	360	336	282
	(132)	(196)	(174)	(172)	(221)	(221)	(219)	(324)	(264)	(214)
ICP 8863/SOR	214	305	265	261	333	270	320	488	359	313
	(149)	(202)	(182)	(157)	(246)	(214)	(221)	(366)	(302)	(237)
Mean	207	292	251	250	305	283	297	404	324	290
	(141)	(204)	(163)	(186)	(218)	(226)	(196)	(313)	(265)	(224)
1997-98										
C11	244	376	308	282	443	417	450	698	532	415
	(161)	(254)	(239)	(201)	(353)	(322)	(337)	(583)	(410)	(301)
ICP 8863	263	411	416	286	464	430	457	808	710	472
	(183)	(241)	(302)	(214)	(358)	(310)	(338)	(636)	(548)	(331)
C11/SOR	297	369	349	311	556	463	489	778	693	478
	(196)	(276)	(251)	(226)	(442)	(341)	(366)	(600)	(529)	(344)
ICP 8863/SOR	368	527	433	393	734	494	634	947	895	597
	(266)	(324)	(342)	(264)	(576)	(372)	(484)	(740)	(692)	(456)
Mean	293	402	377	318	547	443	507	808	726	490
	(201)	(301)	(262)	(238)	(422)	(332)	(371)	(636)	(584)	(372)

	Production practices	Cropping systems	Interaction A	Interaction B
1996-97				
S.Ed.	10.2	5.4	16.3	31.7
CD (0.05)	21.6	10.9	32.6	54.6
CV (%)	14.4			
1997-98				
S.Ed.	9.6	5.8	17.3	32.9
CD (0.05)	20.3	11.6	34.7	67.0
CV (%)	17.4			

Note: A - For comparison of two sub-treatments at same level of main treatment
B - For comparison of two main treatments at the same or different levels of sub treatments
Figures in parenthesis are square root transformation values.

Table 38: Effect of integrated disease management package in Vertisols in glass house on *Trichoderma* sp. population (cfu/g soil) during *kharif* 1996-97 and 1997-98

Cropping systems	TREATMENTS								
	Control	Zn	GM	FYM	Zn+GM	Zn+FYM	FYM+GM	SD	IDM	Mean
1996-97										
C11	231	355	300	252	435	387	412	550	495	380
	(148)	(239)	(205)	(189)	(336)	(271)	(309)	(442)	(362)	(272)
ICP 8863	173	346	344	287	473	432	472	608	495	403
	(119)	(242)	(258)	(218)	(358)	(306)	(324)	(456)	(371)	(302)
C11/SOR	237	363	316	304	466	395	425	462	486	391
	(162)	(252)	(232)	(231)	(350)	(296)	(314)	(351)	(351)	(286)
ICP 8863/SOR	228	370	338	392	496	460	438	596	522	427
	(171)	(277)	(244)	(297)	(372)	(325)	(328)	(451)	(396)	(326)
Mean	217	359	325	309	468	419	437	579	498	401
	(152)	(254)	(231)	(231)	(364)	(334)	(320)	(462)	(394)	(314)
1997-98										
C11	194	366	312	257	535	479	490	843	677	467
	(129)	(246)	(201)	(191)	(404)	(362)	(361)	(658)	(517)	(322)
ICP 8863	243	408	412	299	732	479	616	984	699	542
	(164)	(271)	(292)	(209)	(582)	(343)	(443)	(764)	(522)	(415)
C11+SOR	242	446	362	351	600	672	536	935	628	530
	(151)	(331)	(252)	(260)	(422)	(504)	(242)	(729)	(482)	(382)
ICP 8863+SOR	247	487	347	354	728	747	623	1020	748	589
	(179)	(356)	(260)	(251)	(521)	(569)	(467)	(810)	(584)	(437)
Mean	232	427	358	315	649	594	566	946	688	531
	(158)	(302)	(248)	(232)	(456)	(451)	(429)	(739)	(536)	(384)

	Production practices	Cropping systems	Interaction A	Interaction B
1996-97				
S.Ed.	12.8	5.8	17.5	59.6
CD (0.05)	27.2	11.7	35.0	122.1
CV (%)	13.1			
1997-98				
S.Ed.	13.8	9.8	29.3	54.4
CD (0.05)	29.4	19.5	58.6	110.3
CV (%)	10.9			

Note: A - For comparison of two sub-treatments at same level of main treatment
B - For comparison of two main treatments at the same or different levels of sub treatments
Figures in parenthesis are square root transformation values.

A study of interaction effects revealed application of SD resulted in significantly greater population over all other treatments and control under all the cropping systems. IDM treatment was the next best in increasing the population by an additive effect of Zn, GM and FYM as other components in IDM (269 to 359 cfu/g soil) and (532 to 895 cfu/g soil) during 1996-97 and 1997-98 years, respectively. Adoption of all other production practices resulted in greater population over control under all the cropping systems. Similar results were observed in pot study (Table 38).

4.5.2.6 Total antagonistic fungal population

Total antagonistic fungal population was in general observed to be higher in pots (1248 and 1664 cfu/g soil) than in field (960 and 1361 cfu/g soil) during 1996-97 and 1997-98 years, respectively (Tables 39-40). The fungal population was higher during 1997-98 (1361 and 1664 cfu/g soil) than during 1996-97 (960 and 1248 cfu/g soil) in field and pots, respectively. The results revealed significant differences among production practices, cropping systems and their interaction effects for fungal population during both the years of study.

The results of the experiment are presented in Table 39. Perusal of the data in the table indicated that among the production practices studied in field during 1996-97, application of $ZnSO_4$ in combination with green manure had recorded significantly higher population (1204 and 1842 cfu/g soil) than other production practices. IDM treatment followed by Zn + GM was found to be next best in increasing the population (1080 and 1740 cfu/g soil).

Table 39: Effect of integrated disease management package in Vertisols on total antagonistic fungal population (cfu/g soil) during *kharif* 1996-97 and 1997-98

Cropping systems	TREATMENTS									
	Control	Zn	GM	FYM	Zn+GM	Zn+FYM	FYM+GM	SD	IDM	Mean
1996-97										
C11	559	825	864	745	1081	885	793	835	937	836
	(326)	(610)	(639)	(538)	(810)	(653)	(594)	(636)	(728)	(627)
ICP 8863	661	1014	1003	953	1180	922	962	1078	1020	977
	(462)	(754)	(725)	(698)	(894)	(694)	(725)	(818)	(766)	(751)
C11+SOR	624	989	874	922	1182	1001	967	1037	1116	968
	(447)	(726)	(632)	(680)	(909)	(765)	(734)	(752)	(831)	(778)
ICP 8863+SOR	698	1097	966	887	1357	1104	983	1250	1250	1060
	(512)	(811)	(694)	(665)	(1021)	(828)	(769)	(940)	(942)	(802)
Mean	636	981	926	877	1204	934	926	1050	1080	960
	(461)	(749)	(684)	(637)	(923)	(718)	(694)	(782)	(822)	(734)
1997-98										
C11	738	1077	1031	881	1423	1130	1018	1415	1301	1113
	(513)	(807)	(754)	(651)	(1084)	(854)	(784)	(1048)	(970)	(834)
ICP 8863	924	1288	1363	953	1889	1172	1152	1724	1724	1354
	(671)	(942)	(1001)	(714)	(1432)	(887)	(864)	(1293)	(1293)	(1001)
C11+SOR	873	1253	1223	1090	1780	1365	1281	1613	1773	1361
	(624)	(921)	(917)	(809)	(1382)	(1012)	(979)	(1219)	(1340)	(1032)
ICP 8863+SOR	1132	1483	1434	1243	2274	1411	1504	1897	2161	1615
	(819)	(1110)	(1052)	(926)	(1705)	(1059)	(1114)	(1431)	(1593)	(1224)
Mean	917	1275	1263	1042	1842	1270	1240	1662	1740	1361
	(647)	(936)	(931)	(782)	(1394)	(967)	(1141)	(1254)	(1321)	(1032)

	Production practices	Cropping systems	Interaction A	Interaction B
1996-97				
S.Ed.	14.1	5.9	17.8	36.7
CD (0.05)	29.9	11.8	35.5	75.3
CV (%)	18.2			
1997-98				
S.Ed.	14.0	9.7	29.0	54.1
CD (0.05)	29.7	19.4	58.1	109.7
CV (%)	12.6			

Note: A - For comparison of two sub-treatments at same level of main treatment
B - For comparison of two main treatments at the same or different levels of sub treatments
Figures in parenthesis are square root transformation values.

Table 40: Effect of integrated disease management package in Vertisols in glass house on total antagonistic fungal population (cfu/g soil) during *kharif* 1996-97 and 1997-98

Cropping systems	TREATMENTS									
	Control	Zn	GM	FYM	Zn+GM	Zn+FYM	FYM+GM	SD	IDM	Mean
1996-97										
C11	754	1071	1132	865	1426	1268	1169	1342	1390	1157
	(515)	(796)	(842)	(668)	(1144)	(912)	(886)	(1010)	(1032)	(851)
ICP 8863	785	1161	1290	1085	1613	1282	1273	1447	1451	1265
	(538)	(824)	(952)	(813)	(1242)	(996)	(982)	(1086)	(1102)	(962)
C11+SOR	805	1169	1228	1051	1484	1312	1220	1383	1442	1233
	(594)	(851)	(922)	(772)	(1192)	(948)	(925)	(1062)	(1182)	(924)
ICP 8863+SOR	908	1207	1507	1185	1662	1345	1247	1439	1533	1337
	(656)	(889)	(1138)	(902)	(1289)	(1028)	(962)	(1114)	(1141)	(1014)
Mean	813	1152	1289	1047	1546	1302	1227	1402	1454	1248
	(578)	(763)	(946)	(722)	(1194)	(976)	(916)	(1035)	(1066)	(924)
1997-98										
C11	541	1169	1367	855	2060	1476	1290	1660	1885	1367
	(408)	(892)	(1018)	(631)	(1545)	(1106)	(988)	(1232)	(1426)	(1022)
ICP 8863	872	1631	1939	1311	2441	1731	1738	2078	2169	1768
	(623)	(1216)	(1424)	(962)	(1821)	(1248)	(1323)	(1526)	(1644)	(1358)
C11+SOR	879	1519	1588	1201	2149	1755	1535	2005	1998	1625
	(650)	(1138)	(1166)	(904)	(1678)	(1306)	(1158)	(1502)	(1512)	(1216)
ICP 8863+SOR	932	1871	2092	1311	2597	1792	1782	2283	2359	1898
	(712)	(1398)	(1592)	(983)	(1959)	(1388)	(1346)	(1722)	(1784)	(1488)
Mean	806	1547	1747	1169	2312	1688	1586	2006	2103	1664
	(584)	(1122)	(1321)	(892)	(1722)	(1278)	(1156)	(1517)	(1594)	(1262)

	Production practices	Cropping systems	Interaction A	Interaction B
1996-97				
S.Ed.	13.5	7.8	23.4	53.0
CD (0.05)	28.7	15.6	46.7	108.7
CV (%)	14.2			
1997-98				
S.Ed.	13.2	10.5	31.4	57.5
CD (0.05)	27.9	20.9	62.8	116.2
CV (%)	18.2			

Note: A - For comparison of two sub-treatments at same level of main treatment
B - For comparison of two main treatments at the same or different levels of sub treatments
Figures in parenthesis are square root transformation values.

However, all other production practices hads also recorded significantly higher population than control (636 and 917 cfu/g soil) during 1996-97 and 1997-98 years, respectively. The treatment SD was found much better in increasing the population followed by Zn + GM and IDM treatments.

Among the cropping systems, resistant pigeonpea resulted in a significant increase in the population (977 and 1354 cfu/g soil) than C11 (836 and 1113 cfu/g soil) under sole crop during 1996-97 and 1997-98 years, respectively. Intercropping of ICP 8863 with sorghum resulted in greater levels of population (1060 and 968 cfu/g soil) than C11 with sorghum (968 and 1361 cfu/g soil) during 1996-97 and 1997-98 years, respectively.

The interaction effects had also revealed maximum population with the adoption of $ZnSO_4$ in combination with green manure treatment under all the cropping systems. However, SD and IDM treatment were found to be on par with each other and superior over other practices followed by Zn + GM under all the cropping systems. Adoption of other production practices had also resulted in significantly higher population than control under the various cropping systems. A similar trend was also noticed for the year 1997-98 in field and both the years of study in pots (Table 40).

4.5.2.7 Yield of pigeonpea

Average yields were higher during 1997-98 (2.32 kg/plot) and 44.24 g/pot) than 1996-97 (1.96 kg/plot and 35.2 g/pot) in field and pots respectively (Tables 41-42). The results also revealed significant differences

Table 41: Effect of integrated disease management components in Vertisols on yield of pigeonpea (kg/plot) during *kharif* 1996-97 and 1997-98

Cropping systems	TREATMENTS									
	Control	Zn	GM	FYM	Zn+GM	Zn+FYM	FYM+GM	SD	IDM	Mean
1996-97										
C11	0.58	1.02	1.07	1.00	2.76	2.41	2.39	2.97	3.87	2.01
ICP 8863	0.44	1.31	1.31	1.10	2.87	2.46	2.36	2.99	4.30	2.13
C11/SOR	0.54	1.00	1.24	1.33	2.29	2.10	2.08	2.29	3.18	1.78
ICP 8863/SOR	0.39	1.44	1.47	1.21	2.44	2.16	2.11	2.49	3.35	1.90
Mean	0.49	1.20	1.27	1.16	2.59	2.28	2.23	2.68	3.68	1.96
1997-98										
C11	0.36	1.08	2.07	1.06	3.00	2.82	2.70	3.33	4.94	2.36
ICP 8863	0.70	1.35	2.12	1.34	3.31	2.70	2.70	3.54	5.01	2.53
C11/SOR	0.59	1.24	1.30	1.00	2.70	2.61	2.61	3.01	3.66	2.10
ICP 8863/SOR	0.83	1.64	1.50	1.42	2.90	2.58	2.43	3.16	3.98	2.26
Mean	0.62	1.33	1.75	1.21	3.10	2.68	2.61	3.26	4.42	2.32

	Production practices	Cropping systems	Interaction A	Interaction B
1996-97				
S.Ed.	0.12	0.06	0.17	0.38
CD (0.05)	0.25	0.11	0.33	0.78
CV (%)	20.15			
1997-98				
S.Ed.	0.10	0.05	0.15	0.30
CD (0.05)	0.21	0.10	0.30	0.60
CV (%)	12.37			

Note: A - For comparison of two sub-treatments at same level of main treatment
B - For comparison of two main treatments at the same or different levels of sub treatments

Table 42: Effect of integrated disease management components in Vertisols in glass house on yield of pigeonpea (g/pot) during *kharif* 1996-97 and 1997-98

Cropping systems	TREATMENTS									
	Control	Zn	GM	FYM	Zn+GM	Zn+FYM	FYM+GM	SD	IDM	Mean
1996-97										
C11	25.00	30.18	34.26	29.68	31.73	48.48	43.47	36.46	66.78	38.45
ICP 8863	50.37	54.19	54.45	56.21	58.26	54.55	55.92	59.17	77.34	57.83
C11/SOR	5.14	14.04	13.18	14.17	20.67	21.74	19.73	29.46	34.20	19.14
ICP 8863/SOR	9.93	12.81	14.05	12.90	33.92	24.35	24.49	46.07	46.69	25.36
Mean	22.61	27.81	28.98	28.24	36.15	37.28	35.90	42.79	57.00	35.20
1997-98										
C11	29.07	38.83	41.97	34.00	61.94	58.53	55.60	62.17	66.50	49.85
ICP 8863	59.43	67.73	66.23	65.03	75.23	72.18	71.49	75.75	79.83	70.32
C11/SOR	10.69	19.80	21.99	14.17	31.32	30.80	29.20	32.89	36.82	25.30
ICP 8863/SOR	13.48	21.57	22.73	19.10	43.33	34.21	34.30	44.84	49.93	31.50
Mean	28.17	36.98	38.23	33.07	52.96	48.93	47.65	53.92	58.27	44.24

	Production practices	Cropping systems	Interaction A	Interaction B
1996-97				
S.Ed.	0.44	0.23	0.71	1.37
CD (0.05)	0.93	0.47	1.41	2.80
CV (%)	16.19			
1997-98				
S.Ed.	0.50	0.29	0.89	1.69
CD (0.05)	1.07	0.59	1.77	3.44
CV (%)	10.84			

Note: A - For comparison of two sub-treatments at same level of main treatment
B - For comparison of two main treatments at the same or different levels of sub treatments

among production practices, cropping systems and their interaction effects for yield during both the years of stody under field and pot conditions.

Among production practices, IDM treatment recorded significantly higher yield (3.68 kg/plot) than other production practices. Seed dressing treatment (2.68 kg/plot) and Zn + GM (2.59 kg/plot) recorded greater yields followed by IDM treatment than other treatments. SD and Zn+GM were found to be on par with each other and significantly superior over control. However, all other production practices had also recorded significantly higher yield than control (0.49 kg/plot). During 1997-98 significant differences were found among the production practices and over control (Table 41).

Significantly more yield was observed with resistant pigeonpea ICP 8863 (2.13 kg/plot) than C11 (2.01 kg/plot) among the cropping systems studied. Sole cropped susceptible and resistant pigeonpea had resulted in significantly higher than intercropped pigeonpea with sorghum (2.13 and 2.01 kg/plot) and 2.53 and 2.36 kg/plot) during 1996-97 and 1997-98 years, respectively). In pigeonpea/sorghum cropping system ICP 8863/sorghum recorded greater yield (1.90 and 2.26 kg/plot) than C11/sorghum (1.78 and 2.10 kg/plot) during 1996-97 and 1997-98 years respectively. A study of interaction effects revealed IDM treatment recorded significantly greater yield over all other production practices and control under all the cropping systems. However SD and Zn+GM were found to be on par and significantly superior over control. All production practices were found to be significantly superior over control under all the cropping systems studied. Further, it was

Table 43: Effect of integrated disease management components in Vertisol on biomass of pigeonpea (g/plant) during *kharif* 1996-97 and 1997-98

Cropping systems	TREATMENTS								
	Control	Zn	GM	FYM	Zn+GM	Zn+FYM	FYM+GM	SD	IDM	Mean
1996-97										
C11	73	90	92	81	93	95	82	98	105	90
ICP 8863	81	90	93	89	96	96	92	102	109	94
C11/SOR	65	85	89	79	94	91	80	96	104	87
ICP 8863/SOR	69	87	91	79	91	95	81	98	105	88
Mean	72	88	91	82	93	94	84	98	106	90
1997-98										
C11	91	108	110	108	114	111	110	113	124	110
ICP 8863	95	110	113	108	118	117	115	118	128	113
C11/SOR	80	101	109	96	111	110	98	113	123	104
ICP 8863/SOR	82	102	109	97	112	116	99	113	123	106
Mean	87	105	110	102	114	114	105	114	124	108

	Production practices	Cropping systems	Interaction A	Interaction B
1996-97				
S.Ed.	1.3	0.5	1.6	3.3
CD (0.05)	2.8	1.0	3.1	6.8
CV (%)	18.1			
1997-98				
S.Ed.	1.8	0.6	1.9	6.6
CD (0.05)	3.9	1.3	3.8	9.7
CV (%)	19.2			

Note: A - For comparison of two sub-treatments at same level of main treatment
B - For comparison of two main treatments at the same or different levels of sub treatments

Table 44: *Effect of integrated disease management components in Vertisols in glass house on biomass of pigeonpea (g/plant) during kharif 1996-97 and 1997-98*

Cropping systems	TREATMENTS									
	Control	Zn	GM	FYM	Zn+GM	Zn+FYM	FYM+GM	SD	IDM	Mean
1996-97										
C11	71	82	90	81	92	93	85	93	99	87
ICP 8863	73	84	92	84	94	95	84	97	104	90
C11/SOR	53	63	69	63	70	73	66	75	82	68
ICP 8863/SOR	66	77	82	77	83	85	79	88	94	81
Mean	66	77	83	76	85	86	78	88	94	82
1997-98										
C11	81	90	99	90	100	99	94	100	107	95
ICP 8863	85	94	101	93	102	103	95	103	110	99
C11/SOR	67	77	82	77	81	82	78	84	91	80
ICP 8863/SOR	77	87	93	85	92	94	89	96	103	90
Mean	78	87	94	86	94	95	89	96	103	91

	Production practices	Cropping systems	Interaction A	Interaction B
1996-97				
S.Ed.	1.6	0.8	2.5	4.9
CD (0.05)	3.5	1.7	5.0	6.0
CV (%)	12.2			
1997-98				
S.Ed.	0.7	0.5	2.1	3.4
CD (0.05)	1.5	1.1	4.4	7.0
CV (%)	8.5			

Note: A - For comparison of two sub-treatments at same level of main treatment
B - For comparison of two main treatments at the same or different levels of sub treatments

found that application of Zn, GM and FYM had performed well under intercropping systems of both ICP 8863 and C11. A similar trend was also noticed for 1997-98 field study and during both the years of study in pots (Table 42).

4.5.2.8 Biomass

Biomass of pigeonpea was higher during 1997-98 (109 and 92 g/plant) than 1996-97 (90 and 82 g/plant) in field and pots respectively (Tables 43-44). Significant differences among production practices, cropping systems and their interaction effects for biomass during both the years of study under field and pot conditions were observed. Among production practices in field during 1996-97 (Table 43), IDM package had recorded significantly higher biomass (106 g/plant) than other production practices. However, all other production practices had also recorded significantly higher production of dry matter over control (72 g/plant).

Among cropping systems, cultivation of resistant pigeonpea has resulted in significant increase in the dry matter (94 g/plant) compared to moderately susceptible pigeonpea, C11 (90 g/plant). Sole cropping of C11 and ICP 8863 pigeonpea gave significantly higher production of dry matter, compared to intercropping with sorghum.

A study of the interaction effects had also revealed maximum biomass with the adoption of IDM treatment under all the cropping systems. However, adoption of other practices had also resulted in significantly maximum biomass than control under the various cropping systems. A similar trend was also noticed for the results of 1997-98 field study during both the years of study in pots (Table 44).

4.6 EFFECT OF ROOT EXUDATES ON *FUSARIUM UDUM*

Studies were undertaken with root exudates of nine crops groundnut, castor, soybean, sunflower, maize, greengram, cotton, sorghum and pigeonpea to their effects on conidial germination and radial growth of *Fusarium udum* and its antagonistic fungi in comparison to control (water), and the results are presented in Tables 45-46.

4.6.1 Conidial germination

Conidial germination of *Fusarium udum*, *Aspergillus* sp., *Penicillium* sp. and *Trichoderma* sp. in addition to total antagonistic fungi as effected by root exudates of different crops in comparison to control (water) are presented in Table 45.

4.4.1.1 Effect of root exudation *Fusarium udum*

The nine root exudates studied in the present investigation, root exudates of 6 crops significantly inhibited germination of conidia of *Fusarium udum* compared to control (water). In the case of remaining 2 crops, i.e., sorghum and pigeonpea the effect differed with the variety. In sorghum, the root exudates of hybrid (CSH9) inhibited conidial germination.

Table 45: Effect of root exudates of different crops on conidial germination of *Fusarium udum* and its antagonistic fungi

Crop	*Fusarium udum*		*Aspergillus sp.*		*Penicillium sp.*		*Trichoderma sp.*		Average antagonistic fungal conidial germination	
Groundnut	0.00	(0.00)	87.30	(69.12)	61.67	(51.75)	81.30	(64.38)	77.00	(61.40)
Castor	16.11	(23.66)	61.54	(51.67)	66.67	(54.73)	61.27	(51.51)	62.59	(52.29)
Soybean	29.63	(32.97)	58.96	(50.16)	63.43	(52.79)	61.67	(51.75)	61.82	(48.79)
Sunflower	31.88	(34.37)	52.78	(46.59)	49.44	(44.68)	69.50	(50.52)	54.87	(46.21)
Maize	35.93	(36.83)	66.11	(54.39)	72.50	(58.37)	55.56	(48.19)	61.76	(53.58)
Green gram	42.63	(40.76)	58.89	(50.12)	62.22	(51.99)	49.88	(44.93)	56.17	(51.92)
Cotton	79.26	(62.90)	69.05	(56.19)	76.19	(60.79)	77.53	(61.70)	75.01	(60.00)
Sorghum										
Local	71.48	(57.72)	28.15	(32.04)	57.07	(49.06)	38.19	(38.16)	30.33	(38.84)
Hybrid (CSH 9)	25.19	(23.69)	67.76	(55.40)	65.19	(53.84)	87.10	(68.95)	72.95	(58.66)
Pigeonpea										
Susceptible (ICP 2376)	86.07	(68.08)	22.78	(28.50)	48.89	(44.36)	39.81	(39.12)	38.35	(38.26)
Resistant (ICP 8863)	27.48	(31.62)	77.38	(61.23)	80.00	(63.43)	67.14	(55.02)	74.85	(59.90)
Control (Water)	68.29	(55.72)	35.00	(36.27)	50.00	(44.99)	51.85	(46.07)	52.15	(47.17)
S.Ed.		1.05		0.89		0.94		0.66		0.59
C.D. (0.05)		2.17		1.83		1.94		1.37		1.21
CV (%)		5.13		8.57		6.19		10.32		7.11

Note: Values in parenthesis are angular transformation values

The local variety enhanced the germination. In the case of pigeonpea, root exudates of resistant variety CP 8863 suppressed conidial germination. Whereas in susceptible variety ICP 2376 the germination was enhanced. In the case of groundnut, the trend was looking different from the other crops. Exudates of groundnut significantly suppressed germination of conidia of *F. udum* (0%). The root exudates of castor (16.11%), soybean (29.63%), sunflower (31.88%), maize (36.83%), greengram (42.63%), hybrid sorghum (25.19%) and resistant pigeonpea (ICP 8863) (27.48) had also recorded significant inhibition of conidial germination compared to control (68.29%).

4.4.1.2 Effect of root exudates on *Aspergillus* sp

The nine crop root exudates studied in the present study root exudates of seven crops significantly enhanced conidial germination of Aspergillus sp. Maximum enhancement of the conidial germination was found with exudates of groundnut (87.30%) and resistant pigeonpea (77.38%) compared to other crops (52.78-69.05%). In the case of remaining two crops ie., sorghum and pigeonpea the effect differed with the variety. The root exudates of hybrid sorghum (67.76%) and pigeonpea resistant variety ICP 8863 (77.38%) enhanced conidial germination. In case of susceptible pigeonpea variety ICP 2376 (22.78%) and local sorghum (28.15%) the germination was reduced. Among the crops, less conidial germination was found with the root exudates of sunflower (52.78%), greengram (58.89%) and soybean (58.96%).

4.4.1.3 Effect of root exudates on *Penicillium* sp.

All the nine crop root exudates significantly enhanced germination compared to control. Maximum increase in conidial germination of Penicillium sp. was found with the root exudates of resistant pigeonpea (80%) and cotton (76.19%). Root exudates of castor, maize and cotton significantly enhanced the conidial germination. The two varieties of sorghum and pigeonepea, hybrid sorghum (65.19%) and resistant pigeonpea (80%) showed maximum enhancement compared to local sorghum (57.07%) and susceptible pigeonpea (48.89%). The lowest enhancement in conidial germination was found with the exudates of sunflower (49.44%).

4.6.1.4 Effect of root exudates on Trichoderma sp.

All the nine crop root exudates significantly enhanced germination of *Trichoderma* over control. Maximum conidial germination was observed in the root exudates of hybrid sorghum (87.10%) and groundnut (81.30%) whereas the lowest enhancement was recorded in greengram exudates (49.88%). The effect of root exudates of different crops on conidial germination also differed with the variety. Of the two varieties of sorghum and pigeonpea, hybrid sorghum (87.10%) and resistant variety of pigeonpea (67.14%) showed maximum enhancement compared to local sorghum (38.19%) and susceptible pigeonpea variety (39.81%).

Table 46: Effect of root exudates of different crops on radial growth (cm) of *Fusarium udum* and its antagonistic fungi

Crop	*Fusarium udum*	*Aspergillus sp.*	*Penicillium sp.*	*Trichoderma sp.*
Groundnut	2.15	6.90	6.65	7.60
Castor	3.19	5.72	5.92	9.60
Soybean	4.90	5.70	5.75	5.71
Sunflower	3.75	5.50	4.17	4.57
Maize	2.95	5.75	5.00	6.40
Green gram	6.00	6.60	5.65	5.67
Cotton	5.20	6.80	7.25	7.62
Sorghum				
Local	6.77	4.77	4.47	4.87
Hybrid	2.75	6.75	5.75	8.15
Pigeonpea				
Susceptible	7.70	4.87	5.10	5.25
Resistant	1.75	8.00	7.82	7.90
Control	6.50	5.32	4.80	5.40
S.Ed.	0.06	0.02	0.04	0.07
C.D. (0.05)	0.13	0.04	0.09	0.14
CV (%)	3.89	5.76	4.13	5.09

4.6.1.5 Effect of crop root exudates on average conidial germination of three antagonistic fungal population

Out of the root exudates of 9 crops studied, eight crops significantly enhanced conidial germination of all the antagonistic fungi compared to control (52%). Maximum increase in conidial germination was found with the exidates of groundnut (77%) and cotton (75.01%) compared to other crops (54.87 to 62.59%). In the case of sorghum and pigeonpea, the effect differed with the variety. Root exudates of hybrid sorghum (72.95%) and resistant pigeonpea variety (74.85%) enhanced conidial germination. Susceptible pigeonpea variety and local sorghum recorded 38.35% and 30.39% conidial germination respectively. The lowest enhancement of conidial germination was found with the root exudates of sunflower (54.87%) and greengram (56.17%).

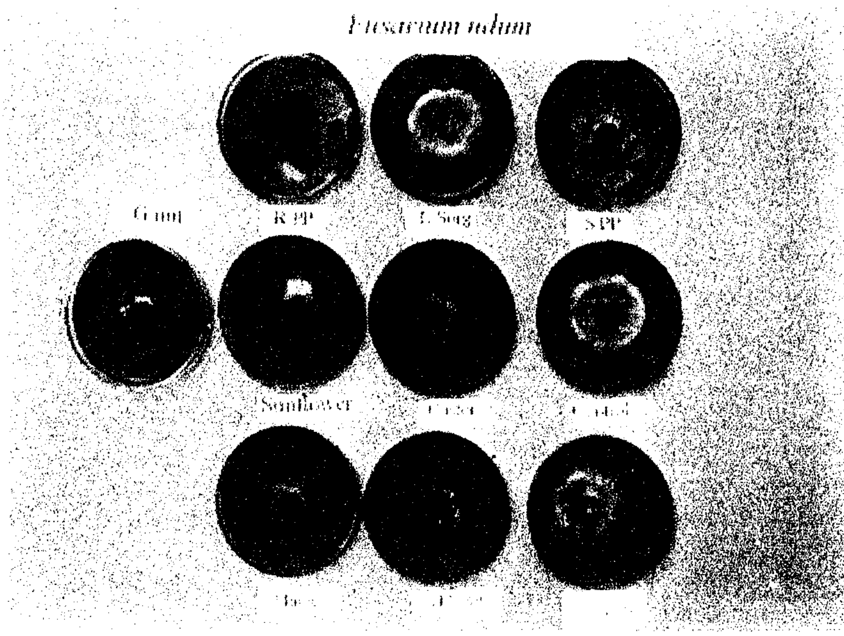
4.6.2 Radial growth of *Fusarium udum* and its antagonists

Radial growth of *Fusarium udum* and its antagonistic fungi, viz., *Aspergillus* sp., *Penicillium* sp. and *Trichoderma* sp., as influenced by root exudates of different crops, in comparision to control (water) are presented in Table 46.

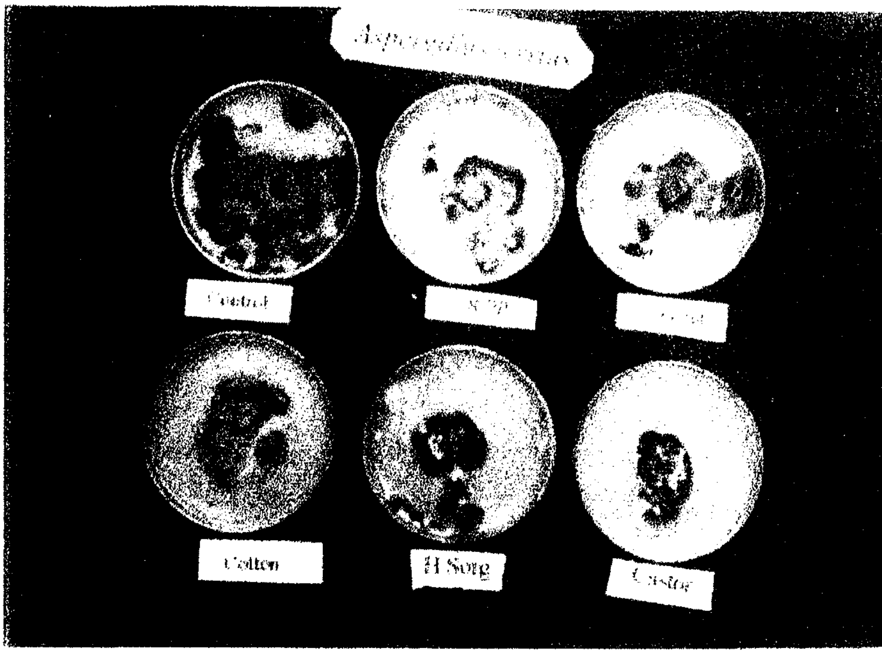
4.6.2.1 *Fusarium udum*

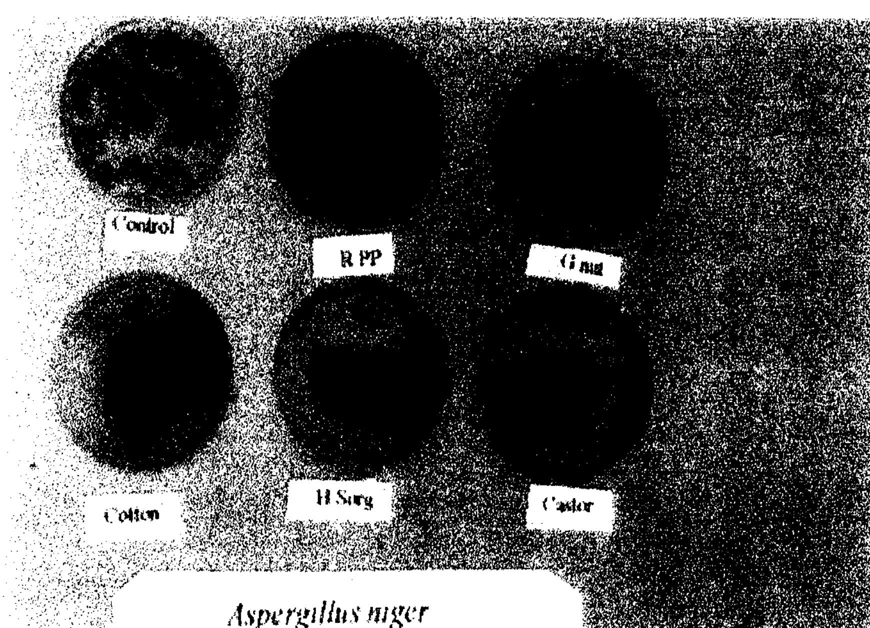
Radial growth of *Fusarium udum* ranged from 2.15 (groundnut) to 7.70 cm (susceptible pigeonpea) in root exudates of different crops. Root exudatess of groundnut (2.15 cm), castor (3.19 cm), soybean (4.90 cm),

Plate 45. Effect of Root exudates of different crops on radial growth of *Fusarium udum* and its *antagonistic fungi*



(a) *Fusarium udum*





(b) ***Aspergillus sp.***

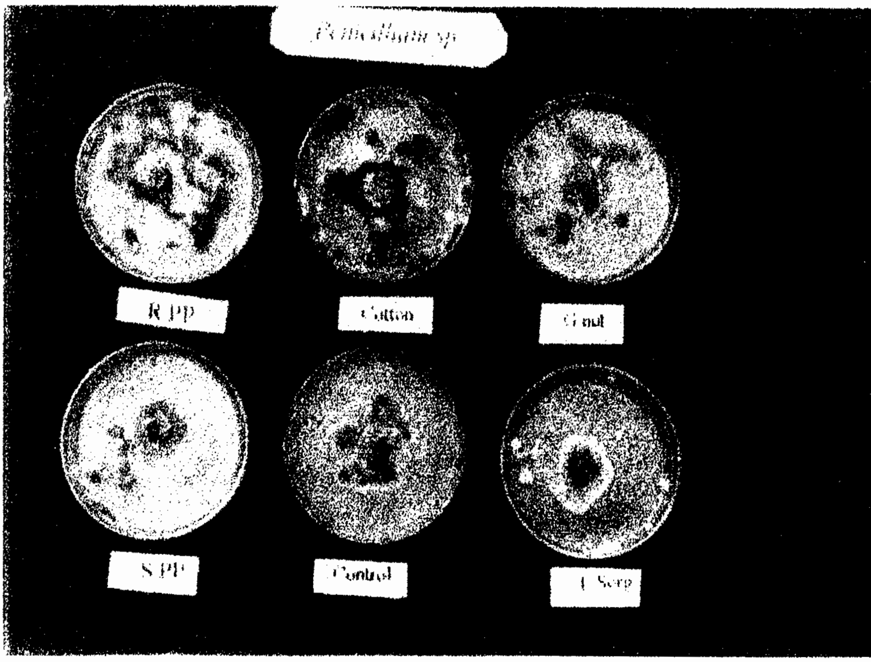
sunflower (3.75 cm), maize (2.95 cm), greengram (6.0 cm), hybrid sorghum (2.75 cm) and resistant pigeonpea (1.75 cm) had recorded significantly lower radial growth of the fungus than control (6.50 cm). In contrast, root exudates of local sorghum (6.77 cm) and susceptible pigeonpea (7.70 cm) had resulted in a significant promotion of radial growth of the pathogen, compared to control (6.50 cm) (Plate 45a).

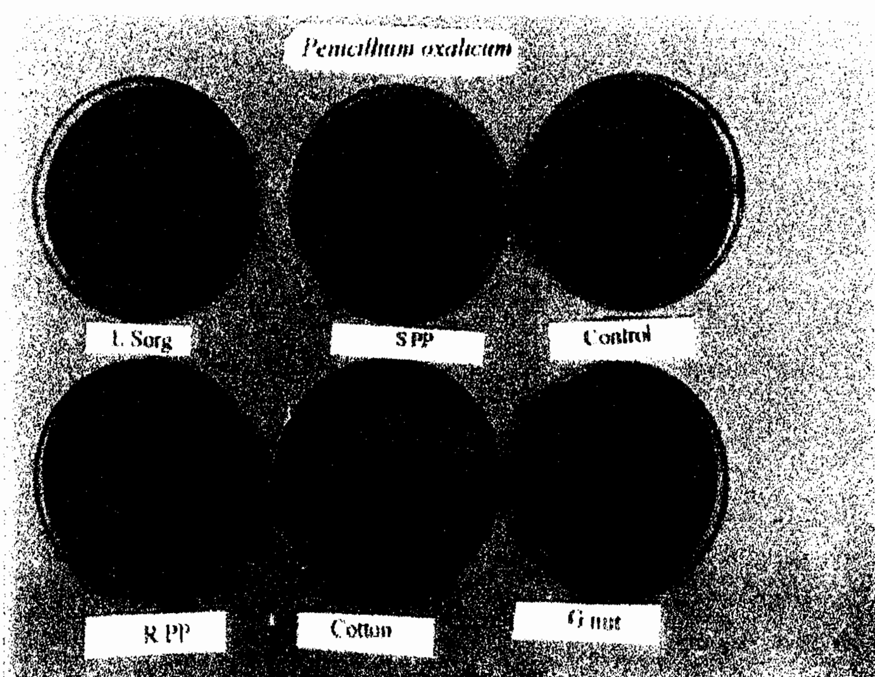
4.6.2.2 *Aspergillus* sp.

Radial growth of *Aspergillus* ranged from 4.77 (local sorghum) to 8.00 cm (resistant pigeonpea) for root exudatess of different crops. Root exudates of groundnut (6.90 cm), castor (5.72 cm), soyabean (5.70 cm), sunflower (5.50 cm), maize (5.75 cm), greengram (6.60 cm), cotton (6.80 cm), hybrid sorghum (6.75 cm) and resistant pigeonpea (8.00 cm) had recorded significantly higher radial growth of the fungus than control (5.32 cm). In contrast, root exudatess of local sorghum (4.77 cm) and susceptible pigeonpea (4.87 cm) had recorded significantly lower radial growth of the fungus than control (Plate 45b).

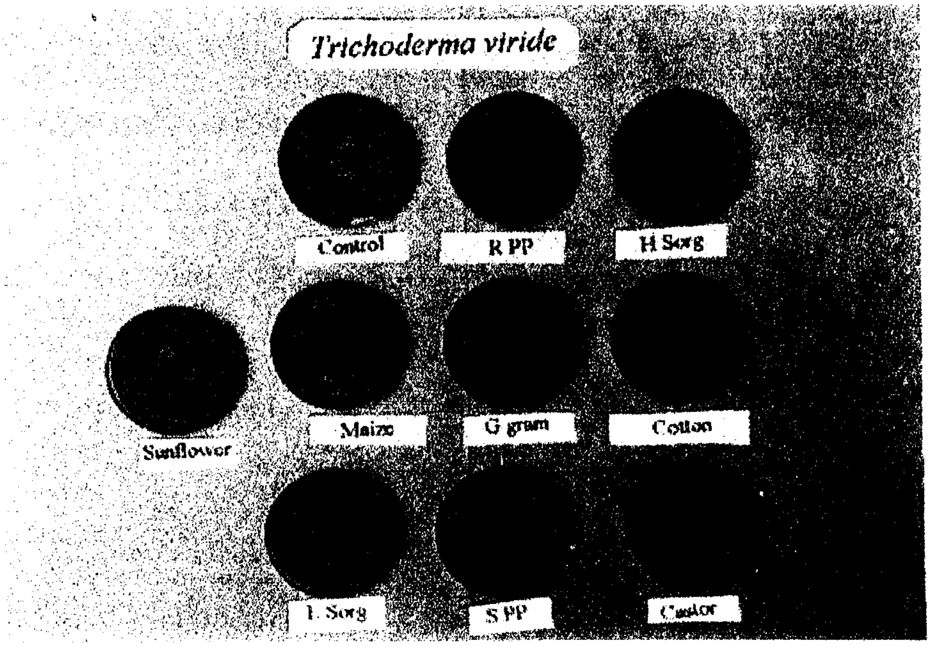
4.6.2.3 *Penicillium* sp.

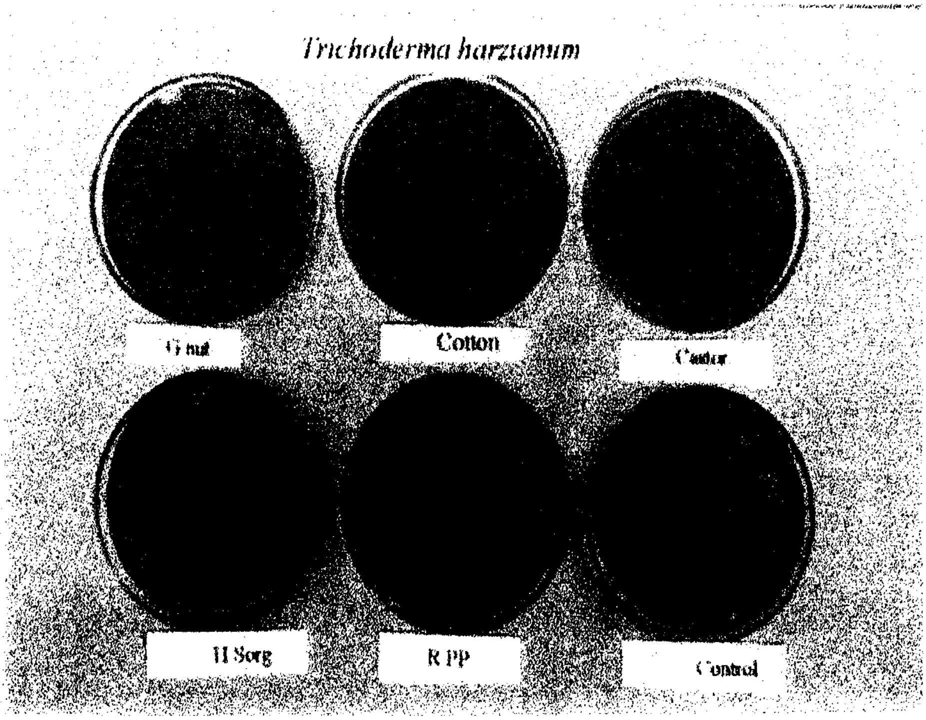
The fungal radial growth ranged from 5.10 (susceptible pigeonpea) to 7.82 cm (resistant pigeonpea) with root exudates of different crops. Root exudates of groundnut (5.70 cm), castor (5.92 cm), soybean (5.65 cm), maize (5.81 cm), greengram (5.65 cm), cotton (7.25 cm), susceptible pigeonpea (5.10 cm), hybrid sorghum (5.75 cm) and resistant pigeonpea





(c) *Penicillium sp.*





(d) *Trichoderma sp.*

(7.82 cm) had recorded significantly higher radial growth of the fungus than control (4.80 cm). In contrast, root exudates of local sorghum (4.47 cm) and sunflower (4.17 cm) had recorded significantly lower radial growth of the fungus than control (Plate 45c).

4.6.2.4 *Trichoderma* sp.

Radial growth of the fungus ranged from 4.57 cm (sunflower) to 8.15 cm (hybrid sorghum) for root exudates of different crops. Root exudates of groundnut (7.60 cm), castor (7.60 cm), soybean (5.71 cm), greengram (5.67 cm), maize (6.40 cm), cotton (7.62 cm), hybrid sorghum (8.15 cm) and resistant pigeonpea (7.90 cm) and had recorded significantly higher radial growth of the fungus than control (5.40 cm) (Plate 45d). In contrast, root exudates of sunflower (4.57 cm) and local sorghum (4.87 cm) and susceptible pigeonpea (5.25 cm) had recorded significantly lower radial growth of the fungus. Root exudates of groundnut and castor were found to be on par with each in the promotion of radial growth of the fungus.

