EFFECT OF SEED SOAKING AND FOLIAR SPRAY OF GROWTH REGULATORS ON RICE (*Oryza sativa* L.)

By

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2001

Dedicated to

My

Beloved Parents

DECLARATION

I hereby declare that this thesis entitled "**Effect of seed soaking and foliar spray of growth regulators on rice (*Oryza sativa* L.)**" 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 of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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CERTIFICATE

Certified that this thesis entitled "**Effect of seed soaking and foliar spray of growth regulators on rice (*Oryza sativa* L.)**" is a record of research work done independently by Ms. Poornima Yadav. P.I. 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.

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LIST OF ABBREVIATIONS

%	Per cent
@	at the rate of
^0C	Degree Celsius
B	Boron
BCR	Benefit – Cost ratio
$CaCl_2$	Calcium chloride
CGR	Crop growth rate
Chl	Chlorophyll
Chl a	Chlorophyll a
Chl b	Chlorophyll b
cm^2	Centimetre square
DAF	Days after flowering
DAS	Days after sowing
DAT	Days after transplanting
DW	Dry weight
F	Foliar spray
Fe	Iron
Fig.	Figure
FYM	Farmyard manure
g	Gram
g ha^{-1}	Gram per hectare
GA_3	Gibberellic acid
ha	Hectare
HI	Harvest index
K	Potassium
kg	Kilogram
kg ha^{-1}	Kilogram per hectare
LAD	Leaf area duration
LAI	Leaf area index

LIST OF ABBREVIATIONS continued

m	Metre
m^2	Metre square
mg	Milligram
Mg	Magnesium
mg g^{-1}	Milligram per gram
mM	Micro molar
mm	Millimetre
mg l^{-1}	Milligram per litre
Mo	Molybdenum
N	Nitrogen
NAR	Net assimilation rate
P	Phosphorus
ppb	Parts per billion
ppm	Parts per million
q ha^{-1}	Quintals per hectare
S	Stages of application
SDH	Succinic dehydrogenase
SOD	Super oxide dismutase
T	Seed soaking
t ha^{-1}	Tonnes per hectare
w/w	Weight by weight
Zn	Zinc
$ZnSO_4$	Zinc sulphate

Introduction

1. INTRODUCTION

Rice is one of the world's leading crop which is extensively cultivated in the Asian region. The crop gives staple food for more than 60 per cent of the world population. In India, rice covers an area of 43.7 million hectare with an annual production of 84.7 million tonnes (Siddiq, 2000). Compared to other countries like China and South Korea the average productivity in India is very low accounting to 1.9 t ha^{-1}. In Kerala, rice covers an area of 3.45 lakh hectare with a productivity of 2.5 t ha^{-1} which is more than the national average (FIB, 2000).

On analysis of the problems in rice cultivation, Swaminathan (2000) pointed out that the possibilities of further expansion of area under rice cultivation has now reached its limits in most of the rice growing countries and the only way to achieve the targeted production in India is to enhance the national yield average from 1.9 t ha^{-1} to 2.8 t ha^{-1}.

The productivity improvement through genotypic, water and nutrient management seems to have reached a plateau (Mathew and Rajan, 1994). An alternate approach of improving the physiological efficiency of the plants in a better manner which will go a long way in increasing the productivity.

Several studies conducted in rice revealed the beneficial effect of seed soaking with biofertilizer in improving the vigour and yield of crop.

Azospirillum plays a vital role in crop germination and growth by secreting growth promoting substances (Sahu *et al.*, 1997). Improvement in rice yield by Azospirillum coating was also observed earlier (Lakhmanan *et al.*, 1993).

Penshibao, a new generation high technology multifunctional foliar liquid containing nutrients such as N, P, K, Zn, B, Mg, Fe, Mn and some other physiologically active compounds is now being widely used. This chemical made in China when used for seed soaking and foliar spray was observed to have a definite role in enhancing productivity of rice.

