EFFECT OF ORGANIC MANURE WITH THE INOCULATION OF NITROGEN FIXING AND PHOSPHATE SOLUBILIZING BACTERIA ON MICROBIAL POPULATION AND NITROGEN FIXING AND PHOSPHATE SOLUBILIZING POWER OF GINGER RHIZOSPHERE

A Thesis
submitted to the
Bidhan Chandra Krishi Viswavidyalaya
for the award of the degree of Doctor of Philosophy
(AGRICULTURE)
in
AGRICULTURAL CHEMISTRY AND SOIL SCIENCE

BY
NIHARENDU SAHA

DEPARTMENT OF AGRICULTURAL CHEMISTRY AND SOIL SCIENCE
FACULTY OF AGRICULTURE
BIDHAN CHANDRA KRISHI VISWAVIDYALAYA
WEST BENGAL, INDIA
1999

Dedicated

To My

late Beloved Father

CERTIFICATE OF APPROVAL

We, the undersigned, having been satisfied with the performance of **Shri Niharendu Saha**, in the Viva-voce Examination, conducted today, the , 1999, recommend that the thesis be accepted for the award of the Degree.

Name	Signature
1. **Prof. Bimal Krishna Dey** Supervisor	.....
2. External Examiner	.....
3. Dean, PG's nominee	.....
4. **Dr. Ranjan Kumar Basak** Head	.....

BIDHAN CHANDRA KRISHI VISWAVIDYALAYA

DEPARTMENT OF AGRICULTURAL CHEMISTRY AND SOIL SCIENCE

FACULTY OF AGRICULTURE

MOHANPURE-741252, NADIA, WEST BENGAL

From : ***Prof. Bimal Krishna Dey***
M.Sc., Ph. D. (IARI)
Professor, Agricultural Chemistry
and Soil Science
(Soil Microbiology)

No. ACSS ..... *Date 10.5. ..... 1999*

CERTIFICATE

This is to certify that the work recorded in the thesis entitled **"EFFECT OF ORGANIC MANURE WITH THE INOCULATION OF NITROGEN FIXING AND PHOSPHATE SOLUBILIZING BACTERIA ON MICROBIAL POPULATION AND NITROGEN FIXING AND PHOSPHATE SOLUBILIZING POWER OF GINGER RHIZOSPHERE"** submitted by **Sri. Niharendu Saha** for the award of the Degree of Doctor of Philosophy (Agriculture) in Agricultural Chemistry and Soil Science of the Bidhan Chandra Krishi Viswavidyalaya, is the faithful and bonafide research work carried out under my personal supervision and guidance. The results of the investigation reported in this thesis have not so far been submitted for any other Degree or Diploma. The assistance and help received during the course of investigation have been duly acknowledged.

Bimal Krishna Dey

(Bimal Krishna Dey)

Supervisor

ACKNOWLEDGEMENT

The author feels immense pleasure to express his deepest sense of gratitude, indebtedness and heartfelt respect to Prof. Bimal Krishna Dey, Professor, Department of Agricultural Chemistry and Soil Science, Faculty of Agriculture, Bidhan Chandra Krishi Viswavidyalaya, for his noble supervision, learned guidance, sustained interest and constant encouragement during the course of investigation.

The author will remember for ever the sustained interest, unceasing guidance and sympathetic understanding offered by Dr. Debatosh Mukherjee, Reader, Department of Agricultural Chemistry and Soil Science, during the preparation of this manuscript.

The author expresses his gratitude to Dr. S. S. Sahu, Prof. A. K. Das, the former Heads and Dr. R. K. Basak, the present Head, Department of Agricultural Chemistry and Soil Science, for providing necessary help.

With an unfading sense of gratitude, the author wishes to extend his heartfelt thanks to Dr. Sk. J. Islam, former Associate Director of Research, Regional Research Station, BCKV, Hill zone, Kalimpong, Darjeeling for providing necessary facilities to conduct the present investigation.

He likes to record a sincer thanks and gratitude to Dr. Jayanta Tarafdar, Sr. Lecturer, RRS, Kalimpong, Dr. Nirmal Mandal, Lecturer, Biotechnology unit, BCKV and Mr. Sandeep Das, Research Scholar, Department of Agricultural Chemistry and Soil Science, for their kind assistance.

The author wishes to record his thanks to M/s. Laser Tech Computer, Kalyani, for preparing the final manuscript.

The author is ever indebted to his late father, the inspiration of the work. Lastly but largely author is gratful to his mother, wife and son Iman for their inspiration.

Place : Mohanpur

Date : The 10th May 1999. Nadia

Niharendu Saha

(Niharendu Saha)

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOMICROGRAPHS

LIST OF PHOTOGRAPHS

CHAPTER I

Introduction

Chapter I

INTRODUCTION

India is a cornucopia of cuisine with an exciting variety of flavours, tastes and visual appeals. Indian cuisines are as diverse as the country itself. Various spices are used in culinary purposes to produce palatable, flavoured and coloured dishes.

India is the land of spices, producing around 30.05 lakh tonnes during 1997-98 with an annual growth rate of 10 percent (Peter, 1999). Consequently, an enormous volume of foreign exchange, the all time record of 316.4 million U. S. dollar, was earned within Feb., 1998 through the export of spices (Peter, 1998).

Ginger is one of the spices. Ginger of commerce or *Adrak* is the dried underground stem or rhizome of zingiberous herbaceous plant of *Zingiber officinale* Rose. It is one of the five most important major spices of India, ranking third or fourth competing with chillies, depending upon the fluctuation in world market prices in accordance with the demand and supply position (Purthy, 1993).

The history of Indian spices, in general, and ginger, in particular, goes back around 7000 years. Although it is not known in a wild state, nor is the country of origin known with certainty but evidences suggest that it was confined to the Old World Tropics with centre of distribution Indo-Malayasia (Encylopaedia Britennica 19).

Ginger is used as a home remedy since the time immemorial. As described by Vaghbhata, ginger has the following properties. It is a carminative, aphrodisiac, good for heart, antiflatulent, appetizer and digestive. It reduces *Kapha* and *Vatha* (Varier, 1988). De *Materia Medica* describes its warming effect on the stomach and as an aid to digestion and antidot to poison. In western country, ginger is widely used for culinary

purposes in gingerbread, biscuits etc. It is used for production of ginger beer and wine. In ayurvedic medicine it is used as cardioactive agent (Kumar and Prabhakar, 1990). Diversified and multipurpose usage of ginger and very recently introduced aromatheraphy make ginger as a classed spices in world wide.

Ginger alone occupies around 63,000 hectors of cultivable land in India, the largest amongst the ginger growing countries in the world. In spite of that the yield per unit area or productivity is very poor with a national average of 2.94 t ha^{-1} against those of 7.47 t ha^{-1} and 6.25 t ha^{-1} in Philippines and Bangladesh, respectively (Peter, 1999). Moreover, the demand for ginger, in the country, both for the export and domestic consumption, is ever increasing. So, the productivity has to be increased in order to achieve the production level of 2.05 lakh tonnes by 2001 as the population density of two major ginger growing states of India, Kerala and West Bengal is on the threshold of population explosion and there is no scope for the horizontal expansion of land under cultivation. Not only the productivity but also the quality of ginger is to be improved in order to secure India's present position in the international market against the potentially emerging countries like Indonesia and China (Peter, 1999). So, there is an ample scope of enhancing both the productivity and quality through the application of low-cost agro-technology. (Thomas and Velappan, 1988).

Ginger, the crop with exhaustive feeding habit, is traditionally grown in the terrace of the hilly belt in India. Terrace cultivation effectuates nutrient losses, particularly through runoff (Kumar and Ramkrshinan, 1989). But ginger requires higher dose of fertilizers for good harvest. Moreover, ginger is mainly cultivated by the poor farmers who are endowed with little investment capacity. Furthermore, the escalating cost of fertilizers due to shortage of fossil fuel compelled the farmers to think about an alternate source of plant nutrients. In this context, it is imperative to explore the utility of locally available most remunerative organic matter and the potentiality of beneficial organisms through biological nitrogen fixation and transformation

of insoluble organic and inorganic phosphorus compounds to soluble forms. Favourable conditions should be created to intensify the processes.

Microorganisms found in the root zone generated interest in the understanding of their influence on plants. The root region of plants is the site at which microorganisms and plants come in close contact resulting in the establishment of a unique and dynamic environment. The environment is unique in the sense that both the root system and soil microorganisms exude and absorb organic materials and thus, facilitate two-way movement of the easily assimilable nutrients. The environment is dynamic since a shift in the quality and quantity of every potential nutrient in the root region offers plenty of scope for a variety of biological activity. The unique environment under the influence of plant roots is called the rhizosphere (Hiltner, 1904). The magnitude of rhizosphere effect varies with the kind and age of plant, nature, treatments of soil and environmental factors (Katznelson, 1965; Dey and Chattopadhyay, 1977).

In light of the information gathered over the years on the activity of the rhizosphere microflora, in the present day agriculture, attempts have been made and are being made to manipulate the rhizosphere microflora which benefit plants either by direct effect or indirectly by controlling or suppressing the harmful organisms. This can be achieved in three different ways, namely a) by adjusting environmental conditions, b) by altering plant metabolism, c) by introducing different organisms into the rhizosphere (Brown, 1974). Adjustment of the soil environment and change in the metabolism of plant can be accomplished by soil and foliar amendments. Plant growth promoting rhizobacteria (PGRB) are generally used for better nutrient acquisition and mobilization in addition to the suppression of deleterious pathogenic organisms (Schippers, *et. al.*, 1987). The objective of present investigation is confined to the study of the rhizosphere of ginger as influenced by the application of organic manure (FYM) along with the inoculation of nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* alone or in combination in the presence of chemical fertilizers.

FYM, the cheap, easily available and most remunerative organic matter, is widely used to improve the physico-chemical properties of soil (Hamdi and Metwally, 1969; Gaur *et al.*, 1971; Mukherjee *et al.*, 1984 and 1985; Hanay *et al.*, 1992; Patil *et al.*, 1993; Yang *et al.*, 1994) in addition to bring about significant influences on the dynamics of soil microbes (Gaur *et al.*, 1971; Dey and Chottopadhyay, 1977; Bhattacharyya *et al.*, 1980; Mukherjee *et al.*, 1985; Hadas *et al.*, 1996) and their activities (Dey, 1977; Gaur *et al.*, 1970; Bhattacharyya *et al.*, 1984 and 1986).

Ginger is mainly cultivated in hilly areas of Kerala, Orissa and West Bengal where farmers knowingly or unknowingly have been using FYM since time immemorial. Scientific literatures regarding the importance of FYM in ginger nutrition are well documented (Rajan *et al.*, 1971; Mohanthy *et al.*, 1978; Power and Patil, 1987; Saha, 1989; Wiroatmodojo *et al.*, 1990; Sugito, 1995; Khandkar *et al.*, 1996). FYM is particularly important in areas like the present experimental site where the terrace cultivation is adopted because the system of cultivation is prone to heavy nutrient losses through water. Organic matter recycling is the best solution for the sustenance of ginger cultivation in the terrace (Kumar and Ramkrishnan, 1989). Moreover, organically produced spices are intrinsically superior to those grown elsewhere in test, flavour, aroma, texture, size and colour.

Plant roots strongly and selectively stimulate the multiplication of bacteria, actinomycetes, fungi and free living nitrogen fixers and phosphate solubilizers. Root exudates play a pivotal role in the selectivity and abundance of microorganisms (Rovira, 1965 and 1969; Dey, 1972 and 1973). This may be very important for the present experimental crop ginger - especially because of the aromaticity and antimicrobial property of ginger root exudates like those of other rhizomatous medicinal plant (De, 1995). Moreover, ginger is a mulched crop. Mulching plays a positive role in the growth and yield of ginger (Mohanthy, 1977; Mohanthy *et al.*, 1978; Roy, *et al.*, 1988; Korla *et al.*, 1990; Babu *et al.*, 1997). The microbial numbers and their activities are also influenced by mulching (Gaur and Mukherjee, 1980).

Though, a very few pathological information of ginger rhizosphere is available (Sharma *et al.*, 1975) yet there is hardly any systematic information regarding the influence of ginger rhizosphere on nutrients and microbial dynamics. So, the exploration of ginger rhizosphere will be an interesting aspect of the present investigation.

The soil is habitat for a vast, complex and interactive community of microorganisms. The activities of microorganism largely determine the chemical and physical properties of the soil as well as the growth of plants. From the germination of seed until a plant reaches the maturity, there is a close association between living plant roots and soil organisms. This association is termed as rhizocoenosis (Lynch, 1983). Within the root region, there is a continuous interaction between plant roots and soil organisms that comprises the rhizosphere. The interaction may be neutral, harmful or beneficial.

Although rhizosphere appears to be too complex to allow its manipulation, specific organism can be inoculated on to the seed or root, which, in turn, may cause an alteration in the composition of the rhizosphere (Dey, 1972; Brown, 1974). Such manipulation may have important and exciting implications. In addition to discourage disease causing organisms, it may be possible to promote the activities of the beneficial ones. Thus, the focus of attention has to be shifted from plant-microbe interaction to plant-microbe-microbe interactions (Saxena and Tilak, 1994). Some investigations have brought to light the instances where biological activities were markedly enhanced by two or three membered association of organisms (Kundu *et al.*, 1980; Tilak *et al.*, 1982; Verma *et al.*, 1989). Such syntrophic association is of ecological importance with implied agricultural significance.

The importance of inoculation of nitrogen fixing bacteria (Dey, 1972; Meshram *et al.*, 1982; Lakshinarayanan *et al.*, 1987) and phosphate solubilizing organisms (Dutta *et al.*, 1982; Banik *et al.*, 1982, 1985; Dey, 1988) alone or in combination of above mentioned organisms in soil fertility *vis-a-vis* crop performance (Shende *et al.*, 1973; Ocampo *et al.*, 1975; Kundu *et al.*, 1980, 1981 and 1982; Gaur and Algawadi, 1989) needs hardly any emphasis.

Though, the literature containing the beneficial effects of co-inoculation and multiple inoculation of nitrogen fixing bacteria and phosphate solubilizing microorganisms on different field crops is available, it is rare in the horticultural crop like ginger. However, there are few exceptions wherein ginger inoculated with diazotrophs (Konde *et al.*, 1990) or with vesicular-arbuscular mycorrhizal fungi (Sharma *et al.*, 1997) increased crop yield. Very recently scientists in Indian Institute of Spices Research are exploiting *Azospirillum*, phosphobacteria and vesicular - arbuscular mycorrhizal fungi, alone and in combination for better yield of various spices (Peter, 1998). Thus, use of nitrogen fixer and phosphate solubilizers singly and in combination will be very important in the degraded agroecosystem of terrace cultivation with ginger.

There are numerous instances in which bacterization onto the seed and root of plants brought about an enhancement in plant growth and yield of crop (Kavimandan *et al.*, 1971; Brown, 1974; Burr *et al.*, 1978; Banik *et al.*, 1982 and 1985; Dey, 1988). Most of the concerned bacteria are of the genera *Azotobacter, Bacillus* and *Pseudomonas*. *Azotobacter* is endowed with the property of fixing atmospheric nitrogen (Shende *et al.*, 1973; Kundu *et al.*, 1980) and can add nitrogen to soil while *Bacillus* and *Pseudomonas* can improve the phosphorus nutrition of the plant (Datta *et al.*, 1982; Banik *et al.*, 1987) by the process of mineralization and solubilization of insoluble organic and inorganic phosphorus compounds to mobile soluble form. Moreover, both of them can fix meagre amount of nitrogen in soil (Alexander, 1977). But, the most interesting peculiarity of all of them is that they are empowered with growth promoting substances besides vitamins and amino acids (Mishustin *et al.*, 1962; Katznelson *et al.*, 1965; Brown *et al.*, 1970 and 1972; Datta *et al.*, 1982; Banik *et al.*, 1987) and, hence, they are called growth promoting rhizobacteria (PGBR). In addition, they secrete toxic metabolites and antibiotics lethal to disease producing organisms (Brown *et al.*, 1963; Singh *et al.*, 1965; Mishustin *et al.*, 1969, Sundaram and Rao, 1980; Sakthivel *et al.*, 1986; Fiddaman *et al.*, 1993). It has been revealed that the nitrogen fixed and phosphorus made available to the plants by the inoculation of concerned

bacteria are not the sole determinant of the performance of crop. It is rather the modification of the 'biological buffering' system in rhizosphere by the cited organisms in such a way to encourage more diversified organisms so as to compete with pathogenic organisms, of importance. Improvement of crop health, more so, yield is the resultant impact of the nutrients, phytohormones and antibiotics.

In spite of the positive measures adopted by State Government and ICAR, ginger is yet susceptible to the soft-rot disease caused by combined action *Fusarium, Pythium and Pseudomonas* (Bhardwaj *et. al.*, 1988; Choi *et. al.*, 1990; Rana *et. al.*, 1991). Farmers, scientists and planners are worried and tensed because of the possible danger to ginger industry (Manicom, 1998). Soft-rot of ginger being a rhizome borne/or soil borne disease, its incidence and intensity depend to a great extent on the nature of seed used, weather conditions and soil. Soil borne pathogenic inoculum and its build up can be prevented or reduced by various practices. A variety of fungicides have the characteristic to forestall the growth of pathogenic organisms but the chemicals are too costly to the ordinary farmer. The convenient organic amendments also bring about suppression of soilborne plant pathogens (Huber and Watson,1970; Hendrix *et. al*, 1973). In this context, FYM is very effective in soil (Toyota and Kimura, 1992). Many organic amendments are also tested in India to control the soft-rot of ginger (Rajan *et. al.*, 1971; Sadanandan *et. al.*, 1986; Thakore *et. al.*, 1987; Dohroo *et. al.*, 1994; Dohroo *et. al.*, 1997). Attempts have been made to control the pathogen biologically by employing *Trichoderma* and *Gliocladium* (Sharma *et. al.*, 1979; Peter, 1998). Rhizome bacterization with *Azotobacter* and *Bacillus* may play a positive role in the control of disease by suppressing the soilborne plant pathogens, or by antibiosis or by increasing the 'biological buffering capacity' in the ginger rhizosphere (Nitta, 1990). However, the information regarding the combined effect of organic amendments and biological tools on soft-rot of ginger is lacking. An attempt has, therefore, been made to investigate the influence of organic manure with the inoculation of *Azotobacter* and Bacillus, alone or in combination on the incidence and intensity of soft-rot of ginger in relation to the performance of crop.

Considering the facts stated above, It has been felt that an investigation of ginger rhizosphere, especially as influenced by the application of well decomposed FYM with the inoculation of *Azotobacter* and *Bacillus*, alone and in combination will be very interesting and useful under degraded agroecosystem of terrace cultivation in hilly areas. So far very little work has been done on this aspect. Hence, in the present investigation, an attempt has been made to study the effect of manure and inoculation of the most efficient ginger rhizosphere non-symbiotic nitrogen fixing *Azotobacter* as well as phosphate solubilizing Bacillus strains, alone and in combination, on some microbiological and chemical properties of rhizosphere soil, *vis-a-vis* the performance of ginger especially in relation to the incidence and intensity of soft-rot disease of ginger.

CHAPTER II

Materials and Methods

Chapter II

MATERIALS AND METHODS

The present investigation embodies several experiments. In the first experiment, the rate of decomposition of two types of FYM, one procured from the local farm house (FH-FYM) and the other from the Regional Research Station (RRS-FYM), Bidhan Chandra Krishi Viswavidyalaya, Hill Zone, Kalimpong, Darjeeling, was evaluated. Henceforth, this experiment will be discussed under the head : decomposition of FYM in soil. In the second experiment nitrogen fixing and phosphate solubilizing bacteria were isolated from the rhizosphere soils of ginger. They were purified and screened in relation to their performance. The most efficient ones were selected for further study which will be read under the head : isolation and screening of non-symbiotic nitrogen-fixing and phosphate solubilizing bacteria from ginger rhizosphere. In the third experiment, the effect of the superior FYM, evaluated in the first experiment, along with inorganic fertilizers as well as the most efficient ginger rhizosphere nitrogen-fixing and phosphate solubilizing bacteria, isolated during the second experiment, on microbial and nutrient dynamics was studied in pot soil which will be narrated under the head : effect of FYM and inoculation of efficient nitrogen fixing and phosphate solubilizing bacteria on microbial as well as nutrient dynamics in soil. The same pot experiment was repeated in the fourth experiment along with ginger crop which will be discussed under the head : effect of FYM and inoculation of efficient nitrogen fixing and phosphate solubilizing bacteria on microbial and nutrient dynamics in the rhizosphere soil as well as performance of ginger in soil. The fifth experiment was carried

out in the field with the similar treatments in order to have better understanding and will be narrated under the head : effect of FYM and inoculation of efficient nitrogen-fixing and phosphate solubilizing bacteria on microbial and nutrient dynamics in the rhizosphere soil as well as performance of ginger in field. In the sixth experiment, plant pathogenic fungi and bacteria were isolated from rotten ginger which were then purified and identified up to the generic level. This will be read under the head : isolation and characterisation of some potential plant pathogenic microflora from rotten ginger. Seventh experiment was an *in-vitro* study of the interaction between the beneficial bacteria isolated during the second experiment and harmful microflora from the sixth experiment. This will be represented under the head : *in-vitro* studies on interaction between plant pathogenic and beneficial organisms. The eighth experiment embodied the treatments of third experiment and the effect of those treatments on some soil borne pathogenic organisms of ginger was determined under the head : enumeration of some soil borne plant pathogenic microflora from pot soil. The treatments of the nineth experiment were similar to those of the fourth experiment and the effect of the cited treatments on some potential pathogenic organisms as well as the soft-rot of ginger disease incidence and intensity, was found out under the head : soil borne plant pathogenic ginger rhizosphere microflora in relation to the soft-rot disease incidence and intensity in pot culture. The treatment of the tenth experiment were similar to those of the fifth experiment and similar effect to those of the nineth experiment was observed and discussed under the head : soil borne plant pathogenic ginger rhizosphere microflora in relation to soft-rot disease incidence and intensity in field condition.

TABLE–1 : Some physico-chemical and Biological properties of soil.

1.	pH (1 : 2.5)	5.84
2.	Water holding capacity (ml 100 g^{-1} dry weight of soil)	33.0
3.	Cation Exchange capacity (meq 100g^{-1} dry soil)	10.2
4.	Organic carbon (%)	0.666
5.	Tota nitrogen (%)	0.03
6.	C : N ratio	22.2 : 1
7.	Available P_2O_5 (kg ha^{-1})	11.0
8.	Available K_2O (kg ha^{-1})	107.0
9.	Available Nitrogen :	
	a) Ammoniacal nitrogen (mg 100 g^{-1} soil)	3.12
	b) Nitrate nitrogen (mg 100 g^{-1} soil)	2.05
10.	Mechanical Analysis :	
	a) Sand (%)	36.0
	b) Silt (%)	38.5
	c) Clay (%)	25.5
11.	Biological Properties of soil :	
	a) Total number of bacteria (CFU x 10^5) g^{-1} dry soil	48.5
	b) Total number of actinomycetes (CFU x 10^4) g^{-1} dry soil	98.0
	c) Total number of fungi (CFU x 10^4) g^{-1} dry soil	25.2
	d) Total number of *Fusarium* (CFU x 10^3) g^{-1} dry soil	23.18
	e) Total number of *Pythium* (CFU x 10^3) g^{-1} dry soil	13.0
	f) Total number of *Pseudomonas* (CFU x 10^3) g^{-1} dry soil	35.0
	g) Total number of nitrogen-fixing bacteria (CFU x 10^4) g^{-1} dry soil	48.8
	h) Total number of P-solubilizing organisms (CFU x 10^4) g^{-1} dry soil	37.5
	i) Nitrogen fixing power (mg N g^{-1} sucrose g^{-1} soil)	9.56
	j) Phosphate-solubilizing power [mg 15 mg^{-1} insoluble P {75mg $Ca_3(PO_4)_2$}] g^{-1} soil 0.15 g^{-1} sucrose	0.025

The details of the experimental methods are given below :

Experiment No. 1 – Decomposition of FYM in soil :

An experiment was conducted in the laboratory of Regional Research Station (RRS), Bidhan Chandra Krishi Viswavidyalaya, Kalimpong, Darjeeling to find out the rate of decomposition of two types of FYM – one procured from the local farmhouse (FH-FYM) and the other from RRS (RRS-FYM). The physicochemical properties of both the types of FYM were analysed and given in table - 2. The decomposition of FYM was carried out in previously ginger cultivated soil.

Collection and preparation of soil samples :

Previously ginger cultivated soil was collected from 0-15 cm. top soil from RRS farm for the experimental purpose. Auger method was adopted for collecting the soil sample. Soil, after collection, was air dried, ground and passed through a 2 mm seive and used for the experimental purpose. Physico-chemical and biological properties of soil were given in table–1.

Treatments :

The treatments were as follows :

1. Control – no FYM, no fertilizer.
2. FH-FYM – 1 + FYM (procured from the local farmhouse)@ 0.5% on soil wt. basis.
3. FH-FYMF – 2 + Inorganic fertilizers (N:P:K::120:60:90)
4. RRS-FYM – 1 + FYM (procured from RRS) @ 0.5% on soil wt. basis.
5. RRS-FYMF – 4 + Inorganic fertilizers (N:P:K::120:60:90).

TABLE-2 : Physicochemical Properties of organic manure (FYM)

Type - I*

1.	pH (1 : 2.5)	7.40
2.	Cation Exchange Capacity (meq 100 g^{-1} dry FYM)	29.50
3.	Organic carbon (%)	21.83
4.	Total nitrogen (%)	0.72
5.	C : N ratio	30.31
6.	Available nitrogen	
	a) Ammonical nitrogen (mg kg^{-1})	205.00
	b) Nitrate nitrogen (mg kg^{-1})	165.00
7.	Available phosphorus -	
	a) Water soluble phosphorus (mg kg^{-1})	45.5
	b) Citrate soluble phosphorus (mg kg^{-1})	1200

TYPE - II**

1.	pH (1 : 2.5)	7.90
2.	Cation Exchange Capacity (meq^{-1} 100g dry FYM)	41.50
3.	Organic carbon (%)	18.00
4.	Total nitrogen (%)	0.91
5.	C : N ratio	19.78
6.	Available nitrogen	
	a) Ammonical nitrogen (mg kg^{-1})	285.00
	b) Nitrate nitrogen (mg kg^{-1})	205.00
7.	Available phosphorus	
	a) Water soluble phosphorus (mg kg^{-1})	67.00
	b) Citrate soluble phosphorus (mg kg^{-1})	1500.00

* Type - I – FYM, Procured from local farm house (FH-FYM)

** Type - II – FYM, Procured from Regional Research Station (RRS-FYM)

The required amount of FYM (on soil wt. basis) and inorganic fertilizers were mixed thoroughly with 100 g air dried and seived soil and placed in one litre capacity conical flasks. The moisture was adjusted to 60% of the water holding capacity of soil. The treatments were replicated thrice and the flasks were incubated at $30^0 \pm 1^0$C. The rate of decomposition of FYM was determined at periodic intervals in term of mg of CO_2 evolved from the various treatments per 100 g soil, following the method of Pramer and Schimidt (1964) by absorbing the evolved CO_2 in NaOH solution and back titrating with HCl. In the initial stages, diurnal measurements of CO_2 evolution were taken followed by estimation at 3 and 7 days intervals until a static level was attained.

Experiment No. 2 – Isolation and screening of non-symbiotic nitrogen-fixing and phosphate solubilizing bacteria from ginger rhizosphere :

For the purpose of isolating non-symbiotic nitrogen fixing and phosphate solubilizing bacteria from ginger rhizosphere, ginger, *Zingiber officinalae* (Rosc.) cv. *Gorubathan* was grown in a terrace by planting 3 budded mother rhizome of 40 g in a raised bed, mulched with dry rice straw. The plot was nourished with N, P_2O_5 and K_2O @ 120 kg/ha as urea, 60 kg/ha as single super phosphate and 90 kg/ha as muriate of potash, respectively. Normal horticultural practices were followed for producing healthy luxuriant growth of ginger clump. After 120 days of planting, at the full growth stage a healthy plant was selected and rhizosphere soils were collected following usual technique (Katznelson, 1946) by uprooting the plant and keeping root system intact as far as possible. The bits of roots and other undesirable materials were completely removed. Nitrogen fixing and phosphate solubilizing bacteria were isolated in Jensen's

nitrogen free and Pikovskaya's agar plates, respectively following enrichment technique (Schlegel and Jannasch, 1967). Seven isolates of each of nitrogen fixing and phosphate solubilizing bacteria were purified and maintained for testing their efficacy towards dinitrogen fixation and insoluble phosphate solubilization. The isolates were coded as NFB_1, to NFB_7 for nitrogen fixing bacteria and PSB_1 to PSB_7 for phosphate solubilizing bacteria. Suffix number indicated the strain number.

Nitrogen fixing and phosphate solubilizing bacteria were isolated from ginger rhizosphere for their better compatibility towards the next ginger crop.

Nitrogen-fixing power of the isolated nitrogen fixing bacteria :

Nitrogen-fixing power of the isolated nitrogen-fixing bacteria was examined by estimating nitrogen after incubating an inoculum of 1.0 ml heavy suspension of each isolate (made by suspending 48 hour growth in one slant with 6.0 ml sterile distilled water) in 100 ml sterile nitrogen free Jensen's broth in 250 ml conical flasks. Four flasks were kept for each organism, of which two flasks were sterilised after adding 1.0 ml of cell suspension to serve as control. The flasks were incubated for 10 days and 15 days at $30^0 \pm 1^0C$. The materials of the flask were analysed for total nitrogen following Kjeldahl's method. Differences in nitrogen content of the non-sterile and sterilized flasks gave the amount of nitrogen fixed, expressed as mg N/g sucrose, as nitrogen fixing power. The residual carbon in the flask was not determined. Average of nitrogen fixation in 10 days and 15 days was considered as the nitrogen fixing power.

Phosphate solubilizing power of the isolated phosphate solubilizing bacteria :

Phosphate solubilizing power of the isolated phosphate solubilizing bacteria from insoluble tricalcium phosphate was examined by estimating water soluble phosphorus after inoculating an inoculum of the pure cultures in four culture tubes containing 15 ml Pikovskaya's broth having tricalcium phosphate as insoluble phosphorus source. The pH of the broth was adjusted to 6.5, after autoclaving, with sterile centinormal HCl or NaOH. Each tube containing 15 ml broth had 15 mg insoluble P, and 0.15 g sucrose as energy material. The inoculum for each tube was 0.1 ml heavy suspension, made by suspending 24 hour growth in one slant with 5.0 ml sterile distilled water. Out of four culture tubes, two tubes were sterilized individually after inoculation. The tubes were then incubated at $37^0 \pm 1^0$C. After 7 and 15 days incubation, materials of the two sterilized and two non-sterilized were centrifuged at 8000 r.p.m. for 20 minutes. From the supernatant, suitable aliquot was taken and water soluble phosphorus was estimated with the help of spectrophotometer following chloromolybdic acid - stannous chloride method (Jackson, 1973). Differences in the amount of soluble phosphorus in the non-sterile and sterilized tubes gave the phosphate solubilizing power expressed as mg of phosphorus solubilized per 15 mg insoluble P per 0.15 g sucrose consumed. Residual carbon in the tube was not determined. The incubation temperature was kept at $37^0 \pm 1^0$C for better solubilization. The incubation period of 7 and 15 days were chosen because in most cases the highest solubilization of phosphorus was observed in the broth within this period. Average of phosphorus solubilized in 7 and 15 days was considered as the phosphate solubilizing power of that organism.

NFB_1 and PSB_4 were the most efficient nitrogen fixing and phosphate solubilizing bacterial isolates identified as *Azotobacter* and *Bacillus* in accordance with Skerman's guide (Skerman, 1967) following the methods of Bowie *et al.* (1973) and the Key (Bergey's Manual of Determinative Bacteriology, 8th Edition, 1974) provided by Skerman and used as inoculants in the subsequent experiments.

Experiment No . 3 – Effect of FYM and inoculation of efficient nitrogen fixing and phosphate solubilizing bacteria on microbial as well as nutrient dynamics in soil :

The most efficient nitrogen fixing *Azotobacter*, NFB_1 and phosphate solubilizing *Bacillus*, PSB_4 were used as inoculants individually and in combination, in a pot culture experiment, without ginger crop for a preliminary study regarding their effect on microbial and nutrient dynamics as well as nitrogen fixing and phosphate solubilizing power of soils.

The experiment was laid out in a completely randomised design in pots of 22.6 cm diameter containing 5 kg of air dried and seived soil. The general characteristics of the soil used were determined following the methods described by Jackson (1973) and given in table-1. FYM @ 10 t ha^{-1} was added to each but the control series. Full dose potassic and phosphatic and half the dose of nitrogenous fertilizers, on the basis of treatments were mixed with the soils of pot. The rest of nitrogenous fertilizer was applied as split dose - half of the rest on the 45th day and another half on the 90th day of the experiment. The efficient strains of *Azotobacter* and *Bacillus*, alone and in combination were inoculated in soil in accordance with the treatments as described below. There were four replications of the following six treatments.

Treatments in pot culture without crop :

1) Control = No FYM, no inorganic fertilizer.

2) M = 1 + FYM (procured from RRS) @ 10 t ha^{-1} .

3) MF = 2 + Inorganic fertilizers at recommended dose i.e N-120 kg ha^{-1} as urea, P_2O_5 - 60 kg ha^{-1} as SSP and K_2O - 90 kg ha^{-1} as muriate of potash.

4) MFA = 3 + *Azotobacter*, NFB_1 : The most efficient nitrogen-fixing strain, isolated from ginger rhizosphere, inoculated by pouring the cell suspension in the soil.

5) MFB = 3 + *Bacillus*, PSB_4 : The most efficient phosphate solubilizing strain, isolated from ginger rhizosphere, inoculated as above.

6) MFAB = 3 + *Azotobacter*, NFB_1 + *Bacillus*, PSB_4 strains, inoculated as above.

Inoculation of bacteria :

The most efficient-nitrogen fixing *Azotobacter*, NFB_1 and phosphate solubilizing *Bacillus*, PSB_4 strains were inoculated by pouring the slurry containing the above mentioned bacterial cultures into soil. The cultures of *Azotobacter* and *Bacillus* were grown in nitrogen free Jensen's and Pikovskaya's broth, respectively, in 500 ml conical flasks. Each of non-symbiotic nitrogen fixing and phosphate solubilizing bacterial cultures were, then, inoculated in flasks containing 200 ml of respective broth by suspending 24 hour growth in one slant in 5.0 ml sterile distilled water. The flasks were incubated for two days on a rotary shaker at 20 rpm for 6 to 8 hours per day to obtain higher cell density. Before inoculation, the optical density of each culture was adjusted to 0.35 at 550 nm in the spectrophotometer

by adding sterile distilled water so that the number of cell per ml of the bacterial suspension was similar in all the cases. The number of viable cell per ml was 3.8×10^7 as revealed by dilution plating. Slurry thus diluted was poured into pot soil. In control, soil was inoculated with respective diluted broth without bacterial cultures.

Experiment No. 4. – Effect of FYM and inoculation of efficient nitrogen fixing and phosphate solubilizing bacteria on microbial and nutrient dynamics in the rhizosphere soils as well as performance of ginger in pot :

Another experiment similar to that of the previous one was carried out with ginger plant. Three budded mother rhizomes, each of 40 g, were inoculated with efficient strains of nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* and planted in each pot in accordance with the treatments. Every pot was mulched with dry paddy straw. Normal horticultural practices were followed.

Bacterization of mother rhizome :

A slurry, containing the most efficient nitrogen fixing *Azotobacter* NFB_1, and phosphate solubilizing *Bacillus*, PSB_4, was prepared following the technique as described earlier. Mother rhizomes after washing with distilled water were soaked for 10 minutes in above mentioned slurry and dried in shade. After 2 hours of drying, the presoaked rhizomes were planted in pots. Rest of the slurry was poured into the soils of pot. In control, the mother rhizomes were soaked with the respective diluted broths without bacterial inoculation.

Experiment No. 5 – Effect of FYM and inoculation of efficient nitrogen fixing and phosphate solubilizing bacteria on microbial and nutrient dynamics in the rhizosphere as well as performance of ginger in field.

The experiment was laid out in a completely randomised design in a terrace having 1.8 cm slope from west to east. The whole terrace was divided into twenty four plots of 2 m x 1 m dimension facing north to south. The drainage channels were 50 cm wide between the blocks. The treatments and replications were similar to the previous experiment. After the preparation of land, furrows were opened by hand drawing tyne 25 cm apart. Presoaked mother rhizomes as described earlier were planted 20 cm apart on the 15th May, 1995. The rest of the slurry containing bacterial cultures was poured along the respective furrows and covered with soil. The soils of each plot were levelled and mulched with dry paddy straw. Plots were weeded as and when required and normal horticultural practices were followed. No irrigation was required as ginger was cultivated under rainfed condition in the hills of Kalimpong, Darjeeling.

The mother rhizomes of ginger for planting purpose were obtained from the RRS, Hill zone, Kalimpong, Darjeeling. The experimental ginger variety was *Gorubathan*, a local variety largely cultivated in three blocks of Kalimpong subdivision where the experimental site was situated.

Sampling of soil :

A composite initial soil sample was prepared at the time of layout by pooling the soil samples collected from all the plots before application of manure and fertilizers. The soil is termed as the initial soil sample.

In case of pot experiment without crop, soil samples were drawn after every month. Samples from each of the replicate under the respective treatments, were mixed thoroughly. A portion of the composite soil sample was kept for the microbiological work and the rest was dried, seived and kept in polypack for the chemical analysis.

In the case of pot culture experiment with crop and field experiment, rhizosphere soils were collected at the sprouting of rhizome, early emergence of pseudostem, late emergence of pseudostem, full growth of pseudostem, near maturity of pseudostem and harvesting stages by usual techniques (Katznelson, 1946) as mentioned earlier. Rhizosphere soils from all the replicated plots under the same treatment were pooled together and mixed in order to have a composite sample. The bits of plant roots and other undesirable substances were completely removed.

Analysis of soil samples :

The initial and rhizosphere soil samples were immediately used without drying for the following experiments to have an effect at natural conditions. Moisture content of the soils were estimated in order to express the results on dry weight basis.

A. Microbiological :

The total number of bacteria, actinomycetes, fungi, aerobic non-symbiotic nitrogen fixing bacteria, phosphate solubilizing organisms in initial, as well as, in pot culture with and without crop and in field soils were counted on agar plates containing appropriate media following serial dilution technique (Pramer and Schmidt, 1965). The media used were as follows :

Total Bacteria :

For counting the total number of viable bacteria, Thronton's agar media (Thronton, 1922) was used.

Thronton agar medium	
Dipotassium hydrogen phosphate (K_2HPO_4)	1.0 g
Magnesium sulphate ($MgSO_4$, $7H_2O$)	0.2 g
Calcium Chloride ($CaCl_2$)	0.1 g
Sodium Chloride (NaCl)	0.1 g
Ferric Chloride ($FeCl_3$, $6H_2O$)	0.002 g
Potassium nitrate (KNO_3)	0.5 g
Asparagine ($C_4H_8N_2O_3$)	0.5 g
Mannitol	1.0 g
Agar agar	15.0 g
Distilled water	1000.0 ml

The pH was adjusted to 7.4 after sterilization.

Actinomycetes :

Jensen's agar medium for actinomycetes (Jensen, 1930) was used for counting the number of total actinomycetes.

Jensen's agar medium (for actinomycetes)	
Dextrose ($C_6H_{12}O_6$)	2.0 g
Casein [dissolved in 10 ml of 0.1 (N) NaOH]	0.2 g
Dipotassium hydrogen phosphate (K_2HPO_4)	0.5 g
Magnesium sulphate ($MgSO_4$, $7H_2O$)	0.2 g
Ferric Chloride ($FeCl_3$, $6H_2O$)	Trace
Agar agar	15.0 g
Distilled water	1000.0 ml

pH maintained at 6.6 after sterilization.

Fungi :

Martin's rose bengal streptomycin agar medium (Martin, 1950) of the following composition, was used to count the total fungi.

Martin's rose bengal streptomycin agar medium	
Dextrose ($C_6H_{12}O_6$)	10.0 g
Potassium dihydrogen phosphate (KH_2PO_4)	1.0 g
Magnesium sulphate ($MgSO_4$, $7H_2O$)	0.5 g
Peptone	5.0 g
Agar agar	15.0 g
Distilled water	1000 ml
Rose bengal (1 : 300 aq.)	10 ml
Streptomycin	30.0 µg/ml

All the ingredients, except rose bengal and streptomycin were heated to dissolve and then the molten agar was added. The mixture was coolded and rose bengal solution (1:300 aq.) at the rate of 1 ml/100 ml of medium was added. Streptomycin was added at the time of plating. A stock solution was prepared by dissolving 10 mg streptomycin in 2.0 ml distilled water. Approximately 0.1 ml of stock solution was added to each plate containing about 15 ml of the medium.

Non-symbiotic nitrogen fixing bacteria :

Jensen's agar medium (Jensen, 1930) was used for counting the aerobic non-symbiotic nitrogen fixing bacteria.

Jensen's Agar Medium :	
Sucrose	10.0 g
Magnesium sulphate ($MgSO_4$, $7H_2O$)	0.5 g
Sodium Chloride (NaCl)	0.5 g

Ferrous sulphate ($FeSO_4$, $7H_2O$)	0.1 g
Sodium molybdate ($Na_2M_0O_4$)	0.005 g
Calcium Carbonate ($CaCO_3$)	2.0 g
Agar agar	15.0 g
Distilled water	1000 ml
pH	6.6

Phosphate solubilizing microorganisms :

Pikovskaja's tricalcium phosphate agar medium (Pikovskaja, 1949) was used for the enumeration of phosphate solubilizing microorganisms.

Pikovskaia's Medium

Tricalcium Phosphate [$Ca_3(PO_4)_2$]	5.0 g
Sucrose	10.0 g
Ammonium sulphate [$(NH_4)_2SO_4$]	0.5 g
Sodium Chloride (NaCl)	0.2 g
Magnesium sulphate ($MgSO_4$, $7H_2O$)	0.1 g
Potassium chloride (KCl)	0.2 g
Yeast extract	0.5 g
Manganese sulphate ($MnSO_4$)	Trace
Ferrous sulphate ($FeSO_4$, $7H_2O$)	Trace
Agar agar	15.0 g
Distilled water	1000 ml
pH	7.4

In dilution plate, counting of the cited microorganisms was carried out after 3, 5, 7 and 10 days incubation. The incubation temperature for all the cases was $30^0 \pm 1^0C$.

Nitrogen fixing and phosphate solubilizing power of the rhizosphere soils :

Nitrogen fixing power of the said soils was examined by estimating nitrogen after incubating 1 g soil at $30^0 \pm 1^0$C in 100 ml sterile nitrogen free Jensen's broth, mentioned earlier, in 250 ml conical flasks. The other procedure were identical as in the case of estimating the same of the nitrogen-fixing bacterial isolates already cited.

Phosphate solubilizing power of the said soils was ascertained by estimating water soluble phosphorus after incubating 1 g soil in culture tubes containing 15 ml of the said Pikovskaia's broth. The other procedures were similar to those adopted for estimating the same of the phosphate solubilizing bacterial isolates mentioned earlier.

Isolation and Identification of microorganisms :

General bacteria, nitrogen fixing and phosphate solubilizing bacteria, actinomycetes and fungi present in initial, pot soil without crop, rhizosphere soils were isolated from respective agar plates, mentioned earlier, meant for counting them. When the colonies developed on the plates, for each treatment, were transferred in agar slant containing the same medium. After purification, on repeated sub-culturing, the isolates were identified up to generic level.

Bacteria and actinomycetes in general, nitrogen fixing and phosphate solubilizing bacteria, in particular, were identified in accordance with Skerman's guide (Skerman, 1967) following the methods of Bowie *et al.* (1973) and the key (Bergey's Manual of Determinative Bacteriology, 8th Edition) provided by Skerman. Although this system does not permit the precise ecological conclusion (Gray, 1969), it served the purpose

of the present work which was designed to indicate the overall picture as a basis for more detailed studies in future.

Fungi were identified up to the generic level according to the key described by Gilman (1957).

B. Chemical :

Soil reaction : The pH of the soil was determined in 1 : 2.5 : : soil : water suspension using Beckman's glass electrode pH meter.

Organic carbon : Organic carbon was determined by wet digestion method of walkley and Black described by Jackson (1973).

Total nitrogen : Total nitrogen was estimated by AOAC method (1985).

Inorganic nitrogen :

Ammoniacal-nitrogen : Ten gram moist soil was taken for each treatment and extracted by shaking in a mechanical shaker for 30 minutes with 100 ml 2 (M) KCl solution. The particles were allowed to settle and the contents were filtered through Whatman No. 42 filter paper. An aliquot of 50 ml of the filtrate was distilled with 3 g of powdered ignited magenisum oxide (MgO) and distilled ammonia was absorbed in 4% boric acid - mixed indicator solution. Absorbed ammonia in boric acid was titrated against standard H_2SO_4 in presence of bromocresol green-methyl red indicator.

Nitrate-nitrogen : After the determination of ammonium nitrogen, the flask was cooled and 2 g of Davarda's alloy was added. It was then again distilled and titrated as above.

Available phosphorus :

Available phosphorus was estimated by Bray method with 0.03 (N) NH_4F in 0.025 (N) HCl. (Bray and Kutz, 1945).

Analysis of plant samples :

Green ginger after harvesting was washed thoroughly with water, air dried, pieced into slices, dried and grinded to powder after keeping the samples in oven at 60°C for five hours followed by keeping in desiccators.

Total nitrogen content :

Total nitrogen of the prepared plant samples was determined by microkjeldahl's method (Jackson, 1973).

Total phosphorus content :

The grinded plant samples, at 500 mg lots were digested with 20 ml triacid mixture HNO_3, $HClO_4$ and H_2SO_4 in the proportion of 10 : 4 : 1 by volume in a hotplate at 140°C until dense white fumes had accumulated. The digested plant materials were diluted with distilled water to 100 ml volume and suitable aliquot (5ml) was used for estimating the phosphorus content of solution spectrophotometrically (Systronic, Model No. 166) following Vanadomolybdophosphoric yellow colour method described by Jackson, 1973.

Moisture content of rhizome was estimated for calculation of uptake of nitrogen and phosphorus by rhizome.

Experiment No. 6 – Isolation and characterization of some plant pathogenic microflora from rotten ginger.

Fusarium, *Pythium* and *Pseudomonas* are generally claimed to be the causal organisms of ginger soft-rot (Bhardwaj *et. al.*, 1988; Choi *et. al.*, 1990; and Rana *et. al.*, 1991). In a view to

isolate those organisms, pieces of infected rhizomes, after washing with distilled water and surface sterilization with 0.1% $HgCl_2$, were placed aseptically in a series of culture tubes, containing sterile distilled water. Rhizomes were then crushed and serially diluted and suspensions were plated in petridishes containing specific medium meant for those organisms. Isolates, thus obtained, were purified and identified following the techniques described earlier. Three *Fusarium* isolates and one *Pythium* isolate were detected and their pathogenicity was confirmed in the pathological laboratory. Cultural characteristics, of those fungal pathogens, comprising hyphal length, micro and macro conidia, no. of septa, nature of growth and pigmentation were recorded.

Five bacterial isolates were obtained from the rotten ginger. They were identified following the general guide described earlier and confirmed them as plant pathogen by observing their physiological behaviour and cultural characteristics in different selective medium as described by Schaad, (1980). The media used for this purpose were as follows.

a) D-1 agar

	g/l
Mannitol	15.0
$NaNO_3$	5.0
LiCl	6.0
$Ca(NO_3)_2 . 4H_2O$	0.02
K_2HPO_4	2.0
$MgSO_4, 7H_2O$	0.2
Bromothymol blue	15.0
pH	7.2

After autoclaving the medium was dark blue in colour.

b)	D-3 agar	g/l
	Sucrose	10.0
	Arabinose	10.0
	Casein hydrolysate	5.0
	LiCl	7.0
	NaCl	5.0
	$MgSO_4 . 7H_2O$	0.3
	Sodium dodecyl sulfate	0.05
	Bromothymol blue	0.06
	Acid fuchsin	0.1
	Agar-agar	15.0

pH of this medium was adjusted to 8.2 with NaOH before autoclaving. The medium has a pH of 6.9-7.1 after autoclaving.

c)	King's Medium B agar	g/l
	Peptone	20.0
	K_2HPO_4	1.5
	$MgSO_4, 7H_20$	1.5
	Glycerol	15.0 ml
	Agar-agar	15.0

d) Yeast-extract-dextros-$CaCO_3$ (YDC)

	g/l
Yeast-extract	10.0
*Dextrose	20.0
$CaCO_3$	20.0
Agar-agar	15.0

* Dextrose was autoclave separately and mixed aseptically.

The characteristics of those isolates in specific media were recorded and a chart was made on the basis of which genus of bacteria was confirmed.

Experiment No. 7 – *In-vitro* studies on interaction between plant pathogenic and beneficial organisms :

Informations are available that *Azotobacter* (Lakshmikumari *et al.*, 1975; Singh, 1977) and *Bacillus* (Agarwal *et al.*, 1978; Hedge *et al.*, 1980; Fiddaman and Rossall, 1993 and Ray *et al.*, 1997) are antagonist to a wide range of pathogens. A laboratory study was designed to explore the antagonistic properties of those two bacteria against target organisms – *Pythium*, *Fusarium* and *Pseudomonas*.

Antagonistic effect of the isolated bacteria, were observed following the inhibition of growth of host pathogen through cross inoculation studies (Hens, 1984; Ganesan *et al.*, 1987; Ray *et al.*, 1997).

Inhibition of growth of host pathogen through cross inoculation studies :

a) For fungi vs fungi : A mycelial plug was removed from actively growing margin of a 4 day old fungal culture and placed just in the center of petri dishes containing PDA medium. The plates were, incubated at 28°C. After 24 h, a similar plug of another fungal culture was placed away from the 1st plug in the same plate. The plates were then reincubated at 28°C for 4 days. Area of growth of the fungal cultures was observed : .

b) For fungi vs bacteria : The active mycelial plugs of pathogenic fungi were placed aseptically just in the center of the PDA plates and allowed to grow for 48 h at 30°±1°C. The bacterial cultures of 48 h were then streaked along the straight line parallel to the fungal culture and the plates were reincubated at 30°±1°C for 4 days. Clear zone in between two cultures were examined from the plates.

3) For bacteria vs bacteria : 48 h old bacterial culture was

streaked just in the center of plate and incubated 24 h at 30°±1°C. Another bacterial cultures of 48 h old was then streaked parallel to the 1st one and reincubated at 30°±1°C. After 5 days the plates were examined for any inhibition or clear zone.

All the observations were recorded and depicted through photographs.

Experiment No. 8 – Enumeration of some soilborne plant pathogenic microflora from pot soil :

Fusarium, Pythium and *Pseudomonas* are generally claimed to be the causal organisms of ginger soft-rot. In order to have a preliminary idea about the abundance of those organisms, an experiment similar to that of third experiment was conducted with sick soil. The pathogenic organisms were enumerated at monthly intervals. The procedures for the enumeration of *Fusarium, Pythium* and *Pseudomonas* were same as discussed earlier except the specific composition of media. Specific media used for the specific organisms were as follows :

***Pythium* :**

Pythium was enumerated in modified Tsao and Ocana medium (1970) with the following ingredients.

Basal medium

Sodium nitrate ($NaNO_3$)	2.0 g
Dipotassium hydrogenphosphate (K_2HPO_4)	1.0 g
Magnesium sulphate ($MgSO_4.7H_2O$)	0.3 g
Potassium chloride (KCl)	0.5 g
Ferrous sulphate ($FeSO_4$, $7H_2O$)	0.015 g
Sucrose	10.0 g
Agar-agar	15.0 g
Distilled water	1000.00 ml

Basal medium fortified with –

Pimericin	200 mg/lit
Vancomycin	100 mg/lit
Streptomycin sulphate	50 mg/lit

***Fusarium* :**

Fusarium was counted in modified PCNB medium as described by Papavizas (1967).

Peptone	15.0 g
Potassium diydrogen phosphate (KH_2PO_4)	1.0 g
Magnesium sulphate ($MgSO_4$. $7H_2O$)	0.5 g
Penta-chloro nitro-benzene (PNCB)	0.5 g
Oxgall	0.5 g
Agar agar	20.0 g
Distilled water	1000 ml
Chlorotetracycline HCl	50 mg
Streptomycine sulphate	100.0 mg

All the antibiotics were mixed aseptically with the basal medium after autoclaving the media.

***Pseudomonas* :**

Pseudomonas population was enumerated in tetrazolium chloride medium of following composition.

Peptone	10.0 g
Casenie hydrolylate	1.0 g
Glucose	0.5 g
Agar-agar	17.0 g
Distilled water	1000 ml

Stock solution of tetrazolium chloride was prepared by dissolving 0.5 g tetrazolium chloride in 100 ml sterile distilled water. 1 ml of stock solution was mixed with 100 ml cooled medium.

Red dotted colony forming units were counted.

Experiment No. 9 – Soilborne plant pathogenic ginger rhizosphere microflora in relation to disease incidence and intensity in pot culture experiment :

Out of 24 diseases of ginger, soft-rot, caused by *Pythium* sp., *Fusarium* sp., and *Pseudomonas* sp., is the most important because of its potentiality to cause great losses to ginger in its growing belt (Dake, 1995). It is equally true for the Kalimpong area of Darjeeling where the experimental site is situated. So, an experiment, similar to that of eighth experiment was conducted with ginger plants to investigate the effect of FYM and bacterization with the most efficient nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* on the preponderance of soft-rot producing organisms in rhizosphere and on the disease incidence and its intensity in pot culture. Disease incidence is defined as the number of plant units infected and is expressed as proportion or percentage of diseased entities within a sampling unit (James, 1974; Horsfall and Cowling, 1978; Seem, 1984).

The following formula gives the disease incidence directly as percentage.

$$\text{Disease incidence \%} = \frac{\text{Number of infected plant units}}{\text{Total No. (healthy and infected) of units assessed}} \times 100$$

Four plants were observed carefully and the disease incidence was recorded. Data thus obtained were transformed for (Sin^{-1} transformation where n = no. of plant) further statistical analysis.

Disease intensity is a general term used to denote amount of disease (James and Teng, 1979) and estimated by the following formula on 0-9 scale. (Mayee and Datar, 1986)

$$\text{Disease intensity (\%)} = \frac{0(X_0) + 1(X_1) + 2(X_2) \ldots\ldots\ldots\ldots}{X_0 + X_1 + X_2 \ldots\ldots\ldots\ldots \text{ X maximum grade used}} \times 100$$

Where, X represent the number of diseased entities within a sampling unit in the respective scale such as 0, 1, 3 ..... 9.

Following scale was used for disease scoring.

Scale	Symptoms
0	No symptoms (healthy)
1	Upper 2/3 leaves become yellow
3	3/4 leaves become yellowish with inward and outward rolling of leaves.
5.	Most of the leaves become yellowish with inward and outward rolling of leaves.
7.	Total wilting of plant and yellowing followed by withering of leaves (drooping).
9.	Drooping of plants and the plants will come easily by gently pooling and death of plant. Foul smelling.

Four plants were kept under strict supervision. Disease was scored on the basis of scale after every 30 days. Percent disease intensity was calculated by the above mentioned formula. Data, thus obtained were transformed ($Sin^{-1}\sqrt{\frac{1}{4n}}$ transformation, where n= no. of plants) for the statistical analysis.

Since this kind of visual assessment keys often set arbitrary levels of disease severity based upon symptomology, several problems exist. Different observers using the key to evaluate diseased plants of similar symptomatology do not always obtain similar estimates of disease severity (Lindow, 1983). However, it served the purpose of the present work which was designed to indicate the over all picture as a basis for more detailed studies in future.

Experiment No. 10 - Soilborne plant pathogenic ginger rhizosphere microflora in relation to disease incidence and intensity in field condition :

An experiment, similar to that of nineth experiment, was conducted in the field to have better understanding of prepondarence of soil borne plant pathogenic microflora in ginger rhizosphere and of soft-rot disease incidence and intensity under natural condition. Twenty ginger plants of each plots having 2 m x 1 m dimension were kept under strict supervision and data were recorded for computation of percent disease incidence and intensity as described earlier. The soil borne plant pathogenic ginger rhizosphere microflora were enumerated following the procedures adopted in eighth experiment. Disease incidence and intensity were also recorded as described earlier.

CHAPTER III

Results

Chapter III

RESULTS

The present investigation has been confined to the study of the decomposition rate of FYM, procured from local farm house and Regional Research Station (RRS), Bidhan Chandra Krishi Viswavidyalaya, Kalimpong, Darjeeling for judging the maturity of FYM and its (better one) subsequent application to soils in pot with or without crop and ultimately to field with or without inoculation of the most efficient ginger rhizosphere nitrogen fixing and phosphate solubilizing bacteria isolated from specially cultivated healthy ginger plant to understand the rhizosphere effects in regard to the pathogenic and nonpathogenic microbial diversity as well as nutrient dynamics, particularly those of nitrogen and phosphorus, around ginger rhizosphere and interactions among pathogens and exotic inoculants existed in ginger rhizosphere to establish a better treatment combination for good harvest of rhizome ginger.

Experiment No. 1 – Decomposition of FYM in soil.

The rate of decomposition of FYM from two different sources, one from the local farmhouse (FH-FYN), the other from the Regional Research Station (RRS-FYM) was studied in soil. The perusal of results (table - 3) revealed that there was profuse carbondioxide evolution from soils on the 1st day of incubation irrespective of treatment. FH-FYM, coupled with inorganic fertilizers, evolved significantly the highest amount of CO_2 from soil followed by those of FH-FYM alone, RRS-FYM along with inorganic fertilizers and RRS-FYM alone, respectively.

Carbondioxide evolved from the control soil was the highest after one day of incubation (table–3). Afterwards there was a gradual decrease in the liberation of CO_2 which continued up to 5th day of incubation. The secondary peak was recorded on the 6th day. Again there was gradual

TABLE–3 : Rate of decomposition of organic manures with or without fertilizers in soil.

Treatment	Rate of decomposition : Amount of CO_2 evolved (mg 100 g $^{-1}$ dry soil) (Average of 3 replications)													
	Days and duration of incubation													
	1st 1 day	2nd 1 day	3rd 1 day	4th 1 day	5th 1 day	6th 1 day	7th 1 day	10th 3 days	13th 3 days	16th 3 days	19th 3 days	22nd 3 days	25th 3 days	28th 3 days
Control	++53.24^{e}	49.42^{d}	32.88^{d}	22.88^{d}	22.44^{c}	30.50^{d}	26.40^{c}	46.93^{b}	49.73^{bc}	40.33	30.80^{c}	30.06	24.80^{b}	32.26
*FH-FYM	65.26^{b}	62.48^{b}	36.72^{c}	26.98^{c}	24.02^{bc}	33.58^{b}	27.42^{bc}	49.12^{ab}	56.46^{a}	45.46	33.73^{ab}	31.53	29.40^{a}	30.80
FH-FYMF	73.85^{a}	69.96^{a}	57.78^{a}	44.04^{a}	27.57^{a}	34.76^{a}	29.18^{a}	52.06^{a}	52.00^{b}	42.53	34.46^{a}	32.26	31.53^{c}	32.53
RRS-FYM	56.40^{d}	49.33^{d}	35.20^{cd}	24.66^{cd}	22.93^{bc}	30.00^{d}	26.80^{c}	47.02^{b}	49.30^{c}	41.83	30.00^{ab}	30.86	27.40^{b}	27.26
RRS-FYMF	59.20^{c}	56.53^{c}	42.33^{b}	35.13^{b}	24.80^{b}	32.00^{c}	28.00^{b}	50.33^{a}	50.00^{bc}	42.00	31.66^{b}	32.00	28.83^{a}	30.00
LSD at 5%	1.37	3.19	2.55	3.02	2.01	0.84	1.11	3.12	2.93	NS	3.38	NS	3.71	NS
at 1%	2.09	4.94	3.84	4.56	3.04	1.28	1.66	NS	NS	NS	NS	NS	5.60	NS

Contd. TABLE–3

Treatment	Days and duration of incubation															
	35th 7 days	42nd 7 days	49th 7 days	56th 7 days	63rd 7 days	70th 7 days	77th 7 days	84th 7 days	91st 7 days	98th 7 days	105th 7 days	112th 7 days	119th 7 days	126th 7 days	133rd 7 days	140th 7 days
Control	69.10^{c}	71.13	67.86^{c}	62.33	56.46^{c}	51.33^{c}	40.33^{c}	39.60^{d}	33.80^{d}	44.00^{b}	37.20^{c}	33.00^{c}	32.40^{d}	41.00	40.40	41.46
FH-FYM	81.40^{ab}	74.06	75.53^{ab}	70.40	63.80^{ab}	67.46^{a}	61.13^{a}	54.26^{a}	44.93^{a}	48.46^{b}	49.26^{a}	43.46^{a}	43.26^{a}	42.53	44.00	43.26
FH-FYMF	83.60^{a}	78.66	77.00^{a}	71.13	65.13^{a}	63.80^{b}	59.40^{a}	53.33^{a}	46.06^{a}	53.53^{a}	50.60^{a}	46.90^{a}	44.00^{a}	44.00	43.30	43.26
RRS-FYM	70.86^{c}	71.13	70.00^{bc}	66.86	58.16^{c}	55.33^{d}	46.86^{b}	46.80^{c}	39.33^{c}	46.00^{b}	43.86^{b}	34.13^{bc}	35.00^{c}	41.80	41.40	41.80
RRS-FYMF	77.73^{b}	71.33	70.16^{bc}	70.00	60.00^{bc}	58.66^{c}	47.86^{b}	50.80^{b}	42.00^{b}	47.80^{b}	46.80^{ab}	38.13^{b}	39.00^{b}	42.86	41.73	42.00
LSD at 5%	4.11	NS	5.53	NS	4.23	2.67	3.82	2.71	2.39	4.45	4.14	4.09	2.11	NS	2.12	NS
at 1%	6.17	NS	NS	NS	6.36	4.03	5.74	4.08	3.56	6.69	6.27	6.17	3.18	NS	NS	NS

' Control = No manure no fertilizers; FH-FYM = FYM collected from local farmer's hourse used @ 0.5%; F = Fertilizer; Nitrogen @ 120 kg ha $^{-1}$ as urea, P @ 60 kg ha $^{-1}$ as single superphosphate and K @ 90 kg ha $^{-1}$ as Muriate of potash; RRS-FYM = FYM Procured from Research Station farm, used @ 0.5%.

'' In each column under each incubation period, means followed by a common letter are not significantly different at the 5% level by Duncan's Multiple Range Test (DMRT).

reduction in CO_2 evolution with tertiary peak on 13th day, quarternary peak on 42nd day, pentanery peak on 98th day and another peak of CO_2 evolution on 126th days of incubation. Then the rate of CO_2 evolution was reduced nearing to almost static level till the completion of the incubation period.

Soil series under FH-FYM evolved maximum amount of CO_2 on the 1st day of incubation Then there was a gradual decrease in the amount of CO_2 up to 5th day The secondary peak of CO_2 evolution was noticed on the 6th day. Again there was gradual reduction in the amount of CO_2 up to 10th day. The magnitude of CO_2 evolution was then increased with a tertiary peak on 13th day. Again there was sharp decline in CO_2 evolution rate up to 25th day followed by small quarternary peak on 28th day. Again, initial high rate of CO_2 evolution was reduced with other small peaks on 49th day, 70th day and 105th days, respectively. After 105th day, there was a near equilibrium in CO_2 evolution till the completion of the experiment.

FH-FYM along with inorganic fertilizers resulted in the release of the highest amount of CO_2 on the very 1st day of incubation. This was, then, retarded up to 6th day and again the rate of CO_2 evolution boosted up with the secondary peak on 6th day. Then there was sharp fall in CO_2 evolution with tertiary and quarternary peaks on the 28th and 98th day, respectively. The rate was, however, more or less uniform from the 119th day till the end of incubation.

RRS-FYM, liberated maximum amount of CO_2 on 1st day of incubation and then there was a gradual decrease noticed up to the 5th day. The secondary peak of CO_2 evolution was observed on the 6th day. Then the rate of CO_2 evolution again decreased from 7th day up to the 10th day. The tertiary peak was observed on the 13th day. Again there was a reduction in CO_2 liberation and the trend was continued up to 35th day. The quarternary and pentanery peak of CO_2 evolution was notice on 42nd day and 98th day, respectively. Thereafter, CO_2 evolution was almost in an equilibrium state.

Soil series treated with RRS-FYM coupled with inorganic fertilizer liberated highest amount of CO_2 on the first day of incubation followed by a decline in the rate of CO_2 release. The secondary peak of CO_2 evolution was detected on 6th day of incubation. Thereafter, there was a gradual decrease in the rate of CO_2 evolution up to 25th day followed by a tertiary peak on 28th day. A sharp decline of CO_2 evolution was continued up to 77th day followed by quarternary peak of CO_2 evolution on 84th day. The other small peaks of CO_2 evolution was recorded on 98th and 126th day of incubation, respectively. Then the evolution of CO_2 approached towards equilibrium till the completion of the experiment.

According to Duncan's Multiple Range Test (DMRT), significantly higher amount of CO_2 was evolved from the 1st day of incubation during first seven days. Then there was a sharp decline up to 5th day followed by a significant increase on 6th day and then a decrease on the next day. During the next seven days higher amount of CO_2 was evolved on the 13th day which was then retarded significantly increase on 28th day, the increment was, however, not significant on the 22nd day. During next seven days significantly higher amount of CO_2 was evolved on the 35th day followed by a steady decline up to the 91st day. However, the differences in CO_2 evolution on the 42nd day and 49th as well as on the 63rd and 70th day of incubation were not significant. After 91st day, the cumulative CO_2 evolution again increased from the 91st to 105th day then there was a sharp significant reduction till the end of experiment.

In a period of 140 days, the cumulative release of CO_2 (table–4) was in the following order : FH-FYM + inorganic fertilizers>FH-FYM alone>RRS-FYM + inorganic fertilizers> RRS-FYM alone> Control.

In a period of 140 days, among the treatments, the highest amount of organic carbon was mineralized in the soil series treated with FH-FYM

TABLE–4 : Cumulative decomposition of organic manures with or without fertilizers in soil

Treatment	Amount of CO_2 evolved (mg $100g^{-1}$ dry soil) (Average of 3 replications)														
	Sampling period in days														
	1 day	2 days	3 days	4 days	5 days	6 days	7 days	10 days	13 days	16 days	19 days	22 days	25 days	28 days	35 days
Control	**53.24^{e}	102.66^{d}	135.54^{e}	158.42^{d}	180.86^{d}	211.36^{d}	237.76^{d}	284.69^{d}	334.42^{c}	374.75^{c}	372.01^{c}	409.21^{c}	436.61^{c}	468.87^{c}	550.27^{c}
*FH-FYM	65.26^{b}	127.74^{b}	164.46^{b}	191.44^{b}	215.46^{b}	249.04^{b}	276.46^{b}	325.58^{b}	382.04^{b}	427.50^{b}	416.23^{b}	492.76^{b}	522.16^{b}	552.96^{b}	630.69^{b}
FH-FYMF	73.85^{a}	143.81^{a}	201.59^{a}	245.63^{a}	273.20^{a}	307.96^{a}	337.14^{a}	389.20^{a}	441.28^{a}	483.81^{a}	514.61^{a}	546.81^{a}	578.34^{a}	610.87^{a}	694.47^{a}
RRS-FYM	56.40^{d}	105.73^{d}	140.93^{d}	165.59^{c}	188.52^{c}	218.52^{c}	245.32^{c}	292.34^{c}	341.64^{c}	383.47^{c}	414.47^{c}	445.33^{c}	470.13^{c}	497.39^{c}	566.49^{c}
RRS-FYMF	59.20^{c}	115.53^{c}	157.86^{c}	192.99^{b}	217.79^{b}	249.76^{b}	277.79^{b}	328.12^{b}	378.12^{b}	420.12^{b}	450.78^{b}	482.78^{b}	511.61^{b}	541.61^{b}	612.47^{b}
LSD at 5%	1.37	3.35	4.75	6.44	6.91	6.95	7.52	7.77	9.57	9.48	11.50	13.13	14.51	16.34	18.62
at 1%	2.09	5.03	7.17	9.96	10.40	10.50	11.35	11.73	14.44	14.30	17.29	19.81	21.90	24.66	28.08

Contd. TABLE–4

Treatment	Amount of CO_2 evolved (mg $100g^{-1}$ dry soil) (Average of 3 replications)														
	Sampling period in days														
	42 days	49 days	56 days	63 days	70 days	77 days	84 days	91 days	98 days	105 days	112 days	119 days	126 days	133 days	140 days
Control	621.40[d]	689.26[d]	751.59[d]	808.05[d]	859.38[d]	899.71[d]	939.31[d]	973.11[e]	1017.11[e]	1054.31[e]	1087.31[d]	1119.71[d]	1161.51[d]	1202.91[d]	1244.71[e]
FH-FYM	704.75[b]	780.28[b]	850.68[b]	914 48[b]	981.94[b]	1043.07[b]	1097.33[b]	1142.26[b]	1195.56[b]	1246.16[b]	1289.62[b]	1332.88[b]	1375.41[b]	1419.41[b]	1462.67[b]
FH-FYMF	773.13[a]	850.13[a]	921.26[a]	986.39[a]	1050.19[a]	1109.59[a]	1162.92[a]	1208.98[a]	1257.44[a]	1306.70[a]	1353.60[a]	1397.60[a]	1441.60[a]	1484.90[a]	1528.16[a]
RRS-FYM	637.62[d]	708.78[d]	775.64[d]	833.80[d]	889.13[d]	935.99[cd]	982.79[d]	1022.12[d]	1068.12[d]	1111.92[c]	1146.05[cd]	1181.05[cd]	1222.38[cd]	1262.38[cd]	1303.84[cd]
RRS-FYMF	683.80[c]	753.80[c]	823.80[c]	883.80[c]	942.46[c]	990.32[c]	1041.12[c]	1083.12[c]	1130.92[c]	1177.72[c]	1215.85[c]	1254.85[c]	1297.71[c]	1339.44[c]	1381.44[c]
LSD at 5%	18.29	19.42	18.74	17.53	18.50	29.68	30.36	27.54	29.83	54.71	52.93	52.84	51.73	52.10	50.27
at 1%	27.56	29.27	28.27	26.41	27.89	44.76	45.75	41.53	44.99	82.49	79.82	79.68	78.02	78.49	75.79

For ' and '' see foot note TABLE–3

coupled with inorganic fertilizers (70% C was mineralized) followed by FH-FYM alone (54%C was mineralized), RRS-FYM coupled with inorganic fertilizers (41% C was mineralized) and RRS-FYM alone (17%C was mineralized), respectively.

Experiment No. 2 – Isolation and screening of non-symbiotic nitrogen fixing and phosphate solubilizing bacteria from ginger rhizosphere.

Nitrogen fixing power of the isolated nitrogen fixing bacteria from ginger rhizosphere :

The table – 5a shows the seven bacterial isolates of nitrogen fixers and their nitrogen fixing capacity. Among the seven isolates, nitrogen fixing power ranged in between 9.33 to 13.86 mg per gram sucrose consumed. Strain NFB_1 fixed the highest amount of nitrogen which corresponded to 13.86 mg. The corresponding figures for NFB_4, NFB_5, NFB_6, NFB_2 and NFB_3 were 13.32, 13.23, 11.85, 11.76 and 11.07 mg, respectively. The least amount of nitrogen was fixed by strain-NFB_7 which corresponded to 9.33 mg nitrogen per gram sucrose consumed. The most efficient stain of nitrogen fixer-NFB_1 was then identified as *Azotobacter* by following standard guide and was considered for using it as an inoculant in subsequent experiments.

Phosphate solubilizing power of the isolated phosphate solubilizing bacteria from ginger rhizosphere :

The table–5b shows the seven bacterial isolates of phosphate solubilizer and their inorganic phosphate solubilizing capacity and corresponding pH of the broth. The table–5b reveals that the highest phosphate solubilization was recorded under the strain PSB_4, solubilizing 17.84 µg 0.15 mg^{-1} insoluble tricalcium phosphate 0.15 g^{-1} sucrose consumed. The corresponding figures for BSB_3, PSB_1, PSB_2, PBS_6, PSB_7, and PSB_5, were 16.04, 15.15, 13.42, 11.55, 8.85 and 7.2 µg, respectively. It is apparent from the table that final pH of broth ranged in between 4.95-

TABLE–5a : Nitrogen fixing power of the nitrogen fixing bacteria isolated in nitrogen free Jensen's agar plates from ginger rhizosphere soils.*

Bacterial isolates Code as	Nitrogen fixed in mg g^{-1} sucrose consumed (Average of duplicate sets) Incubation at 30 ± 1°C (days) (Average of 10-15 days)
** NFB_1	13.86
NFB_2	11.76
NFB_3	11.07
NFB_4	13.32
NFB_5	13.23
NFB_6	11.85
NFB_7	9.33

TABLE–5b : Phosphate solubilizing power of and pH change of broth by phosphate solubilizing bacteria isolated in Pikovskaia's agar plates from ginger rhizosphere soils.*

Bacterial isolates Codes as	P solubilized in µg 15 mg^{-1} insoluble P [75 mg $Ca_3(PO_4)_2$] 0.15 g^{-1} sucrose utilized (Average of duplicate sets)	
	Incubation at 37 ±1°C (Average of (7-10) days	Final + pH of broth
*** PSB_1	15.15	5.03
PSB_2	13.42	5.30
PSB_3	16.04	4.95
PSB_4	17.84	4.89
PSB_5	7.20	5.00
PSB_6	11.55	5.12
PSB_7	8.85	5.30

* Unibacterial cultures were used
Inoculum : 1 ml of heavy suspension of bacteria made by suspending 24 hr. growth in one slant with 5.0 ml sterile distilled water.

** NFB = Nitrogen fixing bacteria

*** PSB = Phosphate solubilizing bacteria
Suffix number = Strain number

\+ Initial pH of the broth = 6.5

5.30 while it was 6.5 in initial broth. Thus, it is clear that the strain PSB_4 was the most efficient phosphate solubilizer among the seven isolates. Isolate PBS_4 caused maximum reduction in pH. PSB_4 was identified as *Bacillus* following the standard guideline and was considered as an inoculant in the subsequent experiments.

At the outset it will be worthwhile to mention that the treatments – Control, M, MF, MFA, MFB and MFAB were symbolized for control, FYM, FYM + inorganic fertilizers, FYM + inorganic fertilizers + *Azotobacter* inoculation, FYM + inorganic fertilizers + *Bacillus* inoculation and FYM + inorganic fertilizers + combined inoculation of *Azotobacter* and *Bacillus*, respectively. However, the treatments – Control, FYM, FYM + inorganic fertilizers, FYM + inorganic fertilizers + *Azotobacter* inoculation, FYM + inorganic fertilizers + *Bacillus* inoculation and FYM + inorganic fertilizers + combined inoculation of *Azotobacter* and *Bacillus*, were represented, from time to time, as control, FYM, inorganic fertilizer, *Azotobacter* inoculation or inoculants of *Azotobacter*, *Bacillus* inoculation or inoculants of *Bacillus* and combined inoculation of *Azotobacter* and *Bacillus* or mixed inoculants, respectively in the text.

Experiment No. 3 – Effect of FYM and inoculation of efficient nitrogen fixing and phosphate solubilizing bacteria on microbial as well as nutrient dynamics in soil.

A) Microbiological analysis :

i) Enumeration of Microorganisms :

a) Total number of bacteria present in soil :

Total number of viable bacteria present per gram dry soils under different treatments are presented in table - 6, fig. 1. Table - 6 shows that the number of viable bacteria present in experimental soils was universally more as compared to initial number.

The treatments - FYM(M), FYM + fertilizers (MF), MF+*Azotobacter*, NFB_1 (MFA), MF+*Bacillus*, PSB_4 (MFB) and MF+*Azotobacter*, NFB_1+ *Bacillus*, PSB_4 (MFAB) exerted higher proliferation of bacteria in soil as compared to that under control at all the stages. MF caused an increase in bacterial number as compared to M in all but S_5 stage. A reverse trend was observed at S_5 stage. Either of MFA or MFB brought about enhancing influence on bacteria at all the stages as compared to that of inanimate amendments. MFAB, in general, increased the population of bacteria as compared to that of either MFA or MFB. Nevertheless, MFA was superior to MFB in relation to bacterial count at S_3 to S_5 stage. The reverse was true at S_1, S_2 and S_6 stages. However, the difference between M and MF from S_2 to S_4 and at S_6, MF and MFA as well as MF and MFB at S_3, MFA and MFB at all the stages was not significant on the basis of DMRT.

The population of bacteria in soil under control, M and MF caused a progressive increase from S_1 to S_3 stage which then gradually decreased from S_4 to S_6 stage. On the other hand, the said organisms under MFA, MFB and MFAB increased progressively from S_1 to S_4 stage and then gradually decreased the same up to S_6 stage. However, the difference in between the stage - S_1 and S_2, S_3 and S_4 for MF, S_3 and S_4 for M and MFA, S_1 and S_2, S_5 and S_6 for MFB, S_2 and S_3, S_5 and S_6 for MFAB was not significant.

On the whole, the treatment combination MFAB entertained the highest bacterial population in soil followed by those of MFA, MFB, MF M and control, respectively. However, the difference between M and MF, as well as MFA and MFB was not statistically significant.

In general, the count of bacteria progressively increased from S_1 to S_4 stage and then gradually declined till the completion of experiment. The difference in between S_3 and S_4 stage was, however, not significant.

TABLE–6 : Total number of bacteria present in the soils as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture without crop.*

Treatment	Number of bacteria (CFU x 10^5) g^{-1} dry soil (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++51.94^{d}	92.71^{c}	131.75^{b}	109.08^{c}	94.71^{d}	81.11^{d}	93.55^{D}
+M	55.97^{d}	109.01^{c}	242.5^{a}	240.27^{b}	167.78^{b}	114.09^{c}	154.93^{C}
MF	93.78^{c}	122.78^{c}	254.02^{a}	244.66^{b}	132.51^{c}	120.24^{c}	161.33^{C}
MFA	133.16^{b}	158.92^{b}	329.55^{a}	335.84^{a}	258.89^{a}	212.26^{b}	242.60^{B}
MFB	157.88^{ab}	194.72^{b}	284.98^{a}	335.08^{a}	240.59^{a}	225.56^{ab}	239.80^{B}
MFAB	187.49^{a}	267.10^{a}	275.03^{a}	345.69^{a}	256.40^{a}	244.87^{a}	262.76^{A}
Mean	113.37^{B}	162.04^{C}	252.97^{A}	268.43^{A}	191.81^{B}	166.35^{C}	
LSD at 5%	33.27	40.92	93.87	13.95	33.95	25.01	
at 1%	50.41	61.99	NS	21.13	51.42	37.89	

		LSD at 5%	at 1%
For Stage	-	16.09	21.59
Treatment	-	16.09	21.59
Interaction (Stage x Treatment)	-	39.41	52.92

* Total number of bacteria in initial soil 48.5 (CFU x 10^5) g^{-1} dry soil.

** $S_1 - S_6$ = 30, 60, 90, 120, 150, 180 days after starting of experiment.

M = Organic manure – FYM @ 10t ha^{-1}

F = Fertilizer; Nitrogen @ 120 kg ha^{-1} as urea, P @ 60 kg ha^{-1} as single superphosphate and K @ 90 kg ha^{-1} as muriate of potash.

A = Inoculated with the most efficient *Azotobacter* strain, NFB_1, and

B = The most efficient phosphate solubilizing *Bacillus* strain PSB_4, isolated from ginger rhizosphere; see Tables - 5a and 5b.

++ In a column under each stage, figures followed by a common letter are not significantly different at 5% level by Duncan's Multiple Range Test (DMRT).

b) Total number of actinomycetes present in soils :

Actinomycete population in the experimental soils was higher than that in initial soil with the exception of that under control at S_3 and S_4 stages wherein a decrease was observed (table–7; fig. 2).

Irrespective of all the stages, actinomycete count was higher under the treatments - M, MF, MFA, MFB and MFAB as compared to that of control with the exception of that under MFB at stage S_1. MF was always superior to M. On the other hand, MF was inferior to MFAB at all the stages and to either of MFA and MFB from S_3 to S_6 stages. As such, MFAB was superior to either of MFA and MFB in relation to actinomycete population though MFB was inferior to MFA. However, the difference in between those of control and M at S_1 and S_3, stages M and MF at S_1, S_2 and S_4 stages, MF and MFA at S_1 to S_3 stage, MF and MFB at S_1, S_3 and S_4 stages as well as MF and MFAB at S_3 stage was not significant by DMRT.

All the treatments but control increased the population of actinomycetes at S_2 stage, true with MF and MFB up to S_3 stage, with MFA up to S_4 stage, following a decrease at the next stage and a progressive increase in the subsequent stages. Treatment MFAB, however, registered a decrease at S_6 stage. As such, the difference in actinomycete population from S_3 to S_6 for M, MFA and MFB, S_2 to S_6 for MF and S_1 to S_6 stage for MFAB was not significant.

On the whole, MFAB reared the highest actinomycete population in soils followed by those of MFA, MFB, MF and control, respectively. However, the difference in actinomycete count between MF and MFB was not significant.

In general, the population of actinomycete increased progressively from S_1 to S_4 stage and then decreased gradually up to S_6 stage. The difference in between S_2 and S_3 stage and from S_3 to S_6 stage was, however, not significant.

TABLE–7 : Total number of actinomycetes present in the soils as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture without crop.*

Treatment	Number of actinomycetes (CFU x 10^4) g^{-1} dry soil (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++127.92^{b}	117.87^{d}	97.82^{b}	97.22^{d}	100.80^{f}	108.25^{e}	108.31^{E}
+M	141.82^{b}	175.35^{bc}	136.23^{b}	163.63^{c}	164.42^{e}	164.42^{d}	157.64^{D}
MF	155.90^{b}	194.01^{d}	214.46^{a}	193.08^{bc}	197.54^{d}	198.77^{C}	192.29^{C}
MFA	150.73^{b}	185.03^{bc}	247.79^{a}	266.03^{a}	239.25^{b}	252.14^{b}	223.49^{B}
MFB	113.40^{b}	167.13^{c}	222.89^{a}	222.29^{b}	226.18^{c}	226.81^{b}	196.45^{C}
MFAB	262.10^{a}	279.97^{a}	273.12^{a}	288.74^{a}	297.94^{a}	283.33^{a}	280.95^{A}
Mean	150.72^{C}	181.56^{B}	198.74^{AB}	205.16^{A}	204.35^{A}	205.61^{A}	
LSD at 5%	44.62	22.88	60.00	38.29	11.17	11.80	
at 1%	67.59	34.65	90.89	58.00	16.92	17.87	

		LSD at 5%	at 1%
For Stage	-	12.24	16.42
Treatment	-	12.24	16.42
Interaction (Stage x Treatment)	-	29.97	40.22

* Total number of actinomycetes in initial soil - 98.0 (CFU x 10^4) g^{-1} dry soil.

For **, + and ++ see foot note Table - 6.

c) Total number of fungi present in soil :

Irrespective of treatments, the number of total fungi in the soils was universally more as compared to that of the initial soil with the exception of that under control at S_6 (table–8; fig. 3).

The treatments - M, MF, MFA, MFB and MFAB brought about an increase in fungal count in soils as compared to that of control with the exception of those under M, MF and MFB at S_4. The treatment MF was superior to M form S_1 to S_3 stage and then at S_5 stage. This was true with MFA as compared to MFB. MFAB maintained its superiority as compared to other treatments in regard to fungal count from S_2 to S_6 stage. However, the difference in fungal count among the treatments MFA, MFB and MFAB at S_1, S_5 and S_6, between MFA and MFAB at S_2 and S_4 M and MF at S_2 and S_6 was not significant by DMRT.

An alternate rise and fall in the population of fungi up to S_4 stage following a gradual decline up to S_6 stage was exhibited by control and M treated soils. On the other hand, an increase at S_2 stage followed by a gradual decrease in fungal population up to S_6 stage was exhibited by MFA and MFAB. Treatments MF, however, registered a gradual decrease up to S_4 stage followed by a rise and fall in fungal population up to S_6 stage. There was an although gradual decline in fungal population up to S_6 stage for the treatment MFB. However, the difference in between S_1 and S_2, S_3 to S_6 for M, S_2 and S_3 for MF, S_3 to S_6 for MFA, S_1 and S_2, S_3 to S_6 for MFB and S_4 to S_6 for MFAB was not significant.

All in all, the treatment combination MFAB exerted maximum stimulation on fungal population in soil which was followed by those of MFA, MF, MFB, M and control, respectively. However, the difference in between control and M as well as MF and MFB was not significant.

In general, the proliferation of fungi exhibited an initial increase at S_2 stage followed by a significant gradual decrease up to final stage.

TABLE–8 : **Total number of fungi present in the soils as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture without crop.***

Treatment	Number of fungi (CFU x 10^4) g^{-1} dry soil (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_n	Mean
Control	++36.33^{d}	43.70^{b}	37.36^{e}	44.82^{b}	33.82^{bc}	24.35^{b}	36.73^{D}
+M	42.63^{cd}	50.63^{b}	40.87^{de}	43.33^{b}	35.58^{c}	30.05^{b}	40.51^{D}
MF	71.89^{a}	57.36^{b}	50.40^{bc}	34.71^{c}	45.63^{a}	28.85^{b}	48.14^{C}
MFA	56.12^{bc}	74.11^{a}	56.60^{b}	51.57^{a}	42.11^{ab}	37.43^{ab}	52.99^{B}
MFB	65.24^{ab}	56.39^{b}	45.80^{cd}	43.53^{b}	38.21^{abc}	31.32^{ab}	46.74^{C}
MFAB	67.89^{ab}	82.90^{a}	66.53^{a}	52.31^{a}	48.71^{a}	44.23^{a}	60.42^{A}
Mean	56.68^{B}	60.84^{A}	49.59^{C}	45.04^{D}	40.67^{E}	32.70^{F}	
LSD at 5%	14.22	15.55	7.68	6.63	10.42	13.03	
at 1%	21.53	23.55	11.63	10.04	15.79	19.73	

		LSD at 5%	at 1%
For Stage	-	3.97	5.31
Treatment	-	3.97	5.31
Interaction (Stage x Treatment)	-	9.72	13.04

* Total number of fungi in initial soil - 25.2 (CFU x 10^4) g^{-1} dry soil.

For **, + and ++ see foot note Table - 6.

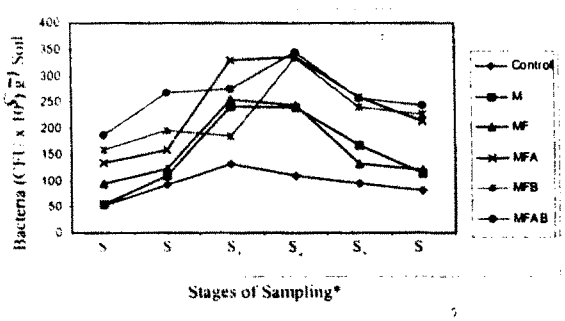


Fig. 1. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation of bacteria in soils in pot without crop.

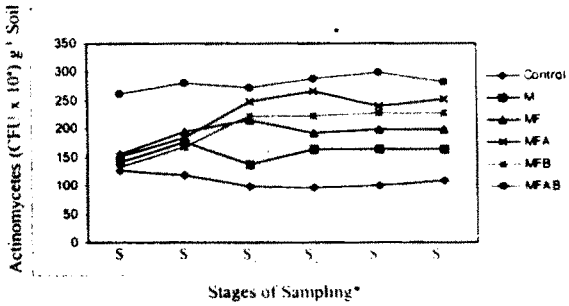


Fig. 2. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation of actinomycetes in soils in pot without crop.

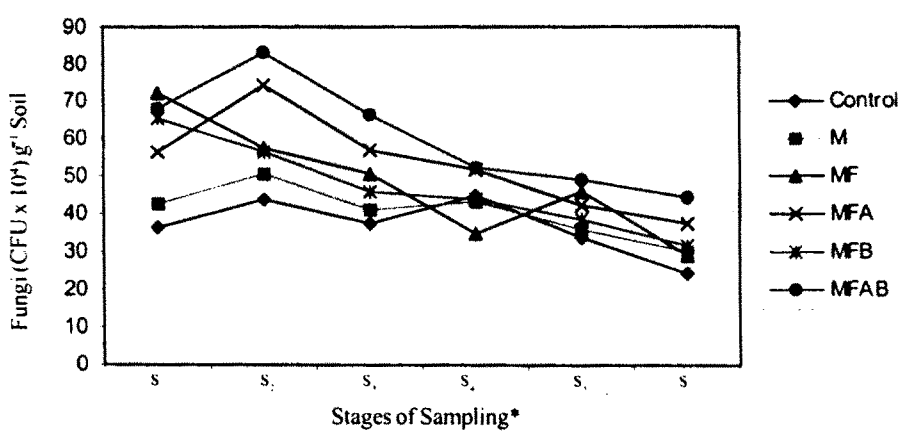


Fig. 3. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation of fungi in soils in pot without crop.

* S_1 - S_6 = 30, 60, 90, 120, 150, 180 days after starting of experiment.

d) Total number of aerobic non-symbiotic nitrogen fixing bacteria present in soils :

The treated and untreated soil series entertained a greater number of non-symbiotic nitrogen fixing bacteria than that of the initial soil (table–9; fig. 4).

In general, the treatments - M, MF, MFA, and MFAB brought about higher proliferation of non-symbiotic nitrogen fixing bacteria as compared to that of control at all the stages. MF was superior to M in relation to the proliferation of the said bacteria in soil. On the other hand, MFAB was superior to MFA, MFB and MF. MFB was, however, superior to MFA at S_2 and then from S_4 to S_6 stage. A reverse trend was exhibited from other stages. MFA and MFB were better than MF in relation to the proliferation of non-symbiotic nitrogen fixing bacteria at S_1 stage and then from S_4 to S_6 stage. The reverse was true from S_2 to S_3 stage. However, the difference in the number of nitrogen fixing bacteria in between M and MF at S_1 and S_2 stage as well as at S_5 and S_6 stage, MF and MFA at all the stages, MF and MFB at S_1 and S_2 stage and then at S_6 was not significant by DMRT.

The treatments - control, M, MF, MFA and MFAB registered a progressive increase in the proliferation of non-symbiotic nitrogen fixing bacteria from S_1 to S_3 stage following a gradual decrease from S_4 to S_6 stage. On the other hand, the population of non-symbiotic nitrogen fixing bacteria under the treatment MFB progressively increased from S_1 to S_4 stage and then gradually decreased up to S_6 stage. However, the difference in between S_1 and S_2 and then from S_4 to S_6 stage for M, S_1 and S_2 as well as S_5 and S_6 for MF, S_1 and S_2 for MFA and MFB and S_5 and S_6 for MFAB was not significant.

All in all, MFAB exerted the highest increase in the population of non-symbiotic nitrogen fixing bacteria followed by those of MFB, MFA, MF, M and control, respectively. However, the difference in between control and M as well as among MF, MFA and MFB was not significant.

TABLE–9 : Total number of aerobic non - symbiotic nitrogen fixing bacteria present in the soils as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture without crop.*

Treatment	Number of nitrogen fixing bacteria (CFU x 10^4) g^{-1} dry soil (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++56.49^{b}	69.53^{c}	107.33^{d}	94.48^{c}	79.83^{c}	71.71^{b}	67.94^{D}
+M	60.90^{b}	76.57^{bc}	122.01^{cd}	96.00^{c}	80.79^{c}	72.63^{b}	84.81^{D}
MF	63.39^{b}	88.42^{b}	172.33^{b}	121.77^{b}	91.94^{c}	73.37^{b}	101.87^{C}
MFA	77.25^{ab}	87.71^{b}	140.48^{c}	156.15^{a}	116.53^{ab}	87.08^{b}	110.86^{B}
MFB	78.50^{ab}	83.53^{bc}	165.40^{b}	122.63^{b}	101.22^{bc}	74.84^{b}	104.35^{BC}
MFAB	101.31^{a}	136.47^{a}	195.81^{a}	160.92^{a}	128.84^{a}	112.16^{a}	139.25^{A}
Mean	72.97^{F}	90.37^{D}	150.56^{A}	125.32^{B}	99.85^{C}	81.96^{E}	
LSD at 5%	23.58	14.85	22.47	24.66	23.00	15.77	
at 1%	NS	22.50	34.03	37.35	34.84	23.89	

		LSD at 5%	at 1%
For Stage	-	7.135	9.58
Treatment	-	7.135	9.58
Interaction (Stage x Treatment)	-	17.48	23.44

* Total number of non - symbiotic nitrogen fixing bacteria in initial soil - 48.8 (CFU x 10^4) g^{-1} dry soil.

For **, + and ++ see foot note Table - 6.

On the whole, the count of non-symbiotic nitrogen fixing bacteria registered a progressive significant increase from S_1 to S_3 stage and then a gradual significant decrease from S_4 to S_6 stage.

e) Total number of phosphate solubilizing microorganisms present in soils :

The proliferation of phosphate solubilizing organisms in treated soils was more than that in the initial soil (table–10; fig. 5).

As compared to control, the treatments - M, MF, MFA, MFB and MFAB exerted higher increase in the number of phosphate solubilizing microorganisms in soil. MF was superior to M at all but S_2 and S_4 stages. On the other hand, MF was inferior to MFAB and MFB at all the stages and to MFA from S_1 to S_4 stage in relation to higher population of phosphate solubilizing microorganisms in soil. However, MFAB was always superior to MFA and MFB though MFB was althrough superior to MFA in relation to abundance of phosphate solubilizing microorganisms in soil. As it were, the difference in between M and MF at all but S_5 stage, MF and MFA all but S_1 stage, MFA and MFB at S_1, S_2, S_4 and S_6 stages and MFB and MFAB at S_2 to S_5 stage was not significant by DMRT.

The treatments - Control, M, MF, MFA, MFB and MFAB registered a progressive increase in the proliferation of phosphate solubilizing microorganisms from S_1 to S_3 stage following a gradual decrease from S_4 to S_6 stage. However, the difference in between S_1 and S_2 stage and from S_4 to S_6 stage for M, S_2 to S_4 and S_5 to S_6 stages for MF, S_1 and S_2 and S_5 to S_6 stages for MFA, S_1 and S_2, S_3 and S_4 and S_5 and S_6 stages for MFB and S_4 to S_6 stage for MFAB was not significant.

All in all, MFAB exerted maximum enhancing influence on the proliferation of phosphate solubilizing microorganisms followed by those of MFB, MFA, MF, M and control, respectively. However, the difference in between M and MF was not significant.

TABLE–10 : Total number of phosphate solubilizing organisms present in the soils as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture without crop.*

Treatment	Number of phosphate solubilizing organisms (CFU x 10^4) g^{-1} dry soil (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	**76.21^{c}	88.34^{a}	90.31^{c}	85.51^{b}	77.12^{d}	65.62^{c}	67.01
+M	80.89^{c}	110.12^{a}	119.49^{b}	106.66^{a}	85.88^{c}	76.67^{bc}	93.28^{C}
MF	87.58^{c}	96.47^{a}	126.01^{b}	102.77^{a}	94.62^{b}	79.19^{b}	97.77^{BC}
MFA	100.37^{b}	102.13^{a}	131.04^{b}	113.45^{a}	87.71^{c}	75.81^{bc}	101.75^{C}
MFB	108.88^{b}	115.57^{a}	166.03^{a}	122.00^{a}	99.99^{b}	85.87^{b}	116.39^{B}
MFAB	128.28^{a}	104.59^{a}	169.83^{a}	129.13^{a}	118.58^{a}	104.48^{a}	125.81^{A}
Mean	93.70^{C}	102.87^{B}	133.78^{A}	109.92^{B}	94.00^{C}	81.73^{D}	
LSD at 5%	11.36	NS	17.74	36.50	5.38	11.34	
at 1%	17.20	NS	26.88	NS	8.15	17.17	

		LSD at 5%	at 1%
For Stage	-	7.35	9.85
Treatment	-	7.35	9.85
Interaction (Stage x Treatment)	-	18.02	24.17

* Total number of phosphate - solubilizing organisms in initial soil - 37.5 (CFU x 10^4) g^{-1} dry soil.

For **, + and ++ see foot note Table - 6.

NS - Non significant

In general, with the progress of experimental period, the proliferation of phosphate solubilizing microorganisms in soils significantly increased up to S_3 stage following a gradual decline up to final stage.

ii) Transformations :

a) Nitrogen fixing power of soils :

Amount of nitrogen fixed per gram soil per gram of sucrose utilized are presented in table–11; fig. 6 . The amount of nitrogen fixed by the treated soils was more than that of the initial soil with the exception those under control at S_4 to S_6 stage, M at S_6 stage, MF at S_1 to S_2 and then S_5 to S_6 stage, MFA, MFB and MFAB at S_1 and S_2 as well as at S_6 stage.

The treatment M caused an althrough increase in nitrogen fixing power of soil from S_1 to S_6 stage. On the other hand, the treatment MF decreased, the same, at all but S_4 stage. However, treatments - MFA, MFB and MFAB increased the nitrogen fixing power of soil as compared to that of control from S_4 to S_6 stage. The reverse trend was, however, observed from S_1 to S_3 stage. Treatment M was superior to MF, MFA and MFB from S_1 to S_6 stage and to MFAB from S_1 to S_5 stage. On the other hand, treatment MF was inferior to MFA, MFB, in general, and MFAB in particular throughout the experimental period. MFA was although superior to MFB but inferior to MFAB from S_1 to S_6 stage. However, the difference in between MF and MFA from S_1 to S_4 stage, MFA and MFB at all but S_5 stage, MFA and MFAB at all the stages as well as MFB and MFAB from S_1 to S_4 stage was not significant by DMRT.

The treatments - MF, MFA and MFB brought about a progressive increase in the nitrogen fixing power of the soils from S_1 to S_4 stage following a gradual decline up to S_6 stage. On the other hand, the treatment MFAB resulted in progressive acceleration in nitrogen fixing power of soil from S_1 to S_5 stage followed by a decrease at S_6 stage. However, M caused enhancement in nitrogen fixation from S_1 to S_2 stage following a gradual,

TABLE–11 : Nitrogen fixing power of the soils as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture.*

Treatment	Amount of nitrogen fixed (mg g^{-1} sucrose g^{-1} pot soil) (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++9.62^{b}	9.89^{b}	10.46^{b}	9.28^{c}	8.33^{c}	8.33^{abc}	9.32^{C}
+M	13.25^{a}	13.68^{a}	13.45^{a}	12.15^{a}	11.47^{a}	9.37^{ab}	12.23^{A}
MF	9.31^{b}	9.44^{c}	9.83^{b}	10.32^{b}	8.07^{c}	7.81^{c}	9.13^{C}
MFA	9.40^{b}	9.45^{c}	9.90^{b}	10.20^{b}	10.14^{b}	9.10^{ab}	9.70^{B}
MFB	9.34^{b}	9.38^{c}	9.86^{b}	10.05^{b}	8.85^{c}	8.18^{bc}	9.27^{C}
MFAB	9.50^{b}	9.52^{c}	10.09^{b}	10.51^{b}	10.59^{ab}	9.55^{a}	9.96^{B}
Mean	10.07^{c}	10.23^{BC}	10.60^{A}	10.42^{AB}	9.57^{D}	8.73^{E}	
LSD at 5%	0.77	0.28	0.90	0.47	0.97	NS	
at 1%	1.15	0.42	1.35	0.70	1.45	NS	

		LSD at 5%	at 1%
For Stage	-	0.28	0.42
Treatment	-	0.28	0.42
Interaction (Stage x Treatment)	-	0.68	1.02

* Nitrogen fixing power of initial soil - 9.56 mg N g^{-1} soil g^{-1} sucrose.

For **, + and ++ see foot note Table - 6.

NS - Non significant

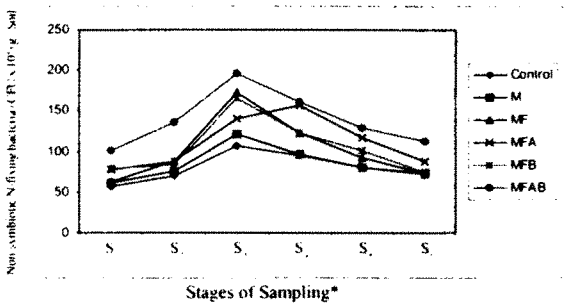


Fig. 4. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation of aerobic non-symbiotic nitrogen fixing bacteria in soils in pot without crop.

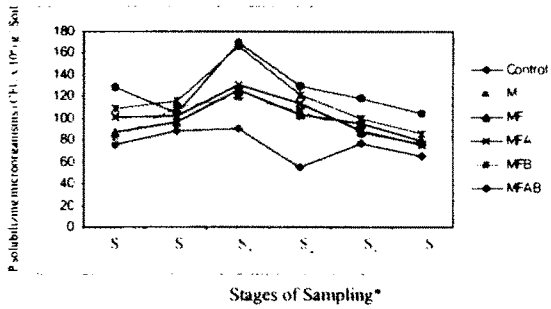


Fig. 5. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation of phosphate solubilizing microorganisms in soils in pot without crop.

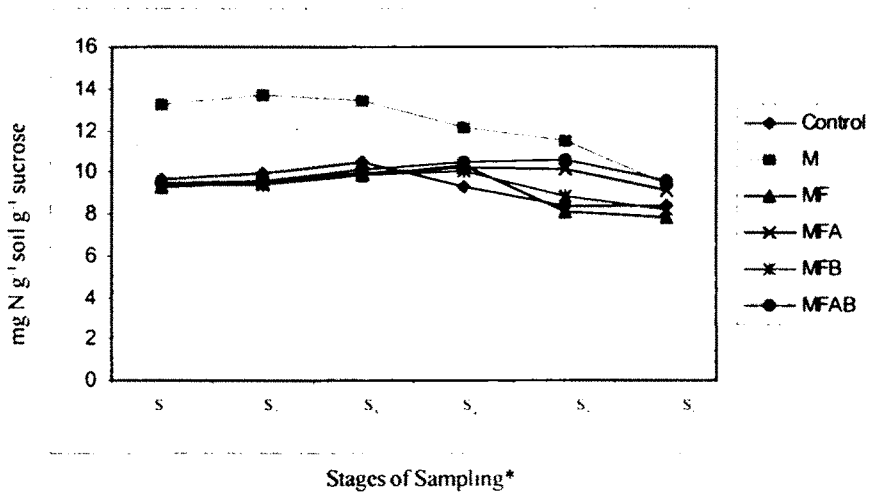


Fig. 6. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on nitrogen fixing power of soils in pot without crop.

* S_1 - S_6 = 30, 60, 90, 120, 150, 180 days after starting of experiment.

decline up to S_6 stage. Nitrogen fixation of control soil increased progressively from S_1 to S_3 stage following a gradual decline up to S_6 stage. However, the difference in between S_3 and S_4 for control, S_3 to S_6 for M, S_4 to S_5 for MF and S_5 to S_6 stage for MFB and MFAB was significant.

All in all, the treatment M brought about the highest nitrogen fixing power of soil followed by those of MFAB, MFA, control, MFB and MF respectively. The difference in between MF and MFB as well as MFA and MFAB was, however, not significant.

With the progress of experimental period, nitrogen fixing power of soils increased from S_1 to S_3 stage and then gradually declined till the end of experiment.

b) Phosphate solubilizing power of the soils :

Table–12; fig. 7 shows the average of amount of insoluble phosphorus solubilized by one gram of soil after 7 and 10 days incubation, in mg per 15 mg insoluble phosphorus per 0.15 gram sucrose utilized. The treated soils solubilized a greater amount of insoluble phosphorus as compared to initial soils with the exception of those under control at S_5 and S_6 stages.

The treatments - M, MF, MFA, MFB and MFAB brought about higher phosphate solubilizing power of soil as compared to that of control. MF resulted in higher phosphate solubilizing power than that of M from S_2 to S_6 stage. MF was superior to MFA from S_3 to S_6 stage but inferior to MFB from S_1 to S_6 stage and to MFAB from S_1 to S_3 stage and then from S_5 to S_6 stage. MFB was, in general, superior to MFA but inferior to MFAB throughout the experimental period. However, the difference in between M and MF at S_2, MFB and MFAB was significant by DMRT.

The treatments - Control, MF and MFA exerted an increase in the phosphate solubilizing power of soil from S_1 to S_2 stage following a gradual decrease up to S_6 stage. On the other hand, the treatment caused a progressive increase in the phosphate solubilizing power of the soil from

TABLE–12 : Phosphate solubilizing power of the soils as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture without crop.*

Treatment	Phosphorus solublized in mg 15 mg^{-1} insoluble P [75 mg $Ca_3(PO_4)_2$] g^{-1} pot soil 0.15 g^{-1} sucrose consumed (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++0.024^{b}	0.029^{b}	0.028^{d}	0.025^{b}	0.022^{b}	0.022^{b}	0.025^{D}
+M	0.035^{b}	0.037^{b}	0.037^{cd}	0.042	0.034^{ab}	0.032^{a}	0.036^{CD}
MF	0.033^{b}	0.058^{a}	0.054^{ab}	0.054	0.041^{ab}	0.039^{a}	0.046^{BC}
MFA	0.036^{b}	0.062^{a}	0.049^{bc}	0.045	0.034^{ab}	0.033^{a}	0.043^{BC}
MFB	0.036^{b}	0.059^{a}	0.062^{ab}	0.058	0.047^{a}	0.041^{a}	0.050^{AB}
MFAB	0.071^{a}	0.062^{a}	0.060^{a}	0.048	0.048^{a}	0.045^{a}	0.055^{A}
Mean	0.038^{BC}	0.051^{A}	0.048^{AB}	0.045^{AB}	0.037^{C}	0.035^{C}	
LSD at 5%	0.016	0.016	0.013	NS	0.019	0.009	
at 1%	0.023	0.023	0.018	NS	NS	NS	

		LSD at 5%	at 1%
For Stage	-	0.010	0.015
Treatment	-	0.010	0.015
Interaction (Stage x Treatment)	-	NS	NS

* Phosphate solubilizing power of initial soil -0.025 mg 15 mg^{-1} insoluble P [75 mg $Ca_3(PO_4)_2$] g^{-1} soil 0.15 g^{-1} sucrose.

For **, + and ++ see foot note Table - 6.

NS - Non significant

S_1 to S_4 stage followed by a gradual decrease up to S_6 stage. The phosphate solubilizing power under the treatment MFB increased, on and on, from S_1 to S_3 stage and then gradually decreased up to the completion of experiment. On the other hand, the phosphate solubilizing power under the treatment MFAB gradually decreased from S_1 to S_6 stage. However, the difference among the treatment at various stages was not significant.

On the basis of overall performances, the treatment MFAB exerted the highest influence on phosphate solubilizing power followed by those of MFB, MF, MFA, M and control, respectively. However, the difference in between MFAB and MFB, MFA and MF as well as M and control was not significant.

With the progress of experimental period, the phosphate solubilizing power of soils increased significantly up to stage S_2 and then gradually decreased till the completion of experimental period.

B) Chemical analysis :

a) Organic carbon content of soils :

Organic carbon content of the soil was more in treated soils as compared to that of the initial soil with the exception of those under control from S_2 to S_6 stage, MFA and MFB at S_6 stage and MFAB from S_4 to S_6 stage (table–13; fig. 8).

The treatments - M, MF, MFA, MFB and MFAB exerted higher enhancing influence in the content of organic carbon in soil as compared to that of control throughout the experimental period with the exception MFAB at S_4 to S_6 stage. In this context, the treatment M brought about the highest increase in the content of organic carbon in soil as compared to other treatments from S_1 to S_6 stage. MFB was, in general, next to MF throughout the experimental period but superior to MFA in relation to content of organic carbon in soil. MFAB exerted the least effect among the additives in the built up of organic carbon in soil. However, the difference

TABLE–13 : Organic carbon content of the soils as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture.*

Treatment	Organic carbon content (%) (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++0.667 (0.816)^{b}	0.660 (0.812)^{c}	0.659 (0.811)^{b}	0.657 (0.810)^{bc}	0.657 (0.810)^{bc}	0.635 (0.797)^{ab}	0.665 (0.816)^{C}
+M	1.08 (1.041)^{a}	1.02 (1.070)^{a}	1.01 (1.005)^{a}	0.924 (0.961)^{a}	0.804 (0.896)^{a}	0.744 (0.862)^{a}	0.960 (0.963)^{A}
MF	0.840 (0.916)^{b}	0.795 (0.891)^{b}	0.773 (0.879)^{b}	0.756 (0.869)^{b}	0.708 (0.841)^{ab}	0.672 (0.819)^{ab}	0.750 (0.865)^{B}
MFA	0.775 (0.880)^{b}	0.765 (0.875)^{a}	0.753 (0.867)^{b}	0.694 (0.833)^{b}	0.704 (0.839)^{b}	0.657 (0.810)^{b}	0.724 (0.851)^{A}
MFB	0.810 (0.900)^{b}	0.785 (0.883)^{bc}	0.742 (0.861)^{b}	0.708 (0.841)^{bc}	0.698 (0.835)^{ab}	0.648 (0.804)^{ab}	0.738 (0.858)^{B}
MFAB	0.795 (0.891)^{b}	0.735 (0.857)^{bc}	0.688 (0.829)^{b}	0.628 (0.792)^{c}	0.564 (0.751)^{c}	0.552 (0.742)^{b}	0.660 (0.810)^{C}
Mean	0.831 (0.910)^{A}	0.794 (0.889)^{AB}	0.772 (0.877)^{BC}	0.729 (0.852)^{CD}	0.689 (0.829)^{DE}	0.651 (0.806)^{E}	
^LSD at 5%	0.090	0.060	0.066	0.067	0.070	0.090	
at 1%	0.136	0.089	0.094	0.099	0.104	NS	

		LSD at 5%	at 1%
For Stage	-	0.026	0.039
Treatment	-	0.026	0.039
Interaction (Stage x Treatment)	-	NS	NS

* Organic carbon content in initial soil - 0.666% (0.816)
For **, + and ++ see foot note Table - 6.
#–Values in the parenthesis are square root transformed values.
^ – LSD calculatd on the basis of transformed values.
NS- Non significant.

in between M and MF from S_1 to S_4 stage as well as MFB and MFAB at S_5 was significant by DMRT.

Organic carbon content of soil series under control, M, MF, MFA, MFB and MFAB gradually decreased from the initiation to the completion of the experiment. However, the difference among the stages for each treatment was not significant.

Altogether, the highest amount of organic carbon was restored in soils under the treatment M. This was followed by those of MF, MFB, MFA, MFAB and control, respectively. Though increase in carbon content under MF, MFA and MFB was not significant.

In general, with the progress of experimental period, organic carbon decreased gradually right from S_1 till the final stage.

b) Total nitrogen content of the soils :

Nitrogen content of the soils was more as compared to that of the initial soil with the exception of that under control at S_5 and S_6 stages where in the total nitrogen content was similar to that of the initial soil (table–14; fig. 9).

The treatments - M, MF, MFA, MFB and MFAB exerted higher enhancing influence in the content of total nitrogen in soil as compared to control throughout the experimental period. Treatment MF was superior to treatment M in relation to enhancing influence on the content of total nitrogen in soil from S_1 to S_6 stage but inferior to MFA from S_1 to S_4 stage and then at S_6 stage. On the other hand, treatment MFAB was superior to treatment MF from S_2 to S_4 stage and then at S_6 stage but inferior to MFA from S_1 to S_3 stage and then from S_5 to S_6 stage. MFB was next to M in relation to total nitrogen content of soil throughout the experimental period. However, the difference in between MF and MFA at S_1 and then from S_4 to S_6 stages, MFA and MFA from S_3 to S_6 stage, MFB and MFAB from S_3 to S_6 stage was not significant by DMRT.

TABLE–14 : **Nitrogen content of the soils as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture without crop.***

Treatment	Nitrogen content of soil (%) (Average of duplicate sets) (Average of 2 replication)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++0.039 #(0.199)^{d}	0.038 (0.195)^{e}	0.035 (0.188)^{c}	0.034 (0.186)^{b}	0.030 (0.173)^{bc}	0.030 (0.173)^{c}	0.035 (0.188)^{D}
+M	0.044 (0.210)^{c}	0.042 (0.205)^{d}	0.043 (0.209)^{b}	0.035 (0.187)^{b}	0.035 (0.187)^{b}	0.031 (0.177)^{c}	0.038 (0.196)^{C}
MF	0.050 (0.224)^{ab}	0.045 (0.213)^{c}	0.045 (0.213)^{b}	0.042 (0.205)^{a}	0.039 (0.199)^{a}	0.034 (0.186)^{b}	0.042 (0.206)^{B}
MFA	0.051 (0.227)^{a}	0.049 (0.222)^{a}	0.049 (0.222)^{a}	0.043 (0.209)^{a}	0.039 (0.197)^{a}	0.039 (0.197)^{a}	0.45 (0.212)^{A}
MFB	0.047 (0.218)^{b}	0.046 (0.216)^{bc}	0.046 (0.214)^{ab}	0.041 (0.204)^{a}	0.039 (0.197)^{a}	0.038 (0.196)^{a}	0.041 (0.204)^{B}
MFAB	0.049 (0.222)^{a}	0.048 (0.219)^{a}	0.048 (0.219)^{a}	0.043 (0.208)^{a}	0.037 (0.194)^{ab}	0.037 (0.194)^{a}	0.043 (0.209)^{A}
Mean	0.046^{A}	0.044^{B}	0.044^{B}	0.39^{C}	0.035^{B}	0.035^{B}	
^LSD at 5%	0.007	0.005	0.006	0.010	0.008	0.006	
at 1%	0.011	0.008	0.009	0.016	0.012	0.009	

		LSD at 5%	at 1%
For Stage	-	0.0026	0.0034
Treatment	-	0.0026	0.0034
Interaction (Stage x Treatment)	-	0.0064	0.0084

* Nitrogen content in inital soil - 0.03% (0.173)

For **, + and ++ see foot note Table - 6.

For * and ^ See foot note Table - 13

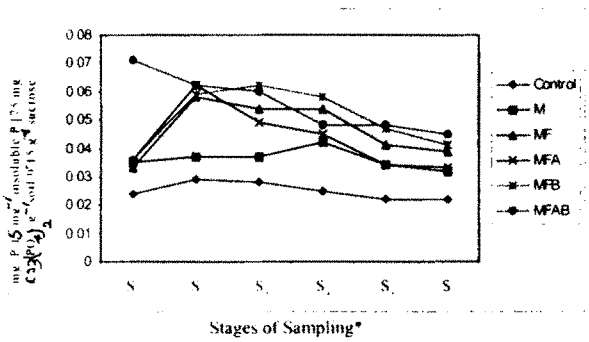


Fig. 7. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on phosphate solubilizing power of soils in pot without crop.

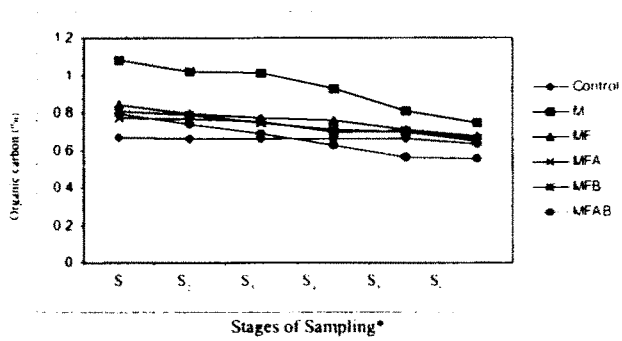


Fig. 8. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the content of organic carbon in soils in pot without crop.

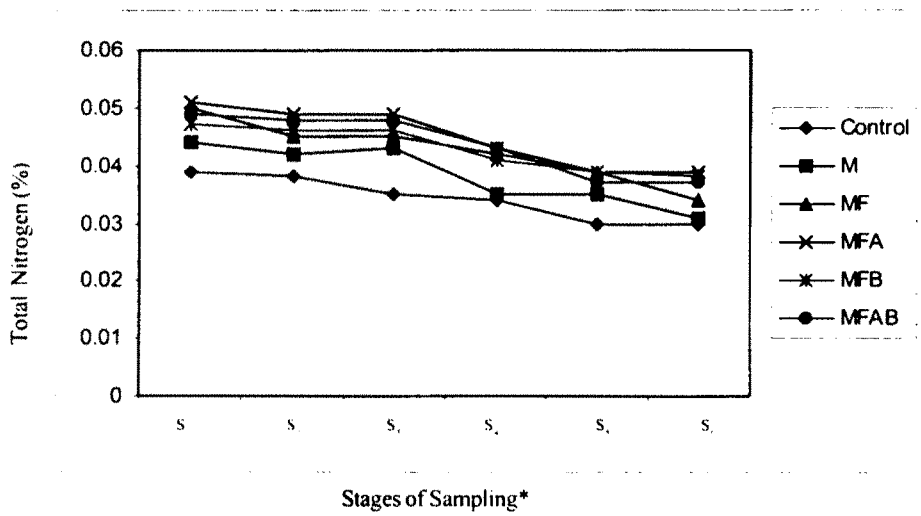


Fig. 9. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the content of total nitrogen in soils in pot without crop.

* S_1 - S_6 = 30, 60, 90, 120, 150, 180 days after starting of experiment.

There was a gradual decrease in the content of total nitrogen from soil series under control, MF, MFA, MFB and MFAB from S_1 to S_6 stage and under M from S_1 to S_2 stage as well as from S_3 to S_6 stage. However, the difference in between S_1 and each of S_3, S_4, S_5 and S_6 for MF, S_1 and each of S_5 and S_6 stages for MFA, S_1 and each at S_5 and S_6 for MFB as well as S_1 and each of S_4, S_5 and S_6 stages for MFAB was only significant.

All in all, the treatment MFA resulted in the highest increase in the content of total nitrogen of soil followed by those of MFAB, MF, MFB, M and control, respectively. The difference in between MF and MFB as well as MFA and MFAB was, however, not significant.

In general, the total nitrogen content of soil decreased gradually from S_1 to S_6 stage. However, the difference in between S_2 and S_3 stages and then S_5 and S_6 stage was not significant.

c) Ammoniacal-nitrogen content of the soils :

Results presented in table–15; fig. 10 indicate that there was an increase in the amount of ammoniacal-nitrogen as compared to that in initial soil with the exception of that under control at S_6 stage.

The treatments - M, MF, MFA, MFB and MFAB resulted in higher accumulation of ammoniacal-nitrogen as compared to that of control at all the stages MF brought about higher increase in the content of ammoniacal-nitrogen than that of M in every stage of sampling. MFB was althrough superior to MF but inferior to MFAB, though MFAB was superior to MFA in relation to the content of ammoniacal-nitrogen from S_1 to S_6 stage. MFA was superior to MFB from S_1 to S_3 stage. The reverse was true from S_4 to S_6 stage. However, the difference in between M and MF at S_2 and then S_4 to S_6 stages was only significant by DMRT.

The content of ammoniacal-nitrogen in soil series under control, MF, MFA, MFB and MFAB decreased with time from S_1 to S_6 stage. On the other hand, soil series under M registered a gradual decrease from S_1 to S_2

TABLE–15 : Ammoniacal - nitrogen content of the soils as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture without crop.*

Treatment	Amount of ammoniacal - nitrogen (mg 100 g-1 dry soils) (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++3.40^{c}	3.36^{c}	3.22^{c}	3.15^{c}	3.15^{c}	3.07^{c}	3.22^{E}
+M	4.20^{bc}	3.57^{c}	3.68^{bc}	3.37^{c}	3.37^{c}	3.26^{c}	3.57^{D}
MF	4.90^{ab}	4.63^{b}	4.44^{ab}	4.35^{b}	4.20^{b}	4.06^{b}	4.43^{C}
MFA	5.53^{a}	5.16^{ab}	5.14^{c}	4.90^{ab}	4.77^{ab}	4.65^{ab}	5.02^{B}
MFB	5.18^{ab}	5.06^{ab}	5.04^{a}	4.93^{ab}	4.81^{ab}	4.69^{ab}	4.95^{B}
MFAB	5.76^{a}	5.60^{a}	5.35^{a}	5.35^{a}	5.20^{a}	4.86^{a}	5.35^{A}
Mean	4.82^{A}	4.56^{AB}	4.47^{BC}	4.34^{BCD}	4.25^{CD}	4.09^{D}	
LSD at 5%	0.99	0.85	0.91	0.60	0.77	0.68	
at 1%	1.50	1.28	1.37	0.90	1.17	1.02	

		LSD at 5%	at 1%
For Stage	-	0.27	0.37
Treatment	-	0.27	0.37
Interaction (Stage x Treatment)	-	NS	NS

* Ammoniacal - nitrogen content in initial soil -3.12 mg 100 g^{-1} soil.

For **, + and ++ see foot note Table - 6.

stage and from S_4 to S_6 stage. However, the difference among the various stages for each treatment was not significant.

All in all, MFAB resulted in the highest increase in the content of ammoniacal-nitrogen in soil followed by those of MFA, MFB, MF, M and control, respectively. However, the difference in between the treatment MFA and MFB was not significant.

In general, the content of ammoniacal-nitrogen of soil decreased gradually from S_1 to S_6 stage. However, the difference in between the following stages was not significant.

d) Nitrate-nitrogen content of the soils :

Results presented in table–16; fig. 11 indicate that there was higher accumulation of nitrate-nitrogen in treated soils as compared to that of initial soil with the exception of that under control at S_6 stage.

The treatments - M, MF, MFA, MFB and MFAB brought about higher accumulation of nitrate-nitrogen in soil as compared to that of control at all the stages. MF produced higher increase in the content of nitrate-nitrogen than that of M in every stage of sampling. MF was, in general, superior to MFB but inferior to MFA at all the stages. On the other hand, MFAB was although superior to MFA. However, the difference in between MFA and MFB at S_2, MFB and MFAB at all the stages was significant by DMRT.

The content of nitrate-nitrogen in soil series under the treatment - M, MF, MFA, MFB and MFAB progressively increased from S_1 to S_6 stage. On the other hand, nitrate-nitrogen content of control soil increased progressively from S_1 to S_3 stage and then decreased gradually from S_4 to S_6 stage. However, the difference in nitrate-nitrogen content among the stages for each treatment was not significant.

On the whole, the highest amount of nitrate-nitrogen was accumulated under MFAB followed by those of MFA, MF, MFB, M and

TABLE–16 : **Nitrate-nitrogen content of the soils as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Asotobacter* and phosphate solubilizing *Bacillus* strains in pot culture without crop.***

	Amount of nitrate-nitrogen (mg 100 g^{-1} dry soils) (Average of duplicate sets) (Average of 2 replications)						
Treatment	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	**2.04^{b}	2.25^{c}	2.35^{c}	2.15^{c}	1.95^{c}	1.86^{c}	1.79^{D}
+M	2.10^{b}	2.66^{c}	2.83^{bc}	2.88^{bc}	3.09^{bc}	3.17^{bc}	2.26^{D}
MF	2.52^{b}	3.08^{bc}	3.12^{bc}	3.31^{bc}	3.55^{ab}	4.30^{ab}	3.31^{BC}
MFA	2.78^{b}	3.92^{ab}	3.64^{ab}	3.60^{ab}	4.06^{ab}	4.17^{ab}	3.69^{B}
MFB	2.66^{b}	2.81^{c}	3.05^{bc}	3.17^{bc}	3.22^{bc}	3.34^{b}	3.04^{C}
MFAB	4.20^{a}	4.18^{a}	4.42^{a}	4.64^{ab}	4.83^{a}	5.04^{a}	4.55^{A}
Mean	2.71^{C}	3.15^{B}	3.23^{AB}	3.29^{AB}	3.45^{AB}	3.64^{A}	
CD at 5%	0.85	0.99	1.00	1.21	1.51	1.35	
at 1%	1.28	NS	1.51	NS	NS	NS	

		CD at 5%	at 1%
For Stage	-	0.40	0.53
Treatment	-	0.40	0.53
Interaction (Stage x Treatment)	-	NS	NS

* Nitrate - nitrogen content in initial soil - 2.05 mg 100 g^{-1} soil.

For **, + and ++ See foot note Table - 6

control, respectively. The difference in between MF and MFA was, however, not significant.

In general, significant higher accumulation of nitrate-nitrogen in soil was observed at S_2 stage and further increase was not significant.

e) Available phosphorus content of the soils :

The amount of available phosphorus in mg per kilogram dry soils is presented in the table–17; fig. 12. The figures in the table show that the amount of available phosphorus was more than that in initial soil with the exception of those under control at S_4 to S_6 stage.

The treatments - M, MF, MFA, MFB and MFAB brought about higher enhancing influence on the content of available phosphorus in soils as compared to that of control. MF resulted in higher increase in the content of available phosphorus than those of M, MFA and MFB from S_1 to S_6, from S_3 to S_6 and from S_3 to S_5 stages, respectively, though MFA and MFB caused greater enhancing influence then that of MF from S_1 to S_2 stage. However, MFB was superior to MFA in relation to the content of available phosphorus from S_2 to S_6 stage but inferior to MFAB at all the stages. As it were, the difference in between MF and MFB as well as MFA and MFB at all stages, MFB and MFAB at S_2 and S_3 stages was, however, not significant by DMRT.

The content of available phosphorus in soil series under control, M, MF, MFA, MFB and MFAB decreased gradually from S_1 to S_6 stage. However, the difference in between S_3 and S_4 and then S_5 and S_6 for MF, S_3 and S_4 for MFA, S_2 and S_3 and then S_3 and S_4 for MFB, S_1 and S_2, S_2 and S_3 and then S_4 and S_5 for MFAB was significant.

On the whole, the highest increase in available phosphorus was registered under MFAB followed by those of MFB, MF, MFA, M and control, respectively. However, the difference in between MF and MFA as well as MFA and MFB was not significant.

TABLE–17 : Available phosphorus content of the soils as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture without crop.*

	Available phosphorus content (mg kg^{-1} pot soil) (Average of duplicate sets) (Average of 2 replications)						
Treatment	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	5.50^{d}	5.30^{d}	5.10^{c}	4.90^{d}	4.60^{d}	4.30^{d}	4.95^{D}
+M	8.41^{c}	8.09^{c}	7.47^{b}	7.13^{c}	7.00^{c}	6.91^{c}	7.50^{C}
MF	12.40^{b}	11.52^{b}	10.82^{a}	9.21^{ab}	8.51^{ab}	7.08^{bc}	9.92^{B}
MFA	12.58^{b}	11.55^{b}	10.49^{a}	8.21^{bc}	7.63^{bc}	7.05^{bc}	9.58^{B}
MFB	12.48^{b}	12.99^{ab}	10.63^{a}	8.89^{b}	7.70^{bc}	7.20^{bc}	9.98^{B}
MFAB	16.60^{a}	13.36^{a}	11.10^{a}	10.56^{a}	9.30^{a}	8.13^{a}	11.50^{A}
Mean	11.32^{A}	10.46^{B}	9.26^{C}	8.15^{D}	7.45^{E}	6.77^{F}	
LSD at 5%	0.95	1.44	1.53	1.50	1.39	0.23	
at 1%	1.44	2.18	2.31	2.26	2.09	0.35	

		LSD at 5%	at 1%
For Stage	-	0.43	0.57
Treatment	-	0.43	0.57
Interaction (Stage x Treatment)	-	1.05	1.40

* Available phosphorus content in initial soil - 5.0 mg kg^{-1} soil.

For **, + and ++ See foot note Table - 6

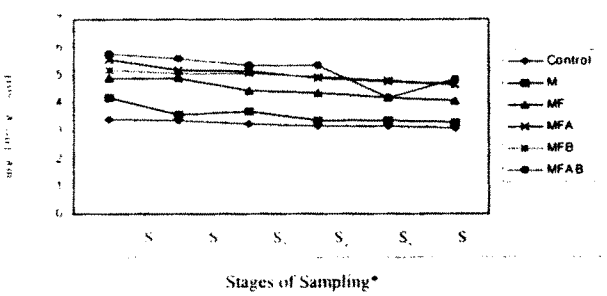


Fig. 10. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the content ammoniacal-nitrogen in soils in pot without crop.

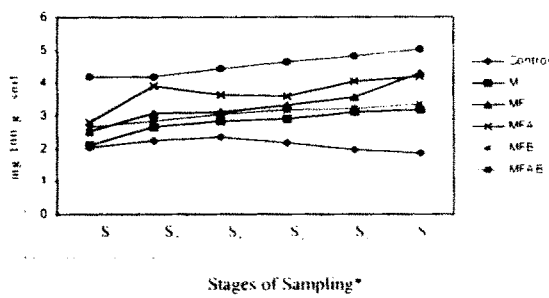


Fig. 11. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the content of nitrate-nitrogen in soils in pot without crop.

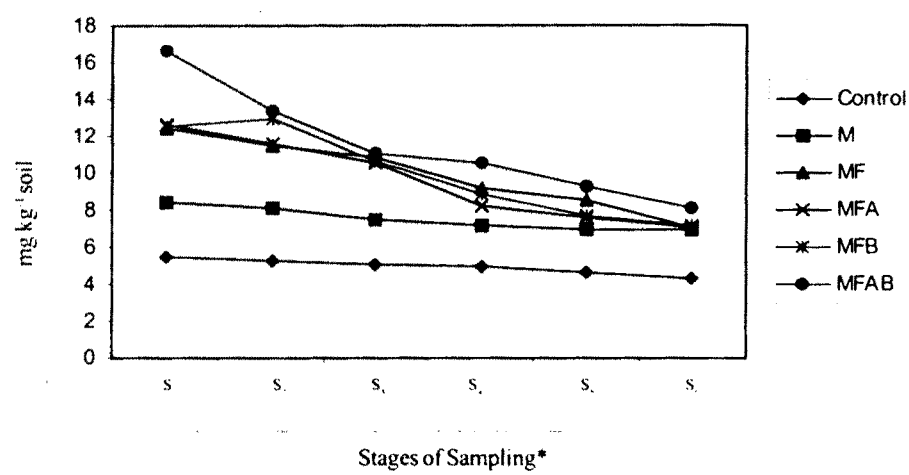


Fig. 12. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the content of available phosphorus in soils in pot without crop.

* S_1 - S_6 = 30, 60, 90, 120, 150, 180 days after starting of experiment.

In general, with time available phosphorus content of soils decreased gradually till the completion of experiment.

Correlations :

Table–18 shows the overall relationships among the different variables when all the stages of sampling was taken into consideration together. From the coefficient of correlation values, it is apparent that the proliferation of bacteria of pot soil was correlated with the proliferation of actinomycetes, fungi, nitrogen fixing bacteria, nitrogen fixing and phosphate solubilizing power, total nitrogen, nitrate-nitrogen, available phosphorus and highly correlated with phosphate solubilizing microorganisms and the content of ammoniacal-nitrogen.

The abundance of actinomycetes of pot soil was highly correlated with phosphate solubilizing power, total nitrogen, ammoniacal and nitrate nitrogen as well as available phosphorus.

The preponderance of fungi in pot soil was correlated with phosphate solubilizing microorganisms, available phosphorus and highly correlated with actinomycetes, phosphate solubilizing power, ammoniacal nitrogen, and total nitrogen.

The proliferation of nitrogen fixing bacteria was correlated with actinomycetes, phosphate solubilizing microorganisms and nitrogen fixing as well phosphate solubilizing power of pot soil.

The incidence of phosphate solubilizing microorganisms was correlated with phosphate solubilizing power, the content of ammoniacal and total nitrogen, available phosphorus and highly correlated with actinomycetes and nitrate nitrogen content of pot soil.

The phosphate solubilizing power of pot soil was correlated with the content total nitrogen.

TABLE –18 : Significant correlations among different variables of pot soil.

Relationship between		Correlation coefficient (r)		
		Observed	Table values	
		5%	5%	1%
Total viable bacteria of soils	and total fungi	0.870*	0.811	0.917
Total viable bacteria of soils	and nitrogen fixing bacteria	0.840*		
Total viable bacteria of soils	and phosphate solubilizing organisms	0.930**		
Total viable bacteria of soils	and actinomycetes	0.910*		
Total viable bacteria of soils	and ammoniacal nitrogen	0.960**		
Total viable bacteria of soils	and nitrate nigtrogen	0.850*		
Total viable bacteria of soils	and available phosphorus	0.880*		
Total viable bacteria of soils	and nitrogen fixing power	0.830*		
Total viable bacteria of soils	and phosphate solubilizing power	0.880*		
Total viable bacteria of soils	and total nitrogen	0.840*		
Total fungi of soils	and actinomycetes	0.980**		
Total fungi of soils	and phosphate solubilizing organisms	0.910*		
Total fungi of soils	and phosphate solubilizing power	0.880**		
Total fungi of soils	and ammoniacal nitrogen	0.930**		

Contd.....

Total fungi of soils	and nitrate nitrogen	0.980**	0.811	0.917
Total fungi of soils	and available phosphorus	0.900*		
Total fungi of soils	and total nitrogen	0.950**		
Total actinomycetes of soils	and ammoniacal nitrogen	0.930**		
Total actinomycetes of soils	and nitrate nitrogen	0.990**		
Total actinomycetes of soils	and available phosphorus	0.940**		
Total actinomycetes of soils	and phosphate solubilizing power	0.930**		
Total actinomycetes of soils	and total nitrogen	0.950**		
Nitrogen fixing bacteria of soils	and phosphate solubilizing organisms	0.890*		
Nitrogen fixing bacteria of soils	and actinomycetes	0.850*		
Nitrogen fixing bacteria of soils	and nitrogen fixing power	0.860*		
Nitrogen fixing bacteria of soils	and phosphate solubilizing power	0.820*		
Phosphate solubilizing organisms of soils	and actinomycetes	0.950**		
Phosphate solubilizing organisms of soils	and ammoniacal nitrogen	0.870*		
Phosphate solubilizing organisms of soils	and nitrate nitrogen	0.940**		
Phosphate solubilizing organisms of soils	and available phosphorus	0.830*		

Phosphate solubilizing organisms of soils	and phosphate solubilizing power	0.810*
Phosphate solubilizing organisms of soils	and total nitrogen	0.890*
Phosphate solubilizing power of soils.	and total nitrogen	0.880*
Ammoniacal nitrogen of soils.	and nitrate nitrogen	0.880*
Amoniacal nitrogen of soils.	and available phosphorus	0.940**
Ammoniacal nitrogen of soils.	and phosphate solubilizing power	0.910*
Ammoniacal nitrogen of soils.	and total nitrogen	0.950**
Nitrate nitrogen of of soils	and available phosphorus	0.900*
Nitrate nitrogen of soils.	and phosphate solubilizing power	0.880*
Nitrate nitrogen of of soils.	and total nitrogen	0.930**
Available phosphorus of soils	and phosphate solubilizing power	0.970**
Available phosphorus of soils	and total nitrogen	0.960**

* Significant at 5%.

** Significant at 1%.

The content of ammoniacal nitrogen in pot soils was correlated with phosphate solubilizing power, nitrate nitrogen and highly correlated with total nitrogen and available phosphorus.

Nitrate nitrogen content of pot soil was correlated with phosphate solubilizing power, available phosphorus and highly correlated with the content of total nitrogen.

The content of available phosphorus was highly correlated with phosphate solubilizing power and the content of total nitrogen in pot soils.

Experiment No. 4 – Effect of FYM and inoculation of efficient nitrogen fixing and phosphate solubilizing bacteria on microbial and nutrient dynamics in the rhizosphere soil as well as performance of ginger in pot :

A) Microbiological Analysis :

i) Enumeration of Microorganisms :

a) Total number of bacteria present in the rhizosphere soils:

Total number of viable bacteria present per gram dry rhizosphere soils of ginger are presented in table-19; fig. 13. The number of bacteria present in the rhizosphere of ginger was universally more than that present in the initial soil.

The treatments - FYM (M), M + fertilizers (MF), MF + *Azotobacter*, NFB, (MFA), MF + *Bacillus*, PSB_4 (MFB) and MF + *Azotobacter*, NFB_1 + *Bacillus*, PSB_4 (MFAB) exerted higher proliferation of bacteria in the rhizosphere soils of ginger as compared to that under control at all the growth stages. MF brought about enhancing influence on the bacterial population in the rhizosphere soils of ginger than that under M at each growth stage. Either MFA or MFB was superior to MF in relation to the proliferation of bacteria in the ginger rhizosphere at all the growth stages. On the other hand, MFAB resulted in higher proliferation of bacteria than

TABLE–19 : **Total number of bacteria present in the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture with crop.***

Treatment	Number of bacteria (CFU x 10^5) g^{-1} dry soil (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	55.62^{d}	96.04^{d}	153.64^{e}	163.82^{e}	156.57^{d}	109.09^{d}	122.46^{D}
+M	71.79^{d}	114.73^{cd}	242.78^{d}	241.51^{d}	230.41^{c}	169.73^{c}	178.49^{D}
MF	113.08^{c}	135.78^{c}	279.18^{c}	298.59^{c}	279.89^{b}	207.90^{c}	219.07^{C}
MFA	169.59^{b}	191.91^{b}	354.79^{a}	370.60^{ab}	336.70^{a}	294.64^{ab}	286.37^{B}
MFB	171.92^{b}	201.00^{ab}	338.36^{b}	359.03^{b}	342.63^{a}	285.71^{b}	283.10^{B}
MFAB	210.72^{a}	225.76^{a}	363.63^{a}	397.18^{a}	353.39^{a}	335.03^{a}	314.28^{A}
Mean	132.12^{E}	160.87^{D}	288.73^{B}	305.12^{A}	283.26^{B}	233.68^{C}	
LSD at 5%	16.59	31.12	16.10	28.24	26.11	42.76	
at 1%	25.12	47.14	24.39	42.77	39.54	64.77	

		LSD at 5%	at 1%
For Stage	-	9.58	12.85
Treatment	-	9.58	12.85
Interaction (Stage x Treatment)	-	23.47	31.49

* Total bacteria present in initial soil - 48.5 (CFU x 10^5) g^{-1} soil

** S_1 - S_6 = For ginger 30, 60, 90, 120, 150, 180 days after planting - at sprouting of rhizome, early emergence of pseudostem, late emergence of pseudostem, full growth of pseudostem, near maturity of pseudostem and harvesting stage of ginger, respectively.

For + and ++ see foot note Table - 6.

either that of MFA and MFB. However, the difference in between M and MF at early emergence of pseudostem (S_2) and harvesting stage (S_6), MFA and MFB at all but late emergence of pseudostem stage (S_3), MFA and MFAB from late emergence of pseudostem (S_3) to harvesting stage (S_6) of ginger and MFB and MFAB at early emergence of pseudostem (S_2) and near maturity of pseudostem (S_5) stages was not significant by DMRT.

The population of bacteria in the rhizosphere soils of ginger under control, MF, MFA, MFB and MFAB, progressively increased from sprouting of rhizome (S_1) to full growth of Pseudostem (S_4) stage then gradually decreased up to harvesting stage (S_6) of ginger. On the other hand, the population of bacteria in the rhizosphere soils of ginger under M increased progressively from sprouting of rhizome (S_1) to late emergence of pseudostem stage (S_3) and then gradually decreased up to the harvesting stage (S_6) of ginger, However, the difference in between S_3 and S_4 and then S_4 and S_5 for M, S_1 and S_2 and from S_3 to S_5 for MF, S_1 and S_2 as well as S_3 and S_4 for MFA, S_3 to S_5 for MFB, S_1 and S_2 and then S_5 and S_6 stages for MFAB was not significant.

All in all, MFAB exerted maximum stimulation of bacteria in the rhizosphere soils of ginger followed by those of MFA, MFB, MF, M and control , respectively. However, the difference in between MFA and MFB was not significant.

In general, bacterial population in the rhizosphere soils of ginger progressively increased from S_1 to S_4 stage which then gradually decreased up to S_6 stage.

b) Total number of actinomycetes present in the rhizosphere soils:

Proliferation of actinomycetes in the rhizosphere soils of ginger was higher than that in the initial soil (table–20; fig. 14).

The treatments - M, MF, MFA, MFB and MFAB resulted in higher population of actinomycetes in the rhizosphere soils ginger as compared

TABLE–20 : Total number of actinomycetes present in the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture with crop.*

Treatment	Number of actinomycetes (CFU x 10^4) g^{-1} dry soil (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++136.41^{d}	171.04^{c}	180.98^{c}	190.69^{d}	168.41^{d}	157.13^{d}	167.44^{C}
+M	150.12^{cd}	211.85^{b}	226.37^{b}	234.98^{bc}	241.44^{c}	230.26^{c}	215.83^{B}
MF	170.89^{bc}	177.66^{c}	199.87^{d}	235.06^{bc}	256.06^{b}	242.34^{bc}	213.64^{B}
MFA	148.86^{cd}	195.70^{bc}	212.75^{c}	246.85^{b}	256.32^{b}	261.47^{b}	220.32^{B}
MFB	182.04^{b}	187.61^{bc}	193.40^{d}	222.50^{c}	244.28^{c}	259.16^{bc}	215.33^{B}
MFAB	257.97^{a}	302.93^{a}	309.85^{a}	319.28^{a}	326.50^{a}	338.95^{a}	309.24^{A}
Mean	174.38^{E}	207.79^{D}	220.53^{C}	241.56^{B}	248.83^{A}	248.21^{A}	
LSD at 5%	20.27	23.83	9.87	14.26	8.64	29.26	
at 1%	32.22	36.10	14.94	21.60	13.10	44.32	

		LSD at 5%	at 1%
For Stage	-	6.56	8.79
Treatment	-	6.56	8.79
Interaction (Stage x Treatment)	-	16.06	21.55

* Total number of actinomycetes present in initial soil - 98.0 (CFU x 10^4) g^{-1} dry soil.

** See foot note Table - 19

For + and ++ see foot note Table - 6.

to that of control throughout the growth stage. MF caused higher proliferation of actinomycetes than that of M from S_4 to S_6 stage. On the other hand, MFA brought about greater stimulation of actinomycetes than that of MF from S_2 to S_6 stage. As such, MFAB was superior to MFA or MFB in relation to higher proliferation of actinomycetes at every growth stage. MFA brought about increase in the number of actinomycetes than that of MFB from S_2 to S_6 stage. However, the difference in between M and MF at S_1, S_4 and S_6, MF and MFA at all but S_3 stage, as well as MFA and MFA at S_2 and S_6 was not significant by DMRT.

The population of actinomycetes in the rhizosphere soils ginger under M and MF progressively increased from S_1 to S_5 stage which then gradually decreased up to S_6 stage. On the other hand, the cited organism in the ginger rhizosphere under control increased, on and on, up to S_4 stage followed by gradual decline up to S_6 stage. However, the population of actinomycetes in the rhizosphere soils of ginger under MFA, MFB and MFAB progressively increased from S_1 to S_6 stage. However, the difference in between S_2 and S_3 and then S_3 to S_6 for M, and MFA S_1 and S_2 and then S_5 to S_6 for MF, S_1 to S_3 and S_5 and S_6 for MFB as well as S_4 and S_5 for MFAB was not significant.

On the whole, the highest actinomycetes population was reared by ginger rhizosphere under the influence of MFAB which was followed by MFA, M, MFB, MF and control, respectively. The difference among M. MF, MFA and MFB was, however, not significant.

In general, with the age of the crop, the population of actinomycetes increased from S_1 to S_5 stage and then declined at S_6 stage. However, the difference in between S_5 and S_6 was not significant.

c) Total number of fungi in the rhizosphere soils:

Proliferation of fungi in the rhizosphere soils of ginger was more than that in the initial soil (table–21; fig. 15).

The treatments M and MF resulted in higher proliferation of fungi

in the rhizosphere soils of ginger than that of control at all the growth stage. In this respect MF brought about higher proliferation of fungi as compared to that of M throughout the growth period. On the other hand, MFA, MFB and MFAB exerted detrimental influence on the proliferation of fungi as compared to that of control from S_3 to S_6 stage. However, the cited treatments brought about enhancing influence on fungi during initial stage i.e. up to S_2 stage. MFAB caused higher stimulation of fungi than that of MFA throughout the growth period of ginger and of MFB from S_1 to S_2 and then S_4 to S_6 stages. As such, MFB was, in general, superior to MFA in relation to higher proliferation of fungi in the rhizosphere soil of ginger. However, the difference in between M and MF at all but S_6 stage, MF and MFA at S_2, MFA and MFB at S_1, S_2, S_5 and S_6 stages, MFA and MFAB at S_1 and S_2 and then S_5 and S_6 stages as well as MFB and MFAB from S_1 to S_3 and then S_5 to S_6 stage was not significant by DMRT.

The population of fungi in the rhizosphere soils of ginger under control, M, MF and MFB progressively increased from S_1 to S_4 stage which then gradually decreased up to S_6 stage. On the other hand, there was an alternate rise and fall in the fungal population under MFA and MFAB up to S_4 stage followed by a gradual decrease up to S_6 stage. The difference between S_1 and S_2, S_2 and S_3 for M, from S_2 to S_5 for MFA and MFB as well as S_2 and S_3 and then S_4 and S_5 stage was, however, not significant.

On the whole, MF exerted the highest stimulation on fungal population in the ginger rhizosphere followed by those of M, control, MFAB, MFB and MFA, respectively.

However, the difference in between M and MF as well as MFA and MFB was not significant.

The fungi in the rhizosphere soils of ginger increased with the age of crop up to S_4 stage which, thereafter, decreased up to final harvesting stage (S_6).

d) Total number of aerobic non-symbiotic nitrogen fixing bacteria

TABLE–21 : Total number of fungi present in the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture with crop.*

Treatment	Number of fungi (CFU x 10^4) g^{-1} dry soil (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	**51.65^{b}	60.52^{d}	79.42^{b}	87.15^{b}	75.65^{ab}	54.54^{b}	68.15^{B}
+M	75.71^{a}	82.78^{a}	89.89^{a}	97.90^{a}	74.29^{ab}	56.57^{b}	79.52^{A}
MF	82.72^{a}	90.58^{ab}	97.36^{a}	110.65^{a}	85.78^{a}	68.87^{a}	89.32^{A}
MFA	54.01^{b}	70.70^{bc}	63.13^{d}	67.83^{e}	59.48^{b}	47.19^{b}	60.39^{C}
MFB	54.99^{b}	69.72^{cd}	70.07^{c}	74.58^{d}	65.35^{b}	44.87^{b}	63.26^{C}
MFAB	57.47^{b}	72.70^{bc}	69.14^{c}	79.81^{c}	71.70^{ab}	56.26^{b}	67.84^{B}
Mean	62.75^{D}	74.5^{C}	78.16^{B}	86.32^{A}	72.04^{C}	54.71^{E}	
LSD at 5%	7.32	9.67	4.97	4.98	12.02	11.96	
at 1%	11.08	14.64	7.52	7.54	NS*	NS*	

		LSD at 5%	at 1%
For Stage	-	3.04	4.08
Treatment	-	3.04	4.08
Interaction (Stage x Treatment)	-	7.44	9.98

* Total number of fungi present in initial soil - 25.2 (CFU x 10^4) g^{-1} dry soil.

** See foot note Table - 19

For + and ++ see foot note Table - 6.

NS - Non significant.

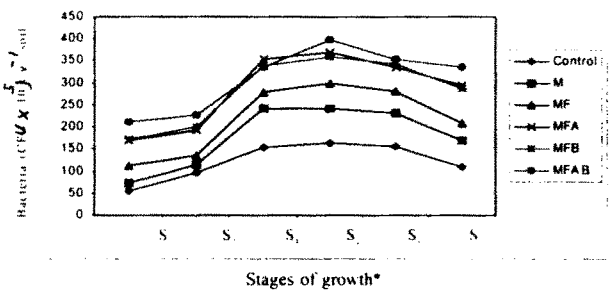


Fig. 13. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation of bacteria in the rhizosphere soils of ginger in pot.

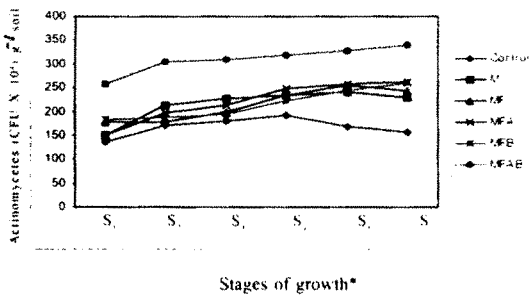


Fig. 14. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation of actinomycetes in the rhizosphere soils of ginger in pot.

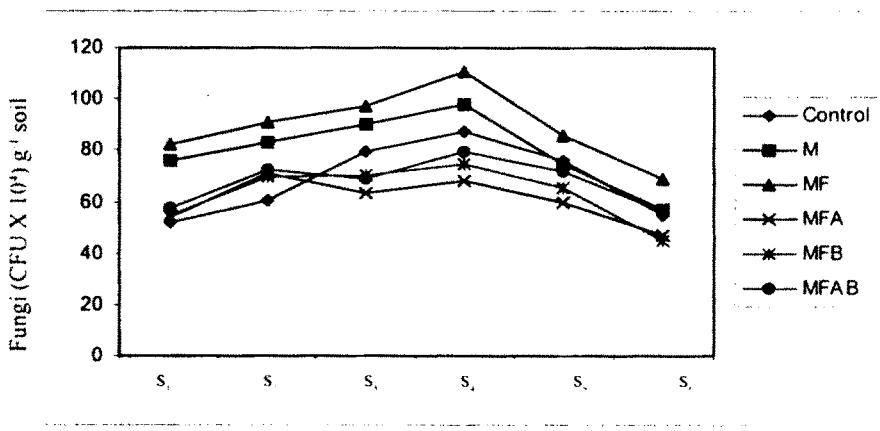


Fig. 15. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation of fungi in the rhizosphere of ginger in pot.

* S_1 - S_6 = For ginger 30, 60, 90, 120, 150, 180 days after planting - at sprouting of rhizome, early emergence of pseudostem, late emergence of pseudostem, full growth of pseudostem, near maturity of pseudostem and harvesting stage of ginger, respectively.

present in the rhizosphere soils :

The rhizosphere soils of ginger entertained a greater number of nitrogen fixing bacteria as compared to initial soil (table–22; fig. 16).

The treatments - MF, MFA, MFB and MFAB resulted in higher proliferation of aerobic non-symbiotic nitrogen fixing bacteria in the rhizosphere soils of ginger right from the beginning to the completion of the experiment as compared to that of control. This was true with M from S_1 to S_4 stage and then at S_6 stage. MFB was superior to M in relation to higher proliferation of said bacteria from S_1 to S_6 stage but inferior to MF at all but S_4 stage. On the other hand, MFA brought about enhancing influence on the abundance of cited bacteria as compared to that of MF from S_2 to S_6 stage. Nevertheless, MFAB exerted higher stimulation of the non-symbiotic nitrogen fixing bacteria in the rhizosphere of ginger than that of MFA at all but S_5 stages. However, the difference in between control and M as well as M and MF from S_3 to S_6, MFA and MFAB from S_4 to S_6 stage was not significant by DMRT.

The population of aerobic non-symbiotic nitrogen fixing bacteria in the rhizosphere soils of ginger under control, M, MF, MFA, MFB and MFAB increased progressively from S_1 to S_4 stage which then gradually decreased up to S_6 stage. However, the difference in between S_4 and S_5 for M, S_1 and S_2, S_3 and S_4 and then S_5 to S_6 for MFA as well as S_1 and S_2 and then S_4 and S_5 for MFAB was only significant.

All in all, MFAB caused the highest proliferation of non-symbiotic nitrogen fixing bacteria in the rhizosphere soil of ginger followed by these under MFA, MF, MFB, M and control, respectively. However, the difference in between MF and MFB was not significant.

In general, the population of non-symbiotic nitrogen fixing bacteria increased, on and on, from S_1 to S_4 stage and then gradually decreased up to S_6 stage.

TABLE–22 : **Total number of aerobic non-symbiotic nitrogen fixing bacteria present in the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture with crop.***

Treatment	Total number of nitrogen fixing bacteria (CFU x 10^4) g^{-1} dry soil (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++60.92^{e}	72.36^{e}	84.63^{d}	93.70^{c}	86.84^{b}	74.02^{c}	78.74^{D}
+M	76.87^{cd}	84.38^{d}	93.90^{cd}	104.19^{bc}	72.68^{b}	82.26^{bc}	85.71^{D}
MF	91.07^{b}	99.11^{c}	104.79^{c}	111.80^{b}	101.26^{b}	88.64^{bc}	99.44^{C}
MFA	69.18^{de}	129.72^{b}	146.32^{b}	165.79^{a}	154.60^{a}	126.31^{a}	131.98^{B}
MFB	80.90^{bc}	92.33^{cd}	98.48^{c}	109.98^{b}	106.59^{b}	98.60^{b}	97.81^{C}
MFAB	117.49^{a}	153.69^{a}	165.17^{a}	176.82^{a}	153.64^{a}	135.54^{a}	130.39^{A}
Mean	82.73^{D}	105.26^{C}	115.54^{B}	127.04^{A}	112.60^{B}	100.89^{C}	
LSD at 5%	11.15	8.69	12.34	12.33	42.25	16.07	
at 1%	16.89	13.15	18.69	18.68	NS	24.33	

		LSD at 5%	at 1%
For Stage	-	6.97	9.35
Treatment	-	6.97	9.35
Interaction (Stage x Treatment)	-	17.08	22.92

* Total number of aerobic non-symbiotic nitrogen fixing bacteria present in initial soil - 48.8 (CFU x 10^4) g^{-1} dry soil.

** See foot note Table - 19

For + and ++ see foot note Table - 6.

NS-Non significant.

e) Total number of phosphate solubilizing microorganisms present in the rhizosphere soils:

The proliferation of phosphate solubilizing organisms in the treated soils was more than that in the initial soil (table–23; fig. 17).

The treatments - M, MF, MFA, MFB and MFAB increased the population of phosphate solubilizing organisms in the rhizosphere soils of ginger as compared to that of control at each growth stage. MF resulted in higher population of the cited organisms than that of M from S_2 to S_6 stage. On the other hand, MFB augmented the abundance of phosphate solubilizing organisms in ginger rhizosphere as compared to those of MF and MFA from S_3 to S_6 stage. Nevertheless, MFAB caused higher proliferation of the cited organisms than that of MFB at all the growth stages. However, the difference in between M and MF from S_1 to S_3 stage, MFA and MFB from S_4 to S_6 stage as well as MFB and MFAB from S3 to S6 stage was not significant by DMRT.

The population of phosphate solubilizing organisms in the rhizosphere soils of ginger under MF, MFA, MFB and MFAB increased progressively from S_1 to S_4 stage which then gradually decreased up to S_6 stage. On the other hand, the cited organisms in the ginger rhizosphere progressively augmented under control and M right from the initial stage to S_4 stage followed by a gradual decrease up to S_6 stage. However, the difference between S_1 and S_2 and then from S_4 to S_6 for M, S_2 to S_5 for MF, S_3 and S_4 for MFA, S_3 to S_6 for MFB as well as S_3 and S_4 and then S_5 and S_6 for MFAB was not significant.

All in all, MFAB resulted in the maximum proliferation of phosphate solubilizing organisms in the rhizosphere soils of ginger followed by those of MFB, MF, MFA, M and control, respectively. However the difference in between MF and MFA was not significant.

The population of phosphate solubilizing organisms, in general, increased progressively with the age of crop up to S_4 stage and then

TABLE–23 : Total number of phosphate solubilizing organisms present in the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture with crop.*

Treatment	Number of phosphate solubilizing organisms (CFU x 10^4) g^{-1} dry soil (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++84.10^{b}	95.39^{d}	110.02^{c}	103.53^{c}	87.49^{c}	72.72^{d}	92.20^{I}
+M	87.46^{b}	101.69^{cd}	129.91^{bc}	108.35^{c}	96.05^{c}	81.57^{d}	100.83^{D}
MF	85.13^{b}	123.73^{b}	131.34^{bc}	149.29^{b}	142.49^{ab}	116.70^{bc}	124.78^{C}
MFA	98.60^{b}	121.23^{b}	141.41^{b}	151.07^{b}	121.82^{b}	111.24^{c}	124.22^{C}
MFB	89.19^{b}	119.31^{bc}	149.61^{ab}	163.31^{ab}	156.96^{a}	131.37^{ab}	134.95^{B}
MFAB	130.90^{a}	149.23^{a}	172.21^{a}	181.98^{a}	160.04^{c}	143.22^{a}	156.26^{A}
Mean	95.89^{E}	118.43^{C}	139.08^{A}	142.92^{A}	127.47^{B}	109.47^{D}	
LSD at 5%	19.34	17.77	23.25	19.87	21.31	16.86	
at 1%	29.29	26.91	35.22	30.10	32.28	25.54	

		LSD at 5%	at 1%
For Stage	-	6.72	9.00
Treatment	-	6.72	9.00
Interaction (Stage x Treatment)	-	16.45	22.08

* Total number of phosphate solubilizing organisms present in initial soil - 37.5 (CFU x 10^4) g^{-1} dry soil.

** See foot note Table - 19

For + and ++ see foot note Table - 6.

gradually reduced up to S_6 stage. However, the difference in between S_5 and S_4 stages was not significant.

ii) Transformations :

a) Nitrogen fixing power of the rhizosphere soils :

Amount of nitrogen fixed per gram soil per gram of sucrose utilized are presented in table–24; fig. 18. The amount of nitrogen fixed by the rhizosphere soils of ginger was uniformly greater than that of initial soil.

MF resulted in mild reduction in nitrogen fixing power of the rhizosphere soils of ginger throughout all but S_3 stage of growth as compared to that of control. On the other hand, M, MFA, MFB and MFAB brought about stimulating influence on the nitrogen fixing power as compared to that of control at every but S_6 stage for MFA and MFB. The treatments - M and MFA yielded higher reflection of nitrogen fixing power as compared to that of MFB at each growth stage of ginger. As such, MFA was superior to M in relation to nitrogen fixing power from S_1 to S_3 stage and then at S_5 stage. MFAB resulted in the highest increase in the nitrogen fixing power of the rhizosphere soils of ginger as compared to those of other treatments with the exception of S_5 stage where in the fixation was less than that of MFA. However, the difference in between M and MF as well as MF and MFA at S_6 stage, MFA and MFB at S_3 and S_6, MFA and MFAB at S_4 and S_6, MFB and MFAB at S_6 stage was not significant by DMRT.

The nitrogen fixing power of the rhizosphere soils of ginger under control, M, MF and MFB increased, on and on, from S_1 to S_4 stage which then gradually reduced up to S_6 stage. On the other hand, the nitrogen fixing power of ginger rhizosphere under MFA and MFAB progressively increased from S_1 to S_3 stage and then gradually decreased till the harvesting of ginger. However, the difference in between S_1 and S_2 and then S_3 to S_4 for M, S_1 and S_2, S_2 and S_3 and then S_5 to S_6 for MF, S_1 and

TABLE–24 : Nitrogen fixing power of the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture with crop.*

Treatment	Amount of nitrogen fixed (mg g^{-1} sucrose g^{-1} pot soil) (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++10.46^{d}	11.12^{d}	11.48^{c}	11.96^{c}	11.35^{c}	10.45^{a}	11.13^{D}
+M	12.62^{c}	13.56^{bc}	14.46^{b}	14.76^{a}	12.34^{b}	11.26^{a}	13.16^{B}
MF	10.06^{d}	11.04^{d}	11.67^{c}	11.72^{c}	10.41^{d}	10.41^{a}	10.88^{D}
MFA	13.82^{b}	14.02^{b}	15.06^{b}	14.24^{a}	13.17^{a}	10.32^{a}	13.43^{B}
MFB	12.24^{c}	12.46^{c}	14.32^{b}	13.38^{b}	11.71^{bc}	10.24^{a}	12.39^{C}
MFAB	16.50^{a}	17.48^{a}	17.78^{a}	14.80^{a}	11.46^{c}	11.45^{a}	14.91^{A}
Mean	12.65^{C}	13.24^{B}	14.12^{A}	13.47^{B}	11.74^{D}	10.68^{E}	
LSD at 5%	1.24	1.18	0.79	0.71	0.67	NS	
at 1%	1.87	1.78	1.20	1.07	1.01	NS	

		LSD at 5%	at 1%
For Stage	-	0.37	0.48
Treatment	-	0.37	0.48
Interaction (Stage x Treatment)	-	0.90	1.20

* Nitrogen fixing power of initial soil - 9.56 mg N g^{-1} soil g^{-1} sucrose

** See foot note Table - 19

For + and ++ see foot note Table - 6

NS-Non significant.

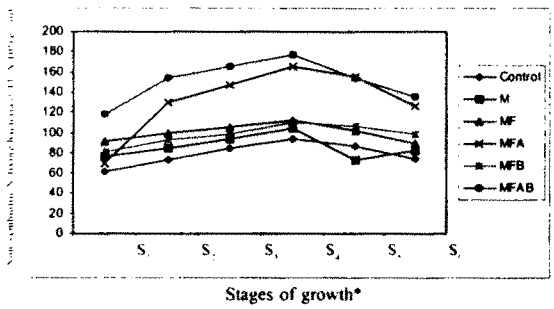


Fig. 16. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation of aerobic non-symbiotic nitrogen fixing bacteria in the rhizosphere soils of ginger in pot.

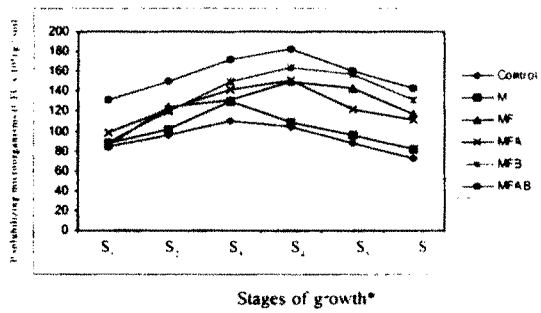


Fig. 17. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation of phosphate solubilizing microorganisms in the rhizosphere soils of ginger in pot.

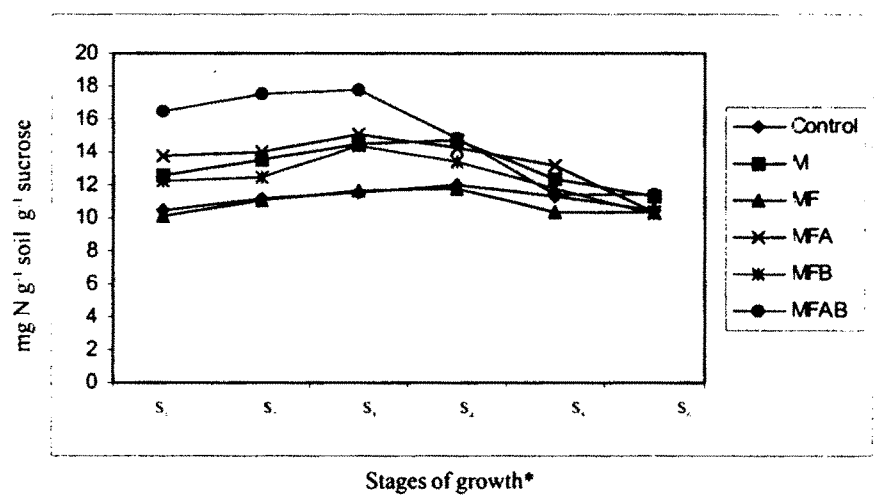


Fig. 18. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on nitrogen fixing power of rhizosphere soils of ginger in pot.

* S_1 - S_6 = For ginger 30, 60, 90, 120, 150, 180 days after planting - at sprouting of rhizome, early emergence of pseudostem, late emergence of pseudostem, full growth of pseudostem, near maturity of pseudostem and harvesting stage of ginger, respectively.

S_2 as well as and S_3 and S_4 for MFA and MFB, S_2 and S_3 for MFAB was not significant.

On the whole, the highest nitrogen fixation was recorded in ginger rhizosphere soil under MFAB followed by those of MFA, M, MFB control and MF, respectively. However, the difference in between MF and control was not significant.

In general, the nitrogen fixing power of ginger rhizosphere soils increased progressively up to S_3 stage which then decreased significantly up to S_6 stage.

b) Phosphate solubilizing power of the rhizosphere soils :

Table–25; fig. 19 shows the average of amount of insoluble phosphorus solubilized by one gram of soil after 7 and 10 days incubation, in mg per 15 mg insoluble phosphorus per 0.15 gm sucrose utilized. The rhizosphere soils of ginger, in general, solubilized a greater amount of insoluble phosphorus as compared to that of the initial soils.

The treatment M exerted an increase in the phosphate solubilizing power of rhizosphere soils of ginger as compared to that of control from S_2 to S_6 stage. On the other hand, MF augmented the phosphate solubilizing power of ginger rhizosphere soils right from the initiation to the harvesting stage as compared to that of M. MFA resulted in reduction in phosphate solubilization as compared to that of MF from S_2 to S_5 stage. On the other hand, MFB caused enhancement of phosphate solubilizing power as compared to MF from S_1 to S_4 stage and to MFA from S_2 to S_6 stage. In this context, MFAB was superior to MFB in the rhizosphere soils of ginger all but S_2 stage of growth. However, the difference in between M and MF at S_1 and S_2 and then at S_6, MF and MFA, MFA and MFB as well as MFB and MFAB at all but S_1, S_4 and S_5, stages respectively was not significant by DMRT.

The phosphate solubilizing power of rhizosphere soils of ginger

TABLE–25 : **Phosphate solubilizing power of the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture with crop.***

Treatment	phosphorus solubilized in mg 15 mg^{-1} insoluble P[75 mg $Ca_3(PO_4)_2$] g^{-1} pot soil 0.15 g^{-1} sucrose consumed. (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	**0.035^{b}	0.037^{a}	0.039^{d}	0.060^{d}	0.067^{d}	0.064^{ab}	0.050^{I}
+M	0.034^{b}	0.044^{a}	0.098^{c}	0.197^{c}	0.120^{c}	0.076^{ab}	0.094^{D}
MF	0.036^{b}	0.061^{a}	0.151^{ab}	0.240^{b}	0.174^{b}	0.097^{ab}	0.126^{C}
MFA	0.059^{a}	0.060^{a}	0.124^{b}	0.230^{b}	0.171^{b}	0.108^{b}	0.125^{C}
MFB	0.052^{ab}	0.086^{a}	0.159^{ab}	0.271^{a}	0.169^{b}	0.106^{ab}	0.140^{B}
MFAB	0.056^{a}	0.076^{a}	0.170^{a}	0.288^{a}	0.222^{a}	0.132^{a}	0.157^{A}
Mean	0.045^{F}	0.060^{E}	0.123^{C}	0.214^{A}	0.153^{B}	0.089^{D}	
LSD at 5%	0.020	NS	0.030	0.026	0.005	0.060	
at 1%	0.029	NS	0.040	0.029	0.008	0.100	

		LSD at 5%	at 1%
For Stage	-	0.013	0.017
Treatment	-	0.013	0.017
Interaction (Stage x Treatment)	-	0.033	0.043

* Phosphate solubilizing power of initial soil - 0.025 mg 15 mg^{-1} in soluble P[75 mg $Ca_3(PO_4)_2$] g^{-1} soil 0.15 g^{-1} sucrose consumed.

** See foot note Table - 19

For + and ++ see foot note Table - 6

NS-Non significant.

under M, MF, MFA, MFB and MFAB increased progressively from S_1 to S_4 stage which then gradually decreased up to S_6 stage. On the other hand, the phosphate solubilizing power in the rhizosphere soils of ginger under control increased, on and on, from S_1 to S_5 stage and then decreased at S_6 stage. However, the difference in between S_1 and S_2 for M, MF, MFA and MFAB was not significant.

All in all, MFAB resulted in the highest stimulation on of phosphate solubilizing power in the rhizosphere soils of ginger followed by those of MFB, MF, MFA, M and control, respectively. However, the difference in between MF and MFA was not significant.

Phosphate solubilizing power of rhizosphere soils of ginger increased, on and on, from S_1 to S_4 stage and then gradually decreased up to S_6 stage.

B) Chemical Analysis :

a) Organic carbon content of the rhizosphere soils :

Organic carbon content of the rhizosphere soils of ginger was much more as compared to that of the initial soil excepting those under control at all the stages, MFA from S_4 to S_5, MFB at S_6 and MFAB from S_4 to S_6 wherein organic carbon content was less than that of the initial soil (table –26; fig. 20).

The treatments M, MF, MFA, MFB and MFAB resulted in an increase in the content of organic carbon in the rhizosphere soils of ginger at all the stages of growth as compared to that of control. In this respect, the treatment M brought about the highest increase in the content of organic carbon content at each growth stage. M and MF brought about enhancement in the content of organic carbon as compared to that of MFA, particularly from S_2 to S_6 stage. On the other hand, MFB increased the content of organic carbon from S_3 to S_5 stage as compared to MFA. However, the treatment MFAB exerted the least influence on the content

TABLE–26 : Organic carbon content of the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot cultur with crop.*

Treatment	Organic carbon content (%) (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++0.657 #(0.810)^{c}	0.657 (0.810)^{d}	0.647 (0.804)^{c}	0.637 (0.800)^{c}	0.620 (0.787)^{b}	0.599 (0.774)^{c}	0.642 (0.802)^{C}
+M	0.998 (0.999)^{a}	0.957 (0.978)^{a}	0.906 (0.952)^{a}	0.895 (0.946)^{a}	0.883 (0.940)^{a}	0.882 (0.939)^{a}	0.920 (0.959)^{A}
MF	0.764 (0.874)^{b}	0.762 (0.872)^{bc}	0.723 (0.850)^{b}	0.711 (0.843)^{b}	0.693 (0.832)^{b}	0.685 (0.828)^{b}	0.723 (0.850)^{B}
MFA	0.764 (0.874)^{b}	0.754 (0.868)^{bc}	0.685 (0.850)^{b}	0.663 (0.843)^{b}	0.663 (0.832)^{b}	0.659 (0.828)^{b}	0.698 (0.840)^{B}
MFB	0.767 (0.876)^{b}	0.742 (0.861)^{b}	0.728 (0.854)^{b}	0.710 (0.843)^{b}	0.696 (0.843)^{b}	0.654 (0.809)^{bc}	0.716 (0.849)^{B}
MFAB	0.742 (0.861)^{bc}	0.686 (0.828)^{cd}	0.673 (0.821)^{c}	0.649 (0.806)^{c}	0.624 (0.790)^{b}	0.615 (0.784)^{bc}	0.681 (0.815)^{C}
Mean	0.785 (0.884)^{A}	0.761 (0.875)^{A}	0.728 (0.856)^{B}	0.710 (0.847)^{BC}	0.696 (0.836)^{CD}	0.681 (0.827)^{D}	
^LSD at 5%	0.044	0.048	0.023	0.020	0.040	0.040	
at 1%	0.062	0.068	0.031	0.026	0.062	0.062	

		LSD at 5%	at 1%
For Stage	-	0.013	0.017
Treatment	-	0.013	0.017
Interaction (Stage x Treatment)	-	NS	NS

* Organic carbon content in initial soil - 0.666% (0.816)

** See foot note Table - 19

For + and ++ see foot note Table - 6

For # and ^ See foot note Table-13

NS-Non significant.

of organic carbon in the rhizosphere soils of ginger at each growth stage. The difference in between MF and MFA as well as MFA and MFB at all the growth stages, MFB and MFAB at S_1 and then S_5 and S_6 stage was, however, not significant by DMRT.

The content of organic carbon in the rhizosphere soils of ginger under all the treatments gradually declined right from beginning to the final stage. However, the differences among the stages under each treatment was not significant.

All in all, the treatment M resulted in the highest increase in the content of organic carbon in the rhizosphere soils of ginger followed by those of MF, MFB, MFA, MFAB and control, respectively. The difference among MF, MFA and MFB was, however, not significant.

In general, there was a gradual decline in the content of organic carbon in the rhizosphere soils of ginger from the beginning to the completion of the experiment. However, the difference between S_1 and S_2, S_3 and S_4 as well as S_5 and S_6 not significant.

b) Total nitrogen content in the rhizosphere soils :

Nitrogen content of the rhizosphere soils of ginger was much more as compared to that of the initial soil with the exception of that under control at S_6 stage (table–27; fig. 21).

The treatments - M, MF, MFA, MFB and MFAB brought about an increase in the content of total nitrogen in the rhizosphere soils of ginger at every stage of growth as compared to control. MF and MFB resulted in higher increase than that of M at each stage though MF was superior to MFB in relation to the content of total nitrogen at S_1 and then from S_3 to S_6 stage. On the other hand, MFA augmented the content of total nitrogen to a greater extent than that of MF from S_1 to S_5 stage. MFAB was next to MFA in relation to the content of total nitrogen at S_1, S_2, S_4 and S_6 stages. However, the difference in between M and MF at S_1, S_4 and S_6 stages, MFA

TABLE–27 : **Nitrogen content of the rhizosphere soils of ginger in pot culture as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture with crop.***

Treatment	Nitrogen content of rhizosphere soil (%) (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++0.036 #(0.190)^{d}	0.037 (0.194)^{c}	0.035 (0.187)^{c}	0.034 (0.184)^{c}	0.032 (0.179)^{c}	0.028 (0.169)^{c}	0.033 (0.184)^{D}
+M	0.040 (0.201)^{c}	0.040 (0.201)^{bc}	0.037 (0.194)^{bc}	0.036 (0.191)^{bc}	0.035 (0.190)^{bc}	0.031 (0.176)^{bc}	0.036 (0.192)^{C}
MF	0.048 (0.219)^{a}	0.044 (0.211)^{ab}	0.042 (0.205)^{ab}	0.041 (0.204)^{a}	0.041 (0.204)^{ab}	0.040 (0.200)^{a}	0.042 (0.207)^{A}
MFA	0.049 (0.221)^{a}	0.047 (0.218)^{a}	0.044 (0.211)^{a}	0.044 (0.210)^{a}	0.042 (0.205)^{a}	0.040 (0.200)^{a}	0.044 (0.211)^{A}
MFB	0.044 (0.211)^{b}	0.044 (0.211)^{ab}	0.041 (0.202)^{ab}	0.040 (0.200)^{ab}	0.038 (0.195)^{ab}	0.034 (0.184)^{abc}	0.040 (0.201)^{B}
MFAB	0.048 (0.219)^{a}	0.046 (0.214)^{a}	0.044 (0.210)^{a}	0.042 (0.206)^{a}	0.042 (0.205)^{a}	0.039 (0.197)^{ab}	0.043 (0.209)^{A}
Mean	0.044 (0.219)^{A}	0.043 (0.208)^{A}	0.040 (0.201)^{B}	0.039 (0.199)^{BC}	0.038 (0.196)^{C}	0.035 (0.188)^{D}	
^LSD at 5%	0.004	0.009	0.012	0.009	0.014	0.020	
at 1%	0.005	0.010	0.015	0.010	0.020	0.031	

		LSD at 5%	at 1%
For Stage	-	0.0043	0.0057
Treatment	-	0.0043	0.0057
Interaction (Stage x Treatment)	-	NS	NS

* Nitrogen content in initial soil - 0.03% (0.173)

** See foot note Table - 19

For + and ++ see foot note Table - 6

For # and ^ See foot note Table-13

NS-Non significant.

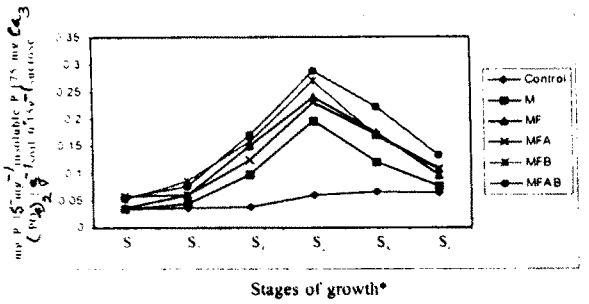


Fig. 19. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on phosphate solubilizing power of rhizosphere soils of ginger in pot.

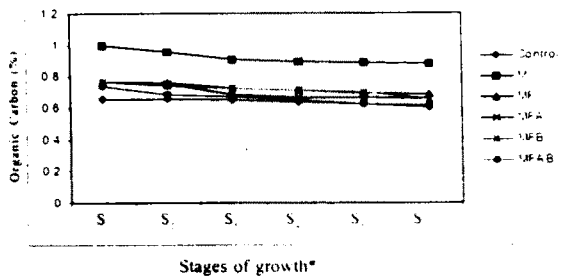


Fig. 20. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the content of organic carbon in the rhizosphere soils of ginger in pot.

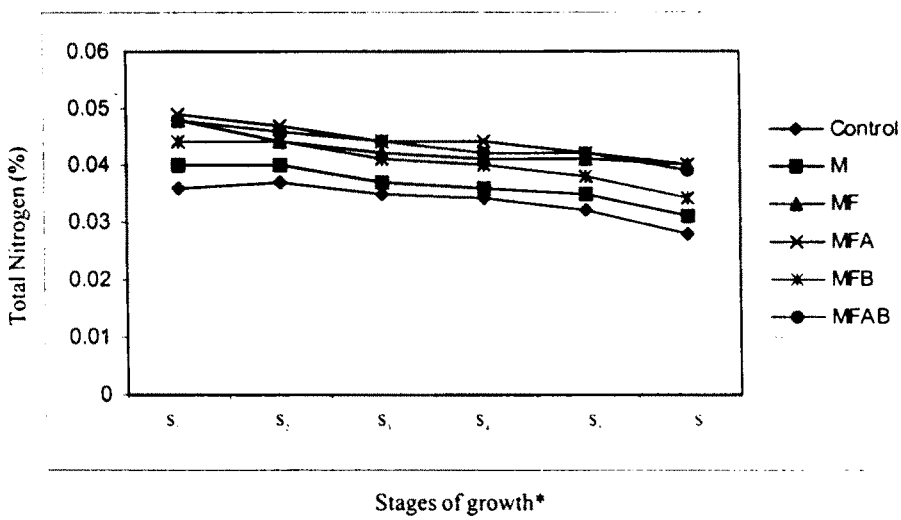


Fig. 21. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the content of total nitrogen in rhizosphere soils of ginger in pot.

* S_1 - S_6 = For ginger 30, 60, 90, 120, 150, 180 days after planting - at sprouting of rhizome, early emergence of pseudostem, late emergence of pseudostem, full growth of pseudostem, near maturity of pseudostem and harvesting stage of ginger, respectively.

and MFB at S_1 as well as MFB and MFAB at S_1 was only significant by DMRT.

The total nitrogen content in the rhizosphere soils of ginger under control decreased gradually from S_2 to S_6 stage. On the other hand, the content of total nitrogen in the rhizosphere soils of ginger under M, MF, MFA, MFB and MFAB decreased with time from S_1 S_6 stage. However, the difference among the stages under each treatments was not significant.

All in all, MFA brought about the highest increase in total nitrogen content in the ginger rhizosphere followed by those of MFAB, MF, MFB, M and control, respectively. There difference among MF, MFA and MFAB was, however, not significant.

With the age of ginger, the nitrogen content of the rhizosphere soils decreased gradually from S_1 to S_6 stage.

c) Ammoniacal - nitrogen content in the rhizosphere soils :

Results presented in table–28; fig. 22 indicate that there was an increase in the amount of ammoniacal - nitrogen as compared to that in initial soil with the exception of those under control at S_5 and S_6 stages as well as M at S_6 stage.

The treatments - M, MF, MFA, MFB and MFAB resulted in an increase in the content of ammoniacal - nitrogen in the rhizosphere soils of ginger as compared to that of control at each growth stage. MFB was superior to M in relation to ammoniacal - nitrogen content at each growth stage. On the other hand, MF brought about an increase in the content of ammoniacal - nitrogen as compared to that of MFB from S_1 to S_4 stage and then at S_6 stage. As such, MFA accumulated more amount of ammoniacal-nitrogen than that of MF from S_2 to S_6 stage. MFAB resulted in the retention of maximum amount of ammoniacal- nitrogen in the rhizosphere soils of ginger at every growth stage. However, the difference in between M and MF at S_4 and S_5, MF and MFA as well as MFB at all but S_4 stages, MFB and MFAB at S_2 stage was not significant by DMRT.

TABLE–28 : Amount of ammonical-nitrogen in the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture with crop.*

Treatment	Amount of ammoniacal-nitrogen (mg 100 g^{-1} dry soils) (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++3.29^{c}	3.25^{c}	3.16^{c}	3.15^{d}	3.07^{d}	2.93^{d}	3.14^{I}
+M	3.45^{c}	3.73^{bc}	3.50^{c}	3.45^{cd}	3.38^{cd}	3.01^{d}	3.42^{I}
MF	4.82^{ab}	4.61^{a}	4.41^{b}	4.24^{bc}	4.20^{bc}	4.20^{ab}	4.41^{C}
MFA	4.81^{ab}	5.16^{a}	4.93^{ab}	4.79^{ab}	4.61^{ab}	4.31^{bc}	4.76^{B}
MFB	4.39^{b}	4.33^{ab}	4.09^{b}	3.82^{cd}	4.34^{bc}	3.89^{c}	4.14^{D}
MFAB	5.29^{a}	5.18^{a}	5.16^{a}	5.00^{a}	4.93^{a}	4.87^{a}	5.07^{A}
Mean	4.34^{A}	4.37^{A}	4.20^{A}	4.07^{AB}	4.08^{AB}	3.86^{B}	
LSD at 5%	0.47	0.84	0.88	0.81	1.12	0.46	
at 1%	0.71	1.26	1.32	1.22	1.69	0.70	

		LSD at 5%	at 1%
For Stage	-	0.27	NS
Treatment	-	0.27	0.36
Interaction (Stage x Treatment)	-	NS	NS

* Ammoniacal-nitrogen content in initial soil - 3.12 mg 100 g^{-1} soil.

** See foot note Table - 19

For + and ++ see foot note Table - 6

NS-Non significant.

The ammoniacal - nitrogen content in the rhizosphere soils of ginger under control and MFAB gradually decreased right from S_1 to S_6 stage. This was true with MF up to S_5 stage. The accumulation of ammoniacal nitrogen under M and MFA increased from S_1 to S_2 stage followed by a decrease up to S_6 stage. On the other hand, the content of ammoniacal - nitrogen under MFB decreased gradually up to S_4 stage and then there was a rise and fall in the content of the same up to S_6 stage. However, the difference among the stages under each treatment was not significant.

On the whole, the highest amount of ammoniacal- nitrogen was accumulated in the rhizosphere soils of ginger under MFAB. This was followed by MFA, MF, MFB, M and control, respectively.

In general, the accumulation of ammoniacal - nitrogen was more at S_1 stage and then declined gradually with the age of crop.

d) Nitrate - nitrogen content in the rhizosphere soils :

Results presented in table–29; fig. 23 indicate that there was higher accumulation of nitrate - nitrogen content in ginger rhizosphere as compared to that found in initial soil with the exception of that under control at S_5 and S_6 stages.

The treatments - M, MF, MFA and MFAB brought about an increase in the content of nitrate - nitrogen in the rhizosphere soils of ginger as compared to control at all the stages. MFB resulted in an increase in the content of nitrate - nitrogen as compared to that of M from S_1 to S_2 stage and then from S_4 to S_6 stage. On the other hand, MFA was superior to MFB in relation to the content of nitrate - nitrogen form S_1 to S_3 stage and then at S_6 stage. As it were, among the treatments, MFAB exerted maximum increase in the content of nitrate - nitrogen at all the growth stages in the rhizosphere soils of ginger. However, the difference in between MFB and MFAB at S_1, S_3 and S_5 stages was significant by DMRT.

TABLE–29 : **Amount of nitrate-nitrogen in the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture with crop.***

Treatment	Amount of nitrate nitrogen (mg 100 g^{-1} dry soils) (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++2.41^{b}	2.41^{a}	2.52^{b}	2.58^{b}	1.99^{c}	2.04^{d}	2.24^{C}
+M	2.43^{b}	2.45^{a}	2.57^{b}	2.67^{b}	2.90^{b}	2.37^{cd}	2.56^{BC}
MF	2.60^{b}	2.60^{a}	2.41^{b}	2.46^{b}	3.59^{a}	2.89^{bc}	2.75^{B}
MFA	2.67^{b}	2.56^{a}	2.60^{b}	2.84^{b}	2.91^{b}	2.96^{b}	2.75^{B}
MFB	2.60^{b}	2.51^{a}	2.50^{b}	2.90^{ab}	2.98^{b}	2.61^{bcd}	2.68^{B}
MFAB	3.43^{a}	3.12^{a}	4.04^{a}	4.43^{a}	3.82^{a}	3.69^{a}	3.75^{A}
Mean	2.69^{BC}	2.60^{C}	2.79^{ABC}	2.98^{AB}	3.03^{A}	2.74^{ABC}	
LSD at 5%	0.59	NS	0.93	1.53	0.55	0.56	
at 1%	0.90	NS	1.40	2.31	0.82	0.85	

		LSD at 5%	at 1%
For Stage	-	0.303	NS
Treatment	-	0.303	NS
Interaction (Stage x Treatment)	-	NS	NS

* Nitrate-nitrogen content in initial soil -2.50 mg 100 g^{-1} soil.

** See foot note Table - 19

For + and ++ see foot note Table - 6

NS-Non significant.

The nitrate - nitrogen content in the rhizosphere soils of ginger under control and M increased progressively from S_1 to S_4 and S_1 to S_5 stage, respectively with a gradual decrease in respective rhizosphere soils up to S_6 stage. On the other hand, the content of nitrate - nitrogen in the rhizosphere soils of ginger under MF, MFA and MFB decreased from S_2 to S_3, S_1 to S_3 and S_1 to S_2 stages, respectively with an immediate progressive increase of the same in the respective series up to S_5, S_5 and S_4 stages followed by a steep decrease up to S_6 stage. As it were, the content of nitrate - nitrogen decreased under MFA from S_1 to S_2 stage followed by an increase up to S_6 stage. However, the difference among the stages under each treatment was not significant.

On an average, the highest amount of nitrate - nitrogen was detected in the rhizosphere soils of ginger under MFAB followed by MF, MFA, MFB, M and control, respectively. However, the difference among MFA, MF and MFB was not significant.

In general, with the age of ginger, the nitrate - nitrogen content in ginger rhizosphere increased from S_1 to S_5 stage and then decreased at S_6 stage.

e) Available phosphorus content in the rhizosphere soils :

The amount of available phosphorus in mg per kilogram dry soil are presented in table–30; fig. 24. The figures show that the amount of available phosphorus in ginger rhizosphere was more as compared to that in initial soil with the exception of that under control at S_5 and S_6 stage.

The treatments - M, MF, MFA, MFB and MFAB resulted in an increase in the content of available phosphorus in the rhizosphere soils of ginger as compared to that of control. In this context, MFA brought about an enhancing influence on the content of the same as compared to M at all the growth stages. On the other hand, MF exerted a higher stimulating effect on the availability of phosphorus in the ginger rhizosphere from S_2

TABLE–30 : Available phosphorus content of the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture with crop.*

Treatment	Available phosphorus content (mg kg^{-1} pot soils) (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	5.38^{c}	5.14^{c}	5.06^{c}	5.00^{d}	4.80^{d}	4.75^{c}	5.02^{D}
+M	7.25^{bc}	7.20^{b}	6.90^{b}	6.52^{c}	6.42^{c}	6.14^{b}	6.73^{C}
MF	10.89^{ab}	10.64^{a}	10.21^{a}	9.68^{a}	9.53^{a}	9.51^{a}	10.07^{B}
MFA	11.13^{a}	10.11^{a}	9.60^{a}	9.08^{b}	8.95^{b}	8.78^{a}	9.60^{B}
MFB	11.75^{a}	10.28^{a}	10.51^{a}	9.78^{a}	9.63^{a}	9.28^{a}	10.20^{B}
MFAB	11.78^{ab}	11.24^{a}	10.91^{a}	9.85^{ab}	9.68^{ab}	9.28^{a}	11.29^{A}
Mean	9.64^{A}	9.10^{A}	8.86^{A}	8.26^{B}	8.10^{B}	7.95^{B}	
LSD at 5%	3.59	1.65	1.64	0.54	0.38	0.69	
at 1%	5.43	2.49	2.47	0.81	0.57	1.05	

		LSD at 5%	at 1%
For Stage	-	0.605	0.812
Treatment	-	0.605	0.812
Interaction (Stage x Treatment)	-	NS	NS

* Available phosphorus content in initial soil -5.0 mg kg^{-1} soil.

** See foot note Table - 19

For + and ++ see foot note Table - 6

NS-Non significant.

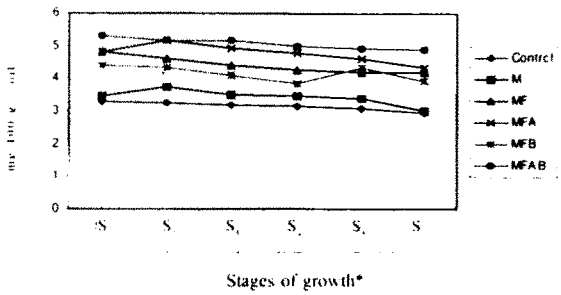


Fig. 22. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the content of ammoniacal-nitrogen in the rhizosphere soils of ginger in pot.

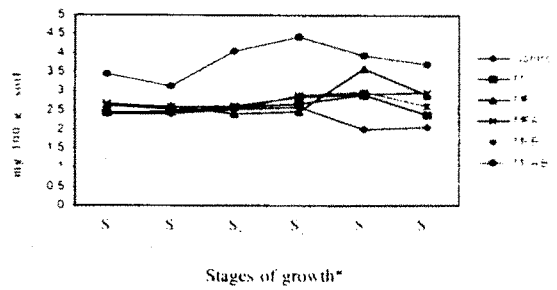


Fig. 23. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the content of nitrate-nitrogen in the rhizosphere soils of ginger in pot.

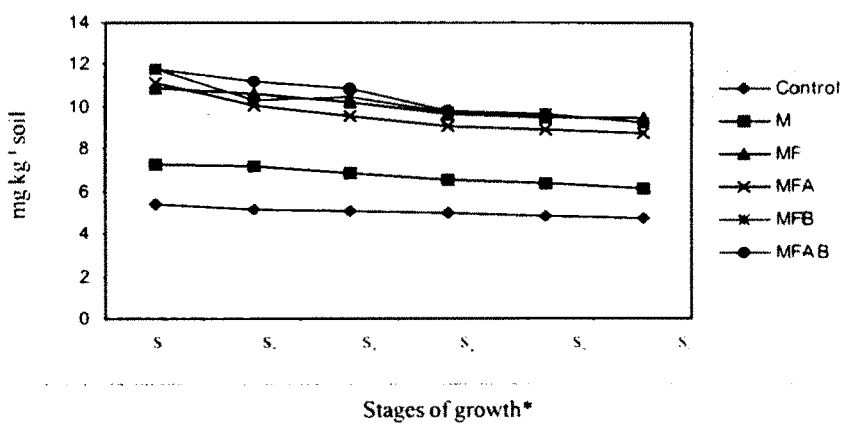


Fig. 24. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the content of available phosphorus in the rhizosphere soils of ginger in pot.

* S_1 - S_6 = For ginger 30, 60, 90, 120, 150, 180 days after planting - at sprouting of rhizome, early emergence of pseudostem, late emergence of pseudostem, full growth of pseudostem, near maturity of pseudostem and harvesting stage of ginger, respectively.

to S_6 stages as compared to MFA. MFB was superior to MF in relation to the content of available phosphorus at S_1 stage and then S_3 to S_5 stage. Above all, MFAB exerted the highest influence on the content of available phosphorus among the treatments at all the growth stages. However, the difference in between M and MF at S1, MF and MFA from S_1 to S_3 and then at S_6, MFA and MFB at all but S_5 and MFB and MFAB at all the stages was not significant by DMRT.

The content of available phosphorus in the rhizosphere soils of ginger under control, M, MF, MFA and MFAB gradually decreased from S_1 to S_6 stage. On the other hand, the content of the same under MFB decreased from S_1 to S_2 stage followed by an increase at S_3 stage which then declined up to S_6 stage. However, the difference among the stages under each treatments was not significant.

On the whole, the highest increase in available phosphorus content was detected in ginger rhizosphere soils under MFAB followed by those of MFB, MF, MFA, M and control, respectively. However, the difference among MF, MFA and MFB was not significant.

In general, with the age of crop, the available phosphorus content in the ginger rhizosphere declined gradually from S_1 to S_6 stage.

f) Uptake of nitrogen and phosphorus as well as yield of rhizome ginger in pot :

Uptake of nitrogen, phosphorus and yield of fresh rhizome ginger under different treatments after final harvest are shown in table-31.

Uptake of nitrogen :

MFAB resulted in the highest uptake of nitrogen by rhizome ginger followed by those of MFA, MFB, MF, M and control, respectively. However, the difference in between M and control as well as MF and MFB was not significant.

TABLE–31 : **Uptake of nitrogen and phosphorus by rhizome and yield of fresh rhizome ginger as influenced by organic manure and inoculation of effecient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture with crop.**

Treatment	Uptake of nitrogen * (g pot^{-1}) Average of 4 replications	Uptake of phosphorus (g pot^{-1}) Average of 4 replications	Yield of rhizome (g pot^{-1}) Average of 4 replications
Control	$^{++}1.23^{d}$	0.011^{d}	93.25^{d}
+M	1.46^{d}	0.015^{d}	119.75^{c}
MF	2.89^{c}	0.027^{c}	170.75^{b}
MFA	3.40^{b}	0.029^{c}	179.82^{b}
MFB	3.19^{bc}	0.035^{b}	175.82^{b}
MFAB	4.16^{a}	0.046^{a}	197.22^{a}
LSD at 5%	0.48	0.004	8.98
at 1%	0.67	0.006	12.60

* Each pot contains 5 kg of soil

For + and ++ see foot note Table - 6

Uptake of phosphorus :

MFAB yielded the highest uptake of phosphorus by rhizome ginger followed by those of MFB, MFA, MF, M and control, respectively. However, the difference in between control and M as well as MF and MFA was not significant.

Yield of ginger :

MFAB resulted in the highest increase in the yield of fresh rhizome ginger followed by those of MFA, MFB, MF, M and control, respectively. However, the difference among MF, MFA and MF was not significant.

Correlations :

Table–32 shows the overall relationships among the different parameters when all the stages of growth were taken into consideration together. From the coefficient of correlation values, it is apparent that the proliferation of bacteria in the ginger rhizosphere pot soil was correlated with the content of total nitrogen, ammoniacal nitrogen, available phosphorus and strongly correlated with phosphate solubilizing microorganisms.

The actinomycete population was correlated with nitrogen fixing and phosphate solubilizing power, content of ammoniacal nitrogen and highly correlated with the content of nitrate nitrogen in ginger rhizosphere pot soil.

The abundance of nitrogen fixing bacteria of rhizosphere pot soil was correlated with nitrogen fixing and phosphate solubilizing power.

Phosphate solubilizing microorganisms of rhizosphere pot soils was correlated with actinomycetes, phosphate solubilizing power, total and nitrate nitrogen, available phosphorus and highly correlated with the content of ammoniacal nitrogen.

Ammoniacal nitrogen content of rhizosphere pot soil was correlated with phosphate solubilizing power, the content of nitrate nitrogen, available phosphorus and strongly correlated with the total nitrogen content.

The content of available phosphorus of ginger rhizosphere pot soil was correlated with the content of ammoniacal nitrogen and highly correlated with phosphate solubilizing power and the content of total nitrogen.

Uptake of nitrogen by rhizome ginger was correlated with nitrogen fixing bacteria and amount of nitrogen fixed, total and nitrate nitrogen, uptake of phosphorus and strongly correlated with total bacteria, phosphate solubilized, ammoniacal nitrogen and available phosphorus.

Uptake of phosphorus by rhizome ginger had a direct relationship with actinomycete population, total and nitrate nitrogen, available phosphorus, uptake of nitrogen and highly correlated with total bacteria, phosphate solubilizing organisms and amount of insoluble phosphate solubilized as well as ammoniacal nitrogen of ginger rhizosphere pot soil.

Besides nitrogen and phosphorus uptake, yield of ginger in pot was also correlated with nitrogen fixing bacteria, and amount of nitrogen fixed, uptake of phosphorus and highly correlated with total bacteria, phosphate solubilizing microorganisms and amount of insoluble phosphate solubilized, total and ammoniacal nitrogen, available phosphorus and uptake of nitrogen.

TABLE–32 : Significant correlations among different variables of ginger rhizosphere pot soil.

Relationship between		Correlation coefficient (r) observed	Table value 5%	1%
Total viable bacteria of rhizosphere soils	and phosphate solubili--zing organisms	0.930**	0.811	0.917
Total viable bacteria of rhizosphere soils	and available phosphorus	0.910*		
Total viable bacteria of rhizosphere soils	and total nitrogen	0.880*		
Total viable bacteria of rhizosphere soils	and ammoniacal nitrogen	0.910*		
Total actinomycetes of rhizosphere soils	and nitrate nitrogen	0.980**		
Total actinomycetes of rhizosphere soils	and phosphate solubilizing power	0.812*		
Total actinomycetes of rhizosphere soils	and ammoniacal nitrogen	0.830*		
Total actinomycetes of rhizosphere soils	and nitrogen fixing power	0.840*		
Nitrogen fixing bacteria of rhizosphere soils	and nitrogen fixing power	0.880*		
Nitrogen fixing bacteria of rhizosphere soils	and phosphate solubilizing power	0.840*		
Phosphate solubilizing organisms of rhizosphere soils.	and nitrate nitrogen	0.890*		

Contd....

Phosphate solubilizing organisms of rhizosphere soils.	and available phosphorus	0.870*	0.811	0.917
Phosphate solubilizing organisms of rhizosphere soils.	and phosphate solubilizing power	0.900*		
Phosphate solubilizing organisms of rhizosphere soils.	and total nitrogen	0.900*		
Phosphate solubilizing organisms of rhizosphere soils.	and ammoniacal nitrogen	0.990**		
Phosphate solubilizing organisms of rhizosphere soils.	and actinomycetes	0.870*		
Ammoniacal nitrogen of rhizosphere soils	and nitrate nitrogen	0.850*		
Ammoniacal nitrogen of rhizosphere soils	and available phosphorus	0.880*		
Ammoniacal nitrogen of rhizosphere soils	and phosphate solubilizing power	0.880*		
Ammoniacal nitrogen of rhizosphere soils	and total nitrogen	0.940**		
Available phosphorus of rhizosphere soils	and phosphate solubilizing power	0.950**		
Available phosphorus of rhizosphere soils	and total nitrogen	0.930**		
Available phosphorus of rhizosphere soils	and ammoniacal nitrogen	0.880*		

Contd....

Uptake of nitrogen by rhizome ginger	and total bacteria of rhizosphere soil	0.960**	0.811	0.917
Uptake of nitrogen by rhizozome ginger	and nitrogen fixing bacteria of rhizosphere soil	0.870*		
Uptake of nitrogen by rhizome ginger	and phosphate solu--bilizing microorganisms of rhizosphere soil	0.960**		
Uptake of nitrogen by rhizome ginger	and nitrogen fixing power	0.860*		
Uptake of nitrogen by rhizome ginger	and phosphate solubilizing power	0.930**		
Uptake of nitrogen by rhizome ginger	and ammoniacal nitrogen	0.950**		
Uptake of nitrogen by rhizome ginger	and nitrate nitrogen	0.812*		
Uptake of nitrogen by rhizome ginger	and available phosphorus	0.930**		
Uptake of nitrogen by rhizome ginger	and total nitrogen	0.870*		
Uptake of nitrogen by rhizome ginger	and uptake of phosphorus	0.870*		
Uptake of phosphorus by rhizome ginger	and total bacteria of rhizosphere soil	0.940**		
Uptake of phosphorus by rhizome ginger	and actinomycete population	0.850*		
Uptake of phosphorus by rhizome ginger	and phosphate solubilizing organisms	0.960**		
Uptake of phosphorus by rhizome ginger	and phosphate solubilizing power	0.940**		

Contd....

Uptake of phosphorus by rhizome ginger	and ammoniacal nitrogen	0.930**	0.811	0.917
Uptake of phosphorus by rhizome ginger	and nitrate nitrogen	0.870*		
Uptake of phosphorus by rhizome ginger	and available phosphorus	0.880*		
Uptake of phosphorus by rhizome ginger	and total nitrogen	0.820*		
Uptake of phosphorus by rhizome ginger	and uptake of nitrogen	0.870*		
Yield of rhizome ginger	and total bacteria of rhizosphere soil	0.960**		
Yield of rhizome ginger	and nitrogen fixing bacteria of rhizosphere soil	0.850*		
Yield of rhizome ginger	and phosphate solubilizing organisms of rhizosphere soil	0.950**		
Yield of rhizome ginger	and nitrogen fixing power	0.820*		
Yield of rhizome ginger	and phosphte solubilizing power	0.950**		
Yield of rhizome ginger	and ammoniacal nitrogen	0.960**		
Yield of rhizome ginger	and available phosphorus	0.980**		
Yield of rhizome ginger	and total nitrogen	0.950**		
Yield of rhizome ginger	and uptake of nitrogen	0.950**		
Yield of rhizome ginger	and uptake of phosphorus	0.820*		

* Significant at 5%.

** Significant at 1%.

Experiment No. 5 – Effect of FYM and inoculation of efficient nitrogen fixing and phosphate solubilizing bacteria on microbial and nutrient dynamics in the rhizosphere soil as well as performance of ginger in field.

A) Microbiological Analysis :

i) Enumeration of Microorganisms :

a) Total number of bacteria present in the rhizosphere soils of ginger in field :

Total number of bacteria present per gram dry rhizosphere soils of ginger are presented in table–33; fig. 25. The number of bacteria present in the rhizosphere of ginger was universally more than that present in the initial soil.

The treatments - M, MF, MFA, MFB and MFAB resulted in higher proliferation of bacteria as compared to that of control in the rhizosphere soils of ginger at all the growth stages. MF brought about an increase in the proliferation of bacteria as compared to that of M in the rhizosphere soils of ginger at each of the growth stage. MFA was superior to MF in relation to higher proliferation of bacteria from S_4 to S_6 stage. The reverse trend was true from S_1 to S_3 stage. On the other hand, MFB caused enhancement of bacterial population as compared to that of MFA at S_1, S_2, S_5 and S_6 stages. MFAB resulted in the highest proliferation of total bacteria at each growth stage among the added biotic and abiotic entities. However, the difference in between control and M as well as M and MF at S_5 at S_6 stages, MF and MFA form S_1 to S_3 stage, MFA and MFB from S_1 to S_2 and then S_4 to S_6 stages and MFB as well as MFAB at S_5 and S_6 stage was not significant by DMRT.

The population of bacteria in the rhizosphere soils of ginger under control, M, MF, MFA, MFB and MFAB progressively increased from S_1 to S_4 stage which , thereafter, gradually decreased up to S_6 stage.

TABLE–33 : Total number of bacteria present in the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in field experiment.

Treatment	Number of bacteria (CFU x 10^5) g^{-1} dry soils (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++62.90^{d}	99.86^{d}	159.73^{e}	171.05^{e}	156.46^{d}	109.20^{c}	126.53^{I}
+M	92.54^{c}	122.73^{c}	258.35^{d}	301.83^{d}	225.51^{cd}	153.34^{bc}	192.38^{D}
MF	180.10^{b}	194.59^{b}	382.03^{b}	378.17^{c}	298.38^{bc}	207.21^{b}	256.74^{C}
MFA	171.03^{b}	188.91^{b}	369.80^{b}	412.60^{b}	327.92^{ab}	290.19^{a}	293.40^{B}
MFB	183.87^{b}	191.43^{b}	350.80^{c}	407.82^{b}	338.36^{ab}	300.50^{a}	295.46^{B}
MFAB	220.12^{a}	247.47^{a}	402.01^{a}	466.66^{a}	394.73^{a}	303.02^{a}	339.00^{A}
Mean	151.76^{F}	174.16^{E}	320.45^{B}	356.35^{A}	290.22^{C}	227.24^{D}	
LSD at 5%	13.74	19.16	16.54	23.71	86.81	54.32	
at 1%	20.81	29.02	25.06	35.92	131.50	82.29	

		LSD at 5%	at 1%
For Stage	-	15.06	20.20
Treatment	-	15.06	20.20
Interaction (Stage x Treatment)	-	36.88	49.50

* Total number of bacteria in initial soil - 48.5 (CFU x 10^5) g^{-1} dry soil.

** See foot note Table-19

For + and ++ See foot note Table - 6

However, the difference in between S_1 and S_2 for M, S_1 and S_2 and then S_3 and S_4 for MF, S_1 and S_2 and then S_5 and S_6 stages for MFA and MFB as well as S_1 and S_2 for MFAB was not significant.

All in all, MFAB exerted the greatest enhancing influence on the bacteria in the rhizosphere soils of ginger followed by those of MFB, MFA, MF, M and control, respectively. However, the difference in between MFA and MFB was not statistically significant.

In general, the population of bacteria in the rhizosphere soils of ginger increased, on and on, from S_1 to S_4 stage which then gradually decreased up to S_6 stage.

b) Total number of actinomycetes present in the rhizosphere soils of ginger in field :

Proliferation of actinomycete population in ginger rhizosphere under field condition was universally more than that in the initial soil (table–34; fig. 26).

The treatments – M, MF, MFA, MFB and MFAB resulted in an increase in the population of actinomycete in the rhizosphere soils of ginger as compared to that of control at each growth stage. MFB caused higher proliferation of actinomycetes than that of M at S_1 and then from S_4 to S_6 stage. MFA brought about an enhancement in the abundance of actinomycete as compared to that of MFB at each growth stage. MF was superior to MFA in relation to higher proliferation of the cited organisms from S_2 to S_5 stage. MFAB induced the highest stimulation of actinomycete population in each growth stage in the rhizosphere soils of ginger. However, the difference in between control and M at S_1 stage, M and MF at all but S_4 and S_5 stages, MF and MFA at all but S_3 and S_5 stages as well as MFA and MFB at all the stages was not significant by DMRT.

The population of actinomycetes in the rhizosphere soils of ginger under M, MF, MFA and MFAB progressively increased from S_1 to

TABLE–34 : Total number of actinomycetes present in the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen-fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in field experiment.

Treatment	Number of actinomycetes (CFU x 10^4) g^{-1} dry soils (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++140.23^{d}	178.98^{c}	188.30^{e}	188.15^{d}	176.19^{d}	167.10^{d}	173.15^{D}
+M	157.45^{cd}	216.40^{b}	228.78^{bc}	239.90^{c}	245.48^{c}	223.58^{c}	218.59^{C}
MF	182.79^{bc}	222.97^{b}	233.91^{b}	257.61^{b}	285.61^{b}	243.26^{bc}	237.69^{B}
MFA	205.41^{b}	208.36^{b}	215.72^{cd}	247.47^{bc}	268.07^{c}	263.81^{ab}	234.14^{B}
MFB	200.24^{b}	189.54^{bc}	200.37^{de}	241.26^{bc}	261.63^{c}	261.99^{bc}	227.50^{BC}
MFAB	267.29^{a}	310.60^{a}	320.31^{a}	342.94^{a}	343.98^{a}	327.64^{a}	318.79^{A}
Mean	192.56^{D}	221.14^{C}	231.23^{B}	254.55^{A}	246.82^{A}	247.89^{A}	
LSD at 5%	24.46	26.28	16.45	16.21	17.30	53.25	
at 1%	37.05	39.80	24.91	24.55	26.20	80.67	

		LSD at 5%	at 1%
For Stage	-	9.73	13.04
Treatment	-	9.73	13.04
Interaction (Stage x Treatment)	-	23.82	31.98

* Total number of actinomycetes in initial soil - 98.0 (CFU x 10^4) g^{-1} dry soil.

For **, + and ++ See foot note Table - 6

NS-Non significant.

S_4 stage which then gradually decreased up to S_6 stage. On the other hand, the cited organisms under the influence of MFB decreased at S_2 and, thereafter, increased up to S_6 stage. However, the population of actinomycetes under control progressively increased from S_1 to S_3 and then decreased gradually at the final harvest. The difference in between S_2 and S_3, S_3 and S_4, S_4 and S_5 as well as S_5 and S_6 stages for M, S_1 and S_2, S_2 and S_3 as well as S_3 and S_4 stages for MF, S_2 and S_3 and then S_4 and S_5 stages for MFA, S_1 and S_2, S_2 and S_3, S_4 and S_5, S_5 and S_6 stages for MFB as well as S_2 and S_3, S_4 and S_5, S_5 and S_6 for MFAB was not significant.

All in all, MFAB clubbed maximum number of actinomycete in the rhizosphere soils of ginger followed by those of MF, MFA, MFB, M and control, respectively. However, the difference among MF, MFA and MFB was not significant.

In general, actinomycetes population progressively increased from S_1 to S_4 stage which, thereafter, reduced up to S_6 stage. However, the difference among S_4, S_5 and S_6 stages was not significant.

c) Total number of fungi present in the rhizosphere soils of ginger in field :

Total number of fungi present per gram dry rhizosphere soils of ginger was universally more than that present in the initial soil (table–35; fig. 27).

The treatments - M and MF brought about an increased in fungal propagules as compared to that of control in the rhizosphere soils of ginger at each growth stage. In this respect MF resulted in higher proliferation of fungi than that of M at every growth stage. MFAB was superior to control in relation to the proliferation of fungi in each but S_3 stage. However, the cited treatment resulted in lower proliferation of fungi as compared to that of control from S_2 to S_6 stage whereas MFB brought about adverse effect on fungi from S_1 to S_6 stage. The impact of MFA was more deleterious

TABLE–35 : **Total number of fungi present in the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in field experiment.***

Treatment	Number of fungi (CFU x 10^4) g^{-1} dry soils (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++58.97^{c}	69.38^{b}	79.86^{c}	88.81^{cd}	72.10^{b}	55.91^{ab}	70.83^{D}
+M	77.76^{a}	90.43^{a}	95.11^{b}	99.73^{ab}	77.31^{b}	57.34^{ab}	82.94^{B}
MF	84.00^{a}	100.91^{a}	106.56^{a}	104.06^{a}	93.41^{a}	66.84^{a}	92.63^{A}
MFA	63.66^{bc}	66.75^{b}	67.00^{e}	75.75^{e}	67.95^{b}	48.99^{b}	65.01^{E}
MFB	58.66^{c}	66.74^{b}	69.90^{d}	85.85^{d}	71.06^{b}	54.28^{ab}	67.74^{DE}
MFAB	69.18^{b}	70.70^{b}	78.51^{cd}	93.58^{bc}	81.45^{ab}	70.07^{a}	77.24^{C}
Mean	68.70^{D}	77.48^{C}	82.82^{B}	91.29^{A}	77.21^{C}	58.90^{E}	
LSD at 5%	6.28	11.92	8.70	7.24	14.14	15.67	
at 1%	9.50	18.05	13.17	10.96	NS	NS	

		LSD at 5%	at 1%
For Stage	-	3.80	5.09
Treatment	-	3.80	5.09
Interaction (Stage x Treatment)	-	9.30	12.47

* Total number of fungi in initial soil - 25.2(CFU x 10^4) g^{-1} dry soil.

** See foot note Table-19

For + and ++ See foot note Table - 6

NS-Non significant.

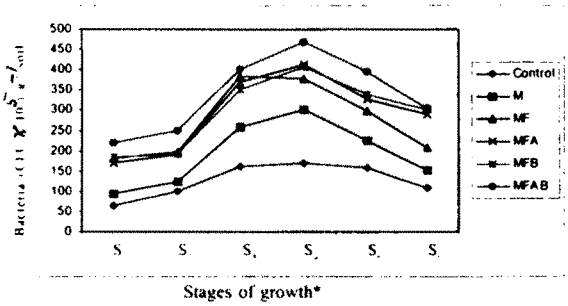


Fig. 25. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation of bacteria in the rhizosphere soils of ginger in field.

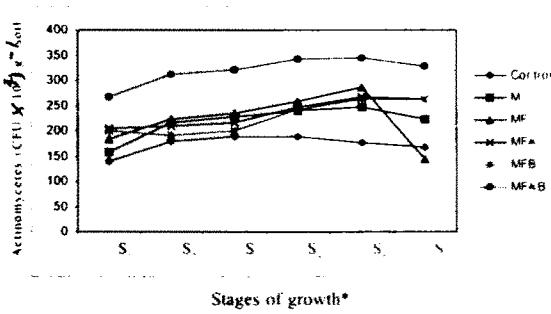


Fig. 26. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation of actinomycetes in the rhizosphere soils of ginger in field.

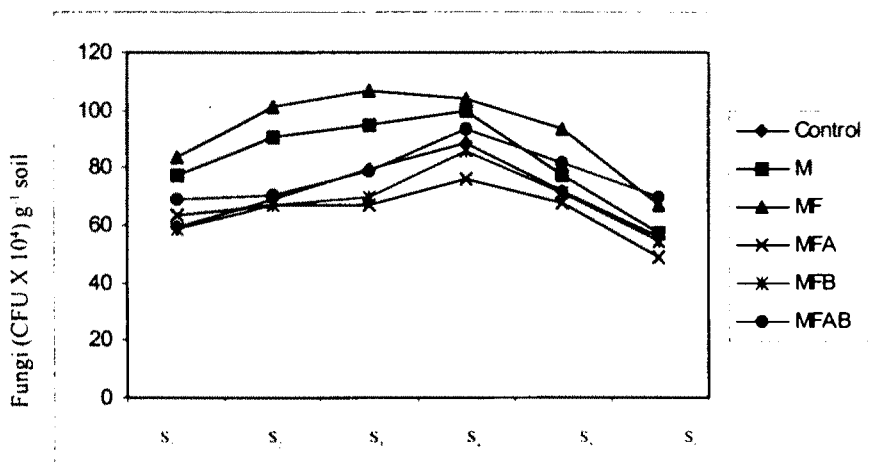


Fig. 27. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation of fungi in the rhizosphere of ginger in field.

* S_1 - S_6 = For ginger 30, 60, 90, 120, 150, 180 days after planting - at sprouting of rhizome, early emergence of pseudostem, late emergence of pseudostem, full growth of pseudostem, near maturity of pseudostem and harvesting stage of ginger, respectively.

than that of MFB from S_3 to S_6 stage. However, the difference in between control and M at S_5 and S_6 stages, M and MF at all but S_3 and S_4 stages as well as MFB and MFAB at S_2, S_3, S_5 and S_6 stages was not significant by DBRT.

The population of fungi in the rhizosphere soils of ginger under control, M, MF, MFA, MFB and MFAB progressively increased from S_1 to S_4 stage which, thereafter, gradually decreased up to S_6 stage. However, the difference among S_2, S_3 and S_4 stages for M and MF, S_1 and S_2, S_2 and S_3 and then S_4 and S_5 stages for MFA, S_1 and S_2 and then S_2 to S_3 for MFB and MFAB was not significant.

All in all, MF caused the highest stimulation of fungi in the rhizosphere soils of ginger followed by those under M, MFAB, control, MFB and MFA, respectively. However, the difference in between MFA and MFB was not significant.

In general, fungal propagules in the rhizosphere soils of ginger increased progressively from S_1 to S_4 stage followed by a gradual decrease up to S_6 stage.

d) Total number of aerobic non-symbiotic nitrogen - fixing bacteria present in the rhizosphere soils of ginger in field :

The rhizosphere soils of ginger entertained a greater number of nitrogen fixing bacteria as compared to that in initial soil (table–36; fig. 28).

The treatments - M, MF, MFA, MFB and MFAB brought about higher proliferation of aerobic non-symbiotic nitrogen fixing bacteria in the rhizosphere soils of ginger as compared to that of control at all the growth stages. MF resulted in increase in the number of bacteria as compared to that of M from S_1 to S_4 stage. On the other hand, the reverse trend was observed during S_5 and S_6 stages. MFB caused reduction in the number of aerobic non-symbiotic nitrogen fixing bacteria as compared to

TABLE–36 : **Total number of aerobic non-symbiotic nitrogen fixing bacteria present in the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in field experiment.***

Treatment	Number of nitrogen fixing bacteria (CFU x 10^4) g^{-1} dry soils (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++63.56^{d}	77.81^{d}	99.34^{c}	105.92^{c}	90.47^{c}	83.54^{c}	86.77^{D}
+M	84.00^{bc}	110.13^{c}	121.31^{b}	131.97^{b}	122.98^{b}	103.60^{b}	112.82^{C}
MF	89.88^{b}	111.45^{c}	124.09^{b}	135.64^{b}	112.83^{b}	91.07^{c}	110.82^{C}
MFA	71.97^{d}	142.76^{b}	168.37^{a}	179.78^{a}	159.78^{a}	139.79^{a}	143.74^{B}
MFB	82.08^{bc}	106.42^{c}	119.22^{b}	131.26^{b}	117.60^{b}	101.64^{b}	109.70^{C}
MFAB	113.20^{a}	156.56^{a}	172.11^{a}	188.46^{a}	154.13^{a}	140.15^{a}	154.10^{A}
Mean	84.11^{F}	117.52^{D}	134.07^{B}	145.50^{A}	126.29^{C}	109.96^{E}	
LSD at 5%	12.19	14.14	14.65	19.54	14.52	9.94	
at 1%	18.45	21.41	22.18	29.60	21.98	15.05	

		LSD at 5%	at 1%
For Stage	-	4.89	6.56
Treatment	-	4.89	6.56
Interaction (Stage x Treatment)	-	11.98	16.09

* Total number of aerobic non-symbiotic nitrogen fixing bacteria in initial soil - 48.8 (CFU x 10^4) g^{-1} dry soil.

** See foot note Table-19

For + and ++ See foot note Table - 6

that of MF from S_1 to S_4 stage. The reverse trend was observed at S_5 and S_6 stages. As such, MFA was superior to the cited additives from S_2 to S_6 stages. MFAB brought about the highest proliferation of aerobic non-symbiotic nitrogen fixing bacteria at each growth stage in the rhizosphere soils of ginger. However, the difference in between M and MF at all the stages, MF and MFA at S_6 stage, was not significant by DMRT.

The population of aerobic non-symbiotic nitrogen fixing bacteria under control, M, MF, MFA, MFB and MFAB progressively increased right from S_1 to S_4 stage which, thereafter, gradually decreased up to S_6 stage. However, the difference in between S_2 and S_4, S_3 and S_4, S_4 and S_5 for M, S_2 and S_3, S_3 and S_4 for MF, S_3 and S_4 for MFA, S_2 and S_3, S_3 and S_4, S_4 and S_5 for MFB, S_2 and S_3 and then S_5 and S_6 stage for MFAB was not significant.

All in all, MFAB induced in highest proliferation of aerobic non-symbiotic nitrogen fixing bacteria in the rhizosphere soils of ginger followed by those of MFA, M, MF, MFB and control, respectively. The difference among M, MF and MFB was, however, not significant.

In general, the count of aerobic non-symbiotic nitrogen fixing bacteria increased progressively in the rhizosphere soils of ginger from S_1 to S_4 stage which then decreased gradually up to S_6 stage.

e) Total number of phosphate solubilizing microorganisms present in the rhizosphere soils of ginger in field :

The proliferation of phosphate solubilizing microorganisms in the ginger rhizosphere soils were universally more than that in the initial soil (table–37; fig. 24).

The treatments - MF, MFA, MFB and MFAB resulted in higher proliferation of phosphate solubilizing microorganisms in the rhizosphere soils of ginger at all the growth stages as compared to that of control. Similar trend was exhibited by M in all but S_5 stage. MF brought about higher abundance of phosphate solubilizing microorganisms than that of

M at each growth stage. Though, MF was superior to MFA in relation to the proliferation of phosphate solubilizing organisms from S_1 to S_5 stage yet MFA brought about higher proliferation of the cited organisms than that of MF at S_6 stage. MFB induced enhancing influence on the proliferation of the said organisms as compared to that of MFA from S_1 to S_5 stage. As it were, MFAB induced maximum proliferation of phosphate solubilizing organisms at each growth stage in the rhizosphere soils of ginger. However, the difference in between control and M at all but stage, M and MF at S_1, S_2 and S_6 stages, MF and MFA as well as MFA and MFB at all the stages, MFB and MFAB from S_3 to S_6 stages was not significant by DMRT.

The population of phosphate solubilizing microorganisms in the rhizosphere soils of ginger under control, M, MF, MFA, MFB and MFAB progressively enhanced right from S_1 to S_4 stage which then declined gradually up to S_6 stage. However, the difference in between S_1 and S_2, S_2 and S_3, S_3 and S_4, S_5 and S_6 stages for M, S_2 and S_3, S_3 and S_4, S_4 and S_5 stages for MF, S_2 and S_3, S_3 and S_4, S_4 and S_5, S_5 and S_6 for MFA, S_3 and S_4, S_4 and S_5 for MFB, S_1 and S_2, S_2 and S_3 for MFAB was not significant.

All in all, MFAB produced maximum proliferation of phosphate solubilizing microorganisms in the rhizosphere soils of ginger followed by those of MFB, MFA, MF, M and control respectively. However, the difference in between MF and MFA as well as MFA and MFB was not significant.

In general, the proliferation of phosphate solubilizing organisms in the rhizosphere soils of ginger increased progressively from S_1 to S_4 stage and then decreased gradually up to S_6 stage.

TABLE–37 : **Total number of phosphate solubilizing organisms present in the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in field experiment.***

Treatment	Phosphate solubilizing organisms (CFU x 10^4) g^{-1} dry soils (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++82.56^{b}	97.92^{c}	98.05^{b}	105.26^{d}	83.67^{b}	78.28^{d}	90.95^{F}
+M	89.96^{b}	107.88^{bc}	113.32^{b}	122.85^{c}	83.11^{b}	94.06^{cd}	101.86^{D}
MF	94.45^{b}	141.05^{ab}	158.55^{a}	165.76^{b}	159.11^{a}	115.52^{bc}	139.073^{CD}
MFA	90.50^{b}	138.53^{ab}	157.74^{a}	167.29^{b}	158.97^{a}	139.44^{ab}	142.078^{BC}
MFB	96.09^{b}	139.16^{ab}	168.22^{a}	178.29^{ab}	161.72^{a}	127.66^{ab}	144.85^{B}
MFAB	138.32^{a}	155.92^{a}	168.34^{a}	187.17^{a}	165.41^{a}	143.93^{a}	159.848^{A}
Mean	98.64^{E}	129.74^{C}	144.04^{B}	154.43^{A}	149.44^{C}	116.20^{D}	
LSD at 5%	16.90	33.37	15.28	14.03	14.25	24.25	
at 1%	25.60	NS	23.15	21.25	21.58	36.72	

		LSD at 5%	at 1%
For Stage	-	7.07	9.49
Treatment	-	7.07	9.49
Interaction (Stage x Treatment)	-	17.32	23.25

* Phosphate solubilizing organisms in initial soil - 37.5 (CFU x 10^4) g^{-1} dry soil.

** See foot note Table-19

For + and ++ See foot note Table - 6

NS-Non significant.

ii) Transformations :

a) Nitrogen fixing power of the rhizosphere soils of ginger in field :

Amount of nitrogen fixed per gram dry rhizosphere soil per gram sucrose utilized are presented in table–38; fig. 30. The amount of nitrogen fixed by the ginger rhizosphere soils was universally greater than that of initial soil.

The treatments - M, MFA, MFB and MFAB increased the nitrogen fixing power of rhizosphere soils of ginger at all the growth stages as compared to that of control. This was true with MF from S_1 to S_3 and then from S_5 to S_6 stages. MFB brought about higher fixation of atmospheric nitrogen than that of MF from S_1 to S_5 stage. On the other hand, M was superior to MFB in relation to nitrogen fixation from S_1 to S_3 and then from S_5 to S_6 stages. However, MFA resulted in higher nitrogen fixing power than that of M from S_2 to S_6 stage. As such, MFAB brought about maximum nitrogen fixation as compared to other treatments at each growth stage in the rhizosphere soils of ginger. However, the difference in between control and M at all but S_1 and S_3 stages, M and MF at all but S_4 stage, MF and MFA at S_1, S_2 and S_6 stages, MFA and MFB at S_1 and S_2 stages was not significant by DMRT.

The nitrogen fixing power of rhizosphere soils of ginger under MF, MFA, MFB and MFAB increased progressively from S_1 to S_3 stage and then decreased gradually up to S_6. On the other hand, the nitrogen fixation under control increased , on and on, up to S_4 stage and then decreased gradually from S_4 to S_6 stage. As such, the amount of nitrogen fixed under M increased from S_2 to S_3 stage followed by gradual decreased up to S_6 stage. However, the difference in between S_1 and S_2 and then S_5 and S_6 stages for M, S_1 and S_2, S_4 to S_5 for MF, S_1 and S_2 for MFB and S_1 to S_3 and then S_5 and S_6 stages for MFAB was not significant.

All in all, MFAB induced the highest nitrogen fixing power of the rhizosphere soils of ginger followed by those of MFA, M, MFB, MF

TABLE–38 : Nitrogen fixing power of the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in field experiment.*

Treatment	Amount of nitrogen fixed in mg g^{-1} sucrose g^{-1} dry soils (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	**10.76^{d}	11.78^{b}	12.13^{c}	12.70^{cd}	11.44^{b}	10.34^{c}	11.52^{D}
+M	12.90^{bc}	12.90^{b}	15.26^{b}	13.20^{bc}	12.11^{b}	11.20^{bc}	12.92^{C}
MF	11.59^{cd}	12.12^{b}	14.12^{b}	12.20^{d}	11.50^{b}	10.88^{bc}	12.06^{D}
MFA	12.40^{bc}	14.18^{b}	16.46^{a}	14.92^{a}	13.17^{a}	11.86^{ab}	13.84^{B}
MFB	12.03^{cd}	12.82^{b}	15.04^{b}	13.38^{b}	12.06^{b}	10.22^{c}	12.59^{C}
MFAB	16.41^{a}	16.69^{a}	17.24^{a}	15.10^{a}	13.32^{a}	12.52^{a}	15.04^{A}
Mean	12.69^{C}	13.41^{B}	15.04^{A}	13.58^{B}	12.26^{D}	11.17^{E}	
LSD at 5%	1.36	1.57	1.05	0.52	1.11	1.11	
at 1%	2.06	2.38	1.59	0.78	NS	NS	

		LSD at 5%	at 1%
For Stage	-	0.40	0.54
Treatment	-	0.40	0.54
Interaction (Stage x Treatment)	-	0.99	1.32

* Nitrogen fixing power of initial soil - 9.56 mg N_2 g^{-1} soil g^{-1} sucrose.

** See foot note Table-19

For + and ++ See foot note Table - 6

NS-Non significant.

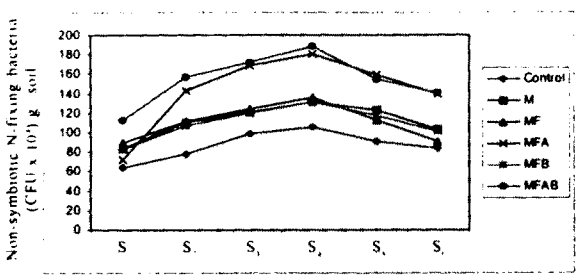


Fig. 28. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferatioin aerobic non-symbiotic nitrogen fixing bacteria in the rhizosphere soils of ginger in field.

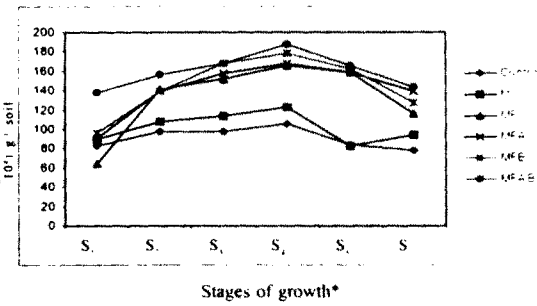


Fig. 29. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation of phosphate solubilizing microorganisms in the rhizosphere soils of ginger in field.

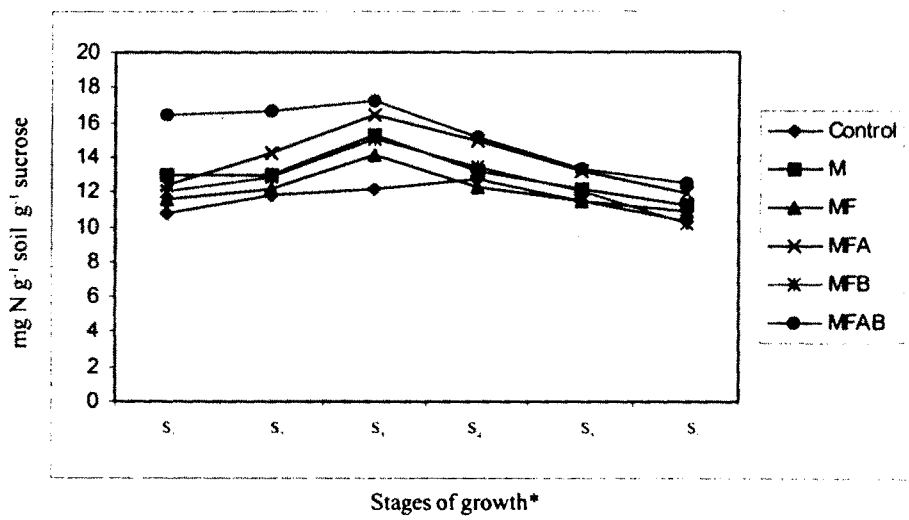


Fig. 30. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the nitrogen fixing power of rhizosphere soils of ginger in field.

* S_1 - S_6 = For ginger 30, 60, 90, 120, 150, 180 days after planting - at sprouting of rhizome, early emergence of pseudostem, late emergence of pseudostem, full growth of pseudostem, near maturity of pseudostem and harvesting stage of ginger, respectively.

and control, respectively. However, in difference in between M and MFB was not significant.

In general, with the age of crop, the nitrogen fixing power in the ginger rhizosphere increased from S_1 to S_3 stage and then decreased up to S_6 stage.

b) Phosphate solubilizing power of the rhizosphere soils of ginger in field:

Table–39; fig. 31 shows the average of amount of insoluble phosphorus solubilized by one gram of rhizosphere soils after 7 and 10 days incubation, in mg per 15 mg insoluble phosphorus per 0.15 gram sucrose utilized. The rhizosphere of ginger, in general, solubilized a greater amount of soluble phosphorus as compared to the initial soils.

The treatments - M, MF, MFA, MFB and MFAB exerted an increase in phosphate solubilizing power of soils as compared to that of control at each growth stage of ginger. In this respect, MFA exerted greater impact than that of M at every growth stage. MF was superior to MFA at each but S_4 stage in respect to solubilization of insoluble phosphate. On the other hand, MFB exerted higher enhancing influence on phosphate solubilization than that of MF from S_1 to S_5 stage. As such, MFAB induced the greatest influence on phosphate solubilizing power at every growth stage than those of others in the rhizosphere soils of ginger. However, the difference in between control and M at S_1, S_2 and S_4 stages M and MF at S_4 stage, MF and MFA as well as MFA and MFB at S_1, S_2 and S_4 stages, MFB and MFAB at S_4 stages was not significant by DMRT.

The phosphate solubilizing power of rhizosphere soils of ginger under control, MF, MFA, MFB and MFAB progressively increased from S_1 to S_4 stage which then decreased gradually with time up to S_6 stage. On the other hand, phosphate solubilizing power under the influence of M increased, on and on, from S_1 to S_5 stage and, thereafter, decreased up to S_6

TABLE–39 : **Phosphate solubilizing power of rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in field experiment.***

Treatment	Phosphorus solubilized in mg 15 mg^{-1} insoluble P[75 mg $Ca_3(PO_4)_2$] g^{-1} field soil 0.15 g^{-1} sucrose consumed (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_n	Mean
Control	++0.033^{c}	0.056^{c}	0.081^{f}	0.086^{c}	0.069^{e}	0.059^{f}	0.064^{D}
+M	0.034^{c}	0.082^{c}	0.119^{e}	0.149^{bc}	0.155^{d}	0.096^{e}	0.105^{C}
MF	0.044^{b}	0.130^{b}	0.182^{c}	0.265^{ab}	0.208^{b}	0.169^{b}	0.166^{B}
MFA	0.041^{bc}	0.112^{b}	0.170^{d}	0.320^{a}	0.186^{c}	0.153^{d}	0.163^{B}
MFB	0.048^{b}	0.144^{b}	0.192^{b}	0.351^{a}	0.210^{b}	0.164^{c}	0.184^{B}
MFAB	0.065^{a}	0.191^{a}	0.242^{a}	0.398^{a}	0.309^{a}	0.190^{a}	0.232^{A}
Mean	0.044^{F}	0.119^{E}	0.164^{C}	0.261^{A}	0.189^{B}	0.138^{D}	
LSD at 5%	.008	.035	.009	0.140	.013	0.004	
at 1%	0.012	0.053	0.014	NS	.020	.006	

		LSD at 5%	at 1%
For Stage	-	0.021	0.027
Treatment	-	0.021	0.027
Interaction (Stage x Treatment)	-	0.051	0.068

* Phosphate solubilizing power of initial soil - 0.025 mg 15 mg^{-1} insoluble P[75 mg $Ca_3(PO_4)_2$] g^{-1} field soil 0.15 g^{-1} sucrose.

** See foot note Table-19

For + and ++ See foot note Table - 6

NS-Non significant.

stage. However, the difference in between S_1 and S_2, S_3 to S_5 for M, S_2 and S_3 and then S_5 and S_6 for MF, MFA and MFB as well as S_2 and S_3 for MFAB was not significant.

All in all, MFAB induced maximum enhancing influence on phosphate solubilizing power of rhizosphere soils of ginger followed by those of MFB, MF, MFA, M and control, respectively. The difference among MF, MFA and MFB was, however, not significant.

In general, phosphate solubilizing power of rhizosphere soils of ginger increased, on and on, from the initiation to S_4 stage and then decreased gradually up to the harvesting stage.

Distribution of Predominant genera of microorganisms in the rhizosphere soils of ginger in field experiment :

The identification was made only up to the generic level for each of ten randomly selected isolates of total bacteria, actinomycetes, fungi, aerobic non-symbiotic nitrogen fixing and phosphate solubilizing bacteria.

a) Genera of bacteria present in the rhizosphere soils of ginger :

The predominant genera of bacteria in the ginger rhizosphere soils under different treatments at two different growth stages are presented in table–40 . Perusal of results reveal that there were altogether ten genera of bacteria in the rhizosphere soils of ginger. *Bacillus* was the predominant genus followed by *Micrococcus* and *Azotobacter*, respectively. Besides them *Arthobacter, Pseudomonas, Flavobacterium, Brevibacterium, Staphylococcus, Rhodospirillum* and *Erwinia* were also present in the rhizosphere soils of ginger. Initial soil maintained five genera of bacteria namely *Arthobacter, Bacillus, Pseudomonas, Micrococcus* and *Staphylococcus*. Among them *Bacillus* was the dominant genus. Control soils harboured *Azotobacter* at the expense of one *Pseudomonas* as compared to initial soil at S_4 stage. M resulted in reduction in the number of *Arthobacter, Micrococcus* and an increase of

Azotobacter as compared to control soil. On the other hand, MF exerted an enhancement of *Pseudomonas*, appearance of *Rhodospirillum* as well as *Erwinia* and the elimination of *Staphylococcus* in the rhizosphere soils of ginger at S_4 stage as compared to that of M. MFA brought about an increase in the number of *Bacillus* as well as *Azotobacter*, appearance of *Brevibacterium*, elimination of *Arthobacter* as well as *Rhodospirillum* and a reduction of *Pseudomonas* at S_4 stage as compared to that of MF. MFB caused an increase in the number of *Bacillus*, *Flavobacterium*, and *Brevibacterium*, resurgence of *Arthobacter* and *Rhodospirillum* as well as elimination of *Pseudomonas* and *Micrococcus* in the ginger rhizosphere at S_4 stage as compared to that of MFA. MFAB increased the number of *Bacillus* and *Azotobacter*, decreased the number of *Brevibacterium*, eliminated *Flavobacterium* and *Rhodospirillum* while adding two genera - one each of *Pseudomonas* and *Micrococcus* in the rhizosphere soil of ginger at S_4 stage as compared to that of MFB.

All in all, the control soil harboured more number of *Arthobacter* and *Micrococcus*. On the other hand, MFB resulted in the greatest enhancing influence on *Flavobacterium* and *Brevibacterium*. However, MF, MFA and MFAB caused the highest stimulation of *Pseudomonas* *Azotobacter* and *Bacillus*, respectively at S_4 stage in the rhizosphere soils of ginger.

In control soil, one each of *Arthobacter* and *Bacillus* were compensated with one each of *Flavobacterium* and *Brevibacterium* at S_6 stage as compared to S_4 stage. M resulted in decrease in the number of *Bacillus* and *Azotobacter*, elimination of *Arthobacter*, increase in *Micrococcus* and resurgence of *Brevibacterium* at S_6 stage as compared to S_4 stage. On the other hand, MF increased the number of *Arthobacter*, *Bacillus* and *Micrococcus*, decrease in the number of *Pseudomonas* and eliminated *Azotobacter* and *Rhodospirillum* while making an impact on the resurgence of *Staphylococcus* at S_6 stage as compared to S_4 stage. MFA increased in the number of *Flavobacterium*, decreased *Eacillus* and

TABLE–40. Distribution of the predominant genera of viable bacteria and actinomycetes in the rhizosphere soils of ginger as influenced by organic manure and inoculation of the efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in field experiment.

Genus	**Growth stage	* Number of strains					
		Control	+M	MF	MFA	MFB	MFAB
Arthobacter	FGS	2	1	1	-	1	1
	HS	1	-	2	1	-	-
Bacillus	FGS	3	3	1	2	3	4
	HS	2	1	2	1	1	1
Azotobacter	FGS	1	2	2	3	1	2
	HS	1	1	-	1	1	1
Pseudomonas	FGS	1	1	2	1	-	1
	HS	1	1	1	-	1	1
Flavobacterium	FGS	-	1	1	1	2	-
	HS	1	1	1	2	2	1
Rhodospirilum	FGS	-	-	1	-	1	-
	HS	-	-	-	-	-	-
Brevibacterium	FGS	-	-	-	1	2	1
	HS	1	1	-	1	1	2
Micrococcus	FGS	2	1	1	1	-	1
	HS	2	3	3	1	2	3
Erwinia	FGS	-	-	1	1	1	1
	HS	-	-	1	1	1	1
Staphylococcus	FGS	1	1	-	-	-	-
	HS	1	2	2	2	1	-
Actinomycetes *Nocardia*	FGS	2	4	3	5	3	2
	HS	4	5	2	5	4	5
Streptomyces	FGS	8	6	7	5	7	8
	HS	6	5	8	5	6	5

* Genera of bacteria -*Arthobacter*-2, *Bacillus*-3, *Pseudomonas*-2, *Micrococcus*-2, *Staphylococcus*-1 and actinomycetes- *Nocardia*-5, *Streptomyces*-5 in initial soil.

\+ See foot note Table - 6

** For FGS - 120 days after planting of rhizome of full growth stage of pseudostem. and HS - 180 days after planting of rhizome of harvesting stage.

Azotobacter as well as eliminated *Pseudomonas* while adding *Arthobacter* and *Staphylococcus* at S_6 stage as compared to S_4 stage. MFB brought about a reduction in the number of *Bacillus* as well as *Brevibacterium* and elimination *Arthobacter* and *Rhodospirillum* while inducing the resurgence of *Pseudomonas, Micrococcus* and *Staphylococcus* at S_6 stage as compared to S_4 stage. However, MFAB caused an increase in the proliferation of *Brevibacterium* and *Micrococcus*, a decrease in the number of *Bacillus* as well as *Azotobacter* and elimination of *Arthobacter* with the resurgence of *Flavobacterium* at S_6 stage as compared to S_4 stage.

b) Genera of actinomycetes in the rhizosphere soils of ginger :

Initial soil reared five strains each of *Nocardia* and *Streptomyces*. There was essentially no qualitative modification of actinomycetes distribution in the rhizosphere of ginger (table–40). Control soils reduced the number of *Nocardia* and increased the isolates of *Streptomyces* at S_4 stages as compared to initial soil in the ginger rhizosphere. M, MF, MFA and MFB resulted in increase in the number of *Nocardia* as compared to that of control. In this respect, MFA caused maximum stimulation on the said genera of actinomycetes followed by that of M at S_4 stage. On the other hand, M, MF, MFA and MFB brought about a decrease in the number of *streptomyces* isolates at S_4 stage as compared to that of control. In this respect, maximum reduction was brought about by MFA followed by that of M.

Control soil reared more of *Nocardia* and less of *Streptomyces* at S_6 stage as compared to S_4 stage in the rhizosphere soils of ginger. M, MFB and MFAB resulted in higher proliferation of *Nocardia* while MF caused a decrease in the number of the said isolates at S_6 stage as compared to S_4 stage. M, MFB and MFAB reduced the number of *Streptomyces* at S_6 stage as compared to S_4 stage whereas, MF increased the said genera.

c) Genera of fungi in the rhizosphere soils of ginger :

The predominant genera of fungi in the rhizosphere soils of ginger under different treatments are presented in table–41. The results show that altogether there were seven genera of fungi - *Aspergillus, Fusarium, Mucor, Penicillium, Trichoderma, Pythium* and *Phytophthora* in the ginger rhizosphere. Initial soil reared all but *Trichoderma*. Control soils harboured a fresh strain of *Phytophthora* with the addition of an isolates of *Fusarium* at the expense of one each of *Penicillium* and *Mucor*. As compared to control, there was an enhancing influence of MFAB on *Aspergillus*, and of MF on *Pythium* and *Fusarium*, M, MF, MFA, MFB and MFAB on *Penicillium* and regeneration of *Trichoderma* by MFA, MFB and MFAB at S_4 stage. On the other hand, there was a deleterious effect of MF on *Aspergillus*, of M and MFB on *Fusarium*, MFB on *Mucor* and elimination of *Fusarium* by MFA and MFAB, *Mucor* by MF and MFAB, *Pythium* by MFA as well as MFB and *Phytophthora* by M as compared to that of control.

There was a harmful influence of M, MFA, MFB and MFAB on *Aspergillus*, of control, M, MF and MFB on *Fusarium*, of M on Mucor, of MFA, MFB on *Trichoderma* and of MF and MFAB on *Pythium* at S_6 stage as compared to that of S_4 stage. On the other hand, there was a stimulating influence of MF, MFA and MFB on *Penicillium*, of M and MF on *Trichoderma*, of MFB on *Pythium* and of control and M on *Phytophthora* at S_6 stage as compared to that of S_4 stage in the rhizosphere soils of ginger.

d) Genera of nitrogen fixing bacteria in the rhizosphere soils of ginger :

Perusal of results reveal the relative distribution of aerobic non-symbiotic nitrogen fixing bacteria in the ginger rhizosphere (table–42). There were altogether three genera of non-symbiotic nitrogen fixing bacteria, namely *Azotobacter, Bacillus* and *Beijerinckia*, in the initial soil. Control soils reared one more strain of *Bacillus* at the expense of an isolate of *Beijerinckia* at S_4 stage in the rhizosphere soils of ginger. M, MFA, MFB and MFAB resulted in higher proliferation of *Azotobacter*. In this context

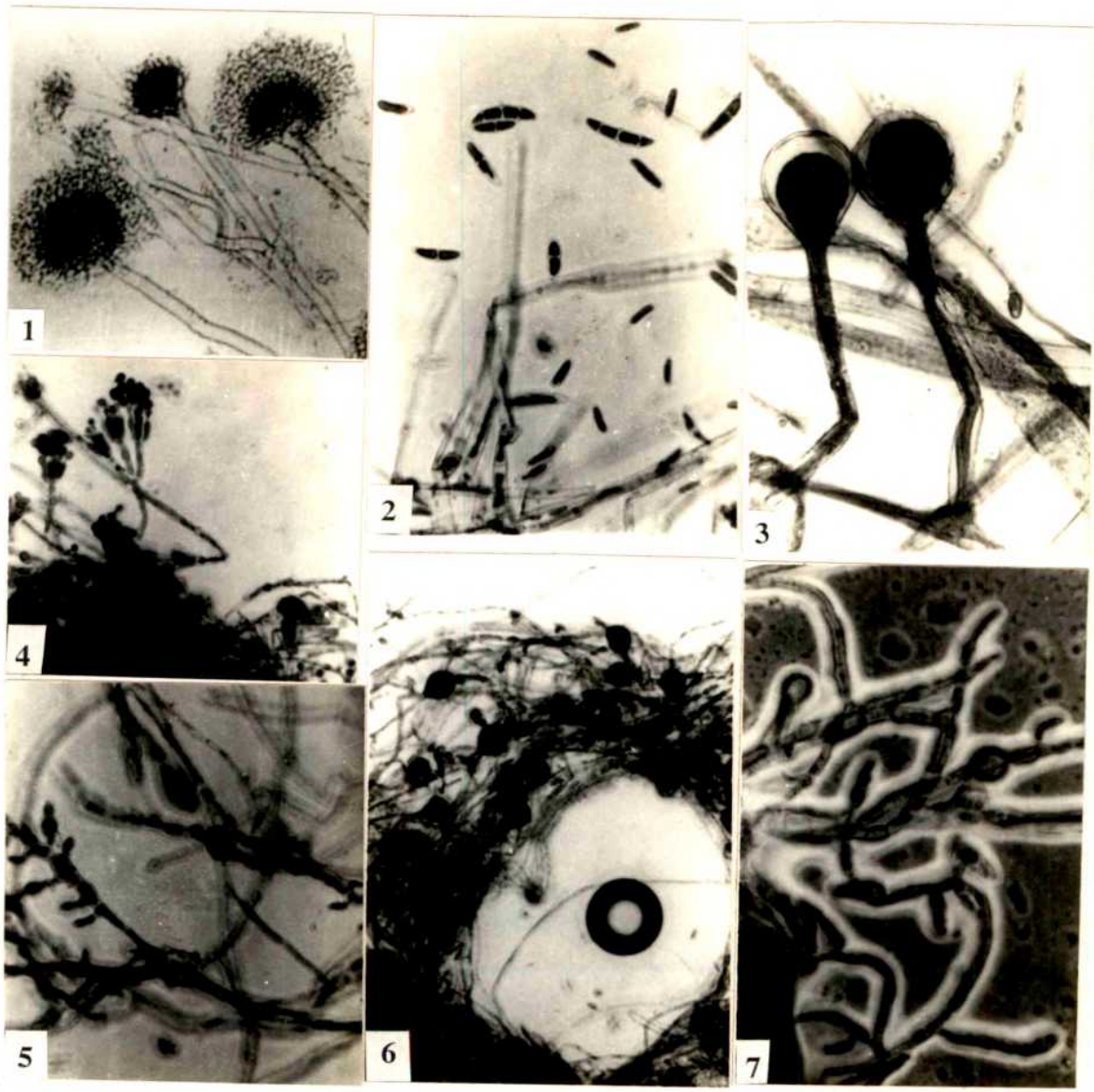
TABLE–41. Distribution of the predominant genera of fungi in the rhizosphere soils of ginger as influenced by organic manure and inoculation the efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in field experiment.

Genus	**Growth stage	* Number of strains					
		Control	+M	MF	MFA	MFB	MFAB
Aspergillus	RGS	2	2	1	2	2	3
	HS	2	1	1	1	1	1
Fusarium	RGS	3	2	4	-	2	-
	HS	1	1	2	1	1	1
Mucor	RGS	2	2	-	2	1	-
	HS	2	1	1	2	1	2
Penicillium	RGS	1	3	3	3	3	4
	HS	2	3	4	4	5	4
Trichoderma	RGS	-	-	-	2	1	1
	HS	-	1	1	1	-	1
Pythium	RGS	1	1	2	-	-	1
	HS	1	1	1	-	1	-
Phytophthora	RGS	1	-	1	1	1	1
	HS	2	2	1	1	1	1

* Genera of fungi in initial soil - *Aspergillus*-2, *Fusarium*-2, *Mucor*-3, *Penicillum*-2, *Pythium*-1.

\+ See foot note Table - 6

** See foot note Table - 40



Predominant genera of fungi in the rhizosphere soils of ginger.

Fig. 1 *Aspergillus* sp. (x 1200), Fig. 2 *Fusarium* sp. (x 1150), Fig. 3 *Mucor* sp. (x 1000), Fig. 4 *Penicillum* sp. (x 1225), Fig. 5 *Trichoderma* sp. (x 1250), Fig. 6 *Pythium* sp. (x 1300), Fig. 7 *Phytophthora* sp. (x 1170).

MFA and MFAB exerted similar influence in relation to the enhancement of the proliferation of the said genera to the highest extent followed by those of M and MFB, respectively. On the other hand, M, MF, MFA, MFB and MFAB exerted deleterious influence on the proliferation of *Bacillus*. As it were, MFB was superior to the others in relation to the proliferation of the said genera. M and MF caused enhancement of the isolates of *Beijerinckia* while MFA and MFB reduced the said isolates and MFAB brought about complete elimination of the said genera from the rhizosphere soils of ginger at S_4 stage. It is interesting to note that MF and MFAB induced the resurgence of *Klebsiella* at S_4 stage in the ginger rhizosphere. In this respect MF was superior to MFAB.

Control soils reared less of the *Azotobacter* and *Bacillus* isolates but more *Beijerinckia* and *Klebsiella* at S_6 stage as compared to that of S_4 stage in the rhizosphere soils of ginger. M, MF, MFA, MFB and MFAB resulted in reduction of *Azotobacter* isolates at S_6 stage as compared to S_4 stage. On the other hand, MF, MFA, MFB and MFAB caused higher proliferation of *Beijerinckia* at S_6 stage than that of S_4 stage. However, M, MF, MFA and MFAB brought about enhancing influence on *Bacillus* though, MFB induced inimical influence on the said genera at S_6 stage as compared to S_4 stage. As such, M caused resurgence of *Klebsiella* while MF induced negative influence on the said genera at S_6 stage as compared to that of S_4 stage.

e) Genera of phosphate solubilizing bacteria present in the rhizosphere soils of ginger :

There were altogether five genera of phosphate solubilizing bacteria namely *Arthobacter, Bacillus, Flavobacterium, Pseudomonas* and *Micrococcus* in the rhizosphere soils of ginger (table–42). Among them, *Bacillus* was the dominant one. Initial soil reared only four genera of phosphate solubilizing bacteria namely *Arthobacter, Bacillus, Micrococcus* and *Pseudomonas*. Control soils reared one extra genera of *Flavobacterium*

TABLE–42. Distribution of the predominant genera of aerobic non-symbiotic nitrogen fixing and phosphate solubilizing bacteria in the rhizosphere soils of ginger as influenced by organic manure and inoculation the efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in field experiment.

Genus	**Growth stage	* Number of strains					
Nitrogen fixing bacteria		Control	+M	MF	MFA	MFB	MFAB
Azotobacter	PGS	3	5	3	7	4	7
	HS	2	2	2	4	3	4
Bacillus	PGS	5	2	2	2	4	2
	HS	4	4	3	3	3	3
Beijerinkia	PGS	2	3	3	1	2	-
	HS	3	3	4	3	4	2
Klebsiella	PGS	-	-	2	-	-	1
	HS	1	1	1	-	-	1
Phosphate solubilizing bacteria							
Arthobacter	PGS	2	2	3	4	-	-
	HS	2	2	3	3	-	-
Bacillus	PGS	2	3	3	3	5	6
	HS	2	2	2	3	3	2
Flavobacterium	PGS	3	2	-	-	-	1
	HS	1	1	-	-	-	3
Pseudomonas	PGS	2	1	3	1	3	2
	HS	2	2	3	2	4	3
Micrococcus	PGS	1	2	1	2	2	1
	HS	3	3	2	2	3	2

* Genera of nitrogen fixing bacteria *Azotobacter*-3, *Bacillus*-4, *Beijerinckia*-3 and phosphate solubilizing *Arthobacter*-2, *Bacillus*-4, *Micrococcus*-3, *Pseudomonas*-1 in initial soil..

** See foot note Table - 40

\+ See foot note Table - 6

and enhanced the proliferation of *Pseudomonas* at the expense of two isolates of *Bacillus* and one isolate of *Pseudomonas* as compared to the initial soil. MF and MFA resulted in stimulation of *Arthobacter* while MFB and MFAB eliminated the same as compared to that of control. In this control MFA exerted the highest stimulating influences on the said genera. On the other hand, M, MF, MFA, MFB and MFAB brought about enhancement of *Bacillus* strains. In this respect MFAB was superior to MFB. M and MFAB exerted deleterious influence on *Flavobacterium* strain while MFA and MFB caused stimulating influence on *Pseudomonas*. However, M and MFA induced negative influence on the said genera at S_4 stage. M, MFA and MFB exerted stimulating influence on the strains of *Micrococcus* at S_4 stage in the rhizosphere soils of ginger.

There was a deleterious influence of MF and MFA on *Arthobacter*, of M, MF, MFB and MFAB on *Bacillus* and of control and M on *Flavobacterium* at S_6 stage when compared with S_4 stage. On the other hand, there was a positive influence of MFAB on *Flavobacterium*, of MFA, MFB and MFAB on *Pseudomonas* and of control, M, MF, MFB and MFAB on *Micrococcus* at S_6 stage as compared to that of S_4 stage.

B) Chemical Analysis :

a) Organic carbon content of the rhizosphere soils of ginger in field :

Organic carbon content of the rhizosphere soils of ginger was more as compared to that of the initial soil with the exception of that under control where in organic carbon content was less than that of the initial soil (table–43; fig. 32).

Perusal of results reveal that the treatments - M, MF, MFA, MFB and MFAB resulted in an increase in the content of organic carbon in the rhizosphere soils ginger as compared to that of control at all the growth stages. MFA exerted greater influence than that of MFAB in relation to retention of organic carbon in rhizosphere soils at each growth stage of

TABLE–43 : Organic content of the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in field experiment.*

Treatment	Organic carbon content (%) (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++0.657 #(0.810)^{d}	0.611 (0.782)^{c}	0.607 (0.779)^{d}	0.603 (0.777)^{c}	0.594 (0.771)^{c}	0.553 (0.744)^{c}	0.613 (0.786)^{I}
+M	1.039 (1.019)^{a}	1.010 (1.005)^{a}	0.960 (0.980)^{a}	0.960 (0.980)^{a}	0.919 (0.958)^{a}	0.906 (0.952)^{a}	0.965 (0.982)^{A}
MF	0.873 (0.934)^{b}	0.796 (0.892)^{b}	0.791 (0.889)^{b}	0.777 (0.881)^{b}	0.761 (0.872)^{b}	0.744 (0.862)^{b}	0.790 (0.889)^{B}
MFA	0.811 (0.900)^{bc}	0.780 (0.883)^{b}	0.762 (0.873)^{bc}	0.725 (0.851)^{b}	0.741 (0.845)^{b}	0.663 (0.814)^{bc}	0.742 (0.861)^{C}
MFB	0.793 (0.891)^{bc}	0.780 (0.883)^{b}	0.767 (0.876)^{bc}	0.741 (0.861)^{b}	0.717 (0.847)^{b}	0.682 (0.826)^{b}	0.746 (0.864)^{C}
MFAB	0.748 (0.866)^{cd}	0.698 (0.835)^{bc}	0.680 (0.824)^{c}	0.680 (0.839)^{b}	0.650 (0.832)^{bc}	0.615 (0.804)^{bc}	0.678 (0.836)^{D}
Mean	0.825 (0.907)^{AB}	0.779 (0.880)^{B}	0.761 (0.873)^{BC}	0.747 (0.865)^{BC}	0.725 (0.854)^{CD}	0.693 (0.834)^{D}	
^LSD at 5%	0.050	0.060	0.040	0.040	0.062	0.060	
at 1%	0.075	0.094	0.062	0.060	0.094	0.092	

		LSD at 5%	at 1%
For Stage	-	0.018	0.246
Treatment	-	0.018	0.246
Interaction (Stage x Treatment)	-	NS	

* Organic carbon content in initial soil - 0.666% (0.816)
** See foot note Table-19
For + and ++ See foot note Table - 6
For # and ^ See foot note Table-13
NS-Non significant.

ginger. On the other hand, MFB exerted greater effect in increasing the content of organic carbon than that MFA. The treatment MF was superior to MFB in relation to the content of organic carbon in rhizosphere soils. As such, M increased the content of organic carbon to the highest extent in each growth stage in the rhizosphere soils of ginger. However, the difference in between control and M as well as M and MF was only significant by DMRT.

The organic carbon content in the rhizosphere soils of ginger under control, MF, MFA and MFB gradually decreases right from the beginning to final stage. On the other hand, the content of the same under M and MFAB decreased from S_1 to S_3 stage and than from S_4 to S_6 stage. However, the difference among the stages under each treatment was not significant.

All in all, the treatment M resulted in an increase in the content of organic carbon in the rhizosphere soils of ginger to the highest extent followed by those of MF, MFB, MFA, MFAB and control, respectively. The difference in between MFA and MFB was, however, not significant.

In general, the content of organic carbon in the ginger rhizosphere soils decreased gradually from S_1 to S_6 stage.

b. Total nitrogen content of the rhizosphere soils of ginger in field :

Nitrogen content of the rhizosphere soils of ginger was more as compared to that of the initial soils with the exception of that under control at S_4, S_5 and S_6 stages where in nitrogen content was similar to that of initial soils (table–44; fig. 33).

The results pointed out that the treatments - MF, MFA, MFB and MFAB brought about an increase in the content of total nitrogen in the rhizosphere soils of ginger at all the growth stages as compared to that of control. The same trend was exhibited by M up to S_5 stage. MFB was superior to M in relation to the content of total nitrogen in the ginger

TABLE–44 : Nitrogen content of the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in field experiment.*

Treatment	Nitrogen content of rizosphere soils (%) (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++0.037 #(0.192)^{e}	0.034 (0.184)^{e}	0.032 (0.180)^{d}	0.030 (0.173)^{f}	0.030 (0.173)^{c}	0.030 (0.173)^{b}	0.032 (0.180)^{E}
+M	0.041 (0.202)^{d}	0.039 (0.197)^{d}	0.039 (0.197)^{c}	0.037 (0.194)^{e}	0.034 (0.184)^{c}	0.030 (0.173)^{b}	0.036 (0.191)^{E}
MF	0.046 (0.216)^{b}	0.045 (0.212)^{bc}	0.042 (0.205)^{bc}	0.042 (0.205)^{c}	0.040 (0.200)^{a}	0.037 (0.192)^{ab}	0.042 (0.207)^{C}
MFA	0.051 (0.227)^{a}	0.045 (0.213)^{b}	0.045 (0.212)^{b}	0.044 (0.210)^{b}	0.041 (0.202)^{b}	0.040 (0.200)^{a}	0.043 (0.211)^{B}
MFB	0.044 (0.210)^{c}	0.043 (0.207)^{c}	0.041 (0.204)^{bc}	0.040 (0.200)^{d}	0.040 (0.201)^{b}	0.038 (0.195)^{a}	0.041 (0.203)^{D}
MFAB	0.052 (0.229)^{a}	0.049 (0.221)^{a}	0.049 (0.221)^{a}	0.048 (0.219)^{a}	0.045 (0.213)^{a}	0.043 (0.207)^{a}	0.047 (0.219)^{A}
Mean	0.045 (0.213)^{A}	0.042 (0.206)^{B}	0.041 (0.203)^{BC}	0.040 (0.200)^{CD}	0.038 (0.198)^{D}	0.036 (0.190)^{E}	
^LSD at 5%	0.0046	0.0054	0.010	0.002	0.010	0.019	
at 1%	0.0068	0.0078	0.015	0.003	0.017	0.026	

		LSD at 5%	at 1%
For Stage	-	0.0037	0.024
Treatment	-	0.0037	0.024
Interaction (Stage x Treatment)	-	NS	

* Nitrogen content in initial soil - 0.03% (0.173)
** See foot note Table-19
For + and ++ See foot note Table - 6
For # and ^ See foot note Table-13
NS-Non significant.

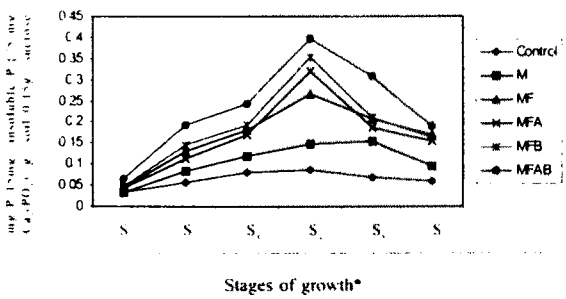


Fig. 31. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the phosphate solubilizing power of rhizosphere of zinger in field.

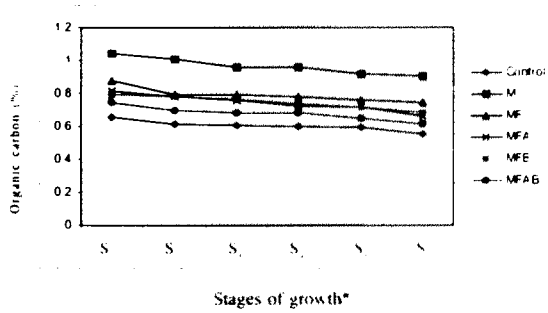


Fig. 32. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the content of organic carbon of rhizosphere soils of ginger in field.

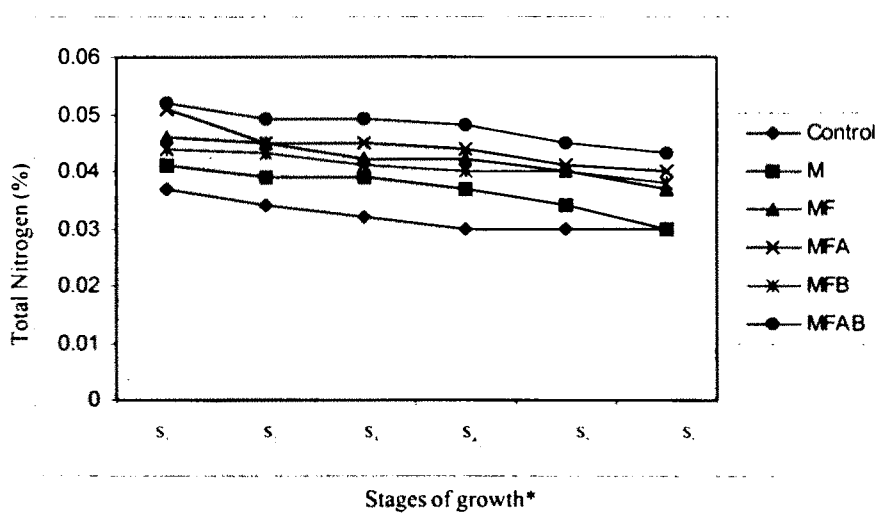


Fig. 33. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the content of total nitrogen of rhizosphere soils of ginger in field.

* S_1 - S_6 = For ginger 30, 60, 90, 120, 150, 180 days after planting - at sprouting of rhizome, early emergence of pseudostem, late emergence of pseudostem, full growth of pseudostem, near maturity of pseudostem and harvesting stage of ginger, respectively.

rhizosphere. On the other hand, MF resulted in greater increase in the content of total nitrogen than that of MFB from S_1 to S_4 stage. However, MFA was superior to MF in each but S_2 stage in respect to the content of total nitrogen in soils. As such, MFAB augmented in total nitrogen content of rhizosphere soils of ginger to the highest extent at each growth stage. The difference in between control and M at S_5 and S_6, M and M and MF at S_3 and S_6, MF and MFA at S_2, S_3 and S_6, MFA at S_3, S_5 and S_6, MFB and MFAB at S_6 stage was, however, not significant by DMRT.

The total nitrogen content of the rhizosphere soils of ginger under control, M, MF, MFA, MFB and MFAB exhibited a slow decreasing tendency with time. However, the difference among the stagers under each treatment was not significant.

All in all, MFAB increased the content of total nitrogen in the rhizosphere soils of ginger to the highest extent followed by those of MFA, MF, MFB, M and control, respectively.

In general, the content of total nitrogen decreased gradually from S_1 to S_6 stage in the rhizosphere soils of ginger.

c) Ammoniacal - nitrogen content of the rhizosphere soils of ginger in field :

The results depicted in the table–45; fig. 34 indicate that there was an increase in the amount of ammoniacal - nitrogen in ginger rhizosphere as compared to that in initial soils with the exception of those under control and M from S_2 to S_6 stage.

Results reveal that the treatments - M, MF, MFA, MFB and MFAB brought about increase in the control of ammoniacal nitrogen in ginger rhizosphere as compared to that of control. MFB resulted in enhancement in the content of ammoniacal nitrogen in soils as compared to that of M at each growth stage of ginger. MFA was superior to MFB in relation to the content of the same in soils at all the growth stages of ginger. On the other

TABLE–45 : **Amount of ammoniacal-nitrogen of the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in field experiment.***

Treatment	Amount of ammoniacal-nitrogen (mg $100g^{-1}$ dry soils) (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++3.24	2.91^{c}	2.85^{c}	2.79^{c}	2.21^{d}	2.10^{d}	2.68^{D}
+M	4.38	2.99^{c}	2.95^{c}	2.84^{c}	2.83^{c}	2.80^{c}	3.13^{D}
MF	4.76	4.67^{b}	4.57^{b}	4.20^{b}	3.91^{b}	3.61^{ab}	4.29^{B}
MFA	4.59	4.68^{b}	4.43^{b}	4.08^{b}	3.78^{bc}	3.51^{ab}	4.17^{BC}
MFB	4.06	4.43^{b}	4.32^{c}	4.06^{b}	3.34^{cd}	3.20^{bc}	3.90^{C}
MFAB	4.99	5.37^{a}	5.40^{a}	5.29^{a}	4.84^{a}	3.93^{a}	4.97^{A}
Mean	4.34	4.18^{AB}	4.09^{B}	3.88^{B}	3.49^{C}	3.19^{C}	
LSD at 5%	NS	0.65	0.64	0.83	0.55	0.57	
at 1%	NS	0.98	0.96	1.25	0.82	0.86	

		LSD at 5%	at 1%
For Stage	-	0.32	0.42
Treatment	-	0.32	0.42
Interaction (Stage x Treatment)	-	NS	NS

* Ammonium-nitrogen in initial soil - 3.12 mg $100g^{-1}$ soil.

** See foot note Table-19

For + and ++ See foot note Table - 6

NS-Non significant.

hand, MF brought about in higher increase in the content of ammoniacal - nitrogen at each but S_2 stage. Above all, MFAB exerted the highest retention of ammoniacal - nitrogen in the rhizosphere soils of ginger at in all the growth stages. However, the difference in between control and M at S_5 and S_6, M and MF as well as MFB and MFAB from S_2 to S_6 was only significant by DMRT.

The ammoniacal - nitrogen content in the rhizosphere soils of ginger under control, M and MF decreased gradually from S_1 to S_6 stage. On the other hand, the content of the same under MFA and MFB increased from S_1 to S_2 and then gradually decreased up to S_6 stage. However, the ammoniacal nitrogen under the treatment MFAB increased progressively from S_1 to S_3 and, thereafter, decreased up to S_6 stage. The difference among the stages under each treatment was, however, not significant.

All in all, MFAB brought about maximum accumulation of ammoniacal - nitrogen in the rhizosphere soils of ginger followed by those of MF, MFA, MFB, M and control, respectively. However, the difference in between MF and MFA as well as MFA and MFB was not significant.

In general, the ammoniacal - nitrogen content of rhizosphere soils of ginger reduced gradually from S_1 to S_6 stage.

d) Nitrate - nitrogen content of the rhizosphere soils of ginger in field :

Table–46; fig. 35 shows that there was higher accumulation of nitrate - nitrogen content in ginger rhizosphere soils as compared to that found in the initial soil.

The treatments - M, MF, MFA, MFB and MFAB resulted in higher retention of nitrate - nitrogen than that of control in the rhizosphere soils of ginger at each growth stage. MF resulted in higher accumulation of the same than that of MFA from S_3 to S_5 stage. On the other hand, MFB brought about higher accumulation of nitrate - nitrogen than that of M from S_1 to S_4 stage and then at S_6 stage. As such, MFAB resulted in the highest retention

TABLE–46 : Nitrate-nitrogen content of the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in field experiment.*

Treatment	Amount of nitrate nitrogen (mg 100g^{-1} dry soils) (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++2.094^{b}	2.088^{d}	2.100^{d}	2.186^{c}	2.300^{b}	2.240^{c}	2.168^{D}
+M	2.324^{b}	2.352^{c}	2.550^{bc}	2.576^{bc}	2.607^{b}	2.310^{bc}	2.453^{C}
MF	2.324^{b}	2.352^{c}	2.408^{cd}	2.522^{bc}	2.607^{b}	2.500^{bc}	2.452^{C}
MFA	2.376^{b}	2.464^{c}	2.128^{d}	2.253^{c}	2.399^{b}	2.716^{bc}	2.389^{C}
MFB	2.632^{b}	2.810^{b}	2.786^{b}	2.716^{b}	2.578^{b}	2.828^{b}	2.725^{B}
MFAB	3.220^{a}	3.268^{a}	3.392^{a}	3.485^{a}	3.660^{a}	3.680^{a}	3.450^{A}
Mean	2.490^{C}	2.555^{BC}	2.560^{BC}	2.620^{ABC}	2.691^{AB}	2.712^{A}	
LSD at 5%	0.525	0.230	0.310	0.340	0.440	0.530	
at 1%	NS	0.350	0.460	0.500	0.660	0.800	

		LSD at 5%	at 1%
For Stage	-	0.140	0.180
Treatment	-	0.140	0.180
Interaction (Stage x Treatment)	-	NS	NS

* Nitrate-nitrogen in initial soil - 2.05 mg 100g^{-1} soil.

** See foot note Table-19

For + and ++ See foot note Table - 6

NS-Non significant.

of the same in the ginger rhizosphere soils at all the growth stages. However, the difference in between control and M at S_2 and S_3, MFA and MFB from S_2 to S_4 as well as MFB and MFAB at all the stage was only significant by DMRT.

The nitrate - nitrogen content in the rhizosphere soils of ginger under M and MF progressively increased from S_1 to S_5 stage and then decreased at S_6 stage. On the other hand, the content of nitrate - nitrogen under MFAB increased, on and on, from S_1 to S_6 stage. However, the content of the same in the rhizosphere soils of ginger under MFA and MFB decreased from S_2 to S_3 and from S_3 to S_5 stages, respectively and then the nitrate - nitrogen content increased progressively up to S_6 stage in their respective series. The control soil exhibited a fall, rise and fall in the content of the same from S_1 to S_2, S_2 to S_5 and S_5 to S_6 stages, respectively. However, the difference among the stages under each treatment was not significant.

All in all, MFAB increased the content of nitrate - nitrogen to the highest extent in the rhizosphere soils of ginger followed by those of MFB, M, MF, MFA and control, respectively. However, the difference among M, MF and MFA was not significant.

In general, the content of nitrate - nitrogen increased progressively from S_1 to S_4 stage and then decreased gradually up to at S_6 in the rhizosphere soils of ginger.

e) Available phosphorus content in the rhizosphere soils of ginger in field :

The figures represented in the table–47; fig. 36 show the amount of available phosphorus in ginger rhizosphere and it was more as compared to that in the initial soil with the exception of that under control from S_4 to S_6 stage.

The results show that the treatments - M, MF, MFA, MFB and MFAB increased the content of available phosphorus in the rhizosphere

TABLE–47 : **Available phosphorus content of the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in field experiment.***

Treatment	Available phosphorus content (mg kg^{-1} field soil) (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++5.35^{d}	5.15^{d}	5.04^{c}	4.75^{d}	4.67^{c}	4.45^{c}	4.90^{F}
+M	7.40^{c}	7.33^{c}	7.06^{b}	6.40^{c}	6.20^{b}	6.20^{b}	6.76^{D}
MF	9.57^{b}	8.86^{b}	8.82^{a}	8.20^{a}	7.70^{a}	7.45^{a}	8.43^{BC}
MFA	9.36^{b}	9.36^{ab}	8.53^{a}	7.64^{b}	7.64^{a}	7.58^{a}	8.35^{C}
MFB	9.83^{b}	9.54^{ab}	8.87^{a}	8.28^{a}	7.80^{a}	7.48^{a}	8.63^{B}
MFAB	10.56^{a}	10.08^{a}	9.39^{a}	8.23^{a}	7.86^{a}	7.53^{a}	8.93^{A}
Mean	8.67^{A}	8.38^{B}	7.95^{C}	7.25^{D}	6.96^{E}	6.78^{F}	
LSD at 5%	0.47	1.03	1.29	0.55	0.44	0.28	
at 1%	0.71	1.55	1.95	0.82	0.67	0.41	

		LSD at 5%	at 1%
For Stage	-	0.26	0.34
Treatment	-	0.26	0.34
Interaction (Stage x Treatment)	-	0.63	0.85

* Available phosphorus in initial soil - 5.0 mg kg^{-1} soil.

** See foot note Table-19

For + and ++ See foot note Table - 6

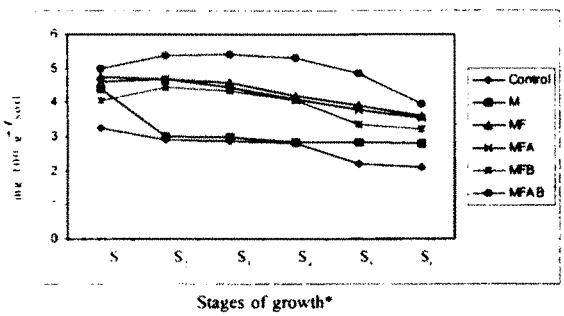


Fig. 34. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the content of ammoniacal-nitrogen of rhizosphere soils of ginger in field.

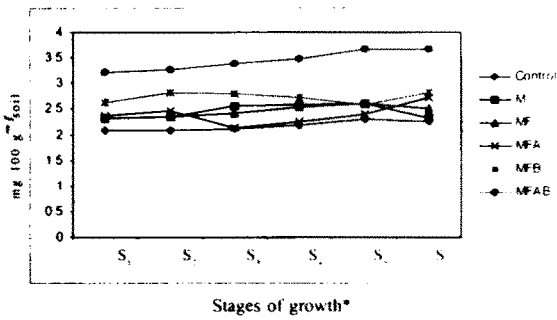


Fig. 35. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the content of nitrate-nitrogen of rhizosphere soils of ginger in field.

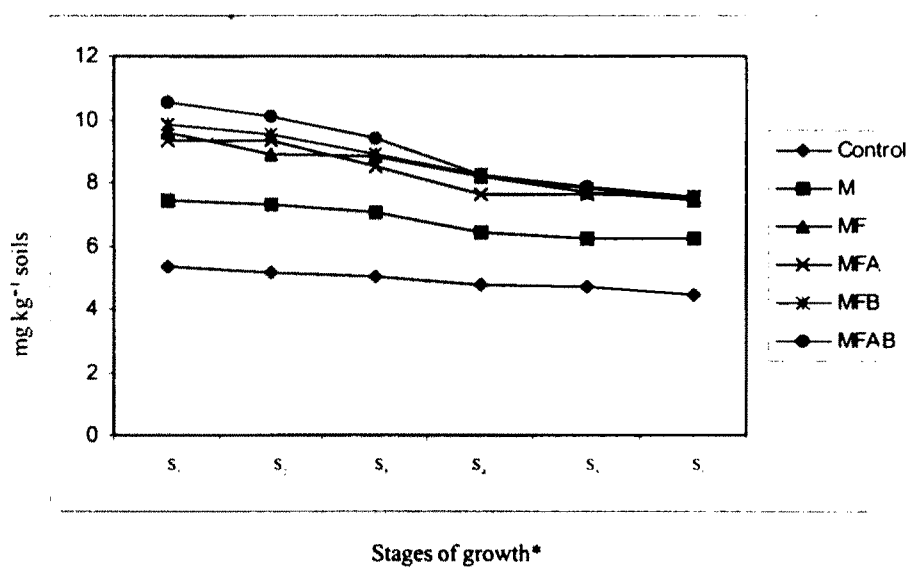


Fig. 36. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the content of available phsophorus of rhizosphere soils of ginger in field.

* S_1 - S_6 = For ginger 30, 60, 90, 120, 150, 180 days after planting - at sprouting of rhizome, early emergence of pseudostem, late emergence of pseudostem, full growth of pseudostem, near maturity of pseudostem and harvesting stage of ginger, respectively.

soils of ginger at every growth stage as compared to the of control. MFA resulted in higher storage of available phosphorus than that of M at each growth stage. MF was superior to MFA in relation to the availability of phosphorus in soils at S_1 stage and then from S_3 to S_5 stage. On the other hand, MFB brought about higher retention of available phosphorus than that of M in ginger rhizosphere at each growth stage. MFAB brought about the highest accumulation of available phosphorus in the rhizosphere soils of ginger at all the growth stages. However, the difference in between control and M as well as M and MF at all the stages, MF and MFA at S_4 stage, MFB and MFAB at S_1 stage was significant by DMRT.

The content of available phosphorus in the rhizosphere soils of ginger under control, M, MF, MFB and MFAB decreased gradually from S_1 to S_6 stage. On the other hand, the content of the same under MFA decreased steadily with the time right from S_2 to S_6 stage. However the difference in between S_1 to S_3 and then S_4 to S_6 stages for M, S_1 and S_2, S_2 and S_3, S_3 and S_4, S_5 and S_6 stages for MF, and MFB S_1 and S_2 and then S_4 to S_6 stages for MFA, S_1 and S_2, S_2 and S_3 and then from S_4 to S_6 stages for MFAB was not significant.

All in all, MFAB increased the content of available phosphorus to the highest extent in the rhizosphere soils of ginger followed by those of MFB, MF, MFA, M and control, respectively. However, the difference in between MF and MFA as well as MF and MFB was not significant.

In general, the content of available phosphorus decreased gradually in the soils of ginger from the initiation to the completion of the experiment.

f) Uptake of nitrogen and phosphorus as well as yield of rhizome ginger in field :

Uptake of nitrogen, phosphorus and yield of fresh rhizome ginger under different treatments after final harvest are shown in table - 48.

TABLE–48 : **Uptake of nitrogen and phosphorus by rhizome and yield of fresh rhizome ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in field experiment.***

Treatment	Uptake of nitrogen * ($g\ plot^{-1}$) Average of 4 replications	Uptake of phosphorus ($g\ plot^{-1}$) Average of 4 replications	Yield of rhizome ($g\ pot^{-1}$) Average of 4 replications
Control	++5.13[d]	0.53[c]	3200.00[c]
+M	5.38[d]	0.60[c]	3767.75[d]
MF	7.36[c]	0.85[b]	4245.00[c]
MFA	9.17[b]	0.89[b]	4727.00[b]
MFB	9.64[b]	0.94[b]	4865.00[b]
MFAB	12.90[a]	1.12[a]	5269.00[a]
LSD at 5%	1.52	0.156	331.90
at 1%	2.14	0.216	466.09

* Plot size 2 m x 1 m

For + and ++ See foot note Table - 6.

MFAB resulted in the highest uptake of nitrogen by rhizome ginger from soil. MFA and MFB brought about similar influence and both of them were next to MFAB in relation to uptake of nitrogen. On the other hand, control and M caused similar influence and resulted in the least influence on the uptake of nitrogen by rhizome of ginger from soil.

MFAB caused the highest influence on uptake of phosphorus by rhizome ginger from soil. MF, MFA and MFB resulted in similar influence and were next to MFAB in relation to uptake of phosphorus by rhizome ginger from soil. On the other hand, M and control resulted in the least impact on the uptake of phosphorus.

MFAB produced the highest yield. MFA and MFB resulted in the similar influence on the yield of ginger and both of them were next to MFAB. MF was inferior to either of MFA or MFB in relation to the yield of fresh ginger. Though, M resulted in higher yield than that of control, the said treatment was inferior to MF in relation to yield of fresh ginger.

Correlations :

Table–49 shows the overall relationships among different variables when all the stages of growth was taken into consideration together. From the coefficient of correlation values, it is apparent that the proliferation of bacteria was correlated with actinomycetes and highly correlated with phosphate solubilizing microorganisms, phosphate solubilizing power, total nitrogen, ammoniacal nitrogen and available phosphorus in the rhizosphere soils of ginger in field.

The preponderance of actinomycetes was correlated with nitrogen fixing bacteria, phosphate solubilizing microorganisms, phosphate solubilizing power and total nitrogen in the rhizosphere soils of ginger.

The abundance of nitrogen fixing bacteria in ginger rhizosphere soils in field was correlated with nitrogen fixing power.

TABLE–49 : Significant correlations among different variables of ginger rhizosphere field soils.

Relationship between		Correlation coefficient (r)		
		Observed	Table value	
			5%	1%
Total viable bacteria of rhizosphere soils	phosphate solubili--zing organisms	0.980**		
Total viable bacteria of rhizosphere soils	and actinomycetes	0.840*		
Total viable bacteria of rhizosphere soils	and phosphate solubilizing power	0.980**		
Total viable bacteria of rhizosphere soils	and total nitrogen	0.970*		
Total viable bacteria of rhizosphere soils	and ammoniacal-nitrogen	0.950**		
Total viable bacteria of rhizosphere soils	and available phosphorus	0.980**		
Total actinomycetes of rhizosphere soils	and phosphate solubilizing power	0.890*		
Total actinomycetes of rhizosphere soils	and total nitrogen	0.880*		
Total actinomycetes of rhizosphere soils	and phosphate solubilizing organisms	0.830*		
Total actinomycetes of rhizosphere soils	and nitrogen fixing bacteria	0.820*		
Nitrogen fixing bacteria of rhizosphere soils	and nitrogen fixing power	0.850*		
Phosphate solubilizing organisms of rhizosphere soils	and phosphate solubilizing power	0.970**		

Contd....

Phosphate solubilizing organisms of rhizosphere soils.	and total nitrogen	0.980**
Phosphate solubilizing organisms of rhizosphere soils.	and ammoniacal nitrogen	0.990**
Phosphate solubilizing organisms of rhizosphere soils.	and available phosphorus	0.950**
Ammoniacal nitrogen of rhizosphere soils	and total nitrogen	0.980**
Ammoniacal nitrogen of rhizosphere soils	and phosphate solubilizing power	0.960**
Ammoniacal nitrogen of rhizosphere soils	and available phosphorus	0.890*
Nitrate nitrogen of rhizosphere soils	and phosphate solubilizing power	0.840*
Nitrate nitrogen of rhizosphere soils	and actinomycetes	0.940**
Available phosphorus of rhizosphere soils	and phosphate solubilizing power	0.940**
Available phosphorus of rhizosphere soils	and total nitrogen	0.940**
Uptake of nitrogen by rhizome ginger	and total bacteria of rhizosphere soil	0.960**
Uptake of nitrogen by rhizome ginger	and nitrogen fixing bacteria	0.870**

Contd....

Uptake of nitrogen by rhizome ginger	and phosphate solubilizing microorganisms	0.960**
Uptake of nitrogen by rhizome ginger	and nitrogen fixing power	0.860*
Uptake of nitrogen by rhizome ginger	and phosphate solubilizing power	0.930**
Uptake of nitrogen by rhizome ginger	and ammoniacal nitrogen	0.950**
Uptake of nitrogen by rhizome ginger	and available phosphorus	0.930**
Uptake of nitrogen by rhizome ginger	and total nitrogen	0.870*
Uptake of nitrogen by rhizome ginger	and uptake of phosphorus	0.870*
Uptake of phosphorus by rhizome ginger	and total bacteria of rhizosphere soil	0.940**
Uptake of phosphorus by rhizome ginger	and actinomycetes of of rhizosphere soil	0.850**
Uptake of phosphorus by rhizome ginger	and phosphate solubilizing organisms	0.960**
Uptake of phosphorus by rhizome ginger	and phosphate solubilizing power	0.940**
Uptake of phosphorus by rhizome ginger	and ammoniacal-nitrogen	0.930**
Uptake of phosphorus by rhizome ginger	and available phosphorus	0.880*
Uptake of phosphorus by rhizome ginger	and total nitrogen	0.820*

Uptake of phosphorus by rhizome ginger	and uptake of nitrogen	0.870**
Yield of rhizome ginger	and total bacteria of rhizosphere soil	0.960**
Yield of rhizome ginger	and nitrogen fixing bacteria	0.850*
Yield of rhizome ginger	and phosphate solubilizing microorganisms	0.950**
Yield of rhizome ginger	and nitrogen fixing power	0.820*
Yield of rhizome ginger	and phosphate solubilizing power	0.950**
Yield of rhizome ginger	and ammoniacal nitrogen	0.960**
Yield of rhizome ginger	and available phosphorus	0.980**
Yield of rhizome ginger	and total nitrogen	0.950**
Yield of rhizome ginger	and uptake of nitrogen	0.960**
Yield of rhizome ginger	and uptake of phosphorus	0.850**

* Significant at 5%.

** Significant at 1%.

The incidence of phosphate solubilizing microorganisms in rhizosphere soils of ginger was highly correlated with the content of total and ammoniacal nitrogen, phosphate solubilizing power and available phosphorus.

The content of ammoniacal - nitrogen was correlated with available phosphorus and strongly correlated with total nitrogen and phosphate solubilizing power of the rhizosphere soils of ginger in field.

The content of nitrate - nitrogen in ginger rhizosphere was directly correlated with phosphate solubilizing power and strongly correlated with actinomycetes.

The content of available phosphorus was highly correlated with total nitrogen and phosphate solubilizing power of rhizosphere soils of ginger in field.

Uptake of nitrogen by rhizome ginger was correlated with nitrogen fixing bacteria, nitrogen fixing power, total nitrogen, uptake of phosphorus and strongly correlated with total bacteria, phosphate solubilizing organisms, phosphate solubilizing power, ammoniacal nitrogen and available phosphorus of ginger rhizosphere soils in field.

Uptake of phosphorus by rhizome ginger had a direct relationship with actinomycetes population, total nitrogen available phosphorus , nitrogen uptake and highly correlated with total bacteria, phosphate solubilizing microorganisms, phosphate solubilizing power, ammoniacal nitrogen of rhizosphere soils of ginger.

Yield of rhizome ginger was moderately correlated nitrogen fixing bacteria, nitrogen fixing power, uptake of phosphorus and strongly correlated with total bacteria, phosphate solubilizing microorganisms, phosphate solubilizing power, ammoniacal nitrogen, available phosphorus, total nitrogen and nitrogen uptake by rhizome.

Experiment No. 6 – Isolation and characterization of some plant pathogenic microflora from rotten ginger.

A) Five isolates of bacteria from rotten ginger and their growth behaviour in specific medium :

From the rotten rhizome, five isolates of bacteria were randomly picked up and identified up to generic level following standard guideline. To establish the genera as plant pathogenic, they were tested against some specific growth media meant for that purpose only.

The table–50a shows that isolate GB_1 was Gram-ve, non fluorescent, having growth on common media, D-3 agar medium and no growth on D-1 agar medium, produced yellow or orange colonies on nutrient agar or Yeast- extract-dextrose-CaCO3 (YDC) medium. Isolates GB_2 and GB_4 were Gram - ve, fluorescent pigmented having profuse on growth common medium and no growth in D-1 and D-3 agar medium, no yellow colonies on nutrient agar or YDC medium. Isolates GB_3 and GB_5 were Gram-ve, non-fluorescent, rendering profuse growth in common medium, and no growth in D-1 and D-3 agar medium. There were no yellow orange colonies in nutrient agar and YDC medium.

B) Cultural characteristics of isolates of *Fusarium* and *Pythium* from rotten rhizome ginger :

Fusarium :

Table–50b exhibits three isolates of *Fusarium* sp. with some cultural characteristics in PDA medium. The isolates-1, 2 and 3 differed from each other in cultural characteristics, i.e., hyphal diameter, conidial (both macro and micro) size, septation, nature of growth and pigmentation Colony forming units (CFU) of isolate-1, 2 and 3 on PDA were pinnotal and mycelial, and mycelial alone, respectively. Isolate-1, exhibited greater hyphal diameter than those of other. On the other hand, isolate-3 had , the greatest micro and macro conidial diameter. However, isolates-2 was in between isolates -1 and 3 in relation to hyphal and conidial diameter. The

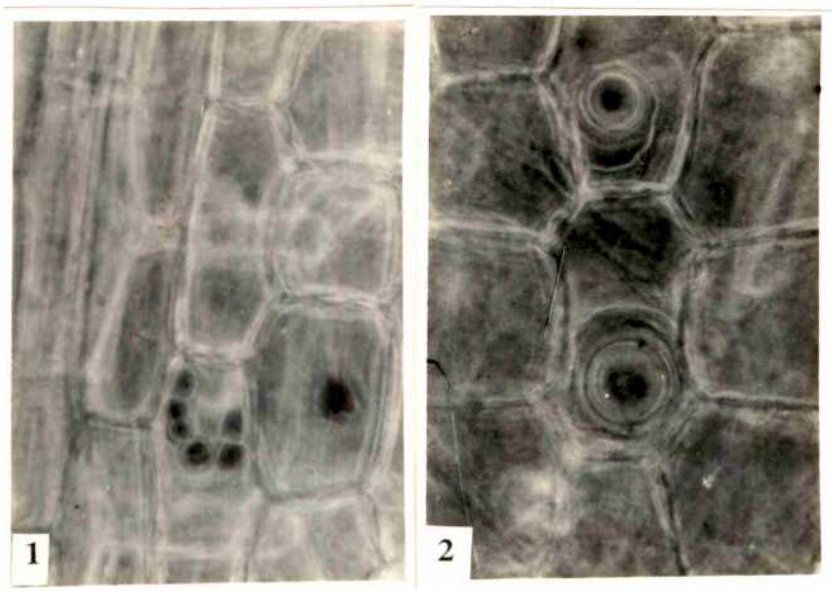
TABLE–50a : Five isolates of bacteria from rotten ginger and their growth behaviour in specific medium.

Character	Bacterial Isolates from rotten rhizome				
	*GB_1	GB_2	GB_3	GB_4	GB_5
Growth on common media	+	+	+	+	+
Gram reaction	-	-	-	-	-
Yellow or orange colonies on NA or YDC	+	-	-	-	-
Fluorescent pigment on KB	-	+	-	+	+
Growth on D - 1 agar	-	-	-	-	-
Growth on D - 3 agar	+	-	-	-	-

* GB = Ginger bacteria as coded
Suffix no. is the strain number

TABLE–50b : Cultural characteristics of three isolates of *Fusarium* and one isolate of *Pythium* from the rotten rhizome of *ginger*.

	CULTURAL CHARACTERS					
Fusarium	Hyphae (µm)	Microconidia (µm)	Macroconidia (µm)	No. of septa.	Nature of Growth	Pigmentation
Isolate - 1	3.7 to 6.8	4.5 - 11.2 x 2.7 - 3.7	14.9 - 29.2 x 3.9 - 4.2	2 - 4	Pionnotal	Violet
Isolate - 2	2.7 to 3.5	3.6 - 11.7 x 1.9 - 3.7	13.5 - 26.8 x 2.7 - 4.2	2 - 3	Pionnotal and mycelial	Green yellow to bluish
Isolate - 3	1.8 to 3.3	5.6 - 9.7 x 2.9 - 3.7	17.6 - 28.9 x 2.9 - 4.6	2 - 3	Mycelial	Green yellow to bluish
Pythium	Hyphae (µm)	Oogonia (µ)	Antheridia	No. of septa	Nature of growth	Pigmentation
Isolate - 1	2.8 - 7.3	22 - 27 (diameter) Spherical; terminal	1 - 2 / Oogonium terminal	Non-septate	Mycelial branched	Hyalin



***Fusarium* and *Pythium* infected cells of rhizome.**

Fig. 1 Fusarial chlamydospore in soft-rot infected ginger cell, Fig. 2 Oogonium of *Pythium* in soft-rot infected ginger cell.

pigmentation was violet in isolate-1 while the same was green yellow to bluish in isolates-2 and 3, moreover, septation of conidia in isolate-1 was 2-4 whereas it was 2-3 in isolates-2 and 3.

Pythium :

Table–50b depicts only one isolate of *Pythium* with some characteristics. The diameter of hyphae and Oogonia varied from 2.8 µm to 7.3 µm and 22-27 µ, respectively. Oogonia was terminal and spherical with 1-2 Antheridia usually intercalary and often terminal. Growth of mycelium on PDA was branched or unbranched, non-septated with no pigmentation.

Experiment No. 7 – *In-vitro* studies on interaction between plant pathogenic and beneficial organisms.

The photographs presented here show some interaction between soft-rot producing pathogens and beneficial bacteria like nitrogen fixer *Azotobacter* and phosphate solubilizer *Bacillus* and *vice versa.*

a) Interaction in between fungi and fungi : *Fusarium* vs *Pythium*

Two prominent causal organisms i.e. *Fusarium* and *Pythium* were cross inoculated on a plate in PDA medium. It was apparent from the photograph-1 that two fungi were independently growing without interfering each other. The diameter of mycelial mat after 4 days of incubation was more or less equal.

b) Interaction between fungi and bacteria : 1) *Fusarium* vs *Azotobacter*

Interaction between soft-rot producing *Fusarium* and nitrogen fixing bacteria, *Azotobacter* was studied in a PDA medium following cross inoculation technique. From the photograph–2 it is clear that there was a zone of inhibition in between *Fusarium* and *Azotobacter*. Moreover, the

***In-vitro* studies on interaction between plant pathogenic and beneficial organisms.**

Fig. 1 *Fusarium* Vs. *Pythium*, Fig. 2 *Fusarium* Vs. *Azotobacter*, Fig. 3 *Pythium* Vs. *Azotobacter*.

tip of mycelial growth was reverse to the growth of *Azotobacter*. In addition, it was also noticed that inoculation of *Azotobacter* in petridishes resulted in no further growth of mycelium of *Fusarium* even after 4 days growth.

ii) *Pythium* vs *Azotobacter*:

From the photograph–3 it was apparent that similar kind of inhibition, as that of the previous experiment was found.

iii) *Fusarium* vs *Phosphate* solubilizer *Bacillus*:

Photograph–4 reveals that phosphate solubilizer, *Bacillus* inhibited the growth of *Fusarium* by its over growth.

iv) *Pythium* vs *Phosphate* solubilizer *Bacillus*:

The photograph–5 reveals that there was clear demarcation between the two growths in the centre of the plate and the direction of mycelial proliferation was opposite to the growth of phosphate solubilizer. Moreover, mycelial tips weithered in the cross inoculated plates. Fungal mycelial growth was strongly suppressed in the presence of phosphate solubilizer.

v) *Fusarium* vs *Pseudomonas*:

The photograph–6 reveals that the growth of *Pseudomonas* was strongly inhibited by the profuse growth of *Fusarium*. The over growth of *Fusarium* arrested the normal growth of *Pseudomonas*. (Photograph-7)

vi) *Pythium* vs *Pseudomonas*:

Similar trend of inhibition as that of the previous one was observed in this experiment.

***In-vitro* studies on interaction between plant pathogenic and beneficial organisms.**

Fig. 4 *Fusarium* Vs. Phosphate solubilizer, *Bacillus*, Fig. 5 *Pythium* Vs. Phosphate solubilizer, *Bacillus*, Fig. 6 *Fusarium* Vs. *Pseudomonas*.

C) Interaction between bacteria and bacteria :

i) Non-symbiotic nitrogen fixing bacteria - *Azotobacter* vs phosphate solubilizing bacteria - *Bacillus* :

24 hours old culture of *Azotobacter* and *Bacillus* was cross inoculated parallel to each other in the centre of petridish. From Photograph-8 it was apparent that after 4 days of incubation, two organisms were growing simultaneously but the rate of growth of *Azotobacter* was higher than that of *Bacillus*.

ii) *Azotobacter* vs *Pseudomonas* :

96 hours old culture of *Pseudomonas* was cross inoculated with 24 hours old active culture of *Azotobacter* in petridishes and was incubated for 4 days. It was observed that further growth of *Pseudomonas* was restricted by the profuse growth of *Azotobacter*. Moreover, there was a clear zone of inhibition in the photograph–9.

iii) *Pseudomonas* vs phosphate solubilizing bacteria *Bacillus* :

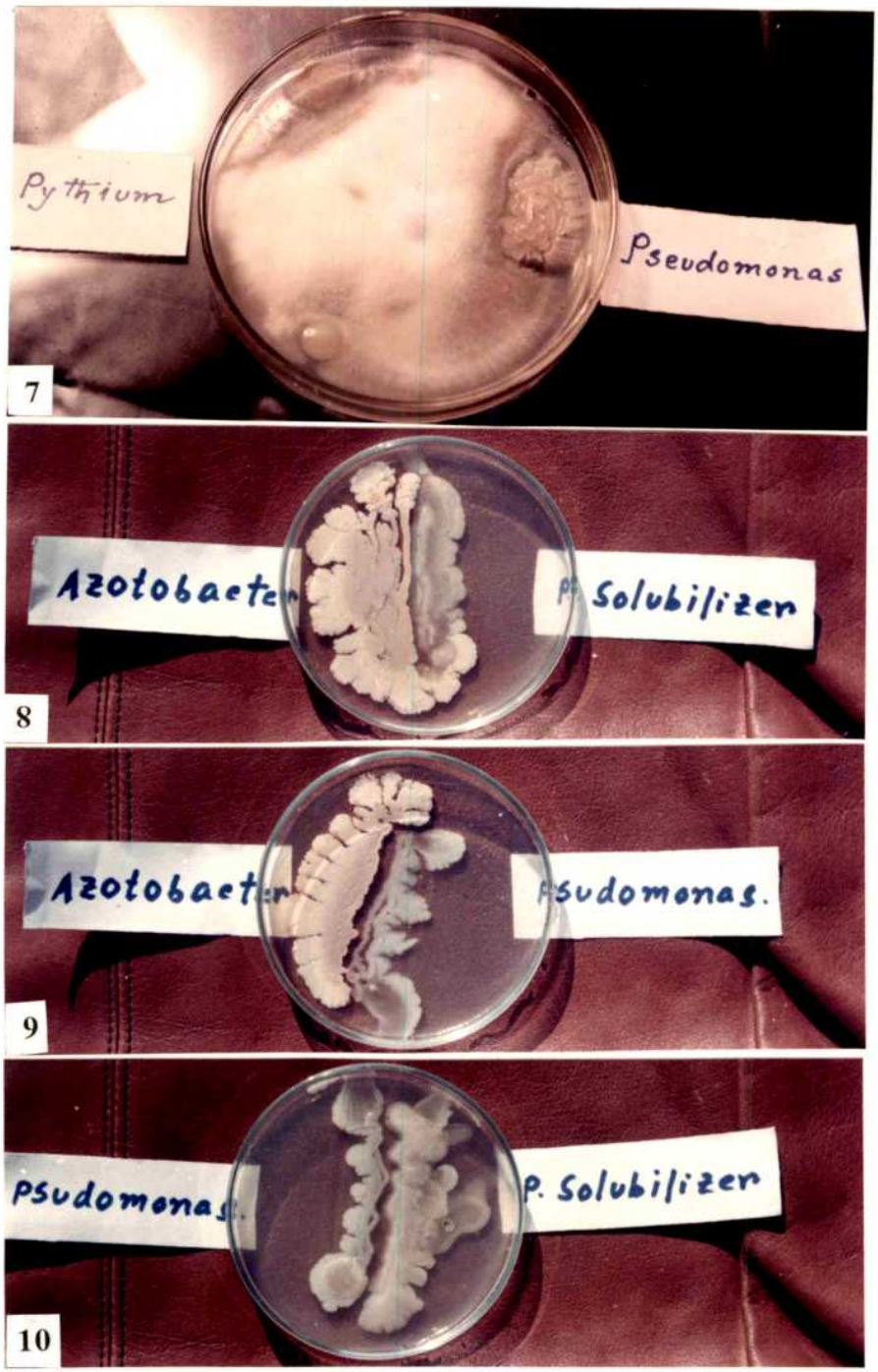
From the photograph–10, it is clear that there was a clear zone of inhibition between the growth of the two bacteria. The growth of *Pseudomonas* was arrested by the phosphate solubilizer *Bacillus*.

Experiment No. 8 – Enumeration of some soilborne plant pathogenic microflora from pot soil :

A. Enumeration of probable pathogenic organisms of soft-rot disease of ginger

a) Total number of *Fusarium* present in soils :

Total number of *Fusarium* present per gram dry soils under different treatments are presented in table–51; fig. 37.



***In-vitro* studies on interaction between plant pathogenic and beneficial organisms.**

Fig. 7 *Pythium* Vs. *Pseudomonas*, Fig. 8 *Azotobacter* Vs. *Bacillus*, Fig. 9 *Azotobacter* Vs. *Pseudomonas*, Fig. 10 *Pseudomonas* Vs. Phosphate solubilizer, *Bacillus*.

TABLE–51 : **Total number of *Fusarium* present in the soils as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture without crop.***

	Number of *Fusarium* (CFU x 10^3) g^{-1} dry soil (Average of duplicate sets) (Average of 2 replications)						
Treatment	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	32.46^{c}	41.71^{ab}	88.04^{a}	72.00^{a}	53.98^{b}	38.64^{ab}	54.47^{B}
+M	26.14^{d}	32.59^{b}	79.69^{ab}	70.08^{ab}	57.71^{b}	44.21^{a}	51.75^{B}
MF	48.72^{b}	56.96^{a}	88.99^{a}	76.83^{a}	70.25^{a}	45.32^{a}	64.51^{A}
MFA	13.28^{e}	25.12^{b}	62.26^{b}	40.48^{c}	22.08^{d}	14.10^{d}	31.90^{D}
MFB	56.50^{a}	43.85^{ab}	72.51^{ab}	55.40^{bc}	40.09^{c}	30.69^{bc}	49.84^{B}
MFAB	13.15^{e}	44.14^{ab}	58.30^{b}	47.68^{c}	30.12^{cd}	25.63^{c}	36.50^{C}
Mean	31.708^{D}	40.728^{C}	74.956^{A}	60.41^{B}	45.70^{C}	33.11^{D}	
LSD at 5%	5.91	24.27	21.15	15.95	10.05	10.24	
at 1%	8.94	NS	NS	24.15	15.21	15.50	

		LSD at 5%	at 1%
For Stage	-	5.41	7.23
Treatment	-	5.41	7.23
Interaction (Stage x Treatment)	-	13.24	17.78

* Total number of *Fusarium* present in initial soil - 23.18 (CFU x 10^3) g^{-1} dry soil.

For **, + and ++ See foot note Table - 6

The figures show that the treatment M resulted in reduction in *Fusarium* propagules in soils from S_1 to S_4 stage as compared to control. On the other hand, MFB caused higher diminution of *Fusarium* propagules than that of control from S_3 to S_6 stage. As such, MFA and MFAB resulted in greater reduction in *Fusarium* propagules as compared to that of control throughout the experimental period. MF invariably exerted higher proliferation of *Fusarium* propagules than that of control at all the stages of experiment. The treatments MFA, MFB and MFAB, in general, induced negative influence on *Fusarium* propagules as compared to that of M. Among the treatments, MFA imposed the worst influence on the *Fusarium* propagules in soil. However, the difference in between control and M at all but S_1, M and MF at S_3, S_4 and S_6, MFA and MFB at S_2 to S_4 as well as MFB and MFAB at all but S_1 stage was not significant by DMRT.

The propagules of *Fusarium* in soil series under control, M, MF, MFA and MFAB progressively increased from S_1 to S_3 stage and then gradually decreased up to S_6 stage. On the other hand, there was an alternate fall and rise of the propagules of *Fusarium* in the soil series under MFB from S_1 to S_3 stage of the experiment following a gradual decrease of the same up to S_6 stage. However, the difference in between S_1 and S_2, S_3 and S_4 as well as S_5 and S_6 for M, S_1 and S_2 and then S_5 and S_6 for MF and MFA, S_1 and S_2, S_4 and S_5 for MFB as well S_2 to S_3 and then S_5 and S_6 stage for MFAB was not significant.

On the whole, MFA exercised the least influence on the proliferation of *Fusarium* propagules in soils followed by those of MFAB, MFB, M, control and MF, respectively. However, the difference among control, M and MFB was not significant.

The *Fusarium* propagules in soils, in general, increased progressively from the beginning to S_3 stage which, thereafter, decreased gradually up to S_6 stage.

TABLE–52 : **Total number of *Pythium* present in the soils as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture without crop.***

	Number of *Pythium* (CFU x 10^3) g^{-1} dry soil (Average of duplicate sets) (Average of 2 replications)						
Treatment	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++31.81^{bc}	28.86^{b}	65.21^{abc}	45.51^{bc}	35.17^{b}	33.82^{a}	40.06^{C}
+M	19.60^{c}	19.55^{b}	61.25^{bc}	59.02^{a}	45.63^{ab}	30.86^{a}	40.69^{C}
MF	54.81^{a}	58.98^{a}	74.21^{ab}	53.99^{ab}	47.95^{a}	38.03^{a}	54.66^{A}
MFA	25.12^{bc}	53.12^{a}	59.11^{bc}	41.01^{c}	23.92^{c}	20.85^{b}	37.18^{C}
MFB	37.20^{b}	55.25^{a}	79.47^{a}	52.65^{ab}	43.85^{ab}	31.32^{a}	49.95^{B}
MFAB	19.13^{c}	52.63^{a}	51.32^{c}	41.05^{c}	35.89^{b}	33.33^{a}	38.89^{C}
Mean	31.27^{D}	44.73^{B}	64.26^{A}	48.87^{B}	38.73^{C}	37.00^{D}	
LSD at 5%	14.16	13.45	16.62	9.40	11.07	9.36	
at 1%	21.45	20.37	NS	NS	NS	NS	

		LSD at 5%	at 1%
For Stage	-	4.29	5.73
Treatment	-	4.29	5.73
Interaction (Stage x Treatment)	-	10.50	14.08

* Total number of *Pythum* present in initial soil - 13.0 (CFU x 10^3) g^{-1} dry soil.

For **, + and ++ See foot note Table - 6

NS- Non significant

b) Total number of *Pythium* present in soils :

Table–52, fig. 38 shows the total number of *Pythium* present per gram soils. Irrespective of treatments, the number *Pythium* propagules present in the soils was universally more as compared to the initial number.

The treatment M resulted in reduction in *Pythium* propagules in soil from S_1 to S_3 stage and then at S_6 stage as compared to that of control. On the other hand, MFA brought about diminution of *Pythium* propagules at S_1 stage and then from S_3 to S_6 stage as compared to that of control. However, MFAB caused negative effect on *Pythium* propagules at S_1, S_3, S_4 and S_6 stages as compared to that of control. MFB induced reduction in *Pythium* propagules only at S_6 stage. Thought MF exerted enhancing influence on *Pythium* propagules as compared to that of control throughout the experimental period. Among the inoculated series, MFAB exerted the worst influence on *Pythium* propagules from S_1 to S_3 stage. The same was true with MFA from S_4 to S_6 stage. However, the difference in between M and MF from S_3 to S_6, MF and MFA at S_2 and S_3, MFA and MFB at S_2 as well as MFB and MFAB at S_2 and then S_5 and S_6 stages was not significant by DMRT.

The propagules of *Pythium* in soil series under the treatments - MF, MFA, MFB and MFAB progressively increased from S_1 to S_3 stage and then gradually decreased up to S_6 stage. On the other hand, there was an alternate fall and rise of the propagules of *Pythium* in the soil series under control and M from S_1 to S_3 stage following a gradual decrease of the same up to S_6 stage. However, the difference in between S_1 and S_2 and then S_3 and S_4 for M, S_1 and S_2 as well as S_4 and S_5 for MF, S_2 and S_3 for MFA, S_4 and S_5 for MFB as well as S_2 to S_3 and then S_5 and S_6 stages was not significant.

All in all, MFA resulted in the least proliferation of *Pythium* in the soils followed by those of MFAB, control, M, MFB and MF, respectively. However, the difference among control, M, MFA and MFB was not significant.

The *Pythium* propagules of rhizosphere soils increased, on and on, from S_1 to S_3 stage which then gradually decreased up to S_6 stage.

c) Total number of *Pseudomonas* present in soils :

The abundance of *Pseudomonas* in treated soils was more than that in the initial soil with the exception of those under control at S_5 and S_6 stage as well as at S_1 stage under MFAB (table–53; fig. 39).

The treatments - M, MF, MFA, MFB and MFAB resulted in higher proliferation of *Pseudomonas* at all the stages of experiment as compared to control with the exception of MFAB at S_1 stage wherein a decrease in number was observed. Among the treatments, MF resulted in the highest proliferation of *Pseudomonas* at all the stages. MFA was next to MF in relation to the preponderance of the cited *bacterium* at S_2, S_3, S_5 and S_6 stages. The treatment M resulted in higher proliferation of *Pseudomonas* at all the stages as compared to MFB. MFAB caused greater influence in *Pseudomonas* as compared to MFB from S_2 to S_6 stages. However, the difference in between M and MF at all but S_2, MF and MFA at all but S_3, MFA and MFB at all but S_2 and S_3, MFB and MFAB at all the stages was not significant by DMRT.

As compared to S_1 stage the population of *Pseudomonas* in soil series under control, M, MF, MFA and MFAB increased at S_2 stage which then gradually decreased up to S_4 stage. However, there was a progressive increase in the population of *Pseudomonas* in soil series under MF, MFA and MFB from S_4 to S_6 stage. A fall followed by a rise in the population of *Pseudomonas* in soil series under M and MFAB as well as a gradual decline up to S_6 stage was observed in control series. However, the difference between the stages from S_3 to S_6 for each treatment was not significant.

On an average, the highest population of *Pseudomonas* was harboured by MF amended soil series. This was followed by MFA, M,

TABLE–53 : Total number of *Pseudomonas* present in the soils as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture without crop.*

	Number of *Pseudomonas* (CFU x 10^3) g^{-1} dry soil (Average of duplicate sets) (Average of 2 replications)						
Treatment	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++71.24^{ab}	105.95^{c}	40.07^{c}	35.86^{b}	28.41^{c}	27.73^{c}	55.68^{C}
+M	96.09^{a}	149.28^{b}	50.99^{bc}	50.59^{a}	47.23^{ab}	49.07^{ab}	73.87^{B}
MF	104.57^{a}	219.29^{a}	55.34^{bc}	52.66^{ab}	53.84^{a}	57.05^{a}	90.45^{A}
MFA	77.02^{ab}	206.65^{a}	61.63^{a}	45.28^{ab}	48.46^{ab}	52.14^{ab}	81.86^{B}
MFB	62.18^{ab}	113.92^{c}	41.98^{bc}	36.27^{b}	41.97^{b}	41.97^{b}	56.38^{C}
MFAB	34.20^{b}	119.25^{c}	46.99^{ab}	43.74^{ab}	43.71^{b}	47.64^{ab}	55.92^{C}
Mean	74.9^{B}	152.39^{A}	49.45^{C}	44.133^{C}	43.93^{C}	45.93^{C}	
LSD at 5%	47.08	25.92	13.73	9.90	8.00	11.93	
at 1%	NS	39.26	NS	NS	12.10	18.06	

		LSD at 5%	at 1%
For Stage	-	8.03	10.77
Treatment	-	8.03	10.77
Interaction (Stage x Treatment)	-	19.68	26.40

* Total number of *Pseudomonas* in initial soil - 35.0 (CFU x 10^3) g^{-1} dry soil.

For **, + and ++ See foot note Table - 6

NS-Non significant.

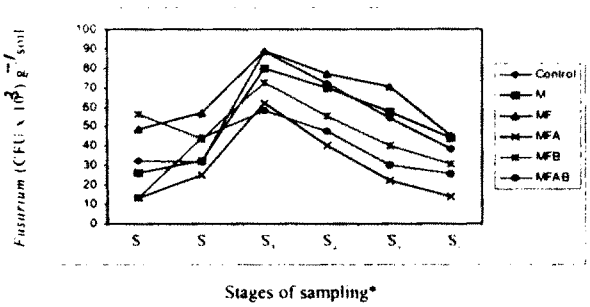


Fig. 37. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation *Fusarium* in soils in pot without crop.

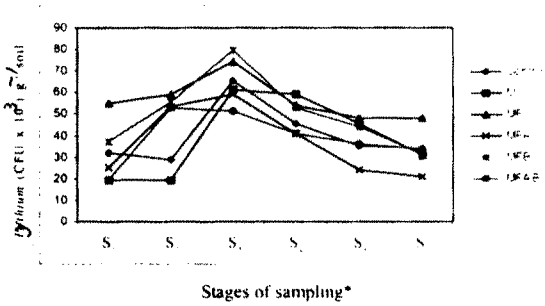


Fig. 38. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation of *Pythium* in soils in pot without crop.

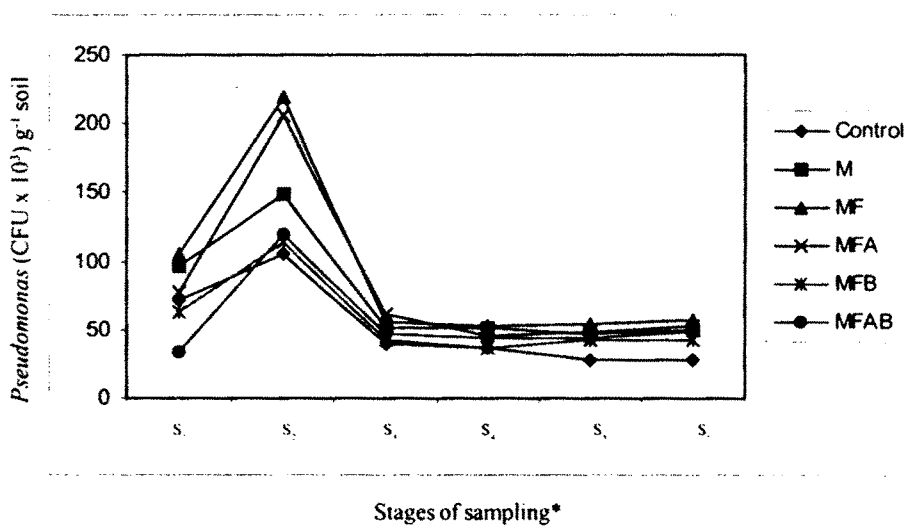


Fig. 39. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation of *Pseudomonas* in soils in pot without crop.

* S_1 - S_6 = 30, 60, 90, 120, 150, 180 days after the starting of experiment.

control, MFB and MFAB, respectively. However, the difference in between M and MFA as well as MFB and MFAB was not significant.

In general, the count of *Pseudomonas* population increased from S_1 to S_2 and then decreased up to S_5 followed by an increase at S_6 stage. However, the difference between the stages from S_3 to S_6 was not significant.

Experiment No. 9 – Soilborne plant pathogenic ginger rhizosphere microflora in relation to disease incidence and intensity in pot culture experiment.

A) Enumeration of probable pathogenic organisms of soft-rot disease of ginger.

a) Total number of *Fusarium* present in the rhizosphere soils of ginger :

Total number of *Fusarium* present per gram dry rhizosphere soils of ginger under different treatments is presented in table–54, fig. 40. The figures show that the number of *Fusarium* sp. present in the rhizosphere soils of ginger was more as compared to the initial number with the exception of those under MFA from S_1 to S_3 and at S_6 stages, MFB at S_1 and MFAB from S_1 to S_2 stages.

The treatment MF resulted in an increase in the proliferation of *Fusarium* in the rhizosphere soils of ginger at all the growth stages as compared to control. On the other hand, the treatments - M, MFA, MFB and MFAB reduced the number of cited propagules from the beginning up to the harvesting stage of ginger. In this respect, MFA exerted the most deleterious effect followed by MFAB and MFB, respectively at each growth stage in the rhizosphere soils of ginger. However, the difference in between control and from S_1 to S_3, MFA and MFB at S_1 and S_6, MFA and MFAB at all but S_4 as well as MFB and MFAB at S_1, S_3, S_5 and S_6 stage was not significant by DMRT.

TABLE–54 : Total number of *Fusarium* present in the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture with crop.*

Treatment	Number of *Fusarium* (CFU x 10^3) g^{-1} dry soil (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++32.44^{b}	49.34^{b}	74.21^{b}	90.43^{b}	73.68^{b}	61.68^{b}	63.63^{B}
+M	28.71^{bc}	41.71^{b}	69.55^{b}	88.11^{d}	57.89^{c}	53.28^{c}	56.54^{C}
MF	55.26^{a}	71.69^{a}	85.65^{a}	106.09^{a}	99.23^{a}	86.73^{a}	84.10^{A}
MFA	15.70^{d}	13.88^{d}	18.93^{d}	25.12^{e}	24.04^{e}	17.85^{d}	19.25^{E}
MFB	22.12^{cd}	28.89^{c}	30.93^{c}	47.40^{c}	35.57^{d}	25.91^{d}	31.80^{D}
MFAB	17.87^{d}	19.76^{d}	24.96^{cd}	36.39^{d}	31.36^{de}	24.93^{d}	25.87^{E}
Mean	28.68^{F}	37.54^{E}	50.70^{C}	65.59^{A}	53.62^{B}	45.06^{D}	
LSD at 5%	7.27	8.04	11.08	7.65	7.85	8.33	
at 1%	11.01	12.17	16.78	11.58	11.88	12.61	

		LSD at 5%	at 1%
For Stage	-	2.86	3.84
Treatment	-	2.86	3.84
Interaction (Stage x Treatment)	-	7.01	9.41

* Total number of *Fusarium* present in initial soil - 23.18 (CFU x 10^3) g^{-1} dry soil.

** See foot note Table - 19

For + and ++ see foot note Table - 6

The proliferation of *Fusarium* propagules in the rhizosphere soils of ginger under control, M, MF, MFB and MFAB increased, on and on, from S_1 to S_4 stage which then gradually decreased till the completion of the experiment. On the other hand, the preponderance of *Fusarium* propagules under MFA exhibited a decline at S_2 stage with an progressive increase up to S_4 stage followed by a gradual decline up to S_6 stage. However, the difference in between S_5 and S_6 for M, S_4 and S_5 for MF, S_1 and S_2 and then S_3 to S_6 for MFA, S_1 to S_3 for MFB as well as S_1 to S_3, S_4 and S_5, S_5 and S_6 for MFAB was not significant.

All in all, MFA exercised the least influence on the proliferation of *Fusarium* propagules in the rhizosphere soils of ginger followed by those under MFAB, MFB, M, Control and MF, respectively.

The *Fusarium* propagules in the rhizosphere soils of ginger, in general, increased progressively from the beginning of the experiment to S_4 stage which, thereafter, decreased in the descending order up to the final stage.

b) Total number of *Pythium* present in the rhizosphere soils of ginger :

The figures depicted in the table–55, fig. 41 reveals that irrespective of the treatment, the number of *Pythium* propagules present in the ginger rhizosphere soils was universally more as compared to the initial number.

MF resulted in a universal increase in the number of *Pythium* propagules in the rhizosphere soils of ginger as compared to that of control. The same was true with MFB at S_1, S_2 and S_6 stages. On the other hand, M, MFA and MFAB brought about reduction in the number *Pythium* propagules as compared to that of control right from the initiation to the final stage. Even MFB resulted in decrease of *Pythium* propagules as compared to that of MF at all the stages of growth. MFAB resulted in

TABLE–55 : **Total number of *Pythium* sp. present in the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture with crop.***

Treatment	Number of *Pythium* (CFU x 10^3) g^{-1} dry soil (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	**25.16^{c}	34.21^{bc}	70.96^{a}	76.66^{ab}	69.73^{b}	54.54^{bc}	55.21^{B}
+M	16.31^{c}	28.02^{cd}	68.89^{a}	67.88^{b}	59.86^{c}	48.68^{cd}	48.27^{C}
MF	55.27^{a}	58.37^{a}	71.69^{a}	79.31^{a}	72.51^{a}	63.77^{a}	66.82^{A}
MFA	23.30^{c}	20.82^{d}	41.66^{b}	54.01^{c}	47.46^{d}	40.81^{e}	38.01^{D}
MFB	39.18^{b}	40.19^{b}	65.02^{a}	66.37^{b}	65.35^{bc}	58.15^{ab}	55.71^{B}
MFAB	16.59^{c}	21.68^{d}	57.57^{b}	54.91^{c}	51.21^{d}	43.47^{de}	40.90^{D}
Mean	29.30^{E}	33.88^{D}	62.63^{B}	66.52^{A}	61.02^{B}	51.57^{C}	
LSD at 5%	10.84	8.99	13.67	10.16	6.23	7.23	
at 1%	16.42	13.61	20.70	15.36	9.43	10.94	

		LSD at 5%	at 1%
For Stage	-	3.32	4.46
Treatment	-	3.32	4.46
Interaction (Stage x Treatment)	-	8.15	10.93

* Total number of *phytium* present in initial soil - 13.0 (CFU x 10^3) g^{-1} dry soil.

** See foot note Table - 19

For + and ++ see foot note Table - 6

lower proliferation of *Pythium* propagules than that of M from S_2 to S_6 stage. In this respect the lowest proliferation was brought about by MFA at every stage of growth in the rhizosphere soils of ginger. However, the difference in between control and M at all but S_5 stage, M and MF at S_3, MFA and MFAB at all the stages as well as MFA and MFAB at S_3 stage was not significant by DMRT.

The *Pythium* propagules in the rhizosphere soils of ginger under control, M, MF, MFB and MFAB progressively increased with the age of ginger up to S_4 stage which then gradually decreased up to S_6 stage of growth. On the other hand, there was an alternate fall and rise in the density of *Pythium* propagules under MFA right from S_1 to S_4 stage followed by a gradual reduction up to S_6 stage. However, the difference in between S_3 and S_4, S_4 and S_5 for M, S_1 and S_2 and then S_3 to S_5 for MF, S_1 and S_2, S_4 and S_5 and then S_5 and S_6 for MFA, S_1 and S_2 and then S_3 to S_5 for MFA as well as S_1 and S_2, S_3 to S_5 stage for MFAB was rot significant.

All in all, MFA resulted in the least proliferation of *Pythium* in the rhizosphere soils of ginger followed by those of MFAB, M, control, MFB and MF, respectively. The difference in between MFA and MFAB was, however, not significant.

The *Pythium* propagules of rhizosphere soil increased, on and on, from S_1 to S_4 stage which then gradually decreased upto S_6 stage. The difference in betweenS_3 and S_5 was not significant.

c) Total number of *Pseudomonas* present in the rhizosphere soils of ginger:

The proliferation of *Pseudomonas* in ginger rhizosphere soils was universally more than that in the initial soil (table–56; fig. 42).

M, MF and MFA resulted in an increase in the proliferation of *Pseudomonas* in the rhizosphere soils of ginger as compared to that of

TABLE–56 : **Total number of *Pseudomonas* sp. present in the rhizosphere soils of ginger in as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture with crop.***

Treatment	Number of *Pseudomonas* sp. (CFU x 10^3) g^{-1} dry soil (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++81.45^{b}	92.10^{c}	99.60^{c}	85.84^{c}	74.99^{cd}	69.47^{c}	83.90^{D}
+M	109.65^{a}	123.85^{b}	118.10^{b}	94.64^{c}	88.15^{c}	75.65^{c}	101.67^{C}
MF	118.80^{a}	145.30^{a}	164.97^{a}	159.46^{a}	129.76^{a}	123.72^{a}	140.33^{A}
MFA	107.40^{a}	117.42^{b}	122.47^{b}	126.88^{b}	110.12^{b}	101.40^{b}	114.28^{B}
MFB	67.00^{c}	51.37^{d}	46.08^{e}	60.68^{d}	55.83^{e}	50.56^{e}	55.25
MFAB	72.79^{bc}	56.11^{d}	66.57^{d}	70.87^{d}	67.22^{de}	61.37^{d}	65.82
Mean	92.84^{C}	97.69^{B}	102.96^{A}	99.72^{AB}	87.67^{D}	80.36^{E}	
LSD at 5%	11.87	15.31	11.33	13.66	14.88	7.25	
at 1%	17.98	23.19	17.15	20.69	22.53	10.98	

		LSD at 5%	at 1%
For Stage	-	4.29	5.75
Treatment	-	4.29	5.75
Interaction (Stage x Treatment)	-	10.51	14.10

* Total number of *pseudomonas* sp. present in initial soil - 35.0 (CFU x 10^3) g^{-1} dry soil.

** See foot note Table - 19

For + and ++ see foot note Table - 6

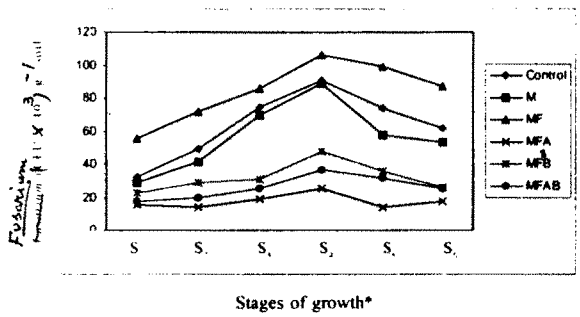


Fig. 40. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation of *Fusarium* in the rhizosphere soils of ginger in pot.

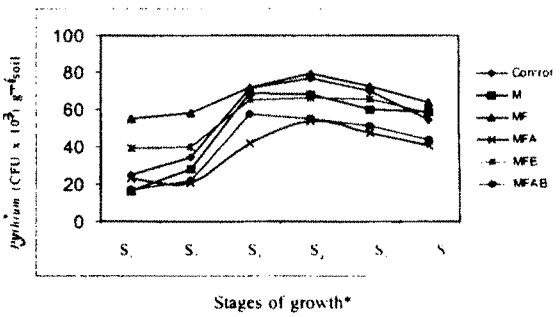


Fig. 41. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation of *Pythium* in the rhizosphere soils of ginger in pot.

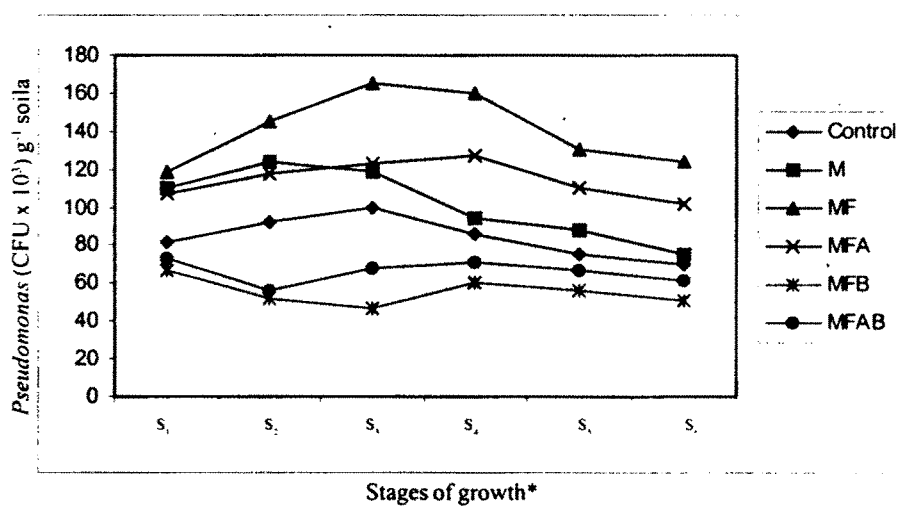


Fig. 42. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation of *Pseudomonas* in the rhizosphere soils of ginger in pot.

* S_1 - S_6 = For ginger 30, 60, 90, 120, 150, 180 days after planting - at sprouting of rhizome, early emergence of pseudostem, late emergence of pseudostem, full growth of pseudostem, near maturity of pseudostem and harvesting stage of ginger, respectively.

control at every growth stage. In this respect MF brought about the highest increase in the number of cited bacterium at all the growth stages. Though, MFA resulted in decrease in the proliferation of *Pseudomonas* at early stages yet the said treatment brought about higher proliferation of the cited bacterium in the rhizosphere soils of ginger from S_3 to S_6 stage than that of M. The treatments MFB and MFAB brought about decrease in the population density of *Pseudomonas* at every growth stage in the ginger rhizosphere soil as compared to that of control. In this respect MFB exerted more adverse effect than that of MFAB. However, the difference in between M and MF as well as MF and MFA at S_1, stage, MFB and MFAB at S_1, S_4 and S_5 stage was not significant by DMRT.

The population of *Pseudomonas* in the rhizosphere soils of ginger under control, M, MF and MFA exhibited a progressive increase from S_1 to S_3, S_1 to S_2, S_1 to S_3 and S_1 to S_4 stages, respectively with a gradual decline in respective rhizosphere soils upto S_6 stage. On the other hand, there was a decrease in the count of *Pseudomonas* in the rhizosphere soil under MFB and MFAB from S_1 to S_3 and from S_1 to S_2 stages, respectively with an immediate increase in the number of the cited bacterium of the respective series extended to S_5 stage. Then the population of both of the cited series declined at S_6 stage. However, the difference in between S_2 and S_3 as well as S_4 and S_5 for M, S_3 and S_4 as well as S_5 and S_6 for MF, S_1 and S_2, S_3 and S_4 as well as S_5 and S_6 for MFA, S_2 and S_3 and then S_4 to S_6 for MFB as well as S_2 and S_3 and S_4 to S_6 for MFAB was not significant.

All in all, MF resulted in the highest proliferation of *Pseudomonas* followed by these of MFA, M, control, MFAB and MFB, respectively.

The abundance of *Pseudomonas* in the rhizosphere soils of ginger increased progressively from S_1 to S_3 stage and then decreased gradually upto S_6 stage.

B) Severity of soft-rot disease of ginger :

a) Incidence of soft-rot disease of ginger in pot :

The table–57; fig. 43 shows the incidence of soft-rot disease of rhizome ginger at different growth stages under different treatment.

MF intensified the disease incidence of soft-rot of ginger from S_3 to S_6 stage as compared to that of control. On the other hand, MFB brought about retardation in the incidence of soft-rot disease at S_4 stage as composed to control but subsequently accelerated the incidence of the disease which was incidentally less intensive as compared to that of MF. Though, M, induced the incidence of disease from S_5 stage, the rate of disease incidence was more as compared to that of control but less as compared to that of MF at S_5 stage . MFA and MFAB exerted similar influence on the incidence of disease, however, the cited treatments brought about lesser impact on the incidence of disease as compared to that of M from S_5 to S_6 stage. However, the difference in between M and MFA, MFA and MFB as well as MFB and MFAB at S_4 was not significant by DMRT.

MF as well as control resulted in the occurrence of disease incidence of soft-rot of ginger from S_3 stage which, thereafter , accelerated progressively in subsequent stages. On the other hand, MFB brought about the incidence of soft-rot of ginger with a progressive rate from S_4 to S_6 stage . As such, M, MFA induced the disease incidence at a progressive note from S_5 stage onward. However, the difference in between S_3 and S_4, S_5 and S_6 for control, S_5 and S_6 for MF was not significant.

All in all, MF induced the highest incidence of disease followed by those of MFB and M. Control was next to MFB and MFA and MFAB resulted in similar influence on the disease incidence and both of them exerted the least impact on the incidence of disease.

TABLE–57 : **Disease incidence of ginger under the influence of organic manure and bacterization with efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture.**

Treatment	* Disease incidence (%) (Average of 4 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	**0.00 #(0.641)	0.00 (0.641)	3.30 (8.82)	10.00 (18.04)^{b}	30.00 (32.59)	50.00 (45.00)	15.55 (17.62)^{BC}
+M	0.00 (0.641)	0.00 (0.641)	0.00 (0.641)	0.00 (0.641)^{c}	50.0 (45.00)	75.0 (60.00)	20.83 (18 72)^{B}
MF	0.00 (0.641)	0.00 (0.641)	8.33 (10.42)	33.33 (35.00)^{a}	75.00 (60.00)	75.00 (60.00)	31.94 (27.78)^{A}
MFA	0.00 (0.641)	0.00 (0.641)	0.00 (0.641)	0.00 (0.641)^{c}	25.00 (25.21)	50.00 (45.00)	12.50 (12.12)^{C}
MFB	0.00 (0.641)	0.00 (0.641)	0.00 (0.641)	8.33 (10.42)^{bc}	41.66 (40.00)	75.00 (60.00)	20.83 (17.92)^{BC}
MFAB	0.00 (0.641)	0.00 (0.641)	0.00 (0.641)	0.00 (0.641)^{c}	25.00 (25.21)	50.00 (45.00)	12.50 (12.12)^{C}
Mean	0.00 (0.641)^{D}	0.00 (0.641)^{D}	1.93 (3.63)^{D}	6.94 (10.90)^{C}	41.11 (38.00)^{B}	62.50 (52.55)^{A}	
^LSD at 5%	Δ -	-	NS	14.28	NS	NS	
at 1%	–	–	NS	NS	NS	NS	

		LSD at 5%	at 1%
For Stage	-	5.91	7.85
Treatment	-	5.91	7.85
Interaction (Stage x Treatment)	-	14.47	NS

* Disease : Soft - rot of ginger occured under natural condition without inoculation of pathogens

** See foot note Table - 19

For + and ++ see foot note Table - 6

Values in the parenthesis are $Sin^{-1}\sqrt{1/4n}$ transformed values, where n= no. of plants

^ See foot note Table - 13

Δ Zero values of varience restrict the analysis.

With the age of crop, the disease incidence intensified progressively from S_3 to S_6 stages.

b) Intensity of soft-rot disease of ginger in pot :

The table-58; fig. 44 shows the intensity of soft-rot disease of ginger at different growth stages under the influence of different treatments.

The treatment MF resulted in higher disease intensity than that of control from S_3 to S_6 stage. On the other hand, M induced the same with lesser intensity than that of control from S_3 to S_5 stage and to that of MF from S_3 to S_6 stage. However, the impact of M on disease intensity was more vigorous as compared to that of control at S_6 stage. MFB brought about lower disease intensity at S_5 stage and high disease intensity at S_6 stage as compared to that of M but lower disease intensity at S_5 and S_6 stages when compared with MF. MFA and MFAB induced the least disease intensity at S_5 stage but subsequently the impact of MFAB on disease intensity was more harsh as compared to that of MFA but less intensive as compared to those of others. However, the difference in between control and M as well as M and MF at S_5 and S_6 stages, MFA and MFB as well as MFB and MFAB at S_4 stage was not significant by DMRT.

Under the control the intensity of soft-rot of ginger accelerated progressively from S_2 to S_6 stage. On the other hand, M and MF resulted in increase in the disease intensity, on and on, from S_3 to S_6 stage. As it were, MFA, MFB and MFAB induced a progressive enhancing influence on disease intensity of soft-rot of ginger from S_5 to S_6 stage. However, the difference in between S_5 and S_6 for control and MF was not significant.

All in all, MF induced the most favourable influence on the disease intensity followed by those of control, M, MFB, MFAB and MFA, respectively. However, the difference between control and M was not significant.

TABLE–58 : **Disease intensity of ginger under the influence of organic manure and bacterization with efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in pot culture.**

Treatment	* Disease intensity : Plant Disease Indese (PDI) (Average of 4 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	**0.00 #(0.641)	0.55 (4.25)	5.00 (12.92)	17.20 (24.50)^{b}	21.80 (27.81)^{ab}	22.00 (27.97)^{ab}	11.09 (16.35)^{B}
+M^{-}	0.00 (0.641)	0.00 (0.641)	3.70 (11.09)	14.81 (22.63)^{c}	20.36 (26.86)^{ab}	25.92 (30.60)^{a}	10.79 (15.40)^{B}
MF	0.00 (0.641)	0.00 (0.641)	11.11 (19.47)	22.22 (28.12)^{a}	28.14 (32.02)^{a}	30.36 (33.43)^{a}	15.30 (19.05)^{A}
MFA	0.00 (0.641)	0.00 (0.641)	0.00 (0.641)	0.00 (0.641)^{d}	3.70 (9.17)^{c}	11.11 (19.46)^{c}	2.46 (4.77)^{I}
MFB	0.00 (0.641)	0.00 (0.641)	0.00 (0.641)	0.00 (0.641)^{d}	14.81 (22.63)^{b}	28.29 (32.00)^{a}	7.18 (9.53)^{C}
MFAB	0.00 (0.641)	0.00 (0.641)	0.00 (0.641)	0.00 (0.641)^{d}	3.70 (9.17)^{c}	17.28 (24.35)^{bc}	3.00 (6.01)^{H}
Mean	0.00 (0.641)^{E}	0.09 (1.24)^{E}	3.30 (7.56)^{D}	9.03 (12.86)^{C}	15.41 (21.59)^{B}	22.49 (27.77)^{A}	
^LSD at 5%	Δ -	-	-	0.513	5.88	5.22	
at 1%	-	-	-	1.07	12.10	10.71	

		LSD at 5%	at 1%
For Stage	-	1.20	1.59
Treatment	-	1.20	1.59
Interaction (Stage x Treatment)	-	2.94	3.89

* See foot note Table - 57

** See foot note Table - 19

For + and ++ see foot note Table - 6

Values in the parenthesis are $Sin^{-1}\sqrt{1/4n}$ transformed values, where n= no. of plants

^ See foot note Table - 13

Δ Zero values of varience restrict the analysis.

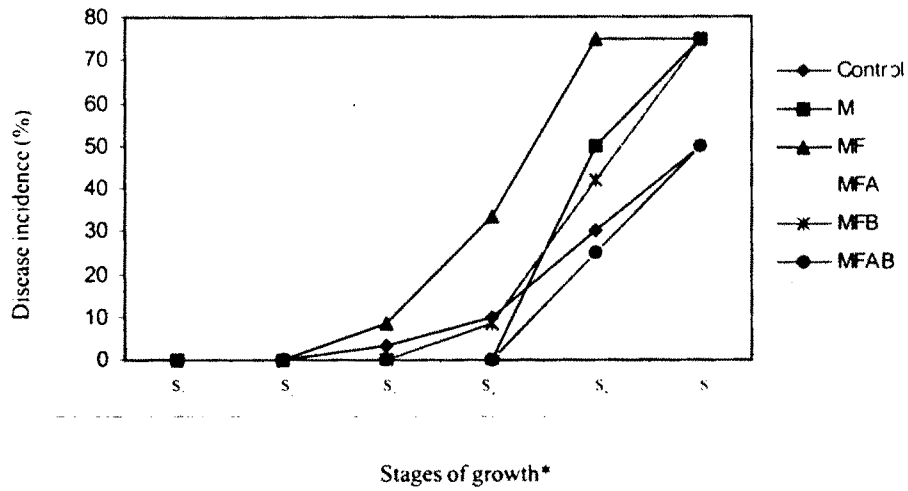


Fig. 43. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the incidence of soft-rot disease of ginger in pot.

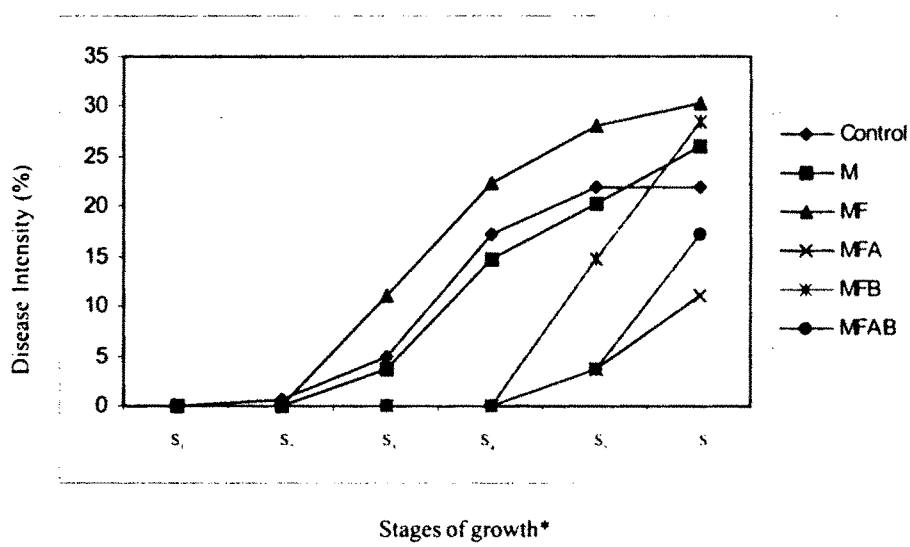


Fig. 44. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the Intensity of soft-rot disease of ginger in pot.

* S_1 - S_6 = For ginger 30, 60, 90, 120, 150, 180 days after planting - at sprouting of rhizome, early emergence of pseudostem, late emergence of pseudostem, full growth of pseudostem, near maturity of pseudostem and harvesting stage of ginger, respectively.

In general, the intensity of soft-rot of ginger accelerated progressively from S_2 to S_6 stage.

Principle Component Analysis :

Correlation study (table–59a) revealed that there existed significant correlation between disease intensity and incidence (r = 0.84), among *Fusarium*, disease incidence (r = 0.87) as well as intensity (r = 0.98) among *Pythium*, disease incidence (r = 0.96) and intensity (r = 0.84). Correlation also existed between *Pseudomonas* and either of disease intensity (r = 0.49) and incidence (r = 0.52) though not significant. Now to adjudge the performance of all six treatments with respect to disease intensity and incidence through causal organisms like *Fusarium*, *Pythium* and *Pseudomonas*, data were analysed using 'Principle Component Analysis' which calculated orthogonal axes (Principle components) through the data matrix in the direction of highest variance. The analysis was performed on the basis of correlation matrix involving above mentioned variables. The score of each treatment on the principle component was plotted in bi-variate Scattergram to allow visual assessment of the position of these treatments in the direction of these components.

Table–59b shows the eigen values and eigen vectors for the principle components obtained from the correlation matrix. About 99.365% of the variation in the pot experiment was explained by the first three components. The 1st component (PC_1) accounted for 79.37% of the variation in the correlation matrix. The variables loading heavily on the PC_1 were disease incidence, intensity, *Fusarium* and *Pythium*. The 2nd component (PC_2) accounted for 14.9% of the total variation which had high loading from the variable *Pseudomonas* count. The 3rd component (PC_3) accounted for 5.09% of the total variation and having positive loading from disease incidence and *Pythium* density. The mean score of components 1 and 2, 2 and 3 are plotted in fig. 45a & 45b and from the fig. 45a, if PC_1 is considered,

TABLE - 59a : Correlations among different pathogenic organisms and disease incidence as well as intensity of soft-rot of ginger in pot. +

	Disease incidence	Disease intensity
Fusarium	0.870*	0.980**
Pythium	0.960**	0.840*
Pseudomonas	0.520	0.490
Disease incidence	-	0.840*

+ v value at 5% = 0.811
1% = 0.917
* = Significant at 5%
** = Significant at 1%

TABLE-59b : Eigen values and eigen vectors for the Principle component obtained from the correlation matrix of the five variables under study for six treatments applied in pot experiment.

Variable	Eigen vectors for Principle Components				
	1	2	3	4	
Disease intensity	0.447	–0.096	–0.573	0.270	–0.601
Disease incidence	0.480	–0.166	0.513	–0.603	–0.360
Fusarium	0.487	–0.009	–0.449	–0.379	0.646
Pythium	0.461	–0.375	0.420	0.616	0.302
Pseudomonas	0.305	0.915	0.173	0.201	0.021
Eigen value	3.969	0.745	0.255	0.019	0.012
Percentage Variance	79.371	14.902	5.092	0.386	0.249
Cumulative Variance	79.371	94.273	99.365	99.751	100.000

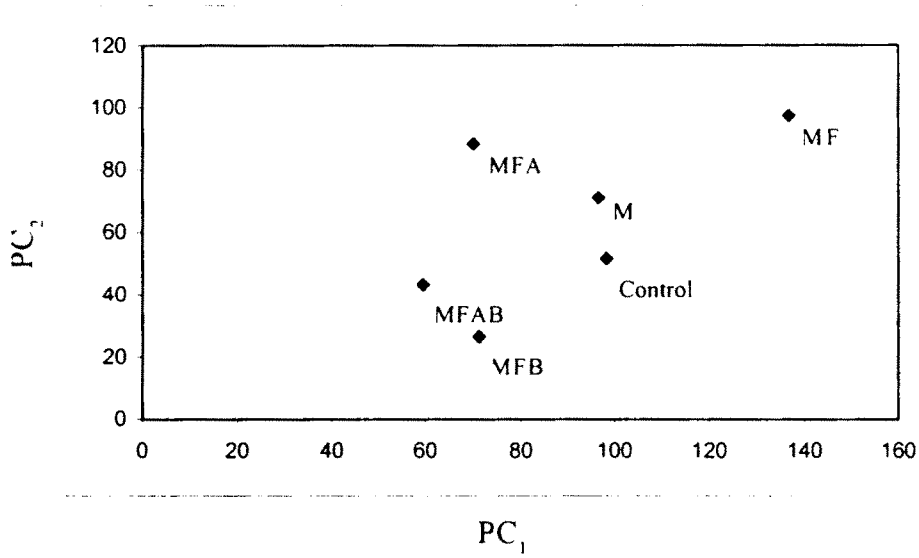


Fig. 45a. PC_1 Vs PC_2 scattergram to show the relative positions of the treatments in relation to disease incidence and intensity of soft-rot ginger in pot.

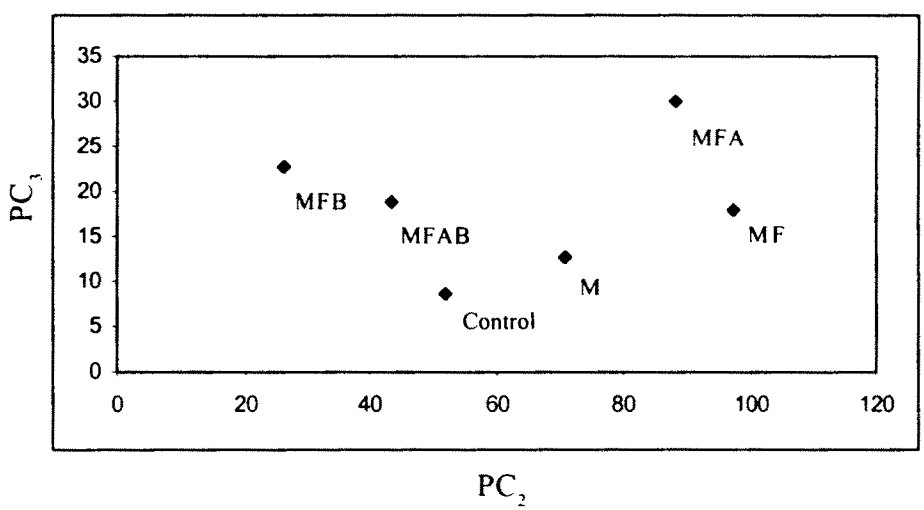


Fig. 45b. PC_2 Vs PC_3 scattergram to show the relative positions of the treatments in relation to disease incidence and intensity of soft-rot ginger in pot.

it is apparent that percent disease incidence and intensity was the highest under fertilizers treated pots and it was cased by *Fusarium* and *Pythium*. The least amount of disease was produced by *Fusarium* and *Pythium* under bacterization of rhizome with *Azotobacter* and *Bacillus* together as compared to individual inoculation. PC_2 revealed that *Pseudomonas* played a role in disease incidence and intensity in fertilizers treated pots. However, least amount of disease was observed under *Bacillus* inoculated series as compared to dual inoculation. Considering PC_3 (fig. 45b), it can be stated that disease incidence under the bacterization series was due to *Pythium*. However, least disease incidence was observed under bacterization of rhizome with dual inoculation.

Experiment No. 10 – Soil borne plant pathogenic ginger rhizosphere microflora in relation to disease incidence and intensity in field condition.

A) Enumeration of probable pathogenic organisms of soft-rot disease of ginger.

a) Total number of *Fusarium* present in the rhizosphere soils of ginger in field :

Total number of *Fusarium* present per gram dry rhizosphere soils of ginger under different treatments are presented in table–60, fig. 47. The number of *Fusarium* present in the rhizosphere of ginger was more as compared to that of initial number with the exception of these under MFA from S_1 to S_3 stage, MFB at S_1 stage as well as MFAB from S_1 to S_3 stage.

The treatment MF resulted in higher proliferation of *Fusarium* propagules in the rhizosphere soils of ginger as compared to those of others at each growth stage. On the other hand, the treatments - M, MFA, MFB and MFAB induced adverse influence on the propagules of *Fusarium* as compared to that of control at all the growth the stages of ginger MFB

TABLE–60 : Total number of *Fusaium* present in the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in field experiment.*

Treatment	Number of *Fusarium* (CFU x 10^3) g^{-1} dry soils (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	**33.41^{b}	55.12^{b}	80.51^{b}	98.02^{b}	72.78^{b}	63.81^{b}	67.27^{B}
+M	28.91^{bc}	47.79^{c}	73.26^{b}	95.79^{b}	70.87^{b}	61.20^{b}	62.97^{C}
MF	63.16^{a}	83.10^{c}	101.87^{a}	109.78^{a}	110.88^{a}	102.93^{a}	95.28^{A}
MFA	16.84^{d}	17.00^{e}	29.55^{c}	47.97^{cd}	31.16^{cd}	23.86^{c}	27.73^{E}
MFB	22.03^{cd}	30.85^{d}	37.45^{c}	52.39^{c}	41.62^{c}	32.82^{c}	36.19^{D}
MFAB	18.23^{d}	15.24^{e}	20.77^{e}	38.45^{d}	28.81^{d}	24.61^{c}	24.35^{E}
Mean	30.43^{E}	41.51^{D}	57.23^{B}	73.73^{A}	71.48^{A}	51.53^{C}	
LSD at 5%	8.28	7.32	8.89	9.66	10.98	13.43	
at 1%	12.55	11.08	13.45	14.63	16.62	20.33	

		LSD at 5%	at 1%
For Stage	-	3.37	4.52
Treatment	-	3.37	4.52
Interaction (Stage x Treatment)	-	8.26	11.08

* Total number of *Fusarium* present in initial soil - 23.8 (CFU x 10^3) g^{-1} dry soil.

** See foot note Table–19

For + and ++ See foot note Table - 6

exerted more drastic effect on the proliferation of *Fusarium* than that of M at every growth stage. The effect of MFA was more deleterious than that of MFB in relation to the abundance of *Fusarium* propagules in the ginger rhizosphere at all the growth stages. Above all, MFAB induces the most inimical influence on the propagules of *Fusarium* at every growth stage of ginger. However, the difference in between control and M as well as, MFA and MFB at all but S_2 stage, MFB and MFAB at S_1 and S_6 stages were not significant by DMRT.

The number of *Fusarium* propagules in the rhizosphere soils of ginger under control, M, MFA, MFB and MFAB progressively enhanced from S_1 to S_4 stage which, thereafter, gradually decreased upto S_6 stage. On the other hand, the proliferation of the cited fungi in the rhizosphere soils of ginger increased, on and on, from S_1 to S_5 stage and then decreased at S_6 stage. However, the difference in between S_3 and S_4, S_4 and S_5, S_5 and S_6 for MF, S_1 and S_2, S_5 and S_6 for MFA, S_1 and S_2, S_2 and S_3 for MFB, S_1 and S_2, S_2 and S_3, S_3 to S_5, S_5 and S_6 for MFAB was not significant.

All in all, the most adverse effect on the propagules of *Fusarium* was induced by MFAB followed by those of MFA, MFB, M, control and MF, respectively. The difference in between MFA and MFAB was, however, not significant.

In general, the propagules of *Fusarium* increased progressively from S_1 to S_4 stage in the rhizosphere of ginger which then gradually decreased upto S_6 stage.

b) Total number of *Pythium* present in the rhizcsphere soils of ginger in field :

Table–61; fig. 48 shows the total number of *Pythium* present per gram dry rhizosphere soils of ginger under different treatment. The number of *Pythium* in ginger rhizosphere was universally more as compared to that occurred in initial soil.

TABLE–61 : Total number of *Pythium* present in the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in field experiment.*

Treatment	Number of *Pythium* (CFU x 10^3) g^{-1} dry soils (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++24.24^{c}	35.01^{c}	70.77^{a}	79.60^{ab}	70.30^{b}	56.57^{b}	56.08^{B}
+M	19.92^{c}	31.65^{c}	64.26^{a}	70.86^{b}	59.91^{c}	53.47^{bc}	50.01^{C}
MF	60.48^{a}	65.53^{a}	79.75^{a}	85.02^{a}	81.31^{a}	70.85^{a}	73.82^{A}
MFA	25.59^{c}	28.96^{c}	37.10^{bc}	54.28^{c}	51.11^{d}	45.22^{cd}	40.37^{D}
MFB	41.59^{b}	46.59^{b}	49.93^{b}	56.81^{c}	53.45^{cd}	50.50^{bc}	49.80^{B}
MFAB	23.89^{c}	26.51^{c}	28.89^{c}	43.58^{d}	41.34^{e}	39.76^{d}	33.99
Mean	32.61^{E}	39.04^{D}	55.11^{B}	65.02^{A}	59.57^{B}	52.72^{C}	
LSD at 5%	12.53	8.12	14.72	10.12	6.74	8.22	
at 1%	18.97	12.29	22.29	15.32	10.74	12.45	

		LSD at 5%	at 1%
For Stage	-	3.53	4.73
Treatment	-	3.53	4.73
Interaction (Stage x Treatment)	-	8.66	11.62

* Total number of *Pythium* present in initial soil - 13.0 (CFU x 10^3) g^{-1} dry soil.

** See foot note Table–19

For + and ++ See foot note Table - 6

The figures depicted in the table–61 reveal that the treatment MF resulted MF resulted in an increase in the number of *Pythium* propagules in the rhizosphere of ginger as compared to that of control at each growth stage. On the other hand, M reduced the same as compared to control at every growth stage. MFB resulted in more drastic influence than that of M on the propagules of *Pythium* from S_3 to S_6 stage. On the other hand, the effect of MFA was more deleterious than that of MFB on the population of the said fungi. As such, MFAB resulted in the most inimical influence on the proliferation of *Pythium* in the rhizosphere soils of ginger at all the growth stages. However, the difference in between control and M at all but S_5 stage, M and MF at S_3 stage. MFA and MFB from S_3 to S_6 stage, MFA and MFAB from S_1 to S_3 and then at S_6 stages was not significant by DMRT.

The number of *Pythium* propagules in the rhizosphere soils of ginger under control, M, MF, MFA, MFB and MFAB progressively enhanced right from the begining to S_4 stage which then declined gradually upto the final stage. However, the difference in between S_3 and S_4, S_5 and S_6 for M, S_1 and S_2, S_3 to S_5 for MF, S_1 and S_2, S_2 and S_3, S_4 to S_6 for MFB and MFAB was not significant.

All in all, MFAB induced the most deleterious effect on the number of *Pythium* propagules in the ginger rhizosphere followed by those of MFA, MFB, M, control and MF, respectively. However, the difference in between M and MFB was not significant.

In general, the count of *Pythium* increased, on and on, from S_1 to S_4 stage which, thereafter, gradually decreased in the succeeding stages.

c) Total number of viable *Pseudomonas* present in the rhizosphere of ginger in field.

The proliferation of *Pseudomonas* in ginger rhizosphere was universally more than that in the initial soil (table–62, fig. 49).

Results show that the treatment MFB and MFAB resulted in decrease in the number of *Pseudomonas* in the rhizosphere soils of ginger at all the growth stage as compared to that of control. In the respect, MFB was more inimical towards the proliferation of the said genera at each growth stage than that of MFAB. On the other hand, M, MF and MFA boosted up the population of *Pseudomonas* as compared to that of control. MFA was superior to M in relation to the proliferation of *Pseudomonas* in each but S_3 stage. On the other hand, MF resulted in the highest proliferation of *Pseudomonas* population at each growth stage of ginger. However, the difference in between control and M from S_4 to S_6 stage, MF and MFA at S_4 stage as well as MFB and MFAB at S_2 and S_5 was not significant by DMRT.

The population of *Pseudomonas* in the rhizosphere soils of ginger under control, M and MF exhibited a progressive increase from S to S_3 stage and then gradually decrease upto S_6 stage. On the other hand, the cited bacterium under the influence of MFA increased, on and on, from S_1 to S_4 stage and then decreased upto S_6 stage. However, the viable count of *Pseudomonas* in the rhizosphere soil of ginger under MFB and MFAB decreased from S_1 to S_3 and from S_1 to S_2 stages, respectively with an immediate progressive increase of the cited bacterium of the respective soil series upto S_6 stage. However, the difference in between S_4 and S_5, S_5 and S_6 for M, S_4 and S_5 MF, S_2 and S_3, S_3 and S_4 for MFA, S_4 and S_5, S_5 and S_6 for MFB, S_2 and S_3 and then S_4 to S_6 for MFAB was not significant.

All in all, MF resulted in the highest proliferation of *Pseudomonas* in the ginger rhizosphere followed by those of MFA, M, Control, MFAB and MFB, respectively.

TABLE–62 : **Total number of *Pseudomonas* present in the rhizosphere soils of ginger as influenced by organic manure and inoculation of efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in field experiment.***

Treatment	Number of *Pseudomonus* (CFU x 10^3) g^{-1} dry soils (Average of duplicate sets) (Average of 2 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++88.46^{c}	101.16^{c}	103.24^{d}	90.12^{bc}	83.67^{c}	80.25^{cd}	91.15^{D}
+M	110.53^{b}	131.78^{b}	117.60^{c}	104.32^{b}	94.06^{c}	88.91^{c}	107.86^{C}
MF	135.75^{a}	155.40^{a}	178.95^{a}	149.11^{a}	143.23^{a}	128.33^{a}	148.46^{A}
MFA	114.85^{b}	127.83^{b}	138.36^{b}	146.46^{a}	127.18^{b}	113.69^{b}	128.06^{B}
MFB	66.08^{e}	52.89^{d}	41.82^{f}	56.18^{d}	66.03^{d}	69.44^{d}	59.24^{E}
MFAB	75.46^{d}	54.29^{d}	55.50^{e}	75.64^{c}	79.56^{cd}	82.06^{c}	70.48^{E}
Mean	98.52^{B}	103.89^{A}	105.91^{A}	103.63^{A}	98.99^{B}	93.78^{C}	
LSD at 5%	9.27	13.26	13.44	15.76	14.20	11.11	
at 1%	14.03	20.08	20.36	23.87	21.50	16.82	

		LSD at 5%	at 1%
For Stage	-	4.40	5.88
Treatment	-	4.40	5.88
Interaction (Stage x Treatment)	-	10.78	14.47

* Total number of *Pseudomonus* present in initial soil - 35.0 (CFU x 10^3) g^{-1} dry soil.

** See foot note Table–19

For + and ++ See foot note Table - 6

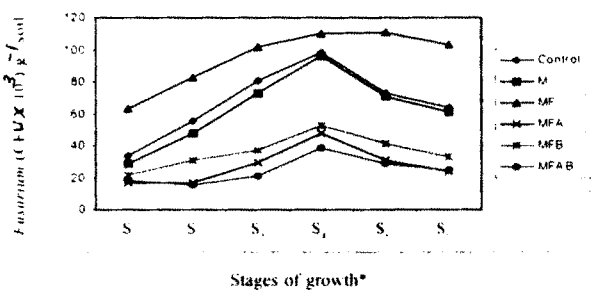


Fig. 46. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation of *Fusarium* in rhizosphere soils of ginger in field.

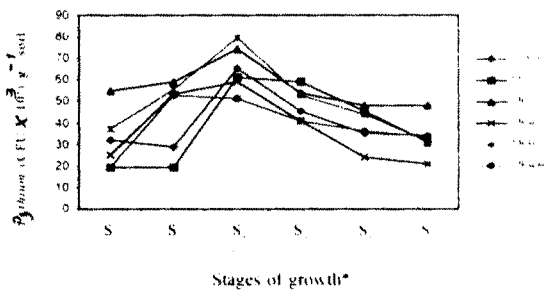


Fig. 47. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation of *Pythium* in rhizosphere soils of ginger in field.

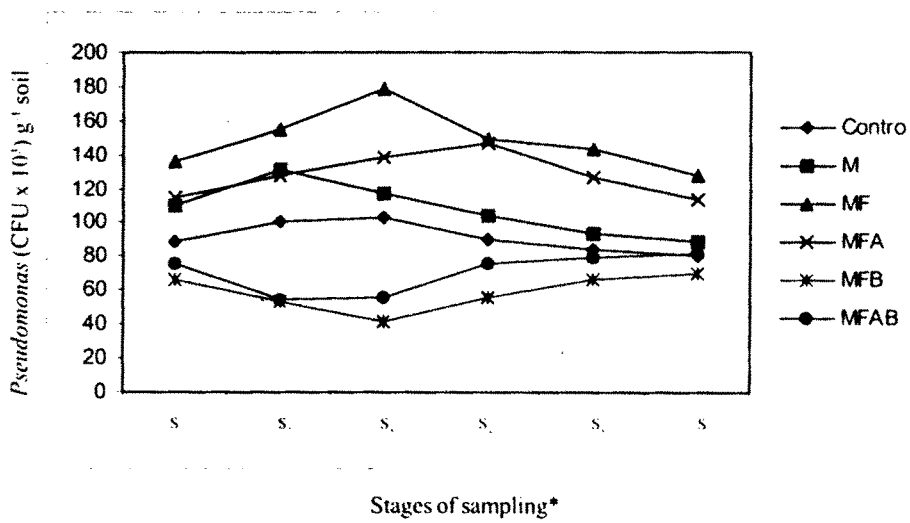


Fig. 48. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the proliferation of *Pseudomonas* in the rhizosphere soils of ginger in field.

* S_1 - S_6 = For ginger 30, 60, 90, 120, 150, 180 days after planting - at sprouting of rhizome, early emergence of pseudostem, late emergence of pseudostem, full growth of pseudostem, near maturity of pseudostem and harvesting stage of ginger, respectively.

In general, the count of *Pseudomonas* increased, on and on, from S_1 to S_3 stage followed by a gradual decrease in subsequent stages. However, the difference among S_3, S_4 and S_5 stage was not significant.

B) Severity of soft-rot disease of ginger in field :

a) Incidence of soft-rot disease of ginger in field condition :

The table–63, fig. 50 shows the incidence of soft-rot disease of rhizome ginger at different growth stages under different treatments.

The figures presented in the table 63 reveals that the treatment MF resulted in acceleration of percent disease incidence of soft-rot of ginger from S_1 to S_6 stage as compared to that of control. On the other hand, M, MFA, MFB and MFAB brought about dimuniting influence on the same throughout the experimental period. However, MFB decreased the percent disease incidence of soft-rot of ginger as compared to that of M from S_2 to S_6 stage. Through, MFAB caused deterioration of disease incidence as compared to that of MFB from S_1 to S_4 stage, the said treatment, thereafter, induced an increasing effect during subsequent stages. MFA resulted in an althrough reduction in the percent disease incidence from S_2 to S_6 stage as compared to that of MFB, through, the same induced high disease incidence than that of MFAB at S_2 stage. However, the difference in between control and M at all the stages, M and MF at all but S_1 stage, MFA and MFB at S_1, S_5 and S_6 stages, MFB and MFAB at all but S_2 and S_3 stages was not significant by DMRT.

The percent disease incidence of soft-rot of ginger under control, M, MF, MFB progressively increased from S_1 to S_6 stage. On the other hand, the percent disease incidence of the same under MFA and MFAB increased, on and on, from S_2 to S_6 stage. However, the difference in between the stages from S_3 to S_6 for M, from S_1 to S_4 and S_5 and S_6 for MF, from S_4 to S_6 for MFA, from S_4 to S_6 for MFB and MFAB was not significant.

TABLE–63 : Disease incidence of ginger under the influence of organic manure and bacterization with efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in field experiment.

Treatment	* Disease incidence (%) (Average of 4 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	++3.33 #(8.82)^{b}	23.33 (28.78)^{a}	33.33 (35.25)^{a}	35.00 (36.27)^{ab}	41.66 (40.17)^{ab}	48.33 (44.04)^{a}	30.83 (32.22)^{B}
+M	1.66 (4.73)^{b}	20.00 (26.07)^{a}	30.00 (33.16)^{a}	33.33 (35.25)^{ab}	40.00 (39.15)^{abc}	41.66 (40.11)^{ab}	27.77 (29.74)^{B}
MF	21.66 (27.59)^{a}	28.33 (32.14)^{a}	36.66 (37.22)^{a}	40.00 (39.14)^{a}	51.66 (45.95)^{a}	51.66 (45.95)^{a}	38.32 (38.00)^{A}
MFA	0.00 (0.641)^{b}	8.33 (10.66)^{b}	11.66 (19.307)^{b}	18.33 (25.30)^{d}	28.33 (32.09)^{c}	30.00 (37.16)^{b}	16.10 (20.19)^{D}
MFB	1.66 (4.73)^{b}	13.33 (21.33)^{a}	26.66 (31.07)^{a}	28.33 (32.09)^{bc}	31.66 (34.18)^{bc}	31.66 (34.18)^{b}	22.21 (26.26)^{C}
MFAB	0.00 (0.641)^{b}	3.33 (8.82)^{b}	13.33 (21.33)^{b}	21.66 (27.59)^{cd}	33.33 (35.25)^{bc}	33.33 (35.25)^{b}	17.49 (21.48)^{D}
Mean	4.71 (7.86)^{E}	16.10 (21.30)^{D}	25.27 (29.55)^{C}	29.44 (32.61)^{B}	37.77 (37.80)^{A}	39.44 (38.78)^{A}	
^LSD at 5%	9.42	10.59	6.57	6.21	7.58	7.36	
at 1%	13.71	15.42	9.54	9.05	NS	10.71	

		LSD at 5%	at 1%
For Stage	-	3.02	4.01
Treatment	-	3.02	4.01
Interaction (Stage x Treatment)	-	7.39	NS

* Disease : Soft - rot of ginger occured under natural condition without inoculation of pathogens

** See foot note Table-19

For + and ++ See foot note Table - 6

^ See foot note Table-13

See foot note Table-57

NS-Non significant.

All in all, MF resulted in the highest disease incidence of soft-rot of ginger followed those of M and control. M and control exerted similar influence and were next to MF in relation to disease incidence of soft-rot of ginger. On the other hand, MFA and MFAB resulted in similar impact on percent disease incidence and both of them exerted the least influence on disease incidence.

In general, the occurrence of disease incidence of soft-rot of ginger accelerated, on and on, from S_1 to S_6 stage.

b) Intensity of soft-rot disease of ginger in field condition :

The table–64, fig. 51 shows the intensity of soft-rot disease of ginger at different growth stages under the influence different treatments.

Results presented in the table–64 reveals that the treatment MF accentuated the disease intensity of soft-rot of ginger from S_1 to S_6 stage as compared to that of control. On the other hand, M and MFA, MFB and MFAB decreased the same from S_3 to S_6 stage as compared to that of control. Though MFB brought about higher disease intensity than that of M at S_2 stage, the said treatment caused less impact on the disease intensity from S_3 to S_6 stage. MFA was next to MFB in relation to disease intensity of soft-rot of ginger from S_2 to S_6 stage. As such, MFAB caused the least impact on the disease intensity. However, the difference in between, control and M at S_2, S_3 and S_5 stage, MFA and MFB as well as MFB and MFAB at S_2 was not significant by DMRT.

Control, MFA and MFAB induced a progressive increase in disease intensity of soft-rot ginger from S_3 to S_6 stage. On the other hand, M and MFB exerted an increasing, on and on, influence on the disease intensity from S_2 to S_6 stage. As such, MF resulted in progressive acceleration of disease intensity from S_1 to S_6 stage. However, the difference in between S_5 and S_6 stage for control, M and MF was not significant.

TABLE–64 : **Disease intensity of ginger under the influence of organic manure and bacterization with efficient ginger rhizosphere nitrogen fixing *Azotobacter* and phosphate solubilizing *Bacillus* strains in field condition.**

Treatment	* Disease intensity : Percent Disease Index (PDI) (Average of 4 replications)						
	**S_1	S_2	S_3	S_4	S_5	S_6	Mean
Control	**0.00 #(0.641)	0.00 $(0.641)^b$	7.21 $(15.57)^{ab}$	17.24 $(24.50)^b$	23.80 $(29.12)^b$	25.10 $(30.06)^b$	12.22 $(16.75)^B$
+M	0.00 (0.641)	0.18 $(1.845)^b$	5.80 $(13.93)^b$	13.33 $(28.29)^c$	21.85 $(27.79)^{bc}$	21.99 $(27.50)^c$	10.52 $(15.77)^B$
MF	0.18 (1.845)	5.00 $(12.921)^a$	9.44 $(17.88)^a$	27.77 $(31.78)^a$	33.33 $(35.26)^a$	36.60 $(37.22)^a$	18.72 $(22.82)^A$
MFA	0.00 (0.641)	0.00 $(0.641)^b$	0.55 $(3.64)^d$	3.33 $(10.41)^e$	8.32 $(16.75)^d$	11.66 $(19.96)^e$	3.91 $(8.97)^D$
MFB	0.00 (0.641)	0.33 $(1.845)^b$	2.03 $(8.06)^c$	7.40 $(15.77)^d$	17.22 $(24.43)^c$	21.47 $(27.60)^c$	8.07 $(13.06)^C$
MFAB	0.00 (0.641)	0.00 $(0.641)^b$	0.36 $(3.04)^d$	2.55 $(9.17)^e$	7.96 $(16.32)^d$	11.44 $(22.26)^d$	3.77 $(8.67)^D$
Mean	0.03 $(0.841)^F$	0.91 $(3.089)^E$	4.06 $(10.36)^D$	11.93 $(18.82)^C$	18.74 $(24.96)^B$	21.37 $(27.43)^A$	
^LSD at 5%	NS	2.14	2.87	3.21	3.45	1.95	
at 1%	NS	3.13	4.16	4.66	5.02	2.68	

		LSD at 5%	at 1%
For Stage	-	0.98	1.30
Treatment	-	0.98	1.30
Interaction (Stage x Treatment)	-	2.39	3.18

* See foot note Table - 63
** See foot note Table-19
For + and ++ See foot note Table - 6
^ See foot note Table-13
# See foot note Table-57
NS-Non significant.

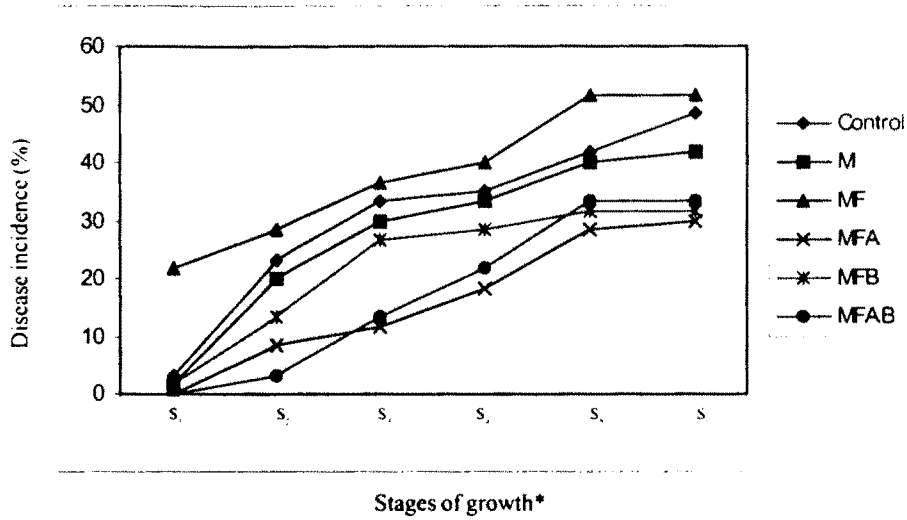


Fig. 49. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the incidence of soft-rot disease of ginger in field.

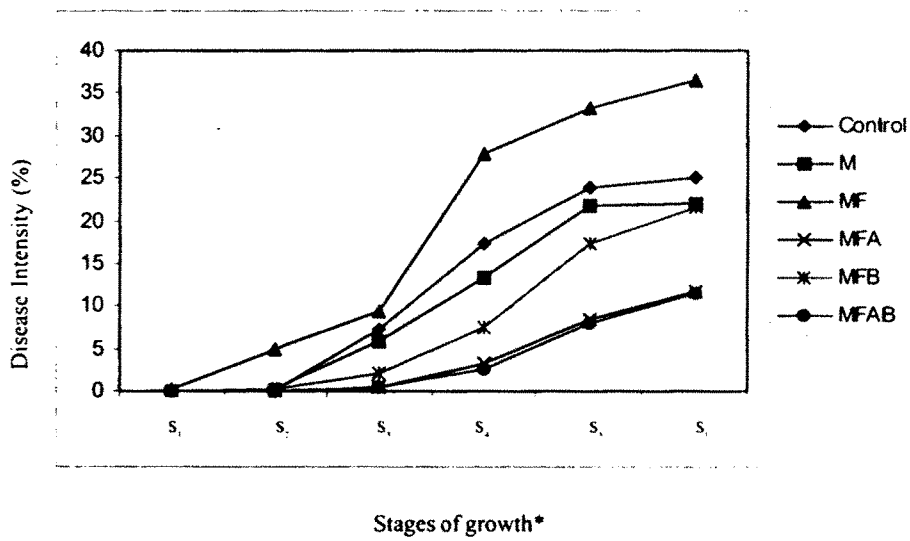


Fig. 50. Effect of organic manure and inoculation of *Azotobacter* and *Bacillus* strains on the intensity of soft-rot disease of ginger in field.

* S_1 - S_6 = For ginger 30, 60, 90, 120, 150, 180 days after planting - at sprouting of rhizome, early emergence of pseudostem, late emergence of pseudostem, full growth of pseudostem, near maturity of pseudostem and harvesting stage of ginger, respectively.

All in all, MF resulted in the highest disease intensity. M and control imparted similar influence on disease intensity and were next to MF. On the other hand, MFA and MFAB exerted similar impact on disease intensity and both of them induced the least influence on the disease intensity of soft-rot of ginger.

In general, the occurrence of the disease intensity of soft-rot of ginger increased progressively from S_1 to S_6 stages.

Principle Component Analysis :

Correlation study (table–65a) revealed that there existed significant correlation between disease intensity and incidence (r = 0.99) among *Fusarium*, disease intensity (r = 0.98) as well as incidence (r = 0.98), among *Pythium*, disease intensity (r = 0.98) as well as incidence (r = 0.96). Correlation also existed among *Pseudomonas*, disease intensity (r = 0.50) and incidence (r = 0.44), though not significant. To adjudge the performance of all the six treatments with respect to disease intensity and incidence through causal organisms like *Fusarium*, *Pythium* and *Pseudomonas*, data were analysed using 'Principle Component Analysis' as described earlier.

Table–65b shows eigen values and eigen vectors for the principle Components obtained from correlation matrix. About 99.93% of the total variation in the field experiment was explained by the first three components. The first component (PC_1) accounted for 85.04% of the variation in the correlation matrix. The variables loading heavily on the PC_1 were disease intensity, incidence, *Fusarium* and *Pythium*. The second component (PC_2) accounted for 13.69% of the total variation on which had high loading from the variable *Pseudomonas* count. The third component (PC_3) accounted for only 1.91% of the total variation and having positive loading from disease intensity and *Pythium* count. The mean score of components 1 and 2, 2 and 3 are plotted in fig. 51a & 51b. From the fig. 51a, if PC_1 is considered, it is apparent that percent disease incidence and

TABLE - 65a. Correlations among different pathogenic organisms and disease incidence as well as intensity of soft-rot of ginger in field. +

	Disease incidence	Disease intensity
Fusarium	0.980**	0.980**
Pythium	0.960**	0.980**
Pseudomonas	0.440	0.500
Disease incidence	-	0.990**

+ r value at 5% = 0.811

1% = 0.917

* = Significant at 5%

** = Significant at 1%

TABLE-65b. Eigen values and eigen vectors for the Principle component obtained from the correlation matrix of the five variables under study for six treatments applied in field experiment.

Variable	Eigen vectors for Principle Components			
	1	2	3	4
Disease intensity	0.478	–0.189	0.042	–0.846
Disease incidence	0.472	–0.272	–0.211	0.425
Fusarium	0.479	–0.051	–0.596	0.155
Pythium	0.475	–0.093	0.774	0.281
Pseudomonas	0.306	0.938	–0.008	–0.011
Eigen value	4.252	0.685	0.060	0.004
Percentage Variance	85.047	13.692	1.911	0.071
Cumulative Variance	85.047	98.738	99.929	100.000

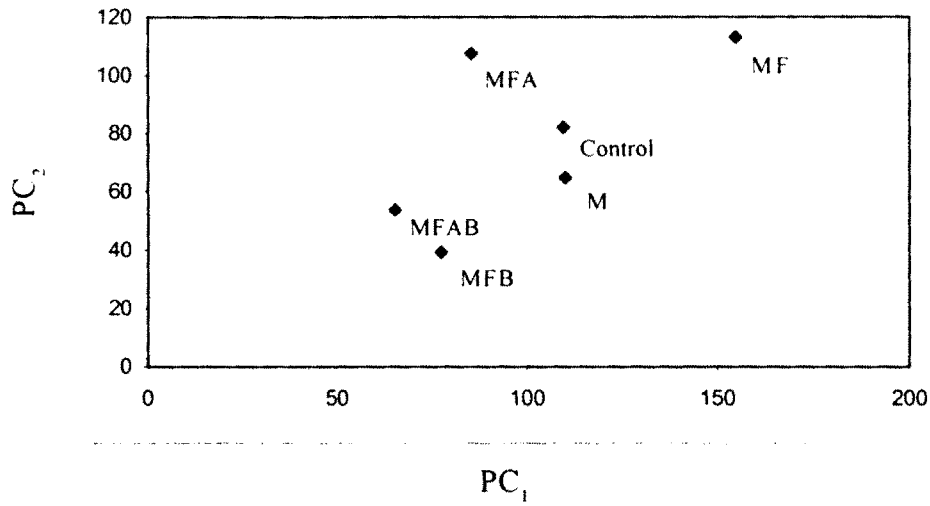


Fig. 51a. PC_1 Vs PC_2 scattergram to show the relative positions of the treatments in relation to disease incidence and intensity of soft-rot ginger in field.

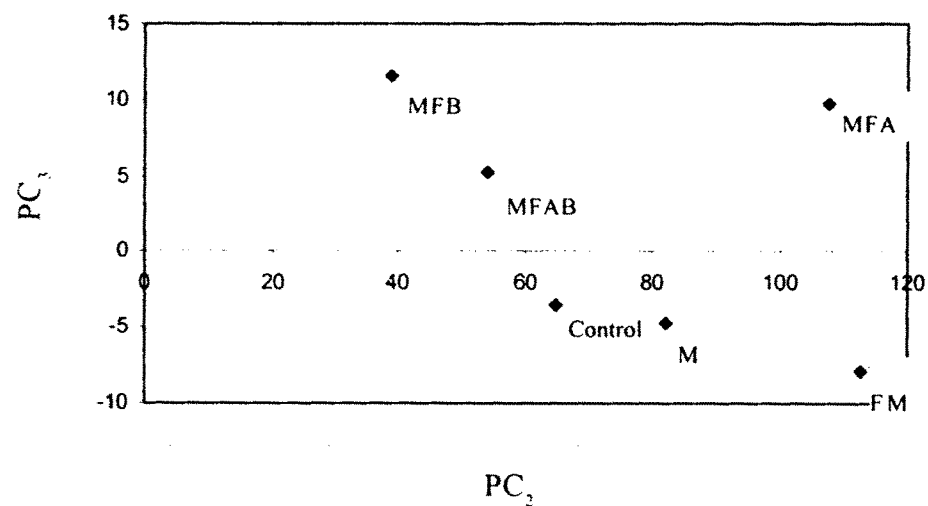


Fig. 51b. PC_2 Vs PC_3 scattergram to show the relative positions of the treatments in relation to disease incidence and intensity of soft-rot ginger in field.

intensity was the highest under fertilizers treated plots and it was caused by *Fusarium* and *Pythium*. The least amount of disease was produced by *Fusarium* and *Pythium* under bacterization of rhizome with combined inoculation of *Azotobacter* and *Bacillus* as compared to individual inoculation. PC_2 reveals that *Pseudomonas* played a role in producing disease in fertilizers treated plots. However, the least amount of disease produced by *Pseudomonas* was observed under *Bacillus* inoculated series as compared to dual inoculation. Considering PC_3 in fig. 51b, it can be stated that disease intensity under bacterization series was due to *Pythium*. However, least disease intensity was observed under bacterization of rhizome with combined inoculation as compared to single inoculation either *Azotobacter* or *Bacillus* alone.

CHAPTER IV

Discussion

Chapter IV

DISCUSSION

Experiment No. 1 – Decomposition of FYM in soil :

Farmyard manure is one of the oldest manures used since the time of cultivating crops was first adopted by mankind. The cited manure is considered as the sustainer of soil fertility. The bulkiness of FYM benefits the physical properties of soil. It adds to soil plant nutrients and improves their availability besides augmenting the reserves of energy and other metabolic requirements of various beneficial soil microorganisms. Moreover, it furnishes soil with fair quantities of growth promoting substances highly beneficial to plant life (Mishustin and Shilnikova, 1971).

As such, FYM is the admixture of excrements of farm animals together with the litter used as bedding in animal shed, the unconsumed fodder and domestic wastes at various stages of decomposition. Cosequently, the composition of FYM generally available in Indian farms varies very greatly.

However, a good quality FYM is the one which is well docomposed as it has the best potentiality of harnessing soil with plant nutrients. Carbondioxide evolution is a measure of microbial activity in soil. (Pramer and Schmidt, 1964). Organic matter on addition to soil is readily attacked by a great variety of microorganisms (Alexander, 1977). As a consequence, carbondioxide is evolved from soil. But the rate of decomposition of organic additives from different sources are not uniform. It depends upon the chemical composition of the organic additives (Mukherjee and Gaur, 1980 and Mukherjee *et. al.*, 1990), density of autochthonous population (Gaur *et al.*, 1973) and various other

environmental factors. Inorganic nutrients often enhance the rate of decomposition of organic matter (Couture and Fortin, 1983). The present investigation envisages the rate of decomposition of two types of FYM in soil.

Two types of FYM – one procured from local farm house (FH-FYM) and the other from RRS, Kalimpong, Darjeeling (RRS-FYM) were incorporated in soil with or without inorganic fertilizers and their rate of decomposition was determined in terms of evolution of carbondioxide.

Perusal of results (table–3) reveals that there was profuse evolution of carbondioxide, irrespective of treatment on the first day of incubation. Profuse evolution of carbondioxide is the reflection of enhanced degradation of native humus as well as dead organisms due to higher microbial activity in the presence of optimum temperature and moisture. The results, thus, substantiated the reports of several workers (Gaur, *et al.*, 1971, Mukherjee and Gaur, 1980). According to Sharabi and Bartha (1993), more than half of the carbondioxide production might represent the mineralization of biomass and soil organic matter, some of it unrelated to the test compounds. Moreover, the soil microbial community in its nongrowing steady state had the ability to convert a much lower percentage of soil organic matter to carbondioxide than a growing soil community capable of responding to a substantial substrate addition.

Incidentally, treated as well as untreated soil series evolved the highest amount of carbondioxide on the first day of incubation. Moreover, there was a gradual reduction in carbondioxide evolution for a few days after the first day. This follows the observations of Hadas and Portney (1997) that soluble components particularly, soluble carbon decomposes rapidly after

the first peak of carbondioxide evolution. Subsequently, several other peaks of carbondioxide resulted in due course of time which indicates the rhythmic periodicity in microbial activity. The rhythmic periodicity in the microbial activity may be attributed to the rate of metabolism and growth velocity of microorganisms. Smith *et al.*, (1935) conceded the possibility of periodic variation in the rate of respiration between the logarithmic growth and logarithmic death phase of microbes. Thus, the appearance of primary, secondary and other peaks might result from the preferential stimulation of microorganisms by the components of added carbonaceous substances, the intermediate formed during the decomposition and autolysed products of the dead microorganisms. This is in the line with the observation of Gaur *et al.*, (1971). FYM, irrespective of source, universally resulted in the higher production of carbondioxide than that of control because of their decomposition with a concomitant liberation of carbondioxide. This results, thus, follow the report of earlier workers (Gaur *et al.*, 1970; Das and Mukherjee, 1988). In this context, the FYM procured from local farm liberated more amount of carbondioxide than that of FYM from RRS. This contradicts the report that narrow C : N ratio organic materials are metabolized rapidly in soil (Gaur *et al.*, 1973). This, however, substantiates the report that C : N ratio is not the sole determining factor in predicting the rate of decomposition of organic matter in soil (Alexander, 1977). Rather chemical composition of the material is a very important factor to be considered while discussing the rate at which organic matter decomposes (Hatchings and Martin, 1994). Probably due to higher soluble carbon and nitrogen content of FYM of local farm house, soil series under that treatment released more amount of carbondioxide during first seven days. This trend was, however, maintained throughout the experimental period.

Inorganic fertilizers further accentuated the rate of decomposition of the respective FYM. This substantiates the finding that nitrogen is a key element to create a favourable environment for microbial decomposition (Alexander, 1977; Couture and Fortin, 1983 and Jothaimani *et al.*, 1997). Though phosphorus may not be as important as nitrogen in relation to the microbial degradation of organic substrates yet the same can bring about a desirable shift in the C : N : P ratio of added substrates for quick mineralization (Tisdel and Nelson, 1985). Potassium may not have significant effect on mineralization but it may promote the process of carbon mineralization.

Though the rate of decomposition of RRS-FYM along with inorganic fertilizer was initially faster than that of RRS-FYM alone yet both of them were degraded almost at a similar rate during later stages. This can be explained in a similar manner as that of Patil *et al.*, (1993). According to them, the decomposition of stable FYM is slow but more uniform because of the higher transformation of FYM into soil organic matter and slower transformation of the resultant by products.

It is interesting to note that during the near completion stages of incubation, particularly from the 126th day and onward there was a steady rate of decomposition, irrespective of treatment. This might be explained in the way that during the course of decomposition easily degradable organic residues are perished and resistant materials are left out which, in turn, are decomposed at a slow and steady rate as those materials are resistant to microbial attack.

At the end of the experiment, the highest significant cumulative carbondioxide was evolved from FH-FYM coupled with inorganic fertilizers followed by those of FH-FYM alone, RRS-FYM

coupled with inorganic fertilizers and RRS-FYM alone, respectively (table–4). This is probably due to higher amount of decomposable carbon (54%) in FH-FYM than that of RRS-FYM (17%). Inorganic fertilizers augmented the rate of mineralization of both types of FYM (70% of added organic carbon was mineralized from FH-FYM whereas it was 41% in case of RRS-FYM).

So, RRS-FYM was more stable than that of FH-FYM.

Experiment No. 2 – Isolation and screening of non-symbiotic nitrogen fixing and phosphate solubilizing bacteria from ginger rhizosphere :

Nitrogen and phosphorus are major nutrients for crop growth. Every year substantial amount of those nutrients are being depleted from soil by crops. The loss has to be replenished in soil in order to sustain agriculture. The replenishment is generally accomplished by incorporation of inorganic fertilizers in soil. But the escalating cost of inorganic fertilizers compelled agricultural scientists to search for alternate source of nutrients for the cultivation of crops. Inorganic fertilizers, moreover, impart detrimental influence on soil health. Some microorganisms are endowed with property of fixing atmospheric nitrogen in soil non-symbiotically (Alexander, 1977; Hill, 1992). Yet there are others which solubilize insoluble inorganic phosphorus compounds in soils (Alexander, 1977; Gaur, 1990). Among them *Azotobacter* and *Bacillus* received maximum attention. In fact, they are now being used as bacterial fertilizer in the form of seed or soil inoculants in order to augment crop yield (Patel, 1969; Brown, 1974; Lang and Kommedahl, 1976). But before using them as biofertilizers their efficiency in relation to nitrogen fixation or inorganic insoluble phosphorus solubilization should be ascertained. Because different strains of *Azotobacter* or *Bacillus* exhibit differential efficiency (Rao *et. al.*, 1987; Gaur, 1990).

The objective of this investigation is to screen out one each of the most efficient strains of *Azotobacter* and *Bacillus* from ginger rhizosphere soils in order to exploit them for subsequent experiments.

The results (table-5a) show the differential amount of atmospheric nitrogen was fixed by the different diazotrophic strains isolated from ginger rhizosphere. This variability in nitrogen fixing power among the isolates was due to their genetical capability to fix dinitrogen (Tilak, 1998). Among the seven strains, NFB_1, was the most efficient nitrogen fixing bacteria. In the subsequent experiments this strain was exploited as an inoculant for atmospheric nitrogen acquisition as well as disease suppression. Like nitrogen fixing bacteria, there was variability in the solubilization of insoluble inorganic phosphate by the different phosphate solubilizing ginger rhizosphere bacteria (table-5b). This differential solubilization of insoluble inorganic phosphate is due to genetical capabilities of those phosphate solubilizing bacteria. The decrease in pH of the broth was due to the production of organic acid during the incubation period. This substantiated the earlier reports of Gaur and Sachar (1980) Banik and Dey (1983). The highest solubilization of insoluble inorganic phosphate and maximum reduction in pH of broth by the strain, PSB_4, confirmed that the cited strain was the most efficient one. This corroborates the reports of several workers (Banik and Dey, 1983; Dey 1988). The strain was exploited as an inoculant in the subsequent experiments for improving the available phosphorus status in soil as well as suppressing the disease producing organisms.

NFB_1 and PSB_4 were exploited in the subsequent experiments as they are indigenous isolates and likely to be more compatible and thrive better in the ginger rhizosphere (Brown, 1974).

Experiment No. 3 – Effect of FYM and inoculation of efficient nitrogen fixing and phosphate solubilizing bacteria on microbial as well as nutrient dynamics in soil :

Soil system is comprised of biotic and abiotic entities. Abiotic entities monitor the qualitative and quantitative composition of biotic entities. Biotic entities, on the other hand, regulate physical and chemical properties of abiotic entities. Moreover, the living entities interact among themselves and make the soil a living dynamic system. However, a temporary equilibrium called biological equilibrium in respect to biological entities is maintained in soil. The equilibrium gets upset by the introduction of exogenous substance in soil. As discussed earlier, soil has to be enriched with organic manures and efficient inoculum of nitrogen fixing and or phosphate solubilizing microorganisms in order to obtain good harvest of crops. But, manures stimulate the population of soil microorganisms especially the beneficial ones (Dey, 1977; Gaur *et. al.*, 1979; Bhattacharyya *et. al.*, 1984 & 1986) besides enhancing the physical and chemical properties of soil (Mukherjee *et. al.*, 1984 & 1985; Patil *et. al.*, 1993; Yang *et. al.*, 1994). On the other hand, biofertilizers increase crop yield (Brown, 1974; Gupta *et. al.*, 1997) by fixing atmospheric nitrogen in soil (Subba Rao, 1981) and transforming insoluble phosphatic compounds - organic and or inorganic to soluble forms in soil (Banik and Dey, 1981; Gaur, 1990), besides elaborating growth promoting substances (Mishustin and Shilnikova, 1972; Brown, 1974), vitamins (Shende *et. al.*, 1977) and other substances beneficial to crop. The present investigation has been undertaken in order to evaluate in relative efficacy of FYM alone, FYM in combination with inorganic fertilizers alone, or together with single or combined inoculation of *Azotobacter* and *Bacillus* in relation to built up of microbial population especially the beneficial ones and their activities, carbon and nitrogen as well as nutrient availability in soil.

Perusal of results (table-6) shows that control soil encouraged an althrough higher proliferation of viable bacteria than that of initial soil because of the provision of one of the most important favourable environmental factors - optimum moisture during the experimental period. Alexander (1977) reported that optimum moisture brings about higher bacterial proliferation. The results, thus, substantiated the above report. As such, all the five different types of additive resulted in higher proliferation of total bacteria than that of control soil throughout the experimental period. That was because of the fact that all of the five different additives had FYM in common which is an organic substrate and the enumerated bacteria are chemoheterotrophs which utilize organic substrates as nutrient and energy sources for their growth and development. So, application of FYM alone or in combination with other additives enriched the soil with nutrient and energy sources which, in turn, brought about higher proliferation of total viable bacteria (Gour *et. al.*, 1971). In between the inanimate additives, FYM in combination with inorganic fertilizers was superior to FYM alone in relation to higher proliferation of bacteria because chemoheterotrophs require not only organic substances but also inorganic nutrients for their cellular synthesis and for this reason there are reports about the rapid growth of bacteria in the presence of inorganic nutrients (Pokorna - Kozova, 1970) especially when bulk of organic matter is more. As it were, inoculation of *Azotobacter* and *Bacillus*, either alone or in combination, along with inanimate sources caused higher proliferation of total bacteria than those of inanimate sources. *Azobacter* and *Bacillus* are known to produce certain growth promoting substances during their growth period (Mishustin and Naumova; 1962, Brown and Walker, 1970, Datta *et. al.*, 1982) and those substances might stimulate rapid proliferation of bacteria. Alternatively, *Azotobacter* is endowed

with the capacity of fixing atmospheric nitrogen and *Bacillus* is capable of transforming insoluble organic and inorganic phosphorus to more mobile soluble ones which, in turn, might induce rapid growth of bacteria. Among the inoculated series, *Azotobacter* inoculation brought about higher proliferation of bacteria in soil than that of *Bacillus* inoculation from S_3 to S_5 stage. On the other hand, *Bacillus* inoculation was superior to *Azotobacter* inoculation during S_1, S_2 and S_6 stages. However, on the whole, *Azotobacter* inoculation was superior to *Bacillus* though not significant in relation to higher proliferation of total bacteria in soil. As such, combined inoculation exerted maximum stimulation on total bacteria in soil. This pointed out the synergistic effect of both of the organisms on the total bacteria (Brown, 1974) by better nutrition in the form of nitrogen and phosphorus besides growth promoting substances. The population of total bacteria in soil increased progressively at the initial stages and then declined gradually during latter stages. The increase in bacteria in initial stages might be due to protocooperative or commensalic effect while the decrease during the latter stages might be due to amensalic effect or depletion of nutrients (Alexander, 1977).

The significant positive correlation between total bacteria and fungi, nitrogen-fixing bacteria, phosphate solubilizing microorganisms, respectively indicated the protocooperative effect of the said organisms in soil.

Experimental soils entertained an althrough higher actinomycete population than that of initial soil with the exception of that under control which reared higher population at S_1, S_2, S_5 and S_6 stages (table–7). Higher count of actinomycetes is due to provision of optimum moisture in soil during the experimental period (Alexander, 1977). As such, FYM caused enhancing

influence on the population of actinomycetes in soil then that of control. This substantiated the reports of Mukherjee and Gaur (1984). This is because of the fact that actinomycetes are chemoorganotrophs and utilize organic matter as carbon, energy and nutrient sources for their cell synthesis (Alexander, 1977). Inorganic fertilizer along with FYM resulted in increase in actinomycete population as compared to that of FYM in soil throughout the experimental period. Similar results were obtained by Venkatesan (1962). The results, thus, reveal that actinomycetes require not only organic substrates but also inorganic nutrients for cell synthesis. Inorganic fertilizer along with FYM, however, inferior to either *Azotobacter* or *Bacillus* inoculation along with inanimate additives especially from S_3 to S_6 stage . Inoculation of *Azotobacter* or *Bacillus* results in the production of vitamin and growth promoting substances in soil besides fixation of atmospheric nitrogen and or transformation of insoluble phosphorus to soluble forms which, in turn, might result in higher population of actinomycetes in soil than that of inorganic fertilizers along with FYM. As such, *Azotobacter* inoculation caused higher population of actinomycetes than that of *Bacillus* inoculation. The results reveal that requirement of nitrogen is more important for the proliferation of actinomycetes than that of phosphorus. This is known that nitrogen is more important than phosphorus for cell synthesis. However, combined inoculation of *Azotobacter* and *Bacillus* resulted in the highest population of actinomycetes in soil throughout the experimental period. That was due to the resultant impact of both of the organism which provided balanced nutrition of nitrogen and phosphorus besides Vietnam and growth promoting substances for the microorganisms in soil. Actinomycetes population in different soil series responded differently during the course of investigation but, on the whole, the population exhibited

an initial progressive increase followed by a gradual decrease. The initial progressive increase reveals protocooperative or commensalic effect (Alexander, 1977). On the other hand, the gradual decrease indicates amensalic effect or depletion of nutrients from soil (Alexander, 1977).

A highly significant correlation between actinomycetes and total nitrogen indicated the existence of protocooperative association in between actinomycetes and nitrogen fixers for the acquisition of nitrogen.

Initial soil, in general, reared less number of fungi as compared to those of treated soil series (table–8). This was due to the unfavourable environmental conditions prevailing in initial soil. Application of FYM brought about enhancing influence on the proliferation of fungi in soil as compared to that of control soil. This corroborated the results of Mukherjee and Gaur (1984). As fungi are chemoheterotrophs, it is obvious that FYM being an organic matter caused higher proliferation of fungi in soil. However, there were a few soil series with less count of fungi at S_4 stage as compared to that of control. The reason remained obscured and need further experimentation. A feeble explanation is that certain toxic metabolites might be produced either by the microorganisms during their metabolic phases in soil or in the process of decomposition of FYM which resulted in lower proliferation of fungi at that stage. The results, thus, substantiated the findings of Toyota and Kimura (1992) that FYM treated soil was more fungistatic than FYM untreated soil. Inorganic fertilizers together with FYM was superior to FYM in relation to higher proliferation of fungi in soil during early stages and then at S_5 stage. The results suggest that fungal flora require not only organic substances but also inorganic nutrients for their growth and activity

(Alexander, 1977). Though inoculation of *Bacillus* induces the production of growth promoting substances (Hussain and Vancura, 1970; Brown, 1974) in soil yet the cited bacteria are capable of inhibiting a great variety of fungi in soil (Broadbent *et. al.* 1977). As a consequence, there was lower proliferation of fungi in soil series under *Bacillus* inoculation from S_1 to S_3 stage and then at S_5 stage. The same explanation is true for higher proliferation of fungi from *Azotobacter* inoculated soil series from S_2 to S_6 stage than that of *Bacillus* inoculated soil series. However, there was higher population of fungi in *Azobacter* inoculated soil series than those of inorganic fertilizer treat soil series from S_2 to S_6 stage. *Azobacter* inoculation also induces the production of vitamins (Mishustin and Naumova, 1962) and growth promoting substances (Brown 1972, 1974) which, in turn, might exert stimulating influence on the fungal population in soil. As it were, combined inoculation of *Azotobacter* and *Bacillus* resulted in the highest population of fungi as compared to all but inorganic fertilizer treated soil series at S_1 stage. This can be interpreted in a similar manner to that of bacteria, described earlier. There was differential stimulation of fungal propagules in control and treated soil series but, on the whole, the fungal propagules exhibited an initial increase followed by a gradual decrease in soil. The same explanation as that of bacteria is applicable in this case also.

The significant positive correlation between fungi and actinomycetes as well as phosphate solubilizing organisms indicated the protocooperative effect of the said organisms in soil.

Initial soil harboured less number of non-symbiotic nitrogen fixing bacteria as compared to the experimental soils (table–9) due to unfavourable moisture (Alexander, 1977). As such, FYM resulted in an increase in the population of non-symbiotic

nitrogen fixing bacteria in soil as compared to that of control because most of the non-symbiotic nitrogen fixing bacteria are chemoheterotrophs and derive their energy and nutrients from the organic sources for proliferation (Rao, 1977; Bhattacharyya *et. al.*, 1984). Nevertheless, inorganic fertilizer together with the organic additives exerted stimulating influence on the population of non-symbiotic nitrogen fixing bacteria in soil than that of organic additives alone (Mishustin and Shilnikova, 1971). The results thus, emphasis the importance of inorganic nutrients for the proliferation of said bacteria in soil. As inorganic nutrients are vital ingradients of biomolecules which are precursors of cell, their importance in cell synthesis hardly need any emphasis. Inoculation of *Bacillus* together with inorganic fertilizers and FYM caused enhancing influence on the population of non-symbiotic nitrogen fixing bacteria in soil as compared to that of inorganic fertilizer and FYM treatment at S_1 and then from S_4 to S_6 stages. *Bacillus* is known to solubilize insoluble phosphorus to soluble forms (Banik and Dey, 1982) besides growth promoting substances and vitamins. (Brown, 1974; Datta *et. al.*, 1982) which, in turn, might cause in proliferation of non-symbiotic nitrogen fixing bacteria in soil. As it were, inoculation of *Azotobacter* together with inorganic fertilizer and FYM induced greater impact on proliferation of the said bacteria in soil than that of *Bacillus* inoculation with inanimate additives. The results, thus, manifested the importance of nitrogen for the proliferation of cell. It is known that *Azotobacter* is an important non-symbiotic nitrogen fixing bacteria (Shende *et. al.*, 1977) and the nitrogen fixed by the bacteria is ultimately added to soil which might induce enhancing influence on the population of the cited bacteria. Besides, *Azotobacter* is also capable of producing some amount of growth promoting substances (Mishustin and Naumova, 1962) and vitamins (Subba Rao, 1981) which, in turn, might

stimulate the growth of non-symbiotic nitrogen fixing bacteria in soil. Combined inoculation of *Azotobacter* and *Bacillus* resulted in the highest population of the said bacteria in soil. This is due to favourable influence of both of the organisms in relation to fixation of atmospheric nitrogen, transformation of organic and inorganic insoluble phosphorus compounds, elaboration of vitamin and growth promoting substances, resulting in the highest population of non-symbiotic nitrogen fixing bacteria in soil (Kundu and Gaur, 1980 & 1982). The population of the said bacteria in different soil series increased, on and on, from S_1 to S_3 stage and then gradually decreased from S_4 to S_6 stage. This can be explained in a similar manner as described earlier.

A moderate correlation between nitrogen fixing bacteria and phosphate solubilizing microorganisms as well as actinomycetes indicated the existence of protocooperative interrelationship within themselves.

The phosphate solubilizing organisms were always higher in experimental soil (table–10) due to the provision of optimum moisture (Alexander, 1977) in the experimental soils throughout the period of incubation. As such, FYM exerted stimulating influence on the preponderances of phosphate solubilizing organisms in soil as compared to that of control. This substantiated the reports of Sinkha (1970) and Fardeau *et. al.* (1971). As phosphate solubilizing organisms are chemoorganotrophs and derive energy and nutrient sources from organic substances for cell synthesis, it is feasible that FYM brought about stimulating influence on the population of the said organisms by furnishing those substances in soil (Banik and Dey, 1982). In between the two inanimate additives, inorganic fertilizers together with FYM resulted in higher population of phosphate solubilizing microorganisms at S_1, S_3, S_5 and S_6 stages

emphasising the requirement of inorganic nutrients for phosphate solubilizing organisms besides organic matter. However, inoculation of *Azotobacter* together with inanimate additives brought about an increase in the population of the cited organisms in soil as compared to that of inorganic fertilizer and FYM from S_1 to S_4 stage. As discussed earlier, *Azotobacter* fix atmospheric nitrogen and elaborates vitamins and growth promoting substances in soil which, in turn, caused higher population of said organisms in soil than that of the treatment - inorganic fertilizer and FYM. As it were, inoculation of *Bacillus* together with inanimate additives, resulted in an enhancing influence on the population of phosphate solubilizers in soil as compared to that of *Azotobacter* inoculation together with inanimate ingradients. This is obvious because inoculation of *Bacillus* will lead to the multiplication of the said organisms in soil especially in the presence of organic and inorganic nutrients as *Bacillus* is endowed with the property of solubilizing insoluble phosphate to soluble form, the multiplication of the said organisms in soil will result in the enhancement of phosphate solubilizing microorganisms in soil. Alternatively, the generation time of *Azotobacter* is higher than that of *Bacillus* (Mulder and Brotonegro, 1974; LaRue, 1976). Consequently, *Bacillus* will grow at a faster rate than that of *Azotobacter*. So, the proliferation of native *Bacillus* will also be rapid which, in turn, might increase the population of phosphate solubilizing microorganisms in soil. Nevertheless, combined inoculation of *Bacillus* and *Azotobacter* together with organic and inorganic nutrients caused the highest stimulation of said organisms in soil. The resultant impact of *Azotobacter* and *Bacillus* might induce the fixation of atmospheric nitrogen and solubilization of insoluble phosphate to mobile soluble form besides elaboration of vitamins and growth promoting substances leading to the highest stimulation of phosphate

solubilizers (Verma and Mathur, 1989; Gaur, 1990). The population of phosphate solubilizing microorganisms in different soil series progressively increased from S_1 to S_3 stage and then gradually decreased from S_4 to S_6 stage. The same explanation as that of bacteria is applicable in this case also.

A highly significant positive correlation between phosphate solubilizing microorganisms and actinomycetes indicated the protocooperative effect of the said organisms in soil.

Control soil had low nitrogen fixing power as compared to that of initial soil from S_4 to S_6 stage (table–11). This can be explained in accordance with the report of patel and Brown (1969) that actinomycetes exert inhibitory effect on the growth and activity of *Azotobacter*. In the present investigation there was progressive proliferation of actinomycetes in control soil (table–7). It is likely that those organisms might have inhibited the growth and activity of the efficient nitrogen fixing bacteria and thus reduced the nitrogen fixing power of control soil during later stages. However, during initial stages, control soil exhibited higher nitrogen fixing power than that of initial soil and that was due to optimum moisture of control soil which helped in bringing about higher microbial activity (Alexander, 1977). In this instance, higher nitrogen fixing power of the control soil. FYM resulted in an althrough increase in the nitrogen fixing power of soil as compared to that of control. The increase in the nitrogen fixing power was in accordance with the proliferation of nitrogen fixing bacteria in soil. FYM by providing energy source to the non-symbiotic nitrogen fixers might increase the efficiency of the cited bacteria in relation to nitrogen fixation in soil. Inorganic fertilizers, in general, brought about a decrease in nitrogen fixing power of soil as compared to that of control. This substantiate the report that

nitrogen induces negative effect on the nitrogenase enzyme - responsible for the fixation of atmospheric nitrogen (De, 1939; Mishustin and Shilnikova, 1971; Alexander, 1977). Inoculation of *Bacillus* along with organic and inorganic additives resulted in higher nitrogen fixing power of soil than that of inorganic fertilizer coupled with FYM. *Bacillus* is known to fix atmospheric nitrogen in soil (Broadbent *et. al.*, 1977) and as a consequence nitrogen fixing power might increase by the inoculation of *Bacillus* in soil. As *Bacillus* fixes very small amount of nitrogen in soil (Broadben *et. al.*, 1977), the overall increase in nitrogen fixation as compared to that of inorganic fertilizer along with FYM was not statistically significant. The cited treatment, moreover, resulted in a significant decrease in nitrogen fixing power of soil as compared to that of FYM. *Azotobacter* inoculation, however, resulted in an althrough increase in nitrogen fixing power of soil as compared to that of *Bacillus* inoculation as *Azobacter* is known to fix more amount of atmospheric nitrogen in soil than that of *Bacillus* (Alexander, 1977). Moreover, the influence of *Azotobacter* inoculation on nitrogen fixing power at S_2, S_4, S_5 and S_6 stages was in accordance with the proliferation of non-symbiotic nitrogen fixing bacteria (table–9). The decrease in nitrogen fixing bacteria in spite of an increase in nitrogen fixing power at S_1 and S_3 stages indicated that *Azotobacter* inoculation exerted better influence on the performance than multiplication the said bacteria. The overall impact of *Azobacter* inoculation was also concurrent with the multiplication of non-symbiotic nitrogen fixing bacteria. Combined inoculation of *Azotobacter* and *Bacillus* caused an althrough increase in nitrogen fixing power of soil as compared to that of *Azotobacter* inoculation alone. The influence of combined inoculation of *Azotobacter* and *Bacillus* on nitrogen fixing power was in accordance with the proliferation of non-symbiotic nitrogen fixing

bacteria in soil (table–9). This corroborated the earlier reports of Shende *et. al.* (1973), Kundu and Gaur (1980). Different types of additives brought about different influence on nitrogen fixing power of soil in relation to the stages of experiment. However, on the whole, there was an initial progressive increase in nitrogen fixing power of soil from S_1 to S_3 stage following a gradual decrease from S_4 to S_6 stage which was in accordance with the proliferation of non-symbiotic nitrogen fixing bacteria in soil.

A significant correlation between nitrogen fixing power and nitrogen fixing bacteria as well as total bacteria indicated that bacteria, in general, and nitrogen fixing bacteria in particularly was related with nitrogen fixing power of soils.

Control soil and initial soil, on the whole, had the same phosphate solubilizing power though there were variations in phosphate solubilizing power at all but S_5 stage (table-12). The increase in phosphate solubilizing power at S_2 and S_3 stages might due to higher efficiency of phosphate solubilizing bacteria due to optimum moisture (Alexander, 1977) while the decrease at S_1, S_5 and S_6 stages could be due to the assimilation of soluble phosphate by soil microflora. However, FYM resulted in an increase in phosphate solubilizing power of soil as compared to that of control. The increase in phosphate solubilizing power might be due to the higher efficiency of phosphate solubilizing microorganisms which obtained energy and nutrients from FYM (Banik and Dey, 1982). Incidentally the increase in phosphate solubilizing power was in accordance with the proliferation of phosphate solubilizing microorganisms in soil (table–10). Inorganic fertilizers in combination with FYM resulted in the higher phosphate solubilizing power of soil than that of FYM alone especially from S_2 to S_6 stage. This contradicts the results of

Narsian *et. al.* (1995), inorganic phosphatic fertilizer resulted in an increase in the phosphate solubilizing power of soil as compared to that of FYM alone. It may be assumed that inorganic phosphatic fertilizer might be converted to insoluble Fe and Al phosphate especially in experimental acid soil or assimilated by microorganisms, thus, creating an environment favourable for solubilization of more insoluble phosphate. Lower number of phosphate solubilizing microorganisms at S_2 and S_4 stages in spite of higher phosphate solubilizing power indicated that inorganic fertilizers exerted better influence on the performance than multiplication of phosphate solubilizing organisms in soil during those stages. *Bacillus* inoculation together with FYM and inorganic fertilizers augmented phosphate solubilizing power of soil as compared to that of FYM and inorganic fertilizer. Inoculation of *Bacillus* resulted in the multiplication of the said organisms in soil especially in the presence of organic and inorganic nutrients. This substantiated the findings of Kundu and Gaur (1980). Moreover, certain other groups of phosphate solubilizing microorganisms are likely to be incited by the presence of organic and inorganic nutrients besides growth promoting substances and vitamins elaborated by *Bacillus*. As such, *Azotobacter* inoculation was better than FYM. Because *Azotobacter* is capable of producing growth promoting substances which, in turn, might increase the growth and activity of the cited organisms in soil. However, *Azotobacter* inoculation caused a decrease in phosphate solubilizing power of soil as compared to that of inorganic fertilizer and FYM from S_3 to S_6 stage. The reason remained obscure though the proliferation of phosphate solubilizing microorganisms at S_5 and S_6 stages were concurrent with the phosphate solubilizing power of soil. Higher phosphate solubilizing microorganisms at S_3 and S_4 stages in spite of lower

phosphate solubilizing power indicated that *Azotobacter* inoculation resulted in better influence on multiplication than performance of phosphate solubilizing mocroorganisms in soil. As it were, combined inoculation of *Azotobacter* and *Bacillus* was superior to *Bacillus* inoculation in relation to phosphorus solubilizing power of soil at S_1, S_2, S_5 and S_6 stages. The increase in phosphate solubilizing power at S_1, S_5 and S_6 stages were in accordance with the proliferation of the said microorganisms in soil. However, a decrease in the number of cited organisms at S_2 stage despite an increase in phosphate solubilizing power indicated that combined inoculation resulted in better influence on performance than multiplication of the said organisms. As such, combined inoculation resulted in the highest overall increase in phosphate solubilizing power of soil. The highest overall increase was the resultant impact of both of the organisms (Shende *et. al.*, 1973) in relation to elaboration of growth promoting substances, fixation of atmospheric nitrogen and solubilization of insoluble phosphorus in soil which, in turn, might induced the efficiency of the said organisms to the highest extent (Verma and Mathur, 1989).

The phosphorus solubilizing power of soil increased at S_2 stage as compared to S_1 stage and then gradually decreased up to S_6 stage. The increase in phosphate solubilizing power from S_1 to S_2 and the decrease of the same from S_3 to S_6 were concurrent with the proliferation of phosphate solubilizing microorganisms in soil.

The significant positive correlation between phosphate solubilizing power and total nitrogen indicated the importance nitrogen nutrition to the phosphate solubilizers.

Control soil retained less amount of organic carbon as compared to that of initial soil from S_2 to S_6 stage (table-13) owing to higher microbial activity in the presence of optimum moisture

(Alexander, 1977). FYM resulted in the restoration of higher amount of organic carbon in soil than that of control. This was due to the presence of carbonaceous material in FYM (Gaur *et. al.*, 1971; Raheja *et. al.*, 1971; Das and Mukherjee, 1989). Inorganic fertilizers in combination with FYM caused low built up of organic carbon in soil as compared to that of FYM. Inorganic fertilizers resulted in higher microbial population in soil as evidenced from higher count of bacteria, actinomycetes and fungi (table–6,7 & 8) which, in turn, caused greater rate of carbon mineralization as evidenced from enhanced production of CO_2 from soil (table–4). Consequently higher rate of carbon mineralization decreased the content of organic carbon in soil. Inoculation of *Bacillus* further lessened the content of the same in soil as compared to that of inorganic fertilizer and FYM. *Bacillus* inoculation might induce the elaboration of growth promoting substances and vitamins besides transformation of insoluble phosphorus to soluble form and increase the growth and activity of different types of microorganism in soil (Menkina, 1963) as evidenced from table–6, 7 & 8. The decrease in the content of organic carbon was, in fact, the reflection of higher microbial activity in soil. *Azotobacter* inoculation also decreased the content of organic carbon in soil as compared to that of inorganic fertilizer and FYM. The explanation will be similar to that of *Bacillus* inoculation by the placement of the word the transformation of insoluble phosphorus compounds with nitrogen fixation. However, *Azotobacter* inoculation, in general, brought about a reduction in the content of organic carbon in soil as compared to that of *Bacillus* inoculation. This substantiated the finding that nitrogen is a major factor in predicting the rate of decomposition of organic matter in soil (Alexander, 1977). As it were, combined inoculation of *Azotobacter* and *Bacillus* resulted in the least built up of soil organic carbon. This might be due to the synergistic effect of both

of the microorganisms which, in turn, result in enhanced growth and activity of microorganisms in soil (Menkina, 1963) as evidenced from table–6, 7 & 8. The least built up of organic carbon was the reflection of the highest microbial activity in soil. The content of organic carbon in different soil series gradually decreased from S_1 to S_6 stage. The decrease in the same might be due to the degradation of humus and or FYM by autochthonas microorganisms in soil (Mukherjee, 1975).

Control soil retained higher amount of nitrogen than that of initial soil from S_1 to S_4 stage (table–14). This might be due to fixation of atmospheric nitrogen in soil by the non-symbiotic nitrogen fixing bacteria in the presence of optimum moisture (Alexander, 1977). Addition of FYM resulted in an increase in the content of nitrogen in soil than that of control owing to the presence of a nitrogenous substrate in FYM. However, inorganic fertilizer was superior to FYM in relation to the content of total nitrogen in soil. This is because of the fact that this treatment received additional dose of nitrogen in the form of urea. *Bacillus* inoculation together with FYM and inorganic fertilizers resulted in an increase the same in soil as compared to that of FYM. This can be interpreted in a similar manner to that of inorganic fertilizers treatment. However, *Bacillus* inoculation resulted in an overall meagre decrease in the content of nitrogen in soil as compared to that of inorganic fertilizers treatment though the reduction was not statistically significant. The decrease might be due to loss of nitrogen from soil through denitrification following enhanced microbial mineralization of organic nitrogen. Combined inoculation of *Azotobacter* and *Bacillus* caused higher retention of nitrogen in soil than that of inorganic fertilizer from S_2 to S_4 stage and then at S_6 stage. Higher retention was the consequence of fixation of atmospheric nitrogen by *Azobacter* (Subba Rao, 1981)

and *Bacillus* (Hill, 1992) in soil as evidenced from higher nitrogen fixing power than that of inorganic fertilizer treatment (table–11). *Azobacter* inoculation resulted in an increase in the content of total nitrogen in soil than that of combined inoculation at S_1, S_2, S_5 and S_6 stages. The reason remained obscure and awaits further investigation. However, combined inoculation might cause greater loss of nitrogen from soil. Because higher proliferation of different groups of microorganisms might result in enhanced rate of denitrification of mineralized nitrogen in soil.

The total nitrogen content of different soil series decreased though not uniformly from S_1 to S_6 stage. The decrease might be due to gradual loss of nitrogen from soil by denitrification (Smith and Douglas, 1970; Mukherjee *et. al.*, 1990) of mineralized nitrogen.

The significant correlation between total nitrogen and nitrogen fixing bacteria as well as total bacteria indicated that bacteria, in general, and nitrogen fixing bacteria, in particular, were involved in the acquisition of nitrogen in soils.

Ammoniacal–nitrogen content of control soil increased as compared to that of initial soil from S_1 to S_5 stage (table–15) due to greater mineralization of organic nitrogen by heterotrophic microorganisms in the presence of optimum moisture (Alexander, 1977). On the other hand, there was a decrease of the same at S_6 stage which might be due to microbial assimilation of inorganic nitrogen (Mukherjee *et. al.*, 1990). Alternatively mineralization was followed by subsequent nitrification and denitrification (Mukherjee *et. al.*, 1990). FYM resulted in higher built up of ammoniacal-nitrogen in soil as compared to that of control because FYM contained some amount of ammoniacal nitrogen (table–2). Moreover, FYM is subjected to mineralization by a great variety of

chemoheterotrophs resulting in the release of ammoniacal-nitrogen in soil. Inorganic fertilizers together with FYM brought about an increase in the content of ammoniacal–nitrogen in soil as compared to that of FYM. The presence of urea in inorganic fertilizer treatment resulted in an enhancement of ammoniacal-nitrogen in soil because urea undergoes enzymatic hydrolysis resulting in the formation of ammonium compounds in soil. As such, inoculation of *Bacillus* together with FYM and inorganic fertilizers resulted in the restoration of more amount of ammoniacal nitrogen in soil than that of inorganic fertilizers treatment. Inoculation of *Bacillus* resulted in the proliferation of different group of chemoheterotrophs, as evidenced from the table–6, 7 and 8, capable of mineralizing organic nitrogenous compound in soil. Alternatively, *Bacillus* has the capacity to fix atmospheric nitrogen in soil (Hill, 1992) and indeed, more amount of nitrogen was fixed in soil by *Bacillus* inoculation than that of inorganic fertilizers (table–11). Those organic nitrogenous compounds might be mineralized by the microorganisms resulting in an enhanced accumulation of ammoniacal-nitrogen in soil. However, the overall impact of *Azotobacter* inoculation was marginally superior to that of *Bacillus* inoculation in relation to the content of ammoniacal–nitrogen in soil. This is because of the fact that *Azotobacter* fixes more amount of atmospheric nitrogen than that of *Bacillus* in soil (Alexander, 1977). As discussed earlier those organic nitrogenous compounds might be mineralized by chemoheterotrophs and converted to ammonium form of nitrogen in soil. As it were, combined inoculation of *Azotobacter* and *Bacillus* resulted in the highest accumulation of ammoniacal- nitrogen in soil. This is due to the synergistic effect of both of the organisms on the enhancement of nitrogen fixation (Kundu and Gaur 1980; Saxena and Tilak, 1994) in soil as evidenced from the table–11 and

subsequent mineralization of those organic nitrogenous compounds in soil. Ammoniacal-nitrogen content of different soils gradually decreased though not uniformly from S_1 to S_6. The decrease was the consequence of nitrification and assimilation of nitrogen by microorganisms in soil (Alexander, 1977; Mukherjee *et. al.*, 1985).

The significant correlation between ammoniacal-nitrogen and total nitrogen indicated that total nitrogen is the substrate of ammoniacal-nitrogen.

Control soil retained more amount of nitrate–nitrogen than that of initial soil from S_2 to S_4 stage (table–16) owing to optimum moisture for the process of nitrification (Alexander, 1977). On the other hand, less accumulation in control soil as compared to initial soil at S_1, S_5 and S_6 stages indicated higher denitrification due to moisture. FYM universally increased the content of nitrate-nitrogen than that of control which indicates higher rate of nitrification of ammonium compounds in soil. As evidenced from the table–15 the substrate for nitrification was more in FYM treated soil series. Consequently the nitrate formation was accelerated by FYM in soil. Inorganic fertilizers together with FYM resulted in higher accumulation of nitrate nitrogen than that of FYM because the cited treatment had an additional nitrogenous compound - urea, which upon subsequent hydrolysis and nitrification released more amount of nitrate-nitrogen in soil. As such, inoculation of *Bacillus* together with FYM and inorganic fertilizers resulted in less accumulation of nitrate-nitrogen in soil as compared to that of inorganic fertilizer. Less accumulation of nitrate nitrogen might be the result of higher denitrification (Brown, 1974) and or assimilation of nitrogen by microorganisms in soil (Alexander, 1977). On the other hand, *Azotobacter* inoculation caused higher retention of nitrate nitrogen in soil than that of inorganic fertilizers and FYM treatment at all

but S_6 stage. This indicated higher rate of nitrification of the accumulated ammonium in *Azotobacter* inoculated series. As it were, inoculation of *Azotobacter* and *Bacillus* together with inorganic fertilizers and FYM resulted in the highest accumulation of nitrate nitrogen in soil. Maximum accumulation of the same was the resultant impact of combined inoculation on nitrogen fixation (table–11) and subsequent process - ammonification and nitrification in soil. Nitrate-nitrogen content of different soil series increased progressively from S_1 to S_6 stage. This indicated higher rate of nitrification in soil.

Control soil retained more amount of available phosphorus than that of initial soil from S_1 to S_3 stage (table–17). This was due to higher microbial activity in the presence of optimum moisture resulting in rapid microbial transformation of insoluble phosphorus compounds - organic and inorganic to available form (Alexander, 1977). On the other hand, less amount of available phosphorus in control soil as compared to that of initial soil from S_4 to S_6 stage manifested microbial assimilation (Banik and Dey, 1981) or fixation of phosphorus (Buckman and Brady, 1974). FYM resulted in higher retention of available phosphorus in soil than that of control (Fardeam and Gruiraurd, 1971) because FYM contained some amount of inherent available phosphorus (table–2). Alternatively FYM might undergo microbiological decomposition and mineralization. Consequently, more of available phosphorus was added to soil (Subramaniam and Gopal Swamy, 1991). FYM, moreover, resulted in the proliferation of microorganisms in soil. The enhance influence of those organisms was reflected in higher phosphate solubilizing power of FYM treated soils (table–12). The increase in available phosphorus might be due to higher phosphate solubilizing power of FYM treated soil (Banik and Dey, 1982). Addition of inorganic fertilizers together

with FYM augmented the content of available phosphorus in soil as compared to that of FYM. Presence of super phosphate played an important role in augmenting the content of available phosphorus in soil. As it were, inoculation of *Azotobacter* together with inorganic fertilizer and FYM caused a marginal decrease in the content of the same in soil as compared to that of inorganic fertilizers and FYM treatment. As discussed earlier, *Azotobacter* inoculation resulted in the proliferation of different types of microorganisms in soil which, in turn, might assimilate phosphorus and reduce the content of available phosphorus in soil. However, *Azotobacter* inoculation was superior to FYM in relation to the content of available phosphorus in soil. In this case, *Azotobacter*, being a chemoheterotroph might cause rapid mineralization of FYM and increase the content of available phosphorus in soil. On the other hand, *Bacillus* inoculation was marginally superior to inorganic fertilizer in regard to the content of available phosphorus in soil. *Bacillus* is known to transform phosphorus in two ways (Hayman, 1975). Firstly, the organisms can mineralize organic phosphorus compounds to soluble inorganic forms. Secondly, the said bacterium also have the ability to convert insoluble inorganic phosphorus to soluble forms. The marginal increase in available phosphorus in soil treated by *Bacillus* inoculation over inorganic fertilizer might be due to the above cited reason. As it were, combined inoculation of *Azotobacter* and *Bacillus* brought about the highest significant increase in the content of available phosphorus in soil. That might be due to the synergistic effect of both of the organisms on the rapid mineralization of organic and solubilization of inorganic insoluble phosphorus compounds to soluble forms resulting in enhanced phosphorus availability in soil. (Ocampo *et. al.*, 1975; Kundu and Gaur, 1980). The content of available phosphorus in different pot soil series gradually

decreased from S_1 to S_6 stage. That might be due to phosphorus fixation by experimental acid soil (Buckman and Brady, 1974) or assimilation by microorganisms (Gaur, *et. al.*, 1973; Banik and Dey, 1981).

The significant positive correlation between available phosphorus and phosphate solubilizing power determined the availability of phosphorus in soil.

Experiment No. 4 – Effect of FYM and inoculation of efficient nitrogen fixing and phosphate solubilizing bacteria on microbial population and nutrient dynamics in the rhizosphere soil as well as performance of ginger in pot :

Soil is an ideal medium for the proliferation of different groups of microorganisms. Consequently, microorganisms of diversified physiological group live in this medium. Some of them are independent while there are others imparting beneficial influence among themselves. However, several microorganisms bring about harmful influence on their associates in soil. The interaction among microorganisms proceeds continuously in soil until an equilibrium, though temporary, is reached. The equilibrium, known as biological equilibrium, is very important from the stand point of soil fertility, in general, and crop productivity, in particular. The equilibrium is disturbed by the addition of exogenous substrates - biotic or abiotic. In most of the cases, added abiotic entities especially organic manures cause beneficial influence on physico-chemical (Mukherjee *et. al.* 1984 & 1985; Hanay *et. al.*, 1992; Patil *et. al.*, 1993; Yang *et. al.*, 1994) chemical and biological properties (Gaur *et. al.*, 1971; Dey, 1977; Hadas and Protnoy, 1994; Hadas *et. al.*, 1996) of soil. Though some abiotic constituents especially inorganic fertilizers result in a

temporary improvement of chemical and biological properties of soil, yet those ingradients ultimately produce detrimental influence on biological properties, in general, and soil biomass in particular. Biotic entities, on the other hand, induce friendly environment for the microorganisms in soil. Among them, biofertilizers impart the most favourable environment for the microorganisms by elaborating vitamins and growth promoting substances (Brown, 1974) besides nourishing in soil with vital plant nutrients - nitrogen and phosphorus. Plants also alter the composition of microflora in soil by the secretion of organic substances through roots or by dead tissues (Rovira, 1965; Dey, 1972). In fact, soils surrounding the root zone - called rhizosphere soils different from non-rhizosphere soils in both qualitative and quantitative composition (Rovira, 1965; Dey, 1972). The impact of plant roots on microflora in soil as compared to normal population is known as rhizosphere effect. The rhizosphere effect varies from plant to plant and with the age of the plant (Ketznelson, 1965; Dey and Chattopadhyay, 1977). The rhizosphere effect of a particular plant also differs for different types of microorganisms in soil. Anything applied for the betterment of crop like organic matter, inorganic fertilizers or inoculants may exert a profound influence on the rhizosphere effect (Katznelson, 1965). The study of rhizosphere effect is very important as it is directly concerned with the crucial zone so far as plant nutrition is concerned. But there is no clear idea about the performance of beneficial organisms especially nitrogen fixing and phosphate solubilizing bacteria in the rhizosphere of ginger especially in the presence of FYM and inorganic fertilizers.

Perusal of results (table–19) shows that control soil of ginger rhizosphere reared more number of total bacteria than that of initial soil because of optimum moisture favourable for the proliferation of the said organisms. Moreover, control soil was

surrounded by the ginger rhizome and, as a consequence , influenced by exudates containing organic substrates. Those exudates of ginger roots resulted in higher population of bacteria providing energy and nutrient sources (Rovira, 1965; Dey, 1972). As such, ginger rhizosphere soils in pot harboured more number of total bacteria than those soils without crop, due to rhizosphere effect (Rovira, 1965). Nevertheless, FYM resulted in higher population of bacteria in the rhizosphere soil than that of control. On the other hand, inorganic fertilizers caused an increase though not significant of the said organism in soil as compared to that of FYM. It is interesting to note that in the previous experiment, fertilizers exerted significant positive influence on the population of bacteria in soil without crop (table–6) as compared to that of FYM while in the present investigation the influence was positive but not significant. The results, thus manifested greater alteration of bacteria in rhizosphere soil under the influence of ginger roots than that of inorganic fertilizers. In other words, rhizosphere effect was more pronounced in comparison with the effect of inorganic fertilizer. However, the effect of *Azotobacter* inoculation on the population of bacteria was marginally higher than that of *Bacillus* inoculation though either of them resulted in a significant increase in the number of bacteria in rhizosphere soil as compared to that of inorganic fertilizers together with FYM treatment. As it were, combined inoculation of *Azotobacter* and *Bacillus*, resulted in the highest significant increase in the number of bacteria in ginger rhizosphere soil. The explanation of higher population of bacteria under the influence of respective treatments in the rhizosphere soil of ginger in pot is similar to those of soils without crop in pot as described earlier (table–6). The sequential enhancement in the population of bacteria under the influence of different treatments in ginger rhizosphere soil in pot was similar to those of soils

without crop (table–6). However, there was higher population of bacteria in almost all the treated soil series of the rhizosphere of ginger, due to the influence of the unique environment, the rhizosphere, than those of soils without crop. This is in the line with the observations of Katznelson (1946), Rovira (1965) and Dey (1972). The population of bacteria in rhizosphere soil under different treatments increased on and on, with the age of crop from sprouting of rhizome to full growth stage of ginger pseudostem and then gradually decreased up to harvesting stage of ginger . This corroborated the results of Katznelson (1965) and Dey (1972). This indicated that the influence of root exudates was more pronounced on the proliferation of the bacteria than that of sloughed off tissues.

The highly significant correlation between total bacteria and phosphate solubilizing microorganisms indicated protocoperative effect of the said organisms in the rhizosphere soils of ginger.

In pot, rhizosphere soils of ginger entertained more number of actinomycetes than that of initial soil (table–20) due to optimum moisture prevailing in rhizosphere soils. Moreover, the exudates of ginger root might result in higher population of actinomycetes in the rhizosphere soils. As such, FYM resulted in a significant increase in the number of actinomycetes in the rhizosphere soil of ginger as compared to that of control. The increase in the number of actinomycetes was also brought about by the additional inorganic fertilizers alone or in combination with single or dual inoculation of *Azotobacter* and *Bacillus* in the rhizosphere soil of ginger. The explanation in relation to the influence of FYM on the proliferation of actinomycetes in the rhizosphere soil of ginger is similar to that of soil without crop (table–7). Additional inorganic fertilizer alone or in combination

with the inoculant of *Bacillus* caused a marginal reduction though not significant in the population of actinomycetes in the rhizosphere soil of ginger as compared to that of FYM alone. On the other hand, the former treatment resulted in a significant increase as compared to that of the latter ones in soil without crop. The results, thus, suggested that inorganic fertilizers alone or in combination with the inoculation of *Bacillus* brought about an induction in ginger crop resulting in the release of exudates stimulatory to other groups of microorganisms. Actinomycetes, being a slow grower (Alexander, 1977), could not compete with them and, as a result, grew at a slower rate. However, *Azotobacter* inoculation resulted in an increase though not significant in the population of actinomycetes in the rhizosphere soil of ginger as compared to that of *Bacillus* inoculation. On the other hand, inoculation of *Azotobacter* brought about a significant increase in the number of the cited organisms in soil without crop as compared to those of *Bacillus* inoculation. The results, thus, manifested greater negative impact of exudates of ginger roots than the positive impact of *Azotobacter* inoculation in relation to the proliferation of actinomycetes in the *Azotobacter* inoculated rhizosphere soil of ginger than that in *Azotobacter* inoculated soil without crop supported the above view. Combined inoculation of *Azotobacter* and *Bacillus* caused the highest proliferation of actinomycetes in the rhizosphere soil of ginger. The explanation is similar to that of soils without crop as discussed earlier. The population of actinomycetes increased, on and on, with the age of ginger crop from sprouting of mother rhizome to full growth stage of ginger pseudostem and then gradually decreased up to harvesting stage. This substantiated the reports of Katznelson (1965) and Dey (1972). The results, thus, exhibited greater enhancing influence of root exudates on the proliferation of actinomycetes than that of dead tissues in the rhizosphere soil of ginger.

The significant positive correlation between actinomycetes and phosphate solubilizing microorganisms as well as phosphate solubilizing power of ginger rhizosphere soils indicated the involvement of actinomycetes in the process of insoluble phosphate solubilization.

Rhizosphere soils of ginger maintained higher population of fungi than that of initial soil (table–21) due to optimum moisture. Moreover, the exudates or dead tissue of ginger roots and scale of rhizome might result in an increase in the number of fungal propagules in the rhizosphere soils of ginger (Rovira, 1965). The number of fungal propagules significantly increase in the rhizosphere soils of ginger by the addition of FYM, more so, with the addition of inorganic fertilizer as compared to that of control. This can be explained in a similar manner to that of soils without crop as described earlier (table–8). Inoculation of *Azotobacter* or *Bacillus*, either alone or in combination together with FYM and inorganic fertilizers resulted in a decrease in the number of fungal propagules in the rhizosphere soil of ginger as compared to that of control. The interpredation is that ginger root produces certain antifungal biomolecules (Chauhan and Singh 1991, De, 1995). On the other hand, the inoculants of *Azotobacter* and *Bacillus* elaborate some antifungal agents in soil (Broadbent *et. al.*, 1977; Meshram and Jager, 1983). However, the inoculants might induce the ginger crop to exude antifungal biomolecules at a concentration inimical to the growth of fungi in the rhizosphere soil of ginger. In this respect, the worst effect in relation to the proliferation of fungi was imposed by the inoculants of *Azotobacter* followed by those of *Bacillus*, respectively. As such, the difference in the effect of *Azotobacter* to that of *Bacillus* on the proliferation of fungi in the rhizosphere soils of ginger was not statistically significant. But both of the inoculants exerted significant negative influence on fungal population in the rhizosphere soils of ginger as compared

to that of mixed inoculant. Mixed inoculant though lessened fungal propagules in the rhizosphere soils, the effect was not statistically significant as compared to that of control. The results, thus, manifested that mixed inoculant were able to countermand much of the evil effect of inoculation in relation to the proliferation of fungi in the rhizosphere soil of ginger. On the whole, fungal propagules increased, on and on, from sprouting of mother rhizome to the full growth stage of ginger pseudostem and then gradually decreased up to harvesting stage in the ginger rhizosphere. The results, thus manifested greater impact of the root exudates on the fungal propagules than that of dead tissues in the rhizosphere soil of ginger.

Rhizosphere soils of ginger maintained higher population of non-symbiotic nitrogen fixing bacteria as compared to that of initial soil (table–22) due to prevail optimum moisture in rhizosphere soil. Exudates and dead tissues of ginger rhizome and roots might also play an important role in the higher population of nitrogen fixing bacteria in the rhizosphere soils of ginger. FYM resulted in an increase, though not significant, in the population of the cited organisms in the ginger rhizosphere soils as compared to that of control. This can be explained in a similar manner to that of soil without crop as described earlier (table–9). Inorganic fertilizers either alone or in combination with in inoculants of *Bacillus* exerted significant enhancing influence on the population of nitrogen fixes in the rhizosphere soil of ginger as compared to that of FYM. Similar results were observed in the soil without crop experiment. However, it is interesting to note that rhizosphere soil treated with inorganic fertilizers alone or inoculation with *Bacillus* entertained lower population of nitrogen fixing bacteria than those of respective soil series without crop. The results, thus, manifested negative influence of root exudates on the population of non-

symbiotic nitrogen fixing bacteria. Inorganic fertilizers or *Bacillus* inoculants might induce the ginger plants to exude biomolecules stimulatory to other groups of microorganisms (Brown, 1974). Many of the non-symbiotic nitrogen fixing bacteria grow at a slow rate (LaRue, 1976). Consequently the nitrogen fixing bacteria could not compete with other diversified groups of microorganisms in the rhizosphere soils of ginger. Inoculation of *Azotobacter* resulted in a significant increase in the population of non-symbiotic nitrogen fixing bacteria in the rhizosphere soils of ginger as compared to that of *Bacillus* inoculation. The significant increase was the reflection of compounded impact of both of the root exudates and the treatment because inoculants of *Azotobacter* caused a non-significant increase in the population of nitrogen fixing bacteria as compared to those of *Bacillus* inoculation in soil without crop. In this experiment, inoculants of *Azotobacter*, by virtue of elaborating growth promoting substances, might induce the crop to exude bimolecules stimulatory to the growth of non-symbiotic nitrogen fixing bacteria in the rhizosphere soil of ginger. As it were, combined inoculation of *Azotobacter* and Bacillus brought about the highest stimulation of non-symbiotic nitrogen fixing bacteria in the rhizosphere soil of ginger. Similar influence was obtained from the soils without crop experiment. So similar explanation may be given. The population of non-symbiotic nitrogen fixing bacteria increased progressively with the age of crop from sprouting of mother rhizome to full growth stage of ginger pseudostem and then gradually decreased up to harvesting stage of ginger. The results thus revealed that the influence of root exudates was greater than that of dead tissues in the rhizosphere soil of ginger.

The significant positive correlation between nitrogen fixing bacteria and nitrogen fixing as well as phosphate solubilizing power indicated that nitrogen fixing power indicated

that nitrogen fixing bacteria were involved in the fixation process. In addition they also took part in the process of solubilization of insoluble phosphate in ginger rhizosphere.

Rhizosphere soils of ginger held more number of phosphate solubilizing organisms than that of initial soil (table-23) due to optimum moisture prevailing in rhizosphere soils. The exudates and dead tissues of ginger root and scale of rhizome might also play an important role for the higher population in the rhizosphere soils. As such, FYM brought about a significant increase in the population of the cited organisms in the rhizosphere soils of ginger as compared to that of control. Similar influence of FYM was recorded from the soil without crop experiment. So similar explanation may be given. Additional inorganic fertilizer alone or in combination with the inoculants of *Azotobacter* resulted in a significant increase in the number of phosphate solubilizers in the rhizosphere soils as compared to that of FYM alone. The influence of *Azotobacter* inoculant, in this experiment, was similar to that of soils without crop experiment described earlier. However, inorganic fertilizers resulted in a non-significant increase in the population of phosphate solubilizing microorganisms in the soil without crop as compared to that of FYM. The results, thus, suggested that exudates as well as dead tissues of ginger root might play an important role in enhancing the population of the cited organisms in the rhizosphere soils of ginger. An interesting feature of this experiment is that rhizosphere soil under *Azotobacter* inoculation entertained marginally less number of phosphate solubilizers as compared to that under inorganic fertilizers while the reverse trend was found in soil without crop experiment. So it can be suggested that the inoculants of *Azotobacter* induced ginger plants to exude biomolecule inhibitory towards the proliferation of phosphate

solubilizers in the rhizosphere soils. Such inhibitory effect by other rhizomatous plant on some microorganisms was observed by (De *et. al.*, 1995). Alternatively, inoculants of *Azotobacter* might induce the ginger crop to exude substances stimulatory towards other groups of organisms in the rhizosphere soils (Menkina, 1963). Phosphate solubilizers could not compete with them, consequently there were lower proliferation of phosphate solubilizers in rhizosphere soils. *Bacillus* inoculation resulted in a significant enhancement of the population of phosphate solubilizing microorganisms as compared to additional inorganic fertilizers alone or in combination with *Azotobacter* inoculation in the rhizosphere soil of ginger. Similar influence of *Bacillus* was recorded in soil without crop experiment. So similar explanation can be put forward. As it were, combined inoculation of *Azotobacter* and *Bacillus* resulted in the highest stimulation of phosphate solubilizers in the rhizosphere soil of ginger. Similar influence of dual inoculation of *Azotobacter* and *Bacillus* was noticed in the previous experiment and hence similar explanation can be given. The population of phosphate solubilizing microorganisms increased progressively with the age of crop from sprouting of mother rhizome to the full growth stage of ginger pseudostem and then gradually decreased up to harvesting stage of ginger. The results, thus, substantiate the earlier reports that magnitude of rhizosphere effect towards microbial abundance largely depends on active growth of the plant (Katznelson, 1965; Rovira, 1965). Moreover, the root exudates have greater impact on the proliferation of phosphate solubilizers than that of sloughed off and dead tissues of ginger root as well as scale of rhizome.

Phosphate solubilizing microorganisms were moderately correlated with phosphate solutions power as well as available phosphorus. This indicated the participation of those organisms

in mineralization and solubilization of insoluble phosphate, leading to higher availability of phosphorus in ginger rhizosphere.

Rhizosphere soils maintained higher nitrogen fixing power than that of initial soil (table–24) because of the favourable influence of exudates as well as the optimum moisture favourable for the activity of nitrogen fixing bacteria. FYM resulted in a significant increase in nitrogen fixing power as compared to that of control in the rhizosphere soils of ginger. The increase in nitrogen fixing power was accelerated marginally by the additional fertilizers along with the inoculation of *Azotobacter* and significantly by combined inoculation of *Azotobacter* and *Bacillus*. This corroborated the earlier findings of Kundu and Gaur (1980 & 1982). The increase in nitrogen fixing power by each of the cited treatment over their respective counterparts was concurrent with the proliferation of non-symbiotic nitrogen fixing bacteria in the rhizosphere soil of ginger (table–22). However, the marginal increase in nitrogen fixing power of rhizosphere soils of ginger by additional fertilizer together with *Azotobacter* inoculation over that of FYM in spite of significant enhancement on the population of non-symbiotic nitrogen fixing bacteria suggested that inoculation of Azotobacter exerted better influence on the proliferation of nitrogen fixers (Ocampo *et. al.*, 1975; Kundu and Gaur, 1982) than on the performance. However, the influence of the cited treatment was improved in the rhizosphere soil of pot culture experiment as compared to that of pot culture experiment without crop as evidenced from the results of soil without crop wherein *Azotobacter* inoculation resulted in a significant decrease in nitrogen fixing power of soil as compared to that of FYM. That was due to rhizosphere effect. The explanation is that *Azotobacter* inoculation might induce the crop to exude substances stimulatory to the growth and activity of nitrogen fixers in the rhizosphere soils of

ginger to fix more nitrogen (Sundara Rao *et. al.*, 1963). It is interesting to note that FYM resulted in a significant increase in nitrogen fixing power of soil as compared to that of dual inoculation of *Azotobacter* and *Bacillus* in spite of significant decrease in the population of nitrogen fixing bacteria in pot culture experiment without crop. There it was mentioned dual inoculation brought about better influence on the multiplication of non-symbiotic nitrogen fixers than on their performance in relation to nitrogen fixation in soil. But in the rhizosphere soils of pot culture experiment, combined inoculation of *Azotobacter* and *Bacillus* not only significantly enhanced the proliferation but also the performance of the said bacteria as compared to that of FYM. Similar trend of increase of nitrogen fixers was also observed by Ocampo *et. al.* (1975); Kundu and Gaur (1982).

Bacillus inoculation resulted in a significant decrease in the nitrogen fixing power of rhizosphere soil as compared to that of *Azotobacter* inoculation. Similar detrimental effect of *Bacillus* inoculation over *Azotobacter* inoculation was noticed in pot culture experiment without crop. So, similar explanation can be put forward. Like that of pot culture experiment without crop, inorganic fertilizer brought about a decrease, though not significant, in the nitrogen fixing power of rhizosphere soil of pot culture experiment as compared to that of control. This can be explained in a similar manner to that of pot culture experiment without crop. However, ginger crop definitely induced positive rhizosphere effect as evidenced from higher nitrogen fixing power of rhizosphere soils of pot culture experiment by inorganic fertilizer than that of the respective soil without crop. The nitrogen fixing power of ginger rhizosphere increased, on and on, with the age of crop starting from the sprouting of mother rhizome to the full growth stage of ginger pseudostem and then decreased gradually

up to the harvesting stage of ginger. The results, thus, indicated that root exudates were more important on nitrogen fixing power than that of dead tissues of roots and scale of rhizome.

Rhizosphere soils of ginger kept up higher phosphate solubilizing power as compared to that of initial soil (table-25) owing to the influence of the exudates of roots in addition to optimum moisture favourable for the activity of the phosphate solubilizing microorganisms. FYM resulted in a significant increase in phosphate solubilizing power of rhizosphere soils of pot culture experiment as compared to that of control. The increase in phosphate solubilizing power was significantly accelerated by inorganic fertilizers alone or in combination with the inoculation of *Azotobacter* which was further intensified by *Bacillus* inoculation, more so, by combined inoculation of *Azotobacter* and *Bacillus* . This substantiated the finding of Verma and Mathur (1989). The sequential enhancing influence of two treatments on phosphate solubilizing power was in accordance with the proliferation of phosphate solubilizing microorganisms in the rhizosphere soil of pot culture experiment (table-23). So, it may be suggested that the respective treatments not only resulted in favourable sequential influence on the population but also the performance of phosphate solubilizing microorganisms in the rhizosphere soils in relation to insoluble phosphate solubilization. The results maintained similarity in respect to the sequential effect of treatments with the pot culture experiment without crop and hence similar explanation can be put forward. However, the enhance influence of different treatments were intensified to about three folds in the rhizosphere soils as compared to those of non-rhizosphere soils of pot culture experiment. Such tremendous increase in phosphate solubilizers was also observed by Ocampo *et. al.* (1975), Kundu and Gaur (1980). The phosphate solubilizing

power of ginger rhizosphere, in general, increased progressively with growth of ginger plant starting from sprouting of mother rhizome to the full growth stage of ginger pseudostem and then declined gradually up to the harvesting stage of ginger. The results, thus, indicated that the influence of root exudates was more pronounced on phosphate solubilizing power than that of sloughed off tissues.

Rhizosphere soils contained less amount of organic carbon as compared to that of initial soil (table–26) because of intense microbial activity under the influence of the exudates of roots and or decomposed root tissues. Optimum moisture of rhizosphere soils could also resulted in higher population of heterotrophic microflora (Alexander, 1977) capable of carrying out carbon mineralization at a faster rate. It will be worth while to mention that a decrease in the content of organic carbon reflects higher rate of carbon mineralization from soil. FYM resulted in the highest increase in the content of organic carbon in the rhizosphere soil of ginger in pot culture experiment followed by those of inorganic fertilizers, *Azotobacter* inoculation, *Bacillus* inoculation and combined inoculation of *Azotobacter* and *Bacillus*, respectively. The sequential influence of the treatments on the content of organic carbon in the rhizosphere soils of ginger in pot culture experiment are similar to those of non-rhizosphere soils (table–13). Hence similar explanation in relation to relative influence of different treatments on the content of organic carbon to those of non-rhizosphere soils can be put forward. However, the exudates and or dead tissues of ginger root accelerated the relative enhancing influence of different treatments on the mineralization of organic carbon in the rhizosphere soils of ginger with the exception of that of combined inoculation *Azotobacter* and *Bacillus* as compared to those of non-rhizosphere soils. The enhancement was due to the

rhizosphere effect as evidenced from higher population of different types of microorganisms (table–19, 20 & 21) in the rhizosphere soils of ginger as compared to those of non-rhizosphere soils (table–6, 7 & 8). But, it is not clear why the exudates and or dead tissues of roots of ginger decelerate the influence of combined inoculation of *Azotobacter* and *Bacillus* on the mineralization of organic carbon in the rhizosphere soil as compared to those of non-rhizosphere soil. The content of organic carbon in the rhizosphere soils of ginger gradually decreased from sprouting of mother rhizome to the harvesting of daughter ginger rhizome. This substantiated the earlier reports of Mukherjee (1975) and Mukherjee *et. al.* (1990), that organic carbon decreased from soil with time. This was due to intense microbial activity in this unique zone leading to carbon mineralization (Hiltner, 1904).

Rhizosphere soils of ginger kept up higher amount of nitrogen as compared to that of initial soil (table–27) due to optimum moisture which might result in the acceleration of growth and activities of non-symbiotic nitrogen fixing bacteria in soil (Alexander, 1977). Alternatively, the ginger crop might induce positive rhizosphere effect on the growth and activities of non-symbiotic nitrogen fixing bacteria in the rhizosphere soil as evidenced from the higher nitrogen fixing power of rhizosphere soils of pot culture experiment (table–24), resulting in upliftment of nitrogen. FYM resulted in a significant increase in the content of nitrogen in the rhizosphere soils as compared to that of control. This might be due to the inherent nitrogenous substances of FYM (Mukherjee and Gaur, 1984). The increase in the content of nitrogen was accelerated progressively, in the ascending order, by the inoculation of *Bacillus*, inorganic fertilizers, combined inoculation of *Azotobacter* and *Bacillus* and inoculation with *Azotobacter*, respectively. The sequential influence of various treatments on the

content of nitrogen in the rhizosphere soils of ginger in pot culture experiment was similar to those of non-rhizosphere soils. Hence, similar explanation can be given. However, rhizosphere soils, in general, clubbed less amount of nitrogen as compared to those of non-rhizosphere soils (table–14). This might be due to higher loss of nitrogen from rhizosphere soils by denitrification (Smith and Douglas, 1970) and assimilation of nitrogen by plant and microorganisms (Vasantharajan and Bhat, 1967; Alexander, 1977) following enhanced mineralization of organic nitrogen by enhanced microbial population as evidenced from in results (table–28 & 29) as compared to those of non-rhizosphere soils.

Rhizosphere soils under control gathered more amount of ammoniacal–nitrogen from the sprouting of rhizome to full growth stage of ginger pseudostem as compared to that of initial soil (table–28) due to greater mineralization of organic nitrogen as evidenced from higher population of microorganisms in control rhizosphere soils. On the other hand, low built up of ammoniacal –nitrogen in the rhizosphere control soil as compared to that of initial soil from near maturity of ginger pseudostem to harvesting stage might be due to loss of nitrogen from the rhizosphere soils by denitrification (Smith and Douglas, 1970) and assimilation of ammoniacal nitrogen by plant and microorganisms (Alexander, 1977). FYM resulted an increase in the content of ammoniacal nitrogen in the rhizosphere soils of pot culture experiment as compared to that of control. The increase was further intensified progressively, in an ascending order, by fertilizers, inoculation of *Bacillus*, inoculation of *Azotobacter* and combined inoculation of *Azotobacter* and *Bacillus*, respectively in the rhizosphere soils of ginger. The sequential influence of different treatments on the content of ammoniacal-nitrogen in the rhizosphere soil was similar to those in non-rhizosphere soil of pot culture experiment with the

exception of that inorganic fertilizers resulted in higher build up of ammoniacal-nitrogen than that of inoculation of *Bacillus* in the non-rhizosphere soil (table–15). In this context, it may be assumed that *Bacillus* inoculants might induce the crop to exude substances stimulatory to the growth and activity of nitrogen mineralizing microorganisms which, in turn, resulted in the higher release of ammoniacal-nitrogen in the rhizosphere soil of ginger crop than those of inorganic fertilizers. Alternatively, the inoculants under the influence of the exudates or dead tissues of root might yield metabolites stimulatory to the growth and activities of nitrogen mineralizing microorganisms in the rhizosphere soils. For rest of the treatments, the relative influence was similar to those of non-rhizosphere soils and hence similar explanation can be put forward. It is interesting to note that rhizosphere soils universally expressed low build up of ammoniacal-nitrogen as compared to those of non-rhizosphere soils. That was due to higher loss of nitrogen from rhizosphere soils by denitrification and or assimilation of nitrogen by microorganisms and crop following rapid mineralization by enhanced microbial population. In general, the ammoniacal nitrogen content of rhizosphere soils of pot culture experiment significantly decreased at harvesting stage as compared to that of early emergence of ginger pseudostem stage. The decrease in the content ammoniacal-nitrogen might be due to assimilation by crop as well as microorganisms besides the process of nitrification.

The significant positive correlation in between ammoniacal-nitrogen and total nitrogen indicated higher rate of ammonification of nitrogenous compound in ginger rhizosphere soils.

Rhizosphere control soil retained more amount of nitrate-nitrogen than that of initial soil (table–29) from the sprouting of mother rhizome to the full growth stage of ginger pseudostem.

This might be due to higher rate of nitrification in the presence of optimum moisture favourable for the growth and activities of nitrifying bacteria in the rhizosphere soils (Alexander, 1977). On the other hand, less amount of nitrate-nitrogen in the control soil during near maturity of ginger pseudostem and harvesting stages as compared to that of initial soil suggested the higher rate of denitrification and or assimilation of nitrogen by microorganisms in the rhizosphere control soil. FYM resulted in an increase in the content of nitrate nitrogen in the rhizosphere soils as compared to that of control. The increase in nitrate nitrogen was further marginally accelerated by the inoculation of *Bacillus* which was further intensified by inorganic fertilizers and or inoculation of *Azotobacter*, more so, significantly by combined inoculation of *Azotobacter* and *Bacillus*. The sequential influence of various treatments on the content of nitrate nitrogen in the rhizosphere soil of pot culture experiment was similar to that in non-rhizosphere soil with the exception of that the influence of *Azotobacter* was superior to that of inorganic fertilizers in the non-rhizosphere soil in relation to the content of nitrate nitrogen. On the other hand, inoculation of *Azotobacter* could not bring about any impact on the content of nitrate nitrogen in the rhizosphere soils as compared to that of inorganic fertilizers. This indicated the neutral effect of *Azotobacter* inoculation on the process of nitrification in the rhizosphere soils of ginger. Alternatively, the positive impact of *Azotobacter* inoculation could be nulified by the negative impact of exudates and or dead tissues of ginger roots in relation to the process of nitrification in the rhizosphere soil. It is known that the process of nitrification is associated with the metabolisms of certain chemoautotrophic bacteria (Alexander, 1977) and the population of chemoautotrophs, and so, the process of nitrification is adversely affected by the exudates or dead tissues of roots (Alexander, 1977;

Mukherjee *et. al.*, 1991) It is likely that the process of nitrification was adversely affected in ginger rhizosphere soil. As such, the influence of various treatments was adversely affected on the process of nitrification in the rhizosphere soil as compared to those of the respective treatments in non-rhizosphere soil (table–16). That was due to the deleterious influence of the exudates and dead tissues of root on the process of nitrification. However, the inoculation of *Azotobacter* might also result in higher proliferation of denitrifying bacteria and hasten the process in the rhizosphere soil of ginger. Even the ginger crop as well as microorganisms might assimilate inorganic nitrogenous compounds resulting in a decrease in the content of nitrate-nitrogen in the rhizosphere soils. The sequential influence of other treatments on the content of nitrate-nitrogen in the rhizosphere soils. The sequential influence of other treatments on the content of nitrate-nitrogen in the rhizosphere soil was similar to those in non rhizosphere soils. Hence similar explanation can be given. It is interesting to note that the content of nitrate- nitrogen was less than that of ammoniacal-nitrogen in the rhizosphere soils of pot culture experiment. This suggested that the rate of nitrification was slower than that of ammonification.

Rhizosphere control soil retained higher amount of available phosphorus than that of initial soil (table–30) from the sprouting of mother rhizome to the full growth stage of ginger pseudostem due to greater rate of mineralization and solubilization of organic and inorganic insoluble phosphatic compounds by microorganisms in the presence of favourable environmental conditions (Hayman, 1975). The decrease in available phosphorus during near maturity of ginger pseudostem and harvesting stages of ginger might be due to the fixation of phosphate ions in clay colloids (Datta, *et. al.*, 1982) or formation of insoluble phosphate

compounds in the experimental acid soils (Datta *et. al.*, 1982) besides the uptake of phosphorus by ginger plants. Microorganisms might play an important role in the reduction of available phosphorus by the precess of assimilation in the rhizosphere soils (Gaur *et. al.*, 1973; Banik and Dey, 1981). FYM resulted in a significant increase in the content of available phosphorus in the rhizosphere soils as compared to that of control. The increase in the content of the same was accelerated by the inoculation of *Azotobacter*, more so, by inorganic fertilizers which was then intensified by the *Bacillus* inoculants and further by combined inoculation of *Azotobacter* and *Bacillus*. The sequential enhancing influence of various treatments on the content of available phosphorus in the rhizosphere soils was similar to those of the respective treatments of non-rhizosphere soil. Hence similar explanation can be given. The influence of all the treatments but FYM was accelerated in the rhizosphere soils as compared to those of respective treatments in non-rhizosphere soils. This indicated positive influence of rhizosphere. On the other hand, the influence of FYM was diminutive in relation to the content of available phosphorus in ginger rhizosphere soils as compared to that of non-rhizosphere soils. In this context, it may be suggested that FYM might induce the crop to secrete substances inhibitory to the growth and activity of microorganisms capable of mineralizing and solubilizing insoluble organic and inorganic phosphorus compounds in the rhizosphere soils of ginger. Alternatively, crop might assimilate a substantial portion of phosphorus resulting in decrease in the content of available phosphorus in the rhizosphere soils. The available phosphorus content in the rhizosphere soils of ginger in pot culture experiment decreased gradually from sprouting of mother rhizome to the harvesting of daughter rhizome. The decrease was due to fixation of phosphate ions (Datta *et. al.*, 1982),

assimilation by microorganisms (Gaur *et. al.*, 1973) and uptake of phosphorus by crop plants (Vasantharajan and Bhat, 1967).

The significant positive correlation in between available phosphorus and phosphate solubilizing power indicated intensive solubilization of native insoluble phosphatic minerals, leading to the availability of phosphorus.

FYM resulted in marginal improvement in the uptake of nitrogen by ginger rhizome as compared to that of control. (table–31) This is in the line with observation of Mukherjee and Gaur (1984). The improvement in the uptake of nitrogen was further accelerated in an ascending order by the influence of inorganic fertilizers, inoculation of *Bacillus*, inoculation of *Azotobacter* and combined inoculation of *Azotobacter* and *Bacillus*, respectively. This corroborated the earlier reports that single inoculation with *Azotobacter* (Konde *et. al.*, 1990) and combined inoculation with *Azotobacter* and *Bacillus* (Kundu and Gaur, 1982) increased the uptake of nitrogen by crop. It is known that a crop assimilates nitrogen and translocates the same to roots and shoots. The assimilation of nitrogen by a plant is usually more from a soil containing more amount of available nitrogen. Therefore, the content of ammoniacal and nitrate nitrogen is one of determinant of the uptake of nitrogen by a crop. The sequential influence of various treatments on the uptake of nitrogen by ginger rhizome was, in general, in accordance with the relative influence of respective treatments on the content of ammoniacal and nitrate nitrogen, in the rhizosphere soil (table–28 & 29). Consequently a significant correlation in between the uptake of nitrogen and the content of ammoniacal-nitrogen ($r = 0.950^{**}$) and nitrate-nitrogen (0.812^{*}) was obtained. However, there was an exception wherein inorganic fertilizers resulted in an increase in the content of ammoniacal and

nitrate nitrogen as compared to that of *Bacillus* inoculation in the rhizosphere soils while inoculation of *Bacillus* caused higher uptake of nitrogen by ginger rhizome than that of inorganic fertilizers. In this context, it may be stated that inoculation of *Bacillus* often results in the elaboration of phytohormones in the rhizosphere soils (Hussain and Vancura, 1970; Brown, 1974; Datta *et. al.*, 1982) which, in turn, cause increased root system and an improvement in the vigour of crop leading to higher uptake of nitrogen (Vasantharajan and Bhat, 1967 . As a whole, there was greater uptake of nitrogen as compared to that of phosphorus. This substantiated the earlier results (Haag *et al.*, 1990).

The significant positive correlation between uptake of nitrogen and total bacteria, nitrogen fixing and phosphate solubilizing power, ammoniacal and nitrate-nitrogen, available phosphorus and total nitrogen, respectively indicated the involvement of heterotrophic bacteria in the process of fixation of atmospheric nitrogen followed by its mineralization.

FYM resulted in a marginal improvement in the uptake of phosphorus by ginger rhizome as compared to that of control. The improvement in the uptake was further accelerated in an ascending order, by the influence of inorganic fertilizers, inoculation of *Azotobacter*, inoculation of *Bacillus* and combined inoculation of *Azotobacter* and *Bacillus*, respectively. The sequential influence of various treatments on the uptake of phosphorus by ginger rhizome was, in general, in accordance with relative influence of the respective treatments on the content of available phosphorus in the rhizosphere soils (table-30). Therefore, a positive significant correlation in between uptake of phosphorus and the content of available phosphorus ($r = 0.880^*$) was found. However, there is an exception wherein it was found that the influence of the inoculation

of *Azotobacter* was better than that of inorganic fertilizers on the uptake of phosphorus by ginger rhizome in spite of the fact that inorganic fertilizer was superior to *Azotobacter* inoculation in relation to the content of available phosphorus in the rhizosphere soils. This can be explained in a similar manner to that of uptake of nitrogen in the rhizosphere soils of the pot culture experiment. Inoculation of *Azotobacter* might induce the formation of growth promoting substances (Brown, 1974) and, thus, result in greater uptake of phosphorus following an increased root system (Konde, *et. al.*, 1990).

The significant correlation in between uptake of phosphorus and phosphate solubilizing organisms, phosphate solubilizing power as well as available phosphorus indicated the involvement of phosphate solubilizing organisms in the process of solubilization resulting in enhancement of available phosphorus leading to higher uptake.

FYM resulted in a significant increase in the yield of ginger rhizome as compared to that of control (table–3). The results thus, substantiated the reports of several workers (Rajan *et. al.*, 1971; Mohanthy *et. al.*, 1978; Power *et. al.*, 1987; Sadananda *et. al.*, 1988; Sugito, 1995; Khandkar *et. al.*, 1996). The increase in the yield of ginger was further accelerated progressively by the influence of inorganic fertilizers, inoculation of *Bacillus*, inoculation of *Azotobacter*, respectively, and, more so, by the influence of combined inoculation of *Azotobacter* and *Bacillus*. The increase in yield on inoculation substantiated the reports of Patel (1969) and Brown (1974). The sequential influence of various treatments on the yield of ginger rhizome was in accordance with the relative influence of respective treatments on the uptake of nitrogen. As a consequence, a significant correlation in between the yield and

uptake of nitrogen by ginger rhizome (r = 0.950**) was obtained. Similarly the sequential influence of various treatments on the yield was, in general, concurrent with the relative influence of the respective treatments on the uptake of phosphorus. So, a significant correlation in between yield and uptake of phosphorus (r = 0.820*) was obtained. Though, inoculation of *Bacillus* resulted in a significant increase in the uptake of phosphorus by ginger rhizome as compared to that of inoculation of *Azotobacter*, yet, the influence of the latter treatment was marginally superior to that of the former one in relation to yield. This indicates that nitrogen is more important than phosphorus in relation to the yield of ginger which is a modified stem. However, an increase in yield is a resultant impact of the availability of nutrients in relation to uptake by crop, influence of phytohormones and the activities of beneficial microorganisms in relation to disease suppression (Sakthivel *et. al.*, 1986 and Schippers *et. al.*, 1987). In this respect, combined inoculation of *Azotobacter* and *Bacillus* was the best treatment. This substantiated the earlier reports of Kundu and Gaur (1980). This was followed by inoculation of *Azotobacter*, inoculation of *Bacillus*, inorganic fertilizers and FYM, respectively. The differences among the treatments - inoculation of *Azotobacter*, inoculation of *Bacillus* and inorganic fertilizers - were not statistically significant.

Rhizome yield was significantly correlated with the nitrogen fixing and phosphate solubilizing organisms. In addition yield was directly related with uptake of nitrogen and phosphorus. This indicated the importance of nitrogen and phosphorus nutrition of ginger. Moreover, both nitrogen fixing and phosphate solubilizing bacteria elaborate phytohormones which, in turn, increased the yield of ginger.

Experiment No. 5 – Effect of FYM and inoculation of efficient nitrogen fixing and phosphate solubilizing bacteria on microbial and nutrient dynamics in the rhizosphere soil as well as performance of ginger in field :

Natural fertility is a rare phenomenon. Moreover, soil is deprived of huge amount of nutrients by its association with crop. So, in order to obtain good harvest, soil has to be enriched with nutrients. Generally in organic fertilizers are used as sources of nutrients for crop. Though fertilizers fulfill physiological requirements of crop yet the inanimate inorganic entities also encourage pathogenic entities. In addition, inorganic fertilizers exert adverse impact on soil health. Organic manures are alternate source of nutrients for crops. Manures provide not only nutrients but also growth promoting substances (Mishustin and Shilnikova, 1971) which, in turn, impart good vigour in crop. Strains of *Azotobacter* and *Bacillus* are capable of enriching the soil with nitrogen and phosphorus, respectively, besides providing growth promoting substances (Mishustin and Shilnikova, 1971 ; Brown, 1974) and Chemicals toxic to Pathogenic organisms (Lakshmi Kumar *et al*, 1975; Broadbent *et al*, 1977). Their inoculation on to seed or in soil ensures good vigour and yield in different crops (Brown, 1974; Gupta *et al*, 1997). However, there are contradicting reports regarding the effect of inoculation of *Azotobacter* or *Bacillus*, single or dual, on the biological and chemical properties of soil *vis a vis* the yield of different crop (Ravira, 1963; Brown, 1974; Meriman *et. al.*, 1974). Moreover, there are many reports that the results obtained from field are not consistent with those under controlled conditions (Broadbent *et al*, 1977; Burr *et al*, 1978; Kalepper *et al*, 1980). The above views, necessitated to conduct a field experiment of *Azotobacter* and *Bacillus* on some microbiological and chemical properties of soil *vis a vis* the performance of ginger crop.

Perusal of results showed (table–33; fig. 25) that control soil of ginger rhizosphere in the field experiment reared more number of bacteria than that of initial soil. This can be explained in a similar manner to that of rhizosphere soils of pot culture experiment. FYM resulted in a significant increase in the population of bacteria in the rhizosphere soil of field experiment as compared to that of control. The increase in the number of bacteria was further significantly accelerated by either of inoculation of *Azotobacter* or *Bacillus*, more so, by combined inoculation of *Azotobacter* and *Bacillus*. The sequential influence of various treatments on the proliferation of bacteria in the rhizosphere soils of field experiment were in accordance with those of the relative influence of respective treatments in the rhizosphere soils of pot culture experiment. Hence similar explanation in relation to the influence of various treatments on the proliferation of bacteria to that of rhizosphere soils of pot culture experiment can be put forward. It is interesting to note that the rhizosphere soils of field experiment harboured more number of bacteria than those of rhizosphere soils of pot culture experiment. This indicated more positive influence of rhizosphere in field experiment than that in pot culture experiment. This might be due to the extensive network of root system of ginger, resulting in more positive rhizosphere effect in the field experiment under natural condition as compared to that in pot culture experiment. The population of bacteria in the rhizosphere soil under different treatments increased, on an on, with the age of crop from sprouting of mother rhizome to full growth stage of ginger pseudostem and then gradually decreased up to harvesting stage of ginger. This substantiated the finding of Ketznelson (1965) that the rhizosphere effect depended on the age of crop plants. This indicated that the influence of root exudates was more pronounced on the

proliferation of the bacteria than that of sloughed off tissues.

The significant positive correlation between total bacteria and actinomycetes as well as phosphate solubilizing microorganisms indicated the protocooperative effect of the said organisms in the rhizosphere soils of ginger.

Rhizosphere soils of field experiment reared higher population of actinomycetes than that of initial soil (table–34). The explanation is similar to that of rhizosphere soils of pot culture experiment. FYM resulted in an increase in the population of actinomycetes as compared to that of control in the rhizosphere soils of field experiment. As such, inoculation of *Bacillus* caused marginal increase in the population of actinomycetes in the rhizosphere soils of field experiment as compared to that of FYM. On the other hand, inoculation of *Bacillus* resulted in a marginal decrease in the population of actinomycetes as compared to that of FYM in the rhizosphere soils of pot culture experiment. This exhibited differential influence of the cited treatments on the population of actinomycetes in the rhizosphere soils of pot culture and field experiments. The reason remained obscure and awaits further investigation. However, the extensive network of root system in the field condition might play an important role in this regard. *Azotobacter* inoculation was marginally superior to *Bacillus* inoculation in relation to their influence on the population of actinomycetes in the rhizosphere soils of field experiment. The relative influence of the cited inoculants in the rhizosphere soils of field experiment was similar to that in the rhizospheres soils of pot culture experiment. It is interesting to note that inorganic fertilizers caused significant stimulating influence on the proliferation of actinomycetes as compared to that of FYM in the rhizosphere roils of field experiment. On the other hand, inorganic

fertilizers resulted in a marginal decrease in the population of actinomycetes as compared to that of FYM in the rhizosphere soils of pot culture experiment. The results, thus, exhibited differential influence of the treatments in the rhizosphere soils of pot culture and field experiments. As it were, combined inoculation of *Azotobacter* and *Bacillus* bought about the highest stimulating influence on the proliferation of actinomycetes in the rhizosphere soils of field experiment. The influence of the cited treatment was similar to that in the rhizosphere soils of pot culture experiment. So, similar explanation to that in the rhizosphere soils of pot culture experiment can be put forward. With the age of ginger plants, the population of actinomycetes in the rhizosphere soils invariably increased right from sprouting of rhizome to full growth stage of ginger pseudostem and, thereafter, decreased up to final harvest. This might be due to higher accumulation of root exudes in active full growth stage of ginger which, in turn, encouraged more population on that stage. On the contrary, less number during harvesting stage might be due to less organic source available for actinomycetes in the ginger rhizosphere during its senescence stage.

The significant correlation between actinomycetes and nitrate-nitrogen indicated the importance of nitrate-nitrogen in the nutrition of actinomycetes in ginger rhizosphere.

Rhizosphere control soil of field experiment maintained higher population of fungi as compared to that of initial soil (table - 35). The explanation is similar to those of rhizosphere soils of pot culture experiment. FYM resulted in a significant stimulating influence on fungal propagules as compared to that of control. The stimulating influence was further significantly accelerated by inorganic fertilizers. The sequential influence of FYM and

inorganic fertilizers over control on the population of fungi in the rhizosphere soils of field experiment was similar to those of respective treatments in the rhizosphere soils of pot culture experiment. Hence similar explanation can be put forward. As such, inoculation of *Bacillus* resulted in marginal deleterious influence on the population of fungi as compared to that of control in the rhizosphere soils of field experiment. On the other hand, the inoculation of *Bacillus* caused significant deleterious influence on fungal propagules as compared to that of control in the rhizosphere soils of pot culture experiment. This indicated that the adverse effect was mitigated to a great extent in the field condition. Inoculation of *Azotobacter*, however, brought about significant detrimental influence on the population of fungi as compared to that of control in the rhizosphere soils of field experiment. Similar adverse influence of *Azotobacter* inoculants on fungal propagules was obtained from the rhizosphere soils of pot culture experiment. So similar explanation can be put forward. As such, combined inoculation of *Azotobacter* and *Bacillus* resulted in a significant enhancing influence on the population of fungi in the rhizosphere soils of field experiment as compared to that of control. On the other hand, combined inoculation of *Azotobacter* and *Bacillus* exerted marginal harmful influence on the population of fungi as compared to that of control in the rhizosphere soils of pot culture experiment. This indicated that rhizosphere soils of field experiment not only countermanded the adverse effect but also caused beneficial influence on the population of fungi. Higher proliferation of fungi in the rhizosphere soils of field experiment than those of rhizosphere soils of pot culture experiment further strengthened the above finding. The population of fungi in the rhizosphere soils under different treatments progressively increased from the sprouting of mother rhizome to the full growth

stage of ginger pseudostem and then gradually declined up to the harvesting stage of ginger. This indicated that the influence of root exudates was more pronounced on the proliferation of fungi than that of dead and muribond tissues of ginger roots.

Rhizosphere soils of field experiment reared more number of non-symbiotic nitrogen fixing bacteria than that of initial soil (table-36). Similar results were obtained from rhizosphere soils of pot culture experiment. Hence, similar explanation can be put forward. FYM resulted in a significant increase in the population of non-symbiotic nitrogen fixing bacteria as compared to that of control in the rhizosphere soils of field experiment. On the other hand, the cited manure brought about a marginal increase (non significant) as compared to that of control in the rhizosphere soils of pot culture experiment. The results, thus, exhibited differential influence of the cited treatment in the rhizosphere soils of pot culture and field experiment. Inorganic fertilizers alone or in combination with the *Bacillus* inoculants exerted a marginal depressing influence on the proliferation of non-symbiotic nitrogen fixing bacteria in the rhizosphere soils of field experiment as compared to that of FYM. On the other hand, the cited treatments caused significant enhancing influence on the population of non-symbiotic nitrogen fixers as compared to that of FYM in the rhizosphere soils of pot culture experiment. So, the influence of inorganic fertilizers alone or in combination with *Bacillus* in relation to that of FYM was not consistent in the rhizosphere soils of pot culture and field experiments. Such inconsistency in inoculation experiments in various aspects was reported by several earlier workers in different crops (Broadbent *et al*, 1977 ; Burr *et al*,1978). However, inoculation of *Bacillus* resulted in a deleterious influence, though not significant as compared to that of inorganic fertilizers in the rhizosphere soils of field experiment. The results

were similar to that of rhizosphere soils of pot culture experiment. Inoculation of *Azotobacter* caused significant stimulation of non-symbiotic nitrogen fixing bacteria as compared to that of inorganic fertilizers in the rhizosphere soils of field experiment. As it were, combined inoculation of *Azotobacter* and *Bacillus* resulted in the highest proliferation of non-symbiotic nitrogen fixing bacteria in the rhizosphere soils of field experiment. The sequential influence of the cited treatments on non-symbiotic nitrogen fixing bacteria in the rhizosphere soil of field experiment was in accordance with those in the rhizosphere soils of pot culture experiment. Hence, similar explanation can be put forward. Rhizosphere soils of field experiment, universally, reared more number of non-symbiotic nitrogen fixing bacteria than those of rhizosphere soils of pot culture experiment. The extensive root system in the rhizosphere soils of field experiment might play an important role in this regard. Being a heterotroph, the nitrogen fixing bacteria proliferated, on and on, with the assurance of greater supply of root exudates from the sprouting of rhizome to full growth stage of ginger plants. Less number of the said bacteria in the rhizosphere soils at harvesting stage might be due to senescence stage of crop incapable of satisfying the organic nutrients requirement of the said bacteria.

A significant correlation between nitrogen fixing bacteria and nitrogen fixing power indicated that nitrogen fixing bacteria were directly involved in the process of atmospheric nitrogen fixation in the rhizosphere soil of ginger.

Rhizosphere soils of field experiment clubbed more number of phosphate solubilizing microorganisms than that of initial soil (table–37). The rhizosphere effect of control soil in field experiment was, however, less as compared to that of pot culture

experiment. FYM resulted in a significant increase in the population of phosphate solubilizing microorganisms as compared to that of control in the rhizosphere soils of field experiment. The influence of FYM on the proliferation of phosphate solubilizers in the rhizosphere soils of field experiment. The influence of FYM on the proliferation of phosphate solubilizers in the rhizosphere soils of field experiment was similar to that in the rhizosphere soils of pot culture experiment. Inorganic fertilizers caused a significant enhancing influence on the proliferation of phosphate solubilizing microorganisms as compared to that of FYM, in the rhizosphere soils of field experiment. Inorganic fertilizers brought about similar stimulating influence on the said organisms in the rhizosphere soils of pot culture experiment. So similar explanation regarding the influence of the cited treatments can be put forward. Inoculation of *Azotobacter* resulted in a marginal increase in the population of phosphate sulubilizers as compared to that of inorganic fertilizers in the rhizosphere soils of field experiment. On the other hand, inoculation of *Azotobacter* caused a marginal decrease in the population of phosphate solubilizing microorganisms as compared to that of inorganic fertilizers in the rhizosphere soils of pot culture experiment. The result, thus, exhibited differential influence of the cited treatments on the population of the cited organisms in the rhizosphere soils of pot culture and field experiments. Inoculation of *Bacillus* resulted in a marginal increase in the proliferation of phosphate solubilizers as compared to that of inoculation of *Azotobacter* in the rhizosphere soils of field experiment. On the other hand, *Bacillus* inoculants cause a significant increase in the population of phosphate solubilizers as compared to that of *Azotobacter* inoculants in the rhizosphere soils of pot culture experiment. The results, thus, manifested inconsistency regarding the effect of cited

treatment on the population of phosphate solubilising microorganisms in between the rhizosphere soils of pot culture and field experiments. This inconsistency was probably due to less establishment of *Bacillus* inoculants in diverse soil ecosystem in field condition (Brown, 1974; Broadbent *et al*, 1977; Burr *et al*, 1978). As it were, inoculation of *Azotobacter* and *Bacillus* brought about maximum stimulating influence on the population of phosphate solubilizing microorganisms in rhizosphere soil of field experiment. The results were similar to that of the stimulating influence of dual inoculation of *Azotobacter* and *Bacillus* on the population of the said organisms in the rhizosphere soils of pot culture experiment. So, similar explanation to that of pot culture experiment can be put forward. As such, different type of additives reared more number of phosphate solubilizing microorganisms in the rhizosphere soils of field experiment as compared to the respective additives in the rhizosphere soils of pot culture experiment. The extensive ramification of root system in the rhizosphere soils of field experiment might play an important role in augmenting the population of phosphate solubilizing microorganisms in the rhizosphere soils of field experiment. The population of phosphate solubilizing microorganisms increased progressively with the age of crop from sprouting of rhizome to full growth stage of ginger pseudostem and then decreased up to harvesting stage of ginger. The same explanation as that of nitrogen fixing bacteria is applicable in this case also.

The nitrogen fixing power of rhizosphere soils of field experiment was more than that of initial soil (table–38). The results were similar to those of rhizosphere soils of pot culture experiment. Hence, similar explanation can be put forward. FYM resulted in a significant increase in the nitrogen fixing power as compared to that of control in the rhizosphere soil of field experiment. Manures

treatment on the population of phosphate solubilising microorganisms in between the rhizosphere soils of pot culture and field experiments. This inconsistency was probably due to less establishment of *Bacillus* inoculants in diverse soil ecosystem in field condition (Brown, 1974; Broadbent *et al*, 1977; Burr *et al*, 1978). As it were, inoculation of *Azotobacter* and *Bacillus* brought about maximum stimulating influence on the population of phosphate solubilizing microorganisms in rhizosphere soil of field experiment. The results were similar to that of the stimulating influence of dual inoculation of *Azotobacter* and *Bacillus* on the population of the said organisms in the rhizosphere soils of pot culture experiment. So, similar explanation to that of pot culture experiment can be put forward. As such, different type of additives reared more number of phosphate solubilizing microorganisms in the rhizosphere soils of field experiment as compared to the respective additives in the rhizosphere soils of pot culture experiment. The extensive ramification of root system in the rhizosphere soils of field experiment might play an important role in augmenting the population of phosphate solubilizing microorganisms in the rhizosphere soils of field experiment. The population of phosphate solubilizing microorganisms increased progressively with the age of crop from sprouting of rhizome to full growth stage of ginger pseudostem and then decreased up to harvesting stage of ginger. The same explanation as that of nitrogen fixing bacteria is applicable in this case also.

The nitrogen fixing power of rhizosphere soils of field experiment was more than that of initial soil (table-38). The results were similar to those of rhizosphere soils of pot culture experiment. Hence, similar explanation can be put forward. FYM resulted in a significant increase in the nitrogen fixing power as compared to that of control in the rhizosphere soil of field experiment. Manures

were reported to bring about a significant influence on the performance of diazotrophic heterotrophs (Asmus,1970; Rao, 1977). On the other hand, inorganic fertilizers alone or in combination with the inoculation of *Bacillus* resulted in a decrease in the nitrogen fixing power of the rhizosphere soils of field experiment as compared to that of FYM. The decrease was, however, marginal in the case of *Bacillus* inoculation and significant in regard to the treatment-inorganic fertilizers. Decrease in nitrogen fixation under the influence of inorganic fertilizers is in conformity with those of De (1939), Jensen (1965) and Alexander (1977), Because, urea, the component of inorganic fertilizers, undergoes enzymatic hydrolysis and resulted in ammonium compounds which repressed the nitrogenase enzyme responsible for nitrogen fixation. Hence less amount of nitrogen was fixed. As such, inoculation of *Azotobacter* caused an enhancement in the nitrogen fixing power of rhizosphere soil as compared to that of FYM in the field experiment. However, combined inoculation of *Azotobacter* and *Bacillus* resulted in the highest increase in the nitrogen fixing power of the rhizosphere soils of field experiment. The increase was, moreover, significant as compared to that of single inoculation of *Azotobacter*. The sequential influence of various treatment on nitrogen fixing power of rhizosphere soils of field experiment was almost similar to that of the relative influence of respective treatments in the rhizosphere soils of pot culture experiment. However, FYM resulted in a marginal increase in the nitrogen fixing power as compared to that of inoculation of *Bacillus* in the rhizosphere soils of field experiment. On the other hand, the same treatment caused a significant increase in the nitrogen fixing power as compared to that of *Bacillus* inoculation in the rhizosphere soil of pot culture experiment. It is interesting to note that the sequential influence of various treatments on nitrogen fixing power was almost in

accordance with the relative influence of respective treatments on the proliferation of non-symbiotic nitrogen fixing bacteria in the rhizosphere soils of field experiment. However, there is an exception wherein the influence of FYM over that of inorganic fertilizer was significant in regard to the enhancement of nitrogen fixing power but meagre in the case of proliferation of non-symbiotic nitrogen fixing bacteria in the rhizosphere soils of field experiment. With the age of ginger plants, nitrogen fixing power of ginger rhizosphere increased up to late emergence of ginger pseudostem and decreased till the harvesting of daughter rhizome. Nitrogen fixing power was in good agreement with the number of nitrogen fixing bacteria in the rhizosphere of ginger at early emergence of pseudostem. Exhaustion of stimulants to the efficiency of nitrogen fixers, present in the manures and root exudes, with time might also be a factor in less amount of nitrogen fixed by the rhizosphere soils at final harvest of ginger (Bhattacharyya *et al.*, 1984).

The phosphate solubilizing power of rhizosphere soils of field experiment was more than that of initial soil (table–39). The results were similar to those of rhizosphere soils of pot culture experiment. FYM resulted in a significant increase in phosphate solubilizing power of rhizosphere soils of field experiment as compared to that of control. On the other hand, inoculation of *Azotobacter* caused a significant enhancement of phosphate solubilizing power of rhizosphere soils of field experiment as compared to that of FYM. However, the influence of inorganic fertilizers was superior to that of inoculation of *Azotobacter* in relation to their influence on phosphate solubilizing power in the rhizosphere soils of field experiment. As such, inoculation of *Bacillus* resulted in an increase in the phosphate solubilizing power of rhizosphere soils of field experiment as compared to that of

inorganic fertilizers. But combined inoculation of *Azotobacter* and *Bacillus* brought about the highest increase the phosphate solubilizing power in the rhizosphere soils of field experiment. The sequential influence of various treatments on phosphate solubilizing power was almost similar to the relative influence of respective treatments on the proliferation of phosphate solubilizing microorganisms in the rhizosphere soils of field experiment. However, there was a marginal decrease in phosphate solubilizing power of rhizosphere soils of field experiment by the inoculation of *Azotobacter* as compared to that of inorganic fertilizer in spite of the marginal enhancing influence of inoculation of *Azotobacter* over that of inorganic fertilizers on the proliferation of phosphate solubilizing microorganisms. This indicated that the cited treatment – *Azotobacter* inoculation – resulted in better influence on the multiplication than on the performance (inorganic phosphate solubilization) of the phosphate solubilizing microorganisms in the rhizosphere soils of field experiment. It is interesting to note that the sequential influence of various treatments on the phosphate solubilizing power in rhizosphere soils of field experiment was almost similar to those of relative influence of respective treatment in the rhizosphere soils of pot culture experiment. However, there was a little bid of inconsistency in relation to the influence of different treatments in the rhizosphere soils of field and pot culture experiments. Firstly, the rhizosphere soils of field experiments maintained higher phosphate solubilizing power than those of rhizosphere soils of pot culture experiment. Moreover, the enhancing influence of *Bacillus* inoculation over that of inorganic fertilizers was substantial in the rhizosphere soils of pot culture experiment whereas the relative influence of the cited treatment. The phosphate solubilizing power of rhizosphere soils increased progressively from sprouting of ginger rhizome to full growth

stage of ginger pseudostem and then decreased up to harvesting stage. The same explanation as that of nitrogen fixing power is also applicable in this case.

Bacillus was the predominant genus followed by *Micrococcus* and *Azotobacter* in the rhizosphere soil of field experiment (table–40). The number of isolates of the *Bacillus* was enhanced by the mixed inoculants of *Azotobacter* and *Bacillus* at the full growth stage while the some was decreased under the influence of inorganic fertilizers alone or in combination with the inoculants of *Azotobacter* at the full growth stage and by FYM and bacterial inoculants at the maturity stage. The results, thus, revealed differential influence of different treatments on the isolates of *Bacillus* in the rhizosphere soil. However, there was higher proliferation of *Bacillus* at the full growth stage as compared to harvest stage. This suggested higher stimulation of *Bacillus* isolates under the influence of root exudates. The isolates of *Micrococcus* were either eliminated or reduced by various types of additive at the full growth stage. The results, thus, revealed the detrimental influence of the root exudates on the isolates of *Micrococcus* in the rhizosphere soil. FYM, inorganic fertilizers and mixed inoculant, however, brought about stimulation of the isolates of *Micrococcus* at the harvest stage as compared to control. As such, the inoculants of *Azotobacter* and *Bacillus* exerted detrimental influence on *Bacillus* at the harvest stage. Though there was differential stimulation of *Bacillus* by different treatments at different stages yet the influence of the dead tissues of root was more marked in the isolates of *Bacillus*. As compared to control, FYM, inorganic fertilizers and inoculation of *Azotobacter* alone or in combination with *Bacillus* exerted enhancing influence on the isolates of *Azotobacter* at the full growth stage. On the other hand, inorganic fertilizers caused adverse effect on *Azotobacter* at the

harvest stage. However, the population of *Azotobacter* was well marked under the influence of the exudates of root as evidenced from the higher proliferation of *Azotobacter* at the full growth stage. All of the additives brought about a reduction in the number of *Arthobacter* as compared to that of control at the full growth stage. The effect of inorganic fertilizers on *Arthobacter* was stimulatory at the harvest stage though inoculation of *Bacillus*, alone or in combination and FYM resulted in diminution of *Arthobacter* isolates at that stage. As such the influence of the exudates was more stimulatory than those of the dead tissues of ginger as evidenced from higher population of *Arthrobacter* at the full growth stage. *Pseudomonas* was stimulated by inorganic fertilizers at the full growth stage but eliminated by *Azotobacter* and *Bacillus* inoculants at the after harvest and full growth stages, respectively. *Rhodospirillum* appeared in the rhizosphere soils by the influence of inorganic fertilizers and *Bacillus* inoculant at the full growth stage. Similarly *Erwinia* appeared at both the stages of growth of ginger crop by the influence of inorganic fertilizers and bacterial inoculants. *Brevibacterium* appeared at the full growth stage by the influence of bacterial inoculants. However, mixed bacterial inoculants resulted in the increase of *Brevibacterium* at the harvest stage as compared to that of control. The cited genus was eliminated from rhizosphere soils by the influence of inorganic fertilizers at the harvest stage, *Flavobacterium* appeared in the rhizosphere soils by the influence of FYM, inorganic fertilizers and inoculants of *Azotobacter* or *Bacillus* at the full growth stage. However, inoculants of *Azotobacter* and *Bacillus* resulted in an increase in the number of the cited genus as compared to that of control at the harvest stage. The results, thus, exhibited differential influence of different types of treatment on the population of the predominant genera of viable bacteria at different stages of growth of ginger crop in the rhizosphere soils of field experiment.

Streptomyces was the most dominant genus of actinomycetes followed by Nocardia in the rhizosphere soil of field experiment (table-40). FYM, inorganic fertilizers and the inoculants of *Azotobacter* or *Bacillus* resulted in a detrimental influence on the proliferation of *Streptomyces* isolates in the rhizosphere soils of ginger as compared to that of control at the full growth stage. On the other hand, the cited treatments exerted beneficial influence on *Nocardia* at that stage. The Inorganic fertilizers, caused a decrease in the number of *Nocardia* isolates at the harvest stage. The said treatment, on the other hand, exerted stimulating influence on the isolates of *Streptomyces* at that stage. The influence of FYM, and the inoculation of Azotobacter alone or in combination with *Bacillus* was stimulatory towards the isolates of *Nocardia* but detrimental towards the isolates of *Streptomyces* at the harvest stage in the rhizosphere soils as compound to that of control. The results, thus, revealed competition in between *Streptomyces* and *Nocardia* for nutrients in the rhizosphere soils. The population of an organism increased under the influence of an additive with the simultaneous decrease in the population of the other one. However, the influence of the root exudes was well marked in the *Streptomyces* as evidenced from the higher proliferation of the said organism at the full growth stage as compared to that at harvest stage. On the other hand, the influence of the dead tissues of roots was more pronounced in *Nocardia* as evidenced from the higher proliferation of *Nocardia* at the harvest stage as compared to that at the full growth stage.

Penicillium was numerically the most dominant genus followed by *Aspergillus* and *Fusarium, Mucor, Phytophthora, Pythium* and *Trichoderma*, respectively (table-41). Combined inoculation of *Bacillus* and *Azotobacter* resulted in an enhancing influence an *Aspergillus* at the full growth stage while inorganic

fertilizers caused detrimental influence on *Aspergillus* at both of the stages of growth. The influence of other additives was also harmful towards the growth of *Aspergillus* at the harvest stage. Inorganic fertilizers resulted in a stimulating influence on *Fusarium* at both of the stages of growth in the rhizosphere soil other additives were harmful towards the growth of *Fusarium* isolates at the full growth stages. The number of Mucor isolates was decreased by inorganic fertilizers and also by the mixed inoculants and the inoculants of *Bacillus* at the full growth stage and by FYM, inorganic fertilizers and inoculants of *Bacillus* at the harvest stage. On the other hand, all of the additives caused an enhancement of the isolates of *Penicillium* at both of the stages. Isolates of *Trichoderma* appeared by the application of bacterial inoculants in soil at the full growth stage and by FYM, inorganic fertilizers and *Azotobacter* or mixed inoculants at the harvest stage. The number of *Pythium* isolates was increased by inorganic fertilizers while the same was decreased by inoculants of *Azotobacter* or *Bacillus* at the full growth stage and by inoculants of *Azotobacter* and mixed inoculants at the after harvest stage. *Phytophthora* was decreased by FYM at the full growth stage and by all but FYM at the harvest stage. As such, the isolates of *Aspergillus* and *Fusarium* responded favourably at the full growth stage isolates. On the other hand, the isolates of *Penicillium* and Mucor favourably responded at the harvest stage. As such exudes of roots were favourable for the isolates of *Aspergillus* and *Fusarium* and dead tissues of roots were favourable for the isolates of *Penicillium* and *Mucor* in the rhizosphere soils as evidenced from the higher population of *Aspergillus* and *Fusarium* at the full growth stage and the higher population of *Penicillium* and *Mucor* at the harvest stage.

Azotobacter was the most dominant non-symbiotic nitrogen fixing bacteria in the rhizosphere soil of ginger followed by *Bacillus, Beijerinckia* and *Klebsiella,* respectively (table-42). FYM resulted in higher isolates of *Azotobacter* in the rhizosphere soils as compared to that of control at the full growth stage. This indicated the stimulation of *Azotobacter* in the presence of carbon, nutrient and energy sources. *Azotobacter* being heterotrophs, its proliferation in the presence of organic matter is a likely phenomenon. Bacterial inoculants brought about stimulation of the isolates of *Azotobacter* as compared to that of inorganic fertilizers. That might be due to the stimulating influence of growth promoting substances. In this respect, inoculants of *Azotobacter,* alone or in combination with *Bacillus* caused maximum proliferation of *Azotobacter* in the rhizosphere soils at the full growth stage. The isolates of *Azotobacter,* generally, decreased at the harvest stage as compared to that at the full growth stage. The population of the isolates of *Bacillus* was adversely affected by the various types of additives in the rhizosphere soil at the full growth stage. The adverse effect was, however, countermanded by FYM at the after harvest stage. FYM alone or in combination with inorganic fertilizers stimulated the isolates of *Beijerinckia* at the both the growth stages. On the other hand, bacterial inoculants depressed the number of the cited non-symbiotic nitrogen fixing bacteria at that full growth stage. The adverse influence was, however, mitigated to a great extent at the after harvest stage by the bacterial inoculants. However, mixed inoculants brought about a meagre deleterious influence at that stage. A new general, *Klebsiella,* appeared under the influence of inorganic fertilizers alone or in combination with the mixed inoculants of *Azotobacter* and *Bacillus* at the full growth stage. The number of the *Klebsiella* reduced at the after harvest stage under the influence of inorganic fertilizers

as compared to that of full growth stage. In general, the number of *Azotobacter* isolates increased at the full growth stage while the number of *Bacillus, Beijerinckia* and *Klebsiella* increased at the after harvest stage. So, the results indicated that the exudates of root were favourable for the isolates of *Azotobacter* while the dead tissues were beneficial to the isolates of other non-symbiotic nitrogen fixing bacteria.

Bacillus outnumbered other genera of phosphate solubilizing bacteria in the rhizosphere soils which was followed by *Pseudomonas, Micrococcus, Arthobacter* and *Flavobacterium*, respectively (table-42). The population of *Arthobacter* was increased by inorganic fertilizer, alone or in combination with the inoculants of *Azotobacter* at both the stages of growth while the same was eliminated from the rhizosphere soils of ginger by the inoculants of *Bacillus* alone or in combination with those of *Azotobacter*. The results, thus indicated favourable influence of inorganic nutrients for the growth of *Arthobacter*. The favourable influence was not modified by the inoculants of *Azotobacter*. But inoculants of *Bacillus* caused antagonistic effect on *Arthrobacter* which could not be mitigated by the inoculants of *Azotobacter*. FYM, inorganic fertilizers and the bacterial inoculants, alone or in combination, caused enhancement of the isolates of *Bacillus* at the full growth stage. But, at the harvest stage, only the inoculants of *Azotobacter* and *Bacillus* caused an increase in the number of *Bacillus* isolates. The results thus indicated that the influence of the additives on *Bacillus* was more pronounced in the presence of root exudates. Inorganic fertilizer and inoculants of *Bacillus* caused an increase in the number *Pseudomonas* isolates at both of the stages while FYM and inoculants of *Azotobacter* alone or in combination with *Bacillus* resulted in a decrease of the same at the full growth stage. Combined inoculation of *Azotobacter* and

Bacillus, however, increased the number of *Pseudomonas* isolates at the harvesting stage. The isolates of *Pseudomonas* and *Micrococcus* responded more favourably at the harvesting stage as compared to that of full growth stage. This indicated that the influence of dead tissues of roots were more favourable for the isolates of *Pseudomonas* and *Micrococcus*. The number of *Micrococcus* isolates increased under the influence of FYM and by the inoculation of *Azotobacter* or *Bacillus* at the full growth stage while the number the cited isolates was reduced under the influence of inorganic fertilizers alone or in combination with the inoculants of *Azotobacter*. The number of *Flavobacterium* was increased by the mixed inoculants only at the harvesting stage though additives, in general, brought about an adverse influence on *Flavobacterium* especially at the full growth stages.

Rhizosphere soils of field experiment retained less amount of organic carbon as compared to that of initial soil (table-43). Similar results were found in the rhizosphere soils of pot culture experiment. Hence, similar explanation to that of pot culture experiment can be put forward. Combined inoculation of *Azotobacter* and *Bacillus* resulted in a significant increase in the content of organic carbon in the rhizosphere soils of field experiment as compared to that of control. There was a progressive acceleration in the content of organic carbon by the inoculation of *Azotobacter*, inoculation of *Bacillus*, inorganic fertilizers and FYM, respectively. The sequential influence of different treatments on the content of organic carbon in the rhizosphere soils of field experiment was similar to those of the relative influence of respective treatments in the rhizosphere soils of pot culture experiment. So, similar explanation, regarding the sequential influence of various treatments on the content of organic carbon in the rhizosphere soils of field experiment, to that of rhizosphere soil

of pot culture experiment, can be put forward. There was, however, a minor inconsistency regarding the enhancing influence of the treatment – inorganic fertilizers over either of the treatments – inoculation of *Bacillus* and inoculation of *Azotobacter*, in between the rhizosphere soils of field and pot culture experiments. In the rhizosphere soils of field experiment, the treatment – inorganic fertilizers resulted in a significant increase in the content organic carbon as compared to either that of *Bacillus* or *Azotobacter* inoculants. On the other hand, the treatment – inorganic fertilizers – was marginally superior to either that of *Bacillus* or *Azotobacter* inoculants in relation to the content of organic carbon in the rhizosphere soils of pot culture experiment. As it were, the content of organic carbon of rhizosphere soils field experiment decreased gradually from the initiation to the completion of the investigation. Similar results were obtained from the rhizosphere soil of pot culture experiment. So, similar explanation to that of pot culture experiment can be put forward in this regard.

Rhizosphere soils of field experiment clubbed up more amount of total nitrogen as compared to that of initial soil (table–44). Similar results were obtained from the rhizosphere soils of pot culture experiment. Hence, similar explanation can be put forward. FYM resulted in a marginal increase in the content of total nitrogen as compared to that of control in the rhizosphere soils of pot culture experiment. The results, thus, exhibited inconsistency regarding the influence of FYM in between the rhizosphere soils of pot culture and field experiment. The results also proved more amount of nitrogen loss from rhizosphere soils of field experiment as compared to that of pot culture experiment. Inoculation of *Bacillus* resulted in a significant enhancement of total nitrogen in the rhizosphere soils of field experiment as compared to that of FYM. The influence of *Bacillus* inoculants over that of FYM was almost

similar in the rhizosphere soils of field and pot culture experiment. As such, the influence of inorganic fertilizers alone was significantly superior to that of *Bacillus* inoculants in the rhizosphere soils of field experiment. Similar observations in relation to the relative influence of inorganic fertilizers and *Bacillus* inoculants on the content of total nitrogen were found in the rhizosphere soils of pot culture experiment. Inoculation of *Azotobacter* caused a significant increase in the built up of total nitrogen in the rhizosphere soils of field experiment as compared to that of inorganic fertilizer. On the other hand, *Azotobacter* inoculants was marginally superior to inorganic fertilizers in the rhizosphere soils of pot culture experiment in relation to the content of total nitrogen. The results, thus, exhibited greater impact of *Azotobacter* inoculants under field condition. As it were, inoculation of *Azotobacter* and *Bacillus* brought about the highest augmentation of the content of total nitrogen in the rhizosphere soils field experiment. But the cited treatment was marginally inferior to *Azotobacter* inoculants in relation to the content of total nitrogen in rhizosphere soil of pot culture experiment. The findings, thus, manifested greater impact of single or dual inoculants in the rhizosphere soils of field experiment as compared to that in rhizosphere soil of pot culture experiment. The content of total nitrogen decreased gradually from the sprouting of matter rhizome to the harvesting of daughter rhizome ginger in the rhizosphere soils of field experiment. The results were similar to those of rhizosphere soils of pot culture experiment. So, similar explanation to that of rhizosphere soils of pot culture experiment can be put forward regarding the gradual depletion of the content of total nitrogen from the rhizosphere soils of field experiment.

Rhizosphere soils under control of the field experiment, in general, held less amount of ammoniacal–nitrogen as compared

to that of initial soil (table–45). The results, thus, exhibited greater loss of ammoniacal-nitrogen from the rhizosphere soils of field experiment as compared to that of the rhizosphere soils of pot culture experiment. The extended roots of ginger might assimilate more amount of ammoniacal–nitrogen from the rhizosphere soils of field experiment following greater mineralization of organic nitrogen by the enhanced microbial population. Alternatively, there might be greater loss of nitrogen from the rhizosphere soils of field experiment by the process of denitrification, leaching and microbial assimilation. As such, FYM resulted in a significant increase in the content of ammoniacal–nitrogen in the rhizosphere soils of field experiment as compared to that of control. The influence of FYM over that of control on the content of ammoniacal–nitrogen in the rhizosphere soils of field experiment was similar to that in the rhizosphere soils of pot culture experiment. Inoculation of *Bacillus* caused significant enhancement of ammoniacal–nitrogen in the rhizosphere soils of field experiment as compared to that of FYM. Inoculants of *Bacillus* exerted similar significant enhancing influence over that of FYM in the rhizosphere soil of pot culture experiment. Inoculants of *Azotobacter* were marginally superior to those of *Bacillus* in relation to their influence in the rhizosphere soils of field experiment. On the other hand, the inoculants of *Azotobacter* were significantly better than those of *Bacillus* in the rhizosphere soil of pot culture experiment. The results, thus, manifested greater impact of the inoculants of *Azotobacter* in relation to the content of ammoniacal–nitrogen in the rhizosphere soils of pot culture experiment than that of field experiment. Inorganic fertilizers caused marginal increase in the content of ammoniacal–nitrogen in the rhizosphere soils of field experiment as compared to that of *Azotobacter* inoculant. On the other hand, *Azotobacter* inoculant was significantly superior to inorganic

fertilizers in relation to the content of ammoniacal–nitrogen in the rhizosphere soil of pot culture experiment. The results, thus, manifested inconsistency regarding the relative influence of inorganic fertilizers and *Azotobacter* inoculant on the content of ammoniacal nitrogen in between the rhizosphere soil of field and pot culture experiments. However, combined inoculation of *Azotobacter* and *Bacillus* resulted in the highest increase in the content of ammoniacal nitrogen in the rhizosphere soils of field as well as pot culture experiments. The content of ammoniacal nitrogen decreased gradually from the sprouting of mother rhizome to the harvesting of daughter ginger rhizome in the rhizosphere soils of field experiment. The results were similar to those of the rhizosphere soils of pot culture experiment. As such, rhizosphere soil of field experiment retained less amount of ammoniacal - nitrogen as compared to that of the rhizosphere soil of pot culture experiment. The extended root system of ginger in the rhizosphere soils of field experiment might play an important role in this regard.

The significant positive correlation in between ammoniacal-nitrogen and total nitrogen indicated higher rate ammonification of nitrogenous compound in the ginger rhizosphere soils.

Rhizosphere soils under control in the field experiment clubbed less amount of nitrate - nitrogen as compared to that of initial soil (table–46). On the other hand, the same soil retained more amount of nitrogen as compared to that of initial soil. The results, thus, depicted more nitrogen less from soil under natural field conditions. Inoculation of *Azotobacter* caused a significant enhancement of nitrate-nitrogen in the rhizosphere soils of field experiment as compared to that of control. The influence of

Azotobacter inoculation over that of control in the rhizosphere soils of field experiment was similar to those in the rhizosphere soils of pot culture experiment. Inorganic fertilizers resulted in a marginal improvement in the status of nitrate - nitrogen in the rhizosphere soils of field experiment as compared to that of inoculation of *Azotobacter*. There was further marginal improvement of the same by FYM in the rhizosphere soils of field experiment. On the other hand, inorganic fertilizers exerted similar influence to that of *Azotobacter* inoculation on the content of nitrate - nitrogen in the rhizosphere soils of pot culture experiment. Moreover, the cited treatment exerted a marginal detrimental influence on the content of nitrate - nitrogen as compared to that of FYM in the rhizosphere soils of pot culture experiment. The results, thus, manifested greater loss of nitrate - nitrogen from the rhizosphere soils of pot culture experiment under the influence of FYM alone or in combination with inorganic fertilizers. In this context, it can be suggested that the roots of ginger rhizome utilized a greater amount of nitrate - nitrogen under the influence of FYM alone or in combination with inorganic fertilizers when compared with those of *Azotobacter* inoculants in the rhizosphere soils of pot culture experiment. Alternatively, there might be greater loss of nitrate - nitrogen under the influence of FYM alone or in combination with inorganic fertilizers from the rhizosphere soils of pot culture experiment by the process of denitrification and microbial assimilation. Inoculation of *Bacillus* resulted in a significant increase in the content of nitrate nitrogen as compared to that of inoculation of *Azotobacter* in the rhizosphere soils of field experiment. On the other hand, *Bacillus* inoculation exerted marginal deleterious influence on the content of nitrate - nitrogen in the rhizosphere soils of pot culture experiment. The results, thus, depicted inconsistency regarding the relative influence of the

inoculants of *Azotobacter* and *Bacillus* in between the rhizosphere soils of field and pot culture experiments. However, combined inoculation of *Azotobacter* and *Bacillus* resulted in the highest built up of nitrate - nitrogen in the rhizosphere soils of field experiment. The influence of *Azotobacter* and *Bacillus* was similar in the rhizosphere soils of pot culture experiment. An interesting feature of the investigation is that rhizosphere soils of field experiment retained less amount of nitrate - nitrogen as compared to that of the rhizosphere soils of pot culture experiment. The results, thus, pointed out greater loss of nitrate - nitrogen from the rhizosphere soils of field experiment. This might be due to greater assimilation of nitrate - nitrogen by the ginger crop through the spreaded root system. Moreover, the spreaded root system of ginger might induce higher proliferation of heterotrophic microbial population, in general, and denitrifiers, in particular, which, in turn, could result in greater loss of nitrogen through the process of microbial assimilation and denitrification. The content of nitrate - nitrogen increased progressively from the sprouting of mother rhizome to the harvesting of daughter rhizome of ginger in the rhizosphere soils of field experiment. This pointed out progressive enhancement of the process of nitrification in the rhizosphere soils of field experiment. Gradual depletion of ammoniacal nitrogen from the rhizosphere soils of field experiment from the sprouting of rhizome to the harvesting stage further strengthened the view that the process of nitrification was accelerated progressively in the rhizosphere soils of field experiment.

Rhizosphere soils under control retained more amount of available phosphorus during initial stages than that of initial soil (table–47) due to greater rate of mineralization of organic phosphorus and or solubilization of insoluble inorganic phosphorus under the influence of exudate of ginger roots. On the other hand,

the cited rhizosphere soils held less amount of available phosphorus during later stages than that of initial soil due to greater assimilation by the ginger crop as well as fixation of phosphate ions by clay colloids especially under acidic condition. FYM resulted in a significant increase in the content of available phosphorus as compared to that of control in the rhizosphere soil of field experiment. The influence of FYM over that of control in the rhizosphere soils of field experiment was similar to that in the rhizosphere soils of pot culture experiment. Inoculation of *Azotobacter* caused significant enhancement of available phosphorus as compared to that of FYM in the rhizosphere soils of field experiment. *Azotobacter* inoculants exhibited similar enhancing influence in the rhizosphere soils of pot culture experiment. Inoculants of *Bacillus* were significantly superior to those of *Azotobacter* in relation to the content of available phosphorus in the rhizosphere soils of field experiment. On the other hand, the inoculants of *Bacillus* were marginally superior to those of *Azotobacter* in the rhizosphere soils of pot culture experiment. So, there was inconsistency regarding the relative influence of the inoculants of *Azotobacter* and *Bacillus* in between the rhizosphere soils of field and pot culture experiments. In this context, the influence of *Bacillus* over those of *Azotobacter* inoculants was more pronounced in the rhizosphere soils of field experiment. However, the treatments – inorganic fertilizers was marginally superior to the treatment – inoculation of *Azotobacter* and marginally inferior to the treatment – inoculation of *Bacillus*, in relation to the content of available phosphorus in the rhizosphere soils of field as well as pot culture experiments. Combined inoculation of *Azotobacter* and *Bacillus* caused the highest increase in the content of available phosphorus in the rhizosphere soils of field experiment. The enhancing influence of the combined

inoculation of *Azotobacter* and *Bacillus* was similar in the rhizosphere soils of pot culture experiment in relation to the content of available phosphorus. It is interesting to note that the rhizosphere soils of field experiment, in general, contained less amount of available phosphorus as compared to that of the rhizosphere soils of pot culture experiment. The extended root system of ginger crop might play an important role in assimilating more amount of phosphorus from the rhizosphere soils of field experiment and thereby causing depletion of available phosphorus. The content of available phosphorus depleted gradually from the sprouting of mother rhizome to the harvesting of daughter rhizome of ginger in the rhizosphere soils of field experiment. The observations were similar to those of rhizosphere soils of pot culture experiment. So, similar explanation to those of rhizosphere soils of pot culture experiment can be put forward.

The significant positive correlation between available phosphorus and phosphate solubilizing power indicated that phosphate solubilizing power determined the availability of phosphorus in the rhizosphere soils of ginger.

FYM resulted in a marginal increase in the uptake of nitrogen as compared to that of control in the field experiment (table–48). The influence of FYM was similar to that of pot culture experiment. Inorganic fertilizer was significantly superior to FYM in relation to their influence in the yield as well as pot culture experiment. Inoculation of *Azotobacter* exerted significant enhancing influence on the uptake of nitrogen by ginger rhizome in the field experiment as compared to that of inorganic fertilizer. The influence of *Azotobacter* inoculants over that of inorganic fertilizers in the field experiment was similar to those of pot culture experiment. *Bacillus* inoculants were marginally superior

to those of *Azotobacter* inoculants in relation to uptake of nitrogen by ginger crop in the field experiment. On the other hand, *Azotobacter* inoculants were marginally superior to *Bacillus* inoculants in the rhizosphere soils of pot culture experiment. So, the relative influence of the inoculants of *Azotobacter* and *Bacillus* was not consistent in the field and pot culture experiments. However, combined inoculation of *Azotobacter* and *Bacillus* caused the highest uptake of nitrogen in the field experiment. The influence of the said treatment was similar to that of pot culture experiment.

FYM caused a marginal increase in the uptake of phosphorus by ginger crop as compared to that of control in the field experiment (table-48). The finding was similar to that of pot culture experiment. On the other hand, inorganic fertilizers brought about a significant enhancing influence on the uptake of phosphorus as compared to that of FYM in the field experiment. Similar enhancing influence of inorganic fertilizers over that of FYM was obtained from the pot culture experiment. The treatment - inorganic fertilizer - was, however, marginally inferior to the inoculants of *Azotobacter* in relation to uptake of phosphorus in the field experiment. The influence of *Azotobacter* inoculation over that of inorganic fertilizer in the field experiment was similar to that of pot culture experiment. As such, inoculation of *Azotobacter* was marginally superior to those of *Bacillus* in relation to the uptake of phosphorus in the field experiment. On the other hand, the inoculation of *Bacillus* was significantly superior to those of *Azotobacter* in relation to uptake of phosphorus by ginger crop in the pot culture experiment. This indicated better influence of *Bacillus* in the pot culture experiment than that of field experiment. However, combined inoculation of *Azotobacter* and *Bacillus* caused the maximum uptake of phosphorus in the field experiment. The

enhancing influence of combined inoculation in the field experiment was similar to that of pot culture experiment.

FYM resulted in a significant increase in the yield of fresh ginger of the field experiment (table-48). On the other hand, inorganic fertilizers caused a significant enhancement in the yield of ginger as compared to that of FYM. However, inoculants of *Azotobacter* or those of *Bacillus* exerted significant enhancing influence on the yield of ginger as compared to that of inorganic fertilizers. Inoculation of *Azotobacter* caused a marginal increase in the yield of ginger as compared to that of inoculation of *Bacillus* in the field experiment. As it were, combined inoculation of *Azotobacter* and *Bacillus* brought about the highest yield of ginger in the field experiment. The sequential influence of various treatments in relation to yield in the field experiment was almost similar to those in pot culture experiment, with the exception of that, the influence of *Azotobacter* inoculation was marginally superior to that of *Bacillus* inoculation in relation to yield of ginger in pot culture experiment. It is interesting to note that combined inoculation of *Azotobacter* and *Bacillus* caused about 64.7 percent increase over control. The corresponding figures for *Bacillus* inoculation, *Azotobacter* inoculation, inorganic fertilizers and FYM were 52 percent, 47.7 percent, 32.7 percent and 17.7 percent, respectively. It will be worthwhile to mention that the influence of various treatments on yield was more pronounced in pot culture experiment as compared to that of field experiment. This kind of inconsistency in the performance of inoculants is very common with inoculation experiments in field conditions. Inoculants, those exhibited better performance under controlled condition may not survive and or thrive better under natural condition. Thus, bacterial inoculation in field level very often results in poor yield. This is true in this case also.

Rhizome yield was significantly correlated with nitrogen fixing and phosphate solubilizing organisms. In addition yield was directly related with uptake of nitrogen and phosphorus. This indicated the importance of nitrogen and phosphorus nutrition in the growth and yield of ginger.

Experiment No. 6 – Isolation and Characterization of some plant pathogenic microflora from rotten ginger.

Rotten ginger harbour various types of microorganisms. Some of them are obligate pathogenic organisms. The degree of pathogenicity also varies among the parasites. Fungi and bacteria in collective association cause the soft-rot disease of ginger. Among the fungi, *Fusarium* and *Pythium* are responsible for the cited disease (Bhardwaj *et. al.*, 1988; Choi *et. al.*, 1990; Lee *et.al.*, 1990; Kim *et. al.*, 1997). *Pseudomonas* also contributes towards the development of soft-rot disease of ginger (Choi and Han, 1990). However, there is variability among the pathogens belonging to some genera (Dohroo and Sharma, 1992). The above views necessitated to conduct an investigation to isolate and to screen out the potent soft-rot producing organisms from rotten ginger.

Perusal of results revealed that five bacterial (table–50a) and four fungal (table-50b) pathogens were associated with the rotten ginger rhizome. Three isolates of *Fusarium* exhibited different cultural characteristics. *Pythium* was the fourth identified isolates. Among the three fusarial isolates, isolate-1 was the most virulent strain in relation to its enhancing influence on inducing wilting. The remaining two were inefficient ones because they brought about meagre wilting of ginger plant. Such variability among the *Fusarium* was reported by Dohroo and Sharma (1992). The *Pythium* isolate showed the pathogenicity in relation to soft-

rot of rhizome in the laboratory. Four, out of five bacterial isolates, were *Pseudomonas* and the rest one was *Erwinia*. The four isolates of *Pseudomonas* were pathogenic in relation to soft-rot of ginger. *Erwinia* did not exhibit pathogenicity towards soft-rot of ginger. It's appearance in the rotten ginger might be due to secondary infection. Out of four isolates of *Pseudomonas*, GB_3 manifested intense rotting of ginger in laboratory. So, *Fusarium* (isolate-1). *Pythium* and *Pseudomonas* (GB_3) were the causal organisms of soft-rot of ginger.

Experiment No. 7 – *In-vitro* studies on interaction between plant pathogenic and beneficial organisms :

Microorganisms never occur in pure culture in an environment. They interact with each other in a unique way. Consequently, various types of association among the organisms occur. Sometimes, microorganisms behave independently. This type of association is called neutralism. However, neutral association among the microorganisms is rear in nature. Generally, beneficial and harmful associations among the microorganisms are prevalent. Symbiosis, protocooperation and commensalism are the three types of beneficial association. On the other hand, competition, parasitism, predation and amensalism are the harmful associations. The above views necessiated to conduct an investigation in regard to the *in-vitro* studies on the interaction between plant pathogenic and beneficial organisms.

Perusal of results showed that *Fusarium* and *Pythium* exhibited neutral association (Photograph No-1). On the other hand, *Azotobacter* manifested antibiosis against *Fusarium* (Photograph No-2), *Pythium* (Photograph No-3) and *Pseudomonas* (Photograph

No-9). This kind of antagonisms of *Azotobacter* against *Fusarium* was reported by Lakshmi Kumari *et. al.* (1975) and Meshram *et. al.* (1983). Cell free biologically active substance might spread in the plate and arrest the mycelial growth or reduce spore germination in *Fusarium*, Oogonia germination in *Pythium* and destruction of *Pseudomonas* cell. *Bacillus* showed antagonisms against *Fusarium* (Photograph No-4), *Pythium* (Photograph No-5) and *Pseudomonas* (Photograph No-10) through competition, volatile antifungal substances and antibiotic production, respectively (Sundaram and Rao, 1980; Podile and Dube, 1985; Lima and Escobar, 1990; Fiddaman and Rossall, 1993). *Fusarium* and *Pythium* hyper parasitized the *Pseudomonas* (Photograph No - 6 and 7) and restricted its normal growth. The existed protocooperation in between *Azotobacter* and *Bacillus* (Photograph No-8). In this association, *Azotobacter* derived more benefit as evidenced from higher growth in plate. This is in the line with Kundu and Gaur (1980).

Experiment No. 8 – Enumeration of some soil borne plant, Pathogenic microflora from pot soil :

Soft-rot is a common disease of ginger. Though many organisms are responsible for the disease yet no particular organism has the potentiality to produce the disease solely. *Fusarium*, *Pythium* and *Pseudomonas* are the three main organisms which in collective association with the host can cause the cited disease (Bharadwaj *et. al.*, 1998; Lee *et. al.*, 1990; Choi and Han, 1990; Kim *et. al.*, 1977). The disease is soil as well as rhizome borne (Thomas and Velappan, 1988). Several inputs are required for maximising the yield of ginger. Out of them, the nutritional inputs are vital for the crop. Ginger is the crop which requires

high amount of nutrients. The demand is generally fulfilled by inorganic and organic nutrients. Inorganic fertilizers, FYM are generally used as the sources of nutrient for the crop by the farmers. Recently, inoculants of *Azotobacter* and *Bacillus* are used in the soil or on to seed rhizome in order to augment crop yield (Konde *et. al.*, 1990; Peter, 1998). The above views necessitated to take up an investigation regarding the influence of FYM and inoculation of *Azotobacter* and *Bacillus* on the population of three potentially pathogenic organisms – *Fusarium*, *Pythium* and *Pseudomonas* – in soil.

Perusal of results (Table-51) showed that control soil reared more number of *Fusarium* propagules than that of initial soil. That was because of the provision of optimum moisture favourable for the proliferation of *Fusarium* propagules in control soil. This substantiated the reports of Alexander (1977) that optimum moisture stimulated the proliferation microorganisms in soil. Inorganic fertilizers caused an increase in the number of *Fusarium* propagules in the soil of the pot culture experiment as compared to that of control. Inorganic nutrients like nitrogen, phosphorus and potassium are the building blocks of microbial cell. Their presence resulted in the stimulation of *Fusarium* isolates in soil especially in the association with reserve energy material, FYM. This confirmed the earlier result of Toussoun *et. al.* (1960) that nitrogen and glucose stimulated the multiplication of *Fusarium* under controlled condition. Moreover, nitrogen stimulate, the germination of Chlamydospore of *Fusarium*. On the other hand, FYM alone, resulted in a marginal decrease in the number of *Fusarium* propagules as compared to that of control in the soils of the pot culture experiment. This substantiates the earlier report (Toyota and Kimura, 1992) that FYM - amended soils are more fungistatic than non amended soil. Cook (1977) suggests that soil

augmentation with organic materials may produce such ameliorating effects on soilborne plant pathogen as reducing numbers of fungal propagules through germination, stimulation followed by lysis, temporarily or permanently inactivating fungal propagules in soil, arresting growth or germlings or lysis the hyphae, serving as food bases for antibiotic and toxic production or as the origin of inhibitory volatile substances. Moreover, FYM might cause the proliferation of certain organisms like *Trichoderma* and *Gliocludium* and other organisms resulting in detrimental influence on the growth of *Fusarium* in soils. These two biological agents are now being widely used to control in soft-rot producing organisms (Sharma *et. al.*, 1979; Peter, 1988). Inoculation of *Azotobacter* or *Bacillus*, alone or in combination brought about significant inimical influence on the *Fusarium* propagules as compared to that of FYM in soil of pot culture experiment. Inoculants of *Azotobacter* and *Bacillus* are known to produce certain anti-microbial substances in soil (Brown,1974; Lakshmi Kumari *et. al.*, 1975; Sundaram and Rao, 1980; Fiddaman and Rossal, 1993). Those anti-microbial substances might result in the deleterious influence on the growth of *Fusarium* propagules in soil. This corroborated reports of Lakshmi Kumar *et. al.* (1975). In this respect, inoculation of *Azotobacter* produced the worst influence on the growth of *Fusarium* in soils. That was followed by those of dual inoculation of *Azotobacter* and *Bacillus* and inoculation of *Bacillus*, respectively. Population density of *Fusarium* increased, on and on, from S_1 to S_3 stage and then gradually decreased till the completion of the experiment. This suggested that the initial decomposed products of FYM were beneficial to *Fusarium* for their multiplication while the advanced products of decomposition were inhibitory. Moreover, the decomposed products of FYM during latter stages might modify the

'biological buffering capacity' of soils in such a way so as to harbour more number of natural antagonists. In addition, due to lack of susceptible host the germlings or mycelium growth might be lysed before the production of new resistant propagules (Papavizas and Lumsden, 1980).

Control soil of pot culture experiment reared more number of *Pythium* propagules than that of initial soil (table-52) due to favourable moisture (Alexander, 1977). FYM resulted in a marginal decrease in the number of *Pythium* propagules in almost all the stages. This can be explained in a similar way as described earlier. Inoculation of *Bacillus* caused a significant increase in the number of *Pythium* propagules as compared to that of FYM. The significant increase might be due to the influence of growth promoting substances liberated by the inoculants of *Bacillus* in soil. Inorganic fertilizers brought about the highest increase in the number of *Pythium* propagules in soil. The results, thus, suggested the utilization of inorganic nutrients for the synthesis of cellular materials by the *Pythium* propagules in soil especially in the presence of FYM. Moreover, nitrogen plays a vital role in the germination of Oogonia of *Pythium* in soil. *Bacillus* inoculants were inferior to inorganic fertilizers in relation to the proliferation of *Pythium* in the soils. The results, thus, indicated antagonistic effect of *Bacillus* on *Pythium*. Such antagonistic effect was reported by Sundaram and Rao (1980). Inoculants of *Azotobacter* alone or in combination with those of *Bacillus* exerted marginal detrimental influence on the isolates of *Pythium* in soil as compared to that of control. The deleterious influence might be due to the anti-microbial substances liberated by the inoculants of *Azotobacter* in soil. *In-vitro* study of interaction in between *Azotobacter* and *Pythium* also confirmed the results (Photograph No-3). Though inoculants of *Bacillus* alone could not significantly reduced the

Pythium propagules as compared to control yet the same inoculants along with those of *Azotobacter* caused a reduction in the number of *Pythium* propagules in soil as compared to that of control. This is probably due to the synergistic effect of both of bacteria on *Pythium* in relation to suppression of *Pythium*. However, the influence of combined inoculation was less intense than those of the inoculants of *Azotobacter* in soil in relation to their detrimental influence in soil. Population density of *Pythium* increased, on and on, from S_1 to S_3 stage and then gradually decreased till the completion of the experiment. The result was similar to that of *Fusarium*, described earlier. So, similar explanation can be put forward.

Control soil, in general, harboured more number of *Pseudomonas* cell than that of initial soil (Table-53). Control soil was provided with moisture which, in turn, brought about favourable condition for the proliferation of *Pseudomonas* in soil. The influence of moisture was more pronounced during initial stages. However, during later stages, there was a fall in the number of *Pseudomonas* in the soils of pot culture experiment. The competition of *Pseudomonas* with other organisms during later stages might result in lower proliferation of the said bacteria in control soil. FYM resulted in a significant increase in the number of *Pseudomonas* in soil as compared to that of control. This indicated utilization of FYM by *Pseudomonas* as carbon, energy and nutrient sources for cellular synthesis. Inorganic fertilizers resulted in the highest increase in the number of *Pseudomonas* in soil. The results, manifested further utilization of inorganic nutrients for cellular synthesis especially in the presence of utilizable energy, nutrient and carbon sources. Though inoculation of *Azotobacter* resulted in a significant increase in the proliferation of *Pseudomonas* in soil as compared to that of control yet the cited

inoculant caused a significant deleterious influence is soil as compared to that of inorganic fertilizers. However, the inoculant was marginally superior to FYM in relation to their influence on the proliferation of *Pseudomonas* in soil. So, it can be suggested that some toxic materials might be elaborated by *Azotobacter* inoculants in soil. *In-vitro* study on interaction in between *Azotobacter* and *Pseudomonas* (Photograph No-9) confirmed the result. Inoculation of *Bacillus*, alone or in combination with *Azotobacter* resulted in a significant decrease in the number of *Pseudomonas* cell in soil as compared to that of FYM. The results, thus, pointed out the elaboration of anti-microbial substances by the inoculants of *Bacillus* in the presence of inorganic fertilizers. Those substances might exert detrimental influence on the population of *Pseudomonas* in soils. It is interesting to note that the influence of *Bacillus inoculants* was more harmful than those of *Azotobacter* in relation to the proliferation of *Pseudomonas* in soil. But, among the inoculated treatment, the combined inoculation of *Azotobacter* and *Bacillus* resulted in the worst influence on the proliferation of *Pseudomonas* in soil. Population of *Pseudomonas* in soil increased, on and on, from S_1 to S_2 stage and then gradually decreased up to S_6 stage. Similar explanation as in the case of *Fusarium* is also applicable here.

Experiment No. 9 – Soil borne plant pathogenic ginger rhizosphere microflora in relation to soft-rot disease incidence and intensity in pot culture experiment :

Fusarium, *Pythium* and *Pseudomonas* are the three predominant genera which can cause the disease – soft-rot of ginger – only when they are in collective association with the host. The disease is boil as well as rhizome borne. Various measures

are adopted to control the disease (Velapan, 1994). Fungicides are often used to control the disease (Kumar and Panday, 1989; Ramchandan *et. al.*, 1989; Choi *et. al.*, 1996). But the chemicals are costly and often pollute the soil environment. Moreover, residual effect sometimes remain in the edible portion of the ginger. So, it is imperative to control the disease through other agents. FYM is generally used by the farmers for the nutrition of ginger. The said manure often controls the disease intensity to a limited extent by suppressing the causal organisms of soft-rot of ginger (Wilai,1989, Toyota and Kimura, 1992, Dohroo *et. al.*, 1994). Though, inorganic fertilizers often fulfills the nutritional demand of ginger yet those substances often result in the proliferation of the potent disease producing organisms. As a consequence, the disease intensity is accelerated. The inoculants of *Azotobacter* and *Bacillus* are often used for increasing the yield (Dey, 1972, Lakshminarayanan *et. al.*, 1987; Dutta *et. al.*, 1982; Dey 1988, Gaur, 1989). The biological agents, moreover, elaborate antimicrobial substances (Brown *et. al.*, 1963; Singh *et. al.*, 1965; Mishustin *et. al.*, 1969; Sundaram and Rao, 1980) and decrease the disease intensity. Keeping the above in view, an attempt has been made to investigate the effect of FYM and inoculation of *Azotobacter* and *Bacillus* on the preponderance of soft-rot producing organisms in the ginger rhizosphere in relation to disease incidence and its intensity in pot culture experiment.

Perusal of results revealed that rhizosphere soils under control clubbed more number of *Fusarium* propagules as compared to that of initial soil (Table-54). The results were similar to that of non-rhizosphere soils of pot culture experiment. FYM caused a significant decrease in the number of *Fusarium* in the rhizosphere soil of pot culture experiment as compared to that of control. On the other hand, FYM resulted in a marginal decrease in the number

of *Fusarium* in the nonrhizosphere soils of pot culture experiment. The results, thus, exhibited intensification in the impact of FYM under the influence of ginger roots of pot culture experiment. However, inorganic fertilizers brought about a significant increase in the number of *Fusarium* propagules in the rhizosphere soils as compared to that of control. The influence of inorganic fertilizers in the rhizosphere soils was similar to that of non-rhizosphere soils of pot culture experiment. So, similar explanation can be put forward. Inoculation of *Azotobacter* and *Bacillus*, alone or in combination caused a significant reduction in the number of *Fusarium* in the rhizosphere soils of pot culture experiment. The influence of the bacterial inoculants in the rhizosphere soil was similar to those of nonrhizosphere soils. Hence, similar explanation to that of nonrhizosphere soils can be put forward. However, inoculation of *Azotobacter* resulted in the lowest proliferation of *Fusarium* propagules in the rhizosphere soils of pot culture experiment followed by those of combined inoculation of *Azotobacter* and *Bacillus* and single inoculation of *Bacillus*, respectively. It will be worthwhile to mention that there was an acceleration in the impact of biological inoculants in the rhizosphere soils as compared to those of nonrhizosphere soils in relation to the proliferation of *Fusarium*. As inoculants were the indigenous inhabitants of ginger rhizosphere soils, their activities in relation to the suppression of *Fusarium* will be accelerated in the rhizosphere soils of ginger as compared to those of nonrhizosphere soils. Population of *Fusarium* in the ginger rhizosphere increased, on and on, from the sprouting of mother rhizome up to the full growth stage of ginger pseudostem and then declined gradually till the harvesting of daughter rhizome. The above observations supported the earlier reports of Katznelson (1965) and Rovira (1965) that number of rhizosphere organisms, in

general, depends to a great extent on the qualitative and quantitative composition of root exudates up to full growth stage of ginger Pseudostem, the plant exuded a group of organic compounds which probably encourage the growth of *Fusarium* in the rhizosphere soils. But in later stages the host probably responded in a different way. With the age of ginger olerisine content was increased in the rhizome . Root exudates probably contained that organic compound which, in turn brought about antifungal activities and that might impart a hostile effect of *Fusarium* propagules in later stages of growth.

Rhizosphere soils under control reared less number of *Pythium* than that of initial soil (table-55). The results were similar to those of nonrhizosphere soils. FYM resulted in a significant decrease in the number of *Pythium* in the rhizosphere soils of pot culture experiment as compared to that of control. On the other hand, FYM was marginally superior to control in relation to their influence in the nonrhizosphere soils. So, it can be suggested that FYM might induce the crop to liberate substance toxic to the propagules of *Pythium*. Alternatively, rhizosphere soils of ginger might modify the rhizosphere microbial environment in such a way so as to harbour more number of natural antagonists resulting in a decrease in the number of *Pythium* propagules. Inorganic fertilizers exerted significant stimulating influence on the population of *Pythium* in the rhizosphere soils as compared to that of control. The influence of inorganic fertilizers in the rhizosphere soils was similar to those of nonrhizosphere soils of pot culture experiment. So, it can be suggested that inorganic fertilizers not only countermanded the adverse influence of FYM but also stimulated the propagules of *Pythium* in the rhizosphere soils of pot culture experiment. The influence of *Bacillus* was significantly inferior to that of inorganic fertilizers in relation to the

proliferation of *Pythium* in the rhizosphere soils. So, it can be said that the inoculants of *Bacillus* might increase the proliferation of antagonists in the rhizosphere soils which, in turn, brought about significant reduction in the number of *Pythium* in soil as compared to that of inorganic fertilizers. Moreover, *Bacillus* might elaborate some volatile anti-fungal biomolecules which, in turn, damaged the hyphae of *Pythium* propagules (Sundaram and Rao, 1980). However, the influence of *Bacillus* was marginally superior to that of control and significantly superior to that of FYM in the nonrhizosphere soils. So, the relative influence of *Bacillus* and FYM in the rhizosphere soil was similar to that in the nonrhizosphere soil. But the impact of *Bacillus* over that of control was more pronounced in the nonrhizosphere soil than that in the rhizosphere soil. Inoculants of *Azotobacter*, alone or along with those of *Bacillus* exerted significant detrimental influence on the propagules of *Pythium* in the rhizosphere soils as compared to that of control. The harmful effect might be due to the anti-microbial substances elaborated by the inoculants of *Azotobacter* in the rhizosphere soils. However, the adverse influence of the *Azotobacter* inoculants alone or in combination with those of *Bacillus* was more prominent in the rhizosphere soil than those of the nonrhizosphere soil. This can be explained in a similar way as described earlier with the age of ginger, the population of *Pythium* in the ginger rhizosphere increased progressively up to full growth stage of ginger pseudostem and then declined gradually till the harvesting of ginger. The same explanation as that of *Fusarium* is applicable here also.

Rhizosphere soils under control, in general, reared more number of *Pseudomonas* as compared to the initial soil (table-56). This can be explained in a similar manner to that of nonrhizosphere soils. FYM exerted significant stimulating influence on the

population of *Pseudomonas* in the rhizosphere soils as compared to that of control. The influence of FYM in the rhizosphere soils was similar to that in the nonrhizosphere soil. Inorganic fertilizers caused maximum stimulation of *Pseudomonas* in the rhizosphere soils of pot culture experiment. The influence of inorganic fertilizers in the rhizosphere soils was similar to those of nonrhizosphere soils. Inoculation of *Azotobacter* resulted in a significant decrease in the number of *Pseudomonas* as compared to that of inorganic fertilizers in the rhizosphere soils of pot culture experiment though inoculants of *Azotobacter* were significantly superior to that of FYM. The relative influence of the treatments – inorganic fertilizers, FYM and inoculation of *Azotobacter* – in the rhizosphere soils was almost similar to those of the respective treatments in the nonrhizosphere soils. However, the impact of *Azotobacter* inoculation as compared to that of FYM was more prominent in the rhizosphere soils than those in the nonrhizosphere soils. Inoculants of *Bacillus* alone or together with those of *Azotobacter* resulted in a significant detrimental influence on the population of *Pseudomonas* in the rhizosphere soil of pot culture experiment as compared to that of control. In this context, *Bacillus* inoculants resulted in the worst influence in the rhizosphere soils of pot culture experiment. So, it can be suggested that the inoculants of *Bacillus* might induce the crop to produce substances harmful to the growth of *Pseudomonas*. Alternatively, rhizosphere soils might result in the proliferation of natural antagonists of *Pseudomonas*, resulting in the decrease of the cited bacteria. Above all, *Bacillus* inoculants might elaborate some anti-fungal volatile substances which, in turn, destroy the viable *Pseudomonas* cell in the rhizosphere soils. However, inoculants of *Azotobacter* countermanded the adverse effect to a great extent in association with inoculants of *Bacillus*. For this reason, combined inoculation

of *Azotobacter* and *Bacillus* resulted in a significant increase the population of *Pseudomonas* in the rhizosphere soil as compared to that of inoculation of *Bacillus*. With the age of the ginger plants, the population of *Pseudomonas* increased, on and on, from the sprouting of mother rhizome to the late emergence of ginger pseudostem and then declined till the harvesting of ginger. The explanation as that of *Pythium* discussed earlier is also applicable here.

FYM resulted in a marginal decrease in disease incidence of ginger crop as compared to that of control during early stages of growth in the pot culture experiment (table-57). The effectiveness of organic amendment in reduction of disease incidence was reported by several workers (Rajan and Singh, 1972; Sadanandam and Iyer, 1986; Sadanandan, 1988). The role of organic amendment in suppression of soilborne plant pathogens has been empty emphasised by Huber and Watson (1970). Reduction in disease incidence upon FYM amendment was due to the reduction in pathogenic population under that treatment, in general, *Fusarium* and *Pythium*, in particular. So, there existed a significant correction between *Fusarium*, *Pythium* and disease incidence (table -59a). Correlation also existed in between *Pseudomonas* and disease incidence though not significant. So, in the later stages of growth nonsignificant increase of disease incidence was due to higher proliferation of *Pseudomonas* in the ginger rhizosphere. Inorganic fertilizers resulted in the highest increase in the disease incidence in the pot culture experiment. The highest increase in disease incidence was the resultant impact of the highest population of *Fusarium*, *Pythium* and *Pseudomonas*. Inoculation of *Bacillus* exerted significant detrimental influence on the disease incidence in ginger crop as compared to that of FYM. The influence of *Azotobacter* inoculants was similar to that of combined inoculation

of *Azotobacter* and *Bacillus* in relation to decrease in disease incidence in pot culture experiment. Bacterization of mother rhizome, in general, reduced significantly the disease incidence of ginger. Bacterial inoculants might give direct protection of plants against the pathogens by virtue of antibiosis, competition and lysis or indirectly might stimulate plants growth by elaborating growth promoting substances so that disease susceptibility was decreased (David, 1988). The inoculants of *Azotobacter*, however, caused a significant reduction of disease incidence as compared to that of *Bacillus* in the pot culture experiment. The lowest proliferation of *Fusarium* and *Pythium* under the influence of *Azotobacter* inoculants might result in the minimum incidence of disease of ginger in the pot culture experiment. Though combined inoculation of *Azotobacter* and *Bacillus* caused higher proliferation of *Fusarium* and *Pythium* in the rhizosphere soils of pot culture experiment as compared to that of single inoculation of *Azotobacter* yet the former treatment exerted similar influence to that of the later one in relation to the incidence of disease. Dual inoculation might induce resistance in the ginger crop and cause minimum disease incidence. In early parts of ginger growth there was practically no or very negligible amount of disease incidence. This might be due to the fact that FYM amendment and rhizome bacterization with *Azotobacter* and *Bacillus* exerted their action the pathogenic organisms and controlled them effectively. But with the age of crop, so many antagonists of *Azotobacter* and *Bacillus* appeared in the rhizosphere that the survival rate of *Azotobacter* and *Bacillus* was reduced, resulting in increase of disease incidence. In the later part of growth of ginger, though, inoculum potentiality was in lower magnitude yet disease incidence was enhanced. Disease expression in these stages was independent of pathogens. After infection, pathogens multiplied within plant system and caused wilting and

rotting of plant cells. Depending of rate of wilting and rotting disease was expressed.

FYM resulted in a marginal decrease in disease intensity as compared to that of control (table-58) though the cited treatment caused a marginal increase in disease incidence. The reduction in disease intensity under FYM amendment might be due to the altered nutritional status of host which, in turn, induced the host to respond in different way. Moreover, plant vigour might be increased in a better physical and nutritional status of soil leading to negative influence on pathogens (Sadanandan *et. al.*, 1988). Inorganic fertilizers, however, caused the highest disease intensity in ginger crop. The influence of inorganic fertilizers on disease intensity was in accordance with the disease incidence of ginger in pot culture experiment. In other words, the highest incidence of disease under the influence of inorganic fertilizers was reflected upon the highest intensity of the disease so, there existed a significant correlation in between disease incidence and intensity (table-59a). Huber and Watson (1970) observed that disease intensity was increased with nitrogen nutrition to the host. Inoculants of *Bacillus* resulted in significant decrease in disease intensity as compared to that of inorganic fertilizers. The influence of *Bacillus* inoculants on disease intensity was concurrent with the disease incidence. Combined inoculation of *Azotobacter* and *Bacillus* caused marginal decrease in disease intensity as compared to that of inoculation of *Bacillus* though the former treatment resulted in a significant decrease in disease incidence as compared to the later one. In this connection it can be suggested that combined inoculation of *Azotobacter* and *Bacillus* did not modify the metabolism of host to respond against the pathogens. As it were, inoculation of *Azotobacter* resulted in the lowest disease intensity in ginger crop. The influence of *Azotobacter* on disease

intensity was in accordance with the disease incidence in the ginger crop. Bacterial inoculants, in general, reduced the disease intensity of soft-rot of ginger. According to Davis and Dimand (1953) phytohormones elaborated by the bacterial inoculants induced changes in host metabolism that either regulated the parasite growth and toxic production or modified host response. In early part of ginger growth there was practically no or very negligible amount of intensity of soft-rot disease of ginger. This was in accordance with the disease incidence of those parts. With the age of the crop, disease intensity was increased with the increasing amount of disease incidence. It is interesting to note that in spite of having less inoculum potentiality in the later stages of growth of ginger yet the intensity of disease was increased. This was due to autoinfection (Baker, 1965) which was independent of pathogens. Rather it is dependent on resistance capacity of plants against pathogens. Moreover, not only inoculum potentiality but also other abiotic factors like weather was also important for development of soft-rot of ginger.

From the principle component analysis – fig. 45a, if PC_1 was considered, it was apparent that percent disease incidence and intensity was the highest under fertilizers treated pots and it was cased by *Fusarium* and *Pythium*. The least amount of disease was produced by *Fusarium* and *Pythium* under bacterization of rhizome with *Azotobacter* and *Bacillus* together as compared to individual inoculation. PC_2 revealed that *Pseudomonas* played a role in disease incidence and intensity in fertilizers treated pots. However, least amount of disease was observed under *Bacillus* inoculated series as compared to dual inoculation. Considering PC_3 (fig. 45b), it can be stated that disease incidence under the bacterization series was due to *Pythium*. However, least disease incidence was observed under bacterization of rhizome with dual inoculation.

Experiment No. 10 – Soilborne plant pathogenic ginger rhizosphere microflora in relation to soft-rot disease incidence and intensity in field :

Some organisms parasitise the ginger roots in succession and cause soft-rot in ginger. The roots of ginger is initially infected by *Fusarium* and, as a result, wilting of the ginger crop occurs (Dohroo and Sharma, 1992). The process of wilting is followed by secondary infection by *Pythium* (Kim *et. al.*, 1997) which initiate the rotting in ginger rhizome. The rotting is further accelerated by the infection of *Pseudomonas* (Choi and Han, 1990). The disease in ginger is influenced by various environmental condition. The important among them are the types of substances added to soil. Biotic and abiotic entities are added to soil in order to fulfill the nutritional demand of the crop. Among them, inorganic fertilizers accelerates the disease intensity. On the other hand, FYM, reduces the intensity of soft-rot of ginger to a limited extent. However, bacterial inoculants increase the vigour of crop and in this ways impart disease resistance (Davis and Dimond, 1953). The intensity of soft-rot a ginger is also dependent upon the density of pathogenic organisms in the rhizosphere soils. Infected rhizomes also spread the soft-rot ginger surface. However, there may be higher disease incidence and intensity even with lesser number of pathogenic microorganisms. Above views necessitated to conduct on investigation to enumerate the soilborne plant pathogenic organisms in relation to soft-rot disease incidence and intensity in field condition.

Perusal of results (table–60) shows that – rhizosphere soils under control of field experiment reared more number of propagules of *Fusarium* as compared to that of initial soil. The observation was similar to that of rhizosphere soils of pot culture experiment. FYM exerted significant detrimental influence on the

propagules of *Fusarium* as compared to that of control in the rhizosphere soil of field experiment. FYM exhibited similar influence in the rhizosphere soils of pot culture experiment. Inorganic fertilizers caused a significant enhancement of the cited fungal propagules in the rhizosphere soils of field experiment as compared to that of control. The results thus indicated that inorganic fertilizers not only countermanded the adverse effect of FYM but also stimulated the cited fungal propagules in the rhizosphere soils of field experiment. The influence of inorganic fertilizers over that of control in the rhizosphere soils of field experiment was similar to that in the rhizosphere soils of pot culture experiment. Inoculants of *Bacillus* resulted in a significant reduction of the cited fungal propagules in the rhizosphere soils of field experiment as compared to that of inorganic fertilizers. The relative influence of the inculants of *Bacillus* and that of inorganic fertilizers in the rhizosphere soils of field experiment was similar to that in the rhizosphere soils of pot culture experiment. Inoculants of *Azotobacter* were inferior to those of *Bacillus* in relation to their influence on the population of *Fusarium* in the rhizosphere soils of field experiment. The observations in regard to the relative influence of the inoculants of *Azotobacter* and those of *Bacillus* in the rhizosphere soils of field experiment were similar to those in the rhizosphere soils of pot culture experiment. Combined inoculation of *Azotobacter* and *Bacillus* exerted marginal diminuting influence on the propagules of *Fusarium* in the rhizosphere soils of field experiment as compared to that of inoculation of *Azotobacter*. On the other hand, the former treatment caused significant enhancing influence on *Fusarium* propagules in the rhizosphere soils of pot culture experiment. The results, thus, exhibited inconsistency regarding the relative influence of the inoculants *Azotobacter* and those of mixture of

Azotobacter and *Bacillus* in the rhizosphere soils of field and pot culture experiment. Population density of *Fusarium* in the ginger rhizosphere increased, on and on, from the sprouting of mother rhizome up to the full growth stage of ginger pseudostem and then declined gradually till the harvesting stage of ginger. Similar explanation as that of *Fusarium*, discussed under the experiment-9 is also applicable here.

Rhizosphere soils under control of field experiment clubbed more number of *Pythium* than that of initial soil (table-61). That was because of the favourable influence of moisture as well as root exudates and dead tissues of ginger roots. FYM exerted significant adverse influence on the population of *Pythium* in the rhizosphere soils of field experiment. The influence of FYM over that of control in the rhizosphere soils of field experiment was similar to that in the rhizosphere soils of pot culture experiment. On the other hand, inorganic fertilizers brought about a significant enhancing influence on the propagules of *Pythium* as compared to that of FYM in the rhizosphere soils of field experiment. This pointed out that inorganic fertilizers not only mitigated the adverse influence of FYM on *Pythium* but also brought about higher population of the cited fungus in the rhizosphere soils. The finding was similar to those in the rhizosphere soils of pot culture experiment. Bacterial inoculants, alone or in combination, caused significant detrimental influence on the population of *Pythium* as compared to that of inorganic fertilizers in the rhizosphere soils of field experiment. The influence of the inoculants was even significantly inferior to that of control. In the context, combined inoculation of *Azotobacter* and *Bacillus* caused the lowest proliferation of *Pythium* in the rhizosphere soils of field experiment. That was followed by those of inoculation of *Azotobacter* and inoculation of *Bacillus*, respectively. The

sequential influence of various treatments in the rhizosphere soils of field experiment was almost similar to those in the rhizosphere soils of pot culture experiment. The relative influence of the mixed inoculants of *Azotobacter* and *Bacillus* and those of *Azotobacter* inoculants in the rhizosphere soils of field experiment was not similar to that in the rhizosphere soils of pot culture experiment. The influence of *Azotobacter* inoculants was marginally superior to those of the mixed inoculants in the rhizosphere soils of pot culture experiment. This pointed out that the relative influence of the inoculants of *Azotobacter* and those of *Azotobacter* and *Bacillus* in combination was not consistent in the rhizosphere soils of field and pot culture experiments. Population density of *Pythium* in the ginger rhizosphere increased, on and on, from the sprouting of mother rhizome up to the full growth stage of ginger pseudostem and then declined gradually till the harvesting stage of ginger. Similar explanation as that of *Fusarium*, discussed under the experiment-9 is also applicable here.

Rhizosphere soils under control harboured more number of *Pseudomonas* cells as compared to that of initial soil (table–62). The explanation is similar to that of *Pythium* in the rhizosphere soils of pot experiment. FYM exerted significant enhancing influence on the number of *Pseudomonas* cells as compared to that of control in the rhizosphere soils of field experiment. On the other hand, inorganic fertilizers brought about a significant enhancement of in the number *Pseudomonas* cells as compared to that of FYM in the rhizosphere soils of field experiment. However, bacterial inoculants, alone or in combination caused a significant detrimental influence on the population of *Pseudomonas* in the rhizosphere soil of field experiment as compared to that of inorganic fertilizers. As such, inoculants of *Azotobacter* were superior to that of control in relation to their influence on the population of *Pseudomonas* in the

rhizosphere soils of field experiment. But, the inoculants of *Bacillus* , alone, and those of *Bacillus* and *Azotobacter*, in combination were significantly inferior to that of control in relation to their influence on the proliferation of *Pseudomonas* in the rhizosphere soils of field experiment. As it were, mixed inoculants of *Azotobacter* and *Bacillus* were superior to those of *Bacillus* but inferior to those of *Azotobacter* in relation to their influence on the population of *Pseudomonas* in the rhizosphere soils of field experiment. The sequential influence of various treatments on the population of *Pseudomonas* in the rhizosphere soils of field experiment was similar to those of the relative influence of the respective treatments in the rhizosphere soils of pot culture experiment. Population density of *Pseudomonas* in the ginger rhizosphere increased, on and on, from the sprouting of mother rhizome up to the late emergence of ginger pseudostem and then declined gradually till the harvesting stage of ginger. Similar explanation as that of *Fusarium*, discussed under the experiment-9 is also applicable here.

FYM marginally brought down the disease incidence in ginger crop as compared to that of control in the field experiment (table–63). However, the cited manure caused a marginal increase in disease incidence as compared to that of control in the pot culture experiment. Inorganic fertilizers, on the other hand, resulted in a significant increase in disease incidence as compared to that of FYM in the field experiment. That might due to influence of the highest population of all of the potentially pathogenic organisms on to the roots of ginger crop by the inorganic fertilizers. The influence of inorganic fertilizers on disease incidence in the field experiment was similar to that in the pot culture experiment. So similar explanation can be put forward. Inoculants of *Azotobacter* and *Bacillus*, alone or in combination, exerted significant detrimental influence on the disease incidence as

rhizosphere soils of field experiment. But, the inoculants of *Bacillus* , alone, and those of *Bacillus* and *Azotobacter*, in combination were significantly inferior to that of control in relation to their influence on the proliferation of *Pseudomonas* in the rhizosphere soils of field experiment. As it were, mixed inoculants of *Azotobacter* and *Bacillus* were superior to those of *Bacillus* but inferior to those of *Azotobacter* in relation to their influence on the population of *Pseudomonas* in the rhizosphere soils of field experiment. The sequential influence of various treatments on the population of *Pseudomonas* in the rhizosphere soils of field experiment was similar to those of the relative influence of the respective treatments in the rhizosphere soils of pot culture experiment. Population density of *Pseudomonas* in the ginger rhizosphere increased, on and on, from the sprouting of mother rhizome up to the late emergence of ginger pseudostem and then declined gradually till the harvesting stage of ginger. Similar explanation as that of *Fusarium*, discussed under the experiment-9 is also applicable here.

FYM marginally brought down the disease incidence in ginger crop as compared to that of control in the field experiment (table–63). However, the cited manure caused a marginal increase in disease incidence as compared to that of control in the pot culture experiment. Inorganic fertilizers, on the other hand, resulted in a significant increase in disease incidence as compared to that of FYM in the field experiment. That might due to influence of the highest population of all of the potentially pathogenic organisms on to the roots of ginger crop by the inorganic fertilizers. The influence of inorganic fertilizers on disease incidence in the field experiment was similar to that in the pot culture experiment. So similar explanation can be put forward. Inoculants of *Azotobacter* and *Bacillus*, alone or in combination, exerted significant detrimental influence on the disease incidence as

compared to that of inorganic fertilizers in the field experiment. The influence of the inoculants were even less than that of control. However, *Azotobacter* inoculants resulted in the lowest disease incidence followed by those of the mixed inoculants of *Azotobacter* and *Bacillus* and the inoculants of *Bacillus*, respectively. The influence of the inoculants of *Bacillus* on disease incidence in the field experiment was in accordance with the proliferation of *Fusarium* and *Pythium* in the rhizosphere soils. The inoculants of *Azotobacter* brought about the lowest disease incidence in the field experiment though the cited treatment exerted enhancing influence on the population of *Fusarium*, *Pythium* and *Pseudomonas* as compared to those of mixed inoculants of *Azotobacter* and *Bacillus* in the rhizosphere soils of field experiment. The results, thus suggested that the population density of potentially pathogenic organisms might not be the sole determinant of disease incidence. The direct linear relationship in between the population density of pathogenic organisms and the disease incidence may not be always true. In early parts of ginger growth there was practically no or very negligible amount of disease incidence but with the age of crop the magnitude of disease incidence was increased. This result is similar to that found in the experiment no. 9. So, similar explanation can be put forward.

FYM resulted in a significant deleterious influence on disease intensity in the field experiment as compared to that of control (table–64). The influence of FYM on disease intensity was in accordance with that of the disease incidence in the field experiment. Similar results were found in the pot culture experiment. On the other hand, inorganic fertilizers exerted significant enhancing influence on disease intensity as compared to that of control in the field experiment. The influence of FYM in the field experiment was similar to that in the pot culture

experiment. However, the influence of FYM on disease intensity was according to that of the proliferation of potentially pathogenic organisms. Inoculants of *Azotobacter* and *Bacillus*, alone or in combination, brought about significant reduction in disease intensity as compared to that of inorganic fertilizers in the field experiment. The influence of the cited bacterial inoculants was even significantly less than that of control. As such, mixed inoculants of *Azotobacter* and *Bacillus* caused the lowest disease intensity followed by those of the inoculants of *Azotobacter* and the inoculants of *Bacillus*, respectively. The influence of the inoculants of *Bacillus* on the disease intensity was in accordance with that of the disease incidence in the field experiment. But, the mixed inoculants of *Azotobacter* and *Bacillus* resulted in the lowest disease intensity though the inoculants of *Azotobacter* brought about the lowest disease incidence in the field experiment. So, it can be suggested that the disease intensity might not always be directly related to the disease incidence. In early parts of ginger growth there was practically no or very negligible amount of disease intensity but with the age of crop the magnitude of disease intensity was increased. This result is similar to that found in the experiment no. 9. So, similar explanation can be put forward.

From the principle component analysis – fig. 51a, if PC_1 was considered, it was apparent that percent disease incidence and intensity was the highest under fertilizers treated plots and it was cased by *Fusarium* and *Pythium*. The least amount of disease was produced by *Fusarium* and *Pythium* under bacterization of rhizome with combined inoculation of *Azotobacter* and *Bacillus* as compared to individual inoculation. PC_2 revealed that *Pseudomonas* played a role in disease incidence and intensity in fertilizers treated plots. However, least amount of disease was observed under *Bacillus* inoculated series as compared to dual inoculation. Considering PC_3 (fig. 51b), it can be stated that disease intensity under the bacterization series was due to *Pythium*. However, least disease intensity was observed under bacterization of rhizome with dual inoculation.

CHAPTER V

Summary and Conclusion

Chapter V

SUMMARY AND CONCLUSION

The effect of manure and inoculation of efficient ginger rhizosphere non-symbiotic nitrogen fixing *Azotobacter* as well as phosphate solubilizing *Bacillus* strains on some microbiological and chemical properties of soil, vis-a-vis the performance of ginger especially in relation to the control of soft-rot disease of ginger was studied at Regional Research Station (RRS), Bidhan Chandra Krishi Viswavidyalaya, Hill zone, Kalimpong, Darjeeling. The investigation was comprised of ten sets of experiment. In the first set, the rate of decomposition of two types of FYM-one procured from local farm house (FH-FYM) and the other from RRS farm (RRS-FYM) alone or in combination with the recommended dose of inorganic fertilizers of ginger was studied in the laboratory. The rate of decomposition of FYM procured from local farm house along with inorganic fertilizers was the fastest in soil followed by those of local farm house FYM alone, Regional Research Station FYM, along with inorganic fertilizers and Regional Research Station FYM respectively. In the second set, seven strains each of ginger root associative *Azotobacter* and *Bacillus* were isolated from ginger rhizosphere soil. The efficiencies in relation to nitrogen fixing and phosphate solubilizing power were evaluated. NFB_1 was the most efficient nitrogen fixing bacteria while PSB_4 was the most efficient phosphate solubilizing bacteria.

The third set was a pot culture experiment without crop while the fourth and fifth sets were pot culture and field experiment, respectively, with ginger crop. The effect of the superior FYM alone, evaluated during the first set of experiment,

along with the recommended dose of inorganic fertilizers alone or together with single and dual inoculation of *Azotobacter* and *Bacillus*, isolated from the second set of experiment, on some microbiological and chemical properties of soil. In addition, the performance of ginger was studied in the third and fourth set of experiments.

Combined inoculation resulted in the highest increase in the proliferation of total bacteria followed by those of *Azotobacter* inoculation, *Bacillus* inoculation, fertilizers, FYM and control, respectively in soil with and without ginger crop in the pot culture experiments. The influence of the treatments was almost similar in the rhizosphere soil of field experiment except that the influence of *Bacillus* inoculation was superior to that of *Azotobacter* inoculation.

Combined inoculation exerted the highest proliferation of actinomycetes followed by those of *Azotobacter* inoculation, *Bacillus* inoculation, fertilizers, FYM and control, respectively in soil without crop in pot culture experiment. The influence of the treatments was almost similar in the rhizosphere soil of pot culture experiment except that the influence of FYM was superior to that of *Bacillus* inoculation. Field soil also maintained similar sequential influence of the treatments to that of pot culture experiment without crop except that the influence of fertilizer was superior to that of *Azotobacter* inoculation.

Inorganic fertilizers resulted in the highest proliferation of fungi in the rhizosphere soils of ginger followed by those of FYM, control, combined inoculation, *Bacillus* inoculation and *Azotobacter* inoculation, respectively in pot culture and field experiments. On the other hand, combined inoculation maintained the highest fungal count in soil without crop in pot culture experiment followed by those of *Azotobacter* inoculation, fertilizers, *Bacillus* inoculation, FYM and control, respectively.

Combined inoculation brought about the highest proliferation of aerobic non-symbiotic nitrogen fixing bacteria in soil without crop in pot culture experiment followed by those of *Azotobacter* inoculation, *Bacillus* inoculation, fertilizer, FYM and control, respectively. The influence of treatments was almost similar in the rhizosphere soils of pot culture experiment except that the influence of fertilizer was superior to that *Bacillus* inoculation. On the other hand, combined inoculation resulted in the highest increase in the number the said bacteria in the rhizosphere soils of field experiment followed by those of *Azotobacter* inoculation, FYM, fertilizer, *Bacillus* inoculation and control, respectively.

Combined inoculation resulted in the maximum number of phosphate solubilizing microorganisms in soils without crop in the pot culture experiment as well as in the rhizosphere soils of field experiment followed by those of *Bacillus* inoculation, *Azotobacter* inoculation, fertilizers, FYM and control, respectively. The influence of the treatments was almost similar in the rhizosphere soil of pot culture experiment, with the exception of that, the influence of fertilizers was superior to that of *Azotobacter* inoculation.

Rhizosphere soil under control stimulated the growth of *Bacillus, Micrococcus, Staphylococcus,* nitrogen fixing *Bacillus,* Phosphate solubilizing *Flavobacterium* and *Pseudomonas, Streptomyces* as well as *Fusarium.* Combined inoculation brought about further stimulation of *Bacillus* at full growth stage of ginger pseudostem, *Micrococcus* and phosphate solubilizing *Flavobacterium* as well as *Pseudomonas* at harvesting stage. FYM and inorganic fertilizers further stimulated the growth of *Micrococcus* and *Staphylococcus* at both of growth stages,

phosphate solubilizing *Pseudomonas* and *Fusarium* at full growth stage *Streptomyces* at harvesting stage. *Staphylococcus* was similarly stimulated by *Azotobacter* inoculation at harvesting stage. Phosphate solubilizing *Pseudomonas* was also similarly stimulated by *Bacillus* inoculation at both of the growth stages.

FYM brought about the greatest enhancing influence on the nitrogen fixing power of soil without crop in pot culture experiment followed by those of combined inoculation *Azotobacter* inoculation, control, *Bacillus* inoculation and control, respectively. On the other hand, combined inoculation caused the highest increase in nitrogen fixing power of rhizosphere soils of ginger in pot culture experiment followed by those of *Azotobacter* inoculation, FYM, *Bacillus* inoculation, control, and fertilizers, respectively. However, the influence of the treatments was almost similar in the rhizosphere soils of field experiment with an alternation of superiority in fertilizer to control.

Combined inoculation registered the highest increase in phosphate solubilizing power of soil with and without crop in the pot culture experiments as well as in the rhizosphere soils of field experiment followed by those of *Bacillus* inoculation, fertilizer, *Azotobacter* inoculation, FYM and control, respectively.

FYM brought about the highest organic carbon built up in the rhizosphere soils of field and pot culture experiments followed by those of fertilizers, *Bacillus* inoculation, *Azotobacter* inoculation, combined inoculation and control, respectively. The influence of the treatments was almost similar in soils without crop in pot culture experiment with the exception of that the influence of control was superior to that of combined inoculation.

Azotobacter inoculation brought about the highest increase in the nitrogen content of soils with and without crop in pot culture experiment followed by those of combined inoculation, fertilizers, *Bacillus* inoculation, FYM and control, respectively. On the other hand, combined inoculation resulted in the highest increase in the nitrogen content of rhizosphere soils of ginger in the field experiment followed by those of *Azotobacter* inoculation, fertilizers, *Bacillus* inoculation, FYM and control, respectively.

Combined inoculation caused the highest accumulation of ammoniacal-nitrogen in the rhizosphere soils of pot culture as well as field experiments followed by those of *Azotobacter* inoculation, fertilizer, *Bacillus* inoculation, FYM and control, respectively. The influence of the treatments was almost similar in soils without crop in pot culture experiment with the exception of that the influence of *Bacillus* inoculation was superior to that of fertilizers.

Combined inoculation resulted in the highest enhancement of nitrate-nitrogen in soils with or without crop in pot culture experiment followed by those of *Azotobacter* inoculation, fertilizers, *Bacillus* inoculation, FYM and control, respectively. On the other hand, combined inoculation yielded the highest increase in the content of nitrate-nitrogen in the rhizosphere soils of field experiment followed by those of *Bacillus* inoculation, FYM, fertilizers, *Azotobacter* inoculation and control, respectively.

Combined inoculation caused the greatest increase in availability of phosphorus in soils with or without crop in pot culture experiment as well as in the rhizosphere soils of field experiment followed by those of *Bacillus* inoculation, fertilizer, *Azotobacter* inoculation, FYM and control, respectively.

Combined inoculation caused the highest uptake of nitrogen by ginger rhizome from soils of pot culture experiment followed by those of *Azotobacter* inoculation, *Bacillus* inoculation, fertilizers, FYM and control, respectively. The influence of the treatments was almost similar in soils with crop in the field with the exception of that the influence of *Bacillus* inoculation was superior to that of *Azotobacter* inoculation.

Combined inoculation resulted in the highest uptake of phosphorus by ginger rhizome from soils of pot culture as well as field experiments followed by those of *Bacillus* inoculation, *Azotobacter* inoculation, fertilizers FYM and control, respectively.

Combined inoculation brought about the highest yield of fresh rhizome of ginger in pot culture experiment followed by those of *Azotobacter* inoculation, *Bacillus* inoculation, fertilizer, FYM and control, respectively. Similar trend in yield was recorded in the field experiment with the exception of that the influence of *Bacillus* inoculation was superior to that of *Azotobacter* inoculation.

In the sixth set, plant pathogenic bacteria and fungi were isolated from rotten ginger in specific media. *Pseudomonas* and *Erwinia* were the plant pathogenic bacterial isolates while *Fusarium* and *Pythium* were the plant pathogenic fungal isolates.

In the seventh set, the interaction between soft-rot producing pathogens and the beneficial bacteria was studied *in-vitro*. There were antagonisms in between *Fusarium* and *Azotobacter* , *Pythium* and *Azotobacter*, *Pythium* and *Bacillus* as well as *Pseudomonas* and *Bacillus* hyperparasitism in between *Fusarium* and *Bacillus*, *Fusarium* and *Pseudomonas*, *Pythium* and *Pseudomonas* as well as *Azotobacter* and *Pseudomonas*, commensalism in between *Azotobacter* and *Bacillus* and neutralism in between *Fusarium* and *Pythium*.

The eighth set was a pot culture experiment without crop while the ninth and tenth sets were pot culture and field experiments, respectively with ginger crop. *Fusarium*, *Pythium* and *Pseudomonas* were enumerated from the treated soils. In addition, the disease incidence and intensity were evaluated in the ninth and tenth sets.

Inorganic fertilizers resulted in the highest proliferation of *Fusarium* propagules in soils with or without crop in the pot culture experiment followed by those of control, FYM, *Bacillus* inoculation, combined inoculation and *Azotobacter* inoculation, respectively. The influence of the treatments was almost similar in the rhizosphere soils in field with the exception of that the influence of combined inoculation was superior to that of *Azotobacter* inoculation.

Inorganic fertilizers caused the highest increase in *Pythium* propagules in soils without crop in pot culture experiment followed by those of *Bacillus* inoculation, FYM, control, combined inoculation and *Azotobacter* inoculation, respectively. The influence of the treatments was similar in rhizosphere soils of pot culture experiment with the exception of that control was superior to FYM. On the other hand, inorganic fertilizers brought about the greatest increase in the said organisms in the rhizosphere soils of ginger in the field experiment followed by those of control, FYM, *Bacillus* inoculation, *Azotobacter* inoculation and combined inoculation, respectively.

Inorganic fertilizers resulted in the highest increase in proliferation of *Pseudomonas* in rhizosphere soils of ginger in the pot culture as well as field experiments. That was followed by those of *Azotobacter* inoculation, FYM, control, combined inoculation and *Bacillus* inoculation, respectively. The influence of the treatments was almost similar in soils without crop in pot

culture experiment with the exception of that the influence combined inoculation was superior to that of control.

Inorganic fertilizers induced the highest disease incidence of soft-rot of ginger in the pot culture experiment followed by those of FYM, *Bacillus* inoculation, control and *Azotobacter* inoculation and combined inoculation, respectively. On the other hand, inorganic fertilizers caused the greatest increase in the disease incidence in field experiment followed by control, FYM, *Bacillus* inoculation, combined inoculation and *Azotobacter* inoculation, respectively.

Inorganic fertilizers exerted the highest influence on soft-rot disease intensity in pot culture experiment followed by those of control, FYM, *Bacillus* inoculation, combined inoculation and *Azotobacter* inoculation, respectively. The influence of the treatments was almost similar in field experiment with the exception of that the influence of *Azotobacter* inoculation was superior to that of combined inoculation.

From the principal component analysis it was found that inorganic fertilizers resulted in the highest disease incidence and intensity in the pot culture and field experiments. *Fusarium* and *Pythium* were found to be the most effective pathogenic microorganisms. On the other hand, combined inoculation of *Azotobacter* and *Bacillus* exerted the least influence on the disease incidence and intensity.

The results thus proved that FYM, inorganic fertilizers and inoculants of *Azotobacter* and *Bacillus*, alone or in combination exerted beneficial effect on the microbiological and chemical properties of soil. The beneficial effect was ultimately reflected on the performance, in general, and yield, in particular,

of ginger. Inorganic fertilizers resulted in disease susceptibility which was mitigated by the inoculants of *Azotobacter* and *Bacillus*, alone or in combination. Combined inoculation of *Azotobacter* and *Bacillus* was the best one among the treatments as it resulted in the highest yield of ginger rhizome in pot as well as field experiments by improving the chemical and microbiological properties of soil. Inoculation of *Azotobacter* and *Bacillus* exerted differential influence on the microbiological and chemical properties of soil as well as yield of ginger rhizome. The influence of *Azotobacter* inoculation was next to that of combined inoculation in the pot culture experiment while the influence of *Bacillus* inoculation was next to that of combined inoculation in the field experiment in relation to the yield of ginger rhizome.

CHAPTER VI

Future Scope of Research

Chapter VI

FUTURE SCOPE OF RESEARCH

The results of the present investigation revealed that organic manures increased the yield of ginger, more so, with in organic fertilizers. However, inorganic fertilizers induced disease susceptibility which could be countermanded by the inoculants of *Azotobacter* or *Bacillus*. As it were, mixed inoculants of *Azotobacter* or *Bacillus* resulted in the highest yield of ginger. Though the inoculants of *Azotobacter* as well as *Bacillus* considerably improved the yield they were next to the mixed inoculants. But, the results were not consistent in the field and pot culture experiment. So, several investigations are to be conducted in regard to the influence of efficient inoculants of *Azotobacter* and *Bacillus* on the microbiological and chemical properties of soil *vis* a *vis* crop performance under different agrochlimatic regions. Efficient bacterial inoculants should be screened out from the rhizosphere soils of different crops under different agroclimatic zones. They should be tested as single, dual or multiple inoculants against different crops under different agroclimatic conditions. Certain strains of fungi are efficient in solubilizing and mineralizing inorganic and organic insoluble phosphorus compounds in soil. They should be isolated from the rhizosphere soils of different crops and exploited along with nitrogen fixing bacterial inoculants in order to augment crop yield. Efforts are to be made to minimise the use of inorganic fertilizers and maximise the exploitation of microbial inoculants in order to obtain targeted yield.

References

REFERENCES

A. O. A. C. 1985. Official Methods of Analysis. Association of Official Agricultural Chemists. Washington - 4, D. C.

Agarwal, S. C., Khare, M. N. and Agarwal, P. S. 1978. Biological control of *Sclerotium rolfsii* causing coller rot of lentil. *Indian Phytopathol.* **30**, 176-179.

Alexander, M. 1977. Introduction to Soil Microbiology. John Wiley & Sons. Inc. New York.

Asmus, F. 1970. Effect of different organic manures on nitrogen content and nitrogne fractions of a sandy brown earth (Rosterde). Thaer-Arch. 17, pp. 775-782.

Babu, P and Jayachandran, B. M. 1997. Mulch requirement of ginger (*Zingiber officinale* Rosc.) under shade. *J. Spices Aromatic Crops.* **6**, 141 - 143.

Baker, R. 1965. The dynamics of inoculum. In : Ecolosy of Soilborne Plant Pathogens. (Baker, K. F. and Snyder, W. C. ed.). Berkeley Univ. Calf. Press. pp. 571.

Banik, S. and Dey B. K. 1982. Available phosphate content of alluvial soil as influenced by inoculation of some isolate phosphate solubilizing microorganisms: *Pl. Soil.* 69, 353 - 364.

Banik, S. and Dey, B. K. 1985. Effect of inoculation with native phosphate solubilizing microorganisms on the available phosphorus content in the rhizosphere and uptake of phosphorus by rice plants grown in an Indian alluvial soil. *Zbl. Mikrobiol.* **140**, 455 - 464.

Banik, S. and Dey, B. K. 1987. Phytohormone producing ability of phosphate solubilizing bacteria. *Indian Agric.* **22**, 93 - 97.

Bergy's Mannual of Determinative Bacteriology. 1974. 8th Edition (Buchanan, R. E. and Gibbons, N. E. eds.). Williams and Wilkins, Baltimore.

Bhardwaj, S. S.; Gupta, P. K.; Dohroo, N. P. and Shyam, K. R. 1988. An addition to fungi causing rhizome rot of ginger. *Pl. Dis. Res.* **3**, 66.

Bhattacharrya, P., Dey, B. K., Nath, S. and Banik, S. 1980. Organic manures in relation to rhizosphere effect. V. Effect of organic manures on the quantitative and qualitative distribution of bacteria, actinomycetes and fungi in the rhizosphere rice. *Indian. Agric.* **34**, 157 - 162.

Bhattacharyya, P. Dey. B. K., Nath, S. and Banik. S. 1984. Organic manure in relation to rhizosphere effect. II. Effect of organic manure on total nitrogen and nitrogen fixing power of rice and succeeding wheat soils. *Zbl. Mikrobiol.* **139**, 21 - 33.

Bhattacharyya, P., Dey, B. K., Banik, S and Nath, S. 1986. Organic manures in relation to rhizosphere effect. iv. Effect of organic manures on phosphate solubilizing power of rice and succeeding wheat rhizosphere soils. *Zbl. Mikrobiol.* **141**, 357 - 365.

Bowie, J. S., Loutit, M. W. and Lautit, J. S. 1973. Identification of aerobic heterotrophic soil bacteria to the generic level by using multi point inoculation technique. *Can. J. Microbiol.* **15**, 297 - 308.

Bray, R. H. and Kurtz, L. T. 1945. Determination of total organic and available forms of phosphorus in soils. *Soils Sci.* **59**, 39-45.

Broadbent, P., Baker, F. K., Franks, N. and Holland, J. 1977. Effect of *Bacillus* sp. on increased growth of seedlings in steamed and nontreated soil. *Phytopathol.* **67**, 1027-1034.

Brown, M. E. 1972. Plant growth substances produced by microorganisms of soil and rhizosphere. *J. Appl. Bacteriol.* **35**, 443 - 451.

Brown, M. E. 1974. Seed and root bacterization. *Phytopathol.* **12**, 181 - 197.

Brown, M. E. and Burlingham, S. K. 1963. *Azotobacter* and plant disease. *Ann. Rept. Rothamsted Exp. Stan.* 73.

Brown, M. E. and Walker, N. 1970. Indolyl - 3 - acetic acid formation *Azotobacter chroococcum. Pl. Soil.* **52**, 250 - 253.

Buckman, H. O. and Brady, N. C. 1974. In : *The Nature and Properties of Soils.* Macmillan Pub. Co., Inc., USA.

Burr, T. J., Schroth, M. N. and Suslow, T. 1978. Increased potato yields by treatment of seed pieces with specific strains of *Pseudomonas fluorescens* and *P. putida. Phytopathol.* **68**, 1377-1383.

Chauhan, V. B. and Singh, U. P. 1991. Effect of volatiles of some plant extracts on germination of zoospores of *Phytophthora drechsleri* f. sp. cajani. *Indian Phytopathol.* **44**, 197-200.

*Choi, I. Y., Lee, W. H., So, I. Y., Choi, I. Y., Lee, W. H. and So, I. Y. 1996. Effects of chemicals on growth of *Pythium zingiberum* causing rhizome rot of ginger and inhibition of the disease development. *Korean J. Pl. Pathol.* **12**, 331 - 335.

*Choi, J. E. and Han, K. S. 1990. Bacterial soft rot and rhizome rot caused by *Erwinia carotovora* sub sp. *carotovora, Pseudomonas marginalis* and *P. solanacerums. Korean J. Pl. Pathol.* **6**, 363-368.

Cook, R. J. 1977. Management of associated microbiota. Quoted from Papavizas and Lumsden, 1980.

*Couture, M. and Fortin, J. A. 1983. *Ecologie et de Biologic du sol.* 20, 493. Quoted from Jothimani *et al.,* 1997.

CTBT with India A New Clear Way to Healthy Cooking - An Explosion of Indian Spice Food. 1998. Palarich -any, ed. *Indian Spices.* **35**, 24 - 25.

Dake, G. N. 1995. Disease of ginger (*Zingiber officinale* Rosc.) and their management. *J. Spicies Aromatic plants.* **41**, 40-48.

Dake, G. N. and Edison, S. 1989. Association of pathogens with rhizome rot of ginger in Kerala. *Indian Phytopathol.* **42**, 116-119.

Das, A. C. and Mukherjee, D. 1988. Decomposition of neem cake and wheat straw in alluvial soil. *Environ. Ecol.* **6**, 1002-1005.

Datta, M., Banik, S. and Gupta, R. K. 1982. Studies on the efficacy of phytohormone producing phosphate solubilizing *Bacillus firmus* augmenting paddy yield in acid soils of Nagaland. *Pl. Soil.* **69**, 365 - 373.

David, M. W. 1988. Biological control of soilborne plant pathogens in the rhizosphere with bacteria. *Ann. Rev. Phytopathol.* **26**, 379-407.

Davis, D. and Dimond, A. E. 1953. Induceing disease resistance with plant growth regulators. *Phytopathol.* **43**, 137-140.

*De pooter, H. L. and Aboutabl, E. A. 1995. Chemical composition and antimicrobial activity of essential oil of leaf, stem and rhizome of Alpinia speciosa grown in Egypt. *Flovour Fragrance J.* **10**, 63-67.

De, P. K. 1939. The role of blue-green algae in nitrogen fixation in rice fields. *Proc. Roy. Soc. B.* **127**, 121-139.

Dey, B. K. 1972. Bacterial inoculation in relation to root exudates and rhizosphere effect. II. Effect of inoculation of Azotobacter in maize (*Zea mays* L.) and Rhizobium in gram (*Cicer arietinum* L.) on the rhizosphere microflora. *Indian. Agric.* **16**, 307 - 314.

Dey, B. K. 1973. Bacterial inoculation in relation to root exudates and rhizosphere effect. III. Effect of root exudates on the rhizosphere microflora of *Azotobacter* inoculated maize (*Zea mays* L.) and *Rhizobium* inoculated gram (*Cicer arietinum L.*). *Indian. Agric.* **17**, 125 - 133.

Dey, B. K. 1988. Phosphate solubilizing microorganisms in improving fertility status of soil. In : *Biofertilizers Potentialities and Problems.* (Sen, S. P. and Palit, P. eds). Naya Prakash. Calcutta. pp. 237 - 248.

Dey, B. K. and Chattopadhyay, D. K. 1977. Effect of spraying zinc on nitrogen economy of rice field. *Indian Agric.* **21**, 174-179.

Dey, B. K. and Chattopadhyay, D. K. 1978. Effect of spraying zinc on nitrogen economy of rice field. *Indian Agric.* **22**, 93 - 97.

Dey, B. K., Banik, S. And Nath, S. 1977. Effect of organic manure on the microbial population and phosphate solubilizing power of rice (*Oryza sativa L.*) rhizosphere soils. Quoted from Dey and Chattopadhyay, 1978.

Dohroo, N. P, Sharma, S. and Sharma, S. 1997. Effect of organic amendments and intercropping on spore density of VAM fungi and yellow of ginger. *Pl. Dis. Res.* **12**, 46-48.

Dohroo, N. P. and Sharma, S., K. 1992. Variability in *Fusarium oxysporum* f. sp. *Znigiberi*, the incitant of ginger yellows. *Indian Phytopathol.* **45**, 247 - 248.

*Dohroo, N. P., Sharma, O., Sharma, M. and Sarlach, S. 1994. Effect of organic amendments of soil on rhizome rot, nematodes and rhizosphere mycoflora of ginger. *Ann. Biol.*, Ludhiana. **10**, 208 - 210.

El - Din - Sharabi, N. and Bartha, R. 1993. Testing some assumptions about biodegradability in soil as measured by carbon dioxide evolution *Appl. Environ. Microbiol.* **59**, 1201 - 1205.

Encyclopaedia Britannica, Inc. William Benton pub, London, 1935. **19**, pp. 1150 - 1155.

*Fardeau, J. C. and Guiraurd, G. 1971. Mobility of phosphorus in a soil receiving farm yard manure for thirty five years. *Compt. Rend.* **57**, 1598-1605.

Fiddaman, P. J. and Rossall, S. 1993. The production of antifungal volatiles by *Bacills subtilis. J. Appl. Bacteriol.* **74**, 119 - 126.

Fuji, U., Toru, H. and Michihiko, Y. 1984. Nitrogen - fixing activities associated with rhizomes and roots of Equisetum species. *Soil Biol. Biochem.* **16**, 663 - 667.

Ganesan, P. and Gnanamanickam, S. S. 1987. Biological control of *Sclerotium rolfsii* Sacc. in peanut by inoculation with *Pseudomonas fluorescens. Soil Biol, Biochem.* **19**, 35 - 38.

Gaur, A. C. 1972. Role of phosphate solubilizing microorganisms and organic matter in soil productivity. Symp. Soil Productivity. 1972, 259 - 268.

Gaur, A. C. 1990. *Phosphate solubilizing Microorganisms as Biofertilizers.* Omega Scientific Publishers, New Delhi. 26.

Gaur, A. C. and Algawadi, A. R. 1989. Interaction of nitrogen fixing phosphate solublizing microorganisms on crop productivity. Plantmicrobe interaction. Proc. Focal Theme Symposium Bot. Sections, ISCA, Bangalore. **87**, 35 - 36.

Gaur, A. C. and Mukherjee, D. 1980. Recycling of organic matter through mulch in relation to chemical and microbiological properties of soil and crop yields. *Pl. Soil.* **56**, 273-281.

Gaur, A. C. and Sachar, S. 1980. *Curr. Sci.* **49**, 553. Quoted from Narsion *et al.*, 1995.

Gaur, A. C. Mathur R. S. and Varshney, T. N. 1970. Decomposition of differnt types of added organic matter in soil. *Agrochimica.* **14**, 524 - 532.

Gaur, A. C. Sadasivam, K. V., Vimal, O. P. and Mathur, R. S. 1971. A study on the decomposition of organic matter in an alluvial soil : CO_2 evolution, microbial and chemical transformations. *Pl. Soil.* **235**, 17 - 28.

Gaur, A. C., Sadasivam, K. V., Vimal, O. P., Mathur, R. S. and Kavimandan, S. K. 1973. Studies on the humification of organic matter in red Rakar soil. *Zb. Bak. Abt. It. Bd.* **128**, 146-161.

Gilman, J. C. 1957. Jर्न : *A Manual of Soil Fungi.* 2nd ed. The collegiate press. Ine. Ames. Iowa.

Gray, T. R. G. 1969. The identification of soil bacteria. In : *The soil Ecosystem.* (Sheals, J. G. ed.). The Systematics Association, London, pp. 73-85.

Gupta, C. R. and Awasthi, O. P. 1997. Effect of mulch material on growth and yield of ginger. *Veg. Sci.* **24**, 13 - 15.

Gupta, R. D., Kharwara, P. C. and Singh, L. N. 1997. Application of locally isolated *Azotobacter* culture alone or in combination with FYM in maize crop. *Dharti* (In press).

*Haag, H. P., Saito, S. and Dechen, A. R. 1990. Accumulation of dry matter and uptake of macro and micronutrient by ginger. *Luiz de Queiroz.* **42**, 435-457.

Hadas, A and Protnoy, R. 1994. Nitrogen and carbon mineralization rates of composted manures incubated in soil. *J. Enviorn. Qual.* **23**, *6*, 1184 - 1189.

*Hadas, A. and Portnoy, R. 1997. Rates of decomposition in soil and release of available nitrogen from cattle manure and municipal waste composts. *Compost-Science-and-Utilization.* **5**, 48-54.

Hadas, A., Kavtsky, L. and Portnoy, R. 1996. Mineralization of composted manure and microbial dynamics in soil as affected by long - term nitrogen management. *Soil. Biol. Biochem.* **28**, 733 - 738.

*Hamdi, H. and Metwally, S. Y. 1969. The effect of different sources of organic manures on nitrogen mineralization and organic matter content in sandy soils. *J. Soil. Sci. Un. Arab Repub.* **9**, 35.

*Hanay, A. and Yardimell, N. 1992. A study on the effects of municipal compost and FYM on the physical and chemical properties of soils and soil water relations. *Doga, Turk Tarim ve ormancilik Dergisi.* **16**, 91-102.

Hayman, D. S. 1975. Phosphorus cycling by soil microorganisms and plant roots. In : *Soil Microbiology* (Walker, N. ed.). Butterworths, London, pp. 67-92.

Hedge, R. K., Kulkarni, S., Siuddaramaiah, A. L. and Krishnaprasad, K. S. 1980. Biological control of *Sclerotium rolfsii* Sacc. Causal agent of foot rot of wheat. *Curr. Res.* **9**, 67-69.

Hendrix, F. F. Jr. and Campbell, W. A. 1973. *Pythium* as plant pathogens. *Ann. Rev. Phytopathol.* **11**, 77 - 98.

Hens, Y. 1984. Interactions between Sclerotium rolfsü and *Trichoderma* spp. : Relationship between antagonism and disease control. *Soil. Biol. Biochem.* **16**, 391 - 395.

Hill, S., 1992. Physiology of nitrogen fixation in free living heterotrophs. In : *Biological Nitrogen Fixation* (Stacey , G; Burris, H. Robert and Evans, J. Harold. eds.), Chapman and Hall, New York, pp. 87 - 134.

Hiltner, L. 1904. *Arb. Dent. Landwirsch Ges.* **98**, 59-78. Quoted from Rovira, A. D., 1965.

Horsfall, J. G. and Cowling, E. B. 1978. Pathometry : The measurement of plant disease. *In : Plant Disease* (Horsfall, J. G. and Cowling, E. B. eds.), A. P., New York, pp. 119 - 136.

Huber, D. M. and Watson, R. D. 1970. Effect of organic amendment on soil-borne plant pathogens. *Phytopathol.* **60**, 22-26.

Hussain, A. and Vancura, V. 1970. Formation of biologically active substances by rhizosphere bacteria and their effect on plant growth. *Folia Microbiol.* **11**, 468 - 478.

Hutchings, I. J. and Martin, T. L. 1934. Influence of the carbon-nitrogen ratio of organic matter on rate of decomposition in the soil *J. Am. Soc. Agron.* **26**, 333 - 341.

Jackson, M. L. 1973. Soil Chemical Analysis. Prentice Hall India Pvt. Ltd. New Delhi. p. 498.

James, W. C. 1974. Assessment of Plant diseases and losses. *Ann. Rev. Phytopathol.* **12**, 27-28.

James, W. C. and Tengh, P. S. 1979. The quantification of production constraints associated with plant disease. In : *Applied Biology. Vol. IV.* (coaker, T. H. ed.). Academic Press. New York. pp. 201-267.

Jensen, H. L. 1930. *Azotobacteriaceae. Bact. Rev.* 189, 195 - 214. Actinomycetes in Danish soil. *Soil Sci.* **30**, 59 - 77.

Jensen, H. L. 1965. Non-symbiotic nitrogen fixation. In : *Soil Nitrogen* No. 10, Series of Agronomy (Bartholomew, W. V. and Clark, F. E. eds.). *Am. Soc. Agron.* Inc. Publisher, Madison pp. 436 - 474.

Jothimani, S.; Sushma, P. K., Jore, A. I. and Allirani, G. 1977. Evolution of carbon dioxide on decomposition of coirpith in oxisols. *J. Indian Soc. Soil Sci.* **45**, 746-750.

Katznelson, H. 1965. Nature and importance of the rhizosphere. In. *Ecology of Soil-borne Plant Pathogens* Prelude to Biological control. (Baker, K. F. and Snyder, W. C. eds.) Univ. Calif. Press, Barkley. pp. 187 - 209.

Katznetson, H. 1946. The rhizosphere effects of mongels on certain groups of soil microorganisms. *Soil. Sci.* **62**, 343 - 354.

Kavimandan, S. K. and Gaur, A. C. 1971. Effect of seed inoculation with *Pseudomonas* sp. on phosphate uptake and yield of maize. *Curr. Sci.* **40**, 439-440.

Khandkar, U. R. and Nigam, K. B. 1996. Effect of farmyard manure and fertility level on growth and yield of ginger (*Zingiber officinale*). *Indian J. Agri. Sci.* **66**, 549 - 550.

*Kim, C. H., Yang, S. S., Hahn, K. D., C. H., Yang, S. S. and Hahn, K. D. 1997, Ecology of ginger rhizome rot development caused by *Pythium myriotylum*. *Korean J. Pl. Path.* **13**, 184 - 190.

*Kim, C. H., Yang, S. S., Park. K. S., Kim, C. H., Yang, S. S and Park, K. S. 1997. Pathogenicity and mycological characteristics of *Pythium myriotylum* causing rhizome rot of ginger. *Korean J. Pl. Pathol.* **13**, 152 - 159.

Kloepper, J. W., Schroth, M. N. and Miller , T. D. 1980. Effects of rhizosphere colonization by plant growth-promoting rhizobacteria on potato plant development and yield. *Phytopathol.*

*Konde, B. K., Patil, R. B. and Raikur, S. K. 1990. Mineral uptake by ginger as influenced by N-levels and inoculation with diazotrophic cultures. In : *Procedings of the International Congress of Plant Physiology.* New Delhi. *Soc. Pl. Physiol. Biochem.* **2**, 1084-1089.

Korla, B. N., Rattan, R. S. and Dahroo, N. P. 1990. Effect of mulches on rhizome growth and yield of ginger. *South Indian Horti.* **38**, 163-164.

Kumar, A. and Ramkrishnan, P. S. 1989. Ecological implications of some cash crop ecosystems in north-eastern India. In : *Proceeding of the Indian Academy of Sciences, Pl. Sci.* **99**, 211-221.

Kumar, Raj and Pandey, J. c. 1989. Chemical control of rhizome rot of ginger by seed and soil treatments. *Progressive Horticulture.* **21**, 130-133.

Kumer, Suresh D. and Prabhakar, Y. S. 1990. A survey of cardioactive drug formulation from Ayurvela, single drug remedies. *Aryavidya.* **4**, 105-108.

Kundu, B. S and Gaur, A. C. 1982. Yield increase of wheat after inoculation with *A. chrooccocum* and phosphobacteria. *Curr. Sci.* **51**, 291 - 293.

Kundu, B. S. and Gaur, A. C. 1980. Effect of nitrogen-fixing and phosphate solublizing microorganisms as single and composite inoculants on cotton. *Indian J. Micobiol.* **20**, 225 - 229.

Kundu, B. S. and Gaur, A. C. 1980. Establishment of nitrogen-fixing and phosphate-solubilizing bacteria in rhizosphere and their effect on yield and nutrient uptake of wheat crop. *Pl. Soil.* **57**, 223 - 230.

Kundu, B. S. and Gaur, A. C. 1981. Effect of single and composite culture on rock phosphate solubilization. *Haryana Agric. Univ. J. Res.* **11**, 559 - 562.

Lakshmi Kumari, M., Vijaylakshmi, K. and Subba Rao, N. S. 1975. Interaction between *Azotobacter* sp. and fungi. 1. *In vitro* studies with *Fusarium moniliforme* Sheld. *Phytopathol.* **75**, 27-30.

Lakshminarayanan, K., Narula, N., Nijhawan, D. C. and Kapoor, R. L. 1987 Effect of *Azotobacter chroococcum* inoculation on pearl millet. *Millet Newslett.* p. 18.

Lang, D. S. and Kommedahl, T. 1976. Factors affecting efficacy of *Bacillus subtilis* and other bacteria as corn seed treatments. *Proc. Am. Phytopathol. Soc.* **3**, 272.

LaRue, T. A. 1976. The Bacteria. In : *A Treatise on Dinitrogen Fixation, Section III, Biology* (Hardy, R. W. F. and Silver, W. S. eds.). Wiley Inc. Pub. N. York. pp 19 - 62.

Lima, D. M. M. and Escobar, C. A. M. 1990. In-vitro inhibition of germination and growth of *Fusarium equiseti* by *Bacillus subtilis. Boletin Micologies.* **5**, 13 - 16.

Lindow, S. E. 1983. Estimating disease severity of single plants. *Phytopathol.* **73**, 1576 - 1591.

Lynch, J. M. 1983. Microbiological factors in crop productivity. In : *Soil Biotechnology* : Black well Scientific Publications, Oxford.

*Manicom, B. Q. 1998. This ginger disease is a threat to the industry. *Neltropika Bulle.* No - 299.

Martin, J. P. 1950. Use of acid, rose bengal and streptomycin in the plate method for estimating soil fungi. *Soil. Sci.* **69**, 215 - 232.

Mayee, C. D. and Datar, V. V. 1986. Measuring diseases by visual observations. In : *Phyto pathometry, Technical Bulletin - 1* (*Special Bulletin - 3*) pp. 16 - 23.

Menkina, R. A. 1963. Bacterial fertilizers and their importance for agricultural plants. *Mikrobiologiya.* **32**, 352-358.

Merriman, P. R., Price, R. D., Kollmorgen J. E., Piggott, T. and Ridge, E. H. 1974. Effect of seed inoculation with *Bacillus subtilis* and *Streptomyces griseus* on growth of cereals and carrots. *Aust. J. Agric. Res.* **25**, 219-226.

Meshram, S. U. 1984. Suppressive effect of *Azotobacter chroococcum* on *Rhizoctonia solani* infestation of potatoes. *Neth. J. Pl. Pathol.* **90**, 127 - 132.

Meshram, S. U. and Jagar, G. 1983. Antagonism of *Azotobacter chroococcum* isolates to *Rhizoctonia salani. Neth. J. Pl. Pathol.* **89**, 199-97.

Meshram, S. U. and Shende, S. T. 1982, Response of maize to *Azotobacter chroococcum. Pl. Soil.* **69**, 265 - 273.

Mishustin, E. N. and Naumova, A. N. 1962. Bacterial fertilizers, their effectiveness and mode of action. *Mikrobioligiya.* **31**, 543 - 555.

Mishustin, E. N. and Shilnikova, V. K. 1971. In : *Biological Fixation of Atmospheric Nitrogen.* London.

Mishustin, E. N., Naumova, A. N., Khokhlova, Yu. M., Oyshtoper, S. N. and Smirnova, G. A. 1969. Antifungal antibiotics produced by *Azotobacter chroococcum. Mikrobiologiya.* **38**, 87 - 90.

Mohanthy, D. C. 1977. Studies on the effect of different nulch material on the performances of ginger in hills of Pottangi. *Orissa J. Hort.* **5**, 11-17.

Mohanthy, D. C. and Sarma, Y. N. 1978. Performances of ginger in tribal areas of Orissa, India, as influences by method of planting, seed treatment and manuring and mulching. *J. Plantation Crops.* **6**, 14-16.

Mukherjee, D. and Gaur, A. C. 1980. A study on the influence of straw incorporation on soil organic matter maintenance, Nutrient release and asymbiotic nitrogen fixation. *Zbl. Bakt. II. Abt.* **135**, 663-668.

Mukherjee, D. and Gaur, A. C. 1984. Effect of incorporation of organic materials on some soil properties and yield of paddy. *Indian Agric.* **28**, 215 - 219.

Mukherjee, D. and Gaur, A. C. 1985. Recycling of organic matter entailling some physico-chemical and microbiological properties of soil in relation to yield of wheat. *Indian Agric.* **29**, 93 - 99.

Mukherjee, D., Ghosh, S. K. and Das, A. C. 1990. A study on the chemical and microbiological changes during the decomposition of straw in soil. *Indian Agric.* **34**, 1-10.

Mulder, E. G. and Brotonegro, S. 1974. Free-living heterotrophic nitrogen-fixing bacteria. In : *The Biology of Nitrogen Fixation* (Quispel, A. ed.). North-Holland Pub. Co. Oxford pp. 48 - 49.

Narsian, V., Thakkar, J. and Patel, H. H. 1995. Mineral phosphate solubilization by *Aspergillus aculeatus*. *Indian J. Expt. Biol.* **33**, 91-93.

Nitta, T. 1990. The stimulation of root activity and a reduction in root diseases of upland crops through improvement in the rhizosphere microflora. *Res. J. Food Agril.* **13**, 15 - 20.

Ocampo, J. A., Barea, J. M. and Monotoya, E. 1975. Interactions between *Azotobacter* and phosphobacterin and their establishment in the rhizosphere affected by the soil fertility. *Can. J. Microbiol.* **21**, 1160 -1165.

Papavizas, G. 1967. Modified PCNB medium for isolation of *Pythium* from soil. *Photopthol.* **57**, 848-852.

Papavizas, G. C. and Lumsden, R. D. 1980. Biological control of soilborne fungal propagules. *Ann. Rev. Phytopathol.* **18**, 389 - 413.

Mukherjee, D. and Gaur, A. C. 1984. Effect of incorporation of organic materials on some soil properties and yield of paddy. *Indian Agric.* **28**, 215 - 219.

Mukherjee, D. and Gaur, A. C. 1985. Recycling of organic matter entailling some physico-chemical and microbiological properties of soil in relation to yield of wheat. *Indian Agric.* **29**, 93 - 99.

Mukherjee, D., Ghosh, S. K. and Das, A. C. 1990. A study on the chemical and microbiological changes during the decomposition of straw in soil. *Indian Agric.* **34**, 1-10.

Mulder, E. G. and Brotonegro, S. 1974. Free-living heterotrophic nitrogen-fixing bacteria. In : *The Biology of Nitrogen Fixation* (Quispel, A. ed.). North-Holland Pub. Co. Oxford pp. 48 - 49.

Narsian, V., Thakkar, J. and Patel, H. H. 1995. Mineral phosphate solubilization by *Aspergillus aculeatus*. *Indian J. Expt. Biol.* **33**, 91-93.

Nitta, T. 1990. The stimulation of root activity and a reduction in root diseases of upland crops through improvement in the rhizosphere microflora. *Res. J. Food Agril.* **13**, 15 - 20.

Ocampo, J. A., Barea, J. M. and Monotoya, E. 1975. Interactions between *Azotobacter* and phosphobacterin and their establishment in the rhizosphere affected by the soil fertility. *Can. J. Microbiol.* **21**, 1160 -1165.

Papavizas, G. 1967. Modified PCNB medium for isolation of *Pythium* from soil. *Photopthol.* 57, 848-852.

Papavizas, G. C. and Lumsden, R. D. 1980. Biological control of soilborne fungal propagules. *Ann. Rev. Phytopathol.* **18**, 389 - 413.

Patel, J. J. and Brown, M. E. 1969. Interactions of *Azotobacter* with rhizosphere and root-surface microflora. *Pl. Soil.* **31**, 273-81.

Patil, M. N, Zade, K. B., Naphade, K. T. and Kharkar, P. T. 1993. Decomposition of organic materials in soil in relation to nutrient mineralization. *J. Maharashtra Agri. Univ.* **18**, 348 - 351.

*Pavlovich, D. Ya. 1959. Inter-relations of *Azotobacter* with other groups of soil microorganisms. Trudy Inst. Mikrobiol. Acad. Nank. Latv. SSR. 8, 127 - 143.

Peter, K. V. 1998. Research Highlights 1997-98, (Zachariah. J. and Eapen, J., Santosh, eds.) published by Directrate of Research, Indian Institute of Spices Research, Calicut, Kerala, India. pp. 5 - 8.

Peter, K. V. 1999. Spices, makings of a global leader. In : The Hindu Survey of Indian Agriculture. (Ravi, N. ed). The Hindu group, Pub. Chennai, pp. 81 - 84.

Pikovskaia, R. I. 1949. Solubilisation of phosphate in soil in connection with the vital activities of some microbial species. Mikrobiologiya. **17**, 362 - 370.

Podile, A. R. and Dube, H. C. 1985. Effect of *Bacillus subtilis* on the growth of vascular wilt fungi. *Curr. Sci.* **54**,1282 - 1283.

Pokorna-Kozova, J. 1970. Cellulose decomposition in the presence of differential manuring. *Zbl. Bakt. Abt.* II, **125**, 471-477.

Power, H. K. and Patil, B. R. 1987. Effects of application of NPK through FYM and fertilizers and time of harvesting on yield of ginger. *J. Maharastra Agri Univ.* **12**, 350-354.

Pramer, D. and Schmidt, E. L. 1965. *Experimental Soil Microbiology.* Burgess publishing Company, Minnesota.

Purthy, J. S. 1993. Ginger. In : *Major Spices of India : Crop Mangement. Post Harvest Technology*. ICAR.

Raheja, S. K., Prajad, R. and Jain, H. C. 1971. Long term fertilizer studies in crop production *Proc. Int. Symp. Soil Fertility Evaluation.* **1**, 881.

Rajan, K. M. and Singh, R. N. 1971. Effet of organic ammendments of soil on plant growth, yield and incidence of soft-rot of ginger. *J. Plantation Crops.* **1**, 119-123.

Ramchandan, N., Dake, G. N. and Sharma, Y. R. 1989. Effect of systemic fungicides as *in-vitro* growth of *Pythium,* the rhizome rot of ginger. *Indian Phytopathol.* **42**, 463-465.

Rana, K. S. and Arya, P. S. 1991. Rhizome rot and yellow disease of ginger in Himachal Pradesh. *Indian J. Mycol. Pl. Pathol.* **21**, 60-62.

Rao R., V. Effect of organic and mineral fertilizers on *Azotobacter* in flooded rice field. *Curr. Sci.* **47**, 118-119.

Rao, V. R., Jana, P. K. and Adhya, T. K. 1987. Inoculation of rice with nitrogen fixing bacteria - problems and perspectives. *Biol. Fertil. Soils.* **4**, 21-26.

Ray, S. K. and Mukherjee, N. 1997. Studies on in vitro antagonism of some bacterial isolates against *Sclerotium rolfsii* Sacc. causing foot rot of groundnut and sugarbeet. *J. Mycopathol. Res.* **35**, 99 - 105.

Rovira, A. D. 1965. Interaction between plant roots and soil microorganisms. *Am. Rev. Microbiol.* **19**, 241 - 266.

Rovira, A. D. 1969. Plant root exudates, *Bot. Rev.* **35**, 17 - 34.

Roy, A. R. and Wamanan, P. P. 1988. Influence of mulch on growth and yield of ginger. *Enviorn. Ecol.* **6**, 630-632.

Sadanandan, A. K. and Iyer, R. 1986. Effect of organic ammendment on rhizome rot of ginger. *Indian cocoa, Arecanut and spices J.* 9, 94-95.

Sadanandan, A. K. and Iyer, R. 1986. Effect of organic ammendments in rhizoms rot of ginger. *Indian Cocoa Arecanut and Spices J.* 9, 94-95.

Sadanandan, N. and Sasidharan, V. K. 1979. A note on the performances of ginger under graded doses of nitrogen. *Agri. Res. J. Kerala.* **17**, 103-104.

Saha, A. K. 1989. Response of ginger to manure and different source of N and P under terrace conditions of mid-altitude Mizoram. *South Indian Horti.* **37**, 1, 64-65.

Sakthivel, N., Sivamani, E., Unnamalai and G. Nickam 1986. Plant Growth-Promoting rhizobacteria in enhancing plant growth and suppressing plant pathogens. *Curr. Sci.* **55**, 22 - 26.

Saxena, A. K. and Tilak, K. V. B. R. 1994. Interaction among beneficial soil microorganisms. *Indian J. Microbiol.* **14**, 91 - 106.

Schaad, N. W. 1980. Key to the commonly isolated genera of plant pathogenic bacteria. Quoted from Martyn, R. D. and Stack, J. P. Biological Control of Plant Pathogens by antagonistic fungi. In : *Laboratory Exercise in Plant Pathology,* Aps Press.

Schippers, B., Bakker, A. W. and Bakker, P. A. H. M. 1987. Interactions of deleterious and beneficial rhizosphere microorganisms and the effect of cropping practices. *Ann. Rev. Phytopathol.* **25**, 339 - 358.

Schlegel, H. G. and Jannasch, H. W. 1967. Enrichment cultures. *Ann. Rev. Microbiol.* **21**, 49.

Seem. R. C. 1984. Disease incidence and severity relations *Ann. Rev. Phytopathol.* **22**, 133 - 150.

Sharma, K. L., Bajaj, J. C., Das, S. K. and Rao, U. M. B. 1992. Nutrient transformation in soil due to addition of organic manure and growing crops. 1. Nitrogen. Fertil. res. Dordrecht : kluwer Academic publishers. **32**, 303 - 311.

Sharma, N. D. and Jain, A. C. 1977. A check-list and selected bibliography of ginger disease of the world. *PANS,* **23**, pp. 474-481.

Sharma, N. D. and Jain, A. C. 1979. Studies on the biological control of *Fusarium oxysporum* f. sp. *Zingiberi,* the causal organism of yellow disease of ginger. *Indian Phytopathol.* **31**, 260 - 261.

Sharma, N. D. and Joshi, L. K. 1975. Studies on rhizosphere mycoflora of ginger. (*Zingiber officinale* Rosc.). *Curr. Sci.* **44**, 525 - 526.

Sharma, S. K. and Dohroo, N. P. 1990. Occurance and distribution of fungi causing of yellows in H. P. *Pl. Dis. Res.* **5**, 200-202.

Sharma, S., Dohroo, N. P. and Korla B. N. 1997. Effects of VAM inoculation and other field practices on growth parameters of ginger. *J. Hill Res.* **10**, 74 - 76.

Shende, S. T., Apte, R. G. and Singh, T. 1977. Influence of *Azotobacter* on germination of rice and cotton seeds. *Curr. Sci.,* **46**, 675.

Shende, S. T., Arora, C. K. and Sen, A. 1973. Interaction between *Azotobacter Chroococcum, Bacillus megatherium* var. Phosphaticum and *Rhizobium* sp. *Zbl. Bakt. Abt.* 11Bd. 128, 668 - 677.

Shinkina, A. P. 1961. Effect of organo-mineral and bacterial fertilizers on yield, utilization and quality of potato tubers. IZV. Akad. Nauk. Kazaks. SSR. *Ser. Bot. Podyobed.* **1**, 13 - 14.

Singh, P., Vasudeva, R. S. and Bajaj, B. S. 1965. Seed bacterization and biological activity of bulbiformin. *Ann. Appl. Biol.* **55**, 89 - 97.

Singh, T. 1977. Studies on interaction between *Azotobacter chroococcum* and some plant pathogens. IARI Ph. D. thesis, New Delhi.

Sinkha, M. K. 1970. Effect of composting soil with straw on mobility and uptake by plants of difficulty soluble soils phosphates. IZV. timiryazev. Sel. - Khoz. Akad. **6**, 222-225.

Skerman, V. B. D. 1967. Guide to the Identification of the Genera of Bacteria. 2nd Edn. Williams and Wilkins. Baltimore.

Smith, F. B., Brown, P. E. and Millar, R. C. 1935. Rhythmical nature of microbiological activity in soil as indicated by the evolution of carbondioxide. *J. Amer. Soc. Agron.* **27**, 104.

Smith, J. H. and Douglas, C. L. 1970. Influence of silica and nitrogen content and straw application on decomposition of grains wheat straw in soil. *Soil. Sci.* **109**, 341-344.

Srivastava, S. 1994. Management of soft rot of ginger in Sikkim. *Pl. Dis. Res.* **9**, 146 - 149.

Subba Rao, N. S. 1981. *Azotobacter* inoculant. In : *Biofertilizers in Agriculture.* Oxford & IBH Pub. Co. Pvt. Ltd., New Delhi. pp. 77-110.

Subramanian, S. and Gopalswamy, A. 1911. Effect of moisture, organic matter, phosphate and silicate on avialability of silicon and phosphorus in rice soils. *J. Indian Soc. Soil Sci.*, **39**, 99-103.

*Sugito, Y. and Maftuchah, 1995. Influence of rates of farmyard manure and KCl on growth, yield and quality of young ginger (*Zingiber officinale* Rosc.) rhizomes. *Agrivita.* **18**, 67 - 73.

Sundara, Rao. W. V. B., Mann, H. S., Paul, N. B. and Mathur, S. P. 1962. Bacterial inoculation experiments with special reference to *Azotobacter. Indian J. Agric. Sci.* **33**, 279-289.

Sundaram, B. M. and Rao, G. R. 1980. An antimicrobial antibiotics from a species of *Bacillus. Curr. Sci.* **49**; 242.

Thakore, B. B. L., Snch, Mathur., Singh, R. B. and Chakraborthy, B. P. 1987. Soil amendment with oil cakes in ginger field of rhizome rot control. *Korean J. Pl. Protec.* **26**, 267-268.

Thomas, K. G. and Velappan, E. 1988. Prospect for production of ginger, tumeric chillics. In: *proceedings of the National Seminar on Chillies, Ginger and Turmeric.* Speces Board. Ministry of commerce, Govt. of India and Andra Pradesh Agricultural University, Rajendranagar. Hyderabad pp. 210.

Thornton, H. G. 1922. On the development of standardised agar medium for counting soil bacteria with special regard to the repression of spreading colonies. *Ann. Appl. Biol.* **9**, 241 - 274.

Tilak, K. V. B. R. 1998. Azotobacter inoculants. In : *Bacterial Fertilizers.* Publications and Information Division, ICAR, New Delhi. pp. 34-39.

Tilak, K. V. B. R., Singh, C. S., and Subba Rao, N. S. 1982. *Azospirillum* and *Azotobacter* inoculation. Effect on yield of maize and sorghum. *Soil Biol. Biochem.* **14**, 417 - 418.

Tisdale, S. L. and Nelson, W. L. 1985. In : *Soil Fertility and Fertilizers, 4th edn.* The Macmillan Co., Ltd., New York.

Tousoun, T. A., Nash, M. S. and Synder, C. W. 1960. The effect of nitrogen sources and glucose on the pathogenesis of *Fusarium solani F. phaseoli. Phytopathol.* **50**, 137-140.

*Toyata, K. and Kimura, M. 1992. Population dynamics of *Fusarium oxysporum* f. sp. *raphani* in soils of different fungistatic capacity. *F. E. M. S. Microbiol. Lett.* Fed. Eur. Microbiol. Soc. **102**, 15 - 20.

Tsao, P. H. and Ocana, K. 1970. Selective media for isolation of pathogenic fungi. *Ann. Rev. Phytopathol.* **8**, 157-186.

Varier, P. S. 1988. Ginger and its ayurvedic uses. *Species News Letter.* March, 1988. 13.

Varma, S. and Mathur, R. S. 1989. Biocoenotic association between nitrogen-fixing and phosphate solubilizing microorganisms. *Curr. Sci.* **38**, 1099 - 1100.

Vasantharjan, V. N. and Bhat, J. V. 1967. Interrelations of soils microorganisms and mulberry. I. Phytohormone production by soil and rhizosphere bacteria and their effect on plant growth. *Pl. Soil.* **27**, 261-272.

Velapan, E. 1994. An integrated programme for spices development in India during VIII five year plan (1992-93 to 1996-97). *Indian Cocoa, Arecanut and spices J.* **18**, 1-4.

Venkatesan, R. 1962. Studies on the actinomycetes of paddy soil. Ph. D. thesis. Annamalai Univ., Annamalai nagar.

Wilai, N. 1989. Effect of volatile substances from decomposition of organic amendments on *Pythium aphanidermatum* (Edson) fitzp. Bangkok (Thiland). 147 leaves.

*Wiroatmodojo, J., Sulistyono, E. and Hendrinova, 1990. The influence of organic and foliar fertilizers on the growth and production of rhizome of ginger (*Zingiber officinale* Rosc.) *Buletin - Agron.* Indonesia. **19**, 33 - 38.

Yang, X., Werner, W., Scherer, H. W. and Sun, X. 1994. Effect of organic manure on solubility and mobility of different phosphate fertilizers in two paddy soils. *Ferti. Res.* **38**, 233 - 238.

---

* Original not seen.