4.7 ECONOMICS OF INTEGRATED DISEASE MANAGEMENT (IDM) TECHNOLOGY FOR PIGEONPEA WILT

Profitability is one of the most important factors influencing the decision making of the farmer in his farming programmes and activities. Profitability depends not only on yield increase but also on costs incurred on various items in the cultivation of crops, the prices of the produce, the gross and net returns. Hence, economic analysis becomes necessary to assess the profitability of the whole crop or technology package or on component of a technology. Hence an attempt is made to study the economics of IDM technology vis-a-vis non IDM (control).

4.7.1 Economics of IDM for pigeonpea in Alfisols (pigeonpea and pigeonpea/groundnut)

4.7.1.1 Economics for pigeonpea

The particulars of the treatments with average yields, costs, gross and net returns are presented in Table 47. It is noted from the data that in case of sole pigeonpea, maximum net returns of Rs.7770 benefit cost ratio of 2.08 obtained with IDM treatment. This was followed by GM with a net returns of Rs.3222 and benefit cost ratio of 1.01. It was observed that the use of FYM alone resulted in low net returns of Rs.328 and benefit cost ratio 0.07, but when it was used in combination with other treatments resulted in maximisation of net returns and benefit cost ratio i.e., in IDM treatment. Untreated check recorded negative net returns of Rs.-748 with a benefit cost ratio of -0.29.

Groundnut crop was used as an intercrop with pigeonpea with the same treatments in intercropping system. C11/groundnut system with IDM treatments resulted in maximum net returns of Rs.3291 and benefit cost ratio of 1.11 than with other treatments. The next best treatment was found to be green manuring with C11/groundnut in increasing the net returns and benefit cost ratio of Rs.994 and 0.37, respectively. Intercropping of pigeonpea with groundnut without any added inputs recorded low net returns and gross

Table 47: Economics of integrated disease management package for pigeonpea wilt in Alfisols

Treatments	Average yield (kg/ha)	Cost of cultivation (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	Benefit-Cost ratio
C11	81	2530	1782	-748	-0.29
C11+ GM	291	3180	6402	3222	1.01
C11+ FYM	210	4292	4620	328	0.07
C11+ IDM	523	3736	11506	7770	2.08
C11/ Gnut	87	2355	1914	-441	-0.18
C11/ Gnut + GM	167	2680	3674	994	0.37
C11/ Gnut + FYM	176	3236	3872	636	0.19
C11/ Gnut + IDM	284	2957	6248	3291	1.11

Note: GM - Green manure
FYM - Farm yard manure
IDM - GM + FYM + seed dressing with Bavistin + Thiram + Trichoderma
G'nut - Groundnut

returns. IDM treatment and green manuring found to be highly beneficial either in the sole or intercropped pigeonpea with groundnut. The gross returns were maximum in both production practices IDM and GM under both the cropping systems. However, it is also beneficial to grow C11/ groundnut with FYM treatment than sole crop with the same treatment as the benefit cost ratio was high in intercropping system inspite of wilt control. It is also profitable to farmer to grow pigeonpea with groundnut with any added inputs i.e., in check with high benefit cost ratio and low gross returns.

4.7.1.2 Economics of IDM in Alfisols for groundnut in pigeonpea/ groundnut system

The economics of pigeonpea as a base crop have already been presented and discussed. Presently the economics of groundnut as an intercrop are discussed in the following paragraph (Table 48).

As already indicated that the added costs are taken into account. These costs covered the seed cost, cost green manure, farm yard manure and the cost of IDM including cost of cultivation. It was observed from the Table 48 that the gross returns of C11/Groundnut system (control) worked out to Rs.4,920 while the net returns amounted to Rs.1,135. The BC ratio was worked out to 0.29.

Green manuring was added in this trial. The cost amounted to Rs.4,110/- while the gross returns and net returns worked out to Rs.8,775 and Rs.4,665 and the BC ratio was 1.13. In the farm yard manure treatment

Table 48: Economics of groundnut intercrop in Alfisols

Treatments	Average yield (kg/ha)	Cost of cultivation (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	Benefit cost ratio
C11/Groundnut	328	3785	4920	1135	0.29
C11/Gnut+GM	585	4110	8775	4665	1.13
C11/Gnut+FYM	515	4666	7725	3059	0.65
C11/Gnut+IDM	709	4387	10635	6248	1.42

the cost worked to Rs.4,666. The gross returns and net returns amounted to Rs.7,725 and Rs.3,059, respectively and the BC ratio was 0.65.

IBM treatment was found to be the increasing the net returns and gross returns of Rs.6248 and Rs.10635, respectively. The benefit cost ratio was 1.42. It may be inferred that the IDM treatment was the most profitable agricultural practice which may be adopted by farmer.

4.7.2 Economics of IDM for pigeonpea in Vertisols (pigeonea and pigeonpea/sorghum

4.7.2.1 Economics of individual treatments

Three individual treatments followed in Vertisols field experiment viz., Zinc sulphate, green manuring and farm yard manure for the year 1996-98 are given in Table 49. The average yields ha^{-1} and the returns for monetary terms for two years are presented in Table. Moderately susceptible pigeonpea C11 resistant pigeonpea ICP 8863 were the sole crops while C11/ sorghum and ICP 8863/sorghum were the intercrops analysed. It is obvious from the Table 49 that application of green manure and resistant pigeonpea alone and in combination with sorghum gave the highest net returns of Rs.4867 and Rs.4207 with the benefit cost ratio of 1.6 and 1.4 respectively. Similarly the ICP 8863 sole crop and intercrop in combination with green manuring treatment gave the highest gross returns and net returns but high benefit cost ratio with intercrop i.e., 1.6.

In the treatments with the application of Zn, the highest net returns were obtained with the ICP 8863 worth Rs.2,885 and Rs.3,454, respectively

Table 49: Economics of integrated disease management package for pigeonpea wilt in Vertisols

Production practices	Cropping systems	Average yield (kg/ha)	Gross returns (Rs/ha)	Cost of cultivation (Rs/ha)	Net returns (Rs/ha)	Benefit cost ratio (Rs/ha)
S.D	C11	656	14432	2485	11947	4.8
	ICP 8863	680	14960	2485	12475	5.0
	C11/ sorghum	552	12144	2368	9776	4.1
	ICP 8863 / sorghum	588	12936	2368	10568	4.4
IDM	C11	919	20218	3730	16488	4.4
	ICP 8863	970	21340	3730	17610	4.7
	C11/ sorghum	713	15686	2996	12690	4.2
	ICP 8863 / sorghum	767	16874	2996	13878	4.6
Zn + GM	C11	600	13200	2834	10366	3.6
	ICP 8863	644	14168	2834	11334	3.9
	C11/ sorghum	520	11440	2727	8720	3.1
	ICP 8863 / sorghum	556	12232	2727	9505	3.4
Zn + FYM	C11	544	11968	3470	8498	2.4
	ICP 8863	538	11836	3470	8366	2.4
	C11/ sorghum	491	10802	3363	7439	2.2
	ICP 8863 / sorghum	494	10868	3363	7565	2.2
FYM + GM	C11	530	11660	3601	8059	2.2
	ICP 8863	527	11594	3601	7993	2.2
	C11/ sorghum	488	10736	3494	7242	2.0
	ICP 8863 / sorghum	473	10406	3494	6912	1.9
GM	C11	326	7172	2965	4207	1.4
	ICP 8863	356	7832	2965	4867	1.6
	C11/ sorghum	264	5808	2573	3235	1.2
	ICP 8863 / sorghum	309	6798	2573	4225	1.6
Zn	C11	218	4796	2703	2005	0.74
	ICP 8863	277	6094	2703	2885	1.1
	C11/ sorghum	233	5126	2596	2750	1.0
	ICP 8863 / sorghum	320	7040	2596	3454	1.3
FYM	C11	214	4708	4236	472	0.11
	ICP 8863	254	5588	4236	1352	0.31
	C11/ sorghum	242	5346	4129	1217	0.29
	ICP 8863 / sorghum	275	6050	4129	1921	0.46
Control	C11	97	1843	2215	-372	-0.16
	ICP 8863	118	2242	2215	27	0.01
	C11/ sorghum	117	2223	2108	115	0.05
	ICP 8863 / sorghum	126	2394	2108	286	0.13

Note: Zn - Zinc sulphate; FYM - Farm yard manure; GM - Green manure;
S.D. - Seed dressing; IDM - Zn + GM + FYM + Seed dressing with Bavistin + Thiram + *Trichoderma*

with the benefit cost ratio of 1.10 and 1.33, respectively under both sole and intercropping system as it recorded maximum net returns of Rs.1,921 and benefit cost ratio of 0.46. In view of low cost of green manuring, the benefit cost ratio was very high and due to high cost of FYM the same ratio was very low in the treatment with FYM under the same cropping systems with the same varieties. Hence there is need to reduce the same at the subsistence level of farming. The above anlysis indicated that green manuring for ICP 8863 and C11 under both sole and intercropping systems would be beneficial. In all the three treatments the net returns from the resistant variety were higher when compared to sole and intercropping sytems of tolerant variety.

4.7.2.2 Economics of different treatment combinations

The details of various treatment combinations are given below.

1. Zinc + FYM
2. Zinc + GM
3. FYM + GM
4. SD
5. IDM
6. Control

It is evident from the Table 49 that IDM treatment in combination with ICP 8863 and C11 had recorded maximum net returns of Rs.17,610 and Rs.16,488 with a benefit cost ratio of 4.7 and 4.4, respectively under sole cropping system. Similar trend was observed with intercropping systems of both cultivars. Seed dressing treatment in combination with tolerant cultivar gave the highest net returns of Rs.11,947 and Rs.9,776 under both sole and intercropped pigeonpea with benefit cost ratio of 4.8 and 4.1 because the cost involved on this treatment was very marginal. The next best treatment Zn+GM recorded maximum net returns of Rs.10,366 and Rs.11,947 under both sole and intercropped pigeonpea C11, respectively followed by SD. However, application of Zn+FYM and FYM+GM were also found to be beneficial with highest net returns and benefit cost ratio in pigeonpea/ groundnut systems. It is also found that the net returns were higher in case of combination of treatments than the individual application of Zn, GM and FYM. Application of Zn and GM alone does not yield highest net returns but in combination resulted in highest net returns and benefit cost ratio. Resistant variety yielded the highest net returns either with the individual components or with the combination of components when compared to the tolerant variety and ICP 8863/Sorghum and C11/Sorghum.

Next to IDM and SD treatments, application of Zn+GM was found to be beneficial with highest net returns than in all other treatments under both cropping systems. The cost of FYM was found to be higher that the cost of Zn, GM and SD and so returns were less with application of Zn+FYM and FYM+GM. The cost of SD was minimum and thus the net returns and benefit cost ratios were high. Regarding the control where the same varieties in monocropping and intercropping systems were used, ICP 8863 yielded the highest net returns followed by ICP 8863/Sorghum. But the negative net returns and benefit ratio of 0.05 in sole C11 was observed.

The data from Table 49 indicated that all the treatments with Zn, GM and combination of treatments Zn+FYM, Zn+GM and FYM+GM, SD and IDM gave the highest gross returns and net returns. Among the individual treatments GM and Zn followed by FYM yielded the highest gross returns. The only exception was with FYM in combination with ICP 8863/Sorghum gave the highest the net returns than with C11. Among the combination of treatments,SD and IDM was to be very effective in reducing wilt incidence in intercropped pigeonpea and beneficial in increasing the net returns. Thus it brings out the importance and significance of seed dressing and IDM in the cultivation of pigeonpea and control of wilt disease. It was also noted that IDM treatment was effective and beneficial with highest gross returns and net returns than all other practices but with a slight decline in benefit cost ratio because of high cost of FYM. Hence the cost of FYM will have to be brought down if IDM has to become popular. It is further suggested that alternative to FYM will have to be found for effective IDM. Vermicompost may replace the same as one of the components in IDM package. The farmers can use their own inputs of FYM and this need be valued, if this component is not valued at market price, IDM will become highly beneficial for sustainable agriculture.

4.7.2.3 Economics of IDM in Vertisols for sorghum in pigeonpea/ sorghum system

The economics of pigeonpea as base crop have already been presented and discussed. Presently the economics of sorghum as an intercrop are discussed in the following paragraphs.

Table 50: Economics of sorghum intercrop in Vertisols

Production practices	Cropping systems	Average yield (kg/ha)	Gross returns (Rs/ha)	Cost of cultivation (Rs/ha)	Net returns (Rs/ha)	Benefit cost ratio (Rs/ha)
SD	C11/ sorghum	846	7614	2534	5080	2.00
	ICP 8863 / sorghum	829	7461	2534	4927	1.94
IDM	C11/ sorghum	1427	12843	3162	9681	3.06
	ICP 8863 / sorghum	1751	11043	3162	7881	2.49
Zn+GM	C11/ sorghum	1229	11061	2719	8342	3.06
	ICP 8863 / sorghum	1199	10791	2719	8072	2.96
Zn+FYM	C11/ sorghum	1239	11151	3037	8114	2.67
	ICP 8863 / sorghum	1196	10764	3037	7727	2.54
FYM+GM	C11/ sorghum	1181	10629	3102	7527	2.42
	ICP 8863 / sorghum	1177	10593	3102	7491	2.41
GM	C11/ sorghum	1077	9693	2784	6909	2.48
	ICP 8863 / sorghum	1080	9720	2784	6936	2.49
Zn	C11/ sorghum	1068	9612	2653	6959	2.62
	ICP 8863 / sorghum	934	8406	2653	5753	2.16
FYM	C11/ sorghum	974	8766	3420	5346	1.56
	ICP 8863 / sorghum	1018	9162	3420	5742	0.59
Control	C11/ sorghum	772	6948	2534	4414	1.74
	ICP 8863 / sorghum	761	6849	2534	4315	1.70

Note: Zn - Zinc sulphate; FYM - Farm yard manure; GM - Green manure;
S.D. - Seed dressing; IDM - Zn + GM + FYM + Seed dressing with Bavistin + Thiram + *Trichoderma*

It is observed from the Table 50 that the application of green manure andresistant pigeonpea in combination with sorghum gave the highest net returns of Rs.6,936with benefit cost ration of 2.49. Similarly the variety C11 in combination with sorghum performs well with the application of zinc sulphate with net returns and fit cost ratio of Rs.6,959 and 2.62, respectively. Among the individual treatments application of green manure and zinc sulphate were found better in increasing the net and gross returns than FYM. It is also beneficial to apply FYM in intercropping system of ICP 8863 as it recorded maximum net returns of Rs.5,742.

Among the combination of treatments, IDM treatment had recorded highest gross returns of Rs.12,843 and Rs.11.043 with C11/Sorghum and ICP 8863/Sorghum, respectively when compared to other practices. Highest benefit cost ratio was found with application of IDM treatment under C11/Sorghum system ie., 3.06. Zn+GM recorded highest net returns of Rs.8,342 and Rs.8,072 with C11 and ICP 8863, respectively followed by IDM. However, Zn+FYM and FYM+GM were also found to be beneficial with highest net returns. It is also found that the net returns were higher in combination of treatments than the individual application of Zn, GM and FYM. Application of Zn and GM alone does not yield the highest net returns but used in combination resulted in highest net returns. Tolerant pigeonpea variety C11 yielded the highest net returns with the combination of treatments when compared to ICP 8863 variety. Hence it is beneficial to adopt IDM with C11/Sorghum or ICP 8863/Sorghum and also Zn+GM and Zn+FYM in combination with tolerant C11/Sorghum.

Regarding the control and SD where the same varieties with out any added inputs. Even the tolerant pigeonpea/Sorghum yielded slightly highest net returns, but the gross returns from control were low.

The above analysis indicate that all the treatments Zn, GM and combination of treatments gave the highest gross returns and net returns. IDM treatment was found beneficial in monetary terms when compared with all other treatments. Thus the above analysis brings out the beneficial and significance of IDM in the cultivation of pigeonpea and control of wilt.

DISCUSSION

CHAPTER V

DISCUSSION

Pigeonpea (*Cajanus cajan* (L.) Mill.sp.) is an important pulse crop, grown widely in the Indian subcontinent. However, its yields are relatively low owing to lack of proper crop management and susceptibility to diseases and pests.

Fusarium wilt is one of the major constraints for low productivity of pigeonpea in India. The disease is wide spread and is known to occur in all major pigeonpea growing areas of the country (Reddy *et al.*, 1990). Fungicidal management of the disease has been reported to be dificult, impractical and uneconomical (Songa, 1990). Therefore, an integrated approach involving combination of cultural, chemical, host plant resistance and biological methods, aimed at reduction of inoculum levels of pathogen coupled with concomitant increase in the antagonistic fungal populations is necessary for effective management of the disease.

Integrated disease management has also been reported to be quite effective for control of soil borne plant pathogens (Upadhyay and Rai, 1989) especially for *furasium* wilt in potato (Srivastava and Saxena, 1968) *chrysanthemum* (Locke *et al.*, 1985), musk melon (Chattopadhyay and Sen, 1996), Snap beans (Silbernagel and Mills, 1990) and chickpea (Upadhyay and Mukhopadhyay, 1986). The present investigations were undertaken in this context to study the efficacy of different control measures towards formulation of an effective integrated *fusarium* wilt management strategy in pigeonpea.

5.1 PIGEONPEA WILT PATHOGEN

5.1.1 Isolation and identification of the pathogen

The fungus was isolated from infected plants showing wilt symptoms and single spore scultures were maintained on PDA. The fungus produces hyaline mycelium, slender, much branched usually with little aerial growth. Microconidia produced on short branched conidiophores. Conidia are aspectate hyaline and elliptical. Macroconidia are borne on conidiophores and they are 3-5 septate fulcate with a distinct foot cell and curved tips. The morphology of the pathogen observed was in accordance with the descriptions given by Holliday (1980).

5.1.2 Pathogenicity

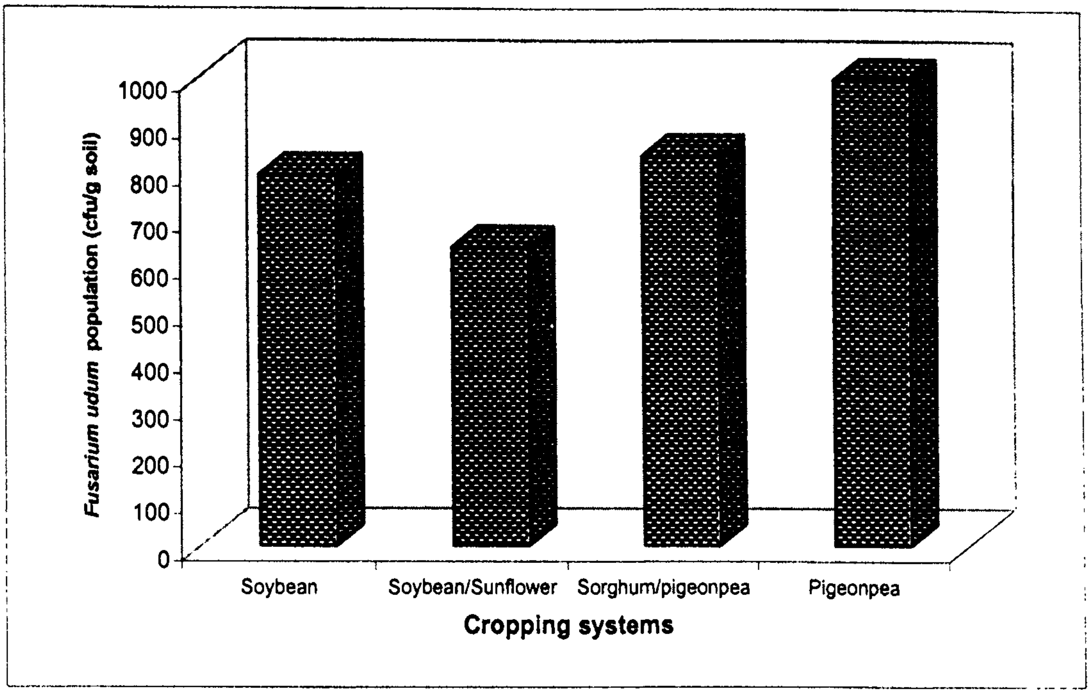
Root dip inoculation technique was adopted for pathogenicity test in three varieties of pigeonpea viz., ICP 2376 (susceptible), C11 (tolerant) and ICP 8863 (resistant). 100 per cent infection of seedlings was observed in the susceptible variety, ICP 2376 with 1-2 week age old inoculated plants, while in C11 variety, 25-50 per cent mortality was observed. In the resistant variety, ICP 8863 only 10-20 per cent mortality was found. Further, wilting was seen upto 2 week age old inoculated plants in the resistant variety and upto 6 week age old inoculated plants in the susceptible and tolerant cultivars. Similar higher levels of fusarium infection upon inoculation of young plants (2 to 4 weeks age old) were reported earlier in pigeonpea (Nene *et al.*, 1980) and Celery (Hart and Endo, 1980).

5.2 SYMPTOMATOLOGY

The disease appeared from 2-3 months stage of crop growth. Initial visible symptoms of the disease included loss of leaf turgidity, intervinal clearing and chlorosis of leaves. Similar type of symptoms due to wilt pathogen in pigeonpea have been reported by Upadhyay and Rai (1989). Symptoms on grown up plants appeared as brown to dark purple bands on the stem surface extending from the base of the plant. The other characteristic symptom of wilt observed at advanced stage of plant growth was browning of the stem below the purple band and browning or blackening of the xylem. Dieback symptoms were also observed on the affected branches extending from the tip downwards, and intensive internal xylem blackening. Patches of dead plants in the wilt infested fields were observed usually when the crop was at flowering or podding. Similar type of symptoms were reported earlier in pigeonpea by Reddy *et al.* (1990). Partial wilting associated with lateral and tap root infection of the plants was also found during advanced stages of plant growth in confirmity with descriptions made by Upadhyay and Rai (1992). The presence of brown to dark purple band on the main stem, partial wilting of the plants, withering and drying of green parts of young and old plants were found to be characteristic symptoms for identification of *fusarium* wilt disease.

5.3 EFFECT OF SOME CROPPING SYSTEMS AND N SOURCES AND LEVELS ON *Fusarium udum* AND ANTAGONISTIC FUNGI

The present investigation on the effect of different N sources and levels revealed that application of 40 kg N ha^{-1} as KNO_3 resulted in maximum reduction of wilt pathogen population (Table 6 and Fig. 5). Application of 20 kg N ha^{-1} through KNO_3 (7.7 cfu/g soil) and 20 kg N ha^{-1} as FYM + 20 kg N ha^{-1} as KNO_3 (727 cfu/g soil) were also effective in inhibiting pathogen population. Application of potassium containing fertilizers had also reduced the severity of *Fusarium* wilt in cotton muskmelon, (Wensley and McKeen, 1965; Ramaswamy and Prasad, 1974) and several other crops (McNew, 1953; Chesler, 1964; Kannaiyan and Prasad, 1974; Srihuttagum and Sivasithanparam, 1991; Chattopadhyay and Sen, 1996). The reduction in pathogen population may also be attributed to the lysis of fungal mycelium and low levels of chlamydospore production in the nitrogen amended soils. Reduced chlamydospore production of *Fusarium oxysporium* f. sp. *ciceri* due to nitrate application in sandy soils (28%) and black soils (25%) was also reported by Satyaprasad and Rama Rao (1983). Similarly, Vinaysagar and Sugha (1998) and Gallegly and Walker (1999) reported reduction in root rot disease caused by *Fusarium oxysporium* f. sp. *pisi* and *R. oxysporium* f. sp. *lycopersici* in peas and tomato, respectively with the application of nitrate and nitrate nitrogen. Huber and Watson (1974) had also cited several examples like reduced damping off of seedlings, and root and cortical rots caused by *Fusarium* sp. with the application of nitrate nitrogen.



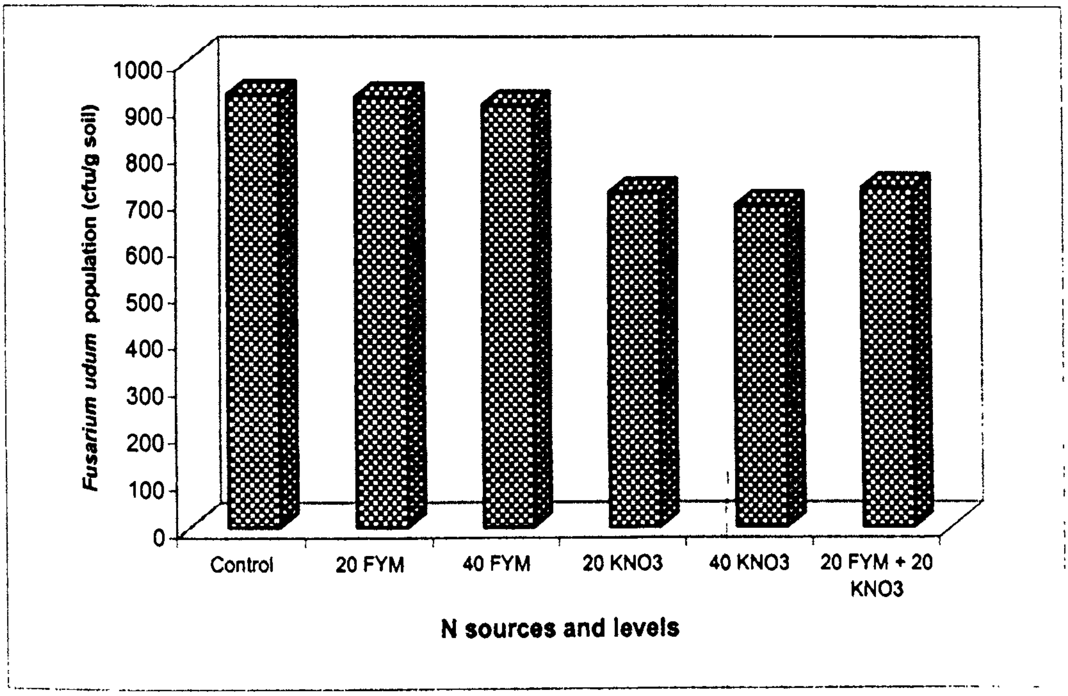
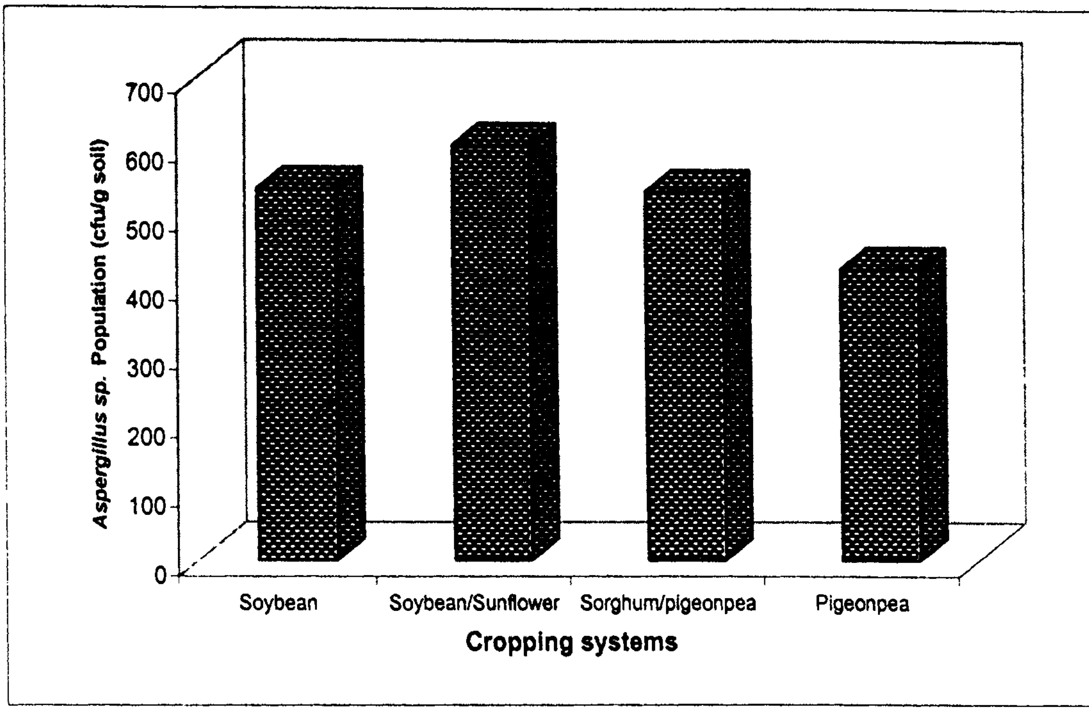


Fig.5: Effect of some cropping systems and N sources and levels on pieonpea wilt pathogen *Fusarium udum* population (cfu/g soil)

Cropping systems had also resulted in a significant reduction in the pathogen population levels, compared to control. Soybean/sunflower cropping system had resulted in minimum pathogen population (636 cfu/g soil) followed by sorghum/pigeonpea system (834 cfu/g soil) compared to sole pigeonpea (996 cfu/g soil). Intercropping of pigeonpea with sorghum was also reported earlier to result in lowered fusarium population (Bhatnagar, 1995 and Naik *et al.*, 1997). Gupta (1961) had also reported considerable wilt control with pigeonpea and sorghum mixed cropping. The beneficial effects of intercropping systems observed in the present study may be attributed to the inhibitory effects of root exudates of non-host crops (Table 45 Fig. 44) and increased antagonistic fungal population (Table 10 and Fig. 9).

A study of the interactive effects of the cropping systems and N sources and levels had revealed minimum levels of pathogen population under sunflower/soybean cropping system with application of 40 kg N ha^{-1} through KNO_3. However, other N sources and levels such as 20 kg N ha^{-1} as KNO_3, 20 kg N ha^{-1} as FYM in combination with 20 kg N ha^{-1} as KNO_3 were also found to significantly reduce the population. However, application of nitrogen through FYM (20 kg N ha^{-1} and 40 kg N ha^{-1}) was found to be effective only under sole cropped pigeonpea and soybean. While 20 kg N ha^{-1} through FYM applied in combination with 20 kg N ha^{-1} as KNO_3 was effective for monocropping of pigeonpea and soybean, in addition to pigeonpea/sorghum intercropping system. Integrated application of fertilizer and FYM coupled with intercropping system provide favourable environment



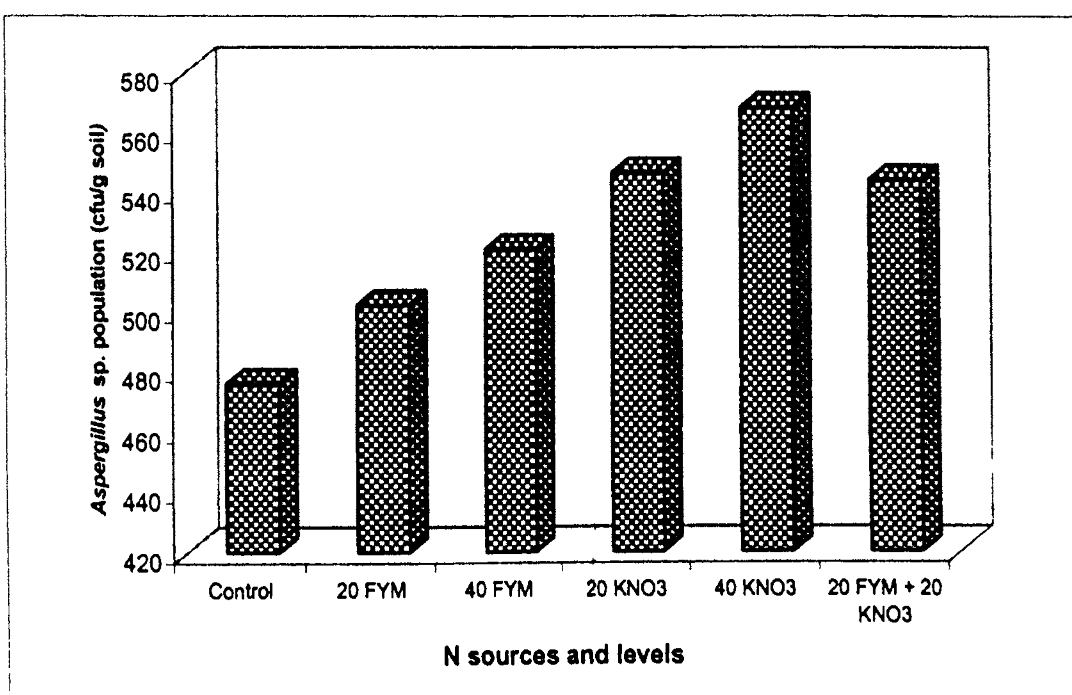
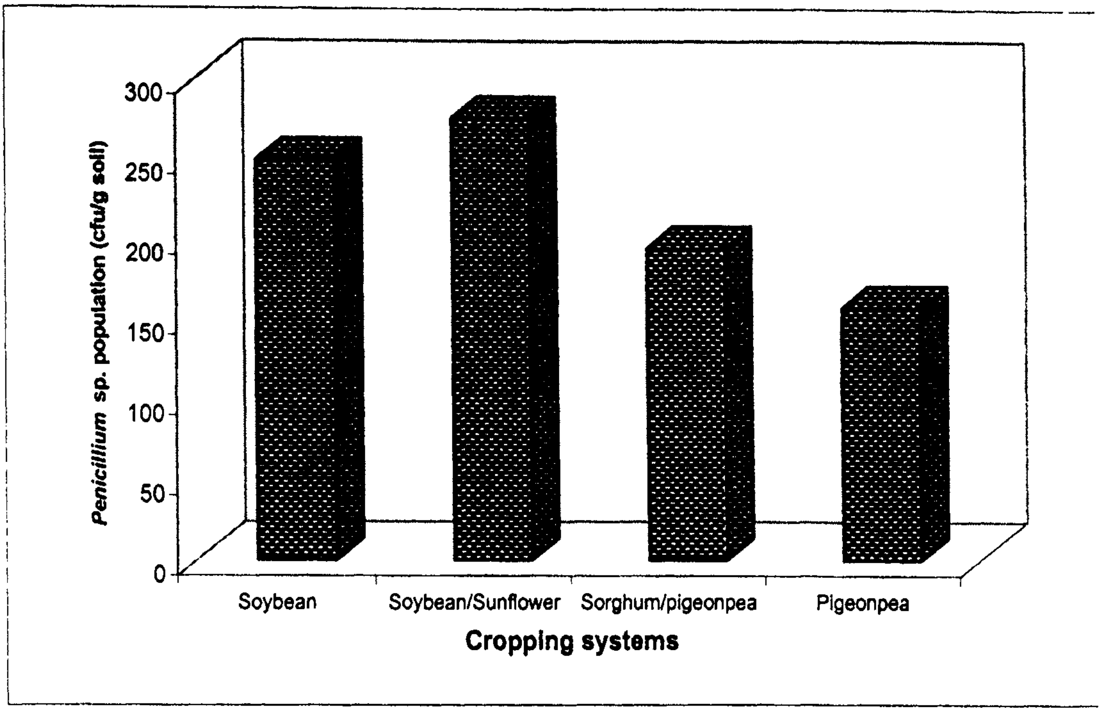


Fig.6: Effect of some cropping systems and N sources and levels on *Aspergillus* sp. population (cfu/g soil)



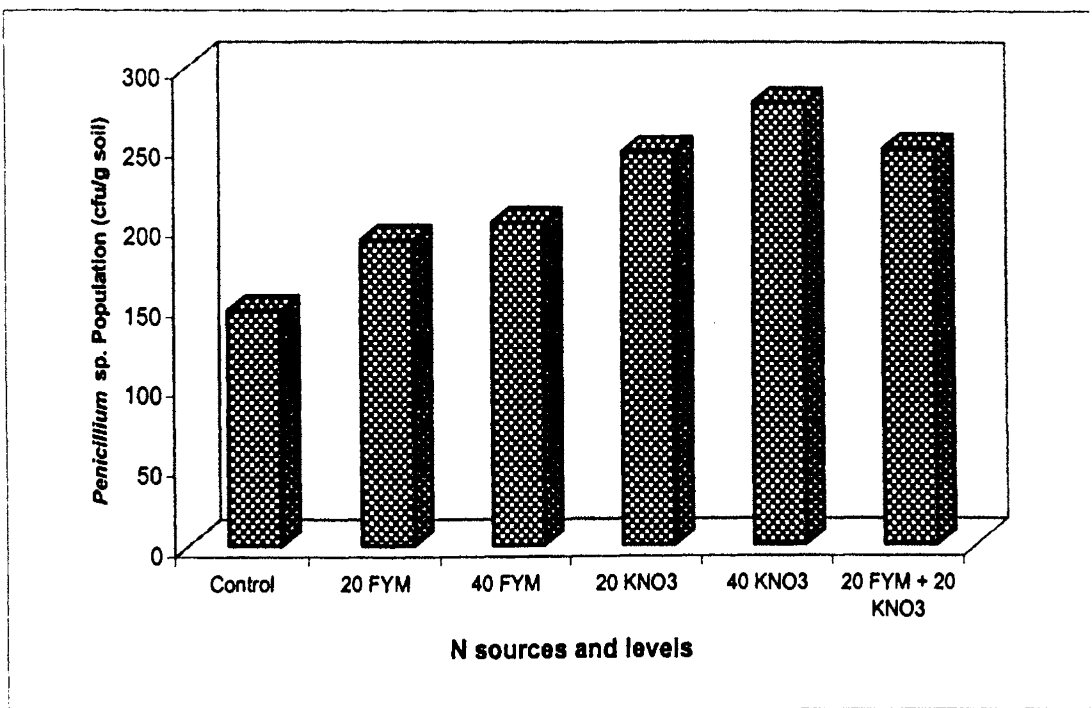
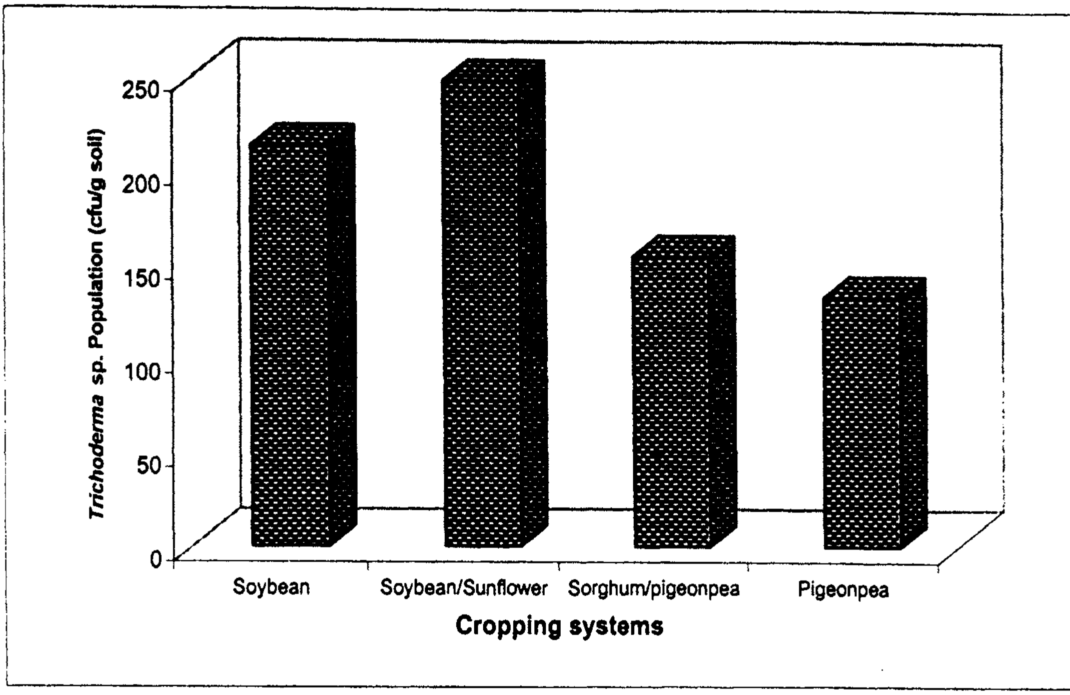


Fig.7: Effect of some cropping systems and N sources and levels on *Penicillium* sp. population (cfu/g soil)



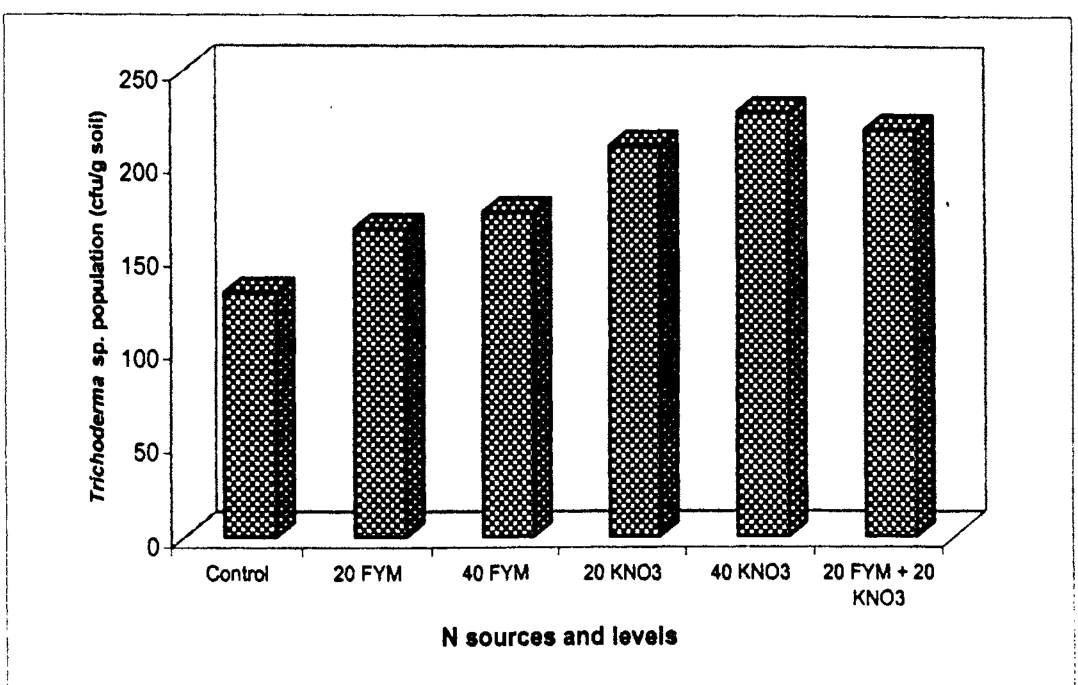
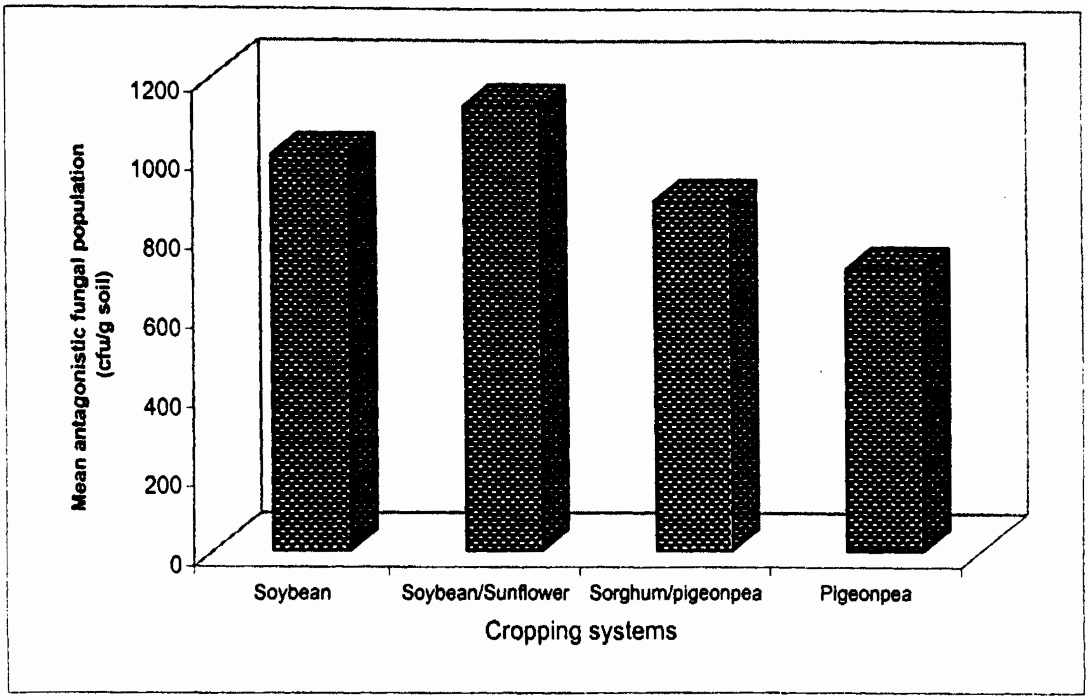


Fig.8: Effect of some cropping systems and N sources and levels on *Tricoderma* sp. population (cfu/g soil)

in the soil for the rhizosphere mycoflora and inhibition of pathogen population through lysis. Singh and Singh (1981) had reported lysis of mycelium of *Fusarium udum* in soils amended with margosa cake and rice husk with or without supplemental nitrogen.