In recent times, the use of growth regulators have been shown to be one of the spectacular and quickest means of increasing rice production. Foliar spray of nutrients and phytohormones have given higher yield in most of the cereals, millets, cotton and many horticultural crops. The use of these growth regulators modify the growth of crops in small amounts and can enhance the longevity and area of leaves including flag leaves and thus increase the total carbon fixed. Growth regulators also enhance the mobilization of photosynthates from source to sink contributing to increase in yield.

Growth regulators like GA_3, kinetin and triacontanol have been shown to be of great use in increasing the rice production. Use of these chemicals for increasing yield by retarding senescence of leaves, flag leaves and panicle (Dehata and Murthy, 1981).

With the above points under consideration the present investigation was undertaken with the following objectives:

(i) To study the effect of a multifunctional foliar nutrient and a biofertilizer on germination, seedling vigour and growth in nursery.

(ii) To study the effect of seed soaking and foliar spray of growth promoters on growth, chlorophyll content, nutrient uptake and yield of rice.

(iii) To workout the economics of various treatments in transplanted rice.

Review of Literature

2. REVIEW OF LITERATURE

Growth regulators are synthetic or organic substances which when added in small amounts, modify the growth of plants, usually by stimulating or inhibiting part of the natural growth regulatory system (Halmann, 1985). At present due to the growing cost of fertilizer and almost full exploitation of other modern techniques for increasing the yield, it is necessary for an alternate approach where in the physiological efficiency including the photosynthetic ability of the plant will go a long way in increasing the productivity of rice. Growth regulator have been shown to be one of the quickest means of increasing production. Studies made on synthetic growth regulators revealed that these substances can modify the growth and development of the plant in the desired direction and to the desired extent. A brief review on the effect of seed soaking and foliar spray of growth regulators on rice, other cereals and millets are reviewed here.

2.1 Effect of seed soaking

Seed soaking is a simple method of treating seeds with needed inputs in liquids/slurry for better germination, vigour and crop growth (Agrawal, 1981).

Plant response to inoculations with Azospirillum in cereals and non-cereals are often reported in terms of increased germination rate, root length and volume, plant height, leaf size, tiller numbers, test weight, number of panicles and grains, enzyme level in plant parts, grain yield and biomass yield, N uptake, reduced insects and disease infestation (Okon, 1985; Boddey and Dobereiner, 1988; Wani, 1990).

Increased root biomass in Azospirillum inoculated plants helped in greater absorption of native nutrients in soil resulting in higher yield. This increased yield by Azospirillum inoculation may also be attributed to indole acetic acid, gibberellins, cytokinins like substances and vitamins produced by the bacterium, besides the ability of the organism to fix atmospheric N and their effect on plants (Rao, 1981).

2.1.1 Effect of Azospirillum on nursery characters

Sahu *et al.* (1997) reported that seeds of rice treated with Azospirillum accelerated the seed germination and produced more number of seedlings. Seed inoculation of rice cv. RP 2365 with *Azospirillum brasilense* showed higher seedling height and vigour index compared to the uninoculated control (Pradhan *et al.*, 1998). Natarajan and Kuppuswamy (1998) reported that the positive effects of *Azospirillum* in rice through the combined application of seed treatment and soil application which increased the seedling vigour, plant height, number of leaves, root volume and root dry matter production in nursery plants of rice cv. ADT 38. Seed treatment with Azospirillum increased the amylase activity during germination. The enzyme level was greater in vigourous seedlings. Secretion of gibberellins by the bacterium may be the reason for this increased amylase activity and subsequent hydrolysis, resulting in enhanced seedling vigour, encompassing speed of germination, seedling length and dry weight in rice (Ramamoorthy *et al.*, 2000).

2.1.2 Effect of Azospirillum on growth and yield

World wide data accumulated over 20 years of inoculation experiments on growth, yield and quality of grain fodder and fibre crops with *Azospirillum brasilense* revealed that this bacterium is capable of increasing the yield of agriculturally important crops in different soils and different climatic regions (Ganguly and Manna, 1999).

Shivaraj (1981) and Karthikeyan (1981) observed that Azospirillum inoculation increased the leaf area index, dry matter production, root, shoot and grain weight of rice. Seed inoculation with *Azospirillum brasilense* produced significant increase in DMP and yield of rice, wheat, barley and sorghum when grown with or without application of N (Subba Rao, 1995). Plant height and chlorophyll content of the newly developed rice leaves were significantly increased after seed inoculation with *Azospirillum brasilense* No. 40 (Ping *et al.*, 2001).

The effect of Azospirillum inoculation on the total yield increase of field grown graminacious crops ranged from 10 to 30 per cent (Kannaiyan *et al.*, 1983 and Negi *et al*, 1987). An increased grain yield in rice ranging from 13 to 35 per cent was reported by Prasad (1987) due to the inoculation of Azospirillum. Omar *et al* (1987) found that inoculation of Azospirillum on seeds and seedlings gave 16 to 22 per cent increase in rice grain yield at maximum recommended N- fertilizer level over uninoculated control.

2.1.3 Effect of micronutrients

2.1.3.1 Effect of micronutrients on the growth of rice

Zinc is essential for many metabolic roles in the plants viz., enzymatic activities, RNA and ribosome formations, stimulate the resistance of plants to dry and hot weather and also to bacterial and fungal diseases (Lindsay, 1974). Zinc is also necessary for chlorophyll production (Thompson and Troch, 1979). The critical concentration of zinc at tillering stage is 10 ppm and in third leaf stage is 21.5 ppm in rice (Swarup, 1983). Zinc application positively influenced shoot length, root weight, vigour index, photosynthetic rate, total dry matter production and grain yield of rice (Srinivasan, 1984). Seed treatment with 0.1 per cent $ZnSO_4$ for four hours markedly increased the zinc content in seeds, germination percentage and plant growth of rice (Gukoua *et al.*, 1985). Root dipping in zinc solution at two per cent concentration increased N uptake (Uddin *et al.*, 1981 and Baskar, 1986).

Kuppuswamy (1983) observed that leaf area index of both the first and residual rice crop was favorably influenced by Zn application. Significant influence of Zinc on DMP of rice was observed by Ilangovan and Palaniappan (1987).

Thompson and Troch (1979) observed that zinc is needed for protein metabolism and it appears to be involved some how in the production of chlorophyll. Brady (1980) indicated that zinc enhanced the absorption of water and grain maturity.

Boron increases the rate of water absorption root growth and translocation of sugars in plants (Brady, 1980). He also stated that boron was involved in the functions of enzyme systems that are necessary for important reactions in plant metabolism.

2.1.3.2 Effect of micronutrients on the yield and yield attributes

Seed coating with $ZnSO_4$ at two per cent increased the grain yield by 13 to 30 per cent in wet and semidry conditions respectively (Lakshmanan *et al.*, 1993). Sahu *et al.* (1993) stated that seedling root dip with four per cent ZnO increased rice yield by 38 per cent when compared to control. Devarajan and Krishnaswamy (1996) observed that the grain and straw yield were increased to the tune of 26 per cent over no zinc treatment.

Muthuvel *et al.* (1981) reported that even though the number of grains per panicle was not altered significantly, the 1000 grain weight was significantly influenced in rice cv. IR8. Zinc application increased the panicle number $hill^{-1}$ in rice (Kuppuswamy, 1983). Seed soaking with zinc salt solution or suspension at 10 ppm concentration for 24 hours was advantageous for higher yield in rice (Devarajan *et al.*, 1987). Root dipping with zinc solution at two per cent increased the rice yield by 9.53 per cent and the same being attributable to higher N - uptake (Gopalakrishnan, 1989). Khanda and Dixit (1996) observed that application of zinc increased the grain and straw yield over control.

Soil application of Cu, Zn, Mn, Fe and Mo or all trace elements plus seed inoculation gave higher yield than untreated control in pearl millet (Jadhav *et al.*, 1990). Treatment with B, Zn or Cu increased seed amylase activity after 72 hour germination in rice (Sheudzhen *et al.*, 1990). Sheudzhen (1990) reported that rice seeds treated with corresponding trace elements markedly increased the rice yield compared with untreated seeds. Sahu *et al.* (1993) reported that when Mo was given as seed treatment plus B at 1.5 kg ha^{-1} increased pod yield in groundnut.

2.1.4 Effect of Penshibao on growth, yield and yield attributes

Kalyanasundaram (1999) also reported that when Penshibao was used for seed soaking along with biodigested slurry and KH_2PO_4 found remarkable and significant difference in germination percentage, CGR, RGR, NAR and yield of direct seeded rice.

2.1.5 Effect of combined application of Penshibao and Azospirillum

Penshibao when used for seed soaking along with other treatments such as Azospirillum seed soaking, phosphobacteria seed soaking and foliar spray with Penshibao and KH_2PO_4 (two per cent), the growth and yield attributes of rice, viz., plant height, LAI, DMP and number of panicles m^{-2} altered remarkably (Babu, 1998). Elankavi (1999) reported that seed soaking with Azospirillum + Penshibao + foliar spray of Penshibao and triacontanol produced maximum yield of 5.75 and 5.41 t ha^{-1} in first and second seasons respectively. The percentage yield increase of this combination compared with control was 50.52 and 59 per cent in first and second seasons respectively.

2.2 Effect of foliar application of growth regulators

2.2.1 Effect of triacontanol on growth characters

2.2.1.1 Plant height, number of tillers and dry weight

Ahamed (1990) reported an increase in plant height in rice varieties with triacontanol application. Stimulation of plant height of rice by different triacontanol formulations was reported by Prasad *et al.* (1991). Significant increase in plant height was observed when wheat was treated with triacontanol (Singh and Uttam, 1994). Rice plants when treated with triacontanol and other growth hormones resulted in increased plant height and number of tillers (Datta *et al.*, 1995). Foliar spray of triacontanol @ 500 ml ha^{-1} was reported to increase plant height significantly over control (Paraye *et al.*, 1995). De and Hague (1996) found that both granular and foliar application of triacontanol increased the plant height considerably over control in rice. Ravi (1997) reported that triacontanol as foliar spray at 1000 ppm concentration recorded maximum plant height and number of tillers in rice.

Increase in dry weight of the entire rice plant was observed by Ries and Wert (1977) within three days of application of triacontanol. Hangarter *et al.* (1978) reported that in tissue culture experiments with several crop species, application of triacontanol increased the dry weight of callus culture by enhancing the cell division. Bittenbender *et al.* (1978) reported that triacontanol applied to rice seedlings in nutrient solution at 10 mg l^{-1} increased the dry weight. Jones *et al.* (1979) observed a higher dry weight of 105.8 mg $plant^{-1}$ compared to control when triacontanol was applied to rice seedlings. Increase in dry weight by the triacontanol application was also noticed by Knowles and Ries (1981).

2.2.1.2 Growth Analysis

Ries and Wert (1977) observed that triacontanol in nutrient cultured solution when applied to rice seedlings at 10 mg l^{-1} caused an increase in leaf area of whole plant. Triacontanol applied to rice plants had an increased functional leaf area of 33.50 cm^2 $tiller^{-1}$ compared to control which had a leaf area of only 19.30 cm^2 $tiller^{-1}$ (Debata and Murthy, 1981). Ries and Wert (1982) reported that triacontanol application to rice and maize seedlings caused a rapid increase in leaf area. They also stated that the newest leaf was visibly larger and other leaves were wider by the same treatment. LAI, NAR, RGR and other growth characters were the highest in wheat plants sprayed with triacontanol than with water (Baruah, 1990). Ravi (1997) reported that triacontanol at 1000 ppm as foliar spray recorded the highest leaf area index.

2.2.1.3 Chlorophyll content

Foliar spray of triacontanol at 7 days after flowering delayed the leaf senescence by maintaining the chlorophyll content (Anonymous 1980). Debata and Murthy (1981) also observed a delay in leaf senescence and panicle senescence, increase in chlorophyll content and more retention of leaf area in triacontanol applied rice seedlings grown in culture solution containing 0.1 ppm triacontanol. Biswas and Choudari (1981) observed that most of the hormones and nutrient applied at post flowering stage of rice increased leaf longevity. Malik and Richa (1984) reported that increase in chlorophyll content especially of chlorophyll 'a' was more pronounced at younger stages of development when the plants were treated with triacontanol. The rate of photosynthesis also increased in paddy leaves when the same treatment given either as foliar spray or seed soaking. They also observed an increased Hills' reaction activity which caused an increase in chlorophyll content. This treatment caused an enhanced carboxylation and photophosphorilation activities besides chlorophyll content. The chlorophyll content in the leaves of paddy increased when triacontanol was applied as seed soak at 1 ppm for 24 hours (Srivastava and Menon, 1987).

2.2.1.4 Yield and yield attributes

Foliar application of triacontanol at 7 days after flowering increased the translocation of carbohydrates to panicle of rice (Anonymous, 1980). Subbiah *et al.* (1980) reported that triacontanol spray at 0.1 mg l^{-1} significantly increased the grain and straw yield of rice. Debata and Murthy (1981) observed that foliar application of triacontanol 10 ppm increased panicle weight as 2.36 g $tiller^{-1}$ compared to control which had a panicle weight of only 1.90 g $tiller^{-1}$.

Triacontanol spray retarded panicle senescence in early rice varieties by maintaining higher succinic dehydrogenase (SDH) activity in the panicles which was a desirable phenomenon for better grain filling (Debata and Murthy, 1981). Lim and Ung (1982) observed that foliar application of triacontanol formulations containing $CaCl_2$ were effective in significantly increasing the yield of rice. Venkataraman *et al.* (1987) observed that mixtalol spray @ 2 ppm at pre flowering increased the yield over control.

A study conducted by Samantasinhar and Sahu (1990) showed that triacontanol and other growth hormones had a significant effect in the yield attributes of rice. They explained that the triacontanol application resulted in increased filled grain percentage, number of grains panicles^{-1} and 1000 grain weight. Harvest index was also higher (48 per cent) for this treatment compared to control (45 per cent). The highest 1000 seed weight and seed yield were observed when rice seeds treated with triacontanol (Ramamoorthy *et al.*, 1990). An increase in panicle length, 1000 grain weight and rough rice yield over control was reported by Prasad *et al.* (1991).

Triacontanol produced the highest grain yields of 4.79 t ha^{-1} in wheat (Singh *et al.*, 1992). Datta *et al.* (1995) reported that the triacontanol and sludge application gave a higher grain yield in rice (4.4 t ha^{-1}). Both seed treatments and foliar application of triacontanol increased grain yield compared to control in wheat as reported by Kumar and Maheswari (1995). Paraye *et al.* (1995) observed that foliar application of triacontanol at 25 and 50 DAT significantly increased the grain panicle^{-1} by 11.20 and 13.50 per cent respectively compared to control. They also reported an increase in number of effective tillers m^{-2}, 1000 seed weight and ultimate yield over control on hormone treatment. Grain and straw yield increased with increasing NPK rate and seed inoculation or spraying with growth regulators in wheat (Thomar *et al.*, 1995). De and Hague (1996) observed a significant increase in grain yield with triacontanol treatment to a tune of 35.75 q ha^{-1} compared to control (28.08 q ha^{-1}). They also observed that the same treatment showed higher filled grains panicle^{-1} and panicle length. Foliar application of 10 ppb triacontanol to rice from heading to maturity grown at 25/15^{0} C increased 1000 grain weight compared with the untreated control (Nagoshi and Kawashima, 1996). Mixtalol (triacontanol) application along with P and $ZnSO_4$ increased the number of effective tillers, test weight, spikelet length and yield compared to control (Singh *et al.*, 1996). Ravi (1997) reported that triacontanol as foliar spray of 1000 ppm concentration recorded highest number of filled grain and grain yield.

2.2.1.5 Uptake studies

Increased P uptake by triacontanol application was reported by Ramani and Kannan (1980). Increased nutrient uptake by triacontanol application was reported by Subbiah *et al.* (1980). The interaction between N and triacontanol was significant in respect of rough rice yield (Prasad *et al.*, 1991). N uptake was highest with 90 kg N as neem coated urea and foliar application of Vipul (Triacontanol) in wheat (Sharma and Jain, 1997).

2.2.2 Effect of GA_3 on growth characters

2.2.2.1 Plant height, tiller number and drymatter production

Application of GA_3 (100 ppm) had increased the plant height (Katayama and Akita, 1989). According to Samanthasinhar and Sahu (1990) the plant height was increased when rice plants were sprayed with GA_3 (10 ppm). GA_3 and kinetin were most effective hormones for seed treatments of wheat which increased the number of leaves $plant^{-1}$, root, stem, leaf and total plant dry weight compared with the untreated control (Singh and Saxena, 1991). Thangaraj and Sivasubramanian (1992) reported that GA_3 @ 25 ppm at panicle initiation significantly increased total drymatter production in rice. Sekimoto *et al.* (1995) reported that GA_3 application increased plant height and culm length in rice. The improvement of growth and yield (leaf area/plant and tiller, average leaf size, total dry weight $plant^{-1}$ and grains per panicle) in diverse rice genotypes by exogenous application of GA_3 was mainly attributed to greater source to sink potential (Singh, 1996). Foliar application of 10 to 1000 ppm of GA_3 induced inter node elongation during the seedling stage in African floating rice (Mochizuki and Kawagoe, 1997). GA_3 applied at 50 and 75 g ha^{-1} increased the plant height (Jagadeeswari *et al.*, 1998) in hybrid rice. GA_3 enhanced the growth of the second leaf sheath and it was due to the increased cell wall extensibility in the elongation zone of the leaf sheath (Matsukuru *et al.*, 1998). GA_3 application increased the plant height and number of tillers per m^2 (Ponnuswamy *et al*, 1998). The second leaf sheath, plant height, panicle axis and the last but one internode of rice cv. Wannianqing increased by GA_3 spray (Shao Bai *et al.*, 1998). Plant height and number of tillers increased when the rice plants were sprayed with 60 ppm of GA_3 (Thirthalingappa *et al.*, 1999).

2.2.2.2 Growth analysis

The increased net assimilation rate by GA_3 was attributed to the increased sink activity of leaf and leaf sheath in rice (Katayama and Akita, 1989). Application of GA_3 (10 ppm) increased the LAI, NAR and RGR in wheat plants (Baruah, 1990). The growth regulators (GA_3 and kinetin) generally increased number of leaves, DW, RGR and NAR in wheat compared with untreated controls (Singh and Saxena, 1991). The improvement of growth and yield in diverse rice genotypes by exogenous application of GA_3 was mainly attributed to increased source and sink potential (Singh, 1996). Spraying GA_3 mixed with fulvic acid at flowering enhanced the filling intensity and increased the kernel dry weight (JiuXing, 1997).

2.2.2.3 Chlorophyll content

Experiments with other growth regulators showed that foliar application of IAA and GA_3 during the vegetative phase increased the total chlorophyll content in rice (Chatterjee *et al.*, 1976). Biswas and Choudari (1981) observed that most of the PGR and nutrients applied at post flowering stage increased the leaf longevity in rice. Spikelet filling and grain yield in rice was improved by increasing the leaf longevity by the application of GA_3 and kinetin (Ray and Choudari, 1981). Increased leaf growth, chlorophyll content, cellulase activity and pectin lyase activity by GA_3 was observed in rice plants grown in saline condition (Acharya *et al.*, 1990). GA_3 significantly increased the total leaf chlorophyll content in rice over the untreated control (Thangaraj and Sivasubramanian, 1992). Chlorophyll content and SOD activity in wheat were increased by spraying plant growth regulators (JiuXing, 1997).

2.2.2.4 Yield and yield attributes

Ray and Choudari (1981) reported that GA_3 application produced a pronounced effect on grain filling as well as P mobilization and the increased yield was possibly by increasing leaf longevity. Application of GA_3 at 25 ppm at panicle initiation stage significantly increased the total dry matter, panicle number, grain filling and grain yield by delaying leaf senescence (Thangaraj and Sivasubramaniyan, 1992). Spraying of GA_3 at 5 ppm once in a week from 25 day after sowing to heading had shown an increase in number of spikelet per panicle in rice (Yamagishi, *et al.*, 1994). GA_3 at 10 ppm increased the number of grains per spikelet in rice (Sekimoto, 1995). GA_3 spraying at 15 to 20 per cent panicle emergence stage increased the panicle exertion and seed yield in hybrid rice seed production (Prabhakaran and Ponnuswamy, 1997). The yield and yield attributes were increased when hybrid rice was sprayed with GA_3 (Jagadeeswari *et al.*, 1998). GA_3 spray at 60 ppm advanced 50 per cent flowering by three days and full flowering by five days in hybrid rice (Lingaraj *et al.*, 1998). GA_3 increased plant height, flag leaf angle, seed set and grain yield when sprayed at a concentration of 125 g ha^{-1} in hybrid rice (Ponnuswamy *et al*, 1998). An increase in yield was noticed when hybrids were sprayed with an increasing concentration of GA_3 (20, 50, 80, 100 and 150 ppm). Among these 150 ppm gave the highest yield and yield attributes i.e., number of effective panicle, grain number per panicle and 1000 grain weight (Yongyua *et al.*, 1998). Application of GA_3 (60 ppm) increased productive tillers per plant, duration of anthesis, panicle length, number of spikelets per panicle, number of filled spikelets $panicle^{-1}$ and seed set (Thirthalingappa *et al.*, 1999).

2.2.2.5 Uptake of nutrients

Wheat seeds when soaked with gibberellic acid increased organic P, total P contents and dry weight (Aldesuquy, 1998). It was shown that both N and GA_3 application had significant influence on wheat N accumulation and utilization (Bull *et al.*, 2000). They also observed that GA_3 treated plants contained higher N compared with control.

2.2.3 Effect of kinetin on growth characters

2.2.3.1 Plant height number of tillers and drymatter

Increase in wheat plant dry weight was noticed by treating with kinetin (Singh and Saxena, 1991). Foliar spray of kinetin 20 ppm at heading stage increased the total drymatter in rice (Thangaraj and Sivasubramanian 1992). Pushpaletha and Padmanabhan (1998) reported that there was maximum callus induction when MS medium was supplemented with 2.5 mg l^{-1} kinetin. Kinetin as foliar spray increased the dry weight of all organs in wheat (Wierzbouska and Nowak, 1998). Kinetin significantly increased plant fresh and dry weight and plant height in wheat seedling under highly chilled climate (Zhenling *et al.*, 1998). Kinetin and PGPR (Plant growth promoting rhizobacteria) treatment increased plant growth in maize (Pan *et al.*, 1999).

2.2.3.2 Growth Analysis

The treatment with GA_3 and kinetin increased total plant dry weight RGR, NAR and leaf weight ratios compared with untreated control in wheat (Dhir *et al.*, 1991). Dashora and Jain (1994) observed that foliar spray of kinetin significantly increased LAI in soyabean. Cold treated seedlings were sprayed and root fed with kinetin at 2 mg l^{-1}, significantly increased the daily growth rate compared with untreated chilled seedling (Zhenling *et al.*, 1998). Kinetin increased the leaf area of maize (Pan *et al.*, 1999).

2.2.3.3 Chlorophyll content

Increased yield in rice was possibly by increasing the leaf longevity by spraying with kinetin (Ray and Choudari, 1981). Delayed leaf senescence in rice was achieved by foliar spray of senesense retardants like kