STUDIES ON EFFICIENT USE OF NITROGEN IN PADDY (*Oryza Sativa* L.) CROP GROWN ON VERTISOLS

THESIS

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By

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1982

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Dedicated
to my Father
LATE SHRI GANPATISHANKAR HARISHANKAR DIKSHIT
(1900 - 1965)

CERTIFICATE-I

This is to certify that the thesis entitled "STUDIES ON EFFICIENT USE OF NITROGEN IN PADDY (ORYZA SATIVA L.) CROP GROWN ON VERTISOLS", submitted in partial fulfilment of the requirements for the degree of "Doctor of Philosophy in Agriculture" of the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, is a record of the bona fide research work carried out by Shri RAMESH CHANDRA GANPATI SHANKAR DIKSHIT under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions.

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

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CERTIFICATE-II

This is to certify that the thesis entitled "STUDIES ON EFFICIENT USE OF NITROGEN IN PADDY (ORYZA SATIVA L.) CROP GROWN ON VERTISOLS" submitted by Shri RAMESH CHANDRA GANPATI SHANKAR DIKSHIT to the J.N. Krishi Vishwa Vidyalaya, Jabalpur in partial fulfilment of the requirements for the degree of Ph.D. in the Department of SOIL SCIENCE AND AGRICULTURAL CHEMISTRY has been approved by the Student's Advisory Committee and External Examiner after an oral examination on the same.

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CHAPTER-I

INTRODUCTION

Nitrogen is an element which is of greatest importance for agriculture in India. The average content of N by volume in earth's atmosphere at sea level is 78.08% (as quoted by Uverov et al., 1971). Out of approximate total atmospheric pressure of 14.72 lbs/sq. inch, 75% by weight i.e. a total pressure of nitrogen alone on each acre of the earth's surface has been calculated to be about 35,000 tonnes (Stevenson, 1965), yet not even a few milli litres of this atmospheric nitrogen can be used directly by plants, as they are incapable of using elemental nitrogen.

It is a general observation that the nitrogenous fertilizers applied to paddy soil are used less efficiently as compared to any other major crop. The reason ascribed for this lower efficiency of nitrogenous fertilizers are that the nitrate forms are lost by leaching and run-off, ammonical nitrogen is lost through volatilization and simultaneous nitrification denitrification reactions in the rhizosphere or after alternate drying and wetting of soils. It is also inefficient in use of soil nitrogen for some of the same reasons, hence not only the efficiency of applied and native soil nitrogen source is required to be increased, but also emphasis has to be placed on greater utilization of atmospheric nitrogen through its biological fixation, as lowering the cost of nitrogen is one of the requirements for the well being of small farmers in India. Availability of sufficient nitrogen along with the efficient water management is the key to successful growth of high yielding paddy varieties.

The energy crisis of late 1960's and early 1970's compelled the scientist to find out cheaper sources of nitrogen and also to find out ways and means to increase the efficiency of applied and native soil nitrogen. In this process, one of the steps was to adopt a strategy of integrated nutrient supply system by a judicious combination of chemical fertilizer, organic manures and biofertilizers.

Mishustin (1970) reported that there exist 100 varieties of non-symbiotic nitrogen fixing micro-organisms. It is claimed that a number of free living bacteria inhabiting the soil fix atmospheric nitrogen in the range of 50 to 100 kg N/ha/year.

Many scientists have studied the effect of fertilizers, manures and submergence on the fixation of nitrogen by free living bacteria.

Rangaswami (1966) observed that some fertilizers, however, have inhibitory effect on specific bacterial types. Addition of nitrates inhibited the activity of free living nitrogen fixing bacteria like Azotobacter.

Singh and Ram (1974) found that ammonium sulphate, ammonium chloride, ammonium nitrate and potassium nitrate in various concentrations stimulated the growth of Clostridium pasteurianum and ammonia and nitrate nitrogen induced better growth of Clostridium pasteurianum than amide nitrogen of urea. With urea better growth was observed at higher concentrations. All forms of nitrogen caused rapid growth during first few days and decline thereafter.

While Yoshida et al. (1973) observed nearly complete inhibition of nitrogenase activity with 160 μg/g of applied inorganic nitrogen in rice soil. Mac Rae (1975) found that application of NH_4-N at 50 ppm and higher concentrations inhibited N_2 fixation in the rice rhizosphere. A similar inhibition was reported when inorganic N was applied as NO_3-N.

The combination of organic manures and fertilizers has been reported to yield better results than addition of one of them to the virtual exclusion of the other. Patnaik (1965) observed that addition of fertilizers accelerated the mineralisation of soil organic N. Rangaswami and Venkatesan (1966) reported that application of FYM and phosphatic fertilizers increased bacterial and actinomycete population in the rice soil.

The role of heterotrophic non-symbiotic N_2 fixing micro-organisms living in the root zone of lowland rice in adding nitrogen to paddy soil has been studied by various workers (Dommergues et al., 1973; Yoshida and Ancajas, 1973). Wills and Green (1948) showed that under flooded and planted conditions, nitrogen accumulated was equivalent to or greater than that utilized by crops. Abd. El Malek (1971) reported that Azotobacter and Clostridia were drought resistant but optimum activity of Azotobacter was at about 60% water holding capacity and that of Clostridia at 100%.

Work on metabolite relationship between Clostridium and Azotobacter has been conducted by a number of workers. According to Bear (1965), a good balance between aerobes and anaerobes in the soil was more beneficial than a condition that favours one of these groups of micro-organism to the virtual exclusion of the other. Rubenchik (1963) reported that filtrate of young Azotobacter culture have a stimulatory effect on Clostridium pasteurianum.

Nitrogen fixing activity of bacteria is found to be variable in different soil types. Conflicting views have been expressed regarding the effect of soil type on bacterial activities. Abd. El Malek (1971) working on Azotobacter and Clostridium in Egyptian soils, reported that the amount of N gained and fixation efficiency were greatest in clay followed by sand and calcareous soils, while Jensen (1965) stated that in contrast to Azotobacteraceae the larger group of Clostridium butyricum and related nitrogen fixing species are practically ubiquitous soil inhabitant, whose presence <u>per se</u> thus does not seem to depend much on soil properties.

Work reported in India regarding efficient use of nitrogen in paddy has been mostly fragmentary nature, i.e. it was either related to fate of applied nitrogenous fertilizer or effect of flooding or effect of different amounts, methods and type of fertilizers or effect of slow release fertilizers or effect of organic manures. In regard to nitrogen fixation and other related aspects the bacterium tried in most cases was the Azotobacter species.

In study reported here, an integrated approach has been followed to tackle the problem of efficient use of nitrogen in paddy. Thus, the objectives set were:

(1) To find out the role played by non-symbiotic nitrogen fixing bacterial cultures in economising the use of nitrogenous fertilizers in paddy grown under submerged conditions.

(2) To find out a suitable combination of nitrogenous fertilizer, organic manure and bacterial cultures in paddy grown under submerged condition.

(3) To find out the effect of organic manures (compost) on the efficiency of bacterial cultures.

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CHAPTER-II

REVIEW OF LITERATURE

Paddy farming, the man has ever known, as extensively done in South East Asia, China, Japan, some regions of North America, West Coast of Africa, and Southern Republics of USSR. Researches on soils and fertilizers management in wetland rice have emanated during the last decade, mostly from the international institute, IRRI in Philippines, and the national institute, CRRI in India and some fundamental studies from EMBRAPA Brazil, and CNRS, France, are certainly voluminous, and spread out in symposia, souvenirs, monographs, newsletters and annotated bibliographies, apart from newer journals such as JARQ and Oryza, the gleanings of the literature is done, omitting mostly those older ones, which are already reviewed out by the scientists working on this theme for the last decade.

2.1. FLOODED SOILS AS N_2 FIXATION HABITAT

In flooded soils the changes are so varied and numerous that it is difficult to bring the chemical changes to a single unified system (Yoshida, 1975). The operations involved in the wet cultivation of rice include (1) submergence of the soil with or without puddling, for the duration of the crop, with or without soil drying in midseason, (2) draining and drying the soils before harvest; and (3) reflooding for the next crop a few weeks to several months after harvest.

Superimposed on these are inherent properties of the soil or environment that affect the microbiological regime in rice soils. Aerobic respiration in flooded soil is involved in the decomposition of organic matter, which proceeds shortly after flooding, and continues upto a few days, and an oxidized layer develops on the surface. There develops an anaerobic respiration, aerobes are replaced by facultative anaerobes, and stepwise biochemical and chemical reduction of the soil occurs, a lowering of Eh and a change in pH, shift equilibrium to near neutrality (Ponnamperuma *et al.*, 1965).

Organic matter is fermented under anaerobiosis to butyric acid + acetic acid within 10-14 days after flooding in normal paddy soils, and the first acid tends to increase in high-yielding paddy soils.

2.1.1. The Rhizosphere of Rice in Flooded Soils

The planted field of rice has a biological meaning in terms of the unique nature of aquatic plants, whose root tissues generally possess an intercellular space under excessive moisture regime of the soil that apparently transports air through stomata. Rice plants grown in flooded soil have the singular characteristic of ability to function efficiently in anaerobic conditions. Molecular oxygen is supplied to the roots creating a well oxygenated environment at the rhizoplane, rhizosphere *sensu stricto*, as well as endorhizosphere or histosphere, described in great detail (Domergues and Rinaudo, 1979). The air-transporting system of the rice plant, which consists of the aranchyma and the lysigenous intercellular space develops to a greater extent under flooded conditions than under upland conditions. Rice roots can oxidize even a portion of the rhizosphere, leading to aerobic oxidation of organic matter (Yoshida, 1975) in the rhizosphere. Consequently nitrogen-fixing activity NFA due to heterotrophic activity, ARA (acetylene reduction activity) is limited not only to anaerobes, but extended to aerobes, and microaerophilic anaerobes and these physiological types of diazotrophs can thrive and complete their assignment to a major or a minor extent. The reductive condition of the rice rhizosphere, at the reproductive phase of the rice plant growth, is enhanced by an increase in organic materials from root exudates or dead cells of root hairs (Dommergues and Rinaudo, 1979). Nitrogen fixation in paddy soils is much higher in fields in which rice is growing than in fallow fields (Wills and Green, 1948; Ponnamperuma, 1972; Yoshida and Ancajas, 1973) and it is higher in flooded soils (Taka <u>et</u> <u>al</u>., 1967; Rao <u>et</u> <u>al</u>., 1973; Purushothaman <u>et</u> <u>al</u>., 1977). Carbohydrates are available as the energy source for the heterotrophic activity in the rhizosphere. The concept of an aerobic-anaerobic interfacial area for active nitrogen fixation at the surface of flooded soil can apparently apply to the rice rhizosphere. The products of anaerobic respiration in flooded soil may diffuse to the aerobic zone near the root surface where aerobic N_2 fixing bacteria may fix more N_2 with a given amount of energy material than anaerobic N_2 fixing bacteria. Considering the supply of molecular nitrogen in the transported air, in large area of aerobic-anaerobic interface, nitrogen fixation by bacteria in the rice rhizosphere is perhaps biochemically and agronomically important (Yoshida, 1975).

2.2. HIGH N RESPONSIVE PADDY VARIETIES AND THEIR N REQUIREMENT

High N responsive paddy varieties were evolved in early sixties, and ever since the establishment of IRRI major varieties have now been adopted in Asia, particularly in India. CRRI breeders gave the rice farmers those varieties which responded to high N fertilization, and which became adopted varieties of choice by the farmers, a big goal in green revolution achieved. However, nitrogen along with water management is the key to the realization of the yield potential of modern rice varieties. In the absence of nitrogen inputs, modern varieties yield little more than their traditional counterparts (Murayama, 1979). The problem is to raise the N utilisation rate of the rice plant and to increase efficiency of absorbed N for grain production, irrespective of the amount of N supplied. The split application of fertilizer N is thus advocated.

2.2.1. Response to Fertilizer N in Yield and Yield Components

Response to fertilizer N at increasing levels from 0-200 kg N ha^{-1} is reported in India by Rao (1977); in the range 0-160 kg N ha^{-1} by Gowda and Panikar (1977) wherein the response to N was linear, and productive tillers and 1000 grain weight contributed 89.5-86.4% of the yields; by Singh and Modgal (1979) in the range of 30-120 kg N ha^{-1}, wherein dry matter accumulation and uptake of N increased with increasing levels of applied N at tillering and panicle initiation stages, and the crop removed on an average 61 kg N ha^{-1}; by Singh and Paliwal (1980) in the range of 0-180 kg N ha^{-1} wherein each incremental applied N level increased the yields; and by Dixit and Singh (1980) in the range of 30-90 kg N ha^{-1} in three different dates. The response is reported to be curvilinear, not resulting in any increase beyond 90 kg N ha^{-1} by Pathak <u>et</u> <u>al</u>. (1980); working in the range of 0-120 kg N ha^{-1}, by Mahapatra and Sharma (1972) in the range of 0-200 kg N ha^{-1} wherein grain yield per earhead, panicle density and earlength was linear with successive increase in levels upto the highest level, but the yield increased only upto the 150 kg N ha^{-1} level; by Panda and Leeuwrik (1972) in the range of 0-200 kg N ha^{-1}, wherein the number of effective tillers increased with each incremental level upto the highest level, but the yield increased only upto the 100 kg N ha^{-1} level; by Singh et al. (1975) in the range of 0-220 kg N ha^{-1}, wherein the yield increased upto the 150 kg N ha^{-1} level; and by Mahatam Singh et al. (1979) in the range of 0-200 kg N ha^{-1} for drilled rice where the plant height, number of productive tillers, length of panicle, fertile spikelet, and grain weight per panicle increased upto 200 kg N ha^{-1}, but the grain and straw yields increased upto 160 kg N ha^{-1} level, and the grain and straw N including P and K increased progressively upto the highest.

2.2.2. Split Application of N

Split applications of fertiliser N as basal, at tillering and at panicle formation stages was reported by Mehrotra and Singh (1982) to be the best for dry matter production. In a recent experiment carried out by Sharma and Prasad (1982) for two years showed that each successive increment in N levels from 60 and 120 kg ha^{-1} caused an increase in number of grain per panicle and 1000 grain weight, and similarly an increase in the grain yield as well.

In four-year trial of fertiliser N levels from 0-200 kg N ha^{-1}, Shiga and Sokiya (1976) found that N uptake increased from 50 to 180 kg ha^{-1}, and the highest rate of uptake occurred between panicle initiation and flag leaf stage. A better return (Patnaik and Rao, 1979) was obtained from a given amount of N when it was applied in suitable amounts to synchronize with the stages of vigorous absorption and efficient N assimilation for grain production, than when it was entirely applied at puddling. Ponnamperuma (1964) finds that soils well supplied with organic matter need no N application, soils with a moderate organic matter content need basal application but may need topdressing at the panicle formation stage, and soils low in organic matter may require both basal application and topdressing.

2.3. NITROGEN NUTRITION OF PADDY

The role in rice production of N from the soil, organic and green manures and chemical fertilizers had been investigated. NH_4-N is the dominant mineral form in flooded soils (Patnaik and Rao, 1979). Air drying of soil before flooding, high temperature, puddling and application of lime and extraneous inorganic N stimulate mineralization of soil N. Even when it receives moderate amounts of chemical N, the soil contributes 65-75% of the N used by the crop (Patnaik and Rao, 1979).

2.3.1. Sources of Fertilizer N and their Efficiency

The efficiency of ammonium and nitrate forms of N, although equal in water culture, is comparably superior in the first form, as concluded from summarized results of field experiments in India (Abhichandani and Patnaik, 1958), and also reported in other countries. Among the ammonium containing fertilizers and ammonium forming fertilizers (urea) the mobility of ammonium fertilisers is relatively low, whereas urea being nonpolar and water soluble runs the risk of being lost in the flowing waters (Patnaik and Rao, 1979). While Crasswell and Vlek (1982) summarising the work of different workers reported that urea is hydrolysed rapidly in most soils, but in flooded system the urease activity of flood water is much lower than that of the soil, so that broadcast urea may persist largely in urea form in flood water for 4 to 5 days after application. Urea is hydrolysed to ammonia which is adsorbed by clay colloids and is therefore much less mobile. Rice plant can take up urea directly also (Crasswell and Vlek, 1979).

2.3.2. Efficiency of Inorganic and Organic N inputs

The maximum utilization rate of applied N was found around the midlife (Murayama, 1979; Patnaik and Rao, 1979). Summary of results of IRRI and the Philippine farmer field and experimental station trials (Atkinson and Kunkel, 1976) shows that N requirements for modern varieties were about 130 kg ha^{-1} for the dry season and 80 kg ha^{-1} for the wet season. N requirement of modern varieties is found to be higher for the dry season than for the wet season (Patnaik, 1970; Russell *et al.*, 1970) optimum N rate for modern varieties was 120 kg ha^{-1} for the dry season and about 70 kg ha^{-1} for the wet season. The native varieties required no N during the wet season and about 40 kg ha^{-1} during the dry season. The efficiency of inorganic N is notoriously low (Crasswell and Vlek, 1979).

As the addition of chemical fertilizers does not diminish the utility of organic fertilizers (Chang, 1975), it has become desirable to conserve organic manures and recycle them into the soil to increase the efficiency of soil nutrients, particularly for maintaining the fertility of paddy soils as shown by Houng (1976) in Taiwan and Japan. Patnaik (1978) considering the pattern of N release in judicious combination of organic and inorganic N, reported that at 40-60 kg N ha^{-1} application, a combination consisting of 50% N as compost applied to the wet soil before or at puddling followed by basal application of another 50% as chemical N gave during the crop growth period a continuous N supply.

2.3.3. Soil N Balance

In order to increase N fertilizer sufficiency in wetland rice and alternative sources of N, basic information from N balance is needed. Nitrogen balance studies are long term, expensive, and time consuming, and have been neglected in favour of immediate type of research on crop productivity particularly in tropical areas (Hauck, 1971). One of the earliest demonstration of a N balance experiment in wetland rice was performed by Wills and Green (1948). They recorded a net gain in the N content especially in the case of the soil-plant-water system occurred during the crop. As is frequently observed on balance work in dryland soils (Allison, 1955, 1966) the quantity of N lost from the system increased as the amount of N increased, data in wetland soils (Watanabe and Cholitkul, 1979) bear this. In Japanese soils there appeared an unexplained excess amount of N to about 15 kg ha^{-1} y^{-1} at Aomori, and 38 kg ha^{-1} y^{-1} at Kagawa, in wetland-dryland situations where no inorganic/organic N was applied. The difference in the net total N content of the rice-soil-water system was statistically significant at IRRI (Koyama and App, 1979). The total soil N values after cropping at IRRI exceeded the values that would be expected if the original soil had been the source of the unaccounted for N.

2.4. BIOLOGICAL N_2 FIXATION IN PADDY SOILS

The fact that N fertility is generally much higher in a wetland rice field than in a dryland field is supported by research data on waterlogged soils of many countries, conducted during the last fifty years. In 1936 De first reported the N gain in paddy soils of Bengal, and the balance sheet of

N in Japanese rice fields drawn at Nagoya University (Yamaguchi, 1979) showed biological fixed at 40 kg ha^{-1}.

Ecologically the biological N_2 fixation is divisible into heterophic and phototrophic. The latter type covers micro-organisms of three classes : photosynthetic bacteria (PSB), cyanobacteria (blue-green algae, BGA), and the fern azollas, all of which are present in the eutrophication of lakes, and are seldom seen in agricultural ecosystem of paddies, except when manipulated. These aspects are well covered in the Nitrogen and Rice (IRRI, 1979) by several workers, and are very recently reviewed by Buresh, Casselman and Patrick (1980) and by Venkataraman (1982).

The heterotrophic N_2 fixers are contributors to a major magnitude in the N economy of wetland paddy soils. Azotobacters (Rouquerol, 1964; Rinaudo, 1974) and clostridia (Bhattacharya, 1958; Sulaiman, 1971; IRRI, 1976) are reported to occur in paddy soils and the second genus is more abundant than the first. Other bacterial sp. like Beijerenckia indica, Methylosmus trichosporum, Bacillus polymixa and Derxia have been reported by different workers to fix N_2 in different ecosystems. The rhizosphere in the region, where heterotrophic N_2 fixing activity is very intense (Yoshida and Ancajas, 1971; Dommergues et al., 1973; Balandreau et al., 1975) and is in all probability associated with the organic exudates from the roots.

2.4.1. Estimates of Biological N_2 Fixation in Paddy Soil Ecosystem

The estimates of biologically fixed N in rice soil ecosystem are done by various methods, mainly in Philippines, Ivory Coast, and USSR, and are tabulated in the following table.

It shows a very wide variation from 5.9 kg ha^{-1} to 490 kg ha^{-1}. Rhizosphere region is better suited for NFA (ARA), than the plow layer or flood water. According to Watanabe and Cholilkul (1979) the N_2 fixation associated with wetland rice is not confined to the rhizosphere. N_2-fixing rates associated with wetland rice seem higher than those associated with dryland plants.

Rhizosphere N_2 fixation has been emphasized by Matsuguchi and Shimomura (1977) and Matsuguchi et al. (1978). Matsuguchi (1979) stated that the soil environemnt rich in decomposable organic matter and available P but poor in combined N, with neutral soil pH and low redox potential must be favourable for heterotrophic N_2 fixation. Matsuguchi (1977) reported enhanced N_2 fixation by rice straw amendment even in the presence of applied nitrogen. Rice straw residues act as the most active N_2-fixing sites in the plow layer, and both rice straw decomposition and the subsequent heterotrophic N_2 fixation proceed not only in the aerobic surface layer but

Nitrogen fixation rates in paddy soils (for different location, workers, systems and methods followed).

Location and worker		System	Estimated rate of N fixation
<u>PHILIPPINES</u>			
Yoshida and Ancajas (1973)	(i)	Planted field, flooded soils, wet season	57 kg N ha^{-1} per 119 days[I]
	(ii)	Unplanted field, flooded soil, wet season	22 kg N ha^{-1} per 119 days[I]
	(iii)	Planted field, flooded soil, dry season	63 kg N ha^{-1} per 119 days[I]
	(iv)	Unplanted field, flooded soil, dry season	28 kg N ha^{-1} per 119 days[I]
Watanabe <u>et</u> <u>al</u>. (1977)		Rice Rhizosphere	0.05 kg N ha^{-1} per day[I]
Watanabe <u>et</u> <u>al</u>. (1978a)	(i)	Planted soil, unfertilized, wet	14 kg N ha^{-1} per 216 day[I]
	(ii)	Planted soil, fertilized, wet	10.8 kg N ha^{-1} per 216 days[I]
Watanabe <u>et</u> <u>al</u>. (1978b)	(i)	Rice Rhizosphere and stem, dry season	50 m.moles/m^{2} per 68 days[I] (5.9 kg N ha^{-1})[a]
	(ii)	Rice Rhizosphere and stem, wet season	90 m.moles/m^{2} per 68 days[I] (8 kg N ha^{-1} per 63 days)[a]
Koyama and App (1979)		Planted field	15.5 kg N ha^{-1} per crop[II]

Location and worker	System	Estimated rate of N fixation
Matsuguchi (1977), reported for:		
(i) Philippines	Flooded	53-77 kg N ha^{-1}[III]
(ii) W. Bengal	Flooded	150-490 kg N ha^{-1}[III]
(iii) Thailand	Flooded	10-54 kg N ha^{-1}[III]
<u>IVORY COAST</u>		
Rinaudo and Balandreau (1971)	(i) Paddy Rhizosphere	2-5 ug N/g soil per day[I]
	(ii) Paddy Rhizosphere	1-3 ug N/g soil per day[IV]
Balandreau <u>et al</u>. (1974)	Planted soil	246.6 u moles/700 cm^2/day[I] (0.32 kg N ha^{-1} per day)[a]
Balandreau <u>et al</u>. (1975)	Planted soil	72 kg N ha^{-1} per year[I]
Balandreau <u>et al</u>. (1974)*	Saturated soil (not water logged)	32 kg N ha^{-1} per 100 days[I]

Location and worker	System	Estimated rate of N fixation
KRASNODAR (USSR)		
Rao *et al*. (1973)	(i) Control variants, not flooded	3.7-10.7 mg N_2 per kg soil per mo^{III}
	(ii) 5-10 t ha^{-1} rice straw, flooded	20-30 mg N_2 per kg soil per mo^{III}
Kalininskaya (1977)	(i) Control	3-9 kg N ha^{-1} per month^{III}
	(ii) 5-10 t ha^{-1} rice straw treated	20-40 kg N ha^{-1} per month^{III}

Note: I - Acetylene reduction method
II - N Balance method
III - With ^{15}N
IV - Kjeldhal's method
(a) - Calculated quantities
* - Reported for Lamto

also in the lower plow layer, although aerobic or microaerophilic conditions of the surface layer, facilitate larger activities of both rice straw decomposition and N_2 fixation.

A novel approach for the determination of the availability of biologically fixed nitrogen to the wetland rice cv IR-26 was made by Ito and Watanabe (1981) through the use of isotopic ^{15}N technique. Mineralization rate for the fixed N was 23.4% and 4.6% for the native soil N after 16 days. Their investigation also showed that rice plants used 34% of the fixed N and 8% of the soil N in 42 days. The fixed N happened to be immobilized as amino acids, and 68% was transported to the rice. These findings were suggestive of the fact that N fixed through heterotrophic N_2 fixers in anaerobic paddy soil was mineralized at a faster rate, and this in turn corraborates the earlier observation of Balandreau _et_ _al_. (1975) that paddy soil appeared to be most efficient nonsymbiotic N_2 fixing ecosystem, as its daily integrated N_2 fixation was of the same order of magnitude as that of a symbiotic system.

2.5. MANIPULATION OF RHIZOSPHERE N_2 FIXATION IN PADDY SOILS

Whereas the genetic manipulation of biological N_2 fixation in rice fields is a thing of future, the manipulation of the environment (Dommergues and Rinaudo, 1979) is possible. Quite well known is the fact that soil organic matter and N content are functions of the environment, agronomic practices, added organic matter, fertilizer N if applied, and concomitant physical properties. The combination of these factors will set an upper limit on the amount of N, that can be fixed or accumulated in the soil by biological N_2 fixation systems (Moore, 1966). Longterm fertility trials in paddy soils (Matsuo and Takahashi, 1977) show conclusively that inorganic N seldom affects the total soil N content. However, the greater the depression of N content below the equilibrium level dictated by various rice cultivars and the environment, the more active the natural system for N_2 fixation. These limitations are to be borne in mind in attempts to develop practices to maximize N fixation in field.

Because the rhizosphere is a component of the whole soil-plant-atmosphere system, the factors affecting soil and atmosphere should affect the activity of the rhizospheric N_2 fixation.

For Clostridium sp. (Bhattacharya, 1958; Ishizawa et al., 1970; Sulaiman, 1971; Matsuguchi et al., 1975; Mishustin and Shlinikova, 1969), the anaerobic bulk of paddy soil (Ponnamperuma, 1972; Burush et al., 1980) is an ideal medium. All the spp. of genus Clostridium are not inhabitants of soil ecosystem but a few (*Cl. butyrium* and *Cl. pasteurianum*) abound in paddy soils (Yamagata, 1924) and also in other agricultural soils in number greater than azotobacters. The anaerobiosis is almost ubiquitous in arable lands whether flooded or not (Knowles, 1977). Azotobacters do occur in rice rhizosphere or in floodwater, where aerobic-anaerobic interface (Rice *et al.*, 1967; Magdoff and Bouldin, 1970) exists; particularly in neutral soils.

The five main physiological features that are assumed to be essential (Dommergues and Rinaudo, 1979) for rhizosphere N_2 fixation are (1) protection against oxygen, (2) competitiveness or ability to colonize rice roots and use the substrates that are available in the different regions of the rhizosphere, (3) N_2-fixing efficiency, (4) ability to fix N_2 in presence of combined N and (5) ability to excrete N_2 fixed as ammonium that can be absorbed directly by the plant. The substrates availability in the rhizosphere is dictated by the exudates, lysates, and litter of roots, and the added organic matter.

Azotobacter benefit from sophisticated protection mechanisms, and a few strains that actively fix N_2 are efficiently protected against inhibition and damage by oxygen (Postgate, 1974; and Yates, 1977).

The addition of NH_4^+-N to soil reduced rhizosphere N_2 fixation but only when the average NH_4^+-N concentration in the bulk rhizosphere soil was at least 40 ppm (Balandreau et al., 1975a). Excretion of ammonium by heterotrophic N_2 fixers for direct absorption by plant roots is only an assumption at present. One elegant experiment using ^{15}N technique done by Ito and Watanabe (1981), has confirmed that heterotrophic N_2 fixers fix N_2 mostly as amino acids, which are mobilized just within 42 days upto 34%, and that 66% of the mobilized N (ammonium) is directly absorbed into the rice plant grown under wetland conditions.

2.5.1. Inoculation with selected rhizosphere microflora

Well expounded principles of microbial ecology - mutualism and synergism (Alexander, 1971) and reported by Lind and Wilson (1942), Fedorov and Kalininspaya (1959); Emtsev (1960); Rubenchik (1963) and Rice and Paul (1972) can be made use of to micromanipulate the rhizoplane-rhizosphere-histosphere activity as regards to exploit the nonsymbiotic system of wetland rice, and to bring it to the level of efficiency of a symbiotic system for which possibilities do exist. As due to reported production of growth-regulators, protection against pathogens, stimulation of rhizosphere micro-organisms, beneficial for the plant, modification of nutrient uptake by plant and enhancement for N_2 fixation.

Azotobacter inoculation is reported to save at least 25% of applied N in wetland rice (Kashirajan et al., 1976) and 15-20% in upland rice (Dommalapaty, 1982). There are cases where improvement is nil (Allison, 1955). Clostridium inoculations have also been tried in dryland crop (Emetsev, 1961, and Rovira, 1965) and gains in yield are reported to be very high. Mixed inoculations in cereals are also reported (Ocampo et al., 1975) who used organic matter amendment. To have an inoculant strain a wayin the rice rhizosphere the above-mentioned five physiological parameters are the ones for which it should be screened, and the energy management through addition of organic matter is the aspect to be taken care of in wetland paddies.

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CHAPTER-III

MATERIALS AND METHODS

General

High N responsive varieties of lowland rice have a high N requirement. The cultural practices for lowland rice are such that submergence is highly favourable to nitrogen fixing activity (NFA). Bacterial cultures of free-living diazotrophs may in combination with manure and fertilizer tend to minimize the demand of fertilizer N. To study this objective, a greenhouse experiment with as many as 40 combination treatments was conducted in the first phase. Thereafter 18 selected treatments were evaluated in field trials for two consecutive years. In the second phase, the agronomic attributes of yield and the N content and soil N balance were investigated.

3.1. Soil and Climate

The soil belonged to a site in Livestock Farm of the University in Adhartal Block. Prior to the conduct of the experiment, it has been under grassland. The soil is vertisol (Tiwari, 1978), a medium black, and its analysis (Appendix Table I) showed that is near neutral, low in soluble salts, low in available N and in available P, and high in K. This very soil was used for greenhouse trial.

Climate of Jabalpur (23°10' N Lat., 79°57' E Long., 323 m above MSL) is subtropical, it being hot and dry summer with cold winters, and having a S.E. monsoon of rainfall, 1300-1400 mm. The detailed meteorological observations for seasons of growth of rice 1976 and 1977 are illustrated in Fig. 1, based on data of Appendix Table III.

3.2. COMBINATION TREATMENTS OF MINERAL, ORGANOMINERAL* AND BACTERIAL CULTURES

Levels of mineral N (urea), organomineral N (urea + compost, 3:1) and bacterial cultures were kept the same for greenhouse (pot culture) and field trials and are shown in Table 1. P (80 kg ha^{-1}) and K (25 kg^{-1}) were applied as basal dressing. N (urea) was applied in 3 splits (50% basal, 25% each at tillering and boot stage), at varying levels, which was combined with compost (whose N analysis yearwise is given in Appendix Table II) in the ratio of 3:1. The asterisk marked treatments were those, which proved their worth in the greenhouse trial, and hence evaluated in the field trial.

3.2.1. Mode and Rate of Bacterial Cultures

One culture of Azotobacter was obtained from Dept. of Biology, Tamil Nadu Agricultural University, Coimbatore, and further one more Azotobacter chroococcum, and Clostridium pasterianum strains were isolated from a heavily manured

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* Organomineral N combination (urea:compost 3:1) simply connotes application of urea and compost, where compost was applied as a basal dose.

FIG. I GRAPH SHOWING METEOROLOGICAL OBSERVATION DURING THE PERIOD FROM JUNE-25 TO OCT-28 (1976 AND 1977)

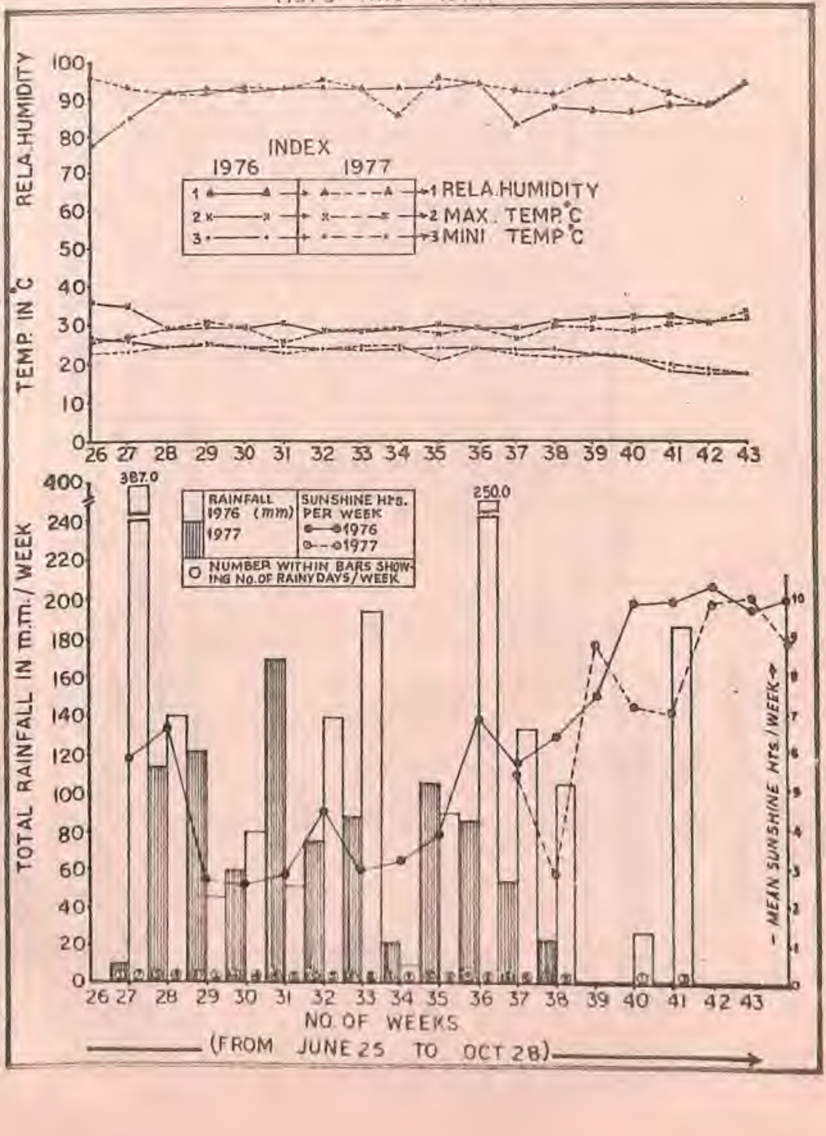


Table 1: Treatment combinations of N fertilizer, compost and Biofertilizers (Diazotroph).

S. No.	Total applied N kg ha^{-1}	Proportion of urea:compost	Code for urea and urea compost combination	Treatment combinations			
				Control^{I} (C)	Azo^{II} (Az)	Clos^{III} (Cl)	Azoclos^{IV} (T)
1.	0	0:0	1.1	C 1.1*	Az 1.1*	Cl 1.1*	T 1.1*
2.	30	1:0	1.2	C 1.2	Az 1.2	Cl 1.2	T 1.2
3.	60	1:0	1.3	C 1.3	Az 1.3	Cl 1.3	T 1.3
4.	90	1:0	1.4	C 1.4	Az 1.4	Cl 1.4	T 1.4
5.	120	1:0	1.5	C 1.5	Az 1.5	Cl 1.5	T 1.5
6.	30	0:1	2.1	C 2.1*	Az 2.1*	Cl 2.1*	T 2.1*
7.	30	3:1	3.1	C 3.1*	Az 3.1*	Cl 3.1*	T 3.1*
8.	60	3:1	3.2	C 3.2*	Az 3.2*	Cl 3.2*	T 3.2*
9.	90	3:1	3.3	C 3.3*	Az 3.3*	Cl 3.3*	T 3.3*
10.	120	3:1	3.4	C 3.4*	Az 3.4*	Cl 3.4*	T 3.4*

Note: Asterisk marked treatment combinations tested under field trials for two consecutive years.

I - Uninoculated control

II - Azotobacter inoculum

III - Clostridium inoculum

IV - Twin cultures i.e. mixture of Azotobacter and Clostridium inoculum in 1:1 proportion.

vertisol of limnic region of Ranital (Jabalpur) where vegetables are intensively cultivated. The two diazotrophs had a N fixing potential of the order of 10 mg/g sucrose. The inoculum was prepared in lignite base from the two having an initial count of 200 millions/gram of carriers. The Azotobacter inoculum, the Clostridium inoculum, and their isometric twin mixture were trivially referred as <u>Azo</u>, <u>Clos</u> and <u>Azoclos</u> cultures. The <u>azo</u> and <u>clos</u> thus happened to be ecotypes as detailed in Microbial Ecology (Alexander, 1971). All these preparations of bacterial cultures (biofertilizers) were done in the laboratories of microbiology section. The rate of application was 400 g ha^{-1} for three types: seed application (50 kg seed), nursery stage, and soil application.

3.3. GREENHOUSE TRIAL

3.3.1. Soil and Variety of Rice

Soil was the same as described in Section 3.1, and variety of rice chosen for the experiment was Cauvery (IET 355), a one that is recommended for cultivation in M.P. It has following characteristics: short statured (100 cm), high N responsive, high yielding, medium tillering ability, resistance to lodging, thousand grain weight, 22.3 g, cultivable under lowland as well as upland conditions, medium fine grain with 4000 kg ha^{-1} yield potential.

The bulk soil sample was collected from field experiment station of Department of Soil Science and Agricultural Chemistry, J.N. Krishi Vishwa Vidyalaya, Jabalpur, particularly from the site in which field experiment was to be conducted in subsequent years.

The bulk soil sample was ground and passed through 2 mm sieve and thoroughly mixed. The experiment was conducted in 15 kg capacity earthen pots, which were thoroughly cleaned, washed and then painted with lead free bitumen based paint, to make them leak proof. Ten kg of soil was placed in each pot.

3.3.2. Raising of Nursery

Nursery was raised separately for each bacterial culture and control in 4 pots, over a uniform basal dose of nitrogen (12 kg N per hectare nursery) through urea.

Paddy seeds were treated with culture @ 400 gm per 50 kg seed and were sown in nursery pots. Forty treatment combinations (Table No. 1) were replicated three times in a randomised block design. To experimental pots total phosphorus (superphosphate) and potash (muriate of potash) and 50% of N were applied as basal dose, at the given rate and remaining nitrogen was applied in two splits at tillering and boot stages, respectively. To bacterial culture treated pots, bacterial culture was applied @ 400 g ha^{-1} (weight basis) and mixed with dry soil.

3.3.3. Management of Experiment

Puddle condition in pots was simulated by manually working the soil after adding sufficient demineralized water. Suspensions of bacterial cultures used were prepared separately. Thirty days old seedlings from nursery pots were taken out and the roots of the seedlings were dipped in respective culture suspension prior to their transplanting in respective pots. Initially 3 seedlings were transplanted at 5 hills at equal space. Two seedlings per hill were uniformly maintained till maturity. Adequate plant protection measures were also taken. Total number of tillers and tillers bearing panicles (effective tillers) were counted from all the 5 hills in each pot and recorded separately at the stage of maturity. Harvesting of above ground portions was done at complete maturity.

Samples from each pots were properly labelled and first dried in sun for 16 hours and then after putting them in paper bags were dried in oven at 55°C for 16 hours. Gross weight for grain and straw samples were then recorded. Grain was then separated and its weight was also recorded, straw yield was recorded by difference in gross weight and grain weight.

3.4. FIELD TRIAL

Field experiments were conducted during the Kharif of 1976 and 1977 on field experimental station of Department of Soil Science and Agricultural Chemistry, J.N. Krishi Vishwa Vidyalaya, Jabalpur, at the same site from which soil was collected for pot culture experiment in Kharif of 1975.

3.4.1. Land Preparation

Experimental field was once ploughed with mould board plough and cross discing with disc harrow was done twice.

3.4.2. Nursery Stage

Nursery was raised in three 6 x 1 m raised (15 cm) nursery beds, placed 100 cm apart from each other, separate nursery was raised for each bacterial culture and control.

Prior to sowing each nursery bed was supplied with well decomposed compost @ 200 quintals and urea @ 10 kg, calculated on the basis of per hectare nursery, in addition 50 gm of zinc sulphate per nursery bed was also supplied against any possible occurrence of Khera disease (a physiological disorder).

Paddy seeds were treated with bacterial culture @ 400 gm per 50 kg of seed, for culture treated nurseries. Seed rate followed was 40 kg ha^{-1} nursery, seeds after sowing were covered with a thin layer of soil and beds were irrigated by shower cans. Later on, irrigation to nursery beds was applied as and when needed. Nursery was raised for 30 days in nursery beds.

3.5. PRETRANSPLANTING OPERATIONS

Soil sampling: A composite soil sample was drawn from the experimental plot.

3.5.1. Layout of Experiment

Layout was done by dividing the 18 treatments into a two tier system and replicated thrice. Thus the total number of plots were 54, in randomized block design.

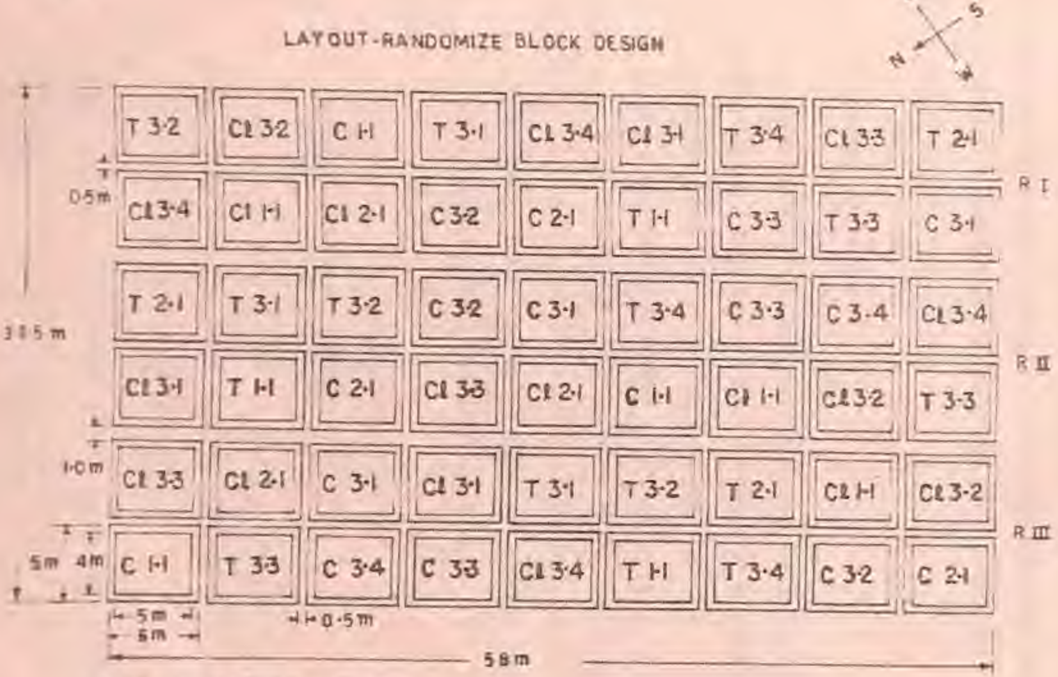
Each plot was surrounded by 50 cm wide bund and separated by channels. Within the replication, the channel size was 50 cm and between the replications it was 1 meter. Net plot size was 5 x 4 meter (20 sq. m). A drain pipe was fixed in each plot at 5 cm level. Layout plan is given in Fig. 2.

3.5.2. Preparation for Transplantation

Individual plots were again dug by showels, clods were broken and plots were levelled. Prior to transplanting the individual plots were filled with water and puddling was done manually. Full dose of phosphorus and potash and 50 per cent

Fig. 2

LAYOUT-RANDOMIZE BLOCK DESIGN



NET PLOT SIZE = 5m x 6m

TOTAL NO. OF PLOTS PER REPLICATION = 18

WIDTH OF BUNDS SURROUNDING EACH PLOT = 0·5m of nitrogen (applied through urea and compost) in each plot was applied as a basal dose as per randomization of treatment combinations. Bacterial cultures were applied as for greenhouse trial (vide 3.3.2).

3.5.3. Transplantation

Transplanting was carried out for individual plots in the following order: (1) Control plots (No bacterial culture) (C); (2) Clostridal culture treated plots (Cl); (3) Mixed culture (Azoclos) treated plots (T). Row to row distance was 20 cm and also hill to hill distance was 20 cm. Two plants per hill were planted. After the seedlings were established, water was filled in plots. A 5 cm water level was maintained throughout the growing season till late milk stage.

3.6. POST-TRANSPLANTING OPERATIONS

After about two weeks time soil application of bacterial culture was done at the rate of 400 g ha^{-1} after diluting it with lignite, near plant rows.

First split (25%) dose of nitrogen was applied at the time of tillering and second split (25%) dose of nitrogen was applied at boot stage as top dressing. Adequate plant protection measures were taken during the growth period.

Count for total number of tillers and tillers bearing panicles (effective tillers) were taken at the stage of maturity, from 10 hills in each plot.

3.7. HARVESTING AND POST-HARVESTING OPERATIONS

One border row from all the 4 sides of each plot was separately harvested to eliminate the border effect.

3.7.1. Harvesting Operation

Net plot was harvested and left for sun drying for one day. A composite sample of known weight from each plot was drawn for determination of moisture in the laboratory at 55°C (for 16 hours).

3.7.2. Post-harvest Operation

Gross weight (grain + straw) of sundried crop was recorded, paddy grain was then separated and its weight was also recorded. Straw yield was recorded by difference in gross weight and grain weight. Grain and straw samples were collected separately, moisture content in grain samples was also determined separately at 55°C (for 16 hours). Necessary correction in grain yield data and straw yield data was done by deducting moisture content. Schedule of operations followed in the year 1976 and 1977 are given in Appendix Table IV, which also shows the soil sampling at different stages of cropping.

3.8. CHEMICAL ANALYSIS

3.8.1. Soil samples were air dried, crushed and passed through 2 mm, 0.5 mm for organic carbon and then subjected to N analyses. Compost sample was similarly processed.

3.8.2. Determination of N in soil and Compost

Total N in soils was determined by salicylic acid modification of Kjeldahl's method (Black, 1965), and in compost by the procedure of Kanwar and Chopra (1959), and available N in soil samples by the procedure of Subbiah and Asija (1956).

3.8.3. Determination of N on Plant Samples

Representative samples of grain and straw were first washed with 0.1 N HCl, then with distilled water, and dried in an oven at 55°C. Samples were ground to 40 mesh. N content was determined by micro Kjeldahl method (Chapman and Pratt, 1961).

3.9. STATISTICAL ANALYSIS AND ASSOCIATED COMPUTATIONS

Factorial concept as outlined by Steel and Torrie (1980) was followed for both greenhouse and field trials. As nonsymbiotic N_2 fixers economise the fertilizer N, its effect was calculated as N equivalence, only for the field trials by the following formula:

$$\left(\frac{Y_{ij} - Y_{i0}}{Y_j - Y_0} - 1\right) \times j,$$

where

Y_{ij} = Yield of plot inoculated with biofertilizer i at j level of applied N,

Y_{i0} = yield at 0 level of applied N, inoculated with biofertilizer i,

Y_j = yield at j level of applied N (uninoculated plot),

Y_0 = yield at 0 level of applied N (uninoculated plot),

i = Biofertilizer - clos, azoclos,

j = levels of applied N,

0 = check (0 level of applied N).

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CHAPTER-IV

RESULTS

For greenhouse trial, tiller counts (total and effective), and yield (grain and straw) were recorded, for the field trials in two consecutive seasons besides the above observations, N content of grain and straw, available and total N in soils, before and after cropping were recorded and statistically analysed and presented in summary tables with mean values, S.E. and C.D. at $P = 0.05$ for all the above cited parameters. Thereupon soil N balance and N equivalence for bacterial cultures were computed. The graphs of the salient findings were presented in a three dimensional pattern, and a few in a simple pattern. Compost treatment (30 kg N ha^{-1}) because of the nonuniformity turned out on outlier and so excluded. Only the statistically significant data are described.

4.1. GREENHOUSE TRIAL

4.1.1. Total tiller count

The data are given in Table 2. The mineral nitrogen (without bacterial culture) gave 35.3 No. per pot at the highest level of applied N. There was an increase in total tiller count with successive increase in N levels irrespective of sources. The organomineral treatment gave a similar

Table 2: Summary table for number of total tillers.

Bacterial cultures	Levels/Sources for nitrogen applied										Mean for cultures
	1.1	1.2	1.3	1.4	1.5	2.1	3.1	3.2	3.3	3.4	
C	19.33	24.00	31.00	33.66	35.33	21.66	25.00	31.66	33.66	38.33	29.36
As	22.66	26.00	28.00	35.33	35.33	20.33	26.66	30.00	34.66	35.00	29.39
Cl	22.33	25.66	31.66	34.33	39.00	23.33	27.33	31.66	35.33	39.66	31.03
T	24.00	28.33	32.00	37.33	41.00	27.00	31.00	32.66	37.33	43.00	33.36
Mean	22.08	26.00	30.66	35.17	37.66	23.08	27.50	31.49	35.24	39.00	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	0.43	0.68	1.37
C.D.(5%)	1.22	1.93	3.85

pattern, 38.3 No. per pot at the highest level of applied N and did not differ to each other significantly. Among bacterial cultures the azo treatment was at par with the uninoculated control, the clos and azoclos treatments were superior to uninoculated control, but the latter was better than the former exhibiting 43 No. at 120 kg N ha^{-1} applied as organomineral N.

4.1.2. Effective Tiller Count

The response was similar to that of total tiller count (vide Table 3), mineral and organomineral not differing among themselves. The azo effect was not apparent, but the clos and azoclos effect caused 6.1 and 14.5% higher than the uninoculated control values and were different amongst themselves.

4.1.3. Straw Yield

Except at 30 kg N ha^{-1} level, organomineral N application at all other levels, was superior over mineral N application (Table 4). The azo effect was nil, and clos and azoclos effects were identical, but superior over uninoculated control and the interaction was nonsignificant.

Table 3: Summary table for number of effective tillers.

Bacterial cultures	Levels/Sources for nitrogen applied										Mean for cultures
	1.1	1.2	1.3	1.4	1.5	2.1	3.1	3.2	3.3	3.4	
C	18.00	21.66	29.33	31.33	34.00	21.33	23.66	29.66	32.00	33.33	27.43
Az	20.33	24.66	26.33	33.66	34.33	18.33	25.00	28.33	31.00	33.33	27.53
Cl	21.00	24.00	29.66	32.33	37.00	23.33	24.66	29.66	32.33	37.33	29.13
T	23.33	26.33	30.00	34.33	37.33	26.66	28.66	31.00	36.00	40.33	31.40
Mean	20.66	24.16	28.83	32.91	35.66	22.41	25.49	29.66	32.83	36.08	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	0.44	0.70	1.40
C.D.(5%)	1.25	1.97	3.94

Table 4: Summary table for straw yield (gms/pot).

Bacterial cultures	Levels/Sources for nitrogen applied										Mean for cultures
	1.1	1.2	1.3	1.4	1.5	2.1	3.1	3.2	3.3	3.4	
C	26.10	33.17	40.73	47.57	51.13	29.20	34.53	41.57	48.47	52.67	40.51
Az	25.07	35.43	40.07	44.30	46.00	21.93	37.13	40.73	47.70	52.40	39.07
Cl	30.00	36.80	43.57	50.17	55.80	35.00	38.83	47.47	56.26	59.83	45.37
T	30.13	37.57	44.77	51.30	56.30	36.10	40.37	49.07	56.80	60.97	46.34
Mean	27.82	35.74	42.28	48.33	52.31	30.56	37.71	44.71	52.31	56.47	

	Bacterial cultures	Level/Sources for N	Cell means
S.E.(m)	0.52	0.93	1.65
C.D.(5%)	1.47	2.33	N.S.

4.1.4. Grain Yield

Except at 30 kg N ha^{-1} level, organomineral N application at all other levels was superior over mineral N application (Table 5). (Fig 3 & Fig 4) The *azo* effect was negative causing a drop of 3.9%, the *clos* and *azoclos* gave rise by 12% and 14% respectively. As far as interaction is concerned, organomineral N was superior to urea alone in the presence of bacterial cultures, *clos* and *azoclos* at 90 and 120 kg N ha^{-1} levels and also at 60 kg N ha^{-1} level in case of the *clos* culture. Urea was superior to compost at 30 kg N ha^{-1} level in uninoculated control in presence of azo.

4.2. FIELD TRIALS

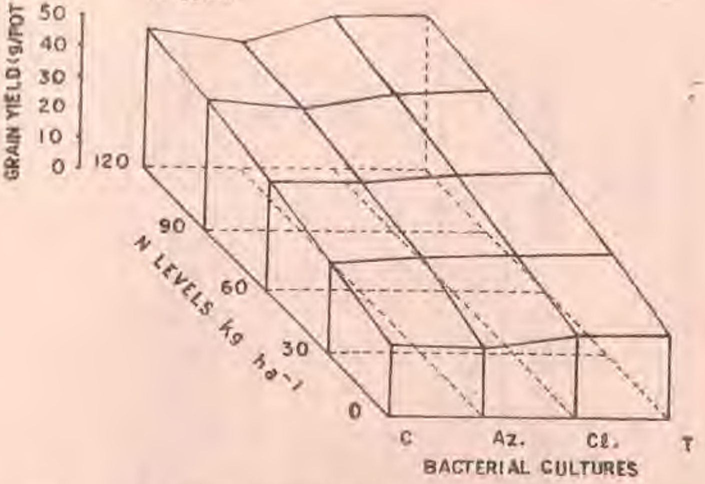
The yield component, and the yield of straw and grain were comparatively lesser in 1977 season than in 1976 season, as the meteorological conditions were different, notably sunshine hours lesser in the latter season.

4.2.1. Total Tiller Count

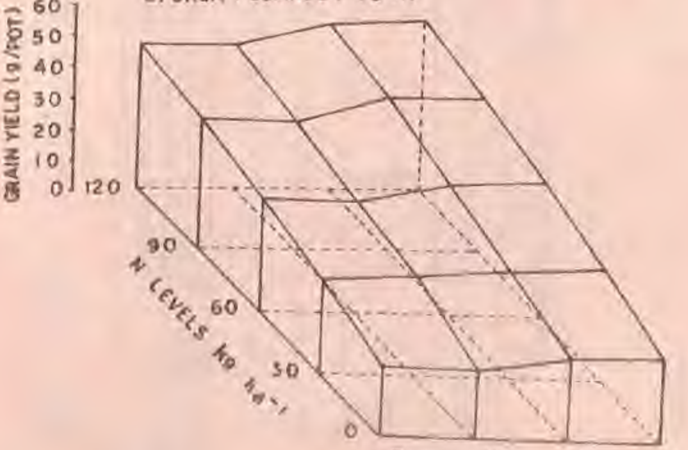
Data for 1976 and 1977 seasons are given in Table 6 and illustrated in Fig. 5. The response to organomineral N happens to be linear, the two, 30 and 60 kg N ha^{-1} levels, and 90 and 120 kg N ha^{-1} levels not differing among themselves. In 1976 season the organomineral N treatment gave

FIG. 3: EFFECT OF BACTERIAL CULTURES ON GRAIN YIELD OF PADDY AT DIFFERENT LEVELS OF NITROGEN (POT CULTURE-1975)

1. UREA



2. UREA + COMPOST (3:1)



C UNNOCULATED CONTROL, Az/ AZOTOBACTER CULTURE, Cl/ CLOSTRIDIAL CULTURE, T/ AZOCLOS CULTURE

Table 5: Summary table for grain yield (gms/pot).

Bacterial cultures	Levels/Sources for nitrogen applied										Mean for cultures
	1.1	1.2	1.3	1.4	1.5	2.1	3.1	3.2	3.3	3.4	
C	23.4	29.5	36.2	42.3	45.4	25.9	30.7	37.0	43.1	46.8	36.03
Az	22.3	31.5	35.6	39.4	40.9	19.5	32.4	36.2	42.4	46.6	34.68
Cl	26.7	32.7	38.8	44.6	49.6	31.1	34.5	42.2	49.9	53.2	40.33
T	26.8	33.4	39.8	45.6	50.0	32.1	35.9	43.6	50.5	54.2	41.19
Mean	24.80	31.77	37.60	42.97	46.47	27.15	33.37	39.75	46.47	50.20	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	0.27	0.43	0.86
C.D.(5%)	0.77	1.21	2.40

FIG. 4 EFFECT OF BACTERIAL CULTURES ON THE GRAIN YIELD OF PADDY AT DIFFERENT LEVELS AND SOURCES OF NITROGEN (POT CULTURE 1975)

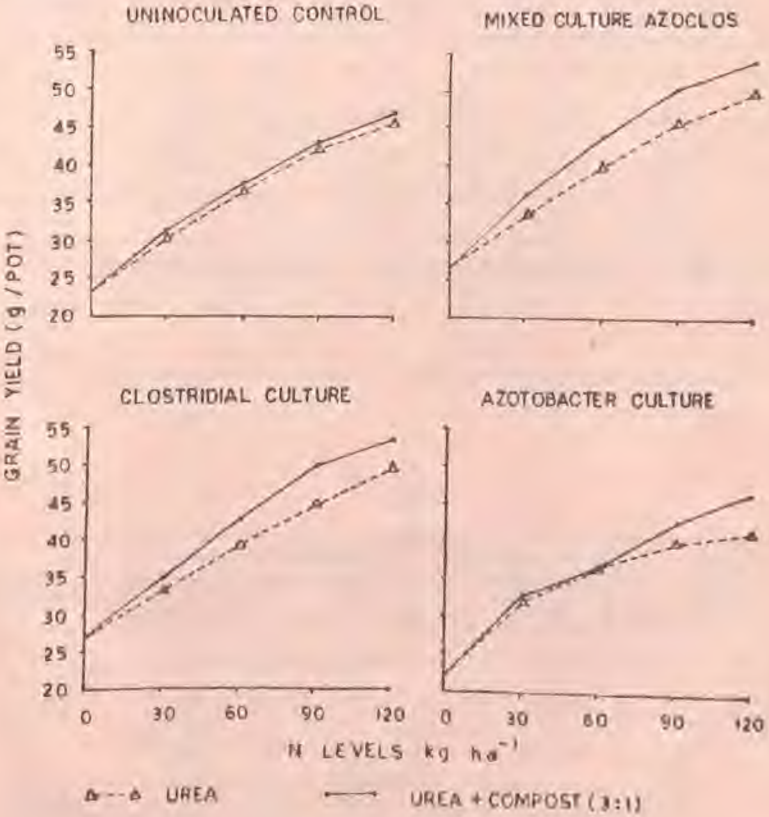


Table 6: Summary table for number of total tillers.

1976

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	2.1	3.1	3.2	3.3	3.4	
C	6.70	7.53	8.93	9.93	11.87	12.26	9.54
Cl	7.76	8.13	9.36	10.30	11.90	12.33	9.96
T	8.30	8.46	10.30	11.16	12.26	13.56	10.67
Mean	7.59	8.04	9.53	10.46	12.01	12.72	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	0.24	0.34	0.59
C.D.(5%)	0.69	0.97	N.S.

1977

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	2.1	3.1	3.2	3.3	3.4	
C	6.90	8.20	8.80	9.30	11.53	12.53	9.54
Cl	6.93	8.87	9.60	10.13	11.70	12.90	10.02
T	7.93	9.40	10.17	10.70	12.90	13.57	10.78
Mean	7.25	8.82	9.52	10.04	12.04	13.00	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	0.35	0.50	0.87
C.D.(5%)	N.S.	1.44	N.S.

18.5% higher total tiller count over compost applied at 30 kg N ha^{-1} level, but it equalled the compost in 1977 season. In both seasons, the clos effect was nil and the azoclos effect was 11.8%, only in the preceding season.

4.2.2. Effective Tiller Count

Data for 1976 and 1977 are given in Table 7 and Fig. 5. The response curve happens to be linear very much similar to those of total tiller count. In 1976 season the organomineral N gave 18.5% higher effective tiller count at 30 kg N ha^{-1}, but it equalled the compost in 1977, and thus it conformed to the pattern of total tiller count. Likewise, the clos effect was nil but the azoclos effect was noticeable in both seasons with a 9.1% and 15.1% upward drift.

4.2.3. Straw Yield

Data for 1976 and 1977 seasons are given in Table 8. The response to organomineral N was linear upto 60 kg N ha^{-1}, the levels of 90 and 120 kg N ha^{-1} not distinguishing among themselves in the succeeding season as well. The organomineral N gave 15% higher yield than the compost at 30 kg N ha^{-1} level in one season and 10% in the next season. Both clos and azoclos effect was observed in a consistent increase in the yield by 8% and 12% respectively in both seasons, and the azoclos effect was superior to the clos effect in both seasons.

FIG.5 EFFECT OF BACTERIAL CULTURES ON TILLER COUNT AT DIFFERENT LEVELS OF NITROGEN

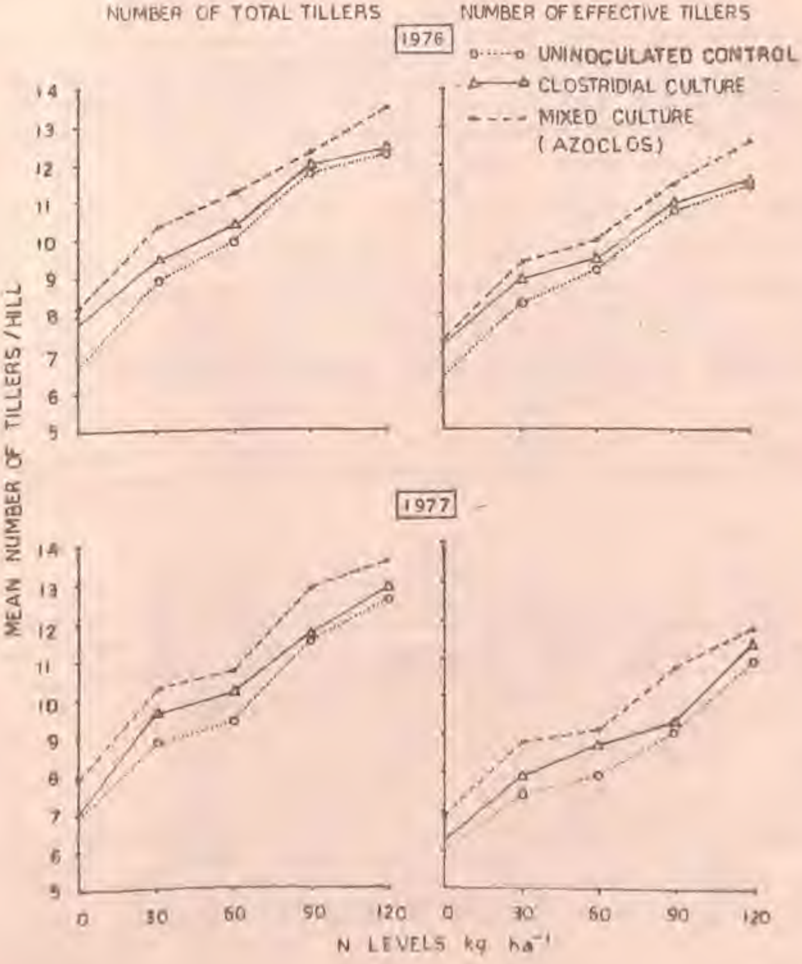


Table 7: Summary table for number of effective tillers.

1976

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	2.1	3.1	3.2	3.3	3.4	
C	6.27	7.00	8.33	9.13	10.70	11.37	8.80
Cl	7.23	7.90	8.90	9.40	10.87	11.40	9.28
T	7.30	7.53	9.33	9.87	11.07	12.57	9.61
Mean	6.93	7.48	8.85	9.47	10.88	11.78	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	0.20	0.29	0.49
C.D.(5%)	0.58	0.82	N.S.

1977

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	2.1	3.1	3.2	3.3	3.4	
C	5.90	7.50	7.40	7.87	9.00	10.90	8.09
Cl	6.23	7.60	7.90	8.73	9.33	11.40	8.53
T	6.93	8.37	8.83	9.10	10.80	11.83	9.31
Mean	6.35	7.82	8.04	8.57	9.71	11.38	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	0.26	0.37	0.65
C.D.(5%)	0.76	1.08	N.S.

Table 8: Summary table for straw yield (kg/ha)

1976

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	2.1	3.1	3.2	3.3	3.4	
C	2168.3	2426.9	2843.4	3199.5	3491.7	3521.9	2941.9
Cl	2260.6	2569.7	3050.0	3563.9	3826.0	3914.9	3197.5
T	2341.3	2850.2	3137.4	3552.2	3908.3	4035.9	3304.2
Mean	2256.7	2615.6	3010.3	3438.5	3742.0	3824.2	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	24.93	35.26	61.08
C.D.(5%)	71.66	101.34	N.S.

1977

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	2.1	3.1	3.2	3.3	3.4	
C	1839.1	2217.0	2490.7	2932.5	3241.5	3396.0	2686.1
Cl	1916.3	2364.8	2672.1	3181.0	3537.1	3695.0	2894.4
T	1995.3	2598.2	2752.7	3258.3	3622.7	3827.6	3009.1
Mean	1916.9	2393.3	2638.5	3123.9	3467.1	3639.5	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	30.03	42.47	73.56
C.D.(5%)	86.31	122.06	N.S.

4.2.4. Grain Yield

Data for 1976 and 1977 seasons are given in Table 9 and illustrated in Fig. 6. The response to organomineral N followed the same trend as the straw yield. Organomineral N gave 15% and 10% higher yields than the compost at 30 kg N ha^{-1} level in both seasons. Like the straw yield the *clos* and *azoclos* effect was also observed in a consistent increase of 8% and 12% respectively in both seasons.

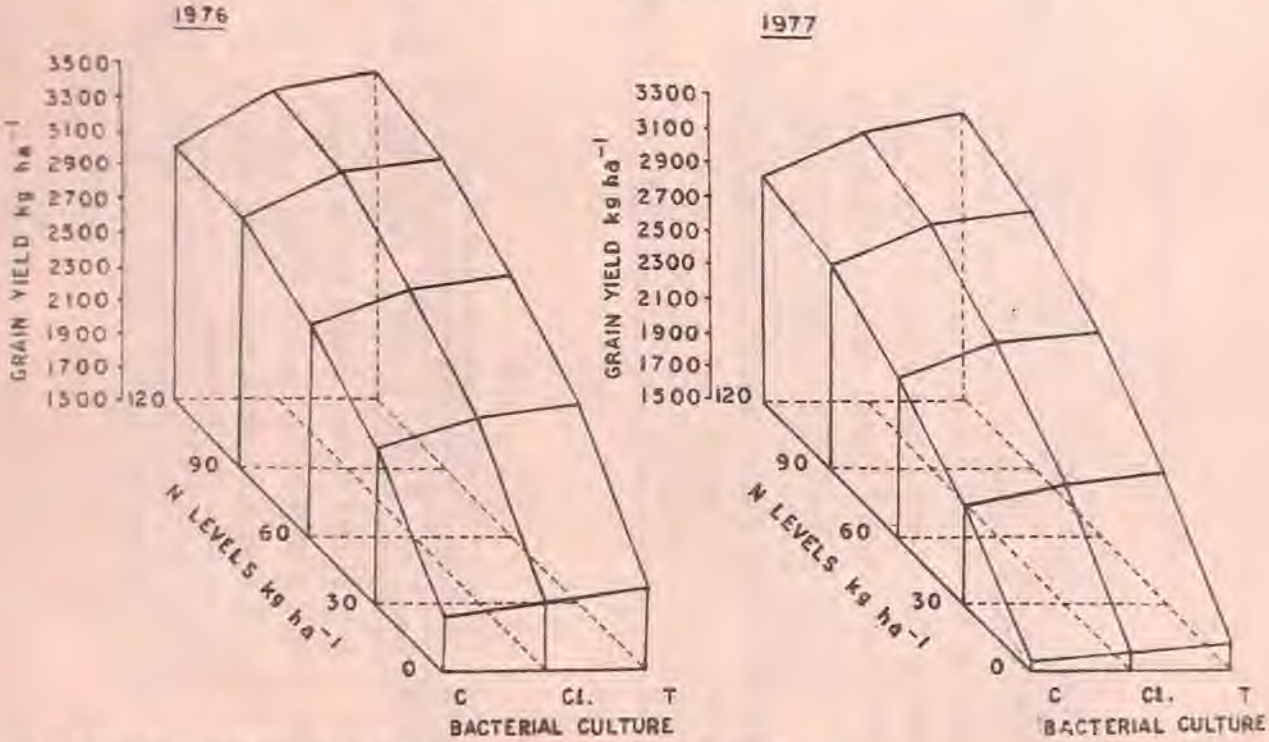
4.2.5. N Uptake

Nitrogen content was determined in straw and grain (Appendix Table V & VI) and the content was multiplied by the yield per ha to obtain the uptake.

4.2.5.1. Straw N uptake

The response pattern (Table 10) showed linearity upto the highest level of applied N. The organomineral turned out via 16.6% and 10.4% higher uptake than the compost at 30 kg N ha^{-1} in two seasons respectively. Both *clos* and *azoclos* were identical in each of the two seasons in enhancing the N uptake by similar magnitude of 20%. Regarding the interaction the *clos* and *azoclos* effect were generally superior over uninoculated controls only in 1976; the increasing levels of organomineral N gave successive N uptake rise only in the *clos* treatments.

FIG. 6: EFFECT OF BACTERIAL CULTURES ON GRAIN YIELD OF PADDY AT DIFFERENT LEVELS OF NITROGEN (FIELD EXPERIMENT)



C - UNINOCULATED CONTROL, CL - CLOSTRIDIAL CULTURE, T - AZOCLOS CULTURE

Table 9: Summary table for grain yield (kg/ha)

1976

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	2.1	3.1	3.2	3.3	3.4	
C	1844.1	2065.8	2420.2	2724.2	2972.8	2997.9	2504.2
Cl	1924.7	2188.4	2594.9	2947.9	3256.6	3330.5	2707.2
T	1993.6	2426.9	2670.5	3023.2	3325.5	3436.3	2812.7
Mean	1920.8	2227.0	2561.9	2898.4	3184.9	3254.9	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	18.14	25.66	44.44
C.D.(5%)	52.14	73.74	N.S.

1977

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.2	2.1	3.1	3.2	3.3	3.4	
C	1531.7	1847.5	2075.9	2443.7	2700.7	2801.5	2233.5
Cl	1597.2	1970.1	2227.1	2650.3	2947.6	3078.6	2411.8
T	1662.7	2166.9	2292.6	2715.8	3018.1	3189.4	2507.6
Mean	1597.2	1994.8	2198.5	2603.3	2888.8	3023.2	

	Bacterial cultures	Levels/Sources for N	Cell means
S.Em(m)	25.44	35.98	62.32
C.D.(5%)	73.12	103.40	N.S.

Table 10: Summary table for uptake of nitrogen (kg/ha) by straw.

1976

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	2.1	3.1	3.2	3.3	3.4	
C	13.01	12.86	17.24	18.24	20.01	20.42	16.96
C1	14.69	14.13	19.51	21.38	23.20	26.60	19.92
T	15.69	18.52	16.31	19.16	25.66	26.76	20.35
Mean	14.46	15.17	17.69	19.59	22.96	24.59	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	0.17	0.24	0.42
C.D.(5%)	0.49	0.70	1.21

1977

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	2.1	3.1	3.2	3.3	3.4	
C	10.85	11.88	14.87	16.42	18.29	19.38	15.28
C1	12.26	12.77	16.65	18.96	21.11	24.77	17.75
T	13.17	16.63	14.04	17.31	23.44	25.01	18.27
Mean	12.09	13.76	15.19	17.56	20.94	23.05	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	0.20	0.28	0.49
C.D.(5%)	0.57	0.81	1.41

4.2.5.2. Grain N uptake

The response pattern (Table 11) almost tallied with the grain yield (vide section 4.2.4). The organomineral N turned out in a 20% higher uptake than the compost at 30 kg N ha^{-1} level in the first season and 17.4% in the second season. Both clos and azoclos were effective in enhancing N uptake by a magnitude of 7.4% and 12-14% respectively in both seasons, the latter being superior to the former. Whereas the interaction in the first season was significant, it became nonsignificant in the second season.

4.2.6. Soil N

Available and total N in the soil samples under variable applied N levels were determined in kg ha^{-1} at precropping and post cropping stages in the two successive seasons of 1976 and 1977. A pooled sample at the commencement of field trials was reckoned for the entire plotted soils, numbering 18 treatments and 3 replications which was 215.8 and 1402.2 kg N ha^{-1} for available and total N, respectively.

4.2.6.1. Available N

Data for the precropping stage (1977) are presented in Table 12. The response to variable N levels was a linear rise (~~range 2.3 to 13 kg N ha^{-1}~~) except at the 60 and 90

Table 11: Summary table for uptake of nitrogen (kg/ha) by grain.

1976

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	2.1	3.1	3.2	3.3	3.4	
C	19.55	19.96	25.65	26.32	32.40	30.85	25.79
Cl	17.94	21.88	27.23	30.94	33.54	34.54	27.68
T	20.93	24.97	27.43	31.11	33.26	36.82	29.09
Mean	19.47	22.27	26.77	29.46	33.07	34.07	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	0.21	0.30	0.53
C.D.(5%)	0.62	0.87	1.51

1977

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	2.1	3.1	3.2	3.3	3.4	
C	16.04	17.19	22.21	23.57	28.31	28.52	22.64
Cl	14.89	19.70	22.99	27.25	30.35	31.40	24.43
T	17.08	21.82	23.70	28.00	31.90	32.86	25.89
Mean	16.00	19.57	22.97	26.27	30.19	30.93	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	0.33	0.47	0.81
C.D.(5%)	0.95	1.34	N.S.

Table 12: Summary table for available soil nitrogen (kg/ha) at precropping stage.

1977

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	2.1	3.1	3.2	3.3	3.4	
C	212.33	216.63	213.53	215.10	215.43	216.47	215.08
C1	211.40	215.70	212.23	213.30	214.03	216.43	213.84
T	211.37	214.50	212.80	213.87	213.93	216.50	213.83
Mean	211.70	215.61	212.85	214.09	214.46	216.47	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	0.09	0.13	0.22
C.D.(5%)	0.26	0.36	0.63

Kg N ha^{-1} levels. The clos and azoclos effect was observed, the latter being superior to the former. The response to variable N levels was a linear rise in the clos and azoclos treatments. Further the available N in uninoculated control treatment was superior to the clos and azoclos treatments, at all levels of applied N except at 120 kg N ha^{-1} level. The post cropping data on available N are presented in Table 13, for the two seasons under observation. The trend of linearity with respect to the applied N levels was the characteristic feature in both seasons, other effects being nonsignificant as in the case of the precropping data. At 30 kg N ha^{-1} applied N, compost proved superior to organomineral in both the season.

4.2.6.2. Total N

The trend was the same as obtained with the available N for both seasons (Table 14, Table 15). Compost was superior to organomineral at 30 kg N ha^{-1} at each sampling.

4.2.7. Soil N Balance

The soil N balance, Balance sheet and summary Table for both seasons are given in Table 16, Table 17, and Table 18 respectively, and the N balance is illustrated in Fig. 7. The curve is definitely curvilinear with a hump at the applied N of 30 kg ha^{-1} level, in 1976 and in between

Table 13: Summary table for available soil nitrogen (kg ha^{-1}) at post cropping stage.

1976

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	2.1	3.1	3.2	3.3	3.4	
C	216.67	221.07	220.17	224.07	226.77	230.97	223.28
Cl	217.93	222.17	221.10	224.53	227.67	230.27	223.94
T	216.63	221.10	221.63	225.13	227.60	230.30	223.73
Mean	217.08	221.45	220.96	224.58	227.35	230.51	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	0.21	0.29	0.52
C.D.(5%)	N.S.	0.85	N.S.

1977

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	2.1	3.1	3.2	3.3	3.4	
C	213.20	221.47	217.77	223.60	226.57	231.00	222.27
Cl	213.10	221.57	217.30	222.00	225.80	230.93	221.78
T	213.13	219.67	218.30	223.00	225.50	231.20	221.80
Mean	213.14	220.90	217.79	222.87	225.96	231.04	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	0.21	0.29	0.50
C.D.(5%)	N.S.	0.84	N.S.

Table 14: Summary table for total soil nitrogen (kg ha^{-1}) at precropping stage.

1977

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	2.1	3.1	3.2	3.3	3.4	
C	1379.8	1408.2	1388.0	1397.8	1400.0	1407.0	1396.8
Cl	1374.6	1401.5	1379.1	1387.3	1390.3	1406.7	1389.9
T	1379.9	1394.8	1382.8	1389.5	1391.0	1406.7	1390.7
Mean	1378.1	1401.5	1383.3	1391.5	1393.8	1406.8	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	0.83	1.17	2.03
C.D.(5%)	2.39	3.37	5.84

Table 15: Summary table for total soil nitrogen (kg ha^{-1}) at post cropping stage.

1976

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	2.1	3.1	3.2	3.3	3.4	
C	1408.2	1436.6	1430.6	1456.0	1473.9	1501.5	1451.1
Cl	1416.4	1444.0	1437.3	1459.0	1479.1	1496.3	1455.3
T	1408.2	1437.3	1441.1	1463.5	1479.9	1497.1	1454.5
Mean	1410.9	1439.3	1436.3	1459.5	1477.6	1498.3	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	1.33	1.88	3.26
C.D.(5%)	N.S.	5.41	N.S.

1977

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	2.1	3.1	3.2	3.3	3.4	
C	1385.8	1438.8	1414.9	1453.0	1473.2	1501.5	1444.5
Cl	1385.8	1440.2	1412.7	1442.6	1468.7	1500.8	1441.8
T	1385.8	1427.6	1418.7	1449.3	1465.0	1503.0	1441.6
Mean	1385.8	1435.5	1415.4	1448.3	1468.9	1501.7	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	1.35	1.91	3.31
C.D.(5%)	N.S.	5.50	N.S.

Table 16: Soil nitrogen balance (balance sheet) for total nitrogen content kg ha^{-1} after cropping season of 1976.

S.No.	Treatments	N source (kg ha^{-1}) Mean soil N before cropping	Fert. N	Total of N	N recovery (kg ha^{-1}) Mean soil N after cropping	Mean total uptake	Total N recovery	N balance (kg ha^{-1})
1.	C 1.1	1402.24	0.0	1402.24	1408.21	32.56	1440.77	38.53
2.	C 2.1	1402.24	30	1432.24	1436.58	32.82	1469.40	37.16
3.	C 3.1	1402.24	30	1432.24	1430.61	42.93	1473.54	41.30
4.	C 3.2	1402.24	60	1462.24	1456.00	44.56	1500.56	38.32
5.	C 3.3	1402.24	90	1492.24	1473.92	52.41	1526.33	34.09
6.	C 3.4	1402.24	120	1522.24	1501.46	51.36	1552.82	30.58
7.	Cl 1.1	1402.24	0.0	1402.24	1416.43	32.63	1449.06	46.82
8.	Cl 2.1	1402.24	30	1432.24	1444.05	36.02	1480.07	47.83
9.	Cl 3.1	1402.24	30	1432.24	1437.33	46.74	1484.07	51.83
10.	Cl 3.2	1402.24	60	1462.24	1458.99	52.33	1511.32	49.08
11.	Cl 3.3	1402.24	90	1492.24	1479.15	56.61	1535.76	43.52
12.	Cl 3.4	1402.24	120	1522.24	1496.32	61.61	1557.93	35.69
13.	T 1.1	1402.24	0.0	1402.24	1408.21	36.50	1444.71	42.47
14.	T 2.1	1402.24	30	1432.24	1437.33	43.49	1480.82	48.58
15.	T 3.1	1402.24	80	1432.24	1441.07	43.72	1484.79	52.55
16.	T 3.2	1402.24	60	1462.24	1463.47	50.29	1513.76	51.52
17.	T 3.3	1402.24	90	1492.24	1479.89	58.92	1538.81	46.57
18.	T 3.4	1402.24	120	1522.24	1497.07	63.27	1560.34	38.10

Table 17: Soil nitrogen balance (balance sheet) for total nitrogen content kg ha^{-1} after cropping season of 1977.

S.No.	Treatments	N source (kg ha^{-1})			N recovery (kg ha^{-1})			N balance (kg ha^{-1})
		Mean soil N before cropping	Fert. N	Total of N	Mean soil N after cropping	Mean total uptake	Total N recovery	
1.	C 1.1	1379.84	0	1379.84	1385.81	26.86	1412.67	32.83
2.	C 2.1	1408.21	30	1438.21	1438.83	29.07	1467.90	29.69
3.	C 3.1	1388.05	30	1418.05	1414.93	37.54	1452.47	34.42
4.	C 3.2	1397.76	60	1457.76	1453.01	40.02	1493.21	35.45
5.	C 3.3	1400.00	90	1490.00	1473.17	46.61	1519.78	29.78
6.	C 3.4	1407.05	120	1527.09	1501.55	48.13	1549.68	22.59
7.	Cl 1.1	1374.61	0	1374.61	1385.81	27.15	1412.96	38.35
8.	Cl 2.1	1401.49	30	1431.49	1440.32	32.80	1473.12	41.63
9.	Cl 3.1	1379.09	30	1409.09	1412.69	39.84	1452.53	43.44
10.	Cl 3.2	1387.30	60	1447.30	1442.56	46.06	1488.62	41.32
11.	Cl 3.3	1390.29	90	1480.29	1468.69	51.47	1520.20	39.87
12.	Cl 3.4	1406.72	120	1526.72	1500.80	56.17	1556.97	30.25
13.	T 1.1	1379.87	0	1379.87	1385.81	30.26	1416.09	36.20
14.	T 2.1	1394.77	30	1424.77	1427.62	38.45	1466.07	41.30
15.	T 3.1	1382.83	30	1412.83	1418.67	37.74	1458.41	43.58
16.	T 3.2	1389.55	60	1449.55	1449.28	45.35	1494.63	45.08
17.	T 3.3	1391.04	90	1481.04	1464.96	55.67	1520.63	39.59
18.	T 3.4	1406.72	120	1526.72	1503.04	57.87	1560.91	34.19

Table 18: Summary table for nitrogen balance for total nitrogen content of soil (kg ha^{-1}).

1976

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	2.1	3.1	3.2	3.3	3.4	
C	38.53	37.16	41.30	38.32	34.09	30.58	36.66
Cl	46.82	47.83	51.84	49.09	43.52	35.69	45.79
T	42.47	48.59	52.55	51.52	46.57	38.10	46.63
Mean	42.60	44.53	48.56	46.30	41.39	34.79	

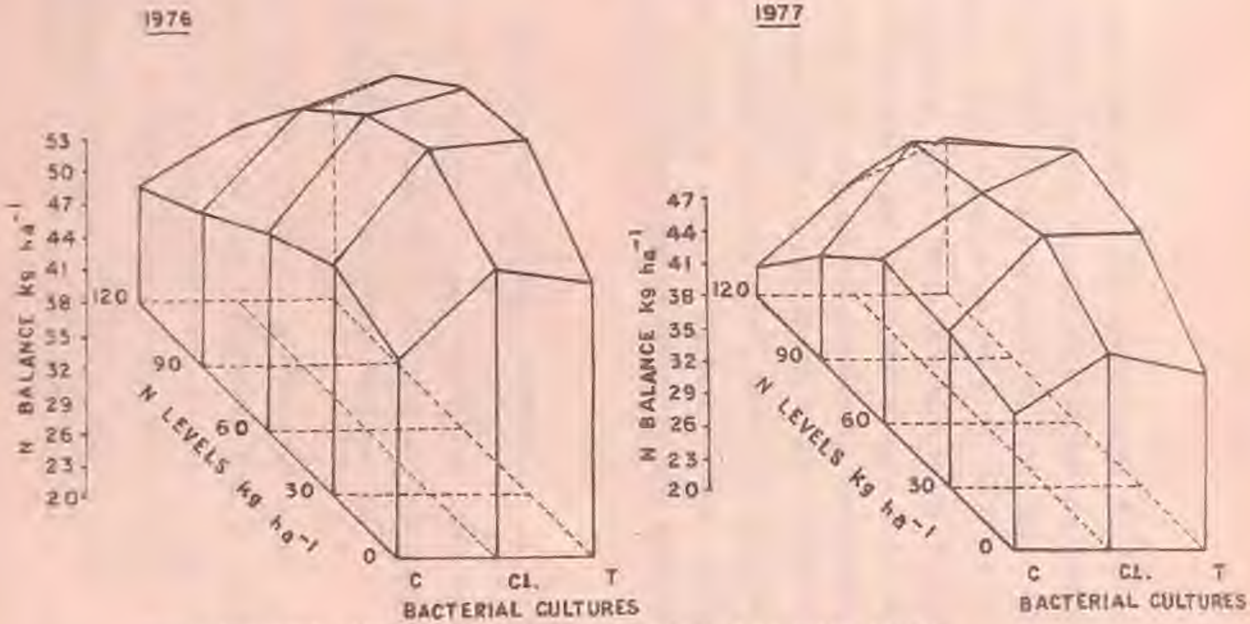
	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	1.34	1.89	3.27
C.D.(5%)	3.84	5.43	9.40

1977

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	211	3.1	3.2	3.3	3.4	
C	32.83	29.69	34.42	35.45	29.78	22.59	30.79
Cl	38.35	41.63	43.44	41.32	39.87	30.25	39.14
T	36.20	41.30	43.58	45.08	39.59	34.19	39.99
Mean	35.79	37.54	40.48	40.62	36.41	29.01	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	1.46	2.07	3.59
C.D.(5%)	4.22	5.97	N.S.

FIG.7: EFFECT OF BACTERIAL CULTURES AND NITROGEN LEVELS ON NITROGEN BALANCE AFTER PADDY CROP



C- UNINOCULATED CONTROL, Cl.- CLOSTRIDIAL CULTURE, T - AZOCLOS CULTURE

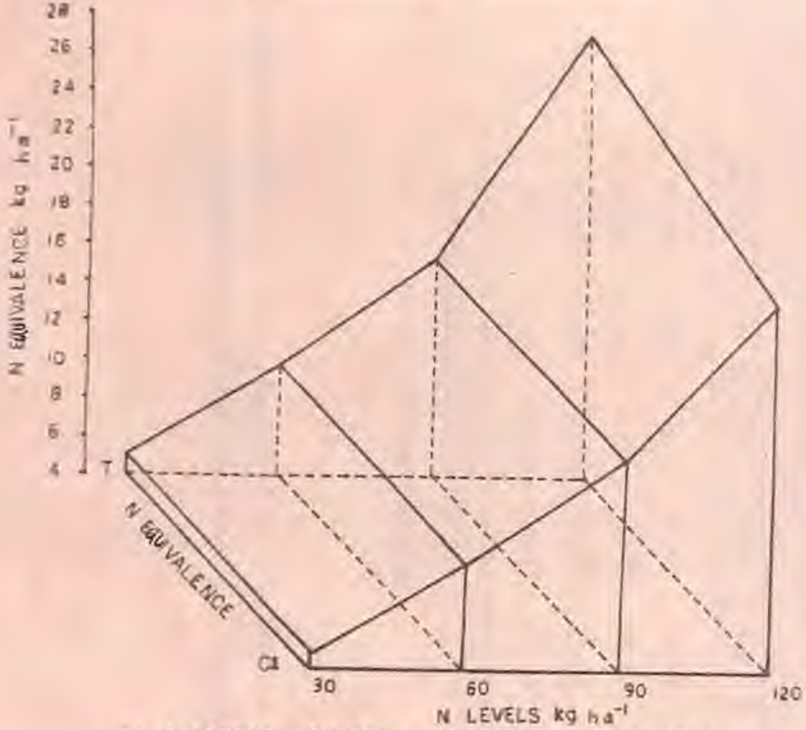
30 and 60 kg ha^{-1} in 1977. The organomineral N created 9.1 and 8.0% higher N balance in soil in both seasons over compost at 30 kg N ha^{-1} level respectively. The clos and azoclos effects were on parity in creating the N balance higher by 25-30% in both seasons, baseline being 36.6 and 30.8 kg N ha^{-1} in the first and second seasons respectively. The interaction that was characteristically significant in the first season became nonsignificant in the second season. In the first season the 30 kg N ha^{-1} level was superior to 120 kg N ha^{-1} level in creating higher N balance, and the clos and azoclos effects were on parity in this respect as well.

4.2.8. N Equivalence of Bacterial Cultures

This is a secondary parameter derived from the primary data on N secretion due to the clos and azoclos inoculations in the paddy and is presented in Table 19.

Data on N equivalence are illustrated in Fig. 8. The N equivalence is derived from the primary data to interpret the effect of the bacterial culture application upon the soil productivity. The clos effect appeared fairly linear for N equivalence, resulting in a boost of N equivalence at the highest level of organomineral application (120 kg N ha^{-1}).

FIG. 8 EFFECT OF BACTERIAL CULTURES AND NITROGEN LEVELS ON NITROGEN EQUIVALENCE OF BACTERIAL CULTURES



Cl - CLOSTRIDIAL CULTURE   T - MIXED CULTURE (AZOCLOS)

Table 19: Nitrogen equivalence of bacterial cultures for different levels of applied N (organomineral N).

S. No.	Levels for applied N kg ha^{-1}	N Equivalence kg ha^{-1}					
		1976		1977		Mean	
		Cl^{i}	T^{ii}	Cl^{i}	T^{ii}	Cl^{i}	T^{ii}
1.	30	4.91	5.26	4.72	4.72	4.81	4.99
2.	60	9.75	10.19	9.28	9.28	9.51	9.73
3.	90	16.20	16.20	13.96	14.35	15.08	15.27
4.	120	26.20	30.05	19.99	24.28	23.09	27.16

(i) Cl. (Clostridial culture)

(ii) T. (Mixed culture azoclos).

The azoclos effect was fairly linear, also resulting in a boost at the highest level of organomineral application.

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CHAPTER-V

DISCUSSION

5.1. RESPONSE TO APPLIED N

The variety Cauvery is a modern rice of medium duration, bred for high N responsiveness. When tested under field conditions for two consecutive seasons it could only just meet the breeder's expectancy (4 t ha^{-1}). Among the two seasons, the yields in the first season were close to the expected value. The second subsequent season was marked with lesser sunshine hours, high rainfall, which were responsible for lowering of spikelet fertility (Murty and Murty, 1980) associated with less degree of ripening due to low temperature, lower solar energy input, and high humidity during the period of ripening (Sreedharan _et_ _al_., 1979). Consequently, in uninoculated control the grain yield fell by 6.6% in highest applied N level (of 120 kg N ha^{-1} level) and by 7.1%, in _azoclos_ combined with the highest applied N level (of 120 kg N).

There was successive increase in tiller count with increase in N levels as also reported by Mahapatra and Sharma (1972), Panda and Leeuwrik (1972), Jain (1974), Gowada and Panikar (1977), Mahatim Singh _et_ _al_. (1979), Sharma and Rajendra Prasad (1982) and also with respect to yield as also observed by Mahapatra and Sharma (1972), Panda and Leeurik

(1972), Singh et al. (1975), Rao (1977), Gowada and Panikar (1977), Pathak et al. (1980), Mehrotra and Singh (1982), and Sharma and Rajendra Prasad (1982). The variety gave almost linear response upto 60 kg ha^{-1} of applied N and curvilinear response thereafter in respect to grain yield in each case. However, clos and azoclos treatments had marked positive effect on response which resulted into an upward drift at the highest level of applied N. Although their effect persisted even in the subsequent season, there was an imposition of an effect of seasonality through the lowering of response by about 7% to 8% at higher level (120 kg ha^{-1}) of applied N for uninoculated control and culture treated plots. Despite best agronomic practices the effect of seasonality could not be overcome. Against the reported recovery of only 30% by crop (Prasad and De Datta, 1979) the efficiency of the applied N in the present study is increased by 18.3% in case of straw and 10.5% in case of grain through the biofertilizers, clos and azoclos. The evidence of the biofertilizer is got through one very good agronomic practice of designing a moat around each experimental plots in randomization, to prevent overflow and intermingling of treatments with adjacent plots.

5.2. ORGANOMINERAL APPLICATION AND BEHAVIOUR OF BIOFERTILIZER INOCULATIONS

Due to energy crisis, much stress is being put upon the use of organic manures in conjunction with mineral

Plate-1

Photograph-1

General view of pot culture experiment

Photograph-2

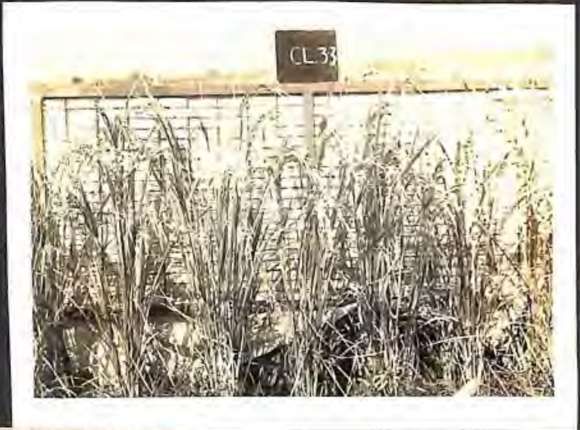
Comparative effect of bacterial cultures & control on the growth of paddy fertilizers and biofertilizers (Swaminathan, 1981). An empirical proportion of 3:1 in the organomineral fertilizer N (~~compost + urea~~ urea : compost) was compared with the mineral N (urea) in greenhouse trial. Further, the biofertilizers of nonsymbiotic micro-organisms: *Azotobacter chroococcum*, Alfisol ecotype, *azo*; *Clostridium pasteurianum*, vertisol ecotype, and their isometric mixture, *azoclos* were applied in repeat inoculations at crucial stages in paddy cultivation to get their maximum efficiency in the organomineral/mineral N combinations (cf. Subba Rao, 1977). The organomineral N in its application was at par with the mineral N with respect to total tillers and effective tillers. However, it proved superior to the mineral N at all levels of applied N except at the lowest level with respect to straw and grain production. It has been suggested (Patnaik, 1965 and Kai and Wada, 1979) that the application of fertilizer N accelerates mineralisation of soil organic N. The response was almost linear upto 60 kg applied N ha^{-1} and then curvilinear in each case (except *azo* treatment). This provided the clue to the appropriateness to use this empirical formulation to test it in the field. Comparative effect of biofertilizer (in pot and field trials) in combination with organomineral N has been amply borne out through photographic plates 1 to 3.

The field trials covering two seasons showed similarity in the above trend which was curvilinear. Even at the

Plate-2

Photograph-3

Photograph-4



Comparative effect of control (C) and <u>clos</u> (Cl) at 90 kg N ha^{-1}

Photograph-5

Photograph-6

Comparative effect of control and <u>clos</u> at 30 kg N ha^{-1}

lowest level, the organomineral treatment established its superiority to compost alone treatment in effective tillers, straw and grain yields, straw and grain N uptake. The paragon performance of the organomineral combination is certainly and obviously linked with the mineralisation rates of the soil organic matter and the added organic matter and the uptake of NH_4-N by the rice plant in the wetland vertisol system (Murayama, 1979).

5.2.1. Erratic Behaviour of the Biofertilizer azo

The fact that azo of Alfisol ecotype in the vertisol was without any effect is not surprising because there are many reports of its success (Lehri and Tiwari, 1976; Kashirajan et al., 1976; Maskey, 1977) and of its failure (Allison, 1955) all related to soil types but what is surprising is the relative effect, i.e., a 4% drop in the yield. An etiological pathway is difficult to guess. Azobacters and clostridia are abundant and more so the latter as reported in Japanese soils (Yamaguchi, 1979). The aerobic sites are available in wide area of the aerobic-anaerobic interface in flooded water and in rice rhizosphere at the air-transporting system of the root-soil environment (Yoshida, 1975), and so native azotobacters are right therein. This ecotype might have induced inorganic toxins, Mn^{++}, H_2S or organic toxins such as butyric acid (Yoshida, 1975) which caused root

Photograph-7

Comparative effect of clos & control at 30 kg N ha^{-1}

Photograph-8

Comparative effect of azoclos & control at 90 kg N ha^{-1}

Photograph-9

Comparative effect of clos and control at 120 kg N ha^{-1}

Photograph-10

Comparative effect of organomineral N and compost with azoclos

Plate-3

injury and thus influenced adversely the transport of nutrients in the soil-plant system. Should caution be exercised in the use of such an ecotype? Answer will be no. The closed system of potted soil may be the cause of these toxins, which is very much likely to undergo temperance, when it finds its way to an open system of field with a widespread area for diffusion and detoxification. Nevertheless this treatment was a dropout among the selected treatments for the field. The vertisol ecotype in upland cultivation of the Cauvery paddy was reported by Dommalapaty (1982) to save 15-20 kg N ha^{-1}. However, the vertisol ecotype did exhibit its higher performance when present in the twin biofertilizer formulation, azoclos, that is amply borne out of the current investigation in the greenhouse and field trials, as well. Improvement of growth conditions by removal of toxic substances which may either be present originally in the growth environment or might have been produced during growth of nitrogen fixing bacteria, as reported by Jensen and Holm (1975) and is probably contributing to the excellent performance of the twin culture azoclos. In this connection special attention has been paid to removal of oxygen. The author expressed the opinion, that it is quite obvious in connection with anaerobic or facultative anaerobic nitrogen fixers, which are active only at low redox potential. Over and again the judicious use and the propriety of the formulation, and the ecotype, are aspects which cannot be questioned.

5.3. CRITIQUE OF N BALANCE STUDIES

The significance of phototrophic N_2 fixation in present vertisol paddy system happened to be remote as neither cynobacteria nor azolla were present in either of the two seasons, but the presence of native heterotroph is inevitable, then a natural question may arise as to how bacterial inoculants (clos and azoclos) contributed to a higher fertility build up of about 25%. The answer comes from the fact that the clostridial and azotobacter ecotypes selected were from that vertisol which constantly receives decomposing organic matter and is subjected to alternate wetting and drying from the water front and is thus endowed with tolerance property (Alexander, 1971) and hence they might have gained superiority over native heterotroph and became more dynamic, as in case of symbiotic system (Alexander, 1971). Moreover, favourable effect of flooding (Taka et al., 1967; Rao et al., 1973; Purushothaman et al., 1977), organic matter (Rao et al., 1973; Mishustin and Yemtsev, 1973; Wada et al., 1978) and of rhizosphere (Gopalakrishnamurthy et al., 1967; Magdoff and Bouldin, 1970) might have helped inoculated bacterial strains in improving nitrogen gains.

It is further supported by the observation of Ponnamperuma (1972), that the anaerobic bulk of soil would be an ideal medium for such anaerobic nitrogen fixers as clostridium especially if organic matter is present and the finding of Rice et al. (1967) that combination of aerobic anaerobic conditions dramatically increased nitrogen fixation in thin layer of soil amended with straw is also very pertinent to current investigation. Observations of Ito and Watanabe (1981) that out of total (biologically fixed) fixed N 34% was absorbed by the rice plant itself in 42 days. It reflects that a part of fixed N contributes towards soil fertility, which is reflected in the present N balance studies. Moreover, Koyama and App (1979) observed that in rice soil, N balance is often in an excess of recovery over supply, particularly when no fertilizer is supplied. This imbalance according to them is assumed due to biologically fixed nitrogen, which was estimated from 15 to 50 kg ha^{-1} per crop (in their studies). Further, according to them, application of N fertilizer usually eliminated this surplus and recovery often became less than the supply. Poor fertilizer efficiency was assumed by them as a result of losses of N and reflected in the reversal of N balance. In present investigation the N balance was in the range of 22 to 52 kg N ha^{-1} for various treatments over two years. Moreover, in present investigation also, lower nitrogen balance was recorded for higher levels of applied nitrogen. Thus the findings are more or less in accordance with the findings of aforesaid workers.

5.4. CONTRIBUTION OF BIOFERTILIZERS TO THE VERTISOL PRODUCTIVITY

The most outstanding, statistically significant, also agronomically significant and contributory to the soil productivity was the outcome that *clos* and *azoclos* in organomineral combination had given benefits through a linear increase in straw yield and curvilinear rise in grain yield. Moreover *azoclos* had statistically significant superiority over *clos* in agronomic benefits drawn from inoculation of these heterotrops. In this respect N equivalence data (as per worked out formula), though not comprehensible in statistical language has very pragmatic message to convey, that the biofertilizer inoculation, at higher levels of applied N, turned curvilinear trend observed in uninoculated control, into a linear one, and this was true for both the seasons. In this context observations made by Kashirajan *et al*., 1976, that the extent to which azotobacter inoculation could replace N for rice, when paddy straw was incorporated, resulted into saving of 25% of recommended dose of fertilizer, is somewhat in agreement to N equivalance data. Also from the longterm fertility experiment at IRRI, Koyama and App (1979) suggested that N input of about 50 kg ha^{-1} is to be replaced, which is removed by the crop. Observations of Mishustin and Yemtsev (1982) that the addition of organic matter, partly or wholly, can provide N input as N_2 fixation tends to increase under anaerobiosis and that the organic substance on decomposition yield such metabolites which are utilizable by clostridia, that are N_2 fixers under anaerobic conditions, provide reasonable explanation for the beneficial effect of biofertilizer inoculation.

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CHAPTER-VI

SUMMARY, CONCLUSIONS, AND SUGGESTIONS

6.1. SUMMARY

6.1.1. Pot Culture

Three factors, namely modern rice varieties, judicious use of fertilizer N whose price is spiralling, and recycling of organic wastes were considered for increasing the efficiency of paddy culture in vertisol to design an experiment of 10 levels of N inclusive of control and compost at 30 kg N ha^{-1} level, and four pairs of mineral and organomineral N (urea : compost ~~compost + urea~~ as 3:1) in multiples of the first level (30 kg N ha^{-1}) upto the highest level of 120 kg N ha^{-1}. On the treatments of mineral and organomineral combination the biofertilizers of two principal heterotrophic diazotrophs : *Azotobacter*, alfisol ecotype, *azo*; *Clostridium* vertisol type, *clos* and the twin inoculum, *Azotobacter* vertisol ecotype plus *Clostridium* vertisol ecotype (1:1), *azoclos* were imposed. The biofertilizers were applied at the rate of 400 g ha^{-1}, (200×10^6 viable cells g^{-1} of carrier) to seed, seedlings and soil seperately. Thus, after including the uninoculated controls, the treatments totalled to 40 and were tested in potted vertisol in greenhouse with the modern rice, Cauvery grown under wetland conditions. The data on total and effective tillers exhibited a critical pattern of response to mineral and organomineral N, which did not differ amongst themselves. The *azo* effect was not apparent, but the *clos* and *azoclos* effect caused 6 and 15% higher than the uninoculated control values and were different amongst themselves.

Likewise straw and grain yield exhibited the identical patterns. Except at 30 kg N ha^{-1} level, organomineral N application at all other levels was superior over mineral N application. The *azo* effect was nil in straw, and negative in grain causing a drop of 4%; the *clos* and *azoclos* gave rise by 12% and 14% respectively. As far as interaction is concerned, it was nonsignificant in the straw but significant in the grain yield. Organomineral N was superior to urea alone in the presence of bacterial cultures, *clos* and *azoclos* at 90 and 120 kg N ha^{-1} levels and also at 60 kg N ha^{-1} level in case of the *clos* culture. Urea was superior to compost at 30 kg N ha^{-1} level in uninoculated control in presence of *azo*. As the *azo* of alfisol type behaved erratically in lowering the yield, it was dropped from the panel of selected treatments for the field testing.

6.1.2. Field Trials

The selected treatments of the greenhouse trial viz. uninoculated control, compost and four organomineral N treatments together with *clos* and *azoclos* numbered 18, and were tested in the vertisol under field conditions for two consecutive seasons. The trend of results in total tiller and effective tiller were identical, the response to organomineral N happened to be linear. In the first season the organomineral N gave 18.5% higher effective tiller count at 30 kg N ha^{-1}, but it equalled the compost in the second season. The *clos* effect was nil but the *azoclos* effect was noticeable in both seasons with a 9.1% and 15.1% upward drift.

The trend of results in straw and grain yields were identical. The response to organomineral N was linear upto 60 kg N ha^{-1}, the levels of 90 and 120 kg N ha^{-1} not distinguishing among themselves in the succeeding season as well. The organomineral N gave 15% higher yield than the compost at 30 kg N ha^{-1} level in one season and 10% in the next season. Both *clos* and *azoclos* effect was observed in a consistent increase in the yield by 8% and 12% respectively in both seasons, and the *azoclos* effect was superior to the *clos* effect in both seasons.

6.1.2.1. N Uptake

The response pattern in straw and grain N uptake almost tallied with each other. In case of grain the organomineral N turned out 20% higher uptake than the compost at 30 kg N ha^{-1} level in the first season and 17.4% in the second season. Both *clos* and *azoclos* were effective in enhancing N uptake by a magnitude of 7.4% and 12-14% respectively in the two seasons, the latter being superior to the former. Regarding the interaction, in the data of straw the clos and azoclos effects were generally superior over uninoculated controls only in 1976; the increasing levels of organomineral N gave successive N uptake rise only in the clos treatments. However, in the case of grain, the interaction in the first season was significant but it became nonsignificant in the second season.

6.1.2.2. Soil N Content

The patterns for available N and total N in soil were found to be identical. Compost was superior to organomineral N at 30 kg ha^{-1} for each sampling in case of total N. The trend of linearity with respect to the applied N levels was the characteristic feature in both seasons, other effects being nonsignificant as in the case of the precropping data. The clos and azoclos effect was observed, the latter being superior to the former. The response to variable N levels was a linear rise in the clos and azoclos treatments. Further the available N in uninoculated control treatment was superior to the clos and azoclos treatments, at all levels of applied N except at the 120 kg ha^{-1} level.

6.1.2.3. Soil N Balance

The response was curvilinear with a hump at the 30 kg N ha^{-1} level in the first season, and in between 30 and 60 kg

ha^{-1} levels in the second season. The organomineral N created 8-9% higher balance in soil in both seasons over compost. The <u>clos</u> and <u>azoclos</u> effects were on parity in creating the N balance at a 25-30% higher level in both seasons. In the first season 30 kg N ha^{-1} level was superior to 120 kg N ha^{-1} level in creating higher N balance, and the <u>clos</u> and <u>azoclos</u> effects were on parity in this respect as well.

6.1.2.4. N Equivalence of Biofertilizers

The <u>clos</u> effect appeared fairly linear for N equivalence, resulting in a boost of N equivalence at the highest level of organomineral application and the <u>azoclos</u> effect followed the pattern of <u>clos</u>.

6.2. CONCLUSIONS

The paragon performance of organomineral combination, which turned out to be a judicious one, was closely linked with the mineralization rates of soil organic matter and the added organic matter.

The use of biofertilizers as singleton <u>clos</u> and the twin <u>azoclos</u> was not only agronomically a gainsome proposition through the enhancing of the applied organomineral N, but also contributory to the soil productivity, as evidenced by the N balance studies.

6.3. SUGGESTIONS

The clostridium vertisol ecotype was a lucky hit. There may be five main characteristics for rhizosphere N_2 fixation viz., (i) protection against oxygen, (ii) competitiveness and ability to colonize rice roots and use the substrates that are available in the rhizosphere, (iii) nitrogen-fixing efficiency, (iv) ability to fix N_2 in presence of combined nitrogen, and (v) ability to excrete fixed N_2 as ammonium. The resultant soil N balance studies in the current investigations may be confirmed by more sophisticated techniques like ^{15}N and acetylene reduction techniques for a rational, cogent and critical assessment. The above conclusions were arrived at from the factorial concept analysis of the field testing that involved horizontal and vertical interactions, and effect of seasons too and happened to be very pertinent from the point of improving the efficiency of fertilizer N in the paddy soil. However, the use of statistical procedures like cluster analysis may provide better and fuller information if computer facilities are available.

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* Original not seen.

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APPENDICES

Appendix-I: Chemical characteristics of the vertisol of the experimental field.

S.No.	Soil properties	Value
1.	pH[1]	7.50
2.	Electrical Conductivity[1] (m.mhos cm^{-1} at 25°C)	0.19
3.	Organic Carbon[2] (%)	0.58
4.	Cation Exchange Capacity[3] (me^{-1} 100 g soil)	48.6
5.	Calcium Carbonate[4] (%)	4.1
6.	Total N[3] (kg ha^{-1})	1402.24
7.	Available N[7] (kg ha^{-1})	215.81
8.	Available P[5] (kg ha^{-1})	7.9
9.	Available K[6] (kg ha^{-1})	363

1. Kanwar and Chopra (1959)
2. Walkley and Black (1934)
3. Black (1965)
4. Piper (1950)
5. Olsen *et al*. (1954)
6. Hanway and Heidel (1952)
7. SUBBIAH AND ASIJA (1956)

Appendix-II: Nitrogen content of compost samples used in greenhouse and field trials.

Year	Unit	Value
1975	(%N)	0.93
1976	(%N)	0.90
1977	(%N)	0.97

Appendix-III: Meteorological Observations - For the period May 1976 to October, 1976.

S.No.	Month & Year	Week No.	Temperature °C (weekly average)		R.H. (%) weekly average	Rainfall mm (weekly total)	No. of rainy days per week	Sunshine hours weekly average
			Maximum	Minimum				
1.	May 1976	22	40.0	24.5	35.0	10.4	1	7.9
2.	June 1976	23	35.5	25.2	76.8	31.8	5	7.4
3.		24	35.9	25.3	68.4	-	-	8.4
4.		25	34.3	25.3	73.1	15.5	2	7.9
5.		26	36.1	26.8	77.4	9.1	3	5.8
6.	July 1976	27	34.7	25.2	85.1	111.7	5	6.6
7.		28	28.6	24.1	92.3	119.4	6	2.7
8.		29	29.7	24.9	92.8	57.4	4	2.6
9.		30	29.0	24.2	92.8	167.4	4	2.8
10.	August 1976	31	29.9	24.5	92.8	74.7	5	4.5
11.		32	28.6	23.9	93.6	86.7	5	2.9
12.		33	28.1	23.9	93.4	22.5	4	3.2
13.		34	28.8	23.7	95.3	114.4	6	3.8
14.		35	30.1	24.0	93.3	85.1	5	6.9
15.	Sept. 1976	36	28.7	23.8	82.7	54.0	6	5.7
16.		37	29.0	23.9	93.7	23.2	4	6.4
17.		38	30.7	23.7	82.7	-	-	7.4
18.		39	31.3	22.6	87.0	-	-	9.9
19.	Oct. 1976	40	32.7	21.7	86.9	-	-	10.0
20.		41	31.9	18.8	86.9	-	-	10.3
21.		42	31.2	17.8	89.3	-	-	9.8
22.		43	32.5	18.2	76.0	-	-	10.0

Appendix-III (Contd...): Meteorological Observations - For the period May 1977 to October 1977.

S.No.	Month & Year	Week No.	Temperature °C (weekly average)		R.H. (%) weekly average	Rainfall mm (weekly total)	No. of rainy days per week	Sun shine hours weekly average
			Maximum	Minimum				
1.	May 1977	22	38.8	29.8	39.4	-	-	7.8
2.	June 1977	23	42.5	29.9	31.4	-	-	7.5
3.		24	35.8	25.8	74.4	42.7	4	0.7
4.		25	37.6	26.6	69.3	61.7	3	-
5.		26	26.7	24.2	95.8	387.2	7	-
6.	July 1977	27	28.2	24.4	93.1	139.1	4	-
7.		28	29.9	25.4	91.4	43.6	2	-
8.		29	30.8	25.6	91.3	77.3	4	-
9.		30	30.2	25.2	93.0	50.6	5	-
10.	August 1977	31	25.8	23.9	92.3	137.7	5	-
11.		32	28.2	24.1	95.3	192.2	6	-
12.		33	29.5	24.6	92.6	10.4	1	-
13.		34	30.1	24.7	85.7	88.9	5	-
14.		35	28.7	21.0	95.3	253.3	5	-
15.	Sept. 1977	36	28.9	24.3	92.7	132.4	5	5.4
16.		37	26.8	23.4	92.1	83.2	5	2.9
17.		38	29.9	23.1	90.8	-	-	8.8
18.		39	29.4	23.3	94.3	28.5	1	7.2
19.	Oct. 1977	40	29.3	22.8	95.1	186.9	3	7.0
20.		41	31.2	20.7	91.7	-	-	9.9
21.		42	32.1	19.4	88.0	-	-	10.0
22.		43	34.9	18.5	93.7	-	-	8.9

Appendix-IV: Schedule of operations in field trials.

S. No.	Operations	Date of operation	
		1976	1977
1.	Preparation of nursery plots	15.6.76	24.6.77
2.	Sowing in nursery beds	22.6.76	29.6.77
3.	Field preparation		
	(i) Ploughing & discing in experimental area	9.7.76	(b)
	(ii) Digging of individual plots	13&14-7-76	19 to 23-7-77
4.	Soil sampling from individual plots	(a)	24.7.77
5.	Application of compost	17.7.76	23.7.77
6.	Filling of water in plots	18.7.76	25.7.77
7.	Puddling of plots	19&20-7-76	26&27-7-77
8.	Application of basal dose of fertilizer	21.7.76	28.7.77
9.	Transplanting of nursery in plots	22.7.76	29.7.77
10.	Application of bacterial cultures	7.8.76	16.8.77
11.	Plant protection measures	10.8.76	18.8.77
12.	1st topdressing of urea	12.8.76	20.8.77
13.	2nd topdressing of urea	2.9.76	9.9.77
14.	Plant protection measures	14.9.76	23.9.77
15.	Tiller count	10&11-10-76	19&20-10-77
16.	Harvesting	18&19-10-76	25&26-10-77
17.	Soil sampling	26.10.76	30.10.77

(a) One composite sample for the entire experimental plot was drawn.

(b) Not done.

Appendix-V: Summary table for nitrogen content (percentage) in straw.

1976

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	2.1	3.1	3.2	3.3	3.4	
C	0.60	0.53	0.61	0.57	0.57	0.58	0.58
Cl	0.65	0.55	0.64	0.60	0.61	0.68	0.62
T	0.67	0.55	0.52	0.54	0.66	0.66	0.60
Mean	0.64	0.54	0.59	0.57	0.61	0.64	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	0.002	0.003	0.006
C.D.(5%)	0.01	0.01	0.02

1977

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	2.1	3.1	3.2	3.3	3.4	
C	0.60	0.52	0.60	0.56	0.56	0.57	0.56
Cl	0.64	0.54	0.63	0.59	0.60	0.67	0.61
T	0.66	0.64	0.51	0.53	0.65	0.65	0.61
Mean	0.63	0.56	0.58	0.56	0.60	0.63	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	0.002	0.003	0.006
C.D.(5%)	0.01	0.01	0.02

Appendix-VI: Summary table for nitrogen content (percentage) in grain.

1976

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	2.1	3.1	3.2	3.3	3.4	
C	1.06	0.97	1.06	0.97	1.09	1.03	1.03
Cl	0.93	1.00	1.05	1.05	1.03	1.04	1.02
T	1.05	1.03	1.03	1.03	1.00	1.06	1.03
Mean	1.01	1.00	1.05	1.02	1.04	1.04	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	0.007	0.009	0.016
C.D.(5%)	N.S.	N.S.	0.05

1977

Bacterial cultures	Levels/Sources for nitrogen applied						Mean for culture
	1.1	2.1	3.1	3.2	3.3	3.4	
C	1.05	0.93	1.07	0.97	1.04	1.02	1.01
Cl	0.93	1.00	1.03	1.03	1.02	1.00	1.00
T	1.03	1.00	1.03	1.03	1.05	1.03	1.03
Mean	1.00	0.98	1.04	1.01	1.04	1.02	

	Bacterial cultures	Levels/Sources for N	Cell means
S.E.(m)	0.008	0.012	0.020
C.D.(5%)	N.S.	0.03	0.06

VITA

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