In the present study, application of 40 kg N ha^{-1} through KNO_3 had recorded maximum levels of *Aspergillus* sp. population (576 cfu/g soil). The application of 20 kg N ha^{-1} as KNO_3 and 20 kg N ha^{-1} as FYM + 20 kg N ha^{-1} as KNO_3 had also recorded significantly higher population of *Aspergillus* sp. compared to control (Table 7 and Fig. 6). The increase in fungal population due to amendment with nitrogen ranged from 6 (20 kg N ha^{-1} as FYM) to 17 (40 kg N ha^{-1} as KNO_3) per cent over control. Intercropping of soybean/sunflower system had also recorded significantly higher population (603 cfu/g soil), compared to sole pigeonpea (430 cfu/g soil). Study of the interaction effects of cropping systems and N sources and levels had revealed significantly higher levels of population under soybean/sunflower system with application of 40 kg N ha^{-1} as KNO_3. The population of *Penicillium* sp. (Table 8 and Fig. 7) was also found to be maximum with application of 40 kg N ha^{-1} as KNO_3 (278 cfu/g soil) followed by 20 kg N ha^{-1} as FYM + 20 kg N ha^{-1} as KNO_3 (249 cfu/g soil). Further, significantly higher population was found in soybean/sunflower cropping system (276 cfu/g soil) followed by sorghum/pigeonpea system (197 cfu/g soil) over sole pigeonpea crop (162 cfu/g soil). Similar trend was also observed for *Trichoderma* sp. population (Table 9 and Fig. 8). Increased population of *Aspergillus* sp. with calcium nitrate application and



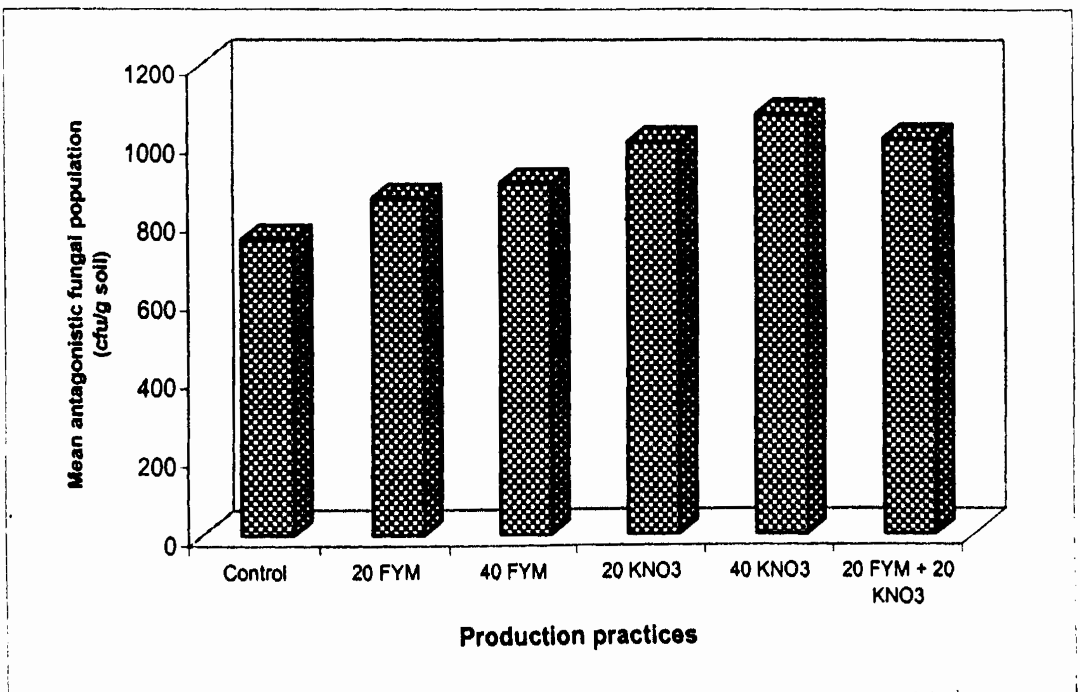


Fig.9: Effect of some cropping systems and N sources and levels on total antagonistic fungal population (cfu/g soil)

Penicillium sp. with NPK fertilizers in antirrhinum plants infected with *Verticillium dahliae* has also been reported by Datta and Isaac (1979).

Total antagonistic fungal population was also significantly influenced by N sources and levels (Table 10 and Fig. 9). Application of 40 kg N ha^{-1} as KNO_3 (1074 cfu/g soil) had recorded the highest population followed by 20 kg N ha^{-1} through FYM + 20 kg N ha^{-1} through KNO_3 (1011 cfu/g soil). The intercropping system of soybean/sunflower had also recorded greater population (1127 cfu/g soil) followed by sole soybean (1002 cfu/g soil) and sorghum/pigeonpea system (886 cfu/g soil), compared to sole pigeonpea (716 cfu/g soil). Analysis of interaction effects had revealed significantly maximum levels of antagonistic fungal population in soybean/ sunflower cropping system in combination with 40 kg N ha^{-1} as KNO_3. However, all other N sources and levels had also resulted in significantly higher antagonistic fungal populations under soybean and soybean/sunflower cropping system; compared to respective controls and sole pigeonpea system indicating that population levels of native antazonists can be enhanced with the use of chemical fertilizers and mixed cropping with nonhost crops to achieve successful control of *Fusarium* wilt disease. Increase in the population of native antagonists in the soil upon application of organic amendments (Khanna and Singh, 1974); Arunaryan and Mathew, 1993; Sivaprakasan, 1990) and inorganic amendments (Kaufman and Williams, 1964; Dutta and Isaac, 1979; Dutta and Dels, 1986; Deb and Dutta, 1992) has also been reported earlier. Soil amendments were also reported to affect the rhizosphere microorganisms in antirrhirum plants infected with *verticillium dahliae* (Dutta and Isaac, 1979; Khanna and Singh, 1974) and in pigeonpea infested with *F. udum* (Upadhyay and Rai, 1981b). The favourable effect of nitrogen in soil on saprophytic colonization of substrates by a number of fungi has also been noted by Tiwari (1971).

5.4 EFFECT OF PREDOMINANT PIGEONPEA INTERCROPPING SYSTEMS ON *Fusarium udum* AND ITS ANTAGONISTIC FUNGAL POPULATIONS IN FARMER FIELDS

5.4.1 On farm studies

Pigeonpea is traditionally intercropped with a variety of other crops, such as sorghum, pearl millet, groundnut, soybean and cotton in the semi-arid tropics of India. Intercropping of pigeonpea with sorghum, greengram, maize, cotton, castor and groundnut were observed to be predominant in the Telangana and Rayalaseema districts of Andhra Pradesh. Intercropping of pigeonpea with sorghum, greengram and cotton in vertisols and with maize, castor and groundnut in Alfisols. The effect of these systems in different soil types were investigated in on-farm and glasshouse studies with regards to wilt incidence and the pathogen and antagonistic fungal populations.

Pigeonpea wilt incidence was found to be influenced by the different cropping systems studied in farmers fields. The results revealed lower wilt incidence in Alfisols (16%) compared to vertisols (26%) on average basis probably due to effectiveness of the inter-cropping systems studied under Alfisol conditions, compared to cropping systems under Vertisols (Table 11 and Fig.10). Root exudates of groundnut, castor and maize were also

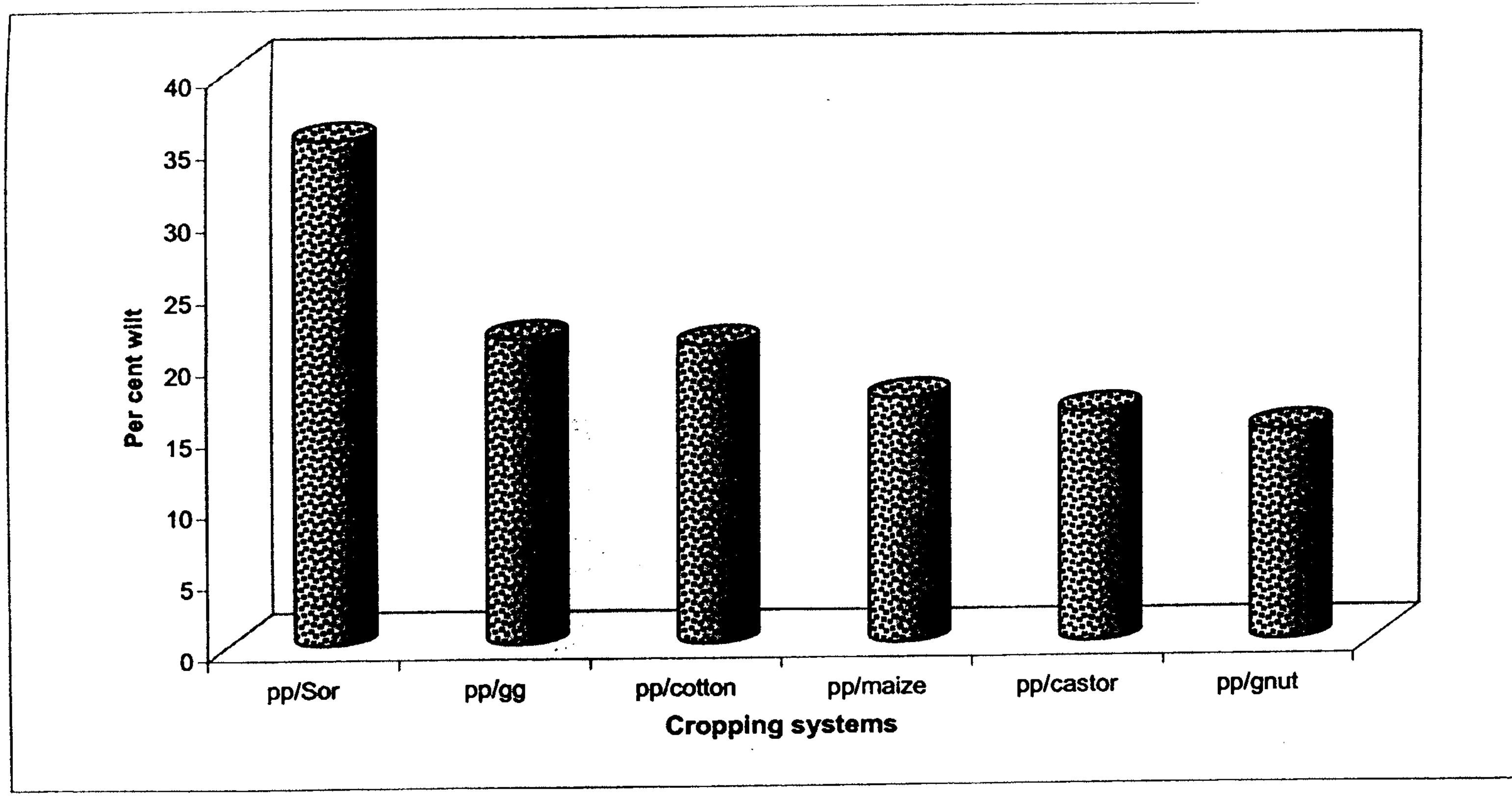


Fig. 10: Pigeonpea wilt incidence (%) in farmers fields in predominant pigeonpea intercropping systems in Andhra Pradesh (1996-97)

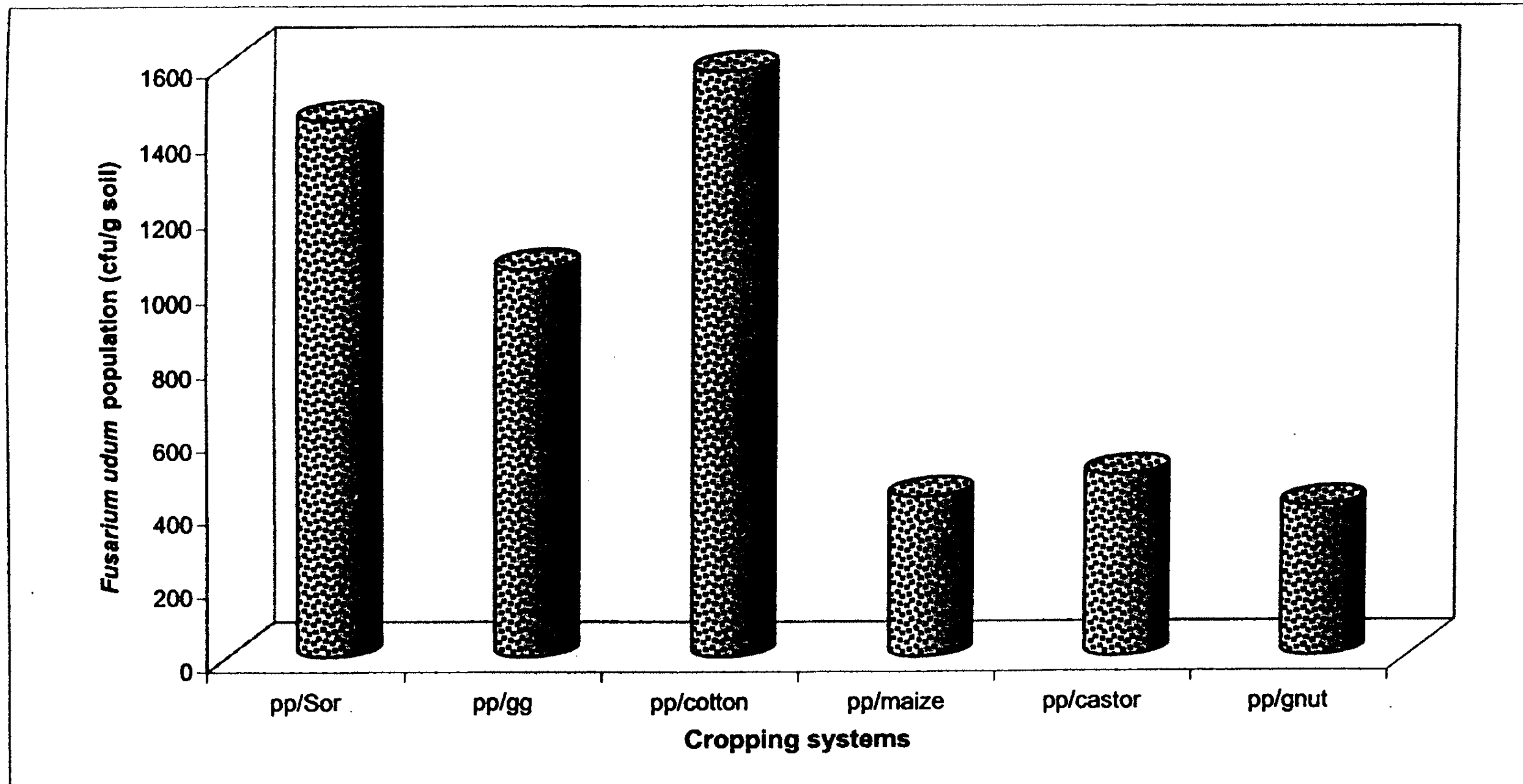


Fig.11: Pigeonpea wilt pathogen (*Fusarium udum*) population (cfu/g soil) in farmers fields in predominant pigeonpea intercropping systems prevalent in Andhra Pradesh (1996-97)

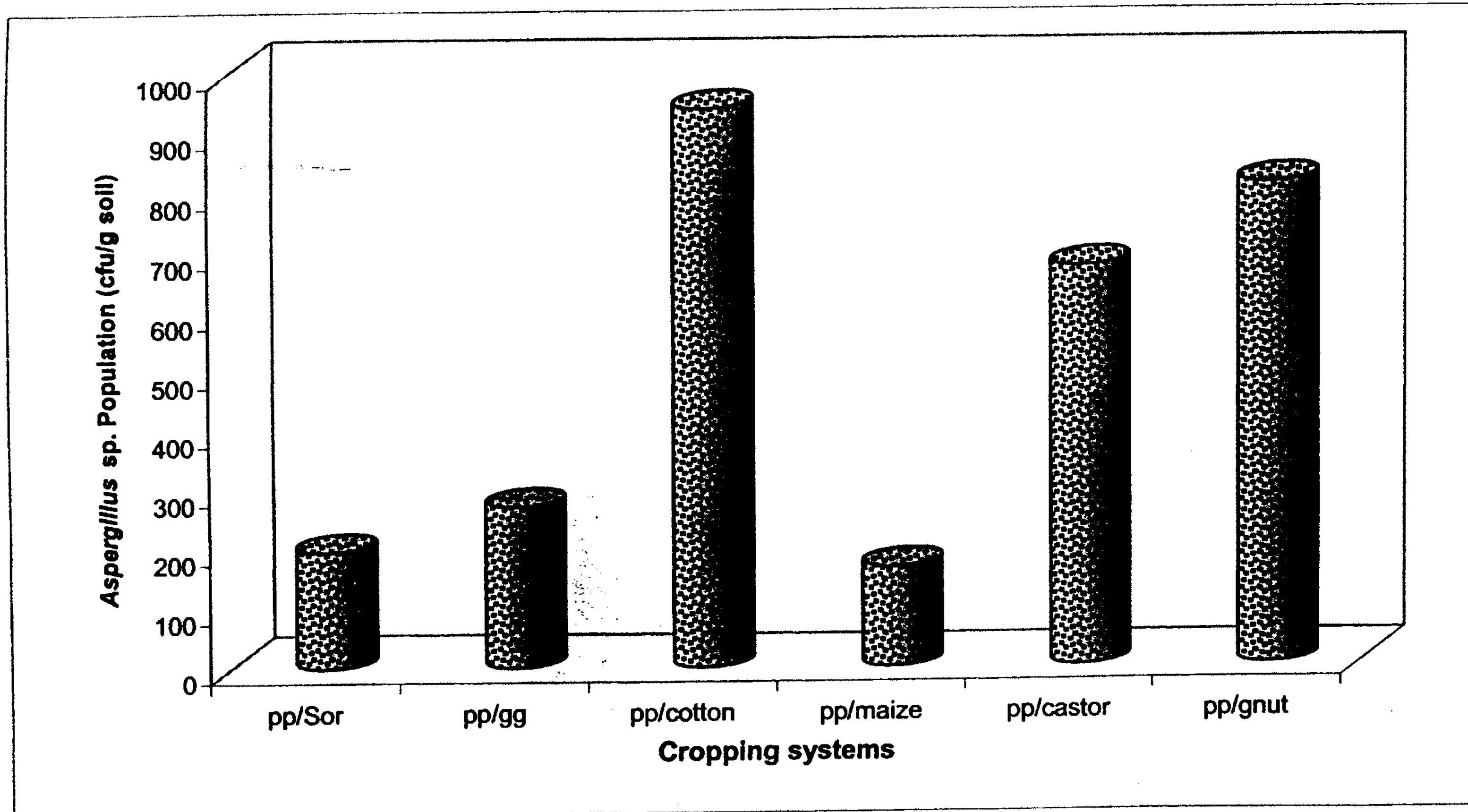


Fig.12: Antagonistic fungus *Aspergillus sp.* population (cfu/g) in predominant pigeonpea intercropping systems prevalent in Andhra Pradesh (1996-97)

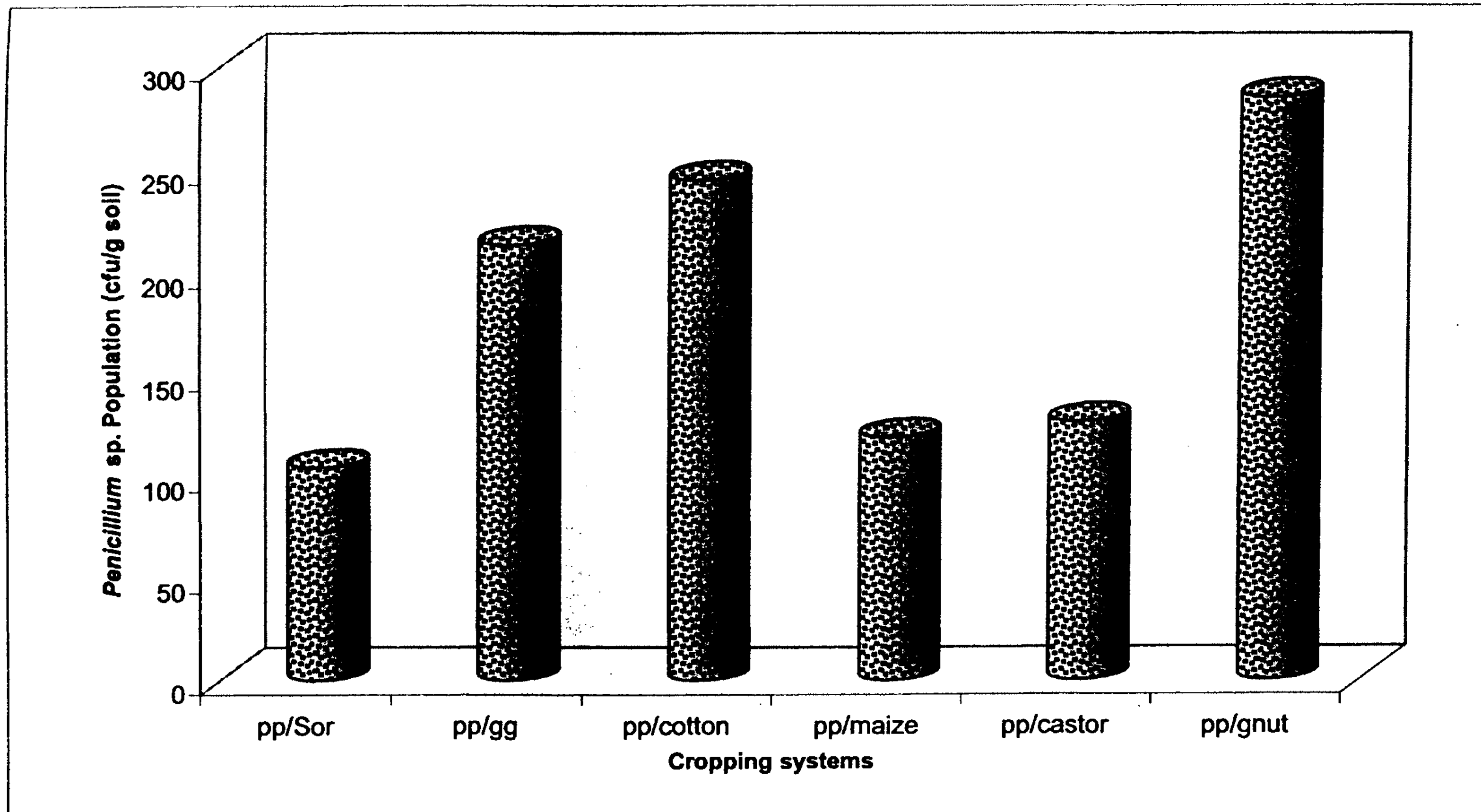


Fig.13: Antagonistic fungus *Penicillium sp.* population (cfu/g) in predominant pigeonpea intercropping systems prevalent in Andhra Pradesh (1996-97)

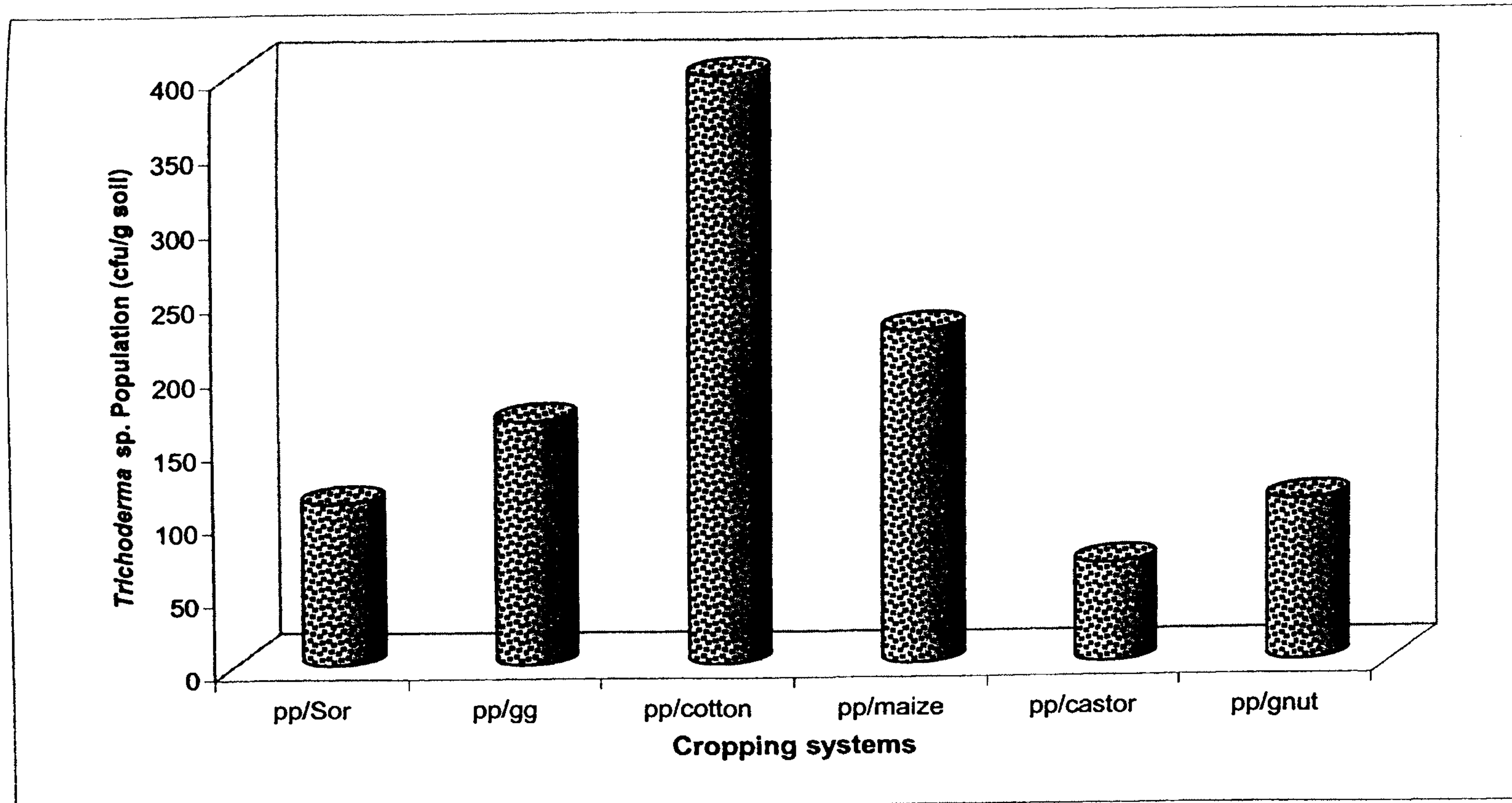


Fig.14: Antagonistic fungus *Trichoderma sp.* population (cfu/g) in predominant pigeonpea intercropping systems prevalent in Andhra Pradesh (1996-97)

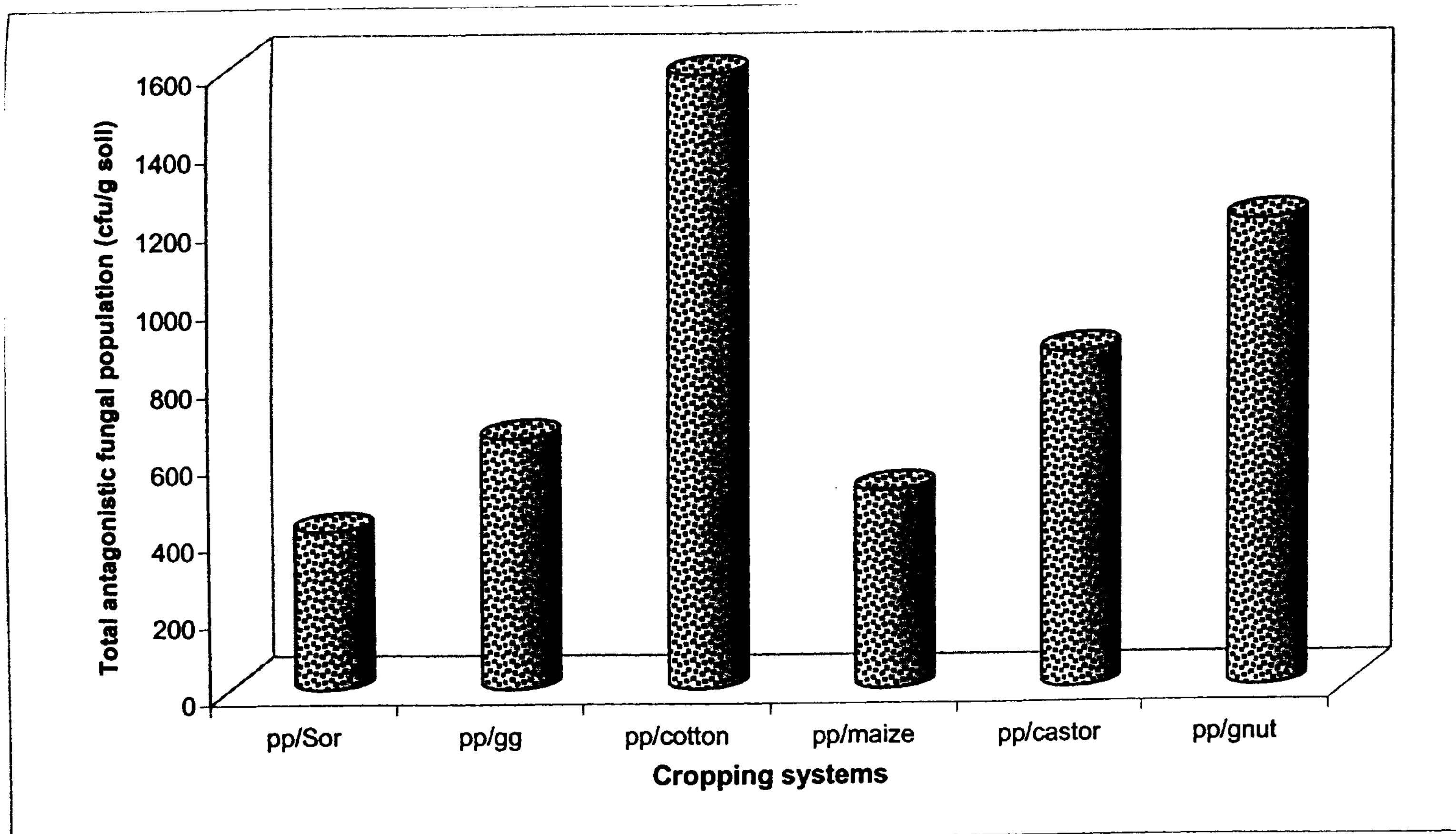


Fig.15: Total antagonistic fungal population (cfu/g soil) in predominant pigeonpea intercropping systems prevalent in Andhra Pradesh (1996-97)

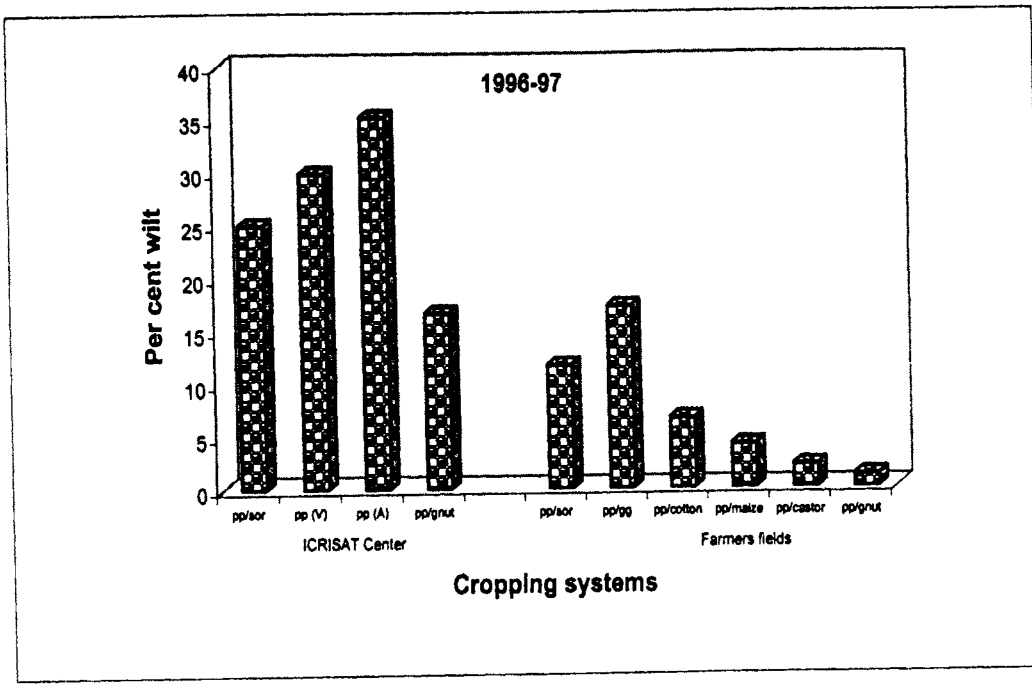
observed to inhibit *F. udum* conidia to a greater extent compared to greengram, sorghum (local) and cotton crops (Table 45 and Fig.44).

Among the cropping systems studied, intercropping with maize and sorghum had resulted in high levels of wilt incidence under Alfisols and Vertisols, respectively due to higher levels of pathogen population, coupled with lower levels of antagonistic fungal populations. Studies on the root exudates of maize and sorghum (local) had also revealed promotion of conidial germination of pathogen. Inhibition of conidial germination of antagonistic fungi was also noticed with root exudates of local sorghum (Table 45). In contrast low wilt incidence was recorded for pigeonpea/ groundnut and pigeonpea/cotton cropping systems in Alfisols and Vertisols, respectively. Pigeonpea/groundnut cropping system had also recorded minimum levels of pathogen population, coupled with maximum levels of antagonistic fungi, compared to other cropping systems investigated under Alfisol conditions. Root exudates of groundnut were also found to inhibit *F. udum* while promoting antagonistic fungi viz., *Aspergillus* and *Penicillium* sp. (Figs. 12 and 13) and *Trichoderma* sp. with pigeonpea/maize in Alfisols and pigeonpea/cotton in Vertisols (Fig. 14). However, pigeonpea/cotton system had recorded higher levels of both pathogen and total antagonistic fungal population (Fig. 15 and 15a). The root exudates of cotton were also found to promote both pathogen and antagonistic fungi studied in the present investigation (Tables 45 and 46). Lower levels of wilt incidence under pigeonpea/cotton system may therefore be attributed to the prevention of root colonization by *F. udum* due to suppression of its competitive saprophytic ability as reported by Rai and Upadhyay (1983). *Fusarium udum* population and antagonistic fungi were also found to be high in Vertisols compared to Alfisols, (Table 12 and Fig. 11) probably due to high organic carbon content of Vertisols. The low Pathogen population in Alfisols might also be attributed to low competitive saprophytic ability of pathogen under moisture stress in Alfisols (Mukhopadhyay and Sengupta, 1991).

5.4.2 Glass house studies

The results obtained in these studies revealed increased wilt incidence in ICRISAT soils compared to soils obtained from farmers fields. This may be attributed to the continued cultivation of pigeonpea for over 20 years and multiplication of *Fusarium udum* for development of wilt sick soils. In ICRISAT soils, increased wilt incidence was recorded in Alfisols (35 and 60%) compared to Vertisols (29 and 40%) during both 1996-97 and 1997-98 seasons, respectively (Table 17 and Fig. 16). This may be attributed moisture stress and injury to root system due to higher sand particles in Alfisols (Shukla, 1975). Upadhyay and Rai (1992) also reported greater wilt incidence (94%) in sandy soils (Alfisols) compared to clayey soils (24%). Further, the reason for low pathogen population in Alfisols compared to Vertisols may be due to low carbon content and high termite infestation resulting in greater degradation of pigeonpea plants and root residues.

In the studies on effect of intercropping systems, on wilt incidence, it was found that in ICRISAT soils pigeonpea intercropped with groundnut



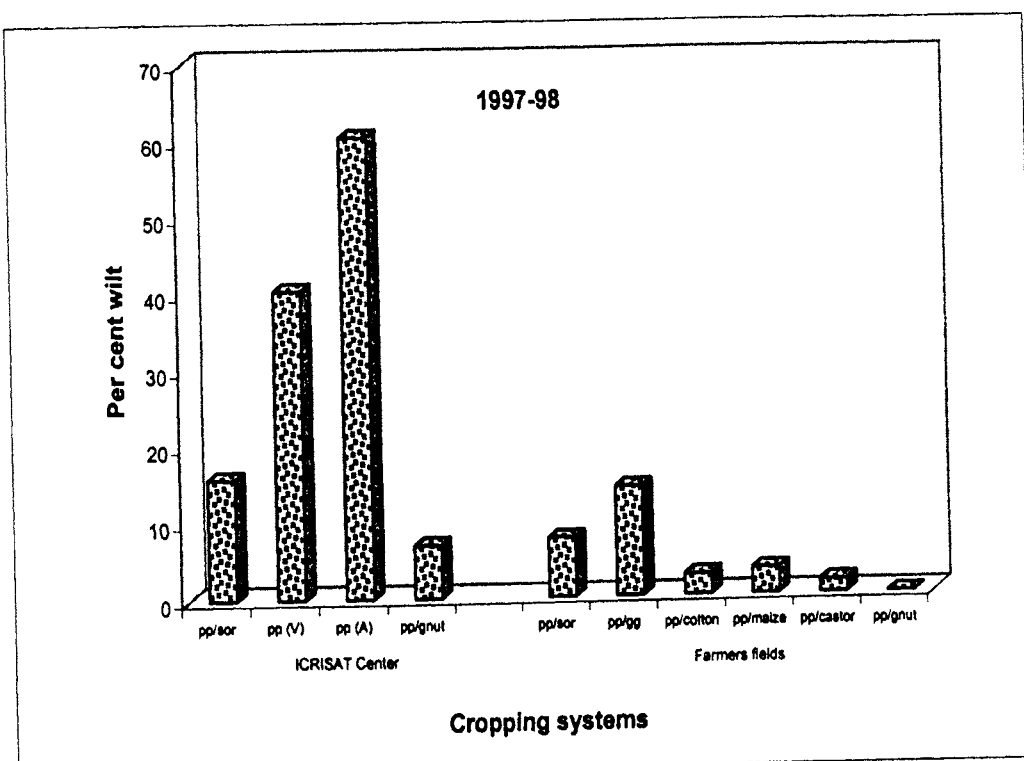
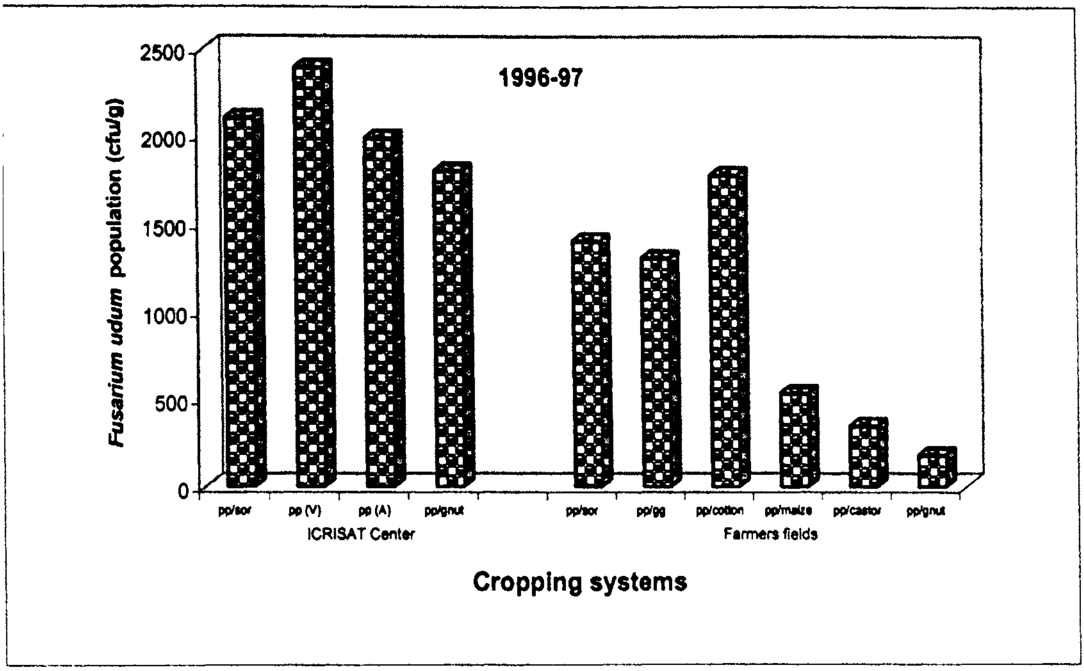


Fig.16: Wilt incidence in soils of predominant pigeonpea intercropping systems prevalent at ICRISAT center and farmers fields in Andhra Pradesh during 1996-98 in glass house studies

had recorded less wilt incidence (16%) in Alfisols and pigeonpea/sorghum in Vertisols (25%) than sole cropped pigeonpea (Fig. 16). In farmers fields, under Alfisols, less wilt incidence was found in the cropping system, pigeonpea/groundnut (1%) followed by castor (2%) and maize (4%). This may be attributed due to lower pathogen population coupled with relatively higher antagonistic fungal population noticed in the intercropping system. Root exudates of groundnut, castor and maize also recorded maximum inhibitory effect on *Fusarium udum* and stimulatory effects on the conidial germination of the antagonistic fungi (Table 45 and Fig. 44). Similar results were reported by Bhatnagar (1995) in her studies on the effect of root exudates with respect to conidial germination of *fusarium* and antagonistic fungi.

Intercropping systems involving sorghum, greengram and cotton were also investigated in comparison to monocropping of pigeonpea under Vertisols and the results revealed low wilt incidence in cotton/pigeonpea system compared to pigeonpea intercropped with sorghum or greengram. Similar results were reported earlier (Naik, 1993; ICRISAT, 1994 and Bhatnagar, 1995). Reduced wilt incidence in the present study under intercropping may be attributed to the prevention of root to root contact of the host crop (Kloos *et al.*, 1987), in addition to the inhibitory and stimulatory effects of root exudates of the intercrops on pathogen and its antagonistic fungi, respectively (Bhatnagar, 1995). In addition, the root system of non-host crops might be diluting the inoculum due to host-pathogen incompatability. A variation in the wilt incidence levels with the



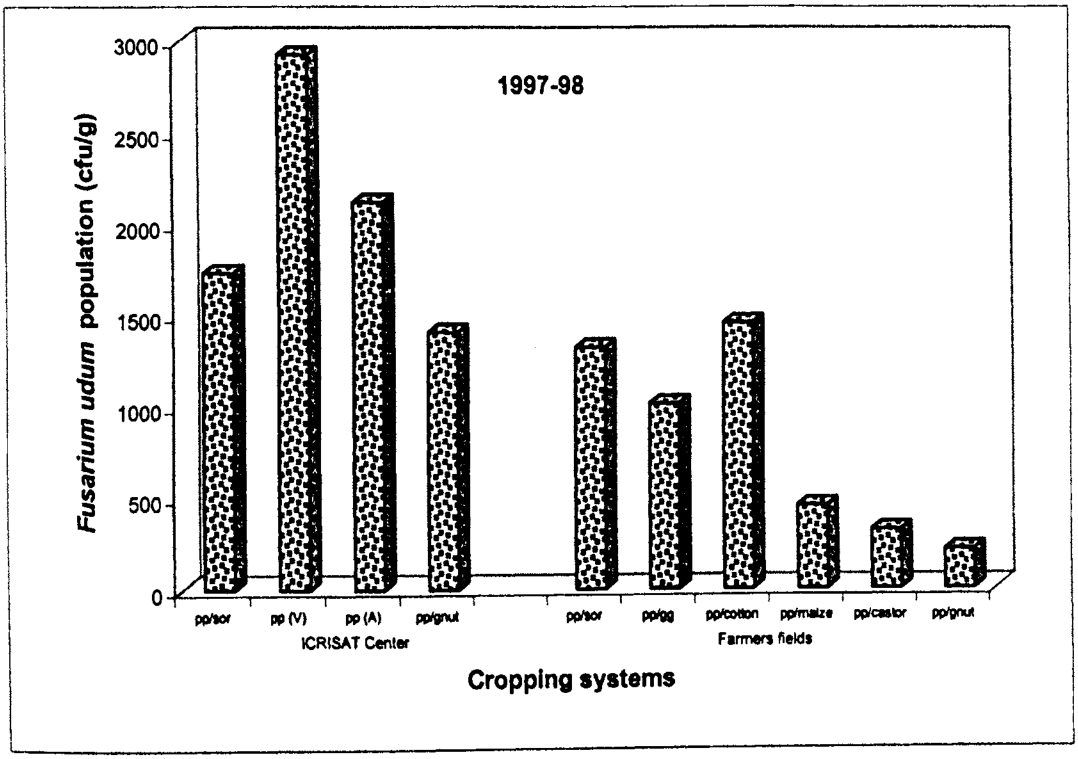


Fig.17: *Fusarium udum* population (cfu/g soil) in soils of predominant pigeonpea intercropping systems prevalent at ICRISAT center and farmers fields in Andhra Pradesh during 1996-98 in glass house studies

intercrop was observed in the present study. Similar results were reported by earlier workers (Raymund, 1983; Kloos *et al.*, 1987; and Midmore, 1988).

Fusarium udum population was also found to be influenced by soil type and cropping systems (Table 18 and Fig. 17). It was also significantly higher in ICRISAT field soil (2071 and 2043 cfu/g soil than farmers field soils (926 and 796 cfu/g soil) during 1996-97 and 1997-98 years, respectively (Fig. 17). The suppression of pathogen population in farmer's field soil may be attributed to increased activity of microbial antagonists (Latham and Watson, 1967).

Greater levels of population was also found in Vertisols (1798 and 1687 cfu/g soil) and less in Alfisols (970 and 903 cfu/g soil) during *kharif* 1996-97 and 1997-98 years, respectively. Although no systematic studies were carried out to understand the reason for such differences. Abawi and Lorbeer (1971) and Bersi *et al.* (1984) were able to detect more of *fusarium* in organic soil (Vertisol) compared to mineral soil in case of *F. oxysporium* f.sp. *Cepae* and *F. oxysporium* f.sp. *albedenis*, respectively. Further, the reason for low pathogen population in Alfisols compared to Vertisols might be due to low carbon content and high termite infestation resulting in greater degradation of pigeonpea plants and root residues. Silty loam soils helps mycelium of the pathogen to grow profusely due to warm soil, better drainage and aerobic conditions which supported maximum population of fusarium as reported by Vinay Sagar and Sugha (1998).

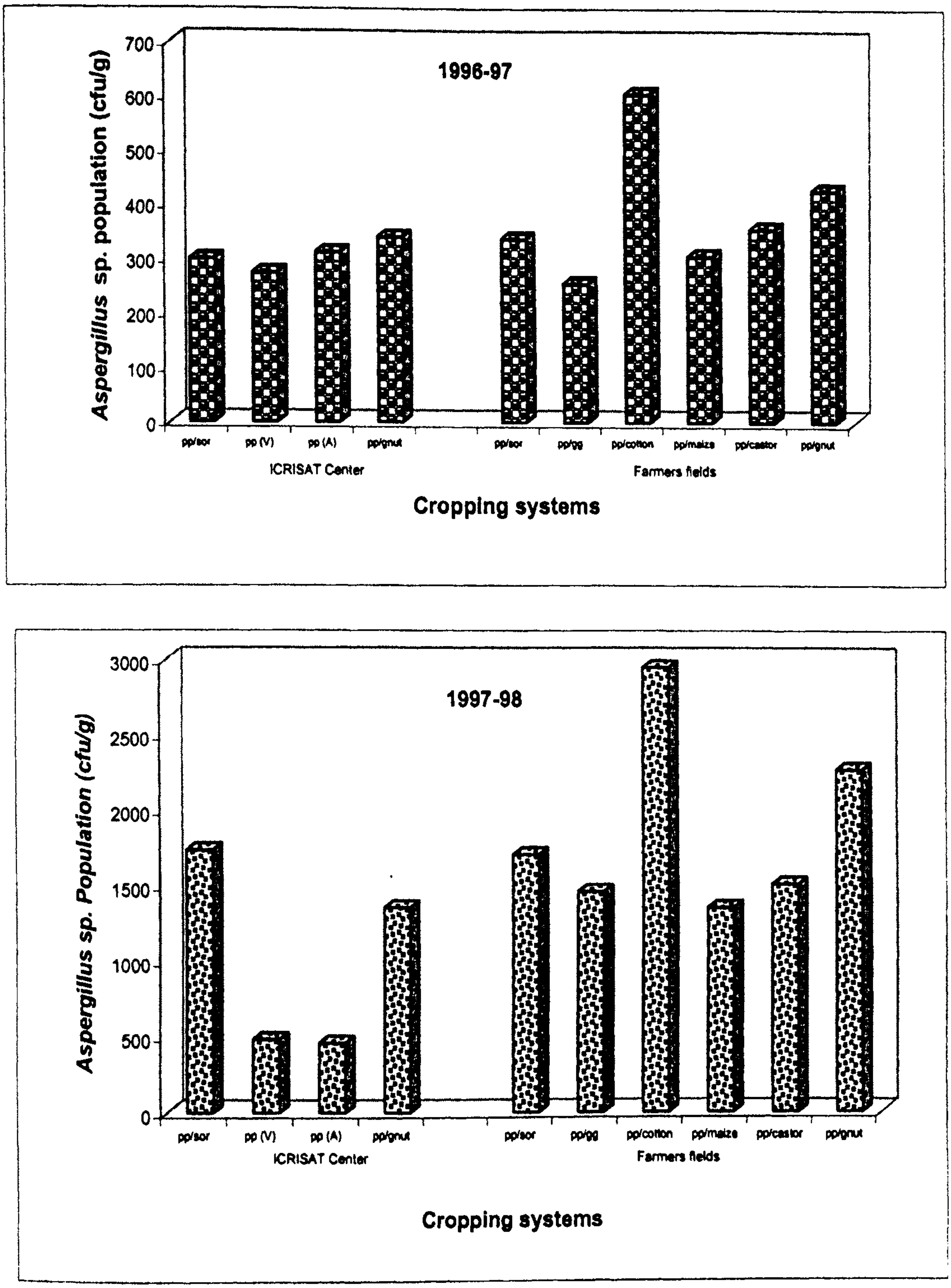
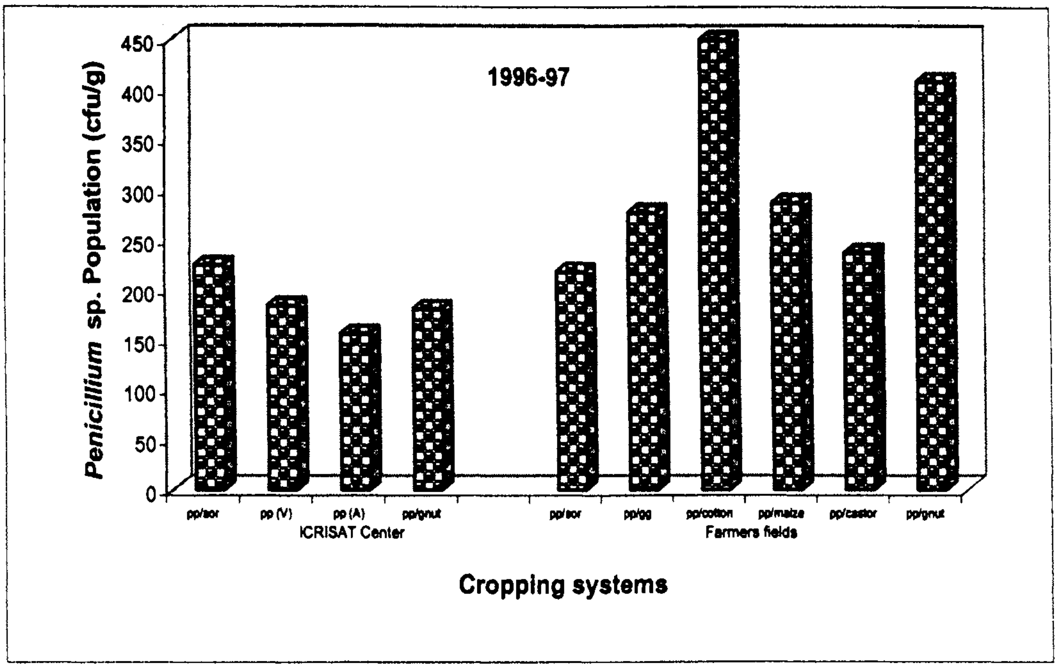


Fig.18: *Aspergillus* sp. population (cfu/g soil) in soils of predominant pigeonpea intercropping systems prevalent at ICRISAT center and farmers fields in Andhra Pradesh during 1996-98 in glass house studies



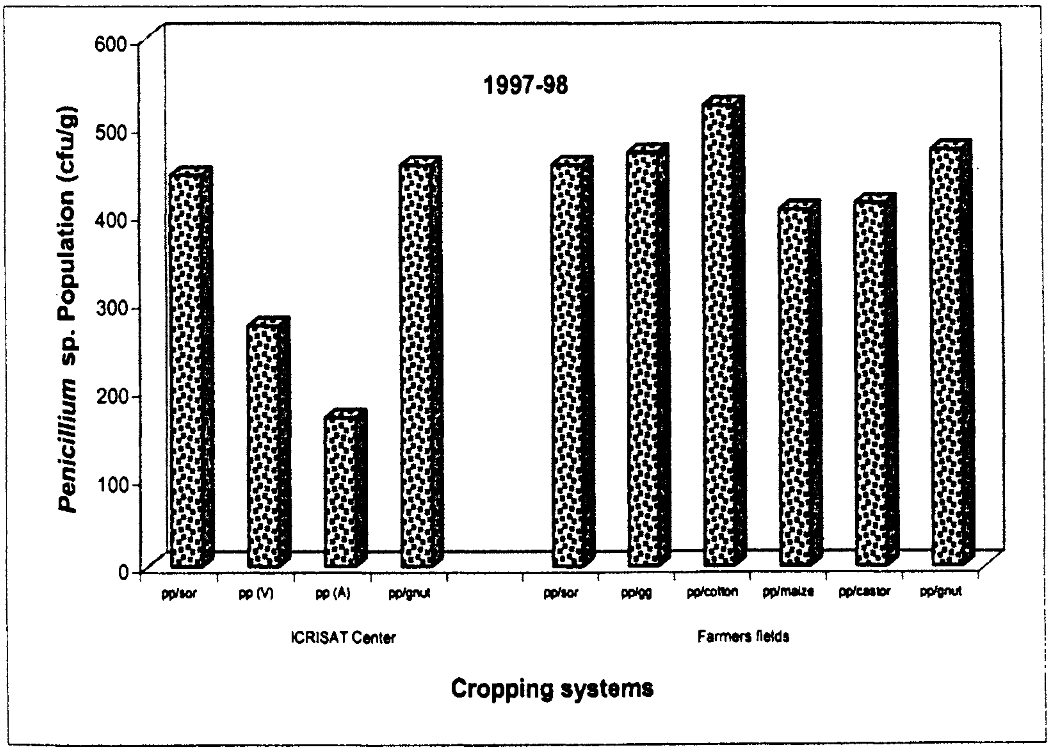


Fig.19: *Penicillium* sp. population (cfu/g soil) in soils of predominant pigeonpea intercropping systems prevalent at ICRISAT center and farmers fields in Andhra Pradesh during 1996-98 in glass house studies

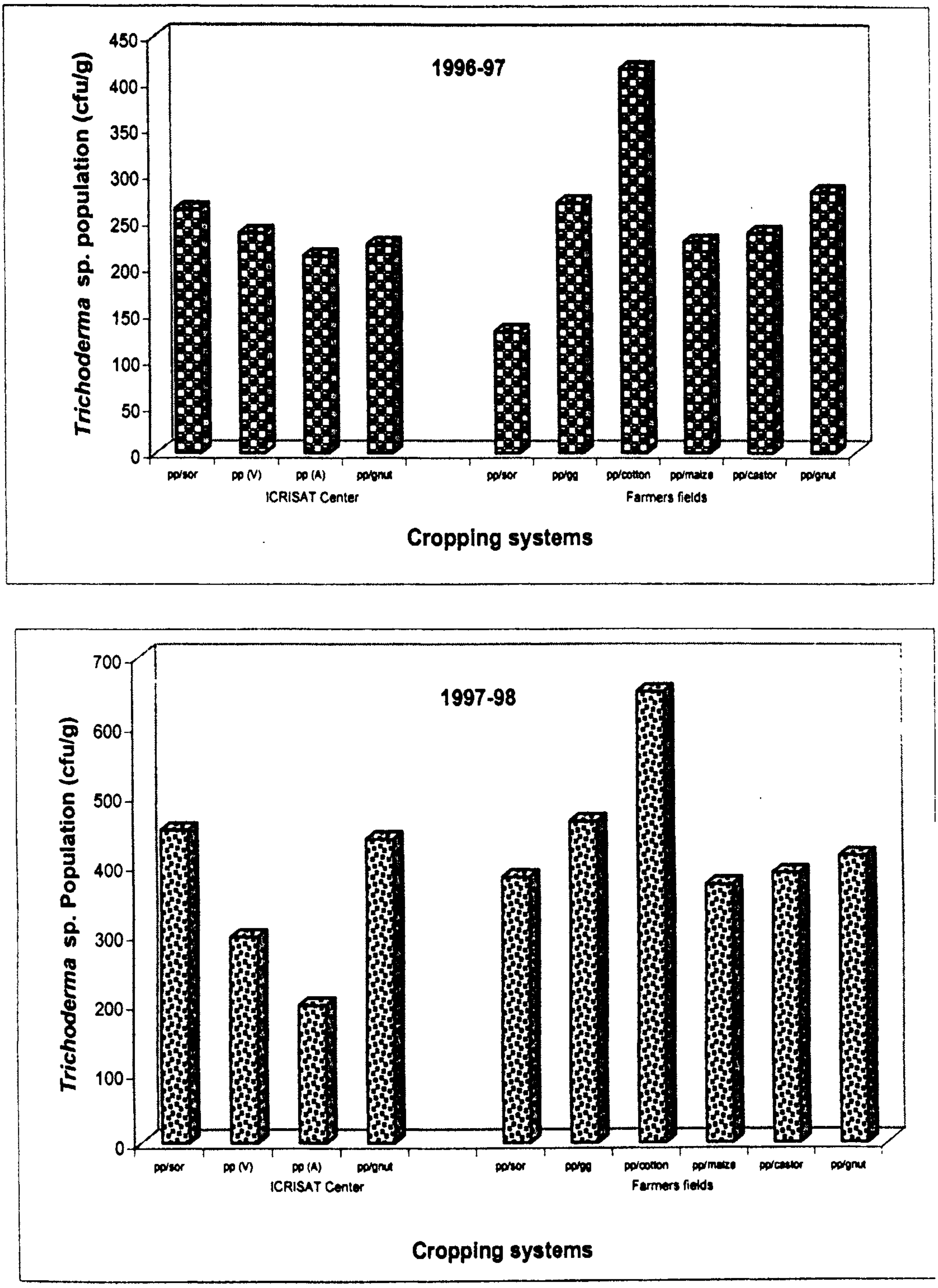
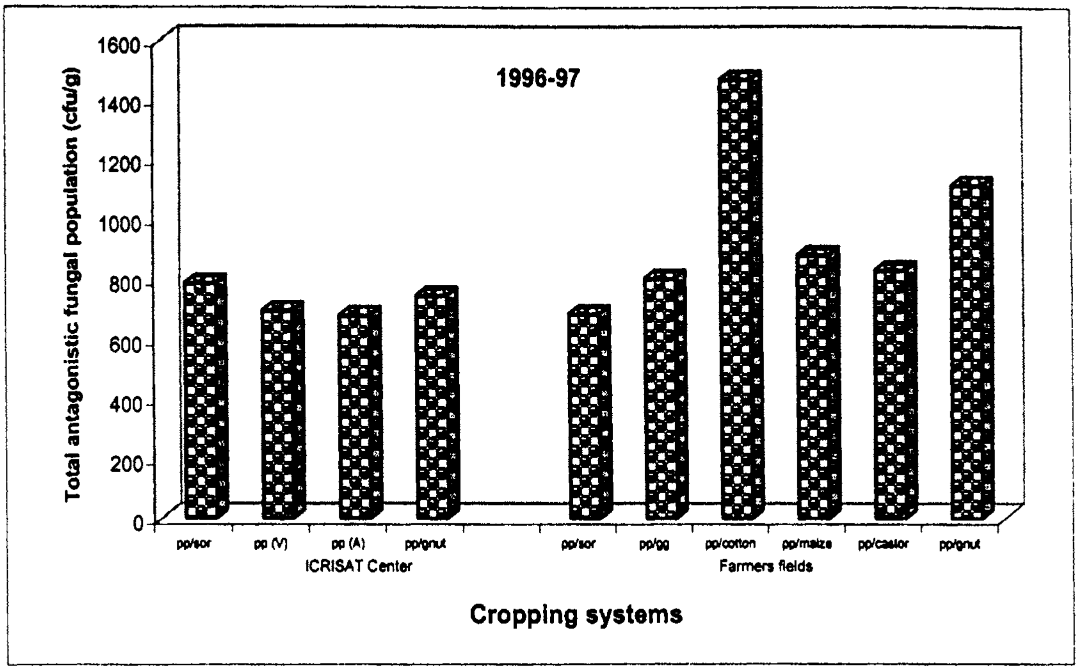


Fig.20: *Trichoderma* sp. population (cfu/g soil) in soils of predominant pigeonpea intercropping systems prevalent at ICRISAT center and farmers fields in Andhra Pradesh during 1996-98 in glass house studies

Intercropped pigeonpea recorded significantly lower levels of population both in Alfisols and Vertisols. Among the different cropping systems studied in soils of farmer's field, intercropping of pigeonpea with groundnut (181 cfu/g soil) and with greengram (1309 cfu/g soil) had recorded significantly lower pathogen population in Alfisols and Vertisols, respectively.

Population of *Aspergillus* sp. (Table 19 and Fig. 18), *Penicillium* sp. (Table 21 and Fig.19) and *Trichoderma* species (Table 21 and Fig.20) were found to be higher during 1997-98 than 1996-97 due to cumulative stimulatory effect of root exudates of intercrops as a result of use of the same soil for studies during 1997-98. The effect of intercropping on soil borne diseases in subsequent years was also reported earlier (Dey, 1947a; Autrique and Potts, 1987). Vertisols recorded significantly higher levels of the antagonistic fungal populations compared to Alfisols. *Aspergillus* sp. population was found to be significantly higher in farmer's field soils (371 and 1873 cfu/g soil) than ICRISAT soils (307 and 1007 cfu/g soil) during 1976-97 and 1997-98 years, respectively. Similarly, *Penicillium* sp. and *Trichoderma* sp. found to be higher in farmer's field soils than in ICRISAT soils. Intercropped pigeonpea had recorded significantly higher levels of the antagonistic fungal populations in both Alfisols and Vertisols of ICRISAT and farmer's field soils (Figs.18-21).

In the present investigation, total antagonistic fungal population (Table 22 and Fig. 21) was found to be higher in the second year. Vertisols recorded significantly higher levels of total antagonistic fungal population



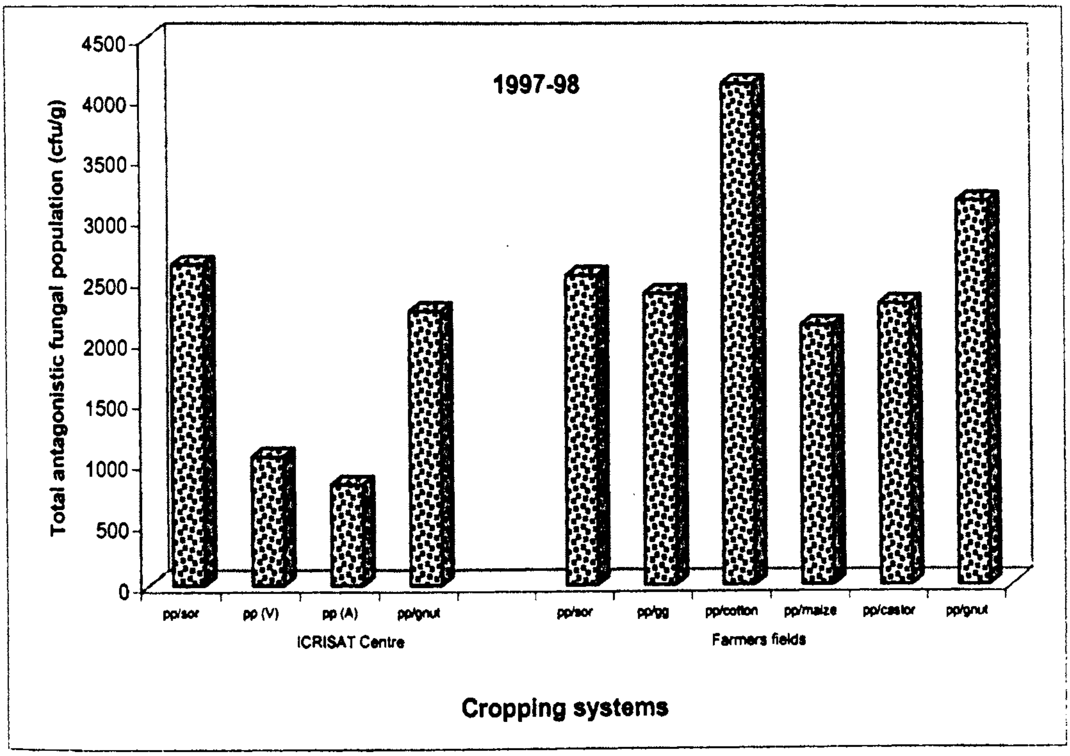


Fig.21: Total antagonistic fungal population (cfu/g soil) in soils of predominant pigeonpea intercropping systems prevalent at ICRISAT center and farmers fields in Andhra Pradesh during 1996-98 in glass house studies

(889 and 2548 cfu/g soil) than Alfisols (853and 2133 cfu/g soil). Higher population in farmer's field soils (945 and 2775 cfu/g soil) than ICRISAT soils (731 and 1689 cfu/g soil) was observed. Wilt suppression in vertisols may be attributed to increased levels of antagonistic microorganisms like *Aspergillus niger, A. flavus, Penicillium citrinum, Trichoderma viride*, which prevented root colonization due to suppression of the competitive saprophytic ability (CSA) of *F. udum* (Rai and Upadhyay, 1983) and fungistatic activity of suppressive soils (Upadhyay and Rai, 1981b).

Thus, it is evident that type of crop combination and soil type govern the chemical properties, microflora and microbial population, densitives in the soil ecosystem. Different plant species release different compounds into their rhizosphere which affect the composition and activitiesof the microbial population present thereby influencing disease development and intensity.

5.5 STUDIES ON INTEGRATED PIGEONPEA WILT MANAGEMENT IN ALFISOLS

In the present investigations, the effects of application of green manure, farm yard manure and integrated disease management (involving seed dressing with fungicides and *Trichoderma* talc based product in addition to basal application of farm yard manure and green manure @ 2.5 tons ha^{-1} prior to planting were investigated under both monocropping and intercropping of pigeonpea during 1996-97 and 1997-98 years under both field and pot conditions.

Wilt incidence has been reported to be in general high in Alfisols (Chand and Thakur, 1969; Shukla, 1975; Upadhyay, 1979; Nene and Reddy, 1981; Upadhyay and Rai, 1989). Further, control of pigeonpea wilt has been reported to be difficult (Upadhyay and Rai, 1981a; Kotasthane *et al.*, 1987; Upadhyay, 1992; Rai and Singh, 1995; Pandey and Upadhyay, 1999) and hence, an integrated approach involving a combination of cultural, chemical, host plant resistance and biological control methods is necessary for effective control of the disease. The effectiveness of integrated disease management for the control of soil borne plant pathogens including *Fusarium* wilt had been reported earlier (Srivastava and Saxena, 1968; Locke *et al.*, 1985; Upadhyay and Rai, 1989).

Reduced wilt incidence was recorded with IDM treatment during 1996-97 and 1997-98 kharif (56 and 35%) seasons under sole pigeonpea. The next best treatment was found to be FYM (62 and 49%) and GM (67 and 55%) in field. Pigeonpea/groundnut combination with IDM treatment significantly recorded less wilt incidence (40 and 28%) over GM (49 and 39%) and FYM (50 and 42%), in field during 1996-97 and 1997-98 years, respectively (Tables 23 to 24 and Figs.22 to 23). Similar results of reduced wilt incidence was found under pot conditions during two consecutive seasons, respectively. The idea of integration of amendments, biological and fungicidal control was supported by many workers on different other crops against soil borne pathogens (Kraft and Papavizes, 1983; Champawat and Pathak, 1988; Sawanth and Mukhopadhyay, 1990; Shrestha *et al.*, 1991; Kaur and Mukhopadhyay, 1992; Chattopadhyay and Sen, 1996; Patel and

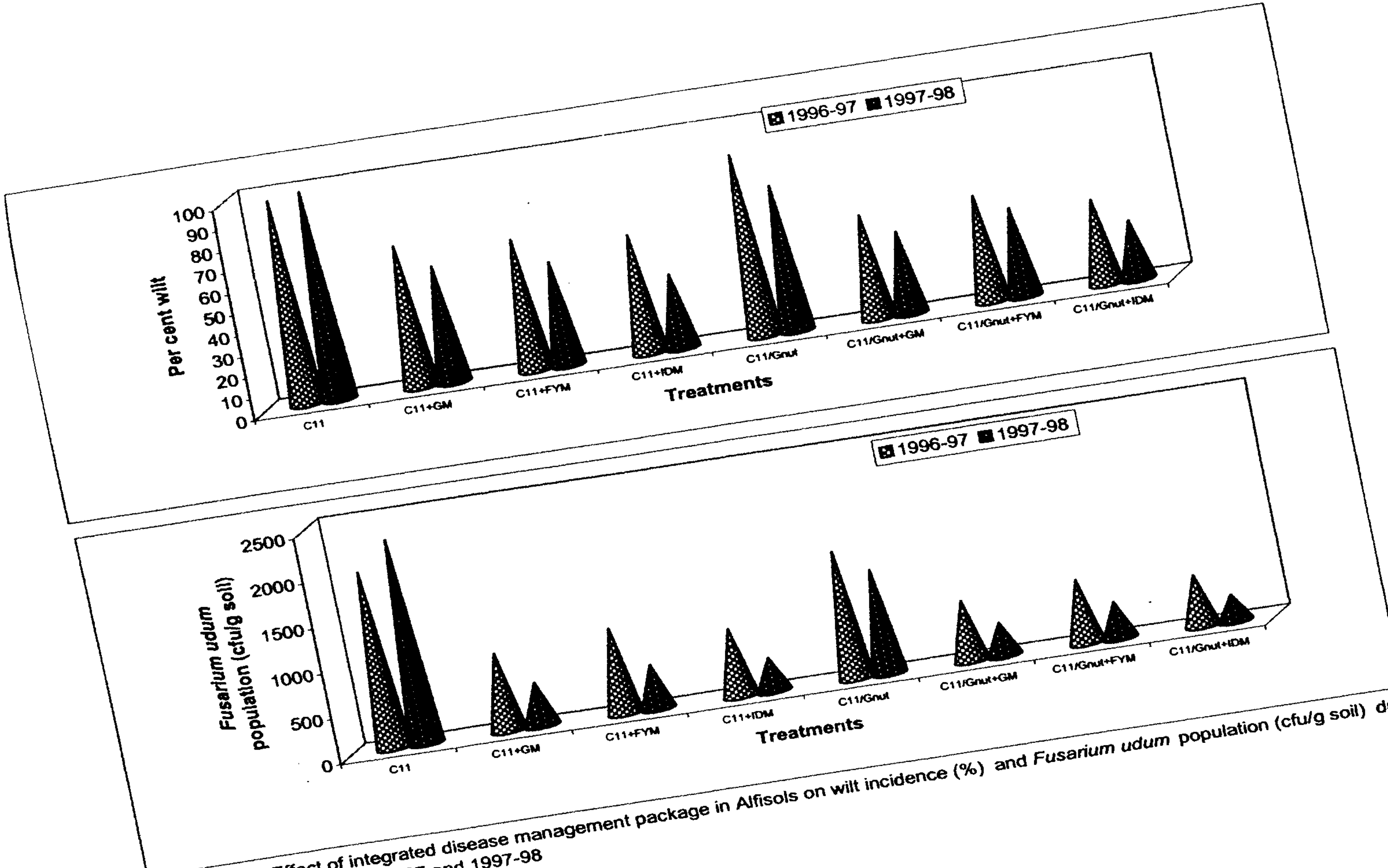


Fig.22: Effect of integrated disease management package in Alfisols on wilt incidence (%) and *Fusarium udum* population (cfu/g soil) during *kharif*, 1996-97 and 1997-98

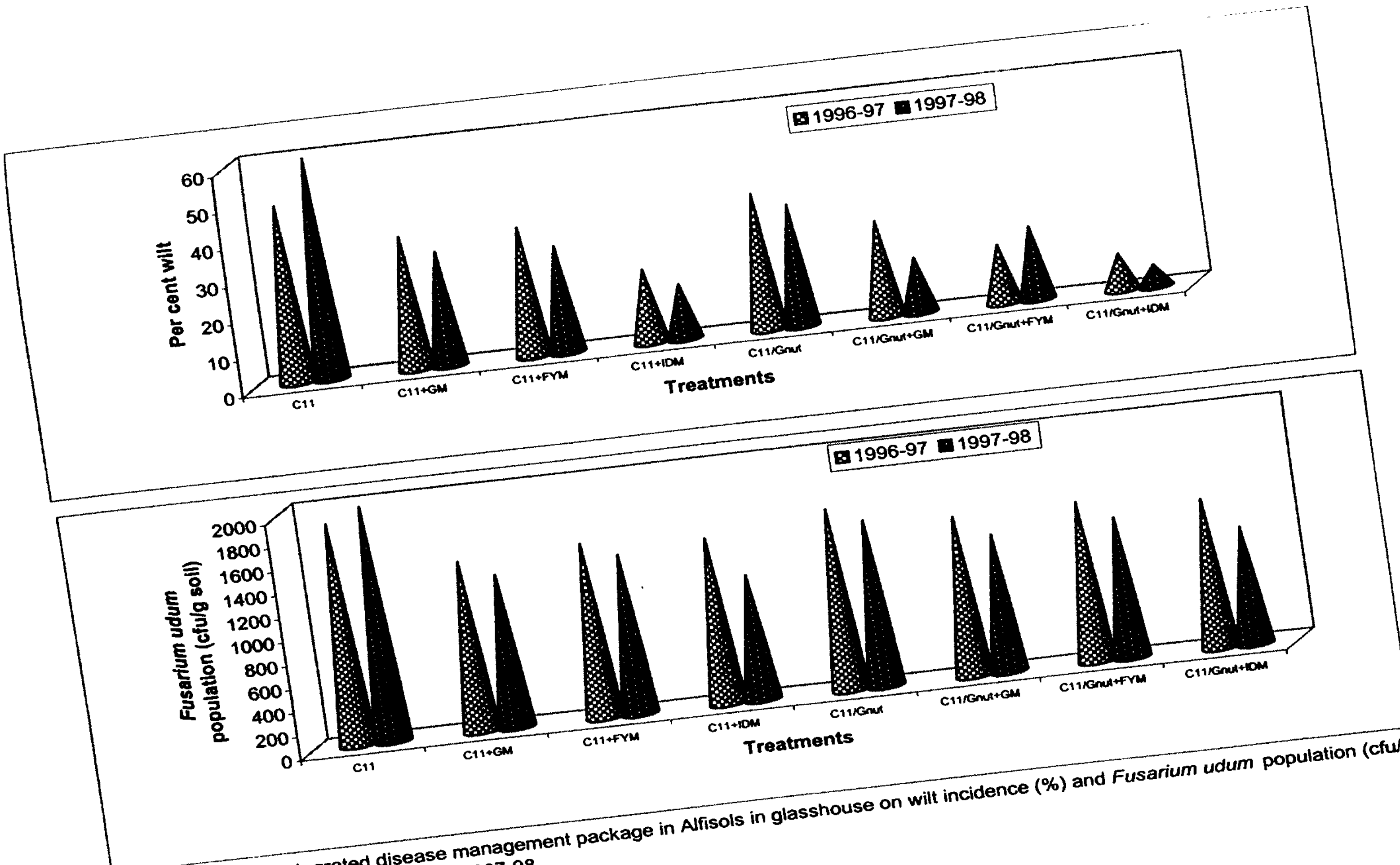


Fig.23: Effect of integrated disease management package in Alfisols in glasshouse on wilt incidence (%) and *Fusarium udum* population (cfu/g soil during *kharif*, 1996-97 and 1997-98

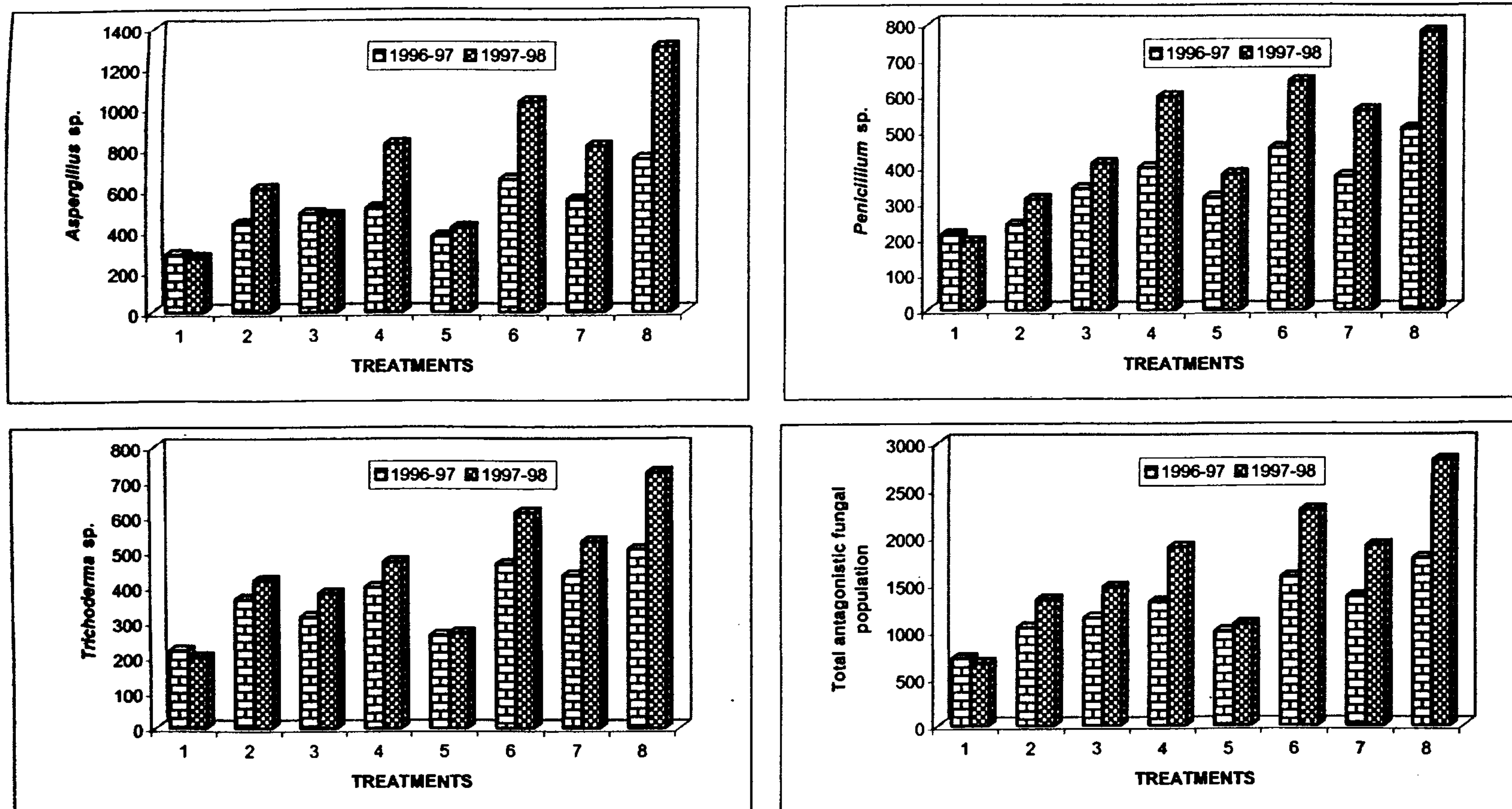
Patel, 1998) but no report is available on integrated effects of different components on *F. udum*. However, Mukhopadhyay *et al.* (1992) found good control of chickpea wilt complex when seeds were treated with *Gliocladium virens* (10^7 conidia/ml) and carboxin 0.1 per cent. In vivo studies of Kotasthane *et al.* (1987) on reduction of wilt with fungicidal seed treatment and benlate + thiram (1:3) in combination with oat crop residues in pigeonpea. Seed pelleting with *Trichoderma viride* and soil amendment with neem cake @ 2.5 tons ha^{-1} was found effective in reducing seedling disease of cotton (Alagarsamy *et al.*, 1987b). However, Pandey and Upadhyay (1999) reported reduced wilt incidence (10%) in pigeonpea with pure powder of *Trichoderma viride* in combination with thiram @ of 0.1 per cent compared to control (83%). Seed dressing with bavistin, bavistin + thiram in reduced amounts was found beneficial (Sumitha and Gaikwad, 1995a) and benlate + thiram (Haware *et al.*, 1986) and with bioagents *T. viride* and *T. harziamum* (Somasekhara *et al.*, 1996) has been found promising in pigeonpea.

The adoption of IDM measures were observed to result in minimum *Fusarium udum* population (Tables 23 to 24 and Figs.22 to 23) in addition to maximum antagonistic fungi under both mono (741 and 367 cfu/g soil) and intercropping systems (554 and 286 cfu/g soil) of pigeonpea, resulting in minimum wilt incidence compared to the adoption of other cultural practices. The additive effect of IDM on the pathogen populations observed may be attributed to the chemical eliminating or reducing soil saprophytes that compete with the bio-control organism for nutrients and thus jeopardise pathogen survival in soil (Papavizas, 1982). This may also be attributed to the increased levels of the total antagonistic fungal population as evidenced from (Table 25 and Figs.24 to 25) due to C/N ratio of amendments green manure and farm yard manure. Similar results of reduced pathogen population and increased antagonists was established by high C/N ratio of amendments such as sawdust and low C/N ratio of oil cakes might result in dual role of reduced competition and increased microbial activity (Khanna and Singh, 1974) and increased population of antagonists due to rhizophere effect of crops (Upadhyay, 1992). This may also be attributed to manipulation of CSA (competitive saprophytic ability) of *F. udum* due to addition of amendments and reduced saprophytic survival in soil as earlier reported by Upahyay and Rai (1983b). A two fold increase of total fungal population in mahua cake applied plots and suppression of fusarial wilt of tomato as earlier reported by Mayakrishnan and Subbaraja (1995). Conversely the increase in the population of *Fusarium* from 1941 to 2251 cfu/g soil under sole cropped pigeonpea and decreased population in the intercropped pigeonpea from 1408 to 1148 might be due to the effect of root exudatess of different intercrops in the stimulation of rhizosphere fungi (Naik, 1993). The increase in the population during crop season could be attributed to increased germination and activation of chlamydospores, micro and macroconidia with the planting of subsequent same crop root exudates in the rhizosphere. In addition, the wilted plants which contain innumerable number of propagules both chhamydospores and conidia are usually returned to soil and thus increase the inoculum load (Katan, 1971). Offseason crop is marked by the absence of two activities resulting in decrease of inoculum load.

The yield and biomass of pigeonpea (Figs.26 to 27) were also found to be higher in the IDM treatment, under both mono and intercropping systems of pigeonpea compared to other production practices, probably as a consequence of reduced wilt incidence.

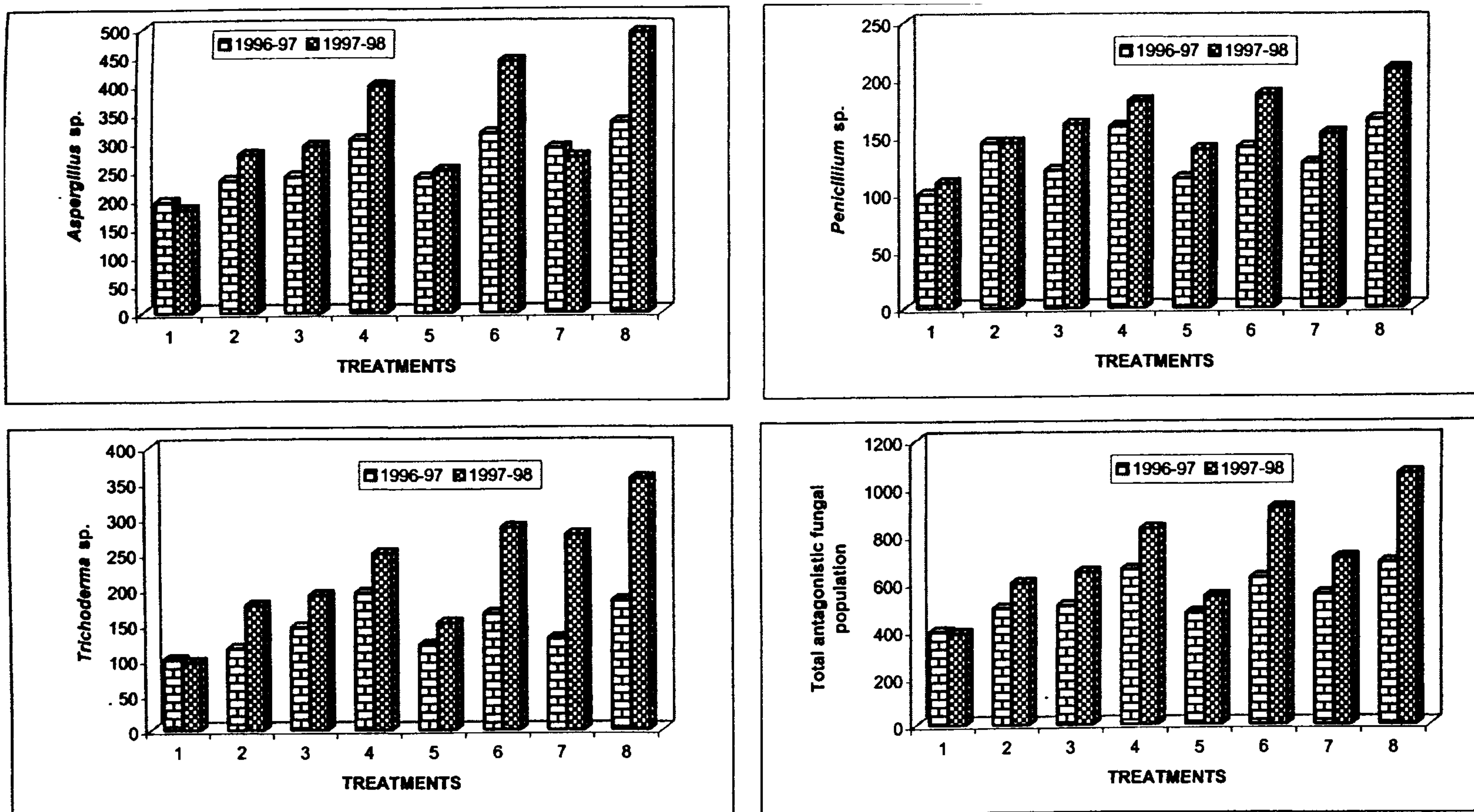
Application of greenmanure and farm yard manure production practices had also resulted in significantly lower levels of wilt incidence, compared to control under both monocropping and intercropping systems. The low wilt incidence noticed for the production practices may also attributed to the reduced fungal pathogen population due to stimulation of the antagonistic fungi. Several reviews have also covered the role of such soil amendments in the management of plant diseases (Baker and Cook, 1974; Papavizas and Lumsden, 1980; Cook and Baker, 1983; Hoitink and Fahy, 1986). The suppressive effect of organic amendments in general (McRae and Shaw, 1933; Mahmood, 1964; and Vasudeva *et al.*, 1963) and green manure (Upadhyay and Rai, 1981a) and farm yard manure (Raghuchander *et al.*, 1992) in particular on *Fusarium udum* has been demonstrated by several workers in pigeonpea. Latha and Watson (1967) and Wajid Khan *et al.* (1974) observed similar trend in onion and egg plants, respectively.

Reduced wilt incidence inspite of greater pathogen population in the FYM treated plot under sole pigeonpea cropping system might be due to high C/N ratio of FYM which results in prevention of chlamydospore germination and nitrogen starvation of the pathogen (Snyder *et al.*, 1959 and Toussan *et al.*, 1960). C:N ratio of soil amendments might also influences



1. C11 2. C11+ GM 3. C11+FYM 4. C11+IDM
5. C11/Gnut 6. C11/Gnut+GM 7. C11/Gnut+FYM 8. C11/Gnut+IDM

Fig.24: Effect of integrated disease management package in Alfisols on *Aspergillus*, *Penicillium* and *Trichoderma* spp. and total antagonistic fungal population (cfu/g soil) during *kharif* 1996-97 and 1997-98



1. C11 2. C11+ GM 3. C11+FYM 4. C11+IDM
5. C11/Gnut 6. C11/Gnut+GM 7. C11/Gnut+FYM 8. C11/Gnut+IDM

Fig.25: Effect of integrated disease management package in Alfisols in glasshouse on *Aspergillus*, *Penicillium* and *Trichoderma* spp. and total antagonistic fungal population (cfu/g soil) during *kharif* 1996-97 and 1997-98

the saprophytic survival of the pathogen in soil and which results in reduced wilt incidence (Khanna and Singh, 1974). This may be probably due to precolonization of pigeonpea substrates by antagonistic microorganisms besides suppressing saprophytic survival of the pathogen. Organic amendments in general influenced the severity of soil borne diseases by (i) increasing the biological buffering capacity of soil (ii) reducing pathogen numbers during anaerobic decomposition of organic matter (iii) affecting nitrification which influences the form nitrogen predominating in the soil (iv) denying the pathogen a host during the interim of unsuitable species. The specific form of nitrogen available to the plant and soil microflora, inturn, influences specific microbial associations and host physiology (Huber and Watson, 1970). Several workers have reported varied concentration of amendments (0.5 to 5%) effectively reduced soil borne diseases (Singh and Pandey, 1967; Ramakrishnan and Jeyarajan, 1986; and Lakshmi and Jeyarajan, 1987). Mukhopadhyay and Sengupta (1991) observed decline in population of the fungus in soil as a result of release of some volatile toxic substances notably ammonia during the decomposition process as demonstrated by Zakaria *et al.* (1980).

The results of increased antagonistic fungal population such as *Aspergillus* sp. (Tables 25 to 26 and Figs.24 to 25) was found with sole and intercropped pigeonpea in combination with IDM treatment. Similar results of increase in the population of *Penicillium* sp. and *Trichoderma* sp. (Figs. 24 to 25) was observed.

Total antagonistic fungal population levels were found to be maximum in IDM treated plot (Table 25 and Figs. 24 to 25). IDM treatment had recorded significantly higher levels of population (1770 and 2814 cfu/g soil) in pigeonpea/groundnut cropping system followed by application of GM and FYM during 1996-97 and 1997-98 years, respectively. The results of the present study are in confirmity with the findings of Naik (1993). Results obtained from studies on root exudates in the present investigation also supports the findings. In sole cropped pigeonpea IDM treatment was found better than other production practices which results in reduced *fusarium* population and enhanced antagonistic fungal population. Similar increase in the population of antagonistic fungi with the use of organic amendments had earlier reported by Mehrotra and Gupta (1989) and green manure Upadhyay (1992). Increased counts of *Trichoderma* ($8x10^2$ cfu/g soil) with talc based product of *Trichoderma* @ 4 g/kg seed had been reported earlier against *Macrophomina phaseolina* in urdbean by Ramakrishnan *et al.* (1994).

Changes in the population of microganisms with the application of amendments has been reported by Canullo *et al.* (1991). Stimulation and increase in the population of native antagonists upon application of neem cake (Khanna and Singh, 1974; margosa cake (Singh and Singh, 1981; neem leaves (Arunaryan and Mathew, 1993) had been reported earlier in pigeonpea in tobacco (Patel and Patel, 1998); and tomato (Prakash *et al.*, 1989). Maximum reduction of root rot in pigeonpea due to inducement of micro-organisms like *Aspergillus flavus, Bacillus subtilis, Penicillion* sp. and

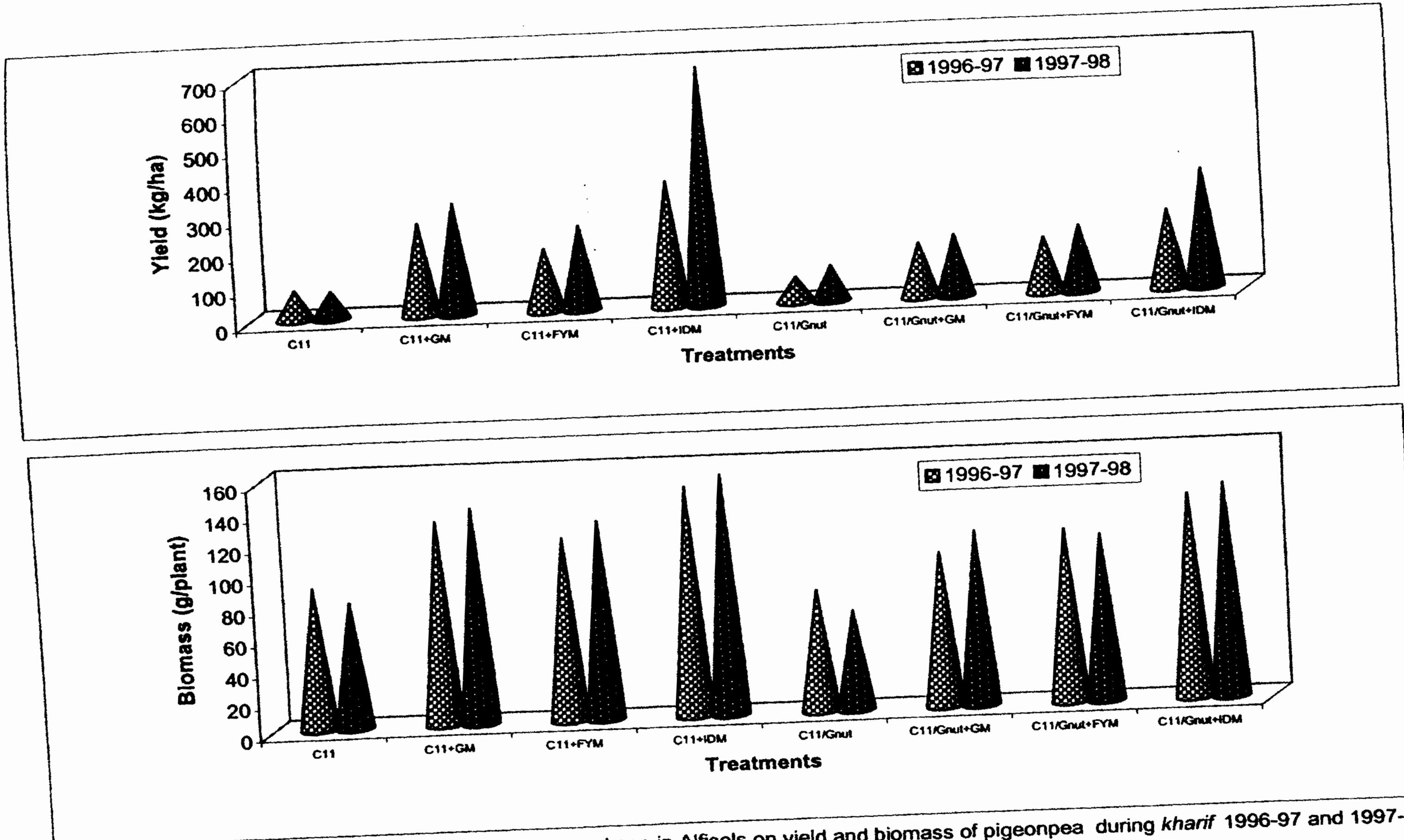


Fig.26: Effect of integrated disease management package in Alfisols on yield and biomass of pigeonpea during *kharif* 1996-97 and 1997-98

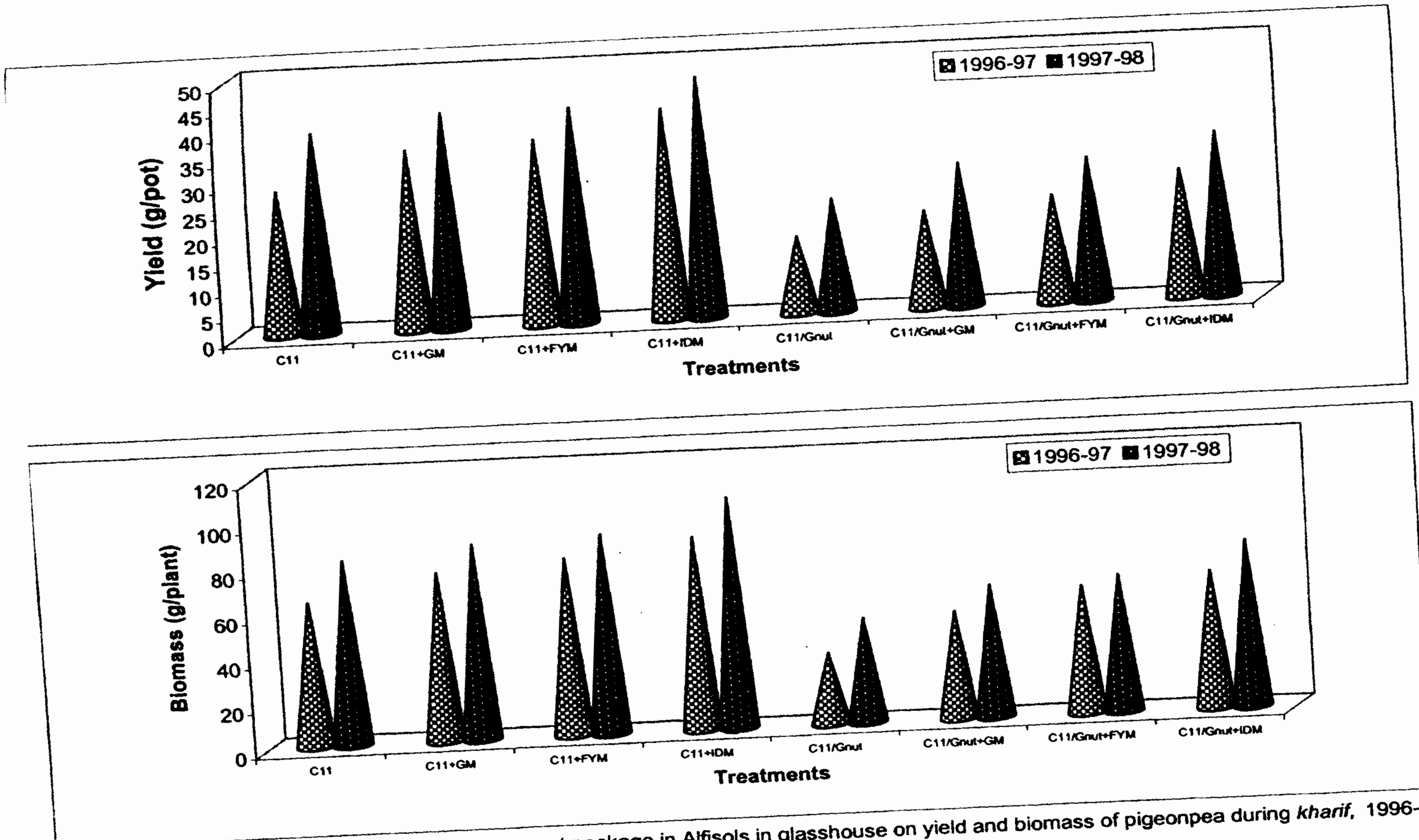


Fig.27: Effect of integrated disease management package in Alfisols in glasshouse on yield and biomass of pigeonpea during *kharif*, 1996-97 and 1997-98

Trichoderma viride in alfalfa amended soils earlier established by Arjunan *et al.* (1987). The decrease in ability of the pathogen to colonize pigeonpea substrates might be due to precolonization of substrates by *Aspergillus niger, A. flavus, penicillium citrinum, Aspergillus terreus* and *T. viride* in soils as earlier rerported by Rai and Upadhyay (1983). Antagonistic activity of *A. niger, A. flavus, A. terreus, Penicillium decumbens, P. pinophyllum, T. viride* and *T. harrianum* has been earlier established by Upadhyay and Rai (1989), Upadhyay (1992) and Naik (1993) as reported in the table 4.

Yield and biomass of pigeonpea was found superior with combination of treatments than their individual components (Tables 27-28 and Figs.26 and 27). This might be attributed to reduced wilt incidence and increase in plant growth due to additive effect of bioagent, amendments which promotes plant growth thereby reducing infection of fungus. Similar increase in yield and dry matter by integrated application of bioagents, fungicides and soil amendments and other methods of control had earlier reported in beans (Elad *et al.*, 1980); sugarbeet (Upadhyay and Mukhopadhyay, 1986); tomato (Mayakrishnan and Subbaraja, 1995); muskmelon (Chattopadhyay and Sen, 1996). Yield and biomass of pigeonpea were observed to be lower under intercropping compared to monocropping system. Similar results were reported earlier (Willey *et al.*, 1981; Natarajan *et al.*, 1985; and Bhatnagar, 1995). These implication of results may be attributed to reduced growth (Dalal, 1974; Ashoka Raja and Ramaiah, 1987) due to increased competition for nutrients in addition to the low population of pigeonpea under intercropping.

Soil physico chemical properties on *Fusarium* sp. such as pH (Upadhyay and Rai, 1987); exchangeable potash (Woltz and Jones, 1981); organic carbon content (Upadhyay, 1989); soil moisture and temperature (Mukhopadhyay and Sengupta (1991) and also C:N ratio of amendments (Khanna and Singh, 1974) influences the saprophytic survival of the pathogen in soil. Further studies are required on the interaction of various factors in the soil.

5.6 STUDIES ON INTEGRATED PIGEONPEA WILT MANAGEMENT IN VERTISOLS

Wilt incidence has been reported in general to be high in vertisols compared to Alfisols by Nene and Reddy (1981), and Reddy *et al.* (1990) inspite of higher levels of pathogen population (Naik, 1993) and higher levels of total antagonistic microorganisms (Upadhyay and Rai, 1985). In the present investigation, efficacy of pigeonpea wilt management in Vertisols was investigated with the adoption of nine production practices, including integrated disease management (involving seed dressing with fungicides and Trichoderma - 3 g of talc based formulation coupled with 1.5 g of Bavistin and thiram mixed in 1:1 proportion, basal application of $ZnSO_4$ @ 6.25 kg ha^{-1}, FYM and GM @ 1.25 tons ha^{-1}, in comparison to control under four cropping systems during two consecutive years 1996-97 and 1997-98 under both field and pot conditions.

The results revealed minimum wilt incidence (Figs. 28 and 29) in the IDM treatment (71-87%) compared to other production practices under

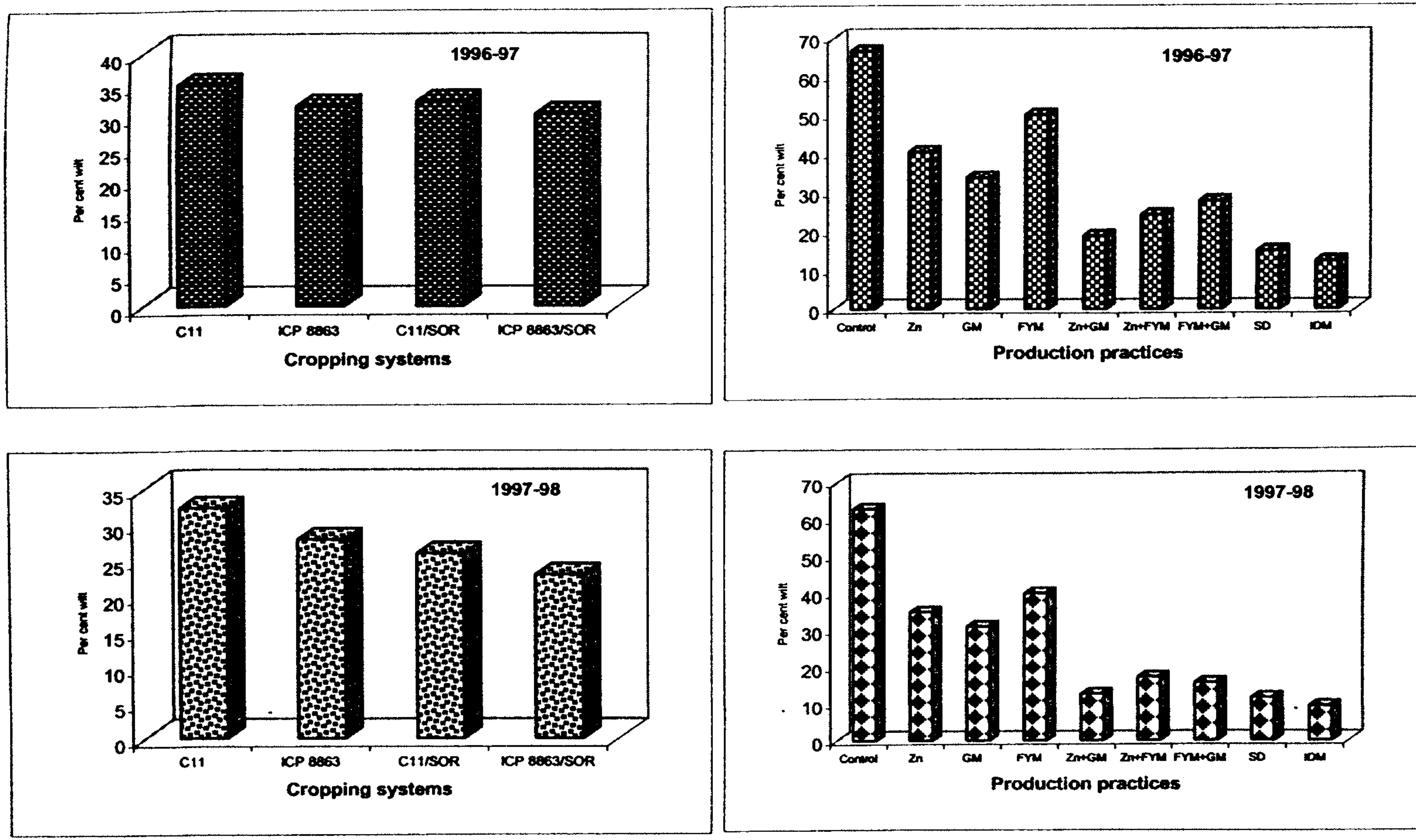


Fig.28: Effect of integrated disease management package in Vertisols on wilt incidence (%) in pigeonpea during *kharif* 1996-97 and 1997-98

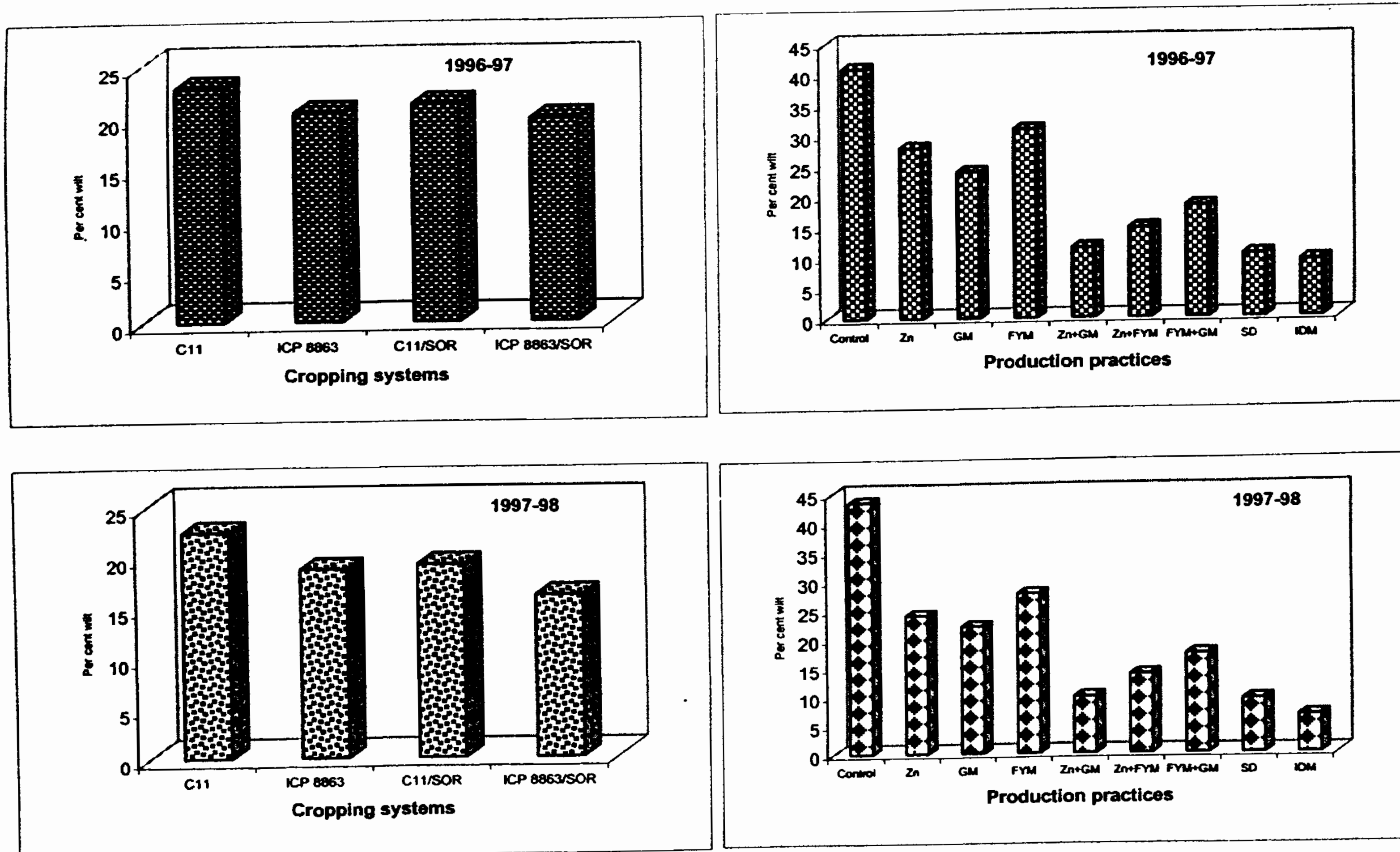


Fig.29: Effect of integrated disease management package in Vertisols in glasshouse on wilt incidence (%) in pigeonpea during *kharif* 1996-97 and 1997-98

all the cropping systems studied in the present investigation under both field and pot conditions during both years, due to a significant reduction in the fungal pathogen population (Figs. 32 and 33) as a result of increase in the antagonistic fungal population resulting in reduced competitive saprophytic ability of the pathogen. The reduction in CFU of *Fusarium* population over control was found to be 42 and 65 per cent over control with IDM treatment during 1996-97 and 1997-98 years, respectively. Similar results were reported by Rai and Upadhyay (1983) and Upadhyay and Rai (1985). The effectiveness of integrated disease management for the control of soil borne plant pathogens has also been reported by several other workers (Srivastava and Saksena, 1968; Elad *et al.*, 1983; Locke *et al.*, 1985; Jimenez and Traperocasas, 1985; Strashnov *et al.*, 1985; Upadhyay and Rai, 1989; Yonkov, 1989; Pandey and Upadhyay, 1999). A considerable reduction in pigeonpea wilt incidence upon fungicidal treatment with benlate and thiram (1:3) in combination with soil amendments of oat crop residues were reported by Kotasthane *et al.* (1987), while the integration of biocontrol agent with fungicides was observed to improve the prospects of *fusarium* wilt control in chickpea (Lifshitz *et al.*, 1985; papavizas, 1985; Upadhyay and Mukhopadhyay, 1986 and Rajib *et al.*, 1996). Chattopadhyay and Sen (1996) observed that integration of *T. viride*, carbendazim and soil amendment with sawdust were most effective in checking muskmelon wilt and improving biomass of the host plant. The integrated use of *Trichoderma*, neem cake and carbendazim reduces pathogen survivability, favours the proliferation of the bioagent and ultimately reduces the disease incidence (Arjunan *et al.*, 1987; Raghuchander *et al.*, 1993; Ratnoo and Bhatnagar, 1992 and Theradimani and Marimuthu, 1993).

Production of toxic metabolites by *Trichoderma* spp. on seed coats might be the principle mechanism in control of *Pythiumdamping* off. Second reason could be due to the poor establishment of the biocontrol agent in the soil due to lack of proper food base. The addition of antagonist to the soil at the proper time and with a suitable food base was considered a key criterion for biological control. Wight (1956) reported that appropriate food base is essential for the production of antibiotics by biocontrol agents. From the literature, it is evident that *Trichoderma* needs a food base to establish in soil (Harman *et al.*, 1981; Papavizes, 1982). This may be the reason, for the better performance of the bioagent integrated by integrated application of seed treatment with chemicals in presence of amendments. Amendments may increase the population of rhizosphere antagonists to pathogen (Upadhyay, 1992). In the present study inorganic and organic amendments might have acted as food base to some extent for the bioagent and inturn increase the total antagonistic fungal populations as evidenced from the Table 41 and Fig. 40.

Seed dressing with reduced amounts of fungicides and Trichoderma talc based product also resulted in effective disease control, through reduced pathogen population (Figs. 30 and 31) as a consequence of increased *Trichoderma* sp. population (Figs. 36 and 37). Antagonists when applied to seeds were found to colonize the rhizosphere and offer protection against the soil borne pathogens (Chao *et al.*, 1986; Turner and Backman, 1991; Harman, 1991). The introduction of antagonist along with the planting material, in the form of seed dressing was also reported to be more economical and effective method of biological control (Cook and Baker, 1983). Talc based product was found effective in reducing root rot (60%) caused by *Macrophomina phaseolina* in artificially infested soils and in farmers fields with sufficient increase in viable population of $80x10^7$ cfu/g soil in urdbean (Ramakrishnan *et al.*, 1994 and $8x10^3$ cfu/g soil in chickpea (Selvarajan, 1990).

Seed treatment with *Trichoderma* sp. was also reported to reduce the fusarium wilt incidence significantly in peas, corn, soybean and melons under both glasshouse and field conditions (Harman *et al.*, 1981; Kommedahl *et al.*, 1981; Windeb and Kommadahl, 1982; Naik, 1989; Sharma, 1989). Many workers have obtained successful control of soil borne diseases by integrating bioagents and fungicides in pigeonpea (Pandey and Upadhyay, 1999); chickpea (Mukhopadhyay *et al.* (1992). Significant reduction in wilt disease with reduced pathogen population was also obtained in cotton, melons and wheat crops with seed treatment of *T. harzianum* (Sivan and Chet, 1986) and crown rot of tomatoes in fields naturally infested with *F. oxysporum* f.sp. *lycopersici* (Sivan *et al.*, 1987) and chickpea with *T. viride* (Gowiley *et al.*, 1995). The seed treatment of pigeonpea with *T. viride* (H) isolate also reported to reduce *Fusarium udum* propagules in soil from 19.4 x 10^2 to 2.5 x 10^2 cfu/g soil, under glasshouse conditions (Somasekhara *et al.*, 1996), similar to the findings of the present investigation.

Zinc sulphate in combination with green manure and zinc sulphate in combination with farm yard manure were also found to be effective in reducing wilt incidence (Figs. 28 and 29) and superior over individual

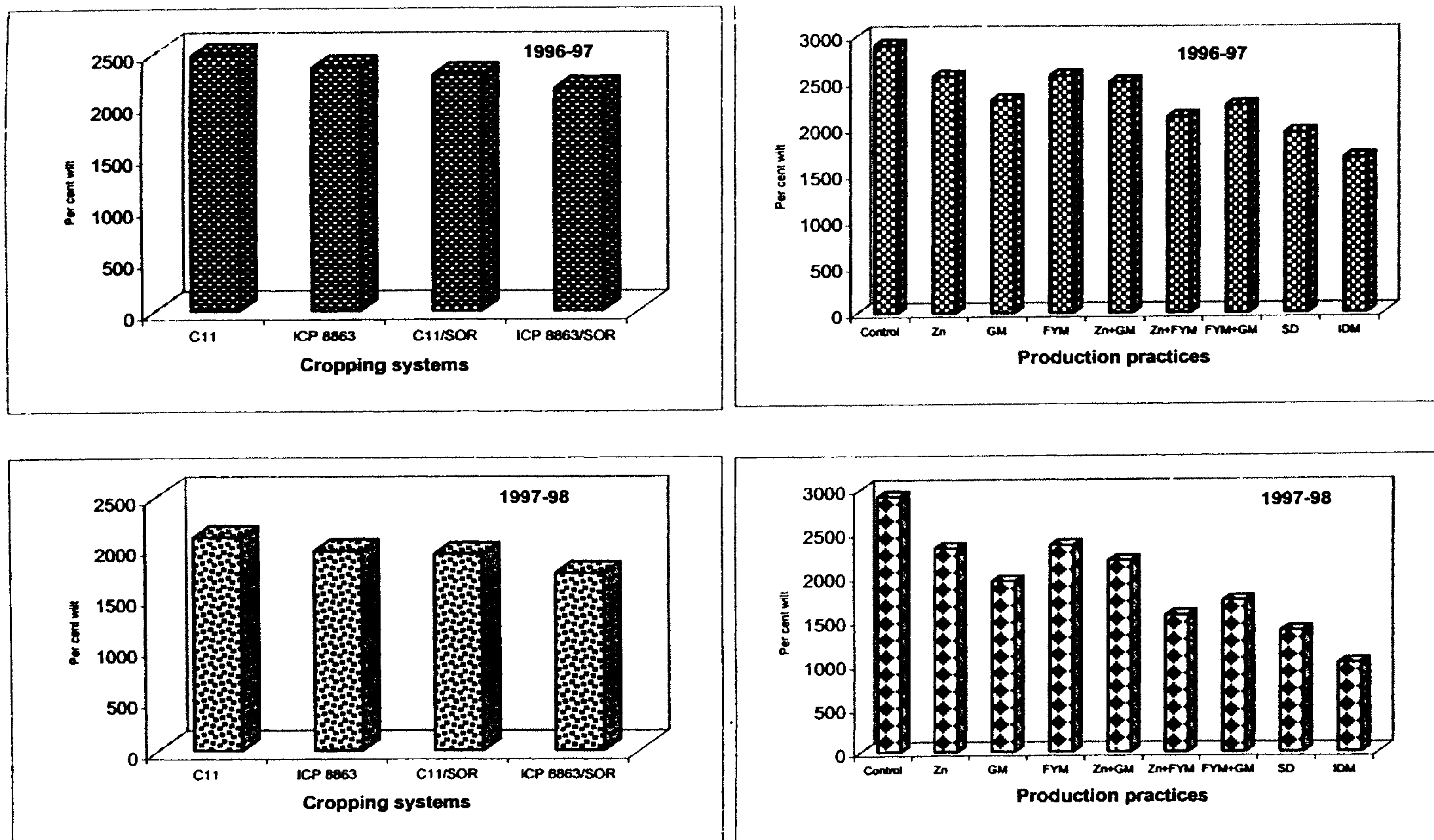


Fig.30: Effect of integrated disease management package in Vertisols on wilt pathogen *Fusarium udum* population (cfu/g soil) during *kharif* 1996-97 and 1997-98

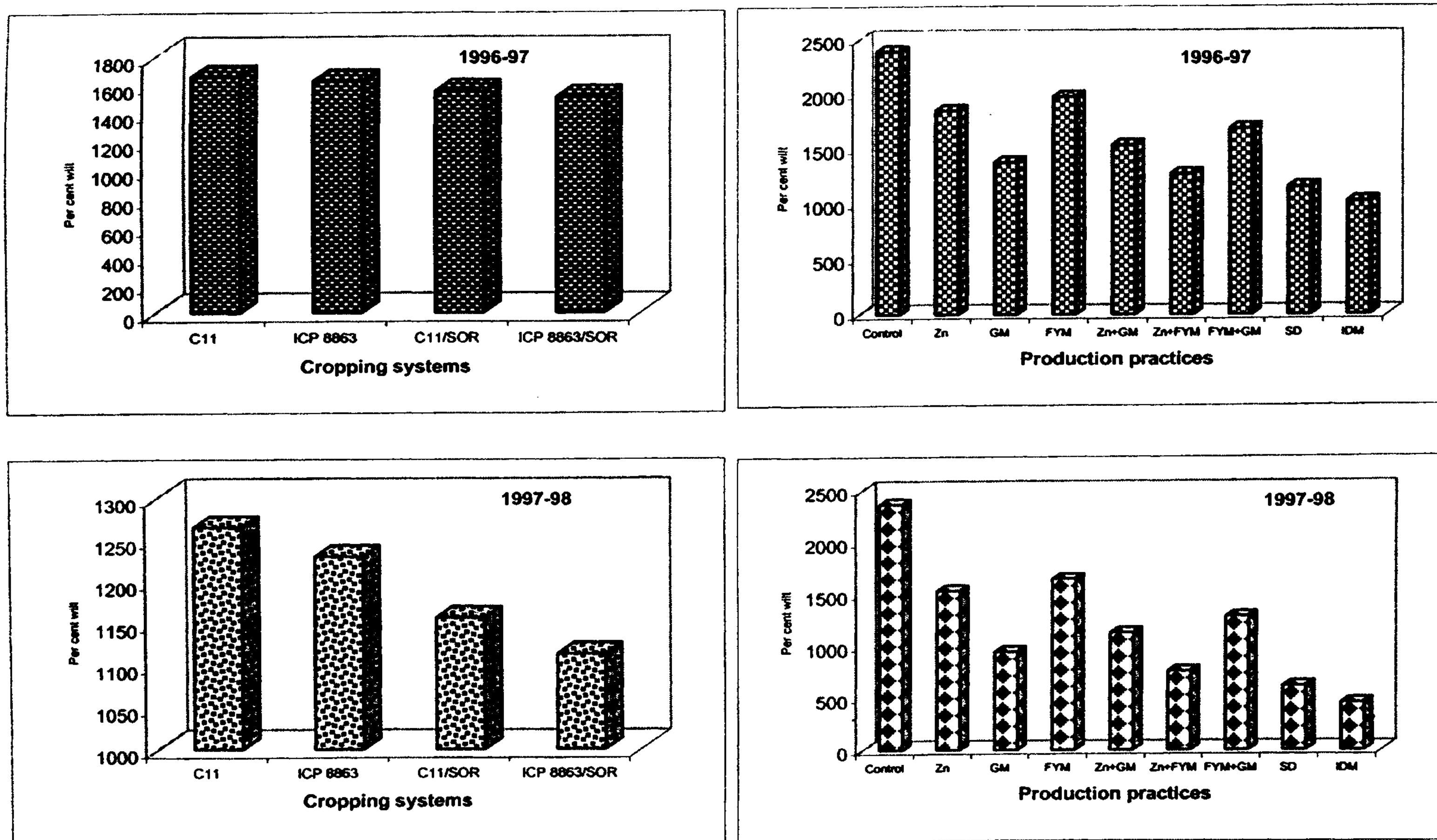


Fig.31: Effect of integrated disease management package in Vertisols in glass house on wilt pathogen *Fusarium udum* population (cfu/g soil) during *kharif* 1996-97 and 1997-98

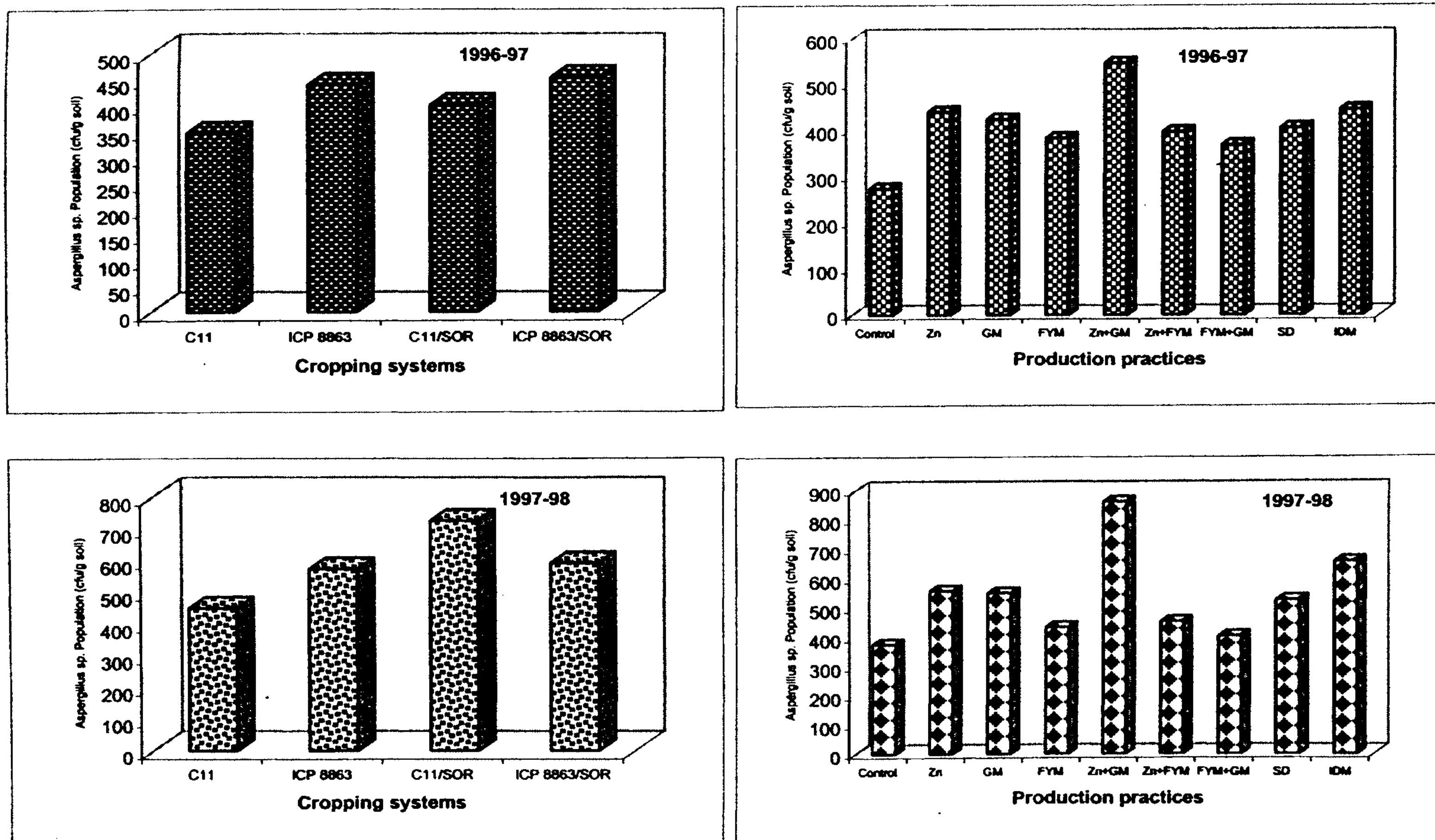


Fig.32: Effect of integrated disease management package in Vertisols on *Aspergillus sp.* population (cfu/g soil) during *kharif* 1996-97 and 1997-98

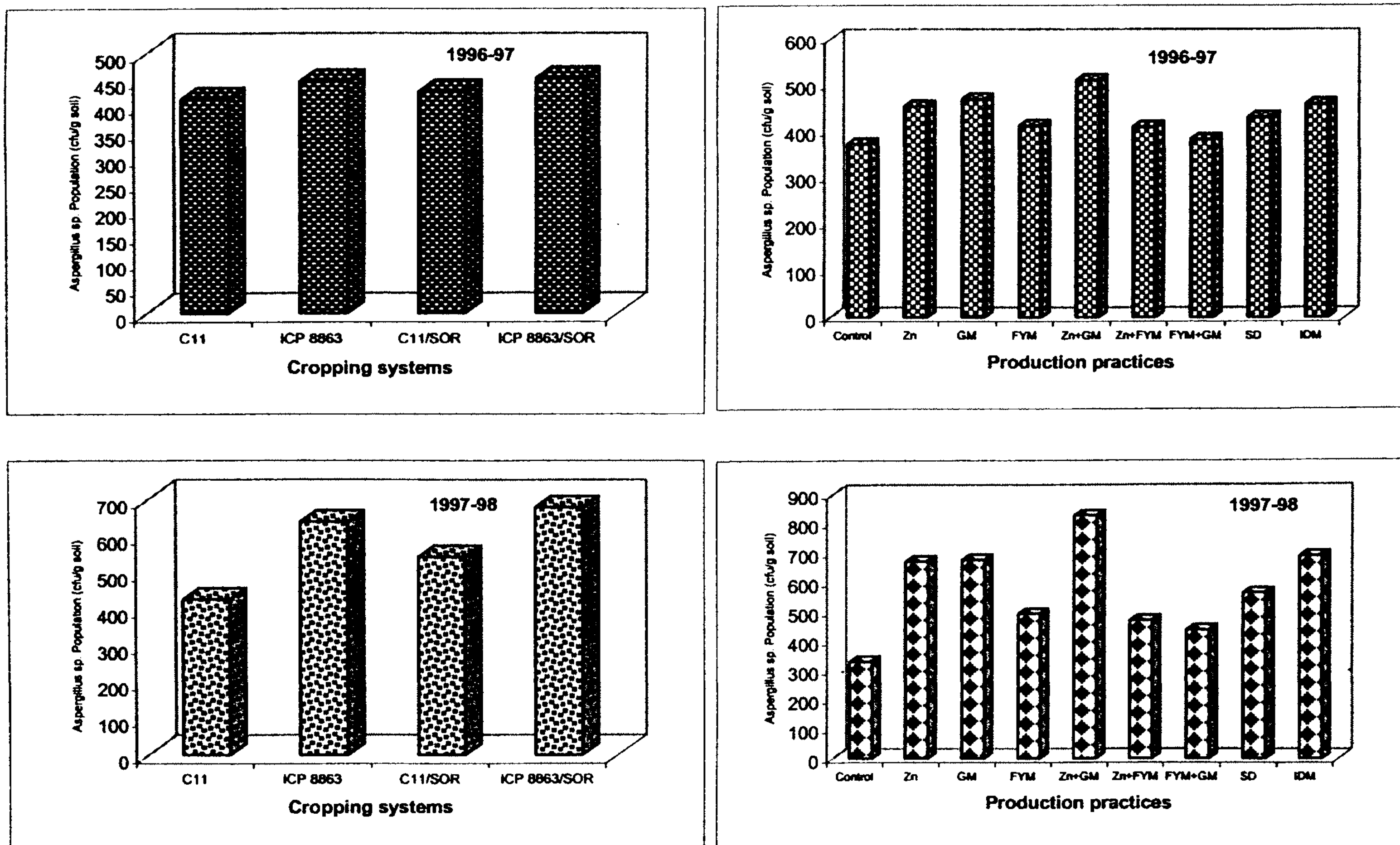


Fig.33: Effect of integrated disease management package in Vertisols in glasshouse on *Aspergillus* sp. population (cfu/g soil) during *kharif* 1996-97 and 1997-98

treatments and control. The reduced wilt incidence inspite of increased population of *Fusarium udum* in the treatments with application of Zn + GM may be attributed to release of more nitrogen, reduced competition and increased general microbial activity and decreased stimulatory effect of this treatment on *Fusarium udum* due to low C/N ratio of green manure crop (12.3%) utilized in the present study. Oswald and Lorenz (1956) and Weinke (1962) demonstrate that disease control is not always related to the number of pathogen propagules in soil. Amendments stimulate microbial activity by antibiosis and enhance the population of selective antagonistic rhizosphere population which ultimately result in reduction of population of soil borne pathogens (Zakaria *et al.*, 1980; Chakrabarti and Sen, 1991 and Patel and Patel, 1998).

The application of organic amendments such as green manure and farm yard manure were also reported to be quite effective in the control of pigeonpea wilt (McRae and Shaw, 1933; Mahmood, 1964; Vasudeva *et al.*, 1962; Upadhyay and Rai, 1981a; Satyaprasad and Rama Rao, 1983; Raghuchander *et al.*, 1992; Upadhyay, 1992 and Rai and Singh, 1995) due to an increase in the population of native antagonists (Khanna and Singh, 1974; Singh and Singh, 1981; Arunaryan and Mathew, 1993). Similarly, results of reduced pathogen population (Figs.30 and 31) and increased population of *Aspergillus* (Figs.32-33) and Penicillium (Figs.34-35) were found in the present investigation. The application of zinc was also reported to retard the colonization of pigeonpea substrates by *F. udum* in the soil (Sarojini, 1950). Deb and Dutta (1992) also reported a significant reduction

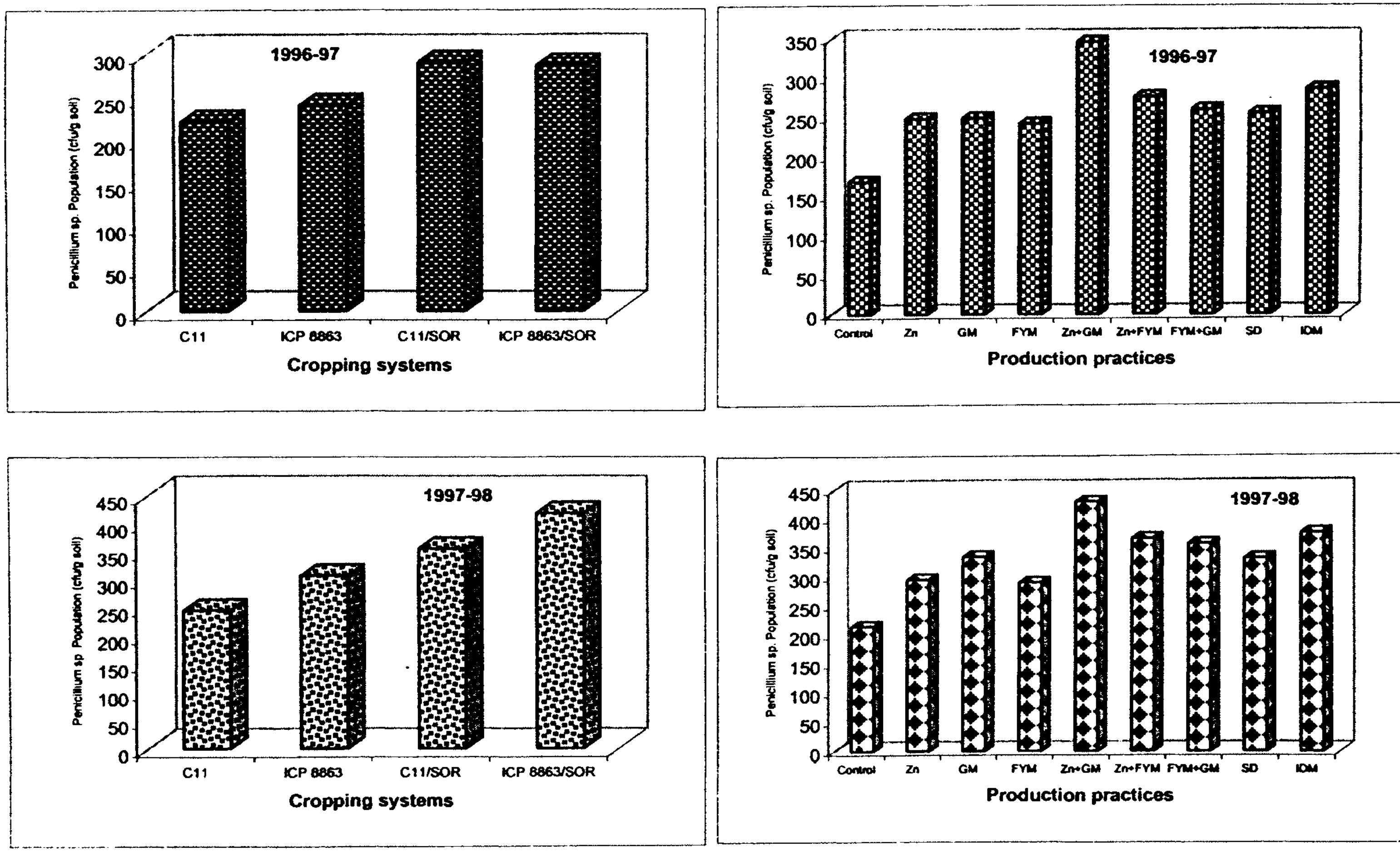


Fig.34: Effect of integrated disease management package in Vertisols on *Penicillium* sp. population (cfu/g soil) during *kharif* 1996-97 and 1997-98

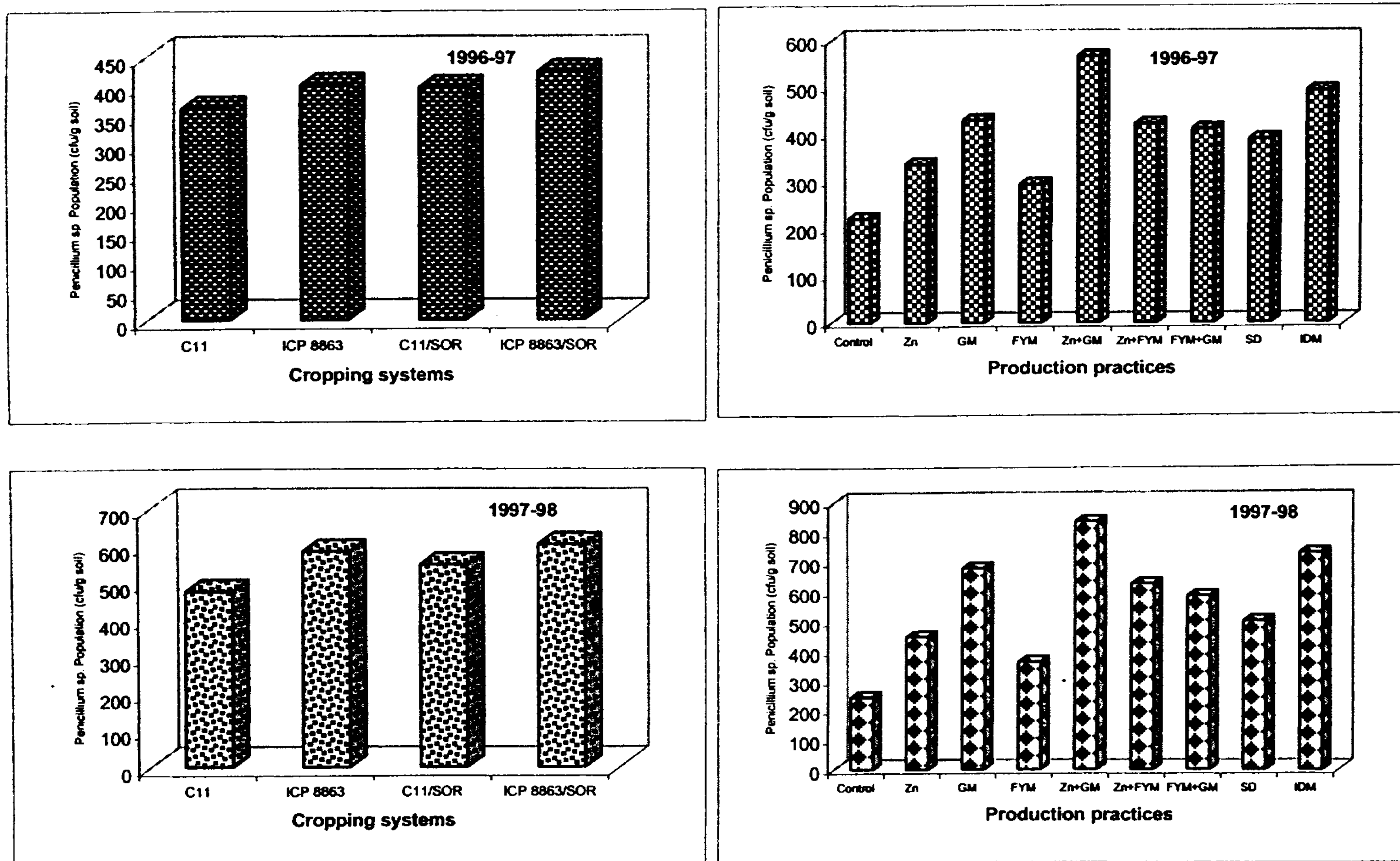


Fig.35: Effect of integrated disease management package in Vertisols in glasshouse on *Penicillium* sp. population (cfu/g soil) during *kharif* 1996-97 and 1997-98

in the disease caused by *Sclerolium rolfsii* of soybean upon application $ZnSO_4$ and reduced pathogen population such as *Fusarium* in pigeonpea with ammonium sulphate and calcium nitrate (Raghuchander *et al.*, 1992). Lysis of mycelium and chlamydospores of *Fusarium udum* might be due to high C:N ratio of amendments such as Farm yard manure (30.5%).

High C\N ratio residues incorporation was postulated to prevent chlamydospore germination or result in nitrogen starvation of the pathogen (Snyder *et al.*, 1959 and Toussan *et al.*, 1960). The initial stages of application of amendments with high C\N ratio known to create conditions of nitrogen deficiency. Reduced competition and increased microbial activity resulting in decreased stimulatory effect of the treatment on *Fusarium* sp. might be due to release of more nitrogen by further decomposition of amendments (Davey and Papavizas, 1963; Garret, 1963; and Khanna and Singh, 1974). Decrease of *fusarium* sp. population in soils amended with carbonaceous and nitrogenous materials has been observed by Gupta (1987). Low C:N ratio of green manure might result in increased number of rhizosphere mycoflora. Hence both were found to be beneficial for effective management of *Fusarium* population as well as for enhancement of antagonists. Suppression of the population of *F. udum* and wilt disease in field by amendments may be attributed to increased number of antagonistic microorganisms (Mahmood, 1964; and Mitchell and Alexander, 1961). The increased number of antagonists may possibly interfers with pathogen activity and reduced wilt incidence (Upadhyay, 1992). Soils with introduced antagonists through amendments were found to be suppressive to *Fusarium*. The utility of suppressive soils for biological control has been advocated by Baker and Cook, 1974. This indicates the involvement of microbial competitors in regulation of fungistatis and suppression of wilt disease in pigeonpea fields.

Among the cropping systems studied, monocropping of resistant pigeonpea (ICP 8863) was observed to result in significantly higher biomass and yields due to low levels of wilt incidence, compared to monocropping with tolerant pigeonpea (C11), as a result of reduced pathogen population as a consequence of increased antagonistic populations, under both field and pot conditions during both the years of study. The results may be attributed to low colonization and wilting of resistant pigeonpea plants and the subsequent reduced return of infected plant debris material to the soil, in contrast to increased inoculum load with the cultivation of susceptible pigeonpea, as a consequence of greater return of wilted plant debris containing innumerable number of pathogen propagules (both chlamydospores and conidia) to the soil, as reported by Katan (1971) and Naik *et al.* (1993). In addition root exudates of susceptible pigeonpea favour germination of the conidial spores of the pathogen, while inhibiting the antagonistic conidial germination as evidenced from the (Table 45 and Fig. 44) explaining the findings of the present investigation. The intercropping of resistant pigeonpea with sorghum had also resulted in significantly lower levels of wilt incidence, reduced pathogen population compared to monocropping, as a direct consequence of increased antagonistic fungal population. This may be attributed to excretion of certain substances in the rhizosphere of resistant cultivars which favour colonization

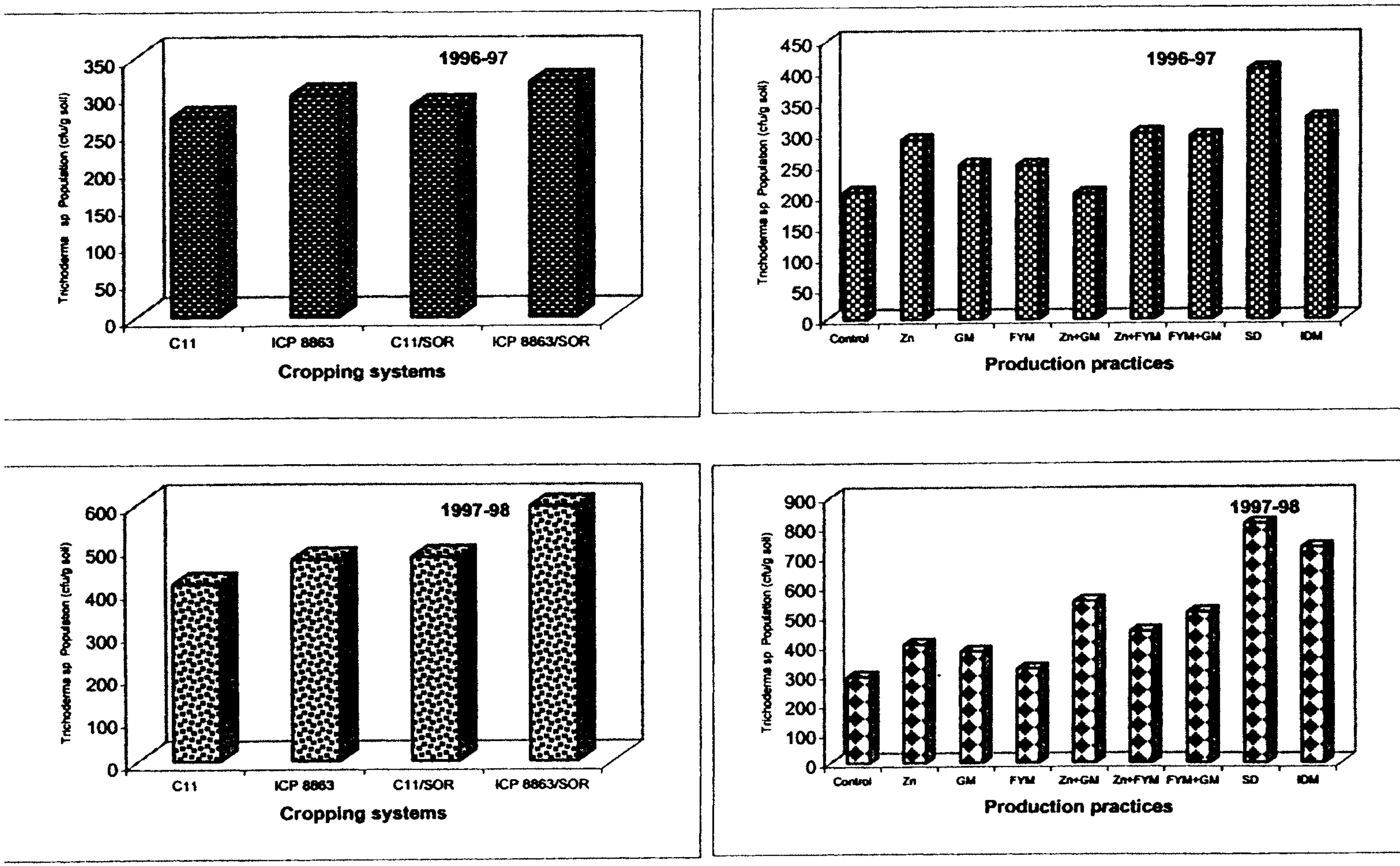
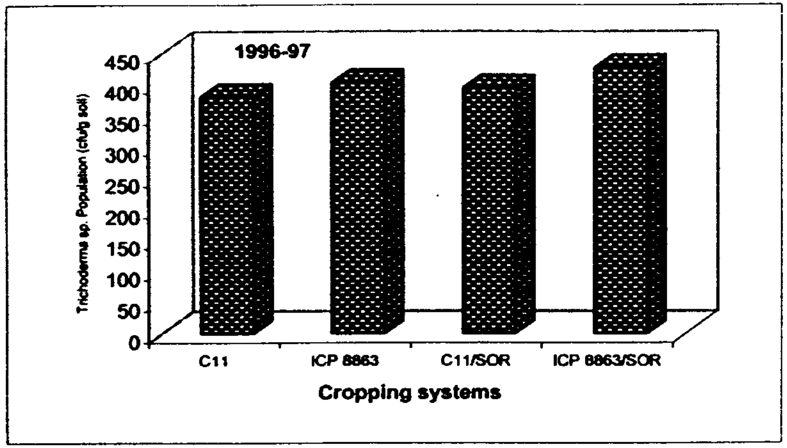
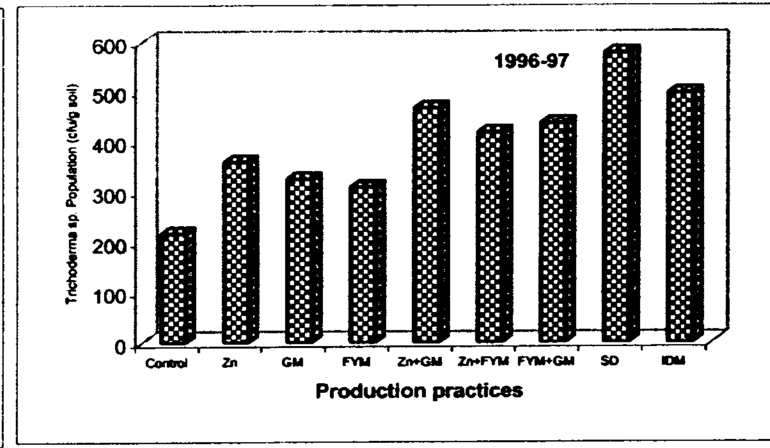
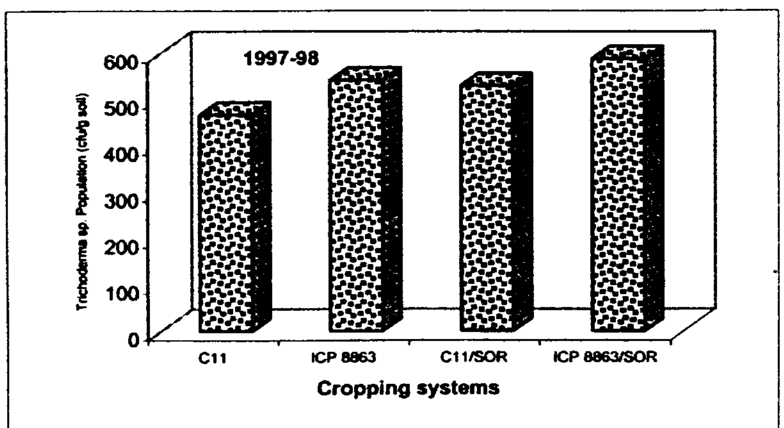


Fig.36: Effect of integrated disease management package in Vertisols on *Trichoderma* sp. population (cfu/g soil) during *kharif* 1996-97 and 1997-98







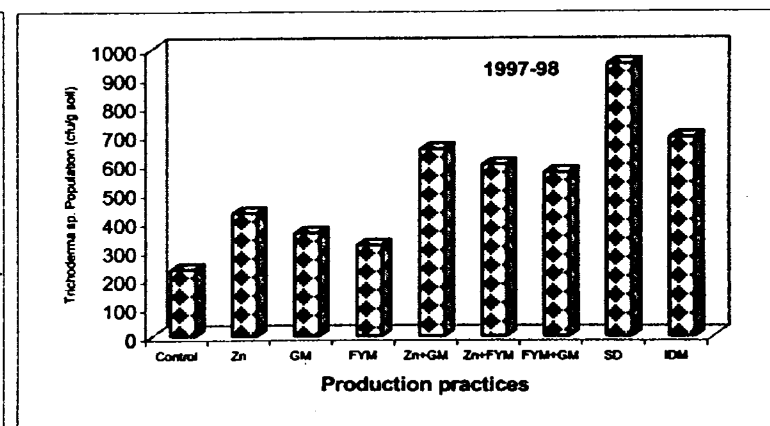


Fig.37: Effect of integrated disease management package in Vertisols in glasshouse on *Trichoderma* sp. Population (cfu/g soil) during *kharif* 1996-97 and 1997-98

of certain fungi in the resistant and pigeonpea/sorghum intercropping system as earlier reported by Natarajan *et al.*, 1985; Sharma *et al.*, 1987; Singh *et al.*, 1990; Naik, 1993; Bhatnagar, 1995; and Naik *et al.*, 1997. Naik (1993) reported decreased population of *Fusarium udum* and increased mycoflora of *Aspergillus niger, A. terreus, Penicillium decumbens; P. pinophyllum* and *T. viride*. With resistant cultivar ICP 8863 (Gaur and Sharma, 1991). Kotasthane *et al.* (1985) reported increased population of *Fusarium udum* with susceptible cultivar ICP 6997 and Naik (1993) with ICP 2376.

A study of interaction effects revealed significant differences among production practices and cropping systems. Integrated application of different treatment combinations in combination with intercropped tolerant pigeonpea (C11) and resistant pigeonpea (ICP 8863) was found to be characteristic. However, Zn.GM and FYM in combination with intercropped pigeonpea results in reduced wilt incidence and pathogen population. This might be due to increased population of antagonists *Aspergillus* (Figs. 32-33), *Penicillium* (Figs.34-35) and *Trichoderma* spp. (Figs.36-37) with the influence of amendments. Amendments effectively increases certain fungi in the soil i.e., neem cake increases *Aspergillus* sp. (Goswamy and Bhattacharya, 1985). Increase of *Trichoderma* population with ammonium sulphate and NPK, *Penicillium* sp. with calcium nitrate (Dutta and Issac, 1979); and *Penicillium* and *Trichoderma* spp. together with $ZnSO_4$ (Deb and Dutta, 1992) respectively. The elevated fungistasis in natural soils amended with leaves of *Azadiracta indica, Eucalyptus globulus* and *crotolaria medicagenia* was established by Upadhyay and Rai (1981b). The changes

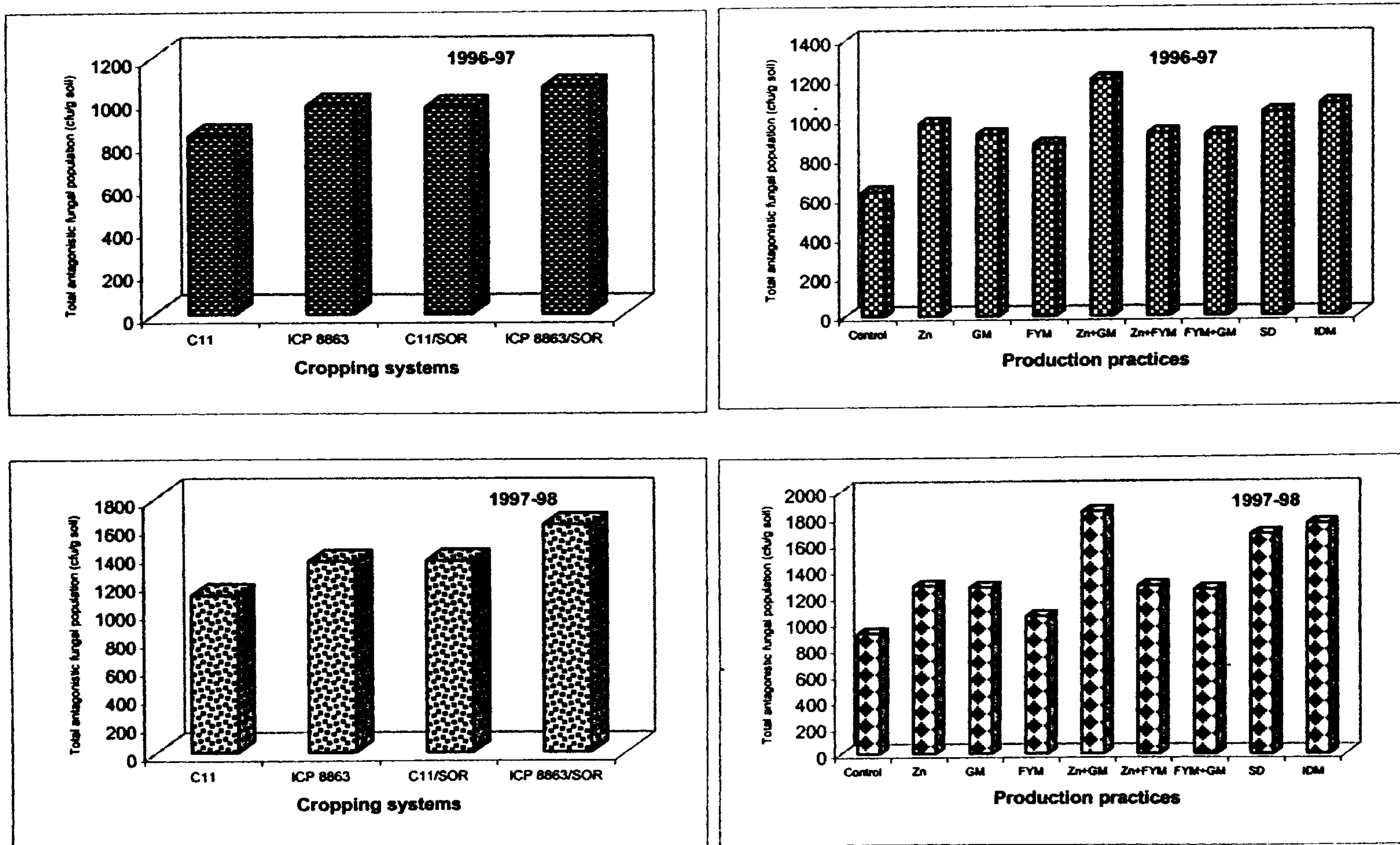


Fig.38: Effect of integrated disease management package in Vertisols on total antagonistic fungal population (cfu/g soil) during *kharif* 1996-97 and 1997-98

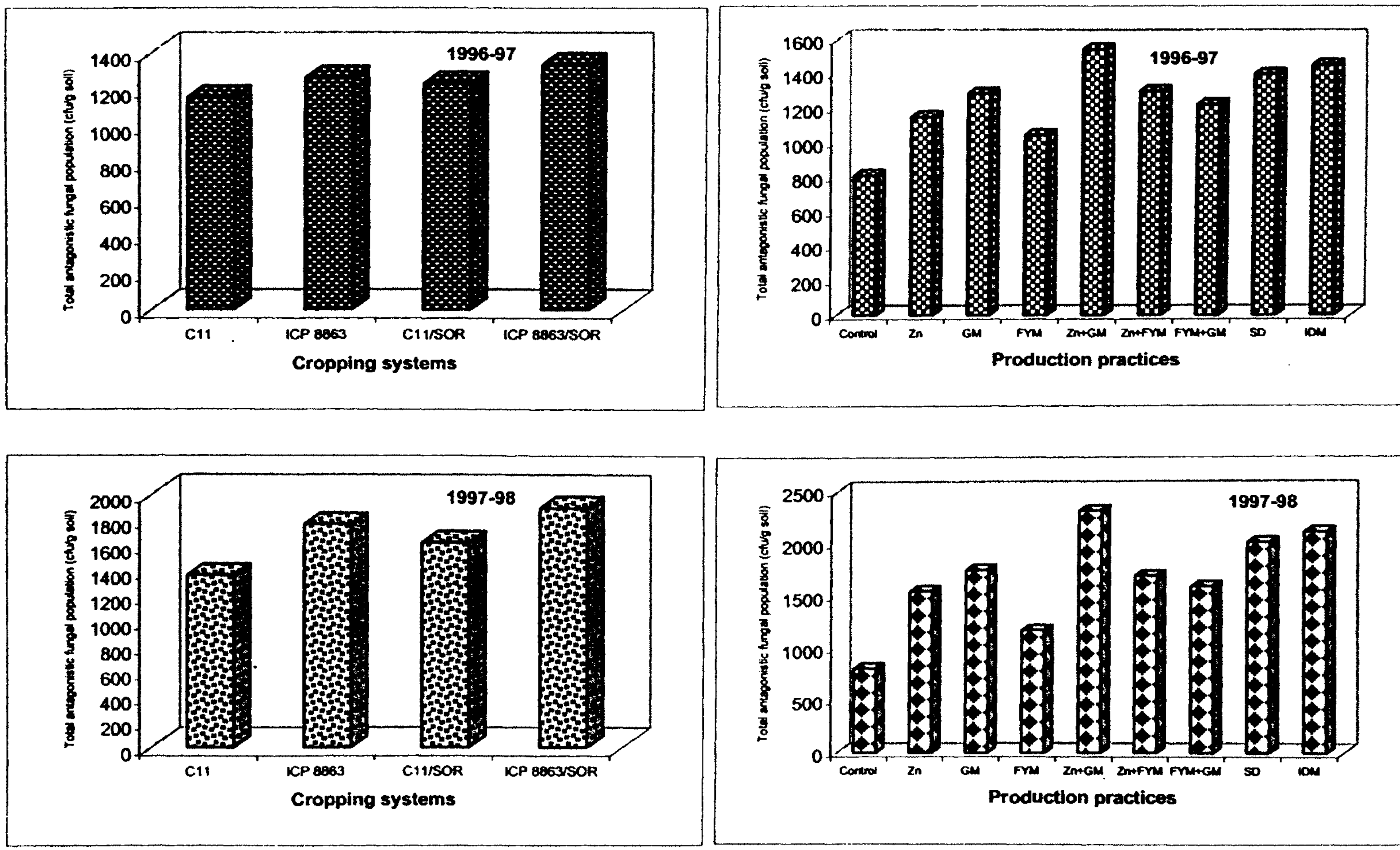


Fig.39: Effect of integrated disease management package in Vertisols in glasshouse on total antagonistic fungal population (cfu/g soil) during *kharif* 1996-97 and 1997-98

in the behaviour of *fusarium* sp. in the rhizosphere of pigeonpea in amended soils could be due to qualitative and quantitative changes in root exudates, better root growth, effects on soil microflora and possible formation of compounds by interaction of root exudates of intercrops and decomposition products.

Integrated disease management not only involves disease suppression but also pathogen management. The importance of pathogen population in soil has been stressed by Wensley and Mckeen (1966) and Naik (1989). In the present study, this job could be done to some extent through amendments by increasing the population of antagonists and bioagent. This integration of SD, $ZnSO_4$, GM and FYM improved the performance demonstrating the advantage of the integration in increasing the yield through suppression of pathogen by antagonists in colloboration with carbendazim and thiram.

In the present study observations on total antagonistic fungal population (Tables 39 to 40 and Figs.38 to 39) Zn + GM recorded maximum population (1204 and 1842 cfu/g soil) followed by IDM (1080 and 1740 cfu/ g soil) and seed dressing (1038 and 1662 cfu/g soil). These treatments had an additive effect in incremental increase in population significantly over control under pot conditions. Variation in the wilt incidence, *Fusarium udum* and population of antagonists in field and pots might be due to influence of microclimatic conditions and narrow spacing of plants in pots. Similar observations on the incremental population of rhizosphere microflora in general by soil amendments reported by (Zakaria *et al.*, 1980; Prakash *et al.*, 1985;

Upadhyay, 1992). Soil amendments may also contribute to inhibition of soil borne pathogens by antibiosis or enhancing the population of selective antagonistic rhizosphere mycoflora which ultimately result in reduction of population of soil borne pathogens (Papavizas and Davey, 1960; Mixon and Curl, 1967; Gautam and Kolte, 1979; Prakash *et al.*, 1985). Prevention of colonization of pigeonpea substrates by *F. udum* and suppression of pathogen population by antagonists like *Ppenicillum citrinum, A. niger, A. flavus* and *A. terreus* and *T. viride* in the soil environment with chemical treatments like bavistin and herbicides viz., 2,4D and machete had earlier reported (Rai and Upadhyay, 1983) and with amendments (Upadhyay, 1992).

Intercropped resistant pigeonpea with sorghum had recorded maximum population (1060 and 1615 cfu/g soil) over tolerant C11 (1361 and 968 cfu/g soil). Antagonists found to colonize the rhizosphere and offers protection against several soil borne pathogens (Turner and Backman, 1991). The rhizosphere environment created by different crops or soils may have a direct influence on the type and population of micro organisms affecting plant growth (Naik, 1993). The variation in the population between resistant and susceptible cultivar might be due to presence of certain toxic substances which in turn favour certain associated antagonists in infested soils (Agnihothrudu, 1955; Upadhyay and Rai, 1983b; Sivan and Chet, 1986; Naik, 1993 and Arunaryan and Mathew, 1993) as reported in Table 2. *Trichoderma viride* and *A. niger* were reported to be dominant mycoflora of resistant pigeonpea cultivar ICP 8858 (Shaik Imam and Nusrat, 1987) and *A. niger* and *P. pinophyllum* with SP-15 (Guar and Sharma, 1991).

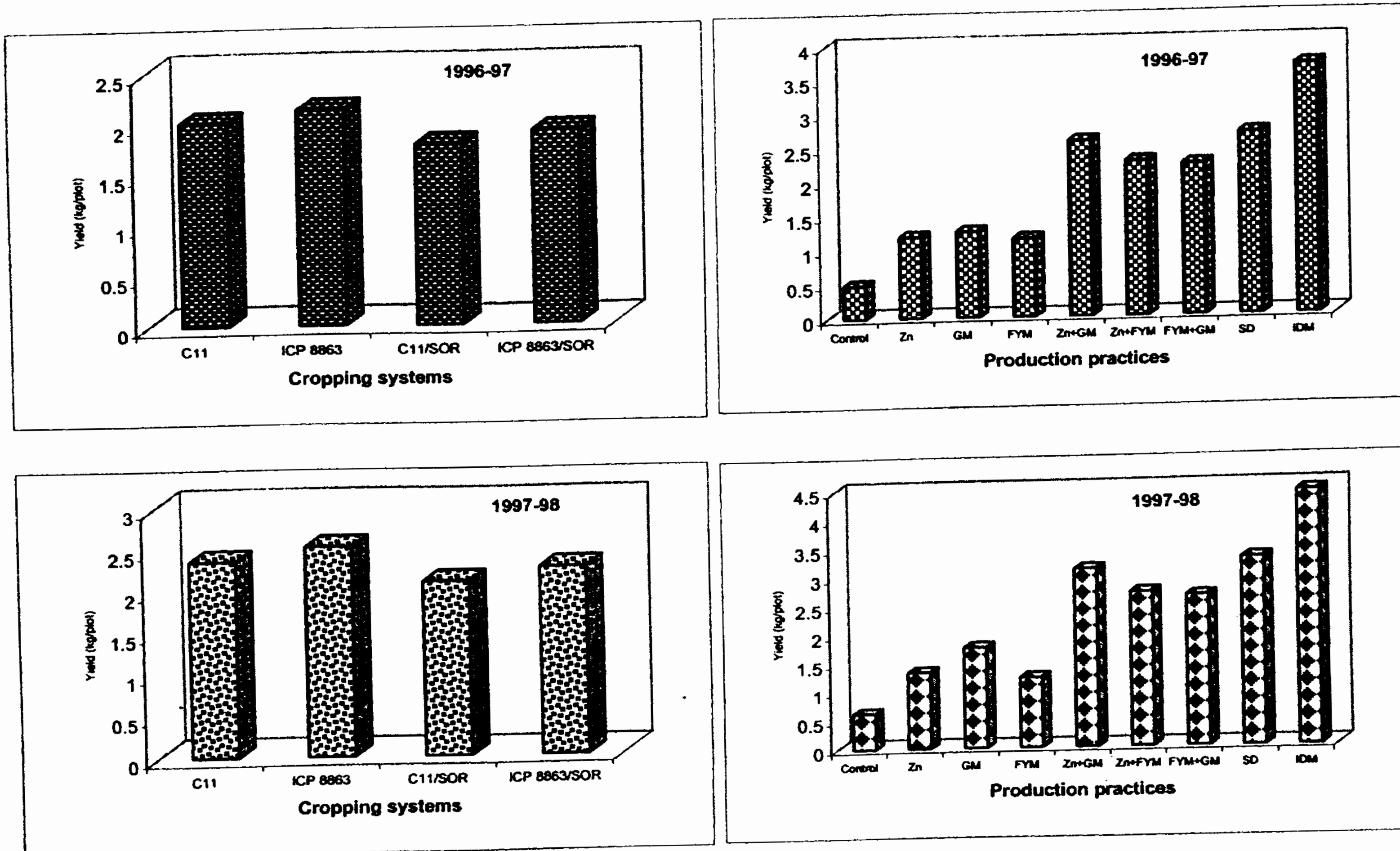


Fig.40: Effect of integrated disease management components in Vertisols on yield of pigeonpea (kg/plot) during *kharif* 1996-97 and 1997-98

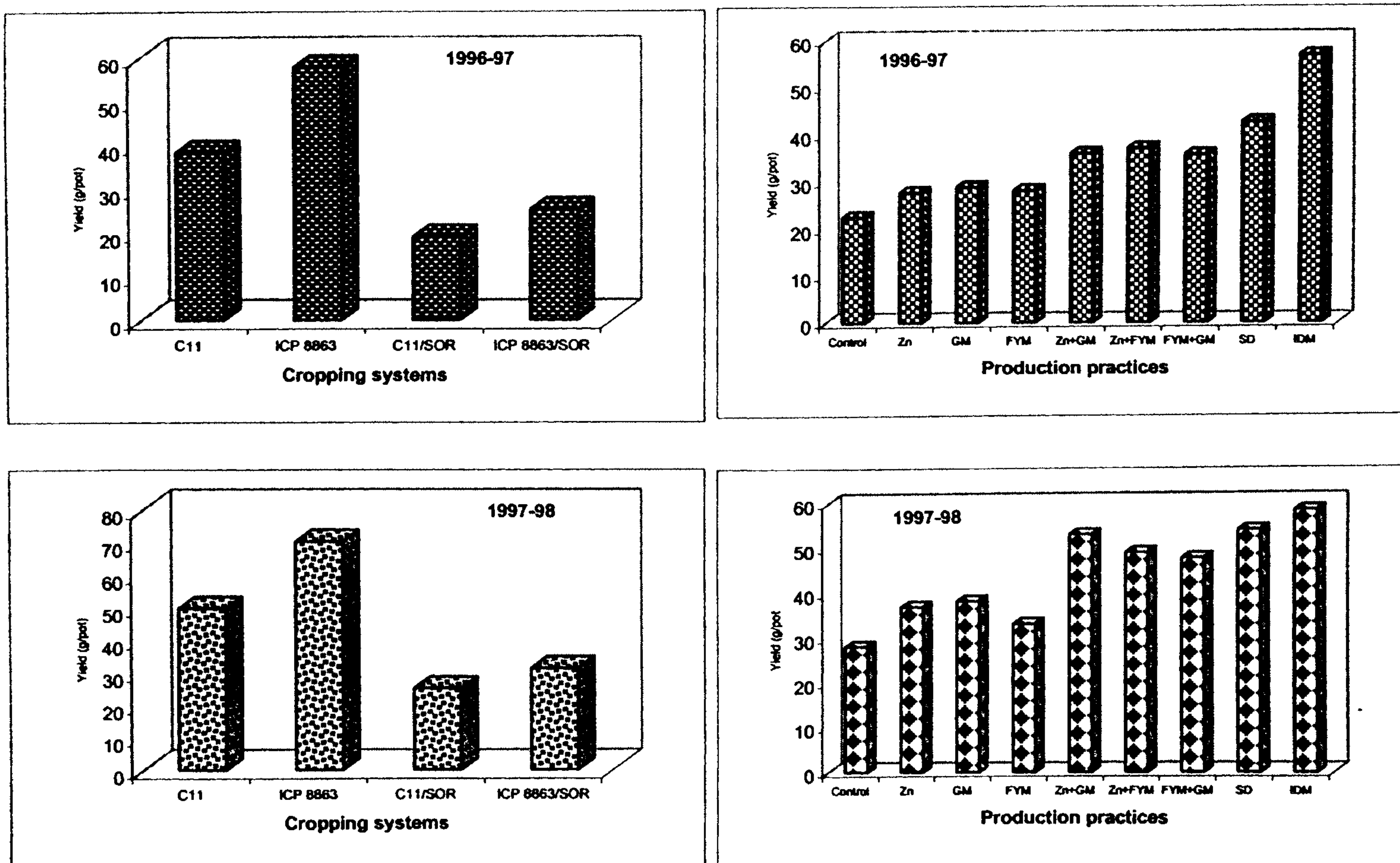


Fig.41: Effect of integrated disease management components in Vertisols in glasshouse on yield of pigeonpea (g/pot) during *kharif* 1996-97 and 1997-98

Predominant mycoflora such as *Aspergillus* spp. *P. pinophyllum* and *T. viride* as reported earlier by Naik (1993) from the rhizosphere of resistant and intercropped pigeonpea with sorghum. Antagonistic activity of several mycoflora in pigeonpea against *F. udum* has reported by several workers presented in Table 4.

Soils with introduced antagonists and enriched soils with antagonists through organic residues becomes suppressive to *F. udum* as well to wilt disease. The utility of suppressive soils for biological control of soil borne plant pathogens has been advocated by Cook and Baker, 1983; Upadhyay and Rai, 1984ab). Some of the suppressive soils with high degree of fungistatic activity found to be richly inhabited by species of *Aspergillus Penicillium* and *Trichoderma* spp. (Upadhyay and Rai, 1979).

The study also revealed, relatively higher yield and biomass of pigeonpea coupled with reduced wilt incidence during subsequent year (1997-98) under both field and pot conditions. Reduced wilt incidence and pathogen population due to an increase the antagonistic fungal population and increased plant growth as a consequence of the use of same plot/soil during the second season might be responsible due to the adoption of same treatment. Further, in integrated disease management the ultimate economic benefit, yield has to be taken into consideration. Combination of treatments had resulted in significant increase in yield and biomass over individual treatments and control (Figs.40 to 43). Sole cropped pigeonpea had recorded more yield than intercropped pigeonpea. Similar results had earlier reported by Willey *et al.* (1981), Natarajan *et al.* (1985) and Sharma (1989)

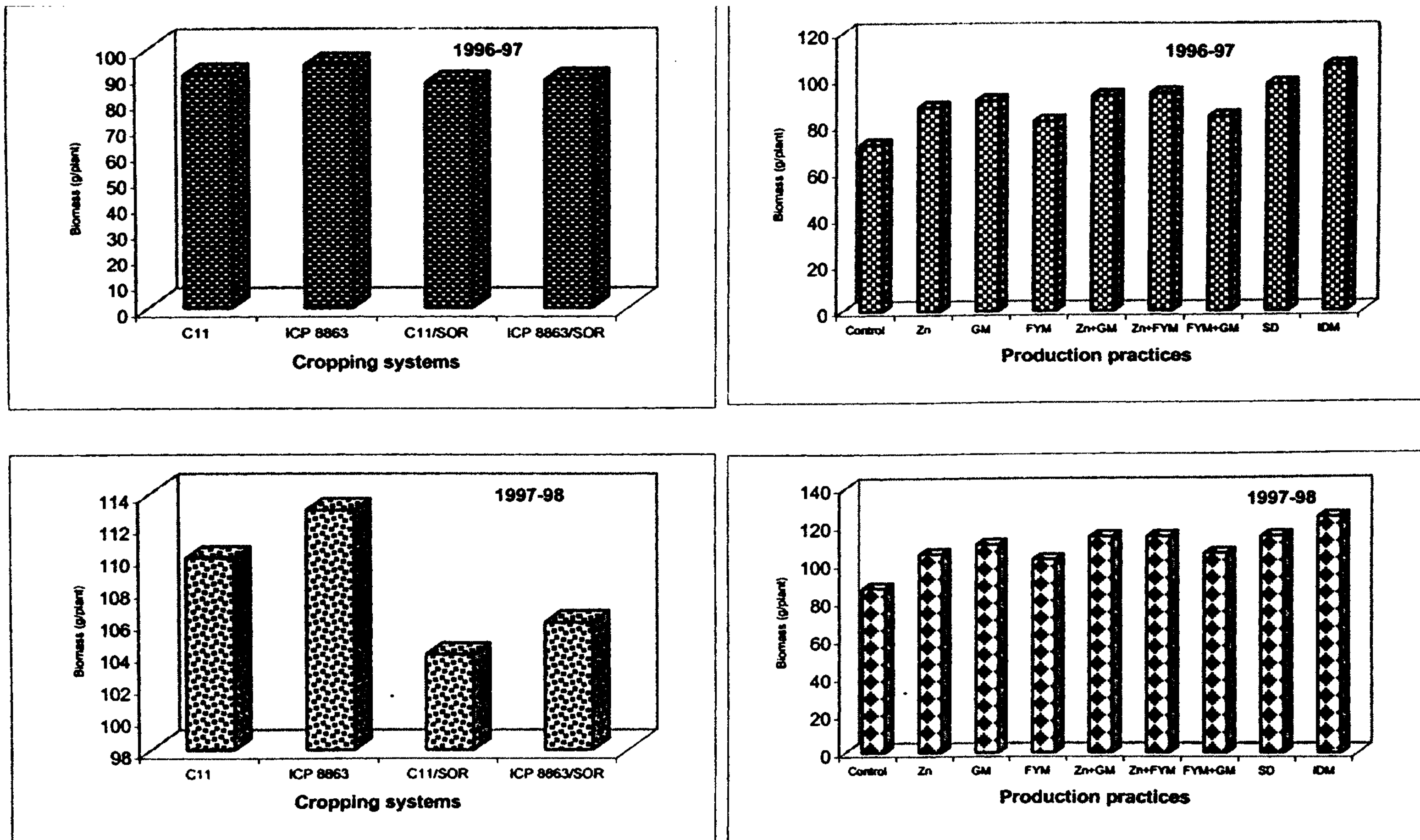


Fig.42: Effect of integrated disease management components in Vertisols on biomass of pigeonpea (g/plant) during *kharif* 1996-97 and 1997-98

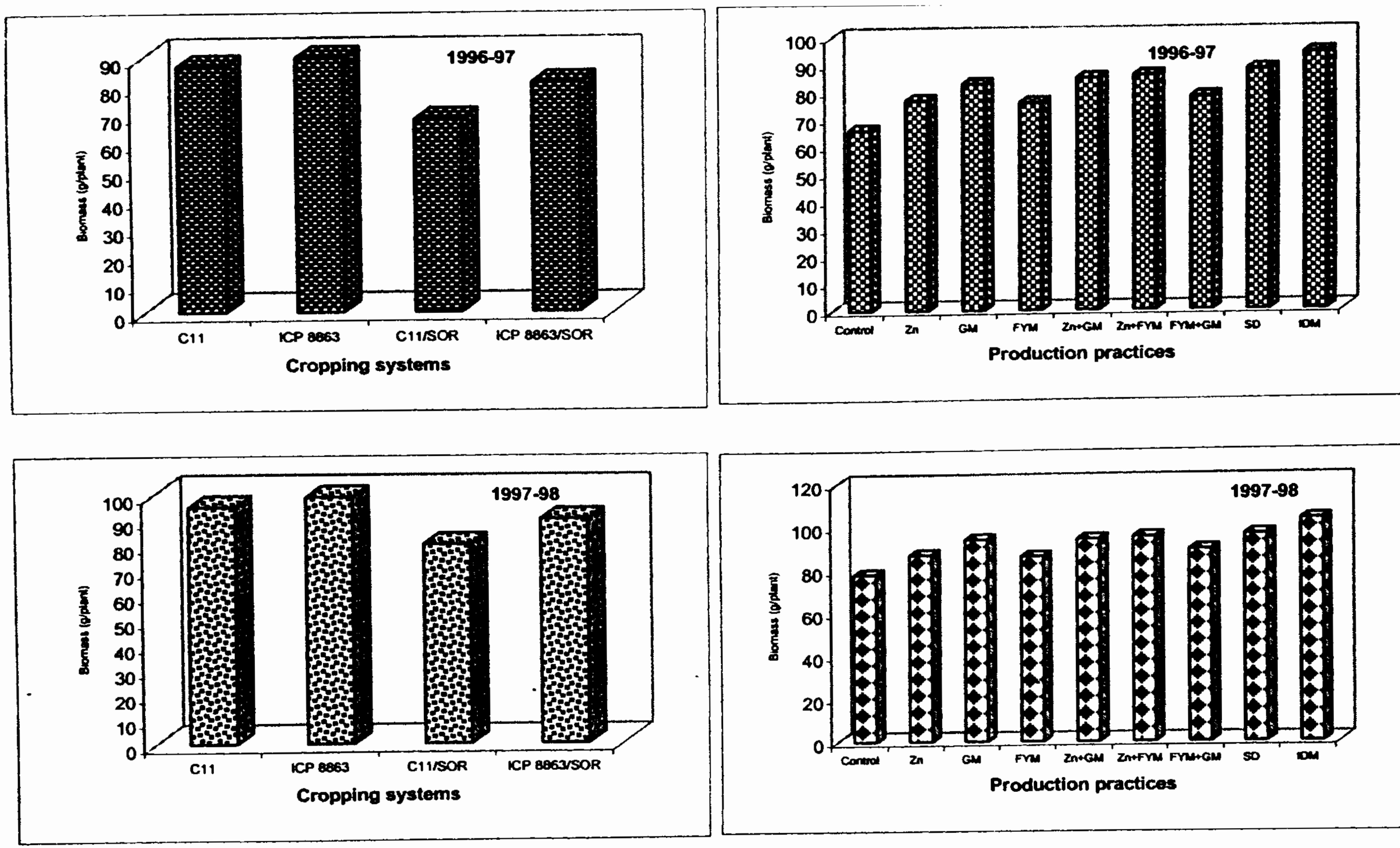


Fig.43: Effect of integrated disease management components in Vertisols in glasshouse on pigeonpea biomass (g/plant) during *kharif* 1996-97 and 1997-98

as a consequence of reduced plant population (Dey, 1947a). Similar yield increase and biomass by integrated application of bioagents, soil amendments and other methods of control in beans (Elad *et al.*, 1980), sugarbeat (Upadhyay and Mukhopadhyay, 1986) and in pigeonpea (Pandey and Upadhyay, 1999). Increase in yield and biomass with integrated treatments, probably as a consequence of improvement of soil tilth, soil physico chemical properties and nutrient status as reported earlier by Sivaprakasan (1990).

In the present study, *Trichoderma* talc based product in combination with sublethal dose of fungicides and soil amendments is one of the most attractive ways of disease control. The rhizosphere environment created by different crops or soils may have a direct influence on the type and population of micro organisms affecting plant growth. Therefore, understanding how micro organisms are influenced by soil environment and identifying the cropping system suitable for favourable microbial enhancement is important to manipulate desired micro organisms and achieve a sustainable and inbuilt disease suppressive system.

It is evident from the results discussed that the integrated disease control is a better strategy. Because of this, in recent years much emphasis has been placed on integrated control of plant pathogens using different components. This approach may prove more effective where no single component is effective, particularly in the control of soil borne diseases. As stated by Klassen (1982) high priority should be given for system research to optimize the joint use of biocontrol agents with other control methods in integrated management of insect pests, plant pathogens, nematodes and weeds.

5.7 STUDIES ON THE ROLE OF ROOT EXUDATES IN PIGEONPEA WILT CONTROL

Plant root exudates affect survival, reproduction and development of various micro organisms in soil through extremely complex phenomena (Snyder, 1960). Schroth and Hilderbrand (1964) explained that plant exudates affect the pathogens directly by inducing their germination, contributing to their nutritional status prior to penetration, or by inhibiting their saprophytic and pathogenic activities, and indirectly by competition and antibiosis by the root microflora whose activities also are mediated by exudates. Therefore, in the present investigation, the effect of different crop root exudates on the conidial germination and radial growth of the wilt pathogen as well as its antagonistic fungi was studied.

The results revealed a significant inhibition of the conidial germination and radial growth of the wilt pathogen with crop root exudates of groundnut, castor, soybean, sunflower, maize, greengram, hybrid sorghum and resistant pigeonpea, compared to control (Tables 45 and 46 and Figs.44 and 45). Maximum inhibition was noticed with the root exudates of groundnut. Similar results were reported by Bhatnagar (1995). Further, the inhibition of conidial germination of *Fusarium udum* observed with the resistant cultivars of pigeonpea may be attributed to the low levels of carbon and nitrogen, reported to be required for the germination of fungal spores

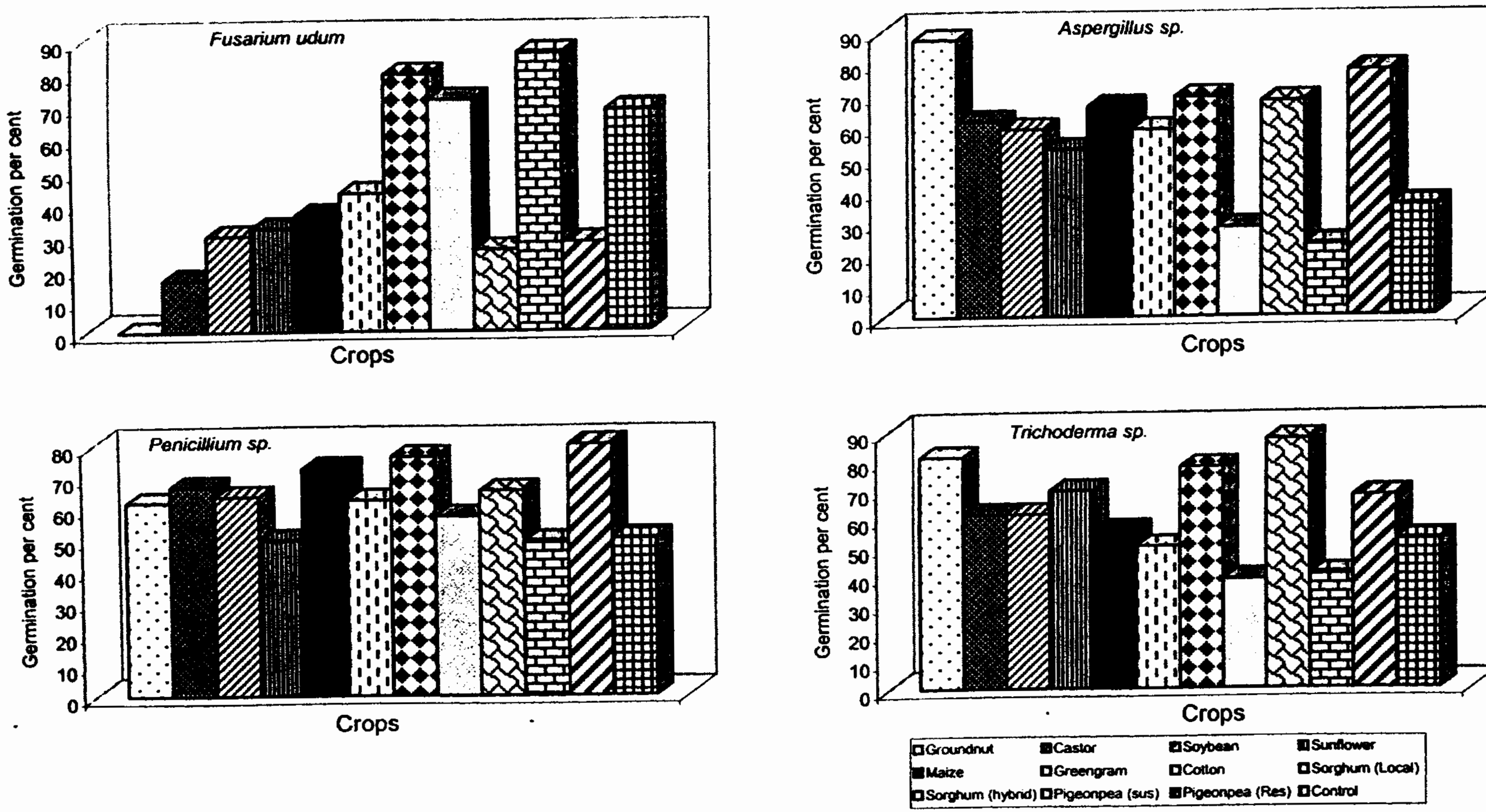


Fig.44: Effect of root exudates of different crops on conidial germination of *Fusarium udum* and its antagonistic fungi

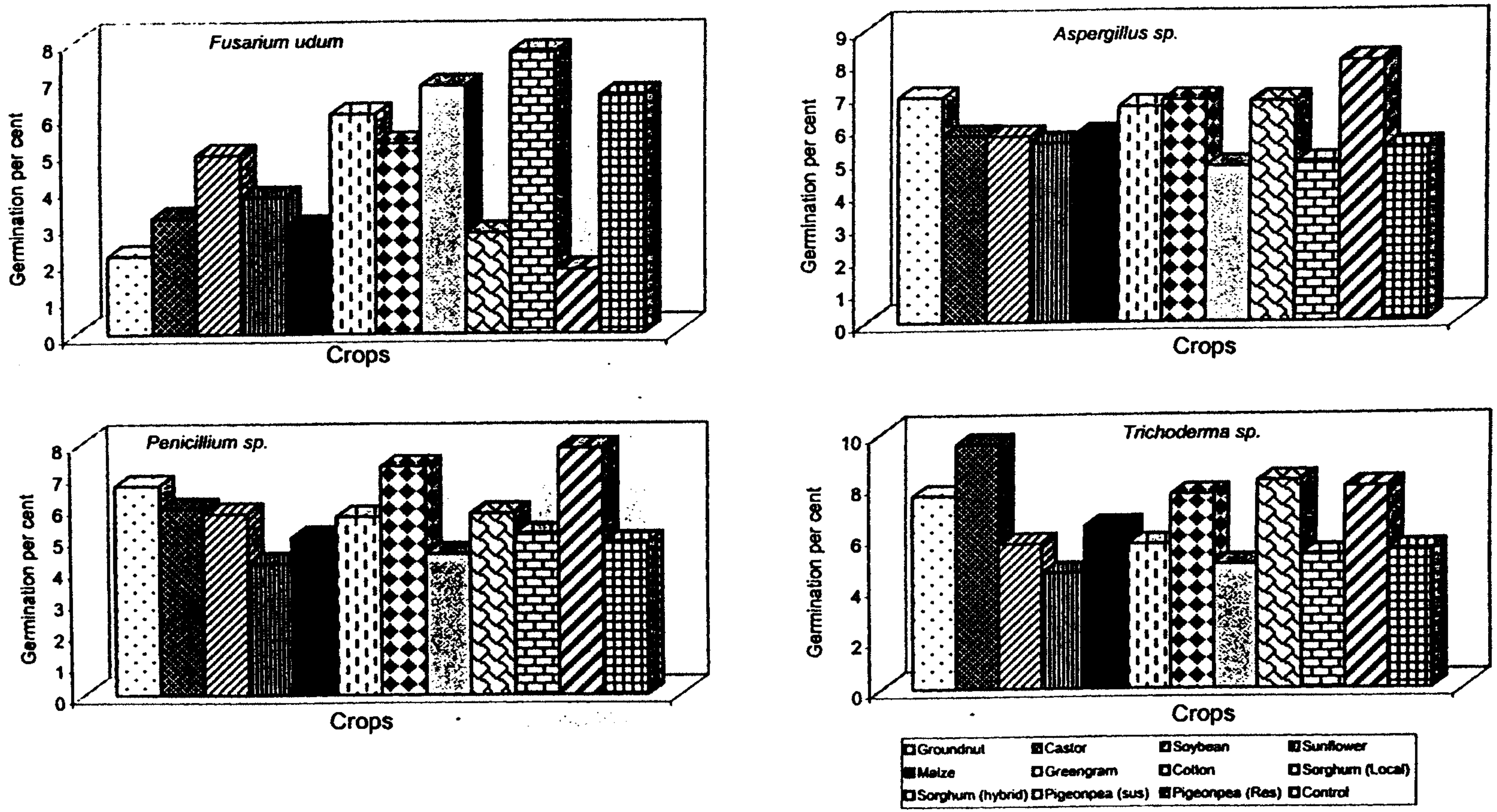


Fig.46: Effect of root exudates of different crops on radial growth (cm) of *Fusarium udum* and its antagonistic fungi

(Cook and Schroth, 1965) and to the high levels of inhibitor phenols present in root exudates of these cultivars, (Murthy and Bhagyaraj, 1985; and Naik, 1993). While, the inhibition of fungal populations of *Fusarium* by root exudates of hybrid sorghum was attributed to the volatile compounds (Rangaswamy and Balasubramanian, 1963) and Cyanide (Natarajan *et al.*, 1985; Sharma *et al.*, 1987) present in its root exudates. In contrast, the root exudates of susceptible pigeonpea and local sorghum had recorded a significant promotion of the wilt pathogen conidial germination and radial growth. A similar enhanced germination of chlamydospores of *Fusarium oxysporum* f.sp. *ciceri* in the root exudates of susceptible cultivars of chickpea was demonstrated by Satyaprasad and Rama Rao (1983); Haware and Nene (1984); and Kotasthane *et al.* (1985). Stevenson and Veitch (1998) identified two compounds viz., cicerfuran and judaicin from wild chickpea which inhibited germination of the fungal spores of *Fusarium oxysporum* f. sp. *ciceris* at natural concentrations in the infested soil than in disease free soil. Hillocks *et al.* (1997) reported the presence of cyanide in root exudates of sorghum and their inhibitory effect on *Fusarium* sp. affecting pigeonpea and cotton. Naik (1993) had also reported a similar variation in the effect of crop root exudates of different pigeonpea cultivars with regards to inhibition of *Fusarium udum*. Further, root exudates of cotton were also observed to promote the wilt pathogen conidial germination and radial growth, similar to the results of Bhatnagar (1995).

Root exudates of groundnut, castor, soybean, sunflower, maize, greengram, hybrid sorghum and resistant pigeonpea had inhibited the conidial germination and radial growth of *Fusarium udum* while promoting the antagonistic fungi viz., *Aspergillus, Penicillium* and *Trichoderma* sp. Similar results were reported earlier by several workers. The indirect effect of root exudates on *Fusarium* spp. through their influence on the rhizosphere microflora was reported by Rangaswamy and Balasubramanian (1963), in their studies on root exudates of sorghum. Root exudates of the crop had inhibited *Fusarium* spp. in the soil, while promoting the antagonistic microflora.

Guar and Sharma (1991) also stated that the rhizosphere soil of resistant SP-15 pigeonpea supported increased fungal and bacterial spp. such as *Aspergillus niger, Streptomyces* sp., *Penicillium* sp. and *Bacillus* sp. Further, Bhatnagar (1995) had reported an inhibition of *Fusarium udum* and promotion of *Trichoderma viride* conidial germination with root exudates of sorghum, maize, groundnut and castor, Based on the differential effects of root exudates of different crops on conidial germination of the wilt pathogen and antagonistic fungi, the crops could be catagorised into following 4 groups.

Category I: Root exudates of crops which inhibited *Fusarium udum* are resistant pigeonpea (ICP 8663), hybrid sorghum (CSH 9), groundnut and cotton.

Category II: Root exudates of crops which inhibited *F. udum* and promoted antagonistic fungi are cotton, local sorghum and susceptible pigeonpea (ICP 2376).

Category III: Root exudates of crops which promoted *F. udum* and inhibited antagonistic fungi are local sorghum and susceptible pigeonpea.

Category IV: Root exudates of crops which promoted *F. udum* and also antagonistic fungi are cotton and greengram.

Conclusions

The studies have revealed an increase in wilt incidence with an increase in the pathogen population. However, disease incidence and pathogen population decreased with an increase in the antagonistic fungal populations. The studies had also revealed the effectiveness of

* Crop rotation (with soybean and sunflower) and intercropping systems (soyabean/sunflower and those of pigeonpea with (sorghum, maize, groundnut, greengram, cotton and castor) with reduced wilt incidence, pathogen population and increased population of antagonistic microorganism in the management of pigeonpea wilt.

* Cultivation of resistant pigeonpea also reduced the disease incidence, significantly by reducing the pathogen inoculum through promotion of the antagonistic fungi.

* Root exudates of non host crops except cotton and local sorghum cultivar inhibited conidial germination and radial growth of the pathogen resulting in reduced growth of *Fusarium udum*. In contrast to stimulatory effects on the antagonistic fungi, explaining the reductions in pathogen inoculum and disease incidence, found in the cropping systems involving these crops.

Application of organic amendments, such as farm yard manure and green manure were also useful in reducing disease incidence levels, significantly below control, in addition to improving biomass production of pigeonpea and population of antagonistic microorganisms and reducing pathogen population.

Application of inorganic amendments, such as KNO_3 and $ZnSO_4$ were also however, found to be in general superior over the organic amendments for control of pigeonpea wilt. The yield and biomass production were also increased with the application of inorganic amendments. Further, the combination of organic amendments (FYM + GM), organic and inorganic amendments (FYM + KNO_3, Zn + GM, Zn + FYM) and seed dressing and an integration of all these production practices (IDM) were also found to be effective in pigeonpea wilt management.

The IDM treatment involving application of organic and inorganic amendments coupled with seed dressing (with both fungicides and *Trichoderma*) was found to be most effective in wilt control, in addition to production of significantly higher yields and biomass of pigeonpea under both Alfisols and Vertisols. However, more detailed studies involving investigations on the changes in soil physico-chemical properties with the continuous adoption of different production practices and cropping systems are necessary for a thorough understanding of the mechanisms involved in the disease control by these practices. Further, detailed investigations aimed at identification of the biochemical nature of compounds, in the crop root exudates, responsible for inhibition or stimulation of the fungi are also necessary.

SUMMARY

CHAPTER V

SUMMARY

The present investigations on "Integrated disease management of Pigeonpea Wilt" were undertaken at International Crops Research Institute for the Semi-Arid Tropics, Patancheru and in farmers fields in predominantly pigeonpea growing areas of Andhra Pradesh during the 1996-97 and 1997-98 seasons. The investigations were carried out to study the effects of different cropping systems and production practices on pigeonpea wilt incidence and population levels of the *Fusarium udum* and its antagonistic fungi in order to formulate an effective and economical pigeonpea wilt mangaement strategy. The experiment was conducted both in Alfisols and Vertisols under field and glasshouse conditions. Studies were also carried out on the effect of different crop root exudates on conidial germination and radial growth of the pigeonpea wilt pathogen and its antagonistic fungi to understand the mechanism of action of cropping systems on pigeonpea wilt.

Investigation on the effect of cropping systems involving non-host crops, such as soybean and sunflower and their intercropping with pigeonpea along with the adoption of several practices (application of organic and inorganic amendments) revealed low levels of *Fusarium udum* population in all the cropping systems investigated compared to monocropping of pigeonpea. Intercropping of sunflower with soybean was however found to be superior in terms of minimum pigeonpea wilt pathogen and maximum antagonistic fungal populations such as *Aspergillus*, *sp. viz.*, *Aspergillus niger, A. flavus and A. terreus; Penicillium* sp. such as *Penicillium pinophyllum, P. decumbens; P. oxalicum and P. citrinum; and Trichoderma* spp. such as *Trichoderma viride, T. harzianum and T. koningii.* Further, application of inorganic N fertilizers (KNO_3) and their combinations with organic sources of N (FYM + KNO_3) were found to be superior compared to sole application of N through organic amendments (FYM) with regard to promotion of antagonistic fungi and inhibition of *Fusarium* wilt pathogen. Application of 40 kg N ha^{-1} through KNO_3 was however found to be consistently superior in all the cropping systems investigated. Application of organic amendments (FYM) however were also effective in reducing the wilt pathogen and oncreasing antagonistic fungal population compared to control.

Studies on the effect of predominant pigeonpea intercropping systems of Andhra Pradesh on wilt incidence, *Fusarium udum* and its antagonistic fungal populations were also carrried out in both on-farm and glass-house conditions. The intercropping systems scuh as pigeonpea/ groundnut, pigeonpea/maize, pigeonpea/sorghum, pigeonpea/castor, pigeonpea/greengram were found to be effective in reducing wilt incidence through reduction of pathogen and increase of antagonistic fungal populations compared to monocropping of pigeonpea under both Alfisol and Vertisol fields. Further results of on farm studies revealed the superiority of intercropping of pigeonpea with groundnut in Alfisols and with cotton and greengram in Vertsols resulted in low wilt incidence, low Fusarium population and high antagonistic fungal populations. Glasshouse studies with soils from farmer's fields of the predominant pigeonpea based intercropping systems during the two consecutive seasons of 1996-97 and 1997-98 confirmed the superiority of intercropping of pigeonpea with groundnut in Alfisols and with cotton and greengram in Vertisols. Further, a high wilt incidence was found in Alfisols compared to Vertisols inspite of relatively lower wilt pathogen population under monocropping of pigeonpea probably due to low levels of antagnoistic fungal populations. In both the soils under intercropping systems viz., pp+groundnut in Alfisol and pp/sorghum in Vertisols wilt incidence was found to be lower with low levels of pathogen population.

The investigations on integrated pigeonpea wilt management in wilt sick Alfisol fields at ICRISAT had revealed the effectiveness of application of soil amendments such as green manure and farm yard manure in the disease management through an inhibition of Fusarial population by stimulation of the antagonistic fungal populations. The treatments also resulted in enhanced crop yields and biomass under both mono and intercropping system, compared to control. The adoption of integrated disease management strategy involving seed dressing with fungicides, *Trichoderma* in addition to basal application of farm yard manure and green manure @ 2.5 tons ha^{-1} was found to be the most effective in wilt management under both monocropping and intercropping systems of pigeonpea during both the years of study, under glasshouse and field conditions compared to other treatments. This IDM treatment also recorded maximum inhibition of wilt pathogen and promotion of antagonistic fungal populations.

Studies on integrated wilt management in Vertisols had also revealed the superiority of integrated disease management strategy involving seed dressing with fungicides and Trichoderma, coupled with the basal application of $ZnSO_4$ @ 6.25 kg ha^{-1}, FYM and green manure @ 1.25 tons ha^{-1}, over other treatments in different cropping systems studied in the present investigation in field and glass house conditions during both the years due to significant reduction in the wilt pathogen populations and increase in the antagonistic fungal populations. This treatment had also recorded significantly higher crop yields and biomass compared to other treatments.

However, combination of organic and inorganic amendments such as Zn+GM, Zn+FYM and FYM+GM and seed dressing treatments were found significantly superior over control and effective in pigeonpea wilt management when compared to their respective individual components. Zn+GM was found to be significantly superior in increasing the antagonistic fungal population over all other treatments and control. These treatments were also found effective in increasing the yields and biomass of pigeonpea compared to control due to inhibition of pathogen population and increased antagonistic fungal populations and favourable effects on nutrient availability in the soil.

Further, cropping of resistant pigeonpea ICP 8863 had resulted in low wilt incidence, higher antagonistic fungal population and relatively higher yields and biomass, compared to monocropping of tolerant pigeonpea C11. Intercropped pigeonpea with sorghum resulted in low wilt incidence and reduced *Fusarium* population compared to monocropped pigeonpea due to stimulation of the antagonistic fungi. However, yields and biomass of pigeonpea were lower under intercropping system due to reduced pigeonpea population.

In both Alfisols and Vertisols, the antagonistic fungal populations such as *Aspergillus* spp. viz., *Aspergillus niger, A. flavus, A. terreus* and *A. nidulans; Penicillium* spp. viz., *Penicillium pinophyllum, P. decumbens, P. oxalicum, P.citrinum* and *Trichoderma* spp. viz., *T. viride, T. harzianum* and *T. koningii* were recorded.

An analysis of the effect of different crop root exudates on conidial germination and radial growth of *Fusarium udum* revealed highly inhibitory effects of groundnut, castor, soybean, sunflower, maize, greengram, hybrid sorghum and resistant pigeonpea root exudates compared to control(water). However, root exudates of these crops had exhibited stimulatory effects on the antagonistic fungi viz., *Aspergillus*, *Penicillium*, and *Trichoderma sp.* In contrast, root exudates of susceptible pigeonpea ICP 2376 and local sorghum had inhibited the antagonistic fungi while promoting germination and radial growth of the wilt pathogen *F. udum*. Root exudates of cotton were however, found to promote both the witl pathogen, as well as its antagonistic fungi. Detailed investigations aimed at identification of the biochemical compounds in the crop root exudates responsible for inhibition or stimulation of the fungi would be more useful. In addition, further studies on effect of different production practices and cropping systems on the physico-chemical properties of soil are also necessary for thorough understanding of the mechanisms involved in the disease control with the adoption of these practices.

Profitability is one of the most important factors influencing the decision making of the farmers. The IDM treatment for wilt in Vertisols gave the highest gross returns and net returns of pigeonpea with a slight decline in benefit cost ratio because of high dosage and cost of FYM including transportation charges which is a component of IDM. Seed dressing alone, which is a component of IDM gave the highest net returns and benefit-cost ratio. In pigeonpea/sorghum cropping system in Vertisols, economics of sorghum yielded the highest gross returns and net returns for IDM and Zn+GM in combination with tolerant and resistant variety. The benefit cost ratio was highest with tolerant variety in combination with IDM and Zn+GM and Zn application among the individual treatments. Hence it is also beneficial to grow tolerant pigeonpea sorghum in combination with IDM, Zn+GM, Zn and FYM. In Alfisols also, IDM package gave the highest gross returns, net returns and benefit cost ratio both in sole pigeonpea and pigeonpea/groundnut cropping system for pigeonpea crop. In pigeonpea/ groundnut cropping system, economics of IDM for groundnut yielded the highest gross and returns and net returns than other treatments with high benefit cost ratio. In contrast, low net returns and benefit cost ratio was obtained in control. Among the individual treatments green manuring treatment alone, which again is component of IDM gave the highest net returns under both cropping systems with C11 and ICP 8863 in Vertisols and with sole pigeonpea and pigeonpea/groundnut in Alfisols. But at the subsistence farmers level, as FYM is their own input they can utilize their input without any investment as one of the IDM component and the then cost of IDM package will be low with a high benefit cost ratio.

LITERATURE CITED

LITERATURE CITED

Abawi G S and Lorbeer J W 1971 Populations of *Fusarium oxysporum* f.sp. *cepae* in organic soils in New York. Phytopathology 61:1042-1048.

Adams P B, Papavizas G C and Lewis J A 1968 Mechanisms of control of *Fusarium* root rot of bean with spent coffee grounds. Phytopathology 58:883-889

*Afifi A F 1976 Volatile and gaseous exudates of either germinating seeds or roots of okra plant in relation to okra wilt disease caused by some *Fusarium* species. Zentralott fur Bakteriologie Parasitenkunde, Infections and Hygiene 131:555-564.

*Agnihothrudu V 1954 "Rhizosphere micro flora in relation to fungal wilts". Ph.D. thesis, Madras University, Madras, India.

*Agnihothrudu V 1955 Influence of fungistatic organisms in the rhizosphere of pigeonpea (*Cajanus cajan*) in relation to the resistance and susceptibility to wilt caused by *Fusarium udum* Butler Naturwiss 42:1-2.

Agricultural Statistics at a glance 1998 pp 128.

Alagarsamy G, Salal Rajan F and Jeyarajan R 1987a Effect of host nutrition in the management of sheath rot of rice. In Biological control of plant diseases - A workshop, Department of Plant Pathology, TNAU, Coimbatore, (Abstract) pp 34.

Alagarsamy G, Salal Rajan F and Jeyarajan R 1987b Biological control of seedling disease of cotton through organic amendments and antagonists. Abstract in Biological Control of Plant Diseases - A Workshop, p.4, Department of Plant Pathology, TNAU, Coimbatore, (Abstract) pp 21.

*Alexander M 1971 Microbial ecology. John Wiley and Sons, New York and London p 511.

Amin K S, Balder B and Williams F J 1976 Differentiation of phytopathora stem blight from *Fusarium* wilt of pigeonpea by field symptoms. FAO Plant Protection Bulletin 24:123-124.

Andrews J H 1983 Future strategies for integrated control. In : Challenging problems in plant health (eds.) Kammodahl T and Williams P H Challenging problems in plant health. American Phytopathological Society, Saint Paul, Minnesota pp 431-440.

Arjunan G, Konda Swamy T and Jeyarajan R 1987 Effect of organic amendments on Macrophomina root rot in pigeonpea (Abstract). In Biological control of plant diseases - A workshop, p. 4, Department of Plant Pathology, CPPS, TNAU, Coimbatore pp 34.

Arunaryan A and Mathew D S 1991 Variation in seed germination of pigeonpea following treatment with fungal metabolites. Indian Phytopathology 44:392-394.

Arunaryan P and Mathew D S 1993 Studies on rhizosphere microflora of pigeonpea : qualitative and quantitative incidence of micro organism after solarization. Indian Phytopathology 46:151-154.

Asokaraja N and Ramaiah S 1987 Effect of redgram based intercropping system on growth analysis, nutrient uptake and yield of redgram. Madras Agricultural Journal 74: 252-254.

Atkinson T G, Neal J L and Larson R J 1975 In: Biology and Control of Soil Borne Plant Pathogens (ed.) Bruchi G W. American Phytopathological Society, Saint Paul, Minnesota pp 116-122.

Autrique A and Potts M J 1987 The influence of mixed cropping on the control of potato bacterial wilt (*Pseudomonas solanacearum*). Annals of applied Biology 111:125-133.

Ayanru D K G and Green R J 1974 Alteration of germination patterns of sclerotia of *Macrophomina phaseolina* on soil surface. Phytopathology 64:595-601.

Baker K F 1981 Biological control. In : Fungal wilt diseases of Plants (eds.) Mace M E, Bell A A and Backman C H, Academic Press, New York, pp 640-664.

Baker K F and Cook R J 1974 Biological control of plant pathogens. W.H. Freeman and Company, San Fransisco pp 381.

Baker R and Nash S M 1965 Ecology of plant pathogens in soil. VI Inoculum density of *Fusarium solani* f. sp. *phaseoli* in bean rhizosphere as affected by cellulose and supplemental nitrogen. Phytopathology 55:1381-1382.

Besri M Zrouri M and Beye I 1984 Appartenance raciale et pathogenic comparee de quelgues isolates de *Verticillium dahliae* (kleb.). Phytopathology 109:289-294.

Bhagyaraj J and Rangaswami G 1967 Effect of fertilizers on the microflora of soil and rhizosphere of ragi (*Eleusine coracana*). Indian Journal of Microbiology 7:29-38.

Bhargava R N 1975 Two new varieties of arhar for Bihar. Indian Farming 25:23.

Bhaskaran K 1954 Crops and crop improvement in Hyderabad, Agricultural College Journal, Osmania University 1:60-63.

Bhatnagar H 1995 Influence of agricultural production systems on plant diseases. Report submitted to crop protection division, International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andhra Pradesh.

Bhatnagar H 1996 Influence of environmental conditions on antagonistic activity of *Trichoderma* sp. against *Fusarium udum*. Indian Journal of Mycology and Plant Pathology 26:58-63.

Bidari V B and Gundappagol R C 1997 *Trichoderma viride* in the integrated management of pigeonpea wilt under dryland cultivation. Advances in Agricultural Research in India 7:65-69.

Bolten H J, Friedrickson J K and Elliot L F 1993 Microbial ecology of the rhizosphere. In: Soil Microbial Ecology : Applications in Agricultural and Environmental Management (eds.) Blaire and Melting Jr., Marcel Dekker, New York.

Booth C 1971 The genus *Fusarium*. Common Wealth Mycological Institute, England pp 137.

Booth C, Mordue J E M and Gibson I A S 1978 CMI descriptions of pathogenic fungi and bacteria, Section 58:571-580, pp 20.

Borner H 1960 Liberation of organic substanaces from higher plants and their role in the soil sickness problem. Botanical Review 26:393-424.

Bouhot D 1981 Induction of biological resistance to Pythium in soils by proportion of organic matter. Soil Biology Biochemistry 13:269-274.

Brust E G and King L R 1994 Effect of crop rotation and reduced chemical inputs on pests and predators in maize agroecosystems. Ecosystems and Environment 48:77-89.

Butler E J 1908 Selection of pigeonpea for wilt disease. Agricultural Journal of India 3:182-183.

Butler E J 1910 The wilt disease of pigeonpea and the parasitism of *Neocosmospora vasinfecta* Smith. Member of Department of Agriculture India (Botany Section) 2:1-62.

Butler E J 1918 (Reprinted 1973) Fungi and Plant Diseases. Bishan Singh and Mahendra Pal Singh, Dehradun and Delhi pp 276.

Buxton F W, Khahfa O and Ward V 1965 Effect of soil amendment with chitin on pea wilt caused by *Fusarium oxysporum* f.sp. pisi. Annals of Applied Biology 55:83-88.

Canullo G H, Kloepper J H and Rodriguez Kabana R 1991 Changes in the population of microorganisms associated with the application of soil amendments to control *Sclerotium rolfsii* Phytopathology 81:1065-1165.

Chakrabarti S K and Sen B 1991 Suppression of Fusarium wilt of musk melon by organic soil amendments. Indian Phytopathology 44:476-479.

*Chakrabarti S and Nandi P 1969 Effect of Griseofulvin on *Fusarium udum* Butler and its host pigeonpea (*Cajanus cajani* L.) Millsp.). Proceedings of Indian Science Academy 56:288 (Abstract).

Chakraborty A, Saha A K and Gupta P K S 1992 Germination of chlamychospores of *F. udum* adjascent to the roots of pigeonpea. Soil Biology and Biochemistry 24:927-928.

Champawat R S and Pathak V N 1988 Role of nitrogen, phosphorus and potassium fertilizers and organic amendments in cumin (*Cuminum cyminum*) wilt incited by *Fusarium oxysporum* f.sp. *cumini*. Indian Journal of Agricultural Sciences 58:728-730.

Chand J N and Thakur D P 1969 Soil types in relation to incidence of Fusarium wilt of tomato in Bihar. Indian Journal of Horticulture 26:87-88.

Chang I P and Kommedahl T 1968 Biological control of seedling blight of corn by coating kernels with antagonistic microorganisms. Phytopathology 58:1395-1398.

Chao W L, Nelson L B, Harman G E and Hoch H C 1986 Colonization of rhizosphere by biocontrol agents applied to seeds. Phytopathology 76:60-65.

Chattopadhyay C and Sen B 1996 Integrated Management of *Fusarium* wilt of muskmelon caused by *Fusarium oxysporum*. Indian Journal of Mycology and Plant Pathology 26:162-170.

Chattopadhyay C and Sen B 1996 Integrated management of Fusarium wilt of muskmelon caused by *Fusarium oxysporum*. Indian Journal of Mycology and Plant Pathology 26:162-170.

Chattopadhyay S N and Mustafee T P 1980 Influence of organic amendments on the growth of soil inhabiting fungal pathogens. Indian Journal of Microbiology 18:69.

Chaube H S 1968 Combating diseases of arhar and gram. Indian Farmers Digest 1:26-27.

Chesler T G 1964 Effect of micronutrient potassium on *Fusarium* wilt of carnation. Plant Disease 49: 168-170.

Chun D and Lockwood J L 1985 Reduction of *Pythium ultimum, Thielaviopsis bassicola* and *Macrophomina phaseolina* populations in soil associated with ammonia generated from water. Plant Disease 69:154-158

*Cook R J and Baker K F 1983 The nature and practice of biological control of plant pathogens. Saint Paul, American Phytopathological Society, Minnesota, USA pp 530.

Cook R J and Schroth M N 1965 Carbon and nitrogen compounds and germination of chlamydospores of *Fusarium solani* f. sp. *phaseoli* in soil. Phytopathology 55:1021-1025.

*Dalal R C 1974 Effect of intercropping maize with pigeonpeas on grain yield and nutrient uptake. Experimental Agriculture 10: 219-224.

*Dasgupta A and Gupta P K S 1989 Effect of different soil amendments on wilt of pigeonpea (*Cajanus cajan* (L.) Millsp.) caused by *Fusarium udum* Butler. Beitragazur tropischen Landwirtschaft and reterinarmendizin, 27:341-345.

*Dastur J F 1946 Report of the imperial mycologist, Scientific reports of the Indian Agricultural Research Institute, 1944-45, IARI, New Delhi, India, pp 66-72.

*Davey C B and Papavizas G C 1963 Saprophytic activity of *Rhizoctonia* as affected by carbon nitrogen balance of certain soil amendments. Soil Science Society of America Proceedings 27:164-167.

De R K, Chaudhary R G and Naimuddin 1996 Comparative efficacy of biocontrol agents and fungicides for controlling chickpea wilt caused by *Fusarium oxysporum* f.sp. *ciceri.* Indian Journal of Agricultural Sciences 66:370-373.

Deb P R and Dutta B K 1992 Effect of inorganic fertilizers on the development of foot rot disease of soybean caused by *Sclerotium rolfsii.* Indian Phytopathology 45(1):89-97.

Deshpande R B, Jeswani L M and Joshi A B 1963 Breeding of wilt resistant varieties of pigeonpea. Indian Journal of Genetics and Plant Breeding 23:58-63.

*Dey P K 1947b NP80, a variety resistant to pigeonpea wilt. Plant Pathology Report, 1944-45, Department of Agriculture, Uttar Pradesh, India, pp 38-40.

*Dey P K 1947a Plant Pathology Report, 1944-45. Department of Agriculture, Uttar Pradesh, India pp 38-40.

Dhirendra Prakash M, Alam M, Shabbir Ashraf and Khan A M 1976 Studies on rhizosphere mycoflora of egg plant in relation to soil amendments. Acta Botanica Indica 4:68-70.

Dutta B K and Isaac I 1979 Effect of inorganic amendments (N, P & K) to soil on the rhizosphere microflora of antirrhinum plants infected with *Verticillium dahliae* Kleb. Plant and Soil 52:561-569.

Dwivedi R S and Tandon R N 1975 "Studies on some aspects of seed mycoflora of pigeonpea". Proceedings of Indian Science Congress 63:63.

*Dutta B K and Deb P R 1986 Effect of organic and inorganic amendments on the soil and rhizosphere microflora in relation to the biology and control of *Sclerotium rolfsii* causing foot rot of soybean. Z Pflkrankh Pfschutz 93:163-171.

Eck W H V 1978 Autolysis of chlamdospore of *Fusarium solani* f.sp. *cucurbitae* in chitin and laminarin amended soils. Soil Biology and Biochemistry 10:89-92.

Elad Y and Chet I 1983 Improved selective media for isolation of Trichoderma spp. and *Fusarium* spp. from soil. Phytoparasitica 11:55-58.

Elad Y, Chet I and Heins Y 1981 Biological control of Rhizoctonia role in strawberry fields by *Trichoderma harziem*. Plant and Soil 60:245-254.

Elad Y, Sivan Z, Zeidan O, Kleifield O and Chet I 1983 Biological and Integrated control of soil borne pathogens as a means for reduction of fungicides. In: Developments in Ecology and Environmental Quality (eds) Shuval H E Balabaru International Science Service, Israel pp 587-594.

Elad Y, Chet I and Katan J 1980 Physical, biological and chemical control for soil borne diseases in potatoes. Phytopathology 70:418-422.

Gallegly M E and Walker J C 1999 Plant nutrition in relation to disease development N : Bacterial wilt of tomato. American Journal of Botany 36:613-623.

*Garret S D 1960 Soil fungi and soil fertility. Perganon Press, Oxford p. 165.

*Garret S D 1963 Soil fungi and soil fertility. Perganon Press Oxford, pp 204.

Gaur V K and Sharma L C 1991 Microorganisms antagonistic to *Fusarium udum* Butler. Proceedings of the Indian National Science Academy Part B Biological Sciences 57:85-88.

Gautam M and Kolte S J 1979 Control of sclerotium wilt of sunflower through organic amendments of soil. Plant Soil ,53:233-238.

*Gerlach W and Nirenberg H 1982 The Genus *Fusarium* - a pictorial Atlas, Berlin and Hamburg, Komnissions Verlag Paul Parey, pp 406.

Gessler C and Kuc J 1982 Production of resistance to Fusarium wilt in cucumber by root and foliar pathogens. Phytopathology 72:1439-1441.

Ghosh M K and Sinha A K 1981 Laboratory evaluation of some systemic fungicides against Fusarium wilt of pigeonpea. Pesticides 15:24-27.

*Ghosh M K 1975 Control of Fusarium wilt of pigeonpea by various treatments. M.Sc. thesis, Bidhan Chandra Krish Viswa Vidyalaya Kalyani, West Bengal.

Goswamy B K and Battacharya D 1998 Efficacy of neem and groundnut oil cakes as influenced by micro organisms; Changes in rhizosphere microflora during the decomposition of oil cakes in sterilized and unsterilized soil. Indian Journal of Nematology 19:72-74.

Gowily A M, Soliman G I, Abd El-Ghany B F 1995 Biological control of chickpea root rot caused by *Fusarium solani*. Annals of Agricultural Science 33:1307-1315.

*Goyal M K and Mehrotra R S 1979 Effect of chemical amendments on the control of root rot of gram. Biological Bulletin of India 1:9-12.

Grodzinsky A M 1962 Phytocoenotic role of physiologically active plant secretion. Ukrain Botanical Bulletin 19:3-20.

*Guillemat J and Mortegut J 1958 Troisieme contribution a lettude de la microflora fongique dersols cultivar. Epiphytology 9: 27-34.

*Gupta S L 1961 The effect of mixed cropping of arhar (*Cajanus cajan* L.) with jowar on incidence of arhar wilt. Agriculture and Animal Husbandry in Uttar Pradesh 3:31-35.

Gupta M C 1987 Population dynamics of Fusarium species in soil amended with carbonaceous and nitrogenous materials. Indian Phytopathology 39:253-258.

Gupta A D and Sengupta P K 1988 Reaction of pigeonpea lines to wilt pathogen, *Fusarium udum*. Indian Journal of Agricultural Science 58:548-586.

Hadar Y, Harman G E and Taylor A G 1984 Evaluation of *Trichoderma koningii* and *T. harzianum* from New York soils for biological control of seed rot caused by *Pythium* spp Phytopathology 74:106-110.

Hakeem A and Ghaffar A 1977 Reduction of the number of sclerotia of *Macrophomina phaseolina* in soil by organic amendments. Phytopathology Zeitschrift 88:272-275.

*Halsted B D 1888 Nitrogen appropriation in clovers A hint. Bulletin of Iowa State Agricultural College, Botany Department 28-33.

Haque M F, Jha D K, Mukherjee A K, Vandermaesen L J G and Kannaiyan J 1984 Evaluation of ICRISAT germplasm for wilt incidence in the plateaue region of Chota Nagpur in India. International Pigeonpea Newsletter 3:36-37.

Harman G E 1991 Seed treatments for biological control of plant disease. Crop Protection 10:166-171.

Harman G E, Chet I and Baker R 1980 *Trichoderma hamatum* effects on seed and seedling disease induced in radish and pea by *Pythium* spp or *Rhizoctonia solani*. Phytopathology 70:1167-1172.

Harman G E, Chet I and Baker R 1981 Factors affecting *Trichoderma harzianum* applied to seed as a biocontrol agent. Phytopathology 71:569-572.

Harrison J A C 1968 *Verticillium* wilt of potatoes. Ph.D. thesis, University of Wales pp 123

Hart L P and Endo R M 1980 The effect of time of exposure to inoculum, plant age, root development and root wounding on fusarium yellows of celery. Phytopathology 71:77-79.

Haware M P and Kanaiyan 1992 Seed transmission of *Fusarium udum* in pigeonpea and its control by seed treatment fungicide. Seed Science and Technology 20:597-601.

Haware M P and Nene Y L 1984 The role of chickpea root exudates in resistance to *Fusarium* wilt. International Chickpea Newsletter 10:12-13.

Hillocks R J, Ekotton Eboa E F, Jones M 1997 Effect of cyamide and root exudates from sorghum on vascular wilt fusaria affecting pigeonpea and cotton. Tropical Science 37:1-8.

Hoitink H A J and Fahy P C 1986 Basis for the control of soil borne plant pathogens with composts. Annual Review of Phytopathology 24:93-114.

*Holliday P 1980 Fungus diseases of tropical crops. Cambridge, UK Press Syndicate of University of Cambridge pp 607.

Huber D M and Watson R D 1970 Effect of organic amendments on soil borne plant pathogens. Phytopathology 60:22-26.

Huber D M and Watson R D 1974 Nitrogen form and plant disease. Annual Review of Phytopathology 12:139-165.

Hundekar A R, Anahosur K A, Patil M S, Kalappanavar I K and Chattannavar S N 1998 Invitro evaluation of organic amendments against stalk rot of sorghum. Indian Journal of Mycology and Plant Pathology 28:26-30.

*IARI 1953 Scientific Reports of the Indian Agricultural Research Institute 1950-51, IARI, New Delhi, India pp 120.

ICRISAT 1994 International Crop Research Institute for the Semi-arid Tropics, Patancheru, A.P., India Annual Report pp 48-50.

Issac I 1957 Effect of nitrogen supply upon the *Verticillium* wilt of antirrhinum. Annals of Applied Biology 45:512-515.

Jacksen B J and Backman P A 1993 Biological and cultural plant disease controls alternatives and supplements in IPM system. Plant Disease 77:311-315.

Jalal A M, Quaiser Ahmad and Mohammad Abu 1980 Screening of fungicides against wilt. Pesticides 10:28-29.

Jimenez D R M and Traperocasas A 1985 Use of fungicide treatments and host resistance to control the wilt and root rot complex of chickpeas. Plant Disease 69:591-595.

Jones J P and Woltz S S 1972 Effect of soil pH and micronutrient amendments on Verticillium and Fusarium wilt of tomato. Plant Disease 56:151-153.

Kannaiyan J, Jain K C, Raju T N and Nene Y L 1983 Wilt resistance sources in vegetable pigeonpea. International Pigeonpea Newsletter 2:42-43.

Kannaiyan J and Nene Y L 1981 Influence of wilt at different growth stages on yield loss in pigeonpea. Tropical Pest Management 27:141.

Kannaiyan J, Nene Y L, Reddy M V, Ryan J G and Raju T N 1984 "Prevalence of pigeonpea diseases and associated crop losses in Asia, Africa and the Americans". Tropical Pest Management 30:62.

Kannaiyan S and Prasad N N 1974 Effect of certain soil amendments on the incidence of muskmelon wilt. Potash Newsletter 9:6-9.

Kannaiyan S and Prasad N N 1981 Effect of NPK nutrition on the survival and saprophytic activity of *Rhizoctonia solani*. Indian Potash Journal 5:19-25.

Kannaiyan J, Reddy M V, Nene Y L, Ryan J G and Raju T N 1981 "Prevalence of pigeonpea wilt and sterility mosaic in India" : 1975-1980. International Pigeonpea Newsletter 1:24-26

Katan J 1971 Symptomless carriers of the tomato wilt pathogen. Phytopathology 61:1213-1217.

*Kato K, Fukaya M and Tomita I 1981 Effect of successive applications of various soil amendments on tomato Fusarium wilt. Research Bulletin Aichi Agricultural Research Center 13:199-208.

Katznelson H 1946 The rhizosphere effect of margels on certain groups of soil microorganisms. Soil Science 62:343-354.

*Katznelson H 1965 Nature and importance of the rhizosphere. In : Ecology of soil borne plant pathogens (eds) Baker K F and Snyder W C, University of California Press, Berkeley pp 187-206.

Kaufman D D and Williams S L E 1964 Effect of mineral fertilization and soil reactions on soil fungi. Phytopathology 54:134-139.

Kaur N P and Mukhopadhyay 1992 Integrated control of chickpea wilt complex by *Trichoderma* and chemical methods in India. Tropical Pest Management 38:372-375.

Kaur S, Arora J S and Khanna K 1989 *Fusarium* wilt is a limiting factor in commercial cultivation of *gladiolus*. Indian Horticulture 36:21-22.

Khalifa O 1965 Biological Control of Fusarium wilt of peas by organic soil amendments. Annals of Applied Biology 56:129-137.

Khanna R N and Singh R S 1974 Rhizospores populations of *Fusarium* species in amended soils. Indian Phytopathology 27:331-338.

Klassen W 1981 The role of biological control in Integrated disease management systems. In: Biological control in crop protection (ed) Papavizas G C. Allanheld, Osman Publishers, New York pp 312-328.

*Kloos J P, Tulog B and Tumapon A S 1987 Effects of intercropping potato on bacterial wilt. Philippines Agriculture Report 70:83-90.

Kommedahl T, Windeb C E, Sarbini G and Wiley H B 1981 Variability in performance of biological and fungicidal seed treatments in corn, peas and soybeans. Protection Ecology 3:55-61.

Konda C R, Parameswarappa R and Rao T S 1986 Pigeonpea ICP 8863 - a boon to Fusarium wilt endemic areas of Karnataka. International Pigeonpea Newsletter 5:36-37.

Konda C R, Parameswarappa R, Rao T S 1992 Pigeonpea ICP 8863 - A boon to Fusarium wilt endemic areas of Karnataka. International Pigeionpea Newsletter 5:36-37.

*Kotasthane S R and Gupta O M 1986 Management of pigeonpea wilt disease by soil amendment. In Management of soil borne disease of crop plants - A seminar, Department of Plant Pathology CPPS, TNAU, Coimbatore pp 45 (Abstract).

Kotasthane S R, Gupta O M and Khare M N 1987 Influence of fungicidal seed treatment and soil amendment on the development of *Fusarium udum* propogules in soil and pigeonpea wilt. Indian Phytopathology 40:197-200.

Kotasthane S R, Khare M N, Gupta O M and Tiwari D P 1985 Studies on root exudates of susceptible and resistant cultivars of pigeonpea. JNKVU Research Journal 17:141-144.

Kraft J M and Papavizas G C 1983 Use of host resistance *Trichoderma* and fungicides to control soil borne diseases and increase seed yields of peas. Plant Disease 67:1234-1237.

*Krishna Mohan G and Kondaswamy T K 1986 Effect of organic amendments and seed dressing fungicides on *R. solani* on cotton. In Management of soil borne diseases of crop plants - A seminar, Department of Plant Pathology, CPPS, TUNAU, Coimbatore pp 29 (Abstract).

Krishna Rao V, Ramachandra Reddy A G and Satyanarayana K 1987 Quantitative changes in the rhizosphere Microflora of wilt resistant and susceptible varieties of pigeonpea. Indian Journal of Mycology and Plant Pathology 17:59-62

Willey R W, Rao M R and Natarajan M 1981 Traditional cropping systems with pigeonpea and their improvement. In : Proceedings of the International Workshop on pigeonpea, volume 1, 15-19 December 1980, ICRISAT Center, India pp 11-25.

Windeb C E and Kommedahl T 1982 Pea cultivar effects of pea seed treatments with *Penicillium oxalicum* in the field. Phytopathology 72:541-543.

Wollenwebber H W 1931 "Fusarium - Monographee Fungi parasitici etc. saprophytici". Z. Parasitenkol. 3:31:269.

Woods F W 1960 Biological antagonisms due to phytotoxic root exudates. Botanical Review 26:546-569.

*Wollenwebber H W and Reinking O A 1935a Die Fusarien, ihre Beschreibung, schadwirking und Bckampfung. Berlin : Paul Parey, p. 1935, 335.

*Wollenwebber H W and Reinking O A 1935b Die Verbreitung. der Fusarien in der Natur, Friedlander und bohn, Berlin 1935a, 80.

Woltz S S and Jones J P 1968 Micronutrient effects on the in vitro growth and pathogenicity of *Fusarium oxysporum* f.sp. *lycopersici*. Phytopathology 58:336-338.

Woods F W 1960 Biological antagonisms due to phytotoxic root exudates. Botanical Review 26:546-569.

Wu W S 1982 Seed treatment by applying *Trichoderma* spp to increase the emergence of soybeans. Seed Science and Technology 10:557-563.

*Yankov I 1989 Fusarial wilt of peas. Zashchita Rasteni (Maska) 4:18.

*Yeshia A H, El-Hassan S A and Ismail F K 1981 Studies on damping off disease of tomato seedlings and its biological control. Mesapotomia Journal of Agriculture 11:115-124.

Young V H, Ware J O and Pope O A 1935 Control of potash hunger and Fusarium wilt in cotton. Phytopathology 25:969.

Zakaria M A, Lockwood J L and Filonow A B 1980 Reduction in Fusarium population density in soil by volatile degradation products of oilseed meal amendments. Phytopathology 70:495-499.

Zaveri P P, Singh R M, Pathak A R, Patel J A, Kher H R, Patel R S and Tikka S B S 1986 BDN 2 a wilt tolerant superior cultivar of pigeonpea for Gujarat. International Pigeonpea Newsletter 5:38-39.

Krishnamurthy A S and Bhaskaran R 1991 Effect of organic amendments and the antagonist *Trichoderma viride* on the biological control of 'Damping-off' diseases of tomato caused by *Pythium indicum* Balakrishnan. Journal of Biological Control 5:61-62.

*Lakshmi R and Jeyarajan R 1987 Biological control of crossandra wilt by organic amendments. In: Biological control of plant diseases - A workshop, Department of Plant Pathology, CPPS, TNAU, Coimbatore pp 34 (Abstract)

Latham A J and Watson R D 1967 Effect of crop residues on soil fungi and onion growth in naturally infested soil. Phytopathology 54:505-509.

Lewis J A and Papavizas G C 1975 Survival and multiplication of soil borne plant pathogens as affected by plant tissue amendments. In: Biology and control of soil borne plant pathogens pp 84-89.

Lifshitz R, Lifshitz S and Baker R 1985 Decrease in incidence of Rhizoctonia pre-emergence dumping-off by use of integrated chemical and biological control. Plant Disease 69:431-434.

Locke J C, Marois J J and Papavizas G C 1985 Biological control of Fusarium wilt of greenhouse grown chrysamthemums. Plant Disease 69:167-169.

Mahmood S K and Rama Rao P 1992 Rhizosphere microbes in relation to N.P.K. Proceedings of National Academy of Sciences, India 62 (B) I : 83-88.

Mahmood M 1964 Factors governing the production of Antibiotics Bulbiforum and its use in the control of pigeonpea wilt. Science and Culture 30:352.

Maiti D and Sen C 1985 Integrated biocontrol of *Sclerotium rolfsii* in wheat with nitrogeneous fertilizers and *Trichoderma harzianum*. Indian Journal of Agricultural Science 55:464-468.

Mandal N C and Sinha A K 1992 An alternative approach for the chemical control of Fusarium wilt of tomato. Indian Phytopathology 45:194-198.

Mandal N C and Sinha A K 1991 Differential effects of root exudates and extracts from tomato cultivars on *Fusarium oxysporum* f.sp. *lycopersici* in relation to their disease reaction. Journal of Mycopatholgoical Research 29:9-16.

Martin G P 1950 Use of acid, rose bengal and streptomycin in plate method for estimating soil fungi. Soil Science 69:215-232.

Mayakrishnan L and Subbaraja K T 1995 Effect of soil amendments on Fusarial wilt and yield of tomato. In : Crop Diseases Innovative Techniques and Management. (eds.) Siva Prakasam M K and Seetharaman N, Kalyani Publishers, Ludhiana pp 268-275.

Mc New G L 1953 The effect of soil fertility In: Plant Diseases the year book of Agriculture US Department of Agriculture U S, Government Printing Office, Washington DC pp 100-114.

*McRae W 1932 Report of the Imperial Mycologist. Scientific reports of the Agricultural Research Institute, PUSA, 1930-31, Pusa, India, pp 73-86.

*McRae W and Shaw F J W 1933 Influence of manures on the wilt disease of *Cajanus indicus* spreng, and isolation of types resistant to the diseases. Part II, The isolation of resistant types. Scientific monograph, Imperial Council of Agricultural Research, Pusa 7, Pusa, India pp 37-68.

*McRae 1928 Report of the imperial mycologist scientific reports of the Agricultural Research Institute 1927-28 PUSA, India pp 51-68.

*McRae W 1930 Report of the imperial mycologist Scientific Reports of the Agricultural Research Institute, 1930-31, PUSA, India, pp 73-86.

*McRae W 1924 Report of the imperial mycologist. Scientific Reports of the Agricultural Research Institute, PUSA 1923-24, PUSA, India, pp 41-51.

*McRae W 1926 Report of the imperial mycologist Scientific Reports of the Agricultural Research Institute, PUSA, 1925-26. PUSA, India, pp 54-69.

Mehata R D, Patel A, Roy K K and Mehta M H 1995 Biological control of soil borne plant pathogens by *Trichoderma harzianum*. Indian Journal of Mycology and Plant Pathology 25:126-128.

Mehrotra R S and Gupta A K 1989 Biological control of plant pathogens. In: Plant Science Research in India (eds.) Trivide M L and Mukherjee K G, Today and Tomorrow's Printers and Publishers, New Delhi pp 595-601

Mehrotra R S 1994 Innovative methods for plant disease control. Plant Disease Research 9:12-17.

Midmore D J 1988 Intercropping potato (*Solanum* spp) with maize in warm climates. In : Proceedings of 7th symposium, International Society for Tropical Root Crops, Guadaloupe, July 1985 INRA, Guadeloupe pp 837-851.

*Mirkova E 1983 Use of *Trichoderma harzianum* Rifai to control wilt of glasshouse carnation caused by *Fusarium oxysporum* f. sp. *dianthi*. Gradinarska i Lozarska Nauka 20: 65-69.

Mitchell R and Alexander H 1961 Chitin and the biological control of *Fusarium* diseases. Plant Disease 45:487-490.

*Mitra M 1924 Report of the Imperial Mycologist. Scientific Reports of the Agricultural Research Institute, Pusa, 1924-25, Pusa, India pp 58-71.

Mixon A C and Curl E A 1967 Influence of plant residues on *Scleriotium rolfsii* and inhibitory soil micro organisms. Crop Science 71:641-644.

Mueller J D, Shorlt B J and Sinclair J B 1985 Effects of cropping history, cultivar and sampling date on the internal fungi of soybean roots. Plant Disease 69:520-523.

Mukhopadhyay D and Sengupta P K 1991 Factors affecting competitive saprophytic activity of *Fusarium udum*, the causal organism of wilt of pigeonpea. Indian Phytopathology 44:73-79.

Mukhopadhyay A N, Shreshta S M and Mukherjee P K 1992 Biological seed treatment for control of soil borne plant pathogens. FAO Plant Protection Bulletin 40:21-30.

*Mukhopadhyay A N and Mukharjee P K 1991 Innovative approaches in biological control of soil borne diseases in chickpea. Proceedings Fourth International *Trichoderma* and *Gliocladium* workshop, Belgirate, Italy, 17-20 July, 1991, Petria pp 146.

Mundkur B B 1935 Influence of temperature and maturity on the incidence of sunhemp and pigeonpea wilt at PUSA. Indian Journal of Agricultural Sciences 5:606-618.

*Mundkur B B 1967 Fungi and plant disease. MacMillan and Company Limited, New Delhi pp 267.

*Mundkur B B 1946 Report of the Imperial Mycologist, Scientific Reports of the Agricultural Research Institute, 1944. IARI, New Delhi, India pp 57-63.

Murthy G S and Bhagyaraj D J 1985 Nature of resistance in *Cajanus cajan* in relation to fusarial wilt. Mysore Journal of Agricultural Science 17:144-146.

Naik M K 1989 Wilt of watermelon caused by *Fusarium oxysporum* Schlecht. Ph.D. thesis, Indian Agricultural Research Institute, New Delhi pp 184.

Naik M K 1993 Ecology and integrated approach for the management of Fusarium wilt of pigeonpea. Legumes Pathology Progress Report 19, pp 100.

Naik M K, Reddy M V, Raju T N and McDonald D 1997 Wilt incidence in sole and sorghum intercropped pigeonpea at different inoculum densities of *Fusarium udum.* Indian Phytopathology 50:337-341.

*Naik M K and Sen B 1991 An integrated approach for management of fusarium wilt of water melon. XII International Plant Protection Congress at Rio de Janeiro, Brazil, August 11-16, 1991.

Nash S M and Snyder W C 1962 Quantitative estimation by plate counts of propagules of the bean root rot *Fusarium* in the field soils. Phytopathology 52:567-572.

Natarajan M, Kannaiyan J, Willey R W and Nene Y L 1985 Studies on the effects of cropping system on fusarium wilt of pigeonpea. Field Crops Research 10:333-346.

Nene Y L 1980 Proceedings of the consultants. Group discussion on the resistance to soil borne diseases of legumes, ICRISAT pp 1-167.

Nene Y L, Kannaiyan J, Haware M P and Reddy M V 1979 "Review of the work done at ICRISAT on soil borne diseases of pigeonpea and chickpea". In Proceedings group discussion on the resistance to soil borne diseases of legumes International Crops Research Institute for Semi-Arid Tropics, Patancheru, A.P. pp 3-35.

Nene Y L, Kannaiyan J, Haware M P and Reddy M V 1980 Review of the work done at ICRISAT on soil borne diseases of pigeonpea and chickpea. In: Proceedings of the consultants group discussion on the resistance to soil borne diseases of legumes 8-11 January 1979, ICRISAT Center, Patancheru pp 3-39.

Nene Y L and Kanaiyan J 1982 Screening pigeonpea for resistance to Fusariam wilt. Plant Disease 66:306-307.

Nene Y L, Kannaiyan J and Reddy M V 1981 Pigeonpea Diseases. Resistance-Screening Techniques. ICRISAT Information bulletin No.9 pp 1-5.

Nene M L and Reddy M V 1981 "Survival of pigeonpea with Fusarium in vertisols and alfisols". In Proceedings workshop on pigeonpeas, Vol.2, Patancheru, ICRISAT, A.P. pp 291.

Nene Y L and Sheila V K 1990 Pigeonpea geography and importance. In : Nene Y L, Hall D and Sheila V K. The Pigeonpea, CABI, ICRISAT, Patancheru, A.P. pp 1-14.

Nene Y L, Sheila V K and Sharma S B 1989a A world list of chickpea (*Cicer arietinum* L.) and pigeonpea (*Cajanus cajan* (L.) Millsp.) pathogens. Legumes Pathology Progress Report 7, Patancheru, A.P., India, ICRISAT, pp 23.

Nene Y L, Kannaiyan J, Reddy M V, Zote K K, Mahmood M, Kotasthane S R and Sengupta K 1989b Multilocational testing of pigeonpea for broad based resistance to *Fusarium* wilt in India. Indian Phytopathology 42: 449-453.

Nene Y L, Sheila V K and Sharma S B 1996 A world list of chickpea and pigeonpea pathogens, fifth edition, ICRISAT, Patancheru, India pp 27.

Nishat Khalis and Manoharachary C 1985 Studies on the mycoflora changes in oil cake amended and unamended soils. Indian Phytopathology 38(3):462-466.

Odunfa V S A 1978 Root exudation in cowpea and sorghum and the effect on spore germination and growth of some soil fusaria. New Phytology 81:607-612.

Ogawa and Komada H 1984 Biological control of Fusarium wilt of sweet potato with cross protection by non pathogenic *Fusarium oxysporum*. In Ecology and Management of soil borne plant pathogen (eds.) Parker C A, Rovira A D; Moore K J, Hong P T W and Kollmorgen J F. The American Phytopathological Society, Saint Paul, Minnessota pp 121-124.

*Oswald J W, Lorenz O A 1956 Soybeans as a greenmanure crop for the prevention of potato scab. Phytopathology 46:22 (Abstract).

*Padmakumari G and Balakrishnan S 1987 Effect of organic amendments on the survival of *R. solani* the sweath blight pathogen. In Biological control of Plant diseases - A workshop, p. 4, Department of Plant Pathology, CPPS, TNAU, Coimbatore pp 34 (Abstract).

Padmodaya B and Reddy H R 1999 Effect of organic amendments on seedling disease of tomato caused by *Fusarium oxysporum* f. sp. *lycopersici*. Journal of Mycology and Plant Pathology 29:38-41.

Padwick G W 1940 "Genus *Fusarium*" 5 : *Fusarium udum* Butler, *F. vasinfectum*. Indian Journal of Agricultural Science 10:863-866

Pandey K K and Upadhyay J P 1999 Comparitive study of chemical, biological and integrated approach for management of Fusarium wilt of pigeonpea. Journal of Mycology and Plant Pathology 29:214-216.

Panse V G and Sukhatme P V 1978 Statistical methods for Agricultural workers. Indian Council of Agricultural Research, New Delhi pp.324.

Papavizas G C 1982 Survival of *Trichoderma harzianum* in soil and in pea and in bean rhizospheres. Phytopathology 71: 121-125.

Papavizas G C 1985 *Trichoderma* and *Gliocladium* : Biology ecology and potential for biocontrol. Annual Review of Phytopathology 23:23-54.

Papavizas G C and Davey C B 1960 Rhizoctonia disease of bean as affected by decomposing green plant materials and associated microflora. Phytopathology 50:516-521.

Papavizas G C and Lewis J A 1988 The use of fungi in integrated control of plant disease. In Fungi in Biological control systems, (ed) Burge M N, Manchester, UK, Manchester University Press pp 235-253

Papavizas G C and Lumsden R D 1980 Biological control of soil borne fungal propagules. Annual Review of Phytopathology 18:389-413.

*Parameswarappa R, Rao T S and Konda C R 1987 ICPL 270 a high yielding wilt resistant pigeonpea variety. Indian Phytopathology 20:126-129.

Parameswarappa R, Rao T S and Konda C R, Rao T S, Raghumurthy M, Eminath V S and Sangappa H K 1986 Maruthi - a wilt resistant redgram variety. Current Research, University of Agricultural Sciences, Bangalore 15:69-70.

Park D 1960 Antagonism the background to soil fungi. In : The Ecology of Soil Fungi (eds.) Parkinson D and Waid J S. Liverpool, Liverpool University Press pp 154-160.

Park D 1961 Isolation of *Fusarium oxysporum* from soils. Transactions of British Mycological Society 44:119-122.

Patel J A, Nafde S D, Patel D B, Zaveri P P and Pathak A R 1988 Field screening of pigeonpea lines for resistance to wilt at Vadodara, Gujarat, India. International Pigeonpea Newsletter 7:27-28.

Patel B K and Patel H R 1998 Effect of soil solarization, rabbing, nematicides and green manuring on population densities of soil microbes in Bidi Tobacco. Journal of Mycology and Plant Pathology 28:279-283.

Patil B G and Sable J E 1973 A role on the screening of tur against wilt disease. Punjabrao Krishi Vidya Peeth Research Journal 2:73-76.

Perrin R M 1977 Pest management in multiple cropping systems. Agro-Ecosystems 3:93-118.

Ploetz R C, Mitchell D J and Galkher R N 1985 Population dynamics of soil borne fungi in a field multicropped to rye and soybeans under reduced tillage in Florida. Phytopathology 75:1447-1457.

Podile A R, Prasad G S and Dube H C 1985 *Bacillus subtilis* as antagonist to vascular wilt pathogen. Current Science 54:864-865.

Potts M J 1990 Influence of intercropping in warm climates on pests and diseases of potato, with special reference to their control. Fields Crops Research 25:133-144.

Prakash D, Alan M M and Ashraf S 1985 Studies on rhizosphere mycoflora of tomato in relation to soil amendments. National Academy of Science Letters 8:133-134.

Punja Z K, Carter J D, Campbell G M and Rossell E L 1986 Effect of calcium and nitrogen fertilizers, fungicides and tillage practices on incidence of *S. rolfsii* on processing carrots. Plant Disease 70:819-824.

Raghchander T, Arjunan G and Samiyappan R 1992 Influence of organic amendments on Fusarium wilt in pigeonpea. Indian Journal of Pulses Research 5:203-205.

Raghuchander T, Arjunan G and Samiyappan R 1993 Effect of forms of nitrogen on Fusarium wilt of pigeonpea. In : Crop Diseases Inovative Techniques and Management. (eds.) Sivaprakasam K and Seetharama N. Kalyani Publishers, Ludhiana pp 430-432.

Rai P K and Singh K P 1995 Efficacy of certain oilcake amendments on *Heterodera cajani, Fusarium udum* and associated wilt of pigeonpea. Indian Journal of Tropical Plant Diseases 13:213-219.

*Rai B and Upadhyay R S 1979 Discovery of perfect state of *Fusarium udum* Butler. Proceedings of the Annual Conference of the Society for Advance Botany 5:25 (Abstract).

Rai B and Upadhyay R S 1982 "*Gibberella indica*, the perfect state of *Fusarium udum*". Mycologia 74:343.

Rai B and Upadhyay R S 1983 Competitive saprophytic colonization of pigeonpea substrate by *Fusarium udum* in relation to environmental factors, chemical treatments and microbial antagonism. Soil Biology and Biochemisrtry 15:187-191.

Rajib K D, Chaudhary R G and Naimuddin 1996 Comparitive efficacy of bio-control agents and fungicides for controlling chickpea wilt caused by *F. oxysporum* f.sp. ciceri. Indian Journal of Agricultural Sciences 66:370-373.

*Ramakrishnan G and Jeyarajan R 1986 Biological control of seedling diseases of cotton caused by *Rhizoctonia solani*. In Management of soil-borne diseases of crop plants - A Seminar - Department of Plant Pathology, CPPS, TNAU, Coimbatore pp 45.

Ramakrishnan G, Jeyarajan R and Dinakaran D 1994 Talc based formulation of *Trichoderma viride* for biocontrol of *Macrophomina phaseolina*. Journal of Biological Control 8:41-44.

*Ramaswamy G and Prasad N N 1974 Influence of potassium nutrition on wilt incidence in muskmelon. Potash Newsletter, Madras 9:3-5.

Rangaswami G and Balasubramanian A 1963 Release of hydrocyanic acid by sorghum roots and its influence on the rhizosphere microflora and plant pathogen fungi. Indian Journal of Experimental Biology 1:215-217.

Ratnoo R S and Bhatnagar M K 1993 Effect of stream oil cakes on ashy grey stem blight *M. phaseolina* of cowpea. Indian Journal of Mycology and Plant Pathology 23:186-188.

Raut N K and Bhombe B B 1971 A review of the work selection of tur varieties resistant to Fusarium wilt at College of Agriculture, Parbhani, Maizine, College of Agriculture, Parbhani 12:37-42.

*Raymuod S A 1983 Major pests of potatoes in hot humid climates and their control. Training document, CIP, Lima, Peru pp 17.

Reddy M V and Raju T N 1998 Evaluation of pigeonpea varieties for resistance to wilt caused by *Fusarium udum* in a perennial system. Indian Journal of Agricultural Sciences 67:437-439.

Reddy M, Raju T N and Naik M K 1993a Infection and colonization of *Fusarium udum* in pigeonpea. Indian Phytopathology 46.268 (Abstr).

Reddy G S and Rao A S 1966 Effect of groundnut and sesamum oil cakes on bacterial and fungal population of soil. Indian Journal of Microbiology 5:53-58.

Reddy M V, Raju T N and Nene Y L 1980 Low wilt incidence in short duration pigeonpeas. International Pigeonpea Newsletter 7:26-27

Reddy M V, Raju T N, Sharma S B, Nene Y L and McDonald D 1993b Hand book of pigeonpea diseases Information Bulletin No.42, pp 8-10.

Reddy M V, Sharma S B and Nene Y L 1990 Pigeonpea: disease management. In: The Pigeonpea (eds) Nene Y L , Hall S D and Sheila V K, CAB International, Wallingford, UK pp 303-347.

*Reinke K E 1962 The influence of nitrogen on the root disease of bean caused by *Fusarium solani* f. *phaseoli*. Phytopathology 52:757 (Abstract).

Robinson D B, Larson R H and Walker 1957 *Verticillim* wilt of potato in relation to symptom epidemiology and variability of the pathogens. Wisconson Agricultural Experimental Station Research Bulletin 2:202.

Rotem J and Palti J 1969 Irrigation and Plant Diseases, Annual Review of Phytopathology 7:267-288.

Rovira A D 1969 Plant root exudates. Botanical Review 35:35-37.

*Sarhan A R T and Hegazi A M A 1988 Effect of N P and K on sensitivity of pepper plants to *Fusarium* wilt toxin. Acta Phytopathologica et Entomologica Hungarica 23:57-60.

*Sarojini T S 1950 Soil conditions and root diseases I Micronutrient elements and disease development of *Fusarium udum* of redgram. Journal of the Madras University, Section B9:1-32.

Satyanarayana G and Kalyansundaram R 1952 "Soil conditions and root diseases. Symptomology of wilted cotton and redgram". Proceedings of Indian Academy Science (B) 36:54.

Satyaprasad K and Rama Rao P 1983 Influence of various amendments on the lysis of conidia and chlamydospore production by *Fusarium oxysporum* f. sp. *ciceri*. Indian Phytopathology 36:67-71.

Sawant I and Mukhopadhyay A N 1990 Integration of metalaxyl with *Trichoderma harzianum* for the control of pythium damping off in sugarbeet. Indian Phytopathology 43:535-541.

Schroth M N and Hilderbrand D C 1964 Influence of plant exudates on root infecting fungi. Annual Review of Phytopathology 2:101-132.

*Schroth M N, Toussoun T A and Snyder W C 1963 Effect of certain constituents of bean exudates on germination of chlamydospore germination of the bean root rot fungus. *Fusarium solani* f. sp. *phaseoli* in soil. Phytopathology 53:809-812.

Schroth M N and Snyder W C 1961 Effect of host exudates on chlamydospore germination of the bean root rot fungus, *Fusarium solani* f.sp. *phaseoli* in soil. Phytopathology 51:389-393.

*Sekiguchi A 1977 Control of Fusarium wilt on chinese yam. Annual Report, Department of Plant Pathology, Entomology, Vegetable Floriculture Experimental Station, Nagono, Japan 1:10-11.

Sequeira L 1962 Influence of organic amendments on survival of *Fusarium oxysporum* f. sp. *cubense* in the soil. Phytopathology 52:976-982.

Shaik Imam and Nusrath 1987 Varietal variation in the rhizosphere and rhizophane mycoflora of *Cajanus cajan* (L.) Millsp. with special reference to wilt disease. Indian Journal of Botany 10:126-129.

*Sharma J 1989 Spectrum and application of the antagonist in the biological control of Fusarium wilt of cucurbits. Ph.D. thesis, Division of Mycology and Plant Pathology IARI, New Delhi pp 123.

*Sharma S K, Bohra M D, Agarwal R K and Satish L 1989 Soil suppressiveness to *Fusarium* wilt and dry root rot of legumes induced by incorporation of cruciferous crop residues. Report of Central Arid Zone Research Institute, Jodhpur pp 44.

Sharma H C, Dixit J P and Saran R N 1987 Effect of intercrops and irrigation levels on the incidence of pigeonpea wilt caused by *Fusarium udum* Butler. Indian Journal of Agricultural Sciences 57:650-653.

Sharma N D and Jain A C 1978 Studies on the biological control of *Fusarium oxysporum* f.sp. *zingiberi*, the causal organism of yellows disease of ginger. Indian Phytopathology 31:260-261.

Sharma R D and Singh R S 1973 A technique for selective isolation of *Fusarium moniliforme* from soil and plant tissues. Indian Journal of Mycology and Plant Pathology 3:67-70.

Sheriff N M, Khan W M A and Iyenperumal S 1977 A note on the study of redgram mutants for resistance to root rot disease under field conditions. Madras Agricultural Journal 64:691.

Shrestha S M C, Mukherjee P K and Mukhopadhyay A N 1991 Integrated approach - a successful/method of controlling lentil wilt complex. Indian Phytopathology 40:436-439.

Shukla D S 1975 "Incidence of *Fusarium* wilt of pigeonpea in relation to soil composition". Indian Phytopathology pp 28:295.

Silbernagel M J and Mills L J 1990 Genetics and cultural control of *Fusarium* root rot in Bush snap beans. Plant Disease 74:61-66.

Singh R S 1974 Effect of host and non host crops seeds on vegetative growth and sporulation of *F. udum* in soil. Indian Phytopathology 27:553-557.

Singh R S 1975 Introduction to principles of plant pathology. Oxford and IBH Publishing Company, New Delhi pp 282.

Singh I J 1978 Introduction to farm management economics pp 1-215.

Singh R S 1995 Studies on *Fusarium*, Research Bulletin No.7, GB Pant University of Agriculture and Technology, Pantnagar, Nainital, U.P.

Singh A P and Bhargava S N 1981 Survival studies on three species of *Fusarium* causing wilt of pigeonpea. Phytopathologische Zeitschrift 100:300-311.

Singh D V and Mishra A N 1976 Search for wilt resistant varieties of redgram in Uttar Pradesh. Indian Journal of Mycology and Plant Pathology 6:89.

Singh S K, Nene Y L and Reddy M V 1990 Influence of cropping systems on *Macrophomina phaseolina* populations in soil. Plant Disease 74:812-814.

Singh R S and Pandey K R 1967 Population dynamics of *Pythium aphanidermatum* in oil cake amended soils. Canadian Journal of Microbiology 13:601-610.

Singh N and Singh R S 1970a Development of wilt causing species of *Fusarium* in fungicide treated soils. Indian Phytopathology 23:545-552.

Singh R S and Singh N 1970b Effect of oil cake amendment of soil on population of some wilt causing species of *Fusarium*. Phytopathologische Zeifschrift 26:160-167.

Singh N and Singh R S 1980 Inhibition of *Fusarium oxysporum* f. sp. *udum* by soil bacteria. Indian Phytopathology 33:356-359.

Singh N and Singh R S 1981 Lysis of mycelium of *F. oxysporum* f.sp. *udum* in soil amended with organic matters. Plant and Soil 59:9-15.

Singh N and Singh R S 1982 Effect of oil cake amended soil atmosphere on pigeonpea wilt pathogen. Indian Phytopathology 35:300-305.

Singh N and Singh R S 1983 Chlamydospore formation in *Fusarium udum* by soil bacteria. Indian Phytopathology 36:165-167.

Singh P, Vasudeva R S and Rajaj B S 1965 Seed bacterization and biological activity of bulbiformin. Annals of Applied Biology 55:89-97.

Sinha I and Upadhyay R S 1990 Fungitoxicity of some pesticides against *F. udum*, the wilt causing organism of pigeonpea. Hindustan Antibiotic Bulletin 32:36-38.

Sinha A K 1975 Control of Fusarium wilt of pigeonpea with Bavistin, a systemic fungicide. Current Science 44:700-701.

Sivan A and Chet I 1986 Biological control of *Fusarium* spp in cotton, wheat and muskmelon by *Trichoderma harzianum*. Journal of Phytopathology 116:39-47.

Sivan A and Chet I 1987 The possible role of competition between *Trichoderma harzianum* and *Fusarium oxysporum* on rhizosphere colonization. Phytopathology 79:198-203.

Sivan A, Ueko O and Chet I 1987 Biological control of *Fusarium* crown rot of tomato by *Trichoderma harzianum* under field conditions. Plant Disease 71:587-592.

Sivaprakasam K 1990 Soil amendment for crop disease management. In Basic research for crop disease management. (ed.) Vidhyasekaran P, Daya Publishing House, Delhi pp 306-315.

Sivaprakasam K, Pillayarsamy K, Rajaram S 1975 Effect of NPK on root rot disease incidence in sunflower. Madras Agricultural Journal 62:308-309.

*Sivaprakasam K and Rajagopalan C K S 1971 Influence of potash nutrition on the incidence of *verticillium* wilt disease of brinjal. Annamalai University Agricultural Research Annual 3:70-74.

Sivaprakasam K and Rajagopalan C K S 1974 Effect of nitrogen on the incidence of *Veriticillum* wilt disease of egg plant caused by *Verticillium dahliae* Kleb. Plant and Soil 40:217-220.

Snyder W C 1960 Antagonism as a plant disease control principle. In Biological chemical control of plant and animal pests. American Association of Advance Science, Washington DC pp 127-136.

Snyder W C, Schroth M N and Christou T 1959 Effect of plant residues on root rot of bean. Phytopathology 49:755-756.

Somasekhara Y M, Anilkumar T B and Siddaramaiah A L 1996 Biocontrol of pigeonpea (*Cajanus cajan* (L.) Millsp.) wilt (*Fusarium udum* Butler). Mysore Journal of Agricultural Sciences 30:159-163.

Songa W A 1990 Screening pigeonpea for resistance to *Fusarium* wilt and other control strategies for this disease. Proceedings of the 2nd KARI Annual Scientific Conference, Nairobi, Kenya, 5-7 Sept. pp 131-135.

Srihuttagum M and Sivasithamparam K 1991 The influence of fertilizers on root rot of field peas caused by *Fusarium oxysporum, Pythium vexans* and *Rhizoctonia solani* inoculated singly or in combination. Plant and Soil 132:21-27.

Srivastava S and Saksena S B 1968 Studies on rhizosphere and rhizophane microflora of potato with special reference to black scurf and wilt disease. Bulletin of Indian Phytopathological Society 4:107-119.

Srivastava U S and Sinha S 1971 Effect of various soil amendments on the wilt of coriander. Indian Journal of Agricultural Science 41:779-782.

Stakman E C and Harrar J G 1957 Principles of Plant Pathology, Ronald Ross Press, New York.

Stevenson P C, Padgham D E and Haware M P 1995 Root exudates associated with the resistance of four chickpea cultivars to two races of *Fusarium oxysporum* f.sp. *ciceri.* Plant Pathology 44:686-694.

Stevenson P C and Veitch N C 1998 A 2-arybenz-zofuran from roots of *Cicer bijugum* associated with *Fusarium* wilt resistance. Phytochemistry 48: 947-951.

Stova R H 1962 The use of organic amendments and green manures in the control of soil borne plant pathogens. Recent Advances in Microbiology 8:267-275.

Strashnov Y, Elad Y, Sivan A and Chet I 1985 Integrated control of *R. solani* by methyl bromide and *T. harzianum.* Plant Pathology 34:146-151.

Subramanian C V 1955 "Studies on south Indian Fusaria IV. 'The Wild Type' in *Fusarium udum* Butler". Journal of Indian Botanical Society 34:29.

Subramanian S 1963 "*Fusarium* wilt of pigeonpea I symptomology and Infection Studies". Proceedings of Indian Academy of Science (Section B) 57:134.

Subramanian S 1971 *Fusarium* wilt of pigeonpea II. Changes in the Host metabolism. Proceedings of Indian Academy of Sciences (Section B) 57:134.

Sudhir Chandra M, Raizada K and Khanna K 1981 Effect of organic amendments on the rhizosphere microflora of tomato. Proceedings of Indian Academy Sciences section B.90:189-197.

Sumitha R and Gaikwad S J 1995a Efficacy of some fungicides against *Fusarium udum* in pigeonpea. Journal of Soils and Crops 5:137-140.

Sumitha R and Gaikwad S J 1995b Checking *Fusarium* wilt of pigeonpea by biological means. Journal of Soils and Crops 5:163-165.

Sumner D R, Doupnik Boosalis B 1981 Effects of reduced tillage and multiple cropping on plant diseases. Annual Review of Phytopathology 19:167-87.

Thakur R P and Mukhopadhyay A N 1972 Nitrogen fertilization of sugarbeet in relation to sclerotium root rot caused by *Sclerotium rolfsii* sacc. Indian Journal of Agricultural Science 42:614-617.

Theradimani M and Marimuthu T 1993 Effect of decomposed coconut coirpith, fungicides and biocontrol agents - on damping off of chillies and dry root rot of blackgram. Indian Journal of Mycology and Plant Pathology 24: 20-23.

Thurston H D 1992 Sustainable practices for plant disease management in traditional farming systems. Westview Press/Oxford & IBH Publishing pp 277.

Timonin M I 1941 The interaction of higher plants and soil micro-organisms III. Effects of byproducts of plant growth on activity of fungi and actinomycetes. Soil Science 52:395-413.

*Tisdale H B and Dick J B 1939 The development of wilt in a wilt resistant and susceptible variety of cotton as affected by NPK ratio in fertilizer. Soil Science Society of American Proceedings 4:333-334.

*Tiwari 1971 Studies on *Helmintho tetramera* MCK of rice plant with reference to its competitive saprophytic ability. Ph.D. thesis, Banaras Hindu University, India pp 187

Toussoun T A, Nash S M and Snyder W C 1960 Effect of nitrogen sources and glucose on the pathogenesis of *Fusarium solani* f.sp. *phaseoli*. Phytopathology 50:137-140.

Trenbath B R 1993 Intercropping for the management of pests and diseases. Field Crops Research 34:381-405.

Tso H P and Zentmyer G A 1979 Suppression of *Phytophthora cinnamoni* and *P. Parasitica* in urea amended soils in soil borne plant pathogens. In : Soil borne plant pathogens. (eds.) Schippers B and Crams D. London, Academic pp 191-199.

Turner J T and Backman P A 1991 Factors relating to peanut yield increases after seed treatment with *Bacillus subtilis*. Plant Disease 75:347-353.

*Upadhyay R S 1979 Ecological studies on *Fusarium udum* Butler causing wilt disease of pigeonpea. Ph.D. thesis, Banaras Hindu University, India.

Upadhyay R S 1987a "Ecology and Biological control of *Fusarium udum*". In Proceedings of the eleventh international congress of plant protection, Manila, 121 (Abstract)

Upadhyay R S 1987b Tolerance to high tempareture by *Aspergillus nidulanns* and its possible implications in biological control of wilt disease of pigeonpea. Plant and Soil 97:273-277.

Upadhyay R S 1991 Ecology and biological control of *Fusarium udum.* In Proceedings 11th International Congress of Plant Protection, Manila, Philippines, 5-9 October 1987 pages, V.2:310-316.

Upadhyay R S 1992 Ecology and biological control of *Fusarium udum* in relation to soil fungistasis of antagonistic microorganisms. Journal of Plant Protection in the Tropics 9:1-9.

Upadhyay J P and Mukhopadhyay A N 1986 Biological control of *Sclerotium rolfsii* by *Trichoderma harzianum* in sugarbeet. Tropical Pest Management 32:215-220.

Upadhyay R S and Rai B 1978 *Micromanospora globosa* Krass : a destructive parasite of *Fusarium udum* Bnubles. Microbios Letter 8:123-128.

Upadhyay R S and Rai B 1979 Ecological survey of Indian soil fungi with special reference to *Aspergilli, Pericilli* and *Trichoderma.* Revue Ecologie Biologie dur Soil 16:39-49.

Upadhyay R S and Rai B 1981a Effect of cultivar practices and soil treatments on incidence of wilt disease of pigeonpea. Plant and Soil 62:309-312.

Upadhyay R S and Rai B 1981b Fungistatic activity of different Indian soils against *Fusarium udum* Butler. Plant and Soil 63:181-187.

Upadhyay R S and Rai B 1987 Studies on antagonism between *Fusarium udum* and root region microflora of pigeonpea. Plant and Soil 101:79-83.

Upadhyay R S and Rai B 1982 Ecology of *Fusarium udum* causing wilt disease of pigeonpea : population dynamics in the root region. Transactions of British Mycological Society 78:209-220.

Upadhyay R S and Rai B 1983a A new disease cycle of wilt of pigeonpea. Current Science 52:978-981.

Upadhyay R S and Rai B 1983b Competative saprophytic ability of *Fusarium udum* Butler in relation to some microfungi of root region pigeonpea. Indian Phytopathology 36:539-544.

Upadhyay R S and Rai B 1984a Ecology of *Fusarium* species causing root diseases. In : Progress in Microbial Ecology, (eds.) Mukerji K G, Lucknow. Print House (India) pp 37-72.

Upadhyay R S and Rai B 1984b Biological control of soil borne plant pathogens. In : Frontiers of Applied Microbiology. (eds.) Mukerji K G and Singh V P. Print House, Lucknow, India pp.261-291.

Upadhyay R S and Rai B 1985 Antagonistic behaviour of root region microflora of pigeonpea against *Fusarium udum*. In : Ecology and Management of soil borne plant pathogens. (eds.) Parker C A, Rovira A D, Moore K J and Kollmorgen J F. American Phytopathological Society, Saint paul. Minnesota, pp 131-133.

Upadhyay R S and Rai B 1987 Studies on antagonism between *Fusarium udum* and root region microflora of pigeonpea. Plant and Soil 101:79-94.

Upadhyay R S and Rai B 1989 Wilt disease of pigeonpea and its causal organism, *Fusarium udum*. Perspectives in plant pathology, Today and Tomorrow's Printers and Publishers, New Delhi, pp 241-275.

Upadhyay R S and Rai B 1989 Wilt disease of pigeonpea and its causal organism *Fusarium udum*. In Perspective of phytopathology. (eds.) Agnihotria V P, Singh U S, Chaube H S, Singh N and Dwivedi T S. Today and Tomorrow's Printers and Publishers, New Delhi pp 241-275.

Upadhyay R S and Rai B 1992 Wilt of pigeonpea. In Plant Diseases of International Importance pages V.1:388-414.

Vaheeduddin S and Nanjundiah S M 1956 Evolving wilt resistant strains in tur (*Cajanus cajan* L.). Proceedings of the Indian Science Congress 43:20 (Abstract).

Vasudeva R S and Roy T C 1950 The effect of associated soil microflora on *Fusarium udum* Butler the fungus causing wilt of pigeonpea (*Cajanus cajan* (L.) Millsp.). Annals of Applied Biology 38:169-178.

Vasudeva R S, Singh G P and Iyengar R S 1962 Biological activity of bulbiformin in soil. Annals of Applied Biology 50:113-117.

Vasudeva R S, Singh P, Sengupta P K and Mahmood M 1963 Further studies on the biological activity of bulbiformin. Annals of Applied Biology 51:415-423.

Vasudeva R S, Subbaiah T V, Sastry M L N, Rangaswamy G and Iyengar M R S 1958 "Bulbiformin" an antibiotic produced by *Bacillus subtilis*. Annals of Applied Biology 46:336-345.

Veeraswamy R, Ranga Swamy P and Sheriff N M 1975 CO2 redgram - a new strain with early maturity and improved plant type. Madras Agricultural Journal 62:541-543.

Verma A and Singh R B 1998 Effect of soil amendment of *Clerodendrum aculeatum* and *Clerodendrum fragrans* on disease incidence of pigeonpea wilt. National Academy Science Letters 21: 9-13.

Vinay Sagar and Sugha S K 1998 Effect of soil type and available nutrients on Fusarial population and severity of pea root rot. Journal of Mycology and Plant Pathology 28:294-299.

*Vrany J, Vacura V and Macura J 1962 The effect of foliar application of some readily metabolised substances, growth regulators and antibiotics on rhizosphere microflora. Folia Microbioilogy 7:61-70.

Wajid Khan M, Khan A M and Saksena S K 1974 Influence of certain oil cake amendments on nematodes and fungi in tomato field. Acta Botanica Indica 1:49-54.

Waksman S A 1922 Microbial analysis of soil as an index of fertility III. Influence of fertilisation upon numbers of micro-organisms in the soil. Soil Science 14:321-346.

Weinke K E 1962 The influence of nitrogen on the root disease of bean caused by *Fusarium solani* f. sp. *phaseoli*. Phytopathology 52: 757 (Abstract).

Wensley R N and Mckeen C D 1965 Some relations between plant nutrition, fungal population and incidence of Fusarium wilt of muskmelon. Canadia Journal of Microbiology 11:581-594.

Wensley R N and McKeen C D 1966 Influence of resistant and susceptible varieties of muskmelon on size of populations of the Fusarium wilt fungus and wilt in naturally infested soils. Canadian Journal of Microbiology 12:1116-1118.

Whilhelm S 1951 Effect of various soil amendments on the inoculum potential of *verticillium* wilt fungus. Phytopathology 41:684-690.

Wight R 1956 Spicilegium Neilgherrense or a selection of Neilgherry plants 2 Frank and Company, Madras pp. 202.

Zote K K, Dandnaik B P and Khalikar P V 1987 Reaction of pigeonpea varieties/lines to Fusarium wilt disease. Journal of Maharashtra Agricultural University 12:102-103.

Zote K K, Thombre P G, Khalikar P V, Dhandnaik B P, Chavan G V and Olekar S S 1983 Breeding pigeonpea for resistance to wilt and sterility mosaic. International Pigeonpea Newsletter 2:43-44.

APPENDIX A

Composition of liquid media

Medium	Contents	Quantity
Potato dextrose broth (PDB)	Peeled potato slices	200g
	Dextrose	20g
	Distilled water	1000ml

APPENDIX B

Composition of solid media

Medium	Contents	Quantity
POTATO DEXTROSE AGAR (PDA)	Peeled potatos	250g
	Dextrose	20g
	Agar - agar	20g
	Distilled water	1000ml

APPENDIX C

Physico-chemical properties of Vertisols and Alfisols experimental fields (sick soil)

Depth	Composition			Bulk density	Field capacity (Dry Wt%)	Available nutrients		
	Sand	Silt	Clay			N	P	K
				VERTISOLS				
0-25	20.3	15.9	63.7	1.3	36.5	137	9.2	739
25-60	30.6	18.7	50.8	1.4	42.0	164	13.2	624
				ALFISOLS				
0-25	64.5	6.0	29.6	1.5	14.5	181	10.4	256
25-60	45.8	7.2	47.2	1.6	17.0	216	7.6	232

Chemical analysis of the soil samples of farmers fields and ICRISAT

Area	N	P	K	OC (%)
Anantapur	538	1.9	91	0.45
Basawapur	376	1.7	84	0.32
Mal	161	3.3	48	0.14
Patancheru	644	0.1	275	0.54
Siddipet	509	2.1	509	0.48
Tandur	538	0.3	411	0.35
Alfisol (ICRISAT)	--	--	--	0.58
Vertisol (ICRISAT)	--	--	--	0.68

APPENDIX D

Medium	Contents	Quantity
Malachite green manure for *Fusarium*	Sodium Nitrate	2g
	Dipotassium phosphate	1g
	$MgSo_4$	0.5g
	Kcl	0.5g
	$FeSo_4$	0.01g
	Sucrose	30g
	Agar	20g
	PC NB	0.667g
	Yeast extract	2g
	Distilled water	1000ml
Mix and autoclane at 15 lbs pressure for 20 mts. than add		
	Dicrysticin	0.750g
	Malachite green	0.025g

APPENDIX E

Medium	Contents	Quantity
Martin Rose Bengal medium	Dextrose	10g
	Peptone	5g
	Potassium dihydrogen phosphate	1g
	Magnisium Sulphate	0.5g
	Rose bengal	0.03g
	Agar agar	20g
	Streptomycin	0.03g
	Distilled water	1000ml
	ph	5

APPENDIX F

Medium	Contents	Quantity
Trichoderma Selective medium	$MgSo_4>H_2o$	0.2g
	K_2HPo_4	0.9g
	Kcl	0.45g
	NH_4No_3	1.0g
	Glucose	3.0g
	Chloramphenicol	0.25g
	Dexon	0.3g
	PC NB	0.2g
	Rose bengal	0.15g
	Agar - Agar	0.15g
	Distilled water	1000ml

As per our convenience/instead of salt we used

	Maltose	20g
	Peptone	2g
	Yeast extract	2g
	Streptomycin	125mg/lit
	Sodium propionate sulphate	50mg/lit

Fungicide capton was added to TSM at 20 mg/l after autoclaving.

APPENDIX - G

WEEKLY METEOROLOGICAL DATA DURING CROP GROWTH PERIOD JUNE 1996 TO MARCH 1998

Standard week	TEMPERATURE (°C) MAXIMUM	TEMPERATURE (°C) MINIMUM	R.H. (%) I	R.H. (%) II	RAIN FALL (mm)	MEAN TEMP.
1996						
22	40.0	27.0	64	60	1.6	33.5
23	36.8	21.7	76	50	42.0	30.7
24	32.2	23.1	87	66	67.2	27.7
25	33.2	23.1	78	51	0.0	28.3
26	35.2	21.8	75	18	20.0	30.0
27	33.6	23.9	76	55	20.5	28.7
28	33.1	23.5	85	57	36.6	28.2
29	30.3	22.9	86	75	76.5	26.6
30	30.0	23.0	84	63	3.7	26.5
31	30.2	23.5	85	66	7.6	26.8
32	29.7	25.5	85	71	34.2	27.6
33	28.5	22.3	87	77	37.6	25.4
34	29.3	21.9	88	75	79.2	25.6
35	28.2	22.2	93	78	67.7	25.2
36	28.7	21.9	95	76	51.2	25.3
37	30.9	21.8	94	71	151.8	26.4
38	30.3	21.6	88	61	2.0	25.9
39	33.1	22.3	91	55	2.8	27.7
40	28.0	21.8	88	77	78.2	24.9
41	31.2	18.5	76	61	0.0	24.8
42	29.1	19.8	82	73	20.5	24.5
43	29.6	21.2	88	65	10.2	25.4
44	30.4	16.1	81	16	0.0	23.2
45	30.0	17.6	88	61	26.0	23.8
46	30.4	16.2	77	49	0.0	23.3
47	28.7	14.7	84	61	0.0	21.7
48	29.0	11.3	77	39	0.0	20.1
49	28.3	13.9	76	46	0.0	21.1
50	28.2	14.1	80	46	0.0	21.3
51	28.5	13.1	70	38	0.0	20.8
52	28.3	10.8	85	32	0.0	19.5
1997						
1	27.3	11.0	83	36	0.0	19.2
2	26.8	15.5	86	64	1.2	21.1
3	27.3	15.8	85	54	36.8	21.6
4	28.8	11.6	81	43	0.0	20.2
5	30.9	14.0	79	31	0.0	22.5
6	31.9	14.5	88	29	0.0	23.2
7	31.9	9.7	82	21	0.0	20.8
8	32.9	15.3	76	28	0.0	24.1
9	34.5	14.1	71	23	0.0	24.3
10	35.6	15.6	71	20	0.0	25.6
11	38.5	19.5	55	21	0.0	29.0
12	37.5	20.6	62	29	0.0	29.1
13	34.4	20.0	75	34	52.4	27.2
14	32.9	20.5	84	41	31.6	26.7
15	37.2	21.3	68	25	0.0	29.3

Contd.

Contd..

Standard week	TEMPERATURE (°C) MAXIMUM	MINIMUM	R.H. (%) I	II	RAIN FALL (mm)	MEAN TEMP.
16	35.7	21.3	67	29	14.0	28.5
17	38.0	21.8	68	26	0.0	29.9
18	35.9	21.4	73	32	2.8	28.7
19	38.8	25.0	65	28	0.0	31.9
20	40.9	25.7	48	20	0.0	33.3
21	40.8	25.3	38	21	0.0	33.1
22	40.6	25.6	56	26	0.0	33.1
23	37.8	24.0	77	38	12.4	30.9
24	35.1	23.6	76	44	52.6	29.3
25	34.5	23.6	71	43	6.0	29.1
26	35.6	23.9	74	40	0.0	29.8
27	30.7	21.9	86	71	72.8	26.3
28	32.3	23.3	80	51	13.2	27.8
29	33.5	23.9	76	45	8.4	28.7
30	31.5	23.4	84	62	36.6	27.4
31	31.1	23.1	86	67	0.4	27.1
32	31.8	22.8	89	67	18.7	27.3
33	32.7	22.7	87	64	15.3	27.7
34	30.9	22.7	82	63	2.2	26.8
35	30.1	21.9	86	64	80.0	26.0
36	32.5	23.3	88	70	76.0	27.9
37	30.4	22.7	91	75	1.6	26.6
38	30.5	22.3	93	69	47.5	26.4
39	31.4	22.1	88	57	0.0	26.7
40	31.8	19.8	89	45	6.2	25.8
41	32.5	18.7	72	40	0.0	25.6
42	32.3	20.5	85	46	0.0	26.4
43	31.0	20.8	89	53	12.7	25.9
44	28.6	20.5	95	67	54.5	24.5
45	30.5	19.2	92	50	1.0	24.8
46	30.0	20.4	94	64	47.1	25.2
47	29.7	20.2	88	60	0.0	25.0
48	29.9	20.6	90	55	1.0	25.2
49	28.8	18.8	94	57	32.2	23.8
50	27.1	17.6	89	63	0.0	22.3
51	28.3	19.1	95	60	4.2	23.7
52	31.2	17.8	92	47	0.0	24.5
1998						
1	28.7	13.9	91	46	0.0	21.3
2	29.4	13.3	88	39	1.2	21.4
3	32.1	17.1	88	39	0.0	24.6
4	31.5	19.8	84	42	0.0	25.6
5	31.5	18.0	89	40	0.0	24.7
6	31.4	18.2	82	36	0.8	24.8
7	31.9	15.8	76	30	0.0	23.9
8	34.3	16.9	71	26	0.0	25.6
9	35.3	20.6	78	30	0.2	28.0
10	35.5	20.9	67	37	0.0	28.2
11	35.3	21.1	63	31	0.0	28.2
12	37.8	21.7	71	28	0.0	29.8
13	36.6	21.9	77	27	0.0	29.3