EFFECT OF BIOFERTILIZERS ON THE GROWTH, YIELD AND NITROGEN ECONOMY OF SESAME GROWN IN SUMMER RICE FALLOWS

By

INDU K. PAUL

THESIS

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COLLEGE OF HORTICULTURE
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DECLARATION

I hereby declare that the thesis entitled "**Effect of biofertilizers on the growth, yield and nitrogen economy of sesame grown in summer rice fallows**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Vellanikkara
2-12-1995

Indu K Paul

INDU K. PAUL

Dr. K. E. SAVITHRI
Associate Professor
Department of Agronomy
College of Horticulture

2-12-1995

Vellanikkara

CERTIFICATE

Certified that the thesis entitled "Effect of biofertilizers on the growth, yield and nitrogen economy of sesame grown in summer rice fallows" is a record of the research work done independently by Indu K. Paul under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

DR. K. E. SAVITHRI
Chairperson

CERTIFICATE

We, the undersigned members of the Advisory Committee of **Indu K. Paul**, a candidate for the degree of **Master of Science in Agriculture** with major in **Agronomy**, agree that the thesis entitled **"Effect of biofertilizers on the growth, yield and nitrogen economy of sesame grown in summer rice fallows"** may be submitted by Indu K. Paul in partial fulfilment of the requirement for the degree.

DR. K.E. Savithri
Chairperson
Associate Professor (Agronomy)
College of Horticulture
Vellanikkara

Dr. E. Tajuddin
Director of Extension
Directorate of Extension
Mannuthy

Dr. M. V. Rajendran Pillai
Associate Professor
Department of Plant Pathology
College of Horticulture
Vellanikkara

Dr. U. Jaikumaran
Associate Professor
Agricultural Research Station
Mannuthy

External Examiner

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INDU K. PAUL

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Introduction

INTRODUCTION

The present level of oil production in India (5.7 mt) is insufficient to meet the oil requirement of 6 mt (Anon, 1994). It is estimated that India will require 9.6 mt of oil by the turn of the century. This necessitates an enhancement in the production of oil seeds.

Sesame is one of the oldest and important annual oil seed crops of India. Enhancement of production of sesame needs intensive cultivation. This requires the use of chemical fertilizers and irrigation. The chemical fertilizers which are based on non-renewable energy sources are not only in short supply but also expensive. Excessive use of chemical fertilizers may also affect the soil health and may lead to a negative impact on soil productivity. But, for sustainable agriculture, all our efforts should be streamlined to protect and maintain the soil health. In this context, now - a - days biofertilizers are gaining importance in agriculture. Results of research work conducted elsewhere in India indicate that biofertilizers can be applied as supplements to chemical fertilizers. But not much work has been done in Kerala in this line.

Sesame, an important oil seed crop of Kerala, is suitable for cultivation in the summer rice fallows. Its inclusion in the rice based cropping system will help to improve the productivity of the crop, maximise the net income and cost benefit ratio (KAU, 1991). In summer rice fallows, the incorporated stubbles of previously harvested rice crop may act as an energy source for the growth and activity of micro - organisms. Hence, the use of biofertilizers may give better results under such a situation. With this background, an investigation was undertaken with the following objectives.

1. To assess the possibility of using biofertilizers (**Azospirillum** and **Azotobacter**) as a source of nitrogen for sesame, grown in summer rice fallows.

2. To find out the effect of combination of chemical fertilizers and biofertilizers on the growth, and yield of the crop in such a situation.

3. To work out the nitrogen economy of sesame due to integration of chemical and biofertilizers.

Review of Literature

REVIEW OF LITERATURE

Some of the major works conducted in India and abroad regarding the various aspects of the biofertilizers, **Azospirillum** and **Azotobacter** are reviewed hereunder.

1. Sesame in summer rice fallows

Sesame is an oil seed crop suitable for summer rice fallows of Kerala. Among the different rice based cropping systems such as, rice-rice- daincha /cowpea /sesame/ fodder maize/short duration rice/fallow, tried in Kerala, rice-rice-sesame gave maximum net income, cost benefit ratio and a positive P balance (KAU 1991). Sarkar and Shit (1991) reported that sesame could be grown profitably in the Gangetic alluvial soils of Eastern India as a catch crop in summer rice fallows. Yadav et al. (1991) also reported that sesame was mainly grown after rice crop during January - May in West Bengal, Bihar and Orissa.

John and Nair (1990) observed that suitable plant architecture of sesame for summer rice fallows was dwarf stature with profuse branching, early flowering and maturity with a large number of capsules containing large sized seeds. Sesame varieties namely Kayamkulam - 2 (Thilothama), ACV-1 (Soma) and ACV-3 (Thilak) which are having similar characters are recommended for cultivation in summer rice fallows of Kerala (KAU, 1993).

2. Azospirillum as a biofertilizer

Azospirillum is an aerobic, nitrogen fixing bacteria which occur as an associative symbiont in the rhizosphere of many crop plants in tropics. Its use as a biofertilizer was reported by many workers. **Azospirillum** was found to increase the growth and yield of many crops like rice, wheat, maize, sweet potato, pulses, oil seeds, fruit crops, vegetables and some plantation crops (Venkateswarlu and Rao, 1983; Hill et al., 1983; Govindan and Purushothaman, 1985). However, its activity is influenced by several factors.

2.1. Genotype

Lee et al. (1977) observed variations in the N fixation rates in the rhizosphere of different rice varieties. The population of **Azospirillum** was distinctly more in the rhizosphere of C_4 plants than in C_3 plants (Purushothaman and Menon, 1984). There wasn't any specific association observed between wheat varieties and **Azospirillum** species (Indu Bala and Kundu, 1988). However, Yadav et al. (1992) observed definite specificity with maize genotype and the introduced **Azospirillum** strain. Wide variation was observed between **Azospirillum** population and different pearl millet cultivars (Purushothaman and Govindarajan, 1993). The sesame variety TMV-6, harboured significantly higher number of **Azospirillum** population than other varities tested namely, CO-1, TMV-3, TMV-4, TMV-5 (Ramanathan and Prasad, 1993).

2.2. Temperature

The optimum temperature for N dependent growth by **Azospirillum** has been found to be between 32°C and 42°C and is similar to the temperature optimum reported for other N fixing bacteria in tropics (Day and Dobereiner, 1976). It was observed by Neyra and Dobereiner (1977) that fast growth of **Azospirillum** was in the temperature range of 32-36°C and maximum nitrogenase activity between 33-40°C. The higher incidence of **Azospirillum** in tropical areas has been attributed to the high temperature requirement of these bacteria (Van Berkum and Bohlool, 1980).

2.3. Light intensity

Effect of light intensity on the association between maize and **Azospirillum** population investigated by Albrecht et al. (1977) showed that it had only a small influence on N fixation. However, Cohen et al. (1980). Obtained highest acetylene reduction rates with high light intensities.

2.4. Soil aeration

Azospirillum is an aerobic microbe (Dobereiner, 1974). Its survival was well established even under low oxygen supply (Day and Dobereiner, 1976; Okon et al., 1976 a). Nelson and Knowles (1978) obtained high rates of acetylene reduction when the dissolved oxygen pressure was between 0.005 and 0.007 atmospheres.

2.5. Soil pH

Azospirillum growth is best at a soil pH near neutrality. Day and Dobereiner (1976) observed that N fixed by **Azospirillum** was on the surface or within the root cells where the specific pH could be met. Most of their growth was reduced at pH 7.8 and very much limited above this range (Okon et al., 1976 a). However, occurrence of **Azospirillum** species with appreciable N fixing ability has been observed in acid sulphate soils with an extremely low pH of 3.2 (Charyulu and Rao, 1980) and also in alkaline and saline soils with a pH of 8.2 to 8.8 (Purushothaman and Oblisami, 1985).

2.6. Soil organic matter

The number of **Azospirillum** cells was found to be positively correlated to soil organic matter. Low organic matter content severely affected associative N fixation (Albrecht et al., 1981). Rhizosphere samples from soils ammended by rice straw, exhibited higher rate of N fixation than from unammended soils. In addition, rice straw application @ 6 t/ha prevented the inhibitory effect of application of fertilizer N on **Azospirillum** (Charyulu et al., 1981). Application of straw and **Azospirillum** resulted in maximum nitrogenase activity in maize compared to **Azospirillum** application alone (Hegazi et al., 1983). According to Rangarajan and Subramanian (1993), there was a significant increase in the population of **Azospirillum** when inoculated along with green leaf manure and cowdung slurry.

2.7. Soil moisture

Soil moisture determined the efficiency of **Azospirillum** establishment (Weir, 1980). Increasing the moisture content in soil, upto field capacity maximised nitrogenase activity of **Azospirillum** on sorghum roots (Hegazi, 1983). A low but significant correlation existed between soil moisture and nitrogenase activity of **Azospirillum** (Wani et al., 1983). Dry conditions were extremely deleterious to **Azospirillum** (Bhatt et al., 1991).

3. Effect of **Azospirillum** on crop plants

3.1. Growth

Subba Rao et al. (1980) reported an increased dry matter production in paddy due to **Azospirillum** inoculation. A significant increase in plant height (Sonoria et al., 1982) and number of tillers per plant (Prasad and Singh, 1984) was observed in rice due to **Azospirillum** inoculation. However, reports by Watanabe and Lin (1984) revealed that **Azospirillum** inoculation either as seedling root dip or as soil application did not increase the total dry matter production of wet land rice. The plant height of rice too did not show any variation due to **Azospirillum** inoculation over control (Gopalaswamy et al., 1989).

Several workers reported that dry matter production in wheat, due to **Azospirillum** inoculation (Kapulnik et al., 1979; Subba Rao, 1979; Dobereiner and Baldani, 1981). Hegazi et al. (1981) observed a non significant increase in height and number of tillers. However, Kapulnik et al. (1981) observed a significant increase in plant height and leaf length of wheat due to **Azospirillum** inoculation. Experiments conducted by Zambre et al. (1984) in Maharashtra and Padshetty et al. (1986) in Karnataka, showed that wheat dry matter production increased with **Azospirillum** inoculation compared to uninoculated control.

Dry weight of maize crop slightly increased due to **Azospirillum** inoculation over uninoculated control (Kapulnik et al., 1979; Cohen et al., 1980; Nur et al., 1980 and Tilak et al., 1982). But Hegazi et al. (1983) reported 200 per cent increase in plant dry weight of maize as a result of **Azospirillum** inoculation. Straw ammendment with **Azospirillum** recorded 343 per cent increase in plant dry weight. However, Prabhakara and Rai (1991) in Bangalore and Fulchieri and Frioni (1994) in Argentina observed no significant effect on dry matter production of maize crop due to **Azospirillum** inoculation.

Subba Rao et al. (1980) observed an increase in dry matter production in barley due to **Azospirillum** inoculation. However, a significant increase in plant height and leaf length was observed in sorghum plants by Kapulnik et al. (1981) when they were inoculated with **Azospirillum**.

Radder et al. (1969) observed an increase in plant height of bajra when inoculated with **Azospirillum**, over uninoculated control. Application of **Azospirillum** significantly increased the dry matter production of bajra (Smith et al., 1978). However, in USA, Bouton et al. (1979) observed only a non significant increase in dry matter production of bajra due to **Azospirillum** inoculation.

According to Reddy (1981), though plant height and number of tillers increased significantly, only a slight increase was recorded in leaf area index of bajra when inoculated with **Azospirillum**, over uninoculated control. Govindan (1982) and Venkateswarlu and Rao (1982) revealed from their experiments that a significantly higher biomass could be produced by **Azospirillum** inoculation in bajra plants but Smith et al. (1984) could obtain only a non significant increase in the same. Gautam et al. (1985) observed a significant increase in the number of tillers per plant and a slight increase in plant height at 30 DAS and 60 DAS when inoculated with **Azospirillum**.

Cohen et al. (1980) and Jagatheesan (1984) observed an increase in plant height, number of stems per m^2 and dry matter production due to **Azospirillum** inoculation in foxtail millet and finger millet respectively.

Sarig et al. (1986) observed that dry matter production in chickpea and gardenpea was not affected by **Azospirillum** inoculation. However, a significant increase in the same was reported by Gallo and Fabbri (1990) and Menon and Pillai (1994).

According to Subbian and Chamy (1984) the plant height of sesame was not affected by **Azospirillum** inoculation. However, the number of branches per plant showed a slight increase. Similar results were reported by Saravanan and Sundaram (1991) in sunflower. Elango et al. (1995) observed that seed inoculation of sunflower with **Azospirillum** gave higher germination per cent, seedling height and vigour compared to uninoculated control.

Konde and Patil (1993) reported a significant increase in dry matter production of green chillies due to **Azospirillum** inoculation over uninoculated control. However, in onion, Subbiah (1994) observed no effect on dry matter production due to **Azospirillum** inoculation.

The above review shows that **Azospirillum** inoculation variably influenced the growth of crop plants, depending upon agro-climatic situations.

3.2. Yield attributes and yield

Grain yield of rice increased due to **Azospirillum** inoculation (Subba Rao, 1979; Natarajan et al., 1980; Subba Rao, 1981). Number of productive tillers, number of grains per panicle and grain yield increased in **Azospirillum** inoculated rice plants (Prasad and Singh, 1984). Inoculation of **Azospirillum** along with fertilizer nitrogen increased the yield and yield components of rice in an experiment conducted at Tamil Nadu (Lakshminarasimhan and Pannerselvam, 1991). **Azospirillum** inoculation through seed plus soil significantly enhanced grain yield of rice compared to uninoculated control (Gopalaswamy et al., 1993).

In wheat plants, **Azospirillum** inoculation increased grain yield (Kapulnik et al., 1979 and Subba Rao, 1979). Application of farmyard manure plus **Azospirillum** increased grain yield of wheat plants significantly (Lal and De, 1980). Kapulnik et al. (1981) observed an early heading and flowering of **Azospirillum** inoculated wheat plants. A significant increase in grain yield of wheat due to inoculation of **Azospirillum** was reported by Avivi and Feldman (1982), Reynders and Vlassak (1982), Rai and Gaur (1982) and Dreesen and Vlassak (1984). Millet and Feldman (1984) in Israel, observed a non significant increase in the number of tillers per plant, number of grains per panicle and grain yield and a significant increase in 1000 seed weight of **Azospirillum** inoculated wheat plants over uninoculated control. Experiments conducted at Maharashtra, showed that grain yield of wheat was higher at all levels of nitrogen (0,30,60,90,120, kg N/ha) when inoculated with **Azospirillum** compared to corresponding uninoculated control, with significant differences between each nitrogen levels and 120 kg N/ha being superior among the levels (Zambre et al., 1984). However, Padshetty et al. (1986) at Karnataka, observed that **Azospirillum** inoculation could not bring about any significant effect on grain yield of wheat.

Kapulnik et al. (1979) observed a non significant increase in maize grain yield due to **Azospirillum** inoculation. However, a significant increase was recorded over uninoculated control by Natarajan and Oblisami (1980). **Azospirillum** inoculation gave higher grain yield of maize over the range of 1/3rd to 2/3rd level of nitrogen fertilization (Konde and Shende 1984). Srinivasan et al. (1992) in Tamil Nadu and Yadav et al. (1992) in Bihar observed a higher grain yield by **Azospirillum** inoculation in maize. Fulchieri and Frioni (1994) in Argentina, reported that seed yield of maize in **Azospirillum** inoculated plots was 1.59 times greater than that in control where as corresponding increase in the inorganic nitrogen fertilized plots was 1.48 fold.

Subba Rao (1979) reported a general increase in grain yield of barley due to **Azospirillum** inoculation. Tilak and Murthy (1983) observed that inoculation of barley with **Azospirillum** increased grain yield from 21.7 per cent to 25.9 per cent in hull less types and 11.6 per cent to 26.7 per cent in hulled types.

Subba Rao et al. (1980) observed 28.3 per cent increase in grain yield of sorghum as a result of **Azospirillum** inoculation over uninoculated control. Kapulnik et al.

(1981) observed that there was an early heading and flowering in sorghum plants due to **Azospirillum** inoculation. Significant increase in 1000 grain weight and yield was noted by Okon et al. (1981) under non irrigated conditions, when sorghum plants were inoculated with **Azospirillum**. Sarig et al. (1981), Subba Rao (1981) and Konde and Shende (1984) reported higher grain yield from inoculated sorghum plants. Similar results were reported by Prabakaran (1991) where the yield increase in sorghum was 27 per cent over uninoculated control.

Azospirillum inoculation brought about significant increase in the number of grains per panicle over uninoculated control in bajra (Patil and Patil, 1970). Significant yield increase in bajra due to **Azospirillum** inoculation was reported by Smith et al. (1977), Kaushik and Gautam (1980), and Purushothaman and Gunasekaran (1980). Reddy (1981) and Govindan (1982) observed a significant increase in the 1000 grain weight of bajra due to **Azospirillum** inoculation. Reynders and Vlassak (1982) noted a significantly higher number of grains per panicle in bajra due to **Azospirillum** inoculation. But, Smith et al. (1984) and Gautam et al. (1985) observed only a non significant increase in grain yield by the same. In Rajasthan, Pareek and Shaktawat (1988) also reported similar results. Seed inoculation with **Azospirillum** along with recommended dose of nitrogen fertilizer (50 kg N/ha) had increased the grain yield of bajra by 38 per cent (Raghuwanshi, 1991).

Cohen et al. (1980) and Subba Rao et al. (1983) observed increased grain yield in foxtail millet and finger millet respectively due to **Azospirillum** inoculation. A non significant increase in 1000 grain weight was observed in finger millet due to **Azospirillum** inoculation by Jagatheesan (1984). Yahalom et al. (1984) observed a significant increase in grain yield of foxtail millet when inoculated with **Azospirillum**.

In chick pea and garden pea, Sarig et al. (1986) observed 29 per cent increase in number of pods per plant and a significant increase in seed yield with **Azospirillum** inoculation. However, there was no effect on the 1000 seed weight due to inoculation.

Subbian and Chamy (1984) observed that in sesame experiments conducted at Coimbatore, higher number of capsules per plant was obtained when farmyard manure was added along with **Azospirillum** inoculation. A significant increase in grain yield of mustard due to **Azospirillum** inoculation was reported by Saha et al. (1985). Sreedhar et al. (1988) also reported the same in sesame crop. Saravanan and Sundaram (1991) observed that inoculation with

Azospirillum resulted in an yield of 1490 kg/ha against 950 kg/ha in uninoculated control. Ram et al. (1992) reported an increase in 1000 seed weight due to inoculation though the effect was not significant.

Sweet potato yield was found to increase due to **Azospirillum** inoculation (Mortley and Hill 1990). Shinde et al. (1991) and Konde and Patil (1993) reported significantly higher yields in sugarcane and green chillies respectively over uninoculated control. Significant increase in the number of bolls per plant, boll weight and seed yield was observed in **Azospirillum** inoculated cotton plants (Prasad and Prasad 1994).

3.3. Quality

Azospirillum inoculation of wheat significantly increased the N content of grains (Kapulnik et al., 1981). However, Millet and Feldman (1984) observed that **Azospirillum** inoculation did not show any effect on the grain protein content when compared to nitrogen fertilized plot. An increase in grain protein content in rice was observed due to **Azospirillum** inoculation though the effects were not significant (KAU, 1991 and Rangarajan and Subramanian, 1993).

Seed inoculation with **Azospirillum** showed a non significant increase in nitrogen content of sorghum grains (Kapulnik et al., 1981 and Okon et al., 1981). In Rajasthan, Pareek and Shaktawat (1988) found no effect on the quality of pearl millet due to **Azospirillum** inoculation.

In mustard, **Azospirillum** inoculation had no influence on protein content of seeds (Saha et al., 1985).

3.4. N, P and K uptake

Prasad and Singh (1984) reported that there was a significantly higher uptake of N, P and K in **Azospirillum** inoculated rice plants while the contents were comparable to uninoculated control. Watanabe and Lin (1984) also observed that there was no increase in N content of wet land rice when inoculated with **Azospirillum**.

Azospirillum inoculation of wheat plants significantly increased total N content in plants (Kapulnik et al., 1981). A non significant increase was observed in the total N uptake of **Azospirillum** inoculated wheat plants (Baldani et al., 1986).

A slight increase in total N content of maize inoculated with **Azospirillum** was obtained over control (Okon et al., 1976 b and Nur et al., 1980). N uptake in maize was increased by 18 per cent (Kapulnik et al., 1981) and total N content by 157 per cent (Hegazi et al., 1983) when inoculated with **Azospirillum**. When this was done along with straw ammendment, 196 per cent increase in total N content was obtained. Experiments conducted at Bangalore revealed that N and P contents in maize plants were increased when treated with **Azospirillum** (Prabhakara and Rai, 1991).

Significant increase in total N content due to inoculation was reported by Kapulnik et al. (1981) in sorghum plants. Pal and Malik (1981) reported that **Azospirillum** inoculation contributed to the N uptake of sorghum to the extent of 5.8 to 19.6 kg N/ha. However, the contribution of **Azospirillum** inoculation to the N needs was increased by addition of farmyard manure @ 10 t/ha. Sarig et al. (1981) observed that N, P and K contents of sorghum were increased due to **Azospirillum** inoculation. Pacovsky et al. (1985) observed that the N uptake, P uptake and N content of sorghum plants inoculated with **Azospirillum** were comparable with those in plots fertilized with N alone.

Bouton et al. (1979) observed a non significant increase in total N uptake in bajra due to **Azospirillum** inoculation. **Azospirillum** in association with foxtail millet increased total N content in plants by 50-100 per cent (Cohen et al., 1980). Ciocco and Caceres (1994) observed an increase in total N uptake by foxtail millet due to **Azospirillum** inoculation.

In mustard, Saha et al. (1985) observed that neither **Azospirillum** inoculation alone nor in combination with applied N could bring about any significant change in the N content of grains but total N uptake was significantly increased by **Azospirillum** inoculation alone. **Azospirillum** inoculation in sunflower increased the N content in plants over uninoculated control (Saravanan and Sundaram, 1991).

Experiments conducted at Maharashtra revealed that **Azospirillum** inoculation did not significantly increase the N content of green chillies. However, the N uptake, P uptake and P content were significantly increased by **Azospirillum** inoculation (Konde and Patil, 1993). Menon and Pillai (1994) observed that **Azospirillum** inoculation of cowpea resulted in 33.1 per cent increase in shoot nitrogen content compared to control. Subbiah (1994) reported that **Azospirillum** inoculation in chillies increased the N and P content and significantly increased N uptake. Subbiah (1994) reported that N, P and K contents in onion were increased significantly when treated with **Azospirillum** but the P uptake alone was significant.

The foregoing review reveals that the yield, quality and N, P, K uptake of crop plants may be enhanced by **Azospirillum** inoculation.

4. Azotobacter as a biofertilizer

Azotobacter is one of the well known aerobic, freeliving, heterotrophic nitrogen fixing bacteria, present in the rhizosphere of crop plants. Bacterization of seeds with **Azotobacter** is well known to improve the yield of a wide range of field crops (Sundara Rao et al., 1963; Brown et al., 1964; Gopalakrishnamoorthy et al., 1967; Patil, 1969 and Mishustin, 1970). Besides N fixation, it has the ability to produce considerable quantities of antifungal antibiotics, fungistatic compounds (Mishustin and Schillinkova, 1972) and to secrete certain growth promoting substances like auxins, gibberillins and cytokinins (Rosario and Barea, 1975). Although inoculation with **Azotobacter** could significantly increase yield, its performance was generally inconsistent due to the complexity of the system (Shende et al., 1991).

4.1. Genotype

Varieties of the same crop differed in their ability to colonise **Azotobacter** and in case of rice, each variety was considered to be specific in harbouring **Azotobacter** in their rhizosphere (Yoshida et al., 1973).

4.2. Temperature

Iswaran and Sen (1958) reported that **Azotobacter** can tolerate temperature as high as 45°C. However, Tilak and Sundaram (1991) observed **Azotobacter** to be a typical mesophilic bacteria and the optimum temperature at which they multiplied better was between 25°C and 30°C.

4.3. Light intensity

Dhar and Seshacharyulu (1939) reported that population of **Azotobacter** slightly decreased with increasing light intensity. Under tropical conditions, where sunlight is abundant, **Azotobacter** does not play a big role in increasing the N status of soil and the effective N fixation gradually decreased with increasing duration of light intensity (Bahadur and Sorabji, 1970).

4.4. Soil aeration

N fixation by **Azotobacter** was inhibited due to higher oxygen tension (Meyerhoff and Burk, 1928). Being aerobic, **Azotobacter** needed continuous supply of oxygen and its needs were unique. At the same time it could also multiply in microaerophilic conditions (Jensen, 1954).

4.5. Soil pH

Subramoney (1950) reported that **Azotobacter** species isolated from soils, with a pH range of 2.5-4.5 grew equally well on media supplied with and without $CaCO_3$. Although Iswaran (1964) observed no correlation between N fixation by **Azotobacter** and soil pH, Rasal et al. (1986) found a neutral to alkaline soil pH good for their growth. However, in Kerala, **Azotobacter** is isolated from the karappadam soils of Kuttanad where the soils are highly acidic.

4.6. Soil organic matter

Gaur and Mathur (1966) observed a beneficial effect of humus on the growth of **Azotobacter**. Gaur et al. (1971) reported that wheat straw stimulated **Azotobacter** population. Monib et al. (1974) also observed that addition of organic matter greatly influenced **Azotobacter** and other soil microflora. Hardy and Havelka (1975) found that availability of photosynthates was the key factor of N fixation. However, Gupta and Tripathi (1986) reported that organic carbon content of soils had no effect on **Azotobacter**.

4.7. Soil moisture

Azotobacter cells required high humidity and their moisture requirement resembled that of higher plants (Mishustin, 1970).

5. Effect of Azospirillum on crop plants

5.1 Growth

Rangarajan and Muthukrishnan (1976) observed an increase in plant height, number of tillers / plant and leaf area in rice when **Azotobacter** was inoculated along with application of farmyard manure. The dry matter production of **Azotobacter** inoculated rice seedlings was higher compared to uninoculated control. Prasad and Singh (1984) observed a non significant increase in the number of tillers per plant due to **Azotobacter** inoculation.

Patil (1969) reported that **Azotobacter** inoculated wheat seedlings were twice as tall as that in uninoculated control. Similar results were reported by Badgire and Bindu (1976). The number of tillers /plant and leaf area were comparable but a significant increase in dry matter production was obtained due to **Azotobacter** inoculation in wheat. Ghai et al. (1976) observed significant increase in plant height in wheat due to **Azotobacter** inoculation whereas

Dhillon et al. (1980) observed a non significant increase in its growth characters. Similar non-significant effects of **Azotobacter** inoculation were reported by Zambre et al. (1984) in Maharashtra and Tomar et al. (1995) in Madya Pradesh.

Dey (1972) observed an increase in dry matter production of **Azotobacter** treated maize plants over uninoculated control, though the effect was not significant. Moreover application of 50 kg N/ha plus **Azotobacter** resulted in a significantly higher dry matter production over 50 kg N/ha alone. Karthikeyan (1981) reported a significant increase in plant height, leaf area index and dry matter production of **Azotobacter** inoculated maize plants. Seedling root dip with **Azotobacter** at the time of transplanting improved the vegetative components over control (Manoharan, 1989).

Wani and Rai (1980) reported an increased dry matter production in sorghum due to **Azotobacter** inoculation over uninoculated control. Experiments conducted at Akola, revealed that the height and leaf area index of sorghum plants were not significantly influenced by **Azotobacter** inoculation. However, the dry matter production showed a significant increase over uninocuated control (Nagre et al., 1990). A significant increase in germination was observed in hybrid sorghum due to **Azotobacter** inoculation (Rasal and Patil, 1993).

Oblisami et al. (1976 a) observed a non significant increase in height of sunflower plants due to **Azotobacter** inoculation. Whereas Elango et al. (1995) reported a significant improvement in germination per cent, seedling height and vigour of sunflower over uninoculated control.

Brown and Carr (1984) reported an increased dry matter production in lettuce during the early stages of growth when inoculated with **Azotobacter**. Singh (1984) observed higher dry matter production in sugarcane due to **Azotobacter** inoculation. Thakre et al. (1992) observed increase in plant height, number of branches / plant and leaf area index in bhindi due to **Azotobacter** inoculation.

5.2. Yield attributes and yield

Mehrotra and Lehri (1971) reported that **Azotobacter** inoculation did not increase rice yield. However, significant increase in rice yield by **Azotobacter** inoculation was reported by Rangarajan and Muthukrishnan (1976). They also observed that the number of productive tillers / plant and the number of grains / panicle were increased significantly over uninoculted control. However, only a slight increase was noticed in the number of grains / panicle, productive tillers, 1000 seed weight and grain yield due to inoculation.

Rao _et_ _al_. (1963) and Badgiri and Bindu (1976) observed an increase in grain yield of wheat due to **Azotobacter** inoculation. A slight increase in the number of grains /year and a significant increase in grain yield of wheat due to **Azotobacter** inoculation was reported by Ghai _et_ _al_. (1976). Though at Hyderabad, Reddy (1981) obtained a significant increase by **Azotobacter** inoculation in the grain yield, Singh _et_ _al_. (1981) found no advantage due to **Azotobacter** inoculation in wheat over chemical N fertilizer. Palarpwar (1983) and Zambre _et_ _al_. (1984) also reported increased grain yield of wheat due to **Azotobacter** inoculation. However Sharma _et_ _al_. (1987) observed that **Azotobacter** inoculation couldn't replace the chemical fertilizer alone in wheat.

Singh _et_ _al_. (1981) observed no advantage of inoculation of maize with **Azotobacter**, whereas Manoharan (1989) found that the yield components of maize were increased due to **Azotobacter** inoculation.

Shetty _et_ _al_. (1976) and Bhargava _et_ _al_. (1981) observed a significant yield increase with **Azotobacter** inoculation in ragi and bajra plants respectively over uninoculated control. But , Yahalom et al. (1984) observed no significant effect on the grain yield of **Azotobacter** inoculated foxtail millet. Naik and Dhagat (1987) revealed from their experiments that **Azotobacter** alone or in combination with farmyard manure did not increase the yield of kodo millet.

Sundara Rao (1965) reported that inoculation of **Azotobacter** in combination with fertilizer is effective in producing more kappas yield of cotton. Application of **Azotobacter** with or without farmyard manure increased the yield of cotton in rainfed black cotton soils of Tamil Nadu (Pothiraj, 1979). Increased yield of cotton by **Azotobacter** inoculation was also reported by Kundu and Gaur (1980) and Malik et al. (1994). An increase in the number of bolls / plant, boll weight, kappas and seed yield of cotton was observed by Prasad and Prasad (1994) due to **Azotobacter** inoculation.

Arunachalam and Venkatesan (1984) and Subbian and Chamy (1984) reported that seed yield of sesame was increased due to **Azotobacter** inoculation. Under field conditions, Agarwal (1985) and Saha et al. (1985) observed 35-60 per cent yield increase in mustard, by **Azotobacter** inoculation. **Azotobacter** inoculation increased the seed yield (52 per cent) of mustard significantly though the number of pods / plant, number of seeds / pod and 1000 seed weight showed only a marginal increase (Singh and Bhargava, 1994).

A significant increase in yield was observed in **Azotobacter** inoculated cabbage plants (Brown et al., 1964). However, Mehrotra and Lehri (1971) reported no significant effect due to **Azotobacter** inoculation in cabbage, tomato and brinjal. An yield increase of 39 per cent in chillies was observed by Shetty et al. (1976) due to **Azotobacter** inoculation. Thakre et al. (1992) observed an increase in yield of bhindi plants when inoculated with **Azotobacter**.

5.3. Quality

Zambre et al. (1984) observed an increase in protein content of wheat grains due to **Azotobacter** inoculation over uninoculated control from experiments conducted at Maharashtra. N concentration of sorghum grains increased slightly with **Azotobacter** inoculation at Akola (Nagre et al., 1990).

5.4. N, P and K uptake

Rao et al. (1963) and Ghai et al. (1976) observed an increase in N and P uptake by **Azotobacter** inoculated wheat plants. In maize plants, Karthikeyan (1981) observed an increased N and K uptake due to **Azotobacter** inoculation. N, P and K uptake by **Azotobacter** inoculated rice plants was significantly higher though the N, P and K contents were almost comparable to uninoculted control (Prasad and Singh, 1984). In sugarcane, the N content was significantly increased with **Azotobacter** inoculation (Singh, 1984). Nagre et al. (1990) observed that N content and N uptake were increased due to **Azotobacter** inoculation in sorghum plants.

The above review reveals that the growth, yield and quality of crops may be enhanced by **Azotobacter** inoculation.

6. Effect of Azospirillum/Azotobacter inoculation on

6.1 Nitrogen economy

In rice, Oblisami et al. (1976 b) reported that the number of grains / panicle, 1000 grain weight and grain yield obtained with **Azotobacter** inoculation plus 75 per cent of recommended dose of fertilizer N were comparable to that of application of cent per cent fertilizer N. But significant yield increase was noticed when **Azotobacter** was inoculated along with cent per cent fertilizer N. Jeyaraman and Ramiah (1986) observed similar results with **Azospirillum** regarding yield components of rice from experiments conducted at Madhurai. However, the grain yield was significantly higher when **Azotobacter** was inoculated along with 75 kg N/ha but comparable when inoculated along with 50 kg N/ha, over the recommended level of 100 kg N/ha alone. Similar results were also reported by Purushothaman (1988) and Gopalaswamy et al. (1989). Kumar and Balasubramanian (1989) observed that **Azospirillum** inoculation in nursery and main field of rice could save 25 to 50 per cent of fertilizer N without reducing grain yield. Kandasamy et al. (1991) reported that beneficial effect of **Azospirillum** in increasing rice grain yield was more pronounced when inoculated along with application of fertilizer N @ 75 kg N/ha.

Dhillon et al. (1980) observed a saving of fertilizer N upto 7 kg/ha in wheat crop on inoculation with **Azotobacter.** Karthikeyan (1981) reported that grain yield of maize obtained with 100 per cent of recommended dose of N (135 kg/ha) without **Azotobacter** inoculation was on par with 75 per cent recommended dose of N (101.25 kg/ha) with **Azotobacter** inoculation.

Field experiments with sorghum revealed that **Azospirillum** inoculation with 75 per cent of the recommended dose of fertilizer N increased grain yield (Smith et al., 1978). Field experiments all over India revealed that mean increase in grain yield of sorghum due to **Azospirillum** inoculation over uninoculated control was equivalent to that obtained by the application of 15-20 kg N/ha (Subba Rao et al., 1980). In sorghum, grain yield obtained with 66 kg/ha of fertilizer N plus **Azospirillum** inoculation was almost equal with 100 kg fertilizer N/ha alone (Desale and Konde, 1984). In Rajasthan, Porwal and Singh (1989) observed in sorghum that 40 kg N/ha of fertilizer N plus seed and soil inoculation with **Azospirillum** gave a grain yield on par with 80 kg fertilizer N/ha alone, giving a maximum net income of Rs. 7157/ha and a cost benefit ratio of 1:2.3. Thus 40 kg N/ha could be saved by **Azospirillum** inoculation without significant reduction in grain and straw yield of sorghum. **Azospirillum** or **Azotobacter** inoculation in sorghum had increased grain yield by 25 per cent over uninoculated control which saved 20 kg N/ha in Maharashtra (Raghuwanshi et al., 1991).

Purushothaman et al. (1979) observed similar results in pearl millet with **Azospirillum** inoculation. Muthukrishnan et al. (1981) reported that **Azospirillum** treatment along with 75 per cent of recommended dose of fertilizer N in finger millet produced yield comparable to full dose of fertilizer N alone.

In sunflower, Oblisami et al. (1976 a) observed a significant yield increase , when 75 per cent of the recommended fertilizer N plus **Azotobacter** inoculation was compared to 100 per cent fertilizer N, thus saving 25 per cent N fertilizer. Seed yield of cotton was significantly increased due to **Azospirillum** inoculation which saved 25-30 kg fertilizer N/ha (Purushothaman and Gunasekaran, 1981). Arunachalam and Venkatesan (1984) at Coimbatore observed that the application of 15 kg fertilizer N/ha plus **Azospirillum** in sesame, produced similar grain yield as that obtained with 30 kg fertilizer N/ha, the full recommended dose, indicating the possibility of reducing 50 per cent of fertilizer N. Subbian and Chamy (1984) reported a 25 per cent saving in the recommended dose of fertilizer N (30 kg/ha) in sesame, when **Azospirillum** or **Azotobacter** was inoculated along with fertilizer N.

Similarly at Karnal, 25 per cent (37.5 kg/ha) of the recommended dose of fertilizer N could be saved if **Azospirillum** or **Azotobacter** was inoculated either on setts or in the soil, in sugarcane, along with fertilizer application (Misra and Naidu, 1990). They also reported that **Azospirillum** or **Azotobacter** inoculation along with 100 per cent inorganic N produced sugarcane yield which was statistically superior to 100 per cent inorganic N alone. Durai and Mohan (1991) reported that application of 225 kg fertilizer N/ha plus **Azotobacter** inoculation gave superior cane yield compared to 275 kg fertilzer N/ha alone. Kumar and Lakshminarasimhan (1993) from their experiments conducted in Tamil Nadu also revealed that 25 per cent of recommended dose of inorganic fertilizer N could be substituted with **Azotobacter** inoculation.

Oblisami et al. (1976) reported that tuber yield of sweet potato obtained by **Azotobacter** inoculation along with 50-75 per cent of recommended dose of fertilizer N was comparable to that obtained by application of cent per cent fertilizer N alone. Experiments conducted at Tamil Nadu in brinjal by Sivakumar et al. (1991) revealed that treating with **Azotobacter** plus 30 kg fertilizer N/acre produced 7.21 per cent more yield than 40 kg fertilizer N/acre without any inoculum. Subbiah (1994) reported that 75 per cent of inorganic N plus **Azospirillum** inoculation gave comparable yield with 100 per cent chemical N alone in green chillies.

The above review shows that **Azospirillum** or **Azotobacter** as a biofertilizer can partially substitute the inorganic fertilizer N needs of crop plants without any adverse effect on seed yield.

6.2 Soil fertility status

Yahalom et al. (1984) reported that N content of soil was not affected by **Azospirillum** inoculation of Setaria italica in Netherlands. In experiments conducted at West Bengal, Saha et al. (1985) observed a significant increase in total N content of rhizosphere soil (16.7 %) due to **Azospirillum** inoculation in mustard over uninoculated control at 40 DAS while no such effect was found at harvest. Subramaniam (1987) reported that available N, P and K contents of the soil were not influenced by treating rice plants with **Azospirillum**. **Azospirillum** inoculation promoted mineralisation of organic matter in the rice fields of Kumarakom, Kerala (KAU, 1991). In sunflower plants inoculated with **Azospirillum**, the available soil N was found to increase (Ram et al., 1992). A significant increase in N, P and K contents in soil were observed by Rangarajan and Subramanian (1993) due to inoculation of **Azospirillum** in rice plants along with application of farmyard manure.

Available N and organic carbon content of soil were increased due to **Azotobacter** inoculation in maize plants (Karthikeyan, 1981). Sharma et al. (1987) observed that available and total N contents of soil increased due to inoculation of wheat plants with **Azotobacter**.

6.3 Microbial count

Vancura and Macura (1959) observed an increased **Azotobacter** population in the rhizosphere of inoculated plants of oats, barley and wheat. However, a decrease in its population was observed towards harvest in sugarbeet

(Brown et al., 1964). Significantly higher number of **Azotobacter** population was observed in inoculated maize rhizosphere over uninoculated control, while only a slight increase was observed when supplemented with 50 kg inorganic N/ha compared to application of 50 kg inorganic N/ha alone. Maximum population was observed at the tillering phase of the crop (Dey, 1972). Shetty et al. (1976) also observed the maximum **Azotobacter** population in the rhizosphere of rice, ragi and chilli plants during vegetative phase and the population was almost negligible at harvest. Kundu and Gaur (1980) reported that the **Azotobacter** population increased significantly in cotton plants when inorganic fertilizers were added along with biofertilizer, showing a synergistic effect on its multiplication over control.

Hegazi et al. (1981); Subba Rao (1981); Saha et al. (1985) and Yadav et al. (1991) observed an increase in **Azospirillum** population in the rhizospheres of inoculated wheat, sorghum, mustard and maize plants. Ramanathan and Prasad (1993) reported that **Azospirillum** population was maximum in the rhizosphere of sesame plants at 25 and 50 DAS and declined by the time of harvest. The population was maximum during flowering stage. **Azospirillum** inoculation along with farmyard manure or green leaf manure further contributed to the increased **Azospirillum** counts in rice rhizosphere (Rangarajan and Subramanian, 1993).

The foregoing review indicates that the population of **Azotobacter** and **Azospirillum** in the rhizosphere of crop plants can be increased by their inoculation and maximum count is at vegetative phase of crop growth.

Materials and Methods

MATERIALS AND METHODS

A field experiment was conducted during the summer season of 1995 to evaluate the effect of biofertilizers on the growth, yield and nitrogen economy of sesame grown in summer rice fallows. The details of materials used and the methods followed are presented below.

1. Experimental site

The experiment was conducted in the rice field of the Agricultural Research Station, Mannuthy, Kerala Agricultural University. It is located at 12° 32'N latitude and 72°20'E longitude and at an altitude of 22.25 m above MSL.

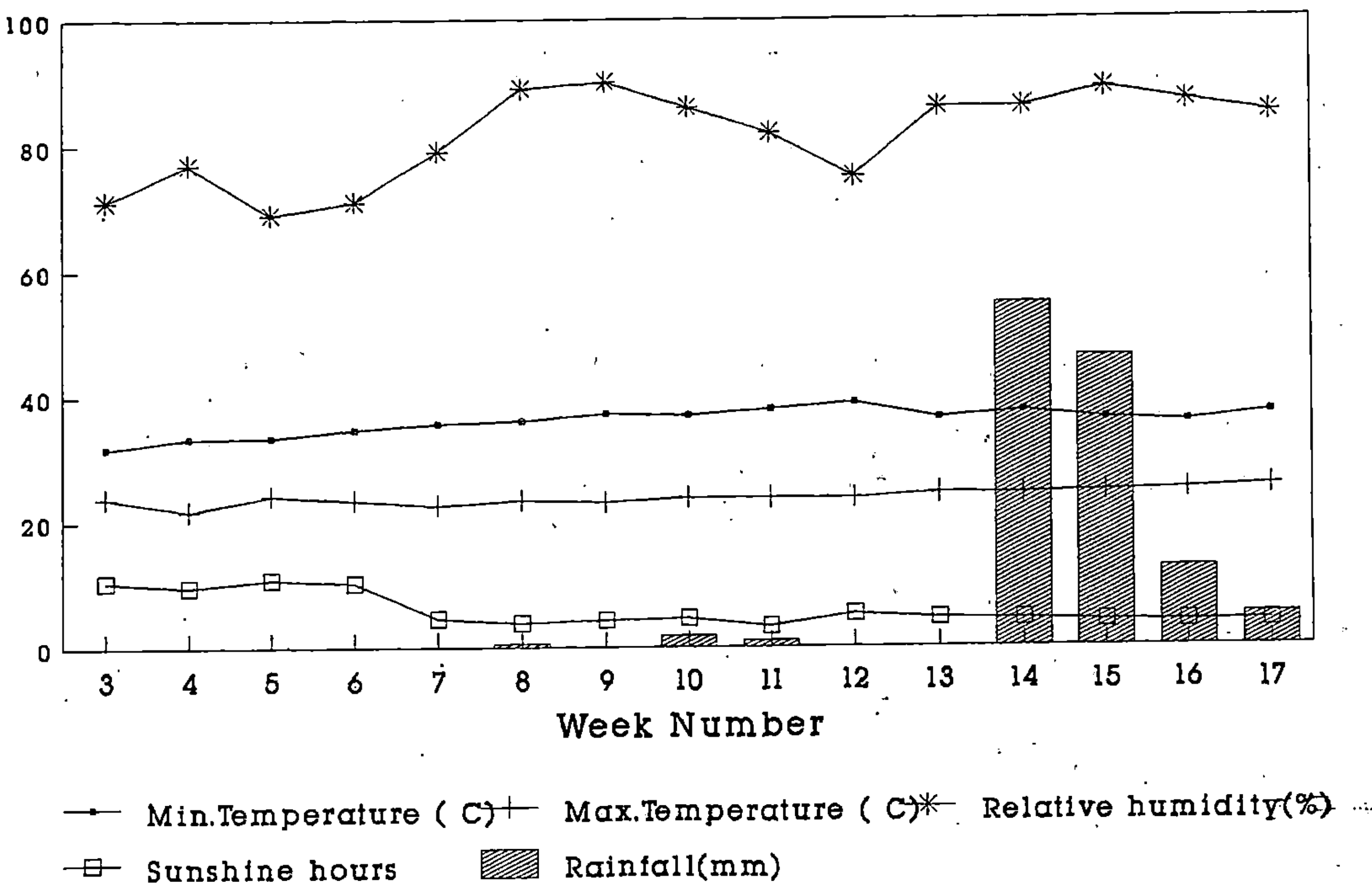
1.1. Soil

Soil of the experimental site was sandy loam. Physical, chemical and biological properties of the soil are presented in Table 1.

2. Season

The experiment was conducted during the summer season (January - April) of 1995. The weather data are presented in Fig. 1 and Appendix - I.

Fig. 1. Weather parameters during the study period



3. Cropping history of the field

The experimental site was under rice crop during the previous two seasons.

4. MATERIALS

4.1. Variety

The variety used was Thilak, a new high yielding stable sesame variety, evolved by pureline selection from North Kerala (Malappuram) type. It is a branching type which matures in 80-85 days.

4.2. Seed material

Seeds of the variety Thilak was obtained from Rice Research Station, Kayamkulam.

4.3. Biofertilizers

Acid tolerant strains of **Azospirillum** and **Azotobacter** were obtained from College of Agriculture, Vellayani and Tamil Nadu Agricultural University, Coimbatore respectively.

4.4. Manures and chemical fertilizers

Cattle manure @ 5 t/ha and chemical fertilizers, urea, mussoriephos and muriate of potash @ 30:15:30 kg NPK/ha were used.

4.5. Lime

Lime was applied @ 600 kg/ha

5. METHODS

5.1. Lay-out and design

The experiment was laid out in randomised block design with 3 replications.

5.1.1. Treatments

The 14 treatments included in the experiment are as follows.

T_1 - 30 kg N/ha as urea (Recommended dose)

T_2 - **Azospirillum** inoculation + 50% N as urea with lime

T_3 - **Azospirillum** inoculation + 50% N as urea without lime

T_4 - **Azospirillum** inoculation + 25% N as urea with lime

T_5 - **Azospirillum** inoculation + 25% N as urea without lime

T_6 - **Azospirillum** inoculation + No inorganic N with lime

T_7 - **Azospirillum** inoculation + No inorganic N without lime

T_8 - **Azotobacter** inoculation + 50% N as urea with lime

T_9 - **Azotobacter** inoculation + 50% N as urea without lime

T_{10}- **Azotobacter** inoculation + 25% N as urea with lime

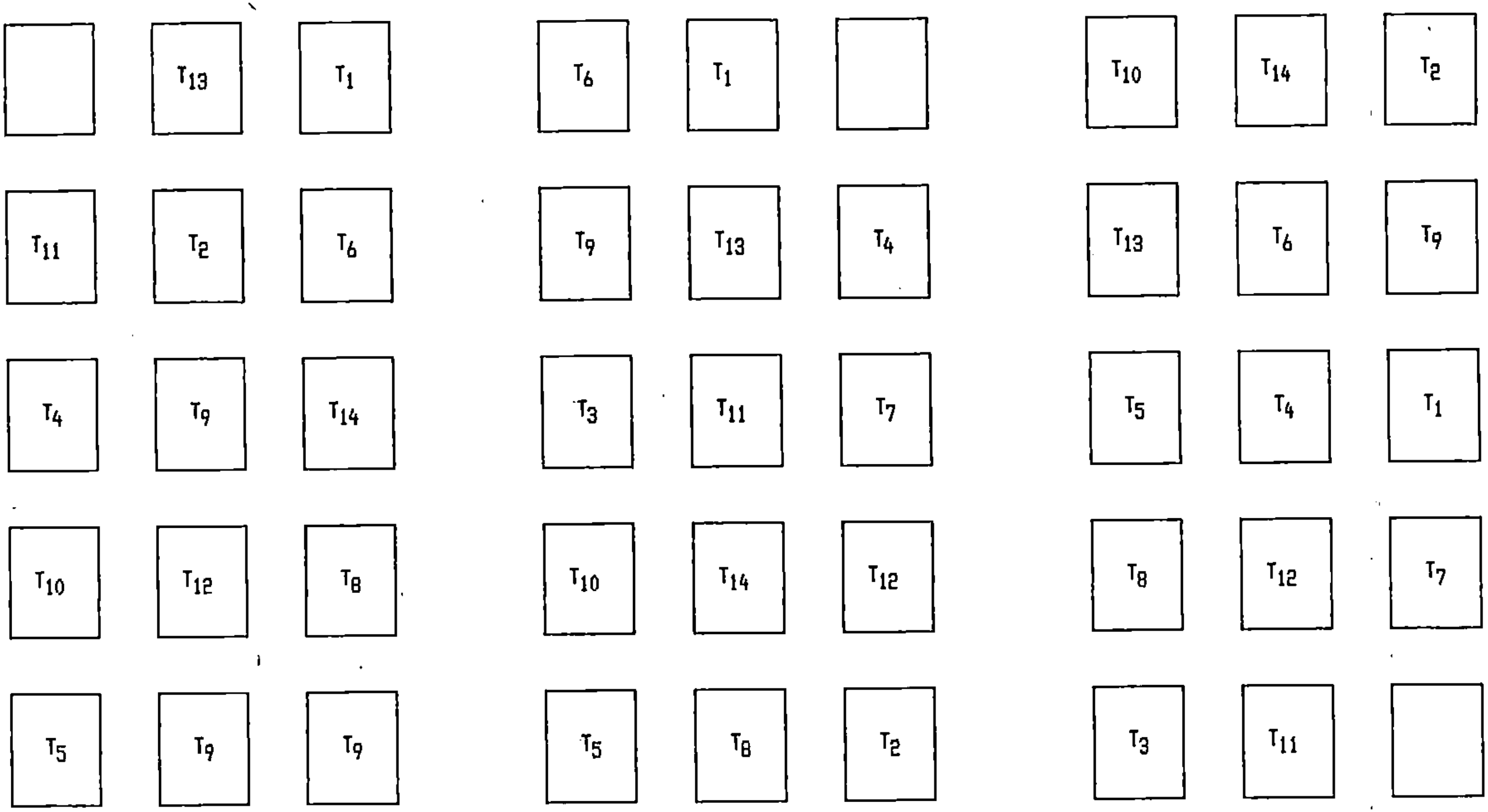
T_{11}- **Azotobacter** inoculation + 25% N as urea without lime

T_{12}- **Azotobacter** inoculation + No inorganic N with lime

T_{13}- **Azotobacter** inoculation + No inorganic N without lime

T_{14}- Absolute control - No biofertilizers and no inorganic N

Fig. 2. LAYOUT PLAN



T_1 - 30 kg N/ha as urea

T_2 - Azospirillum + 50% N+lime

T_3 - Azospirillum + 50% N

T_4 - Azospirillum + 25% N+lime

T_5 - Azospirillum + 25% N

T_6 - Azospirillum + lime

T_7 - Azospirillum

T_8 - Azotobacter +50% N+lime

T_9 - Azotobacter + 50%

T_{10}- Azotobacter +25% N+lime

T_{11}- Azotobacter + 25% N

T_{12}- Azotobacter + lime

T_{13}- Azotobacter

T_{14}- Absolute control

5.1.2. Plot size

Gross plot size : 4 m x 4.5 m.

Sampling area : 0.5 m strip along the 4.5 m side inside the border area

Net plot size : 3.5 m x 2.5 m

The layout plan is given in Fig. 2.

5.2. Field culture

The field was ploughed well and harrowed with a tractor. After incorporating the required quantity of cattle manure, the soil was brought to a fine tilth. Then the field was levelled and laid out into 3 blocks each with 14 plots. Lime was applied in the plots according to the treatments and incorporated into the soil one week before sowing. The fertilizers were applied completely as basal.

5.3. Seed treatment

Seeds were treated separately with **Azotobacter** and **Azospirillum** cultures on the day of sowing. The cultures were mixed with starch solution and the slurry thus obtained was poured over the seeds. This was then thoroughly hand mixed and dried under shade for about half an hour. The cultures were inoculated @ 600 g/ha.

5.4. Sowing

The treated seeds were sown broadcast uniformly in the plots after mixing with sand on 19th January, 1995. Seeds were sown @ 5 kg/ha and covered with soil, by pressing with a wooden plank. Light irrigation was given for 2 days after sowing so as to ensure uniform germination.

5.5. After cultivation

Thinning and intercultural operations were done as per the package of practices recommendations (KAU, 1993).

5.6. Irrigation

The plots were irrigated at the flowering stage of the crop.

5.7. Plant protection

Plant protection measures were taken as and when required. Leaf eating caterpillars and plant hoppers were controlled by spraying 0.05 per cent Monocrotophos.

5.8. Harvesting

Harvesting was done at 86 days after sowing. Plants were uprooted, tied into small bundles and stacked for 3 to 4 days. Then these were spread in the sun and the seeds were separated by beating with sticks. This was repeated until all the seeds were separated. Seeds were cleaned, sundried and weighed.

5.9. Observations

5.9.1. Growth characters

Observations on growth characters were taken from 10 random plants in the net plot at 30 DAS, 60 DAS and at harvest.

(i) Height of plants

Height was measured from the ground level to the growing point and mean plant height was expressed in cm.

(ii) Number of branches / plant.

Number of branches in each plant was counted and the average recorded.

(iii) Leaf area index

Leaf samples were taken from 5 plants uprooted from the destructive sampling area. The area-weight relationship was worked out and the leaf area index (LAI) was calculated using the formula,

$$LAI = \frac{\text{Leaf area / plant}}{\text{Land area occupied / plant}}$$

(iv) Dry matter production

From each plot, 5 plants were collected from the destructive sampling area. The plants were removed by cutting at the ground level. It was dried at 80°C to a constant weight and the average weight was recorded in grams.

5.9.2. Yield attributes and yield

These observations were made on the same plants from which growth observations were taken.

(i) Days to 50 per cent flowering

After commencement of flowering, the crop was observed daily and the number of days taken for 50 per cent flowering was recorded.

(ii) Number of capsules / plant

Total number of mature capsules on the observation plants were counted and mean number recorded.

(iii) Weight of capsules / plant

Capsules of observation plants were dried, weighed and the mean weight recorded.

(iv) Number of seeds / capsule

Number of seeds in 10 capsules were counted and the average recorded.

(v) Seed to capsule ratio (Shelling percentage)

Samples of 10 capsules were drawn and weighed. Weight of seeds obtained from these capsules was recorded and expressed as shelling percentage.

(vi) 1000 seed weight

Samples of 1000 seeds were taken randomly from each plot, weighed and expressed in grams.

(vii) Seed yield /ha

Seeds obtained from each net plot were sundried to 9 per cent moisture, weighed and the seed yield / ha was calculated.

5.9.3. Quality factors

(i) Protein content of seeds

Protein content of seeds was worked out by multiplying nitrogen content of seeds with the constant 6.25 (Simpson *et al*., 1965).

(ii) Oil content

Oil content of seeds was determined using cold percolation method (Kartha and Sethi, 1957).

5.9.4. Soil studies

Soil samples were analysed for available N, P and K before and after the crop. Methods used were as follows:

(i) Available N

Alkaline permanganate method (Jackson, 1973)

(ii) Available P

Available P in soil was extracted by Bray-I extractant and P content was determined by ascorbic acid blue colour method (Watanabe and Olsen, 1965).

(iii) Available K

Available K was extracted by neutral normal ammonium acetate and was read in EEL flame photometer (Jackson, 1973).

5.9.5. Uptake studies

N, P and K uptake by the crop was estimated at 30 DAS, 60 DAS and at harvest. From each plot 5 plants were collected from the area left for destructive sampling. N, P and K contents in the samples were determined by the following methods.

(i) Nitrogen

Microkjeldahl method (Jackson, 1973)

(ii) Phosphorus

Vanadomolybdophosphoric yellow colour method-Spectronic - 20 (Jackson, 1973).

(iii) Potassium

Triple acid extract method using flame photometer (Jackson, 1973).

Values of nutrient content were multiplied by dry matter production to obtain nutrient uptake.

5.9.6. Microbial studies

Population of microbes in the rhizosphere soil were determined initially, 30 DAS, 60 DAS and at harvest using the following methods.

(i) **Azospirillum** - Maximum probable number (MPN) technique (Cochran, 1950) using nitrogen free bromothymol blue (NFB) medium.

(ii) **Azotobacter** - Dilution plate count technique (Pramer and Schmidt, 1966) using Waksman No. 77 agar medium.

5.9.7. Statistical analysis

The data were subjected to analysis of variance and the significance was tested by F test (Panse and Sukhatme, 1985).

Table 1. Physical, chemical and biological properties of the soil in the experimental field.

Particulars	Value	Method employed
A. Physical properties		
Mechanical analysis		Robinson's International Pipette Method (Piper, 1942)
Coarse sand	27.6 %	
Fine sand	24.2 %	
Silt	22.2 %	
Clay	26.0 %	
Bulk density	1.54	Core sampler method (Piper, 1942)
B. Chemical properties		
Available nitrogen	218.4 kg/ha	Alkaline permanganate method (Jackson, 1973)
Available phosphorus	86.7 kg/ha	Ascorbic acid blue colour method (Watanabe and Olsen, 1965)
Available potassium	210 kg/ha	Neutral normal ammonium acetate extract, flame photometry (Jackson, 1973)
Organic carbon	0.67 %	Walkley - Black method (Jackson, 1973)
pH	5.7	1:2.5 soil-water suspension using a pH meter (Jackson, 1973)
C. Biological properties		
Azospirillum count	0.34×10^5 cells/g of soil	MPN technique (Cochran, 1950)
Azotobacter count	3.2×10^5 cells/g of soil	Dilution plate technique (Pramer and Schmidt, 1966)

Results and Discussion

RESULTS AND DISCUSSION

The observations recorded were analysed statistically and the results obtained are presented and discussed in this chapter.

1. Growth characters

1.1. Plant height

The data presented in Table 2 showed that at all stages, plots that received inorganic N @ 30 kg/ha produced slightly taller plants consistently. However, it was numerically lower to the height of plants in plots inoculated with **Azotobacter** or **Azospirillum** along with 50 per cent inorganic N and lime, at 60 DAS and at harvest respectively. At 30 DAS and 60 DAS, inoculation of **Azospirillum** alone or along with 50 per cent or 25 per cent inorganic N resulted in lower plant height compared to that produced by the application of inorganic N alone @ 30 kg/ha. Similar results were obtained with **Azotobacter** at 30 DAS and at harvest. Moreover, plants in absolute control plots produced significantly shorter plants compared to that in plots treated with 30 kg inorganic N/ha. This showed that application of inorganic N alone @ 30 kg/ha favourably influenced plant height of sesame. Similar results were reported by Rahman et al. (1978). The medium

N status of the soil (Table 1) coupled with comparatively higher native population of the microbes, **Azospirillum** and **Azotobacter** (Table 1) along with the added recommended dose of 30 kg N/ha, might have contributed to a better supply of N, which in turn produced taller plants in these plots. It also showed the compatability of biofertilizers with nitrogenous fertilizers. Moreover, the microbes might have helped to improve the physical and chemical nature of the soil and added to the organic matter content of the soil in subsequent periods. These explanations are in accordance with the results reported by Goyal (1991). Thus, nitrogen, an element involved in the vital functions of the plant body (Rao et al., 1990), might have been readily available in sufficient amounts for the sesame crop from the initial growth stage itself.

The data also showed that inoculation of **Azospirillum** or **Azotobacter** alone, or along with 50 per cent or 25 per cent inorganic N, resulted in a slightly higher plant height at 60 DAS and at harvest over uninoculated control. This can be attributed to the higher population of microbes in the inoculated plots (Table 13 and 14) which resulted in higher N supply necessary for plant growth. The production of growth regulating substances or metabolites might have favoured and stimulated plant development after germination thus giving the young

Table 2. Effect of different treatments on height (cm) of sesame

Treatments	30 DAS	60 DAS	Harvest
30 kg N/ha as urea	24.11	73.67	82.16
Azospirillum+50% N+lime	22.89	70.01	83.02
Azospirillum+50% N	22.24	70.10	78.82
Azospirillum+25% N+lime	23.96	68.68	77.50
Azospirillum+25% N	19.62	71.04	76.90
Azospirillum+lime	20.41	69.97	80.91
Azospirillum	22.61	70.34	79.22
Azotobacter+50% N+lime	22.24	74.02	78.60
Azotobacter+50% N	23.60	68.96	78.50
Azotobacter+25% N+lime	23.65	68.94	78.11
Azotobacter+25% N	19.28	69.86	78.98
Azotobacter+lime	21.01	70.98	78.90
Azotobacter	22.78	72.87	78.18
Absolute control	20.43	68.20	76.42
SEm±	0.46	1.05	1.52
CD (0.05)	1.34	3.07	4.43

plants a better vigour, which is in accordance with the reports by Brown et al. (1964). An almost equal performance was observed between the two microbes, **Azospirillum** and **Azotobacter** in their contribution to plant height at 30 and 60 DAS. The influence of favourable weather conditions that prevailed during the season (Appendix I) on the microbes might have also contributed to the increased growth of inoculated plants. Similar results were reported by Wani et al. (1983). However, at harvest **Azospirillum** inoculation showed a slightly better response. Though the **Azospirillum** population (Table 13) was slightly lower to the **Azotobacter** counts (Table 14) in the rhizosphere soil, **Azospirillum** being a better root coloniser of the rhizoplane (Okon et al., 1976 a), would have been able to contribute slightly better than the **Azotobacter** population in the rhizosphere.

It is also clear from the data that height of sesame plants in absolute control plots was on par with that in some of the plots inoculated with **Azospirillum** or **Azotobacter**. This is due to the natural occurrence of these microbes in absolute control plots also (Table 13 and 14).

The data also indicated that application of lime along with the inoculation of microbes had no profound influence on the plant height of sesame grown in summer rice fallows. This shows that while inoculating acid tolerant strains of **Azospirillum** or **Azotobacter**, liming is not necessary. Subramoney (1950) also reported that **Azotobacter** species isolated from Kari soils of Kerala (pH - 2.5 to 4.5) grows equally well on media supplied with or free from $CaCO_3$. **Azospirillum** being closely associated with the roots of plants, can make a favourable environment for plant growth in the rhizoplane, whether the external soil conditions are favourable or not for its growth. Such reports are given by Day and Dobereiner (1976).

1.2. Number of branches / plant

The data regarding the number of branches / plant (Table 3) showed that application of inorganic N @ 30 kg/ha resulted in a numerically higher number of branches / plant at 30 DAS and at harvest. At 60 DAS, though the inoculation of **Azospirillum** along with 50 per cent inorganic N and lime recorded the highest number of branches / plant, application of inorganic N @ 30 kg/ha was on par with it. At 30 DAS and at harvest, inoculation of **Azospirillum** or **Azotobacter** with 50 per cent or 25 per cent inorganic N resulted in lower number of branches / plant, compared to that treated with 30 kg inorganic N/ha alone. Moreover, at 30 DAS plants in the absolute control plots produced slightly lower number of branches compared to that in plots supplied with 30 kg inorganic N/ha alone. This again showed the better vegetative growth of sesame plants in summer rice fallows when supplied with recommended dose of inorganic N @ 30 kg/ha alone. A positive influence of N fertilization on the number of branches / plant of sesame was also reported by Subramanian et al.(1979). In plots supplied with 30 kg inorganic N/ha, the microbial population was not hindered (Table 13 and 14) which along with the reasons discussed earlier, might have led to a favourable effect on plant growth. Dhillon et al. (1980) also observed favourable effect of inorganic fertilizers on the population of **Azospirillum** and **Azotobacter** population.

It is also evident from the data (Table 3) that **Azospirillum** performed better than **Azotobacter** in the production of branches in inoculated plots. The close association of **Azospirillum** with plant roots of sesame (Ramanathan and Prasad, 1993) might have enhanced the nutrient uptake by the crop (Table 9, 10 and 11) thereby giving favourable results. The crop responses might not be caused by N fixation alone but by certain vitamins or growth promoting substances produced by the bacteria or their antagonism to harmful microbes, as observed by Mishustin and Naumova (1962).

It was also found that the number of branches /plant produced by sesame plants in absolute control plots was on par with many microbial inoculated treatments at all stages. The stubbles of rice straw incorporated into the soil before sowing of sesame crop might have served as a suitable substrate for the multiplication of both the microbes in all plots. This is in accordance with reports made by Rangarajan and Subramanian (1993). Thus irrespective of the treatments, a high population of both the heterotrophic microbes were observed even in the initial soil samples (Table 1). Further the farmyard manure added to all plots, irrespective of the treatments at the recommended dose too might have enhanced their population during the crop growth period along with the reasons discussed earlier. All these factors might have led to the similarity of microbial inoculated treatments with uninoculated control.

The data indicated that lime application along with inoculation of microbes (**Azospirillum** and **Azotobacter**) did not result in a favourable influence on the number of branches / plant. This is due to the similar activity of acid tolerant strains of microbes irrespective of lime application.

Table 3. Effect of different treatments on number of branches / plant in sesame

Treatments	30 DAS	60 DAS	Harvest
30 kg N/ha as urea	6.81	7.48	7.98
Azospirillum+50% N+lime	6.63	7.86	7.43
Azospirillum+50% N	6.44	7.39	7.40
Azospirillum+25% N+lime	6.52	7.14	7.23
Azospirillum+25% N	6.48	7.03	7.33
Azospirillum+lime	6.60	7.38	7.40
Azospirillum	6.64	7.4	7.64
Azotobacter+50% N+lime	6.56	7.53	7.41
Azotobacter+50% N	6.62	7.21	7.56
Azotobacter+25% N+lime	6.31	7.22	7.56
Azotobacter+25% N	6.33	7.21	7.63
Azotobacter+lime	6.22	7.24	7.51
Azotobacter	6.46	7.28	7.48
Absolute control	6.42	7.09	7.36
SEm±	0.09	0.21	
CD (0.05)	0.26	0.62	NS

1.3. Leaf area index

It is evident from the data given in Table 4 that leaf area index (LAI) of the crop was not significantly influenced by the different treatments at 30 DAS and at harvest. At 60 DAS, the highest LAI was observed in plots inoculated with either **Azospirillum** or **Azotobacter** along with 50 per cent inorganic N and lime and followed by 30 kg inorganic N/ha alone. However, these were on par with many other treatments, but better than uninoculated control. This nonsignificant influence of different treatments on LAI of sesame at all stages might be due to the natural occurrence of **Azospirillum** and **Azotobacter** in all plots irrespective of treatments (Table 13 and 14) and the medium initial N fertility status of soil (Table 1). Reports by Brown et al. (1964) also revealed that plant growth was affected with at least 10^4 to 10^6 cells / g of rhizosphere soil in field conditions. Such high counts have been observed even in the uninoculated plots of this experiment (Table 13 and 14) which might have contributed to the leaf area indices in almost similar magnitudes.

However, application of 30 kg inorganic N/ha alone was the treatment which produced numerically highest LAI at 30 DAS. This ranked second at 60 DAS and might be

Table 4. Effect of different treatments on leaf area index of sesame

Treatments	30 DAS	60 DAS	Harvest
30 kg N/ha as urea	0.34	0.87	0.24
Azospirillum+50% N+lime	0.34	0.89	0.24
Azospirillum+50% N	0.33	0.82	0.24
Azospirillum+25% N+lime	0.33	0.84	0.25
Azospirillum+25% N	0.32	0.83	0.23
Azospirillum+lime	0.34	0.82	0.25
Azospirillum	0.33	0.84	0.23
Azotobacter+50% N+lime	0.32	0.89	0.23
Azotobacter+50% N	0.34	0.84	0.23
Azotobacter+25% N+lime	0.34	0.83	0.25
Azotobacter+25% N	0.33	0.85	0.24
Azotobacter+lime	0.33	0.86	0.24
Azotobacter	0.33	0.85	0.24
Absolute control	0.33	0.83	0.24
Azotobacter	0.33	0.85	0.24
Absolute control	0.33	0.83	0.24
SEm±		0.01	
CD (0.05)	NS	0.05	NS

due to the better nutrient availability made by the microbes from the medium fertile soil in addition to the added inorganic dose of 30kg N/ha. Similar reports of favourable responses in LAI due to N application and bacterization was reported by Singh and Bhargava (1994) in mustard.

1.4. Dry matter production

The data pertaining to drymatter production, presented in Table 5 and Fig. 2 revealed that application of 30 kg inorganic N/ha alone resulted in highest dry matter production of sesame at all stages, though it was on par with that in plots treated with **Azospirillum** along with 50 per cent inorganic N at 60 DAS and many of the treatments at harvest. Moursi and Gawad (1966) also reported a higher dry matter production in sesame with inorganic N application. The better vigour of the plants in plots treated with 30 kg N/ha might be due to a better root system thus providing maximum surface area for absorption of nutrients. Similar results were reported by Dewan and Rao (1979). Geller (1957) also reported that mineral fertilizers enhanced the effect of bacterial fertilizers. The ready availabiltiy of sufficient N, resulted in highest plant height (Table 2) and number of branches / plant (Table 3), thereby producing the highest dry matter in these plots. Correlation studies also revealed that the dry matter production of sesame plants was positively correlated with plant height and number of branches/plant (Table 15).

Inoculation of **Azospirillum** or **Azotobacter** alone or in combination with 50 per cent or 25 per cent inorganic N, resulted in a lower dry matter production compared to application of 30 kg inorganic N/ha alone. This might be due to the lower plant height (Table 2) and lesser number of branches / plant (Table 3). The performances of both **Azospirillum** and **Azotobacter** was in a similar manner with regard to the production of dry matter at all stages. The initial soil fertility status might have contributed to their similarity.

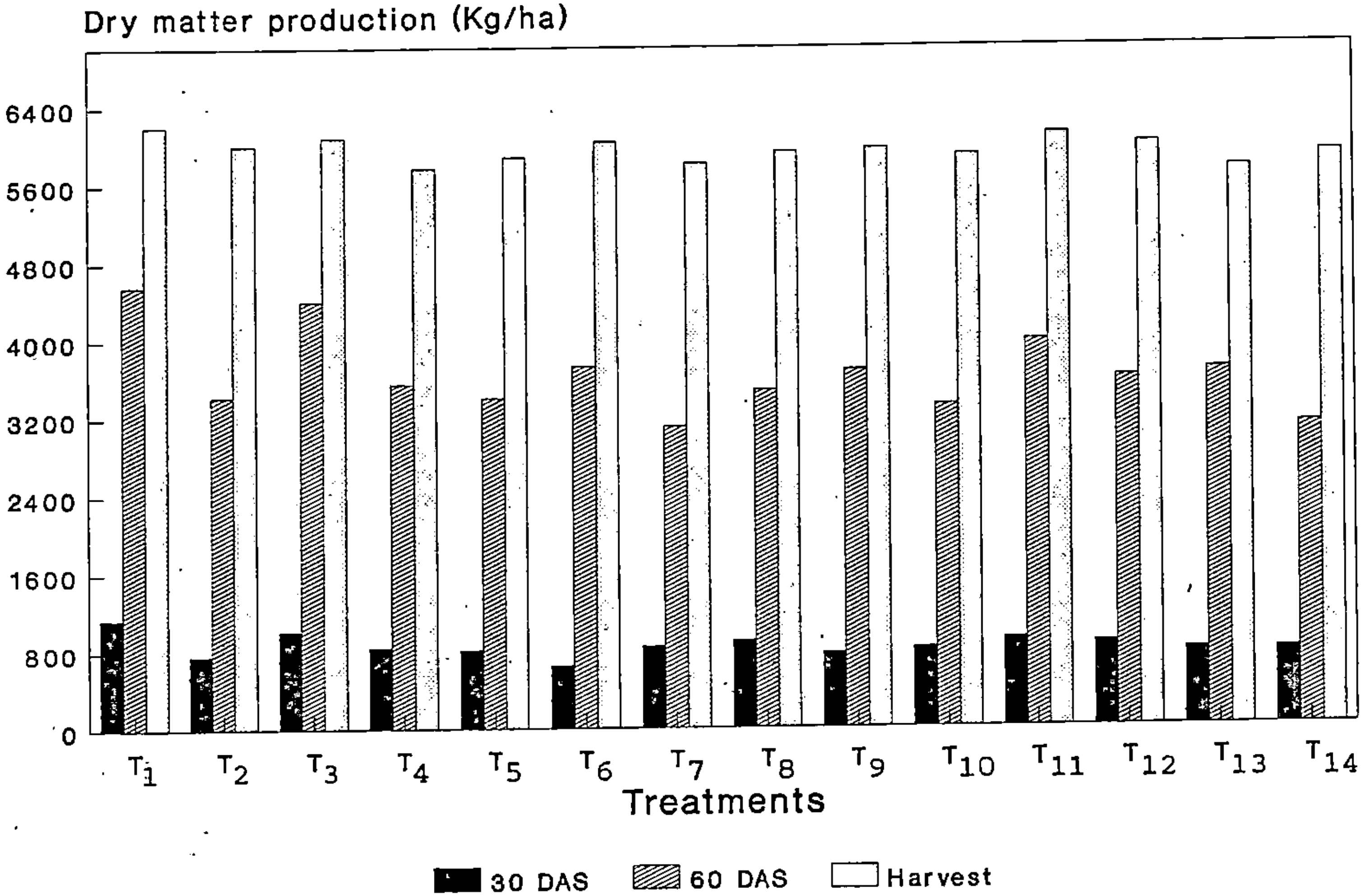
The data indicated that the dry matter production of sesame in absolute control plots was equally good as some of the microbial inoculated treatments with or without inorganic N. This again can be attributed to the better initial soil conditions as discussed earlier.

The data also showed that application of lime along with inoculation of microbes, did not result in any significant effect on dry matter production of sesame. This shows that, while inoculating acid tolerant strains of these microbes liming was not necessary.

Table 5. Effect of different treatments on dry matter production (kg/ha) of sesame

Treatments	30 DAS	60 DAS	Harvest
30 kg N/ha as urea	1133	4563	6201
Azospirillum+50% N+lime	755	3420	6005
Azospirillum+50% N	1010	4400	6085
Azospirillum+25% N+lime	835	3550	5770
Azospirillum+25% N	815	3400	5880
Azospirillum+lime	645	3723	6040
Azospirillum	841	3103	5815
Azotobacter+50% N+lime	895	3473	5925
Azotobacter+50% N	770	3683	5960
Azotobacter+25% N+lime	820	3318	5890
Azotobacter+25% N	908	3973	6105
Azotobacter+lime	870	3598	6003
Azotobacter	785	3665	5750
Absolute control	790	3100	5900
SEm±	26.42	97.14	122.77
CD (0.05)	76.8	282.4	356.90

Fig. 2. Effect of different treatments on dry matter production of sesame.



2. Yield attributes and yield

2.1. 50 per cent flowering

The data presented in Table 6 indicated that sesame plants supplied with inorganic N either in full dose or 50 per cent of recommended dose or even 25 per cent of recommended dose flowered earlier compared to the plots inoculated with microbes alone and absolute control. This is probably due to the ready availability of sufficient N from the initial growth stage itself. The positive influence of inorganic N application on flowering of sesame was also reported by Sivappa and Mariyakulanti (1963). Early flowering resulted in a comparatively higher seed yield of sesame. Moreover, a negative correlation was observed between number of days to flowering and yield of sesame as reported by John and Nair (1990).

The data also revealed that **Azospirillum** inoculated plants flowered slightly earlier than the **Azotobacter** inoculated plants, thus revealing the better efficiency of sesame plants in **Azospirillum** inoculated plots later on to produce higher number of capsules / plant, number of seeds / capsule, 1000 seed weight and serially a higher seed yield (Table 6).

The number of days taken by the plants to attain 50 per cent flowering in absolute control plots was on par with that of many other treatments. This might be due to the favourable nutrient supply to the plants as a result of the natural occurrence of **Azospirillum** and **Azotobacter** and the favourable original N fertility status of the soil and the other soil conditions mentioned earlier.

The data indicated that application of lime did not influence the activity of **Azospirillum** or **Azotobacter** for inducing earliness in flowering. This again showed the ineffectiveness of lime application on the performance of acid tolerant strains of these microbes in summer rice fallows.

2.2. Number of capsules / plant

Application of inorganic N alone @ 30 kg/ha produced a numerically higher number of capsules / plant, compared to most of the microbial inoculated treatments (Table 6). Moreover, sesame plants in absolute control plot produced a significantly lower number of capsules / plant compared to the above treatment. The higher number of capsules / plant in plots applied with 30 kg inorganic N/ha might be due to higher plant height (Table 2) and higher number of branches / plant (Table 3) as a result of favourable N supply during the early growth stage itself. Subramanian et al. (1979) and Girija Devi (1985) also observed an increase in the number of capsules / plant in sesame with inorganic N application. Comparitively a higher number of capsules / plant was observed in all plots. Moreover, in a summer crop of sesame, the percentage of capsule setting might be higher as reported by Ramaniyam et al. (1967).

Inoculation of **Azospirillum** alone or along with 50 per cent inorganic N with or without lime or along with 25 per cent inorganic N without lime produced equal number of capsules / plant compared to application of 30 kg inorganic N/ha alone. Similar results were obtained with **Azotobacter** along with 50 per cent or 25 per cent inorganic N with or without lime. However, plots treated with **Azotobacter** alone or in combination with lime resulted in lower number of pods which showed more similarity with the number of pods obtained from the uninoculated control plot. Thus the data (Table 6) also showed that **Azotobacter** was not as effective as **Azospirillum** in producing higher number of pods in sesame grown in summer rice fallows. Jagnow (1983) reported that **Azospirillum** survived better under high temperatures of 35-45°C and in an N sufficient media. Moreover, it can tolerate wide fluctuations in the environment. The N fertilization is often reported to increase the efficiency and multiplication rate of **Azospirillum** species in soil. However, it has also been reported that bacterial fertilizers did not completely replace but only supplemented the mineral fertilizers (Doronskii, 1962 and Lee and Gaskin, 1982). Similar observations were made in this experiment too, where the supplementations of the native microbes along with inorganic N @ 30 kg/ha was found more effective in the various yield attributes than in plots treated with either 50 per cent or 25 per cent of inorganic N, along with the biofertilizers.

Plants in most of the microbial inoculated plots produced a significantly higher number of capsules / plant compared to uninoculated control. The attributed reason for this is the comparitively higher N supply to the plants by the activity of a higher population of **Azospirillum** or **Azotobacter** in the inoculated plots compared to the uninoculated control (Table 13 and 14).

The data also revealed that application of lime along with inoculation of **Azospirillum** or **Azotobacter** did not make any significant difference in the number of capsules / plant which again showed the ineffectiveness of lime application on the performance of acid tolerant strains of these microbes in summer rice fallows of Kerala.

2.3. Weight of capsules / plant

The data regarding weight of capsules / plant (Table 6), showed that the highest weight of capsules / plant was produced by sesame plants inoculated with **Azotobacter** along with 50 per cent inorganic N and lime which was on par with application of 30 kg inorganic N/ha. These were significantly superior to absolute control. N fertilization along with the presence of native microbes resulted in an increased number of branches / plant and number of capsules /plant in plots supplied with 30 kg inorganic N/ha. The higher weight of capsules / plant might also be due to a comparitively higher LAI, particularly at pod filling stage and a higher growth of plants in this plot. Thus, there would have been a better supply of carbon assimilates and N to the pods due to the presence of a larger photosynthetic surface. Similar results were reported by Singh and Bhargava (1994) in mustard. The presence of microbes also might have enhanced the supply of nutrients and assimilates to the pods as reported by Lin et al. (1983), Kapulnik et al. (1985) and Barten et al. (1986).

Among the microbial treatments, though the performance of both the microbes were in a similar manner, **Azotobacter** inoculated plots produced slightly higher weight of pods unlike in most of the other parameters, where **Azospirillum** performed better. Since plant growth is governed by many factors, all of which can alter the action of the inoculant, variability may be observed while using the bacterial inoculants. Similar reports were also given by Brown (1974).

The weight of capsules / plant, in absolute control plot was found to be equal to that in most of the microbial inoculated plots, either alone or along with 50 or 25 per cent of inorganic N. The obvious reason for which is attributed to the favourable initial soil conditions.

It is also clear from the data that lime application had no significant influence on the activity of either **Azospirillum** or **Azotobacter**, in bringing about any significant difference in the weight of capsules / plant. This again showed that liming could not make any influence on the activity of **Azospirillum** or **Azotobacter** in summer rice fallows of Kerala.

2.4. Number of seeds / capsule

The data pertaining to the number of seeds / capsule, presented in Table 6, showed that the highest values were observed in plots applied with 30 kg inorganic N/ha alone. This might be due to the ready availability of adequate N, more photosynthesis contributed by higher photosynthetic surface and efficient translocation of photosynthates to the pods which developed into maturity. Development of seeds required the mobilisation of sufficient amounts of N to the pods (Singh and Bhargava, 1994). There are also reports suggesting that N fertilization increased the number of seeds / capsule in sesame (Ramakrishnan et al., 1994).

Inoculation of **Azospirillum** or **Azotobacter** along with 50 or 25 per cent inorganic N, showed lower number of seeds / capsule than the plots applied with 30 kg inorganic N/ha alone. Here, the **Azospirillum** treated plots gave higher values compared to **Azotobacter** treated plots due to the better effectiveness of **Azospirillum** as already discussed.

Comparatively lesser number of seeds /capsule was observed in absolute control plots, though it was on par with many treatments. Similarity in the number of seeds / capsule in these might be again attributed to the native occurrence of microbes along with a better initial soil fertility status as mentioned earlier.

Liming could not make any influence on the activity of **Azospirillum** or **Azotobacter**.

2.5. 1000 Seed weight

The 1000 seed weight of sesame was not influenced by the different treatments. The non significant effect of different treatments on 1000 seed weight might be due to the favourable initial soil fertility status combined with the presence of microbes in all plots irrespective of treatments, which enabled the plants to meet their partial N requirement.

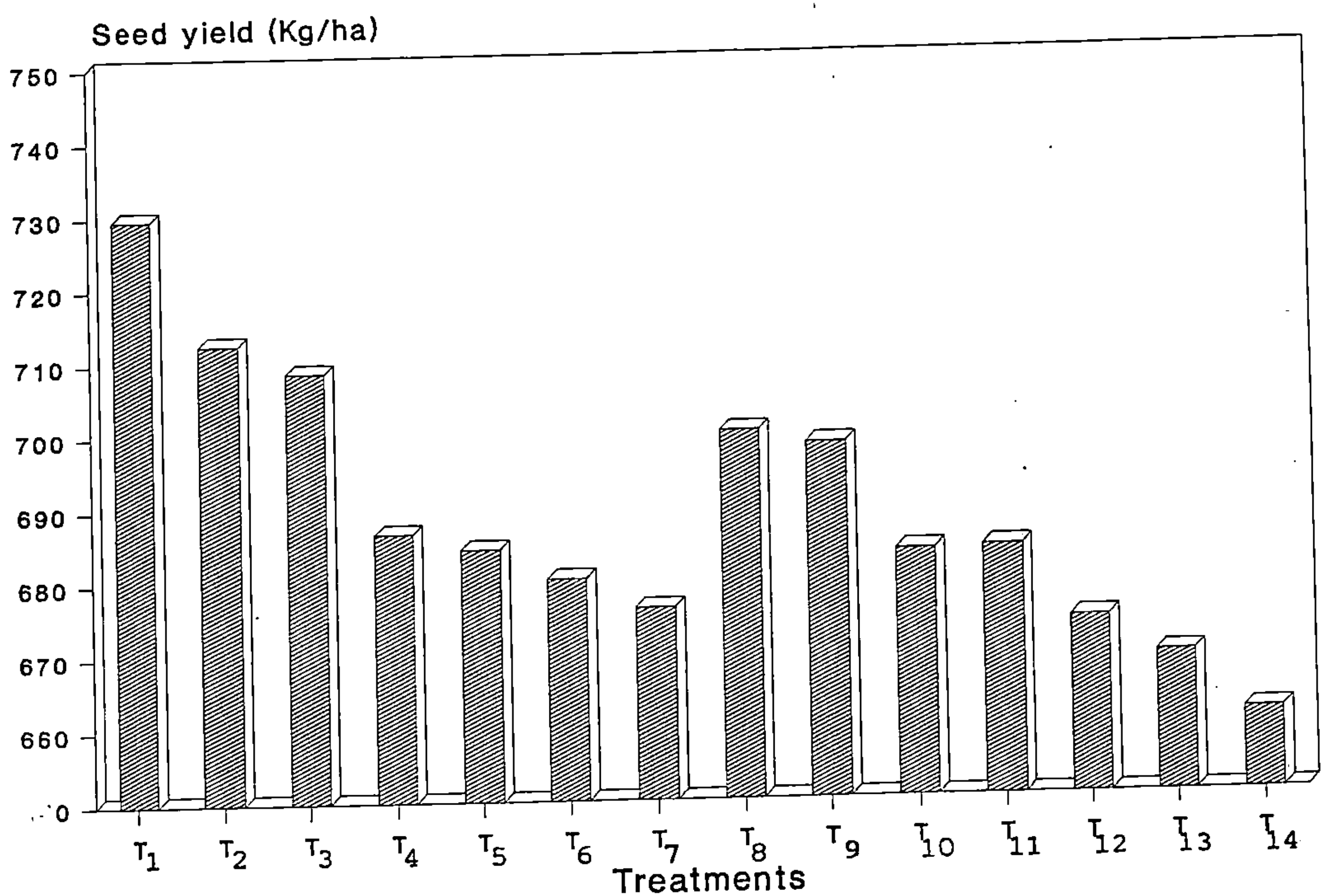
2.6. Seed yield

Seed yield of sesame was significantly influenced by different treatments (Table 6 and Fig. 3). Application of inorganic N @ 30 kg/ha produced significantly highest seed yield of sesame grown in summer rice fallows compared to that produced by inoculation of **Azospirillum** or **Azotobacter** alone or along with 50 or 25 per cent N and uninoculated control. This might be the resultant of comparatively taller plants (Table 2) with more number of branches (Table 3) which produced more number of capsules /plant, higher number of seeds / capsule, 1000 seed weight and weight of capsules / plant (Table 6) in these plots. The ready availability of sufficient N, during the early growth stages resulted in taller plants and more number of branches / plant. This might have led to a greater photosynthetic surface area which in turn produced more photosynthates and the efficient translocation of these photosynthates might have resulted in more number of capsules /plant and seeds / capsule. The cumulative effect of growth characters and yield components might have resulted in the production of highest seed yield of sesame in the plots applied with 30 kg inorganic N/ha. The favourable effects of N on seed yield of sesame due to stimulating effect of N on yield attributes was also reported by Senniayan and Arunachalam (1978).

Table 6. Effect of different treatments on the yield attributes and yield of sesame.

Treatments	Days to 50 % flowering	Number of capsules per plant	Number of seeds per capsules	1000 seed weight (g)	Weight of capsules/ plant(g)	Seed yield (kg/ha)	Shelling percentage
30 kg N/ha as urea	33.33	76.79	58.97	3.36	16.34	729.50	60.2
Azospirillum+50% N+lime	33.00	75.83	58.70	3.51	15.21	712.40	61.52
Azospirillum+50% N	34.00	75.04	57.03	3.24	15.03	708.50	55.13
Azospirillum+25% N+lime	34.67	72.90	53.00	3.08	14.04	686.50	54.65
Azospirillum+25% N	34.00	74.27	55.20	3.46	15.40	684.30	60.11
Azospirillum+lime	34.33	76.59	52.77	3.36	15.00	676.81	59.30
Azospirillum	35.67	76.48	50.73	3.35	14.60	676.10	60.58
Azotobacter+50% N+lime	34.33	74.07	58.00	3.21	16.50	700.00	55.24
Azotobacter+50% N	33.00	73.91	53.60	3.28	15.40	698.20	60.46
Azotobacter+25% N+lime	34.67	75.59	54.87	3.08	13.90	683.50	55.00
Azotobacter+25% N	34.67	74.85	50.37	3.22	15.80	683.80	54.46
Azotobacter+lime	36.12	72.68	54.53	3.22	15.70	673.90	59.32
Azotobacter	35.81	66.00	50.73	3.26	14.04	668.90	55.34
Absolute control	35.33	69.03	53.97	3.23	15.01	660.90	55.79
SEm±	0.72	0.99	1.43		0.45	5.49	0.61
CD (0.05)	2.10	2.90	4.16	NS	1.31	16.01	1.78

Fig. 3. Effect of different treatments on seed yield of sesame



The data also revealed that inoculation of **Azospirillum** or **Azotobacter** along 50 or 25 per cent inorganic N could bring about a higher seed yield of sesame, compared to uninoculated control though the effect was not significant with inoculation of **Azospirillum** or **Azotobacter** alone. The higher seed yield in microbial inoculated plots might be due to the activity of a higher population of microbes (Table 13 and 14) which led to favourable N supply to the plants and resulted in a comparatively greater vegetative growth (Tables 2,3,4 and 5) and yield components (Table 6) compared to uninoculated control. However, comparison between the two microbes revealed the better performance of **Azospirillum**. This might be due to the fact that **Azotobacter** doesn't compete well with the rhizosphere microflora. Similar interpretations were made by Dart and Day (1975).

The lowest yield was recorded by the uninoculated control. However, it was observed to be on par with inoculation of either **Azospirillum** or **Azotobacter** alone (Table 6). The presence of native microbes (Table 1) might be the attributed reason.

The data also indicated that lime application could not bring about any significant influence on the activity of microbes regarding seed yield of sesame grown in summer rice fallows. This again showed the ineffectiveness of liming on acid tolerant strains of these microbes.

2.7. Shelling percentage

The data presented in Table 6, showed that inoculation of **Azospirillum** along with 50 per cent inorganic N and lime resulted in numerically highest shelling percentage which was on par with some of the treatments including the application of inorganic N @ 30 kg/ha. The similarity in shelling percentage of these treatments might be due to the comparatively higher pod and seed yield (Table 6).

As in most of the yield attributing characters, **Azospirillum** showed its superiority over **Azotobacter** in shelling percentage too due to the reasons discussed.

Shelling percentage was low in absolute control plots. However, it was on par with many treatments as evident from Table 6. The natural occurrence of microbes and the medium initial soil fertility status as discussed earlier, might be the attributed reason.

The data also indicated that liming did not enhance the activity of acid tolerant strains of either

Azospirillum or **Azotobacter**, so as to bring about any significant difference in the shelling percentage of sesame.

3. Quality of seeds

3.1. Oil content and oil yield

Oil content of sesame was not influenced by different treatments (Table 7). However, the oil yield was significantly highest in the plot treated with 30 kg inorganic N/ha alone (Table 7 and Fig. 4).

The favourable nutrition of sesame crop from the initial growth period might have resulted in the better vegetative growth (Table 2, 3, 4 and 5), thereby a higher photosynthetic surface for better photosynthesis. The efficient translocation of photosynthates to the reproductive parts resulted in better yield components (Table 6) and thereby highest seed yield (Table 6). The higher oil content (Table 7) and higher seed yield (Table 6) resulted in the production of significantly highest oil yield in the above treatment. Increase in oil yield due to N fertilization was also reported by Michell et al. (1974). It has been reported by Ramakrishnan et al. (1994) that the oil content increased with P and K content in the seed and the seed yield with N content in

Table 7. Effect of different treatments on oil content (%) and oil yield (kg/ha) of sesame.

Treatments	Oil content (%)	Oil yield (kg/ha)
30 kg N/ha as urea	47.27	344.83
Azospirillum+50% N+lime	47.37	337.46
Azospirillum+50% N	47.30	335.12
Azospirillum+25% N+lime	46.00	315.77
Azospirillum+25% N	46.20	316.17
Azospirillum+lime	46.13	313.76
Azospirillum	45.37	306.75
Azotobacter+50% N+lime	46.63	326.46
Azotobacter+50% N	46.83	326.97
Azotobacter+25% N+lime	46.37	316.95
Azotobacter+25% N	45.20	309.09
Azotobacter+lime	45.70	307.99
Azotobacter	45.43	304.00
Absolute control	45.37	299.80
SEm±		2.39
CD (0.05)	NS	6.98

the seed. The better performance of the plots applied with 30 kg inorganic N/ha in the present experiment too revealed comparatively higher values for N, P and K contents in the seed (Appendix II, III and IV) which is in accordance with the above report.

Here again, **Azospirillum** strain showed its slightly better performance over **Azotobacter** (Table 7) due to its mode of inhabitance and other reasons as discussed.

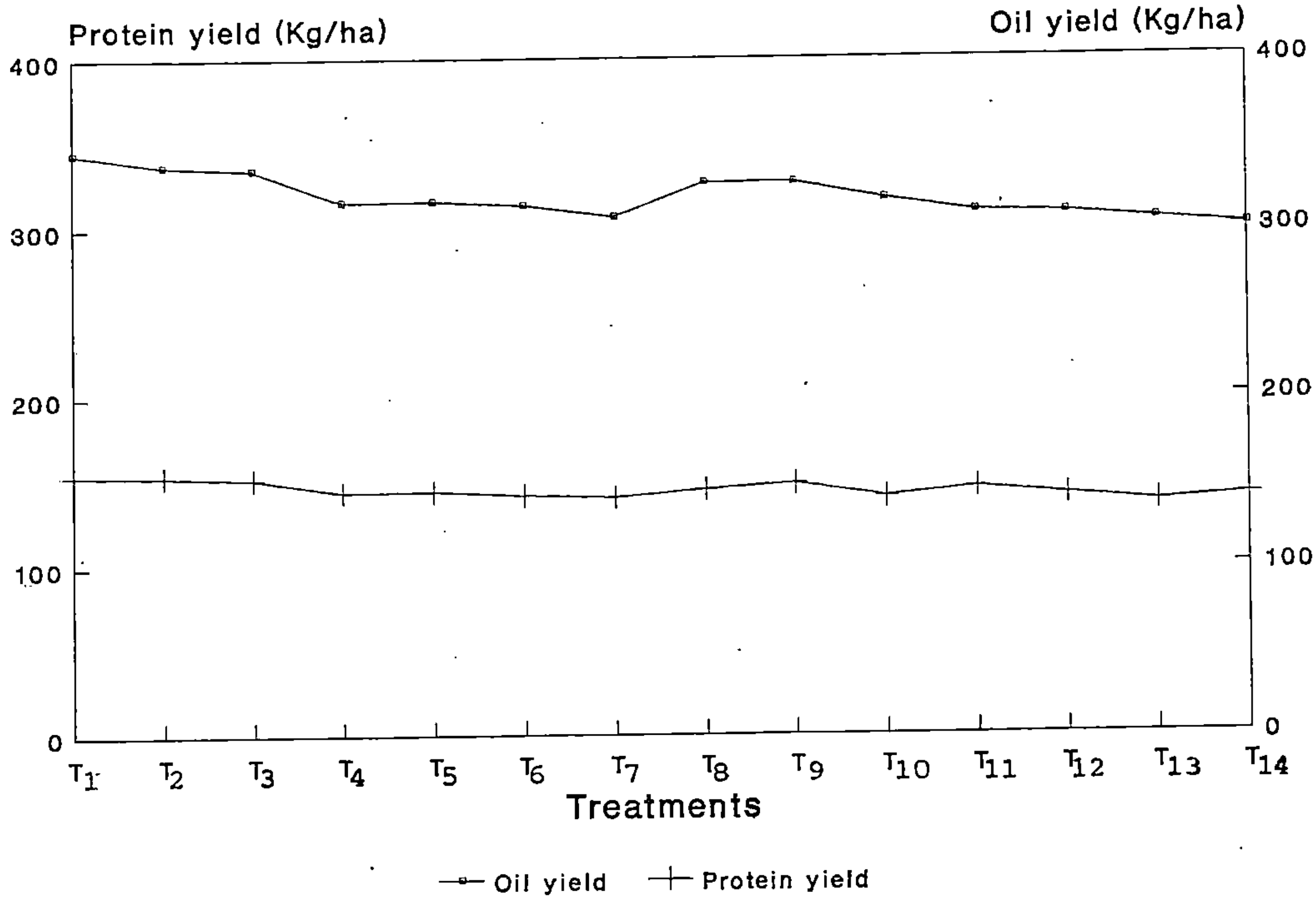
As evident from the Table 7, the uninoculated control showed the lowest oil yield and a comparatively low oil content (Table 7). However, it was on par with plots treated with the microbes alone, probably due to the native occurrence of the microbes and a better initial nutrient status of the experimental field.

The data also indicated the non significant performance of acid tolerant strains of **Azospirillum** or **Azotobacter** with or without lime application.

3.2. Protein content and protein yield

Highest protein yield was obtained from plots treated with inorganic N @ 30 kg/ha alone (Table 8 and Fig. 4). The protein content too was higher in these plots. However, protein yield obtained from most of the plots inoculated with **Azospirillum** or **Azotobacter** was on

Fig. 4. Effect of different treatments on quality of sesame seeds.



par with that obtained from plots supplied with 30 kg inorganic N/ha alone. The numerically higher protein yield obtained from inorganic N treated plots is due to the higher nutrient uptake (Table 9, 10 and 11), higher seed yield (Table 6) and a comparatively higher protein content (Table 8).

The protein yield also showed higher values in plots inoculated with **Azospirillum** than with **Azotobacter** which again indicated the slightly better performance of the former in summer rice fallows. The close association of **Azospirillum** with the roots compared to **Azotobacter** as discussed, might be applicable here too. The uninoculated control plot showed a significantly lower protein yield than from plot supplied with inorganic N alone. However, a non significant difference was observed between most of the inoculated treatments and uninoculated control. The lower protein yield in the absolute control plot might be due to the lower supply of nutrients especially N to the plants which resulted in lower uptake (Table 9, 10 and 11), growth and yield (Table 5 and 6) and thereby protein yield.

The data also showed a nonsignificant influence of liming on acid tolerant strains of these microbes, probably due to the same reasons discussed earlier.

Table 8. Effect of different treatments on protein content (%) and protein yield (kg/ha) of sesame.

Treatments	Protein content (%)	Protein yield (kg/ha)
30 kg N/ha as urea	21.13	154.14
Azospirillum+50% N+lime	21.56	153.58
Azospirillum+50% N	21.44	151.90
Azospirillum+25% N+lime	21.00	144.16
Azospirillum+25% N	21.12	144.52
Azospirillum+lime	20.87	141.95
Azospirillum	20.81	140.69
Azotobacter+50% N+lime	20.75	145.25
Azotobacter+50% N	21.25	148.36
Azotobacter+25% N+lime	20.56	140.52
Azotobacter+25% N	21.25	145.30
Azotobacter+lime	20.93	141.04
Azotobacter	20.43	136.66
Absolute control	21.18	139.97
SEm±		4.65
CD (0.05)	NS	13.56

4. Nutrient uptake

4.1. N uptake

The data presented in Table 9 and Appendix II and Fig. 5. regarding N uptake by sesame, showed that at 30 and 60 DAS, application of inorganic N @ 30 kg/ha resulted in a higher N uptake at all stages. Moreover, the effect was significant at 30 DAS. The positive influence of N, on N uptake by sesame at all stages of growth was reported by Girija Devi (1985) also. The ready availability of sufficient N during early stages resulted in vigourous vegetative growth, which led to a higher dry matter production (Table 5) and higher uptake by plants in these plots.

Inoculation of **Azospirillum** showed better N uptake values compared to **Azotobacter**. The enhanced N uptake by plants in **Azospirillum** inoculated plots might be due to certain enzymatic action of these microbes as described by Konde and Patil (1993). Their reports revealed that **Azospirillum** being a root coloniser has a close contact with the plant roots. It can soften the middle lamellae through the action of pectinolytic enzymes, without causing cell collapse, thus enhancing the mineral absorption surface of the cortex cells.

Table 9. Effect of different treatments on the nitrogen uptake (kg/ha) by sesame.

Treatments	30 DAS	60 DAS	Harvest
30 kg N/ha as urea	27.53	73.46	117.20
Azospirillum+50% N+lime	22.58	63.61	114.12
Azospirillum+50% N	23.33	62.92	117.41
Azospirillum+25% N+lime	20.29	67.81	101.54
Azospirillum+25% N	21.52	64.26	111.12
Azospirillum+lime	17.93	64.40	106.31
Azospirillum	20.73	62.99	102.30
Azotobacter+50% N+lime	21.75	63.55	111.90
Azotobacter+50% N	21.71	65.92	106.62
Azotobacter+25% N+lime	20.88	61.711	103.60
Azotobacter+25% N	22.06	61.18	106.21
Azotobacter+lime	20.09	52.89	107.36
Azotobacter	17.79	51.31	95.13
Absolute control	17.85	52.08	105.58
SEM±	1.25	7.51	
CD (0.05)	3.64	21.89	NS

The uninoculated control plot showed a comparatively lower N uptake value. However, it was on par with some of the microbial inoculated treatments. This might be due to the better initial soil fertility status combined with the presence of microbes as discussed.

Data on N uptake also showed the ineffectiveness of lime application on the activity of acid tolerant strains of **Azospirillum** or **Azotobacter** in bringing about any significant difference in N uptake by sesame.

4.2. P uptake

The data presented in Table 10 and Appendix III and Fig. 5 revealed that plants in plots treated with inorganic N @ 30 kg/ha showed the highest P uptake at all stages, though it was on par with inoculation of **Azospirillum** or **Azotobacter** along with 50 per cent inorganic N at all stages. This again showed the superiority of the recommended dose of inorganic N alone, for sesame grown in summer-rice fallows. This might be due to higher dry matter production (Table 5) resulted from better nutrition of plants from the initial growth stage itself. The favourable nutrition might have also been contributed to better root growth and increased root surface area as reported by Watanabe and Lin (1984), which led to a higher P uptake by plants in these plots.

Table 10. Effect of different treatments on the phosphorus uptake (kg/ha) by sesame.

Treatments	30 DAS	60 DAS	Harvest
30 kg N/ha as urea	3.96	12.32	17.36
Azospirillum+50% N+lime	3.32	11.97	16.21
Azospirillum+50% N	3.93	11.88	16.42
Azospirillum+25% N+lime	3.34	11.22	15.58
Azospirillum+25% N	3.50	11.56	15.28
Azospirillum+lime	2.83	10.79	15.10
Azospirillum	3.19	10.23	15.11
Azotobacter+50% N+lime	3.31	11.80	17.18
Azotobacter+50% N	3.31	11.78	16.69
Azotobacter+25% N+lime	3.20	10.94	16.49
Azotobacter+25% N	3.17	10.72	16.47
Azotobacter+lime	3.04	10.43	15.60
Azotobacter	3.06	10.62	16.12
Absolute control	3.00	10.54	15.36
SEM±	0.24	0.56	0.59
CD (0.05)	0.69	1.62	1.72

Inoculation of **Azospirillum** resulted in a slightly better P uptake at 30 and 60 DAS. The close association of **Azospirillum** with plant roots would have favoured their better contribution to root proliferation.

The uninoculated control plot showed a comparatively lower P uptake value. However, the non significant difference in P uptake by plants in these plots and most of the microbial inoculated plots might be due to the favourable initial nutrient status of the soil which resulted in favourable growth of plants, thereby a higher dry matter production.

The data also revealed that liming along with inoculation of acid tolerant strains of **Azospirillum** or **Azotobacter** was not effective to bring about any substantial difference as discussed earlier.

4.3. K uptake

In sesame plants grown in summer rice fallows at 30 and 60 DAS the K uptake was highest in the plots receiving 30 kg inorganic N/ha, alone (Table 11, Appendix IV and Fig. 5). At harvest, plots treated with **Azotobacter** along with 50 per cent N gave the highest K uptake values. However, the plots which received 30 kg inorganic N/ha alone was on par with the above treatment.

Table 11. Effect of different treatments on the potassium uptake (kg/ha) by sesame.

Treatments	30 DAS	60 DAS	Harvest
30 kg N/ha as urea	30.59	75.28	84.33
Azospirillum+50% N+lime	24.16	71.80	86.44
Azospirillum+50% N	28.58	72.57	79.71
Azospirillum+25% N+lime	24.08	70.31	76.73
Azospirillum+25% N	24.29	71.40	79.96
Azospirillum+lime	20.64	69.62	79.10
Azospirillum	23.80	67.33	76.17
Azotobacter+50% N+lime	25.50	72.93	87.69
Azotobacter+50% N	24.25	69.24	89.98
Azotobacter+25% N+lime	24.19	70.34	80.10
Azotobacter+25% N	24.51	71.51	79.96
Azotobacter+lime	24.62	69.44	78.63
Azotobacter	23.78	69.63	78.20
Absolute control	23.94	67.27	77.29
SEm±	1.37	1.93	4.39
CD (0.05)	3.98	5.63	12.79

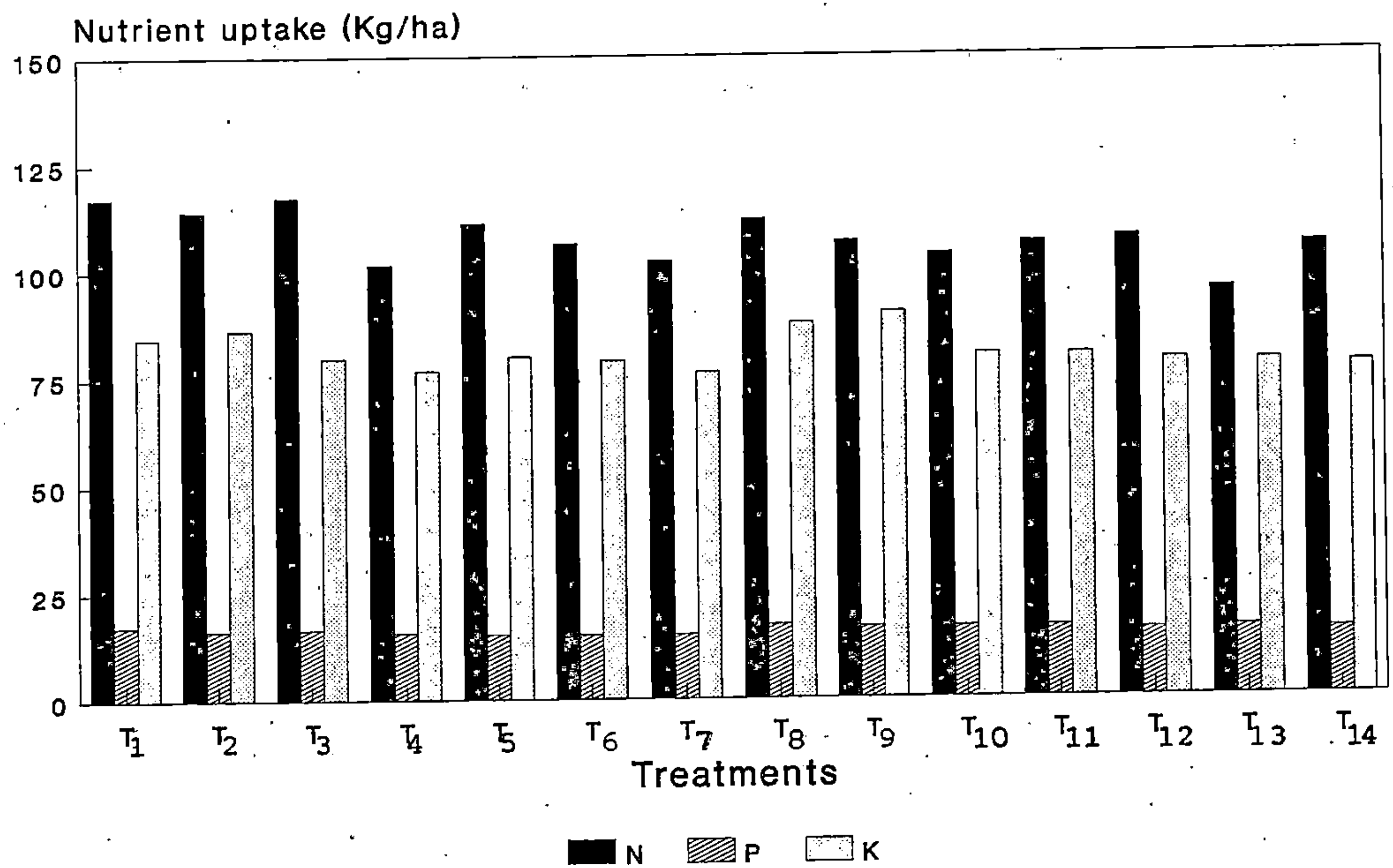
This again showed the requirement of application of 30 kg inorganic N/ha for sesame grown in summer rice fallows, the favourable influence of which was discussed earlier.

Though **Azospirillum** and **Azotobacter** both performed in a similar manner at 30 DAS, 60 DAS and at harvest, the performance of **Azotobacter** was slightly better regarding K uptake. The bacterial inoculants may show inconsistent responses due to the influence of a large number of factors as reported by Brown (1974).

The data further revealed that, uninoculated control, showed a comparatively lower value. The attributed reason for its similarity with many microbial inoculated treatments is the non significant difference in growth (Table 3 and 4) and drymatter production (Table 5), which again is a resultant of the favourable initial nutritional status of the soil and natural occurrence of both the microbes in all plots, irrespective of treatments.

The data on K uptake by sesame again showed the non-significant effect of liming along with the inoculation of acid tolerant strains of **Azospirillum** or **Azotobacter** in summer rice fallows.

Fig. 5. Nutrient uptake by sesame (at harvest) as influenced by different treatments.



5. Soil studies

5.1. Available N

The data regarding available N content of soil after the harvest of sesame crop (Table 12 and Fig. 6) showed a general increase including the absolute control plot, compared to its initial content (Table 1). This might be due to the basal application of farmyard manure and presence of **Azospirillum** and **Azotobacter** in all plots, irrespective of treatments. Similar results were reported by Rangarajan and Subramanian (1993). The highest available N content after harvest was noticed in plots inoculated with **Azospirillum** along with 50 per cent inorganic N and lime. However, this was on par with its inoculation along with 50 per cent inorganic N without lime. Inoculation of **Azotobacter** along with 50 per cent inorganic N, with or without lime and also application of 30 kg inorganic N/ha alone were comparable to the above treatments. This might be due to the addition of more N to soil by microbes in the presence of inorganic N. It is also evident from Table 13 and 14 that the population of microbes decreased by the harvest of the crop. The microbial lysis can release the locked up N at this stage, thus increasing the available N content of the soil. These interpretations are in accordance with the reports by Purushothaman and

Menon (1984). Moreover, the presence of inorganic N can hasten the activity of the microbes as discussed earlier.

The data also showed a decreasing trend in the available N content of the soil, with a decrease in the inorganic N application along with inoculation of either **Azospirillum** or **Azotobacter.** This might be due to the decrease in inorganic N application. Between **Azospirillum** and **Azotobacter,** the former again showed a comparatively higher available N content in soil. This might be due to the better effectiveness of associative symbiosis of **Azospirillum** than the free living **Azotobacter.**

The data further revealed that lime application did not bring about any significant effect on available N content of soil by influencing the acid tolerant strains of either **Azospirillum** or **Azotobacter.**

5.2. Available P

The Table 12 and Fig 6 revealed that inoculation of **Azospirillum** along with 50 per cent inorganic N and lime resulted in the highest available P content of soil after harvest of the crop, closely followed by application of 30 kg inorganic N/ha. However, it was found to be on par with inoculation of **Azospirillum** along with 50 per cent inorganic N without lime and also with **Azotobacter** inoculation along with 50 per cent inorganic N with or without lime. This showed the favourable influence of microbes in the presence of sufficient inorganic N, on the available P content of the soil. Moreover, a decrease in available P content is noticed with a decrease in inorganic N application.

Between **Azospirillum** and **Azotobacter** inoculated plots, inoculation of **Azospirillum** resulted in a slightly better available P content of soil, which again showed the superiority of **Azospirillum** in improving the fertility status of soil.

The least available P content was noticed in the absolute control plot. However, it was on par with many of the microbial inoculated treatments. The natural occurrence of microbes coupled with a medium initial P fertility status of the soil, would have made these treatments at par. The data further revealed the ineffectiveness of lime application on the activity of acid tolerant strains of both the microbes as discussed in earlier sections

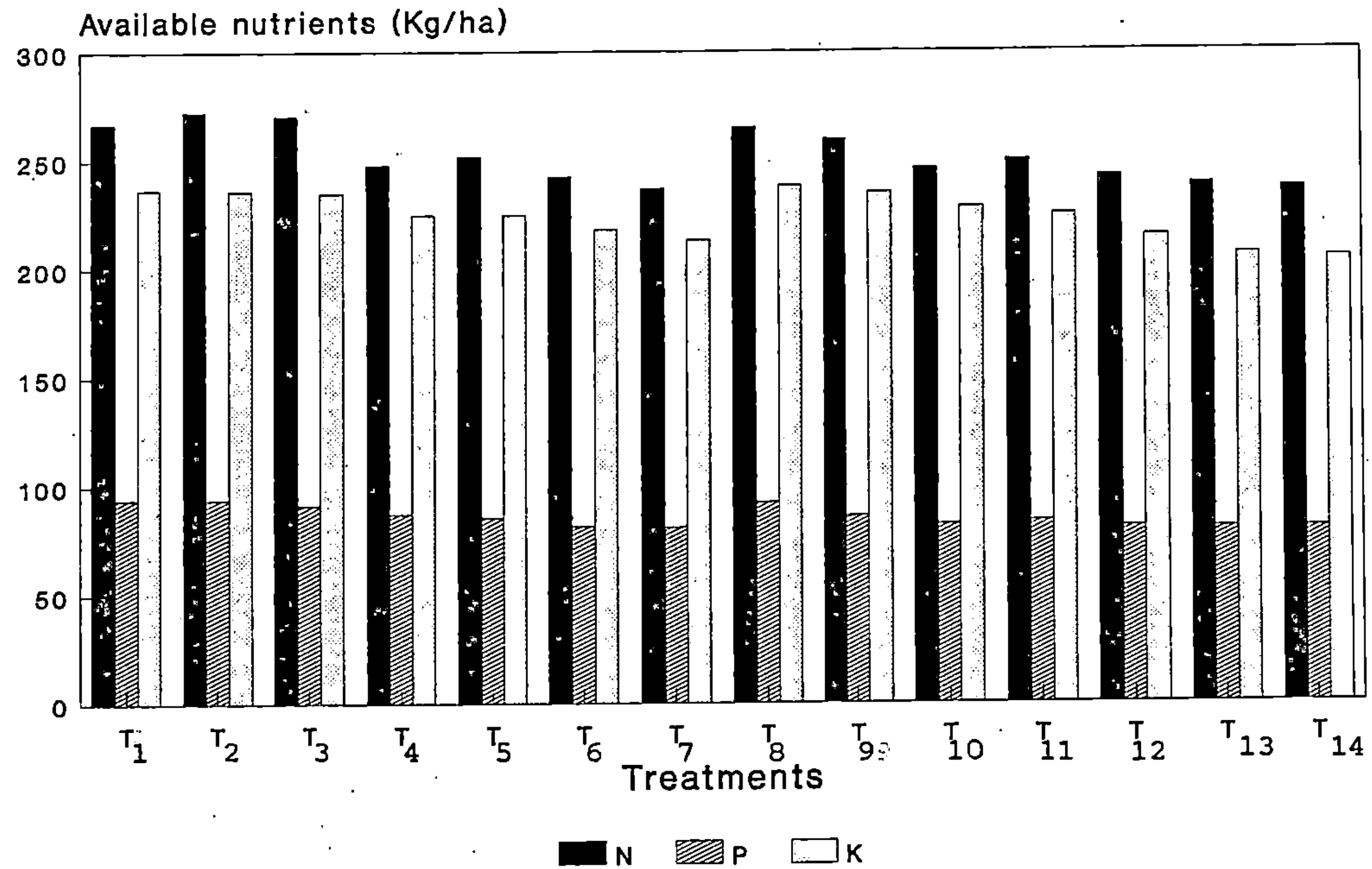
5.3. Available K

Available K content of the soil was highest in plots inoculated with **Azotobacter** along with 50 per cent inorganic N and lime followed by application of inorganic N alone @ 30 kg/ha as evident from Table 12 and Fig.6. Inoculation of

Table 12. Available nitrogen, phosphorus and potassium in soil (at harvest) as influenced by different treatments in sesame (kg/ha)

Treatments	Available nitrogen	Available phosphorus	Available potassium
30 kg N/ha as urea	266.93	94.07	236.67
Azospirillum+50% N+lime	272.53	94.13	236.16
Azospirillum+50% N	270.67	91.23	235.00
Azospirillum+25% N+lime	248.27	87.27	225.00
Azospirillum+25% N	252.00	85.57	225.00
Azospirillum+lime	242.67	81.60	218.33
Azospirillum	237.07	81.03	213.33
Azotobacter+50% N+lime	265.07	92.37	238.33
Azotobacter+50% N	259.47	86.13	235.00
Azotobacter+25% N+lime	246.40	82.17	228.33
Azotobacter+25% N	250.13	83.87	225.00
Azotobacter+lime	242.67	81.03	215.00
Azotobacter	238.93	80.47	214.67
Absolute control	237.07	80.47	212.98
SEm±	6.91	2.79	6.40
CD (0.05)	20.15	8.13	18.68

Fig. 6. Soil nutrient status (at harvest) as influenced by different treatments in sesame



Azospirillum along with 50 per cent inorganic N and that of **Azotobacter** with 25 per cent inorganic N were also on par with the above treatment.

The data also indicated a gradual decrease in available K content of the soil, with a decrease in the application of inorganic N along with inoculation of microbes. This again showed the favourable influence of inorganic N on the activity of microbes in bringing about an increase in the available K content of soil.

The lowest available K content of soil was noticed in the absolute control plots. However, it was on par with the plots that were inoculated with **Azospirillum** or **Azotobacter** alone. The non significant difference between inoculated and uninoculated treatments, might be due to the presence of native microbes.

The data showed that lime application was not necessary when acid tolerant strains of microbes were used. They proliferate equally well in the presence or absence of $CaCO_3$ as discussed.

6. Microbial population

6.1. Azospirillum Population

The data presented in Table 13, indicated that **Azospirillum** was present in all plots irrespective of inoculation at all stages of sesame crop. This showed the natural occurrence of **Azospirillum** in summer rice fallows of Kerala.

However, a comparatively higher population of **Azospirillum** was observed in inoculated plots compared to uninoculated plots at all stages. Among the **Azospirillum** inoculated treatments, its inoculation with 50 per cent inorganic N resulted in highest population at 30 DAS, 60 DAS and at harvest (Table 13). Further, it was on par with its inoculation along with 25 per cent inorganic N. This showed the favourable influence of inorganic N along with inoculation, on the population of **Azospirillum**.

Further, it is evident from the data that population of **Azospirillum** increased and reached a maximum at 60 DAS and then decreased towards harvest, in both inoculated and uninoculated treatments. Similar results were reported by Shetty et al. (1976). The maximum build up of **Azospirillum** population coincided with the active vegetative phase and the capsule formation stage of sesame crop as reported by Ramanathan and Prasad (1993). They also observed a decline of **Azospirillum** population in the rhizosphere of sesame plants by harvest. The active vegetation of the crop at 60 DAS (Table 2, 3 and 4) might have encouraged a congenial humid and viable

Table 13. **Azospirillum** population in the rhizosphere of sesame as influenced by different treatments (x 10^6 cells/g of soil)

Treatments	30 DAS		60 DAS		Harvest	
	T	0	T	0	T	0
30 kg N/ha as urea	5.96	0.92	6.24	1.74	6.22	1.68
Azospirillum+50% N+lime	6.09	1.23	6.46	2.86	6.40	2.54
Azospirillum+50% N	6.09	1.25	6.41	2.25	6.40	2.55
Azospirillum+25% N+lime	6.09	1.24	6.40	2.54	6.39	2.47
Azospirillum+25% N	6.08	1.22	6.44	2.78	6.38	2.42
Azospirillum+lime	5.98	0.97	6.35	2.25	6.36	2.30
Azospirillum	5.99	0.98	6.36	2.28	6.30	2.01
Azotobacter+50% N+lime	5.87	0.75	6.18	1.52	6.18	1.53
Azotobacter+50% N	5.82	0.66	6.15	1.42	6.17	1.49
Azotobacter+25% N+lime	5.87	0.75	6.24	1.72	6.17	1.51
Azotobacter+25% N	5.91	0.82	6.27	1.85	6.24	1.73
Azotobacter+lime	5.92	0.83	6.26	1.84	6.23	1.72
Azotobacter	5.93	0.86	6.27	1.86	6.23	1.70
Absolute control	5.95	0.89	6.26	1.77	6.24	1.73
SEm±	0.03		0.02		0.01	
CD (0.05)	0.08		0.05		0.04	

T - Transformed value   0 - Original value atmosphere in the rhizosphere of the crop for the root colonising microbe, **Azospirillum**, to raise its population at this stage (Okon and Kapulink, 1986).

The data also indicated that lime had no significant influence on population of **Azospirillum.** This showed that while inoculating acid tolerant strains of **Azospirillum** in summer rice fallows of Kerala, liming was not necessary.

6.2. Azotobacter population

The data regarding populations of **Azotobacter** (Table 14), indicated the presence of the microbe in all plots including uninoculated control. The uniform presence of farmyard manure along with the incorporated stubbles might have served as suitable substrates for the multiplication of **Azotobacter.** Moreover, the cellulolytic micro-organisms which degrade plant residues in soil might have encouraged the proliferation of **Azotobacter** in soil (Jensen, 1965).

Among the treatments, **Azotobacter** inoculated plots recorded higher population of the same compared to uninoculated plots. Inoculation of **Azotobacter,** along with 50 per cent inorganic N resulted in highest population which was significantly superior to its

Table 14. **Azotobacter** population in the rhizosphere of sesame as influenced by different treatments (x 10^6 cells / g of soil)

Treatments	30 DAS		60 DAS		Harvest	
	T	O	T	O	T	O
30 kg N/ha as urea	6.58	3.80	6.95	8.89	6.89	7.80
Azospirillum+50% N+lime	6.60	3.99	6.95	8.89	6.88	7.63
Azospirillum+50% N	6.59	3.91	6.95	8.84	6.89	7.69
Azospirillum+25% N+lime	6.57	3.75	6.93	8.42	6.89	7.68
Azospirillum+25% N	6.57	3.68	6.92	8.37	6.84	7.00
Azospirillum+lime	6.55	3.57	6.92	8.30	6.84	6.90
Azospirillum	6.53	3.41	6.91	8.19	6.83	6.83
Azotobacter+50% N+lime	6.77	5.86	7.09	12.35	7.02	10.45
Azotobacter+50% N	6.74	5.50	7.07	11.79	7.02	10.35
Azotobacter+25% N+lime	6.69	4.98	7.05	11.44	7.00	10.03
Azotobacter+25% N	6.70	5.04	7.03	10.73	6.98	9.63
Azotobacter+lime	6.70	5.00	7.00	10.22	6.95	8.83
Azotobacter	6.68	4.84	7.01	10.01	6.92	8.40
Absolute control	6.55	3.54	6.92	8.28	6.88	7.50
SEm±	0.01		0.006		0.006	
CD (0.05)	0.04		0.02		0.02	

T - Transformed value O - Original value inoculation alone or along with 25 per cent inorganic N. This again showed the favourable influence of inorganic N on **Azotobacter** population.

As in the case of **Azospirillum, Azotobacter** population also increased and reached a maximum at 60 DAS after which the population reduced towards harvest. The congenial conditions as mentioned earlier, might be applicable here too.

The data also revealed the non significant influence of lime on the population of **Azotobacter**. This showed that while inoculating **Azotobacter** in summer rice fallows, liming was not necessary.

7. Correlation studies

The data presented in Table 15, showed that the drymatter production and seed yield of sesame were positively correlated with its growth characters such as height, number of branches / plant and leaf area index. They were also positively correlated with N, P and K uptake by the crop at 60 DAS and with the population of **Azospirillum** and **Azotobacter** in the rhizosphere. A positive correlation was observed between seed yield and yield attributes (Table 16) such as number of capsules / plant, number of seeds/capsule, 1000 seed weight, shelling per

Table 15. Correlation of dry matter production and seed yield of sesame with growth characters, nutrient uptake and microbial population at 60 DAS.

	Dry matter	Seed yield
Height	0.36	0.36
Branches/plant	0.18	0.61*
Leaf area index	0.05	0.40
N Uptake	0.42	0.77*
P Uptake	0.50	0.91*
K Uptake	0.73*	0.78*
Azospirillum count	0.06	0.09
Azotobacter count	0.05	0.02

* Significant at 5% level.

Table 16. Correlation of seed yield with yield attributes of sesame

	Seed yield
50 per cent flowering	-0.14
Number of capsules /plant	0.58*
Number of seeds /capsule	0.33
1000 seed weight	0.30
Shelling per cent	0.29
Weight of capsule /plant	0.51

* Significant at 5% level.

cent and weight of capsules/plant. However, the seed yield showed a negative correlation with the number of days to 50 per cent flowering. Similar reports of a significant and positive correlation of seed yield with the number of branches/plant, dry matter production, number of capsules/plant and 1000 seed weight and a negative correlation with number of days to 50 per cent flowering were reported by John and Nair (1990) in sesame grown in summer rice fallows of Kerala. Thus sesame plants with profuse branching , early flowering and production of large number of capsules/plant may be well suited for the summer rice fallows of Kerala.

The correlation studies presented in Table 17, showed that the N, P and K uptake values at harvest were significantly and positively correlated with the quality aspects, though the protein content showed only a low positive correlation with P and K uptake values. Girija Devi (1985) also reported the positive effect of N uptake on the quality of sesame seeds.

The data given in Table 18, indicated that the population of both the microbes, **Azospirillum** and **Azotobacter** showed a low positive correlation with the available N, P and K contents of the soil at harvest.

Table 17. Correlation of nutrient uptake at harvest with quality of sesame.

	N	P	K
Protein content	0.68*	0.09	0.31
Protein yield	0.85*	0.55*	0.61*
Oil content	0.76*	0.57*	0.68*
Oil yield	0.80*	0.64*	0.68*

* Significant at 5% level.

Table 18. Correlation of microbial population with available N, P and K contents of soil at harvest.

	Azospirillum	Azotobacter
N	0.2	0.2
P	0.18	0.16
K	0.24	0.31

* Significant at 5% level.

Jensen (1965) also observed positive correlations between the microbial population and available N and P contents of the soil in the presence of adequate organic matter status.

8. Economics

The cost of cultivation excluding the treatments amounted to Rs. 7110/ha (Table 19). The plots applied with 30 kg inorganic N/ha alone, gave the highest returns, profit and benefit cost ratio, due to its significantly highest seed yield over other treatments. It was followed by the plots inoculated with **Azospirillum** along with 50 per cent inorganic N without lime. Among the microbial treatments, **Azospirillum** treated plots showed a slightly better performance, due to its close association with plant roots, which might have helped in better nutrient uptake and finally contributed to a better seed yield than the **Azotobacter** treated plots, where the microbes are free living. Absolute control plots too produced fairly good profits as compared to some of the treatments, which can be attributed to the better initial soil fertility and the natural occurence of microbes in the field. Moreover, the data revealed that liming was only found to add to the cost of cultivation without any benefit. Thus, it was not necessary to use lime along with inoculation of acid tolerant strains of these microbes.

Table 19. Economics

Treatments	Cost of cultivation excluding the treatment	Cost involved in the treatment	Total cost of cultivation	Total returns	Profit	Benefit cost ratio
30 kg N/ha as urea	7110	230.0	7340.0	11672.0	4332.0	1.59
Azospirillum+50% N+lime	7110	1627.0	8737.0	11398.4	2661.4	1.30
Azospirillum+50% N	7110	127.0	7237.0	11336.0	4099.0	1.56
Azospirillum+25% N+lime	7110	1569.5	8679.5	10984.0	2304.5	1.26
Azospirillum+25% N	7110	69.5	7179.5	10948.8	3769.3	1.52
Azospirillum+lime	7110	1512.0	8622.0	10883.2	2261.2	1.26
Azospirillum	7110	2.0	7112.0	10817.6	3695.6	1.51
Azotobacter+50% N+lime	7110	1627.0	8737.0	11200.0	2463.0	1.28
Azotobacter+50% N	7110	127.0	7237.0	11171.2	3934.2	1.54
Azotobacter+25% N+lime	7110	1569.5	8679.5	10936.0	2256.5	1.25
Azotobacter+25% N	7110	69.5	7179.5	10940.8	3761.3	1.52
Azotobacter+lime	7110	1512.0	8622.0	10782.4	2160.4	1.25
Azotobacter	7110	2.0	7112.0	10702.4	3580.4	1.50
Absolute control	7110	0	7110.0	10574.4	3464.4	1.48

Urea	Rs. 3.5/kg	Lime	Rs. 2.5/kg
Mussorie phos	Rs 1.8/kg	Biofertilizers	Rs. 20/kg
Muriate of potash	Rs. 4/kg	Sesame Seeds	Rs. 16/kg

Summary

SUMMARY

A field experiment was conducted in the rice fallows of Agricultural Research Station, Mannuthy, during the summer season (January - April) of 1995, to find out the effectiveness of biofertilizers on the growth, yield and N economy of sesame.

The experiment was laid out in randomised block design with 14 treatments replicated thrice. The treatments included were, the recommended dose of inorganic N @ 30 kg/ha alone, inoculation of **Azospirillum** or **Azotobacter** with 50 per cent, 25 per cent or no inorganic N, either with or without lime and an absolute control.

The growth characters such as plant height, number of branches/plant, leaf area index and dry matter production were comparatively higher in plots treated with the recommended dose of 30 kg inorganic N/ha alone at all stages of sesame crop. It maintained its superiority over all other treatments tried, regarding the other parameters under study too.

The number of days taken to attain 50 per cent flowering was decreased with the application of inorganic

N. The better vegetative growth of plants during the early stages of the crop, in plots applied with 30 kg inorganic N/ha alone, might have resulted in a larger photosynthetic area and thereby more photosynthates. The efficient translocation of these photosynthates to the reproductive parts might have resulted in the production of larger number of capsules / plant, more number of seeds / capsule, higher weight of capsule / plant and finally the highest seed yield in this treatment.

Though the oil and protein content were not significantly influenced by the treatments, the oil and protein yields were affected significantly. The highest oil and protein yields were observed in plots treated with 30 kg inorganic N/ha alone.

The N, P and K uptake values at all stages of crop growth and the available N, P and K contents of the soil at harvest of the crop were comparatively higher in plots supplied with 30 kg inorganic N/ha alone.

The population of both **Azospirillum** and **Azotobacter** were comparatively high in all plots irrespective of the treatments at all stages. Initial soil analysis also showed the presence of these microbes. This showed the natural occurrence of both these microbes in the summer rice fallows of Kerala. However, the inoculated plots showed a higher population throughout. Another feature noted in the population was that, it increased to a maximum at 60 DAS and then decreased towards harvest in both inoculated and uninoculated treatments.

The natural occurrence of both **Azospirillum** and **Azotobacter**, initial medium fertility status of the soil, incorporation of rice stubbles and farmyard manure, along with the application of recommended dose of 30 kg inorganic N/ha, contributed to a substantial increase in seed yield of sesame and thereby maximum total returns, thus establishing its superiority over other treatments.

Though the microbes, **Azospirillum** and **Azotobacter** showed almost similar performances regarding the various parameters studied, the root colonising microbe **Azospirillum**, was slightly better when compared to the freeliving microbe, **Azotobacter**. Moreover, the result revealed that liming was not necessary in the summer rice fallows of Kerala, when acid tolerant microbial strains are inoculated.

Correlation studies indicated a positive correlation between seed yield and various aspects like growth characters, yield attributes, nutrient uptake, available soil nutrients and the microbial counts. A significant positive correlation was obtained between seed yield and number of capsules / plant and nutrient uptake values.

Thus, the results revealed that application of the recommended dose of 30 kg inorganic N/ha was necessary for sesame grown in summer rice fallows of Kerala. Inoculation of either **Azospirillum** or **Azotobacter** did not give any significant effect on growth, yield and quality of sesame compared to the application of inorganic N alone. This might be due to the natural occurrence of both these microbes in Kerala soil. Between the microbes, **Azospirillum** showed a better effect on the crop. The results also indicated that liming did not bring about any significant influence on the activity of acid tolerant strains of either **Azospirillum** or **Azotobacter**.

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* Originals not seen

Appendices

Week number	Temperature Max°C	Temperature Min°C	Relative humidity (%)	Sunshine (hrs)	Rainfall (mm)
3	31.7	23.8	71	10.5	-
4	33.3	21.8	77	9.6	-
5	33.4	24.2	69	10.8	-
6	34.7	23.4	71	10.3	-
7	35.6	22.6	79	4.6	-
8	36.1	23.4	89	3.8	0.5
9	37.2	23.1	90	4.3	-
10	36.9	23.8	86	4.6	1.8
11	37.8	23.8	82	3.3	1.0
12	38.9	23.7	75	5.2	-
13	36.5	24.5	86	4.6	-
14	37.5	24.4	86	4.4	54.8
15	36.3	24.7	89	4.0	46.2
16	35.7	25.0	87	3.9	12.6
17	37.2	25.5	85	4.0	5.1

APPENDIX - II

Nitrogen content (%) of sesame at different stages

Treatment	30 DAS	60 DAS	Harvest		
			Haulm	Shell	Seed
30 kg N/ha as urea	2.43	1.61	1.56	0.73	3.38
Azospirillum+50% N+lime	2.99	1.86	1.52	0.73	3.45
Azospirillum+50% N	2.31	1.43	1.61	0.74	3.43
Azospirillum+25% N+lime	2.43	1.91	1.24	0.69	3.36
Azospirillum+25% N	2.64	1.89	1.56	0.73	3.38
Azospirillum+lime	2.78	1.73	1.22	0.72	3.34
Azospirillum	2.54	2.03	1.25	0.70	3.33
Azotobacter+50% N+lime	2.43	1.83	1.63	0.72	3.32
Azotobacter+50% N	2.82	1.79	1.31	0.65	3.40
Azotobacter+25% N+lime	2.54	1.86	1.26	0.73	3.29
Azotobacter+25% N	2.43	1.54	1.12	0.70	3.40
Azotobacter+lime	2.31	1.47	1.34	0.68	3.35
Azotobacter	2.26	1.40	1.07	0.65	3.27
Absolute control	2.26	1.68	1.32	0.66	3.39

APPENDIX - III

Phosphorus content (%) of sesame at different stages

Treatment	30 DAS	60 DAS	Harvest		
			Haulm	Shell	Seed
30 kg N/ha as urea	0.35	0.27	0.15	0.16	0.52
Azospirillum+50% N+lime	0.45	0.35	0.14	0.15	0.52
Azospirillum+50% N	0.39	0.27	0.15	0.14	0.52
Azospirillum+25% N+lime	0.40	0.33	0.15	0.13	0.53
Azospirillum+25% N	0.43	0.34	0.13	0.13	0.51
Azospirillum+lime	0.44	0.29	0.12	0.13	0.50
Azospirillum	0.38	0.33	0.15	0.12	0.50
Azotobacter+50% N+lime	0.37	0.34	0.17	0.18	0.52
Azotobacter+50% N	0.43	0.32	0.15	0.16	0.52
Azotobacter+25% N+lime	0.39	0.33	0.14	0.16	0.53
Azotobacter+25% N	0.35	0.27	0.15	0.14	0.52
Azotobacter+lime	0.35	0.29	0.13	0.12	0.52
Azotobacter	0.39	0.29	0.16	0.16	0.51
Absolute control	0.38	0.34	0.12	0.14	0.51

APPENDIX - IV

Potassium content (%) of sesame at different stages

Treatment	30 DAS	60 DAS	Harvest		
			Haulm	Shell	Seed
30 kg N/ha as urea	2.7	1.65	1.67	1.73	0.69
Azospirillum+50% N+lime	3.2	2.10	1.67	1.98	0.67
Azospirillum+50% N	2.83	1.65	1.57	1.70	0.67
Azospirillum+25% N+lime	2.88	1.98	1.60	1.72	0.67
Azospirillum+25% N	2.98	2.10	1.65	1.73	0.70
Azospirillum+lime	3.20	1.87	1.57	1.68	0.69
Azospirillum	2.83	2.17	1.56	1.69	0.69
Azotobacter+50% N+lime	2.85	2.10	1.73	1.97	0.73
Azotobacter+50% N	3.15	1.88	1.83	2.03	0.68
Azotobacter+25% N+lime	2.95	2.12	1.70	1.72	0.66
Azotobacter+25% N	2.70	1.80	1.54	1.72	0.68
Azotobacter+lime	2.83	1.93	1.60	1.68	0.66
Azotobacter	3.03	1.90	1.68	1.72	0.68
Absolute control	3.03	2.17	1.59	1.69	0.66

EFFECT OF BIOFERTILIZERS ON THE GROWTH, YIELD AND NITROGEN ECONOMY OF SESAME GROWN IN SUMMER RICE FALLOWS

By

INDU K. PAUL

ABSTRACT OF A THESIS

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ABSTRACT

A field experiment was conducted in the rice fallows of Agricultural Research Station, Mannuthy, during the summer season (January - April) of 1995, to find out the effectiveness of biofertilizers on the growth, yield and N economy of sesame. The experiment was laid out in randomised block design with 14 treatments replicated thrice. The treatments included were, the recommended dose of inorganic N @ 30 kg/ha alone, inoculation of **Azospirillum** or **Azotobacter** along with 50 per cent, 25 per cent or no inorganic N, either with or without lime and an absolute control.

Most of the growth characters, yield attributes and yield were highest in the plots applied with the recommended dose of 30 kg inorganic N/ha alone. The crop nutrient uptake and available soil nutrients were also higher in the above treatment. The better initial physical, chemical and biological conditions of the soil, along with the added inorganic N fertilizer @ 30 kg/ha might have contributed to a better nutrient supply from the initial growth period itself.

Though, both the microbes, **Azospirillum** and **Azotobacter** showed almost similar performances regarding various

parameters, a slightly better response was shown by **Azospirillum** in most cases. This might be due to the fact that **Azospirillum** is a better root coloniser than the freeliving **Azotobacter**, which led to better nutrient uptake and ultimately yield of the crop, compared to **Azotobacter** inoculated treatments.

Lime application, along with the inoculation of acid tolerant strains of the microbes, had no profound influence on the parameters studied.

Thus, the study revealed the necessity of the application of recommended dose of inorganic N fertilizer @ 30 kg/ha for sesame grown in summer rice fallows. It also showed the lesser possibility of inorganic N substitution with **Azospirillum** or **Azotobacter** inoculation in such a situation. Moreover, liming could not bring about any significant influence on the activity of acid tolerant strains of either **Azospirillum** on **Azotobacter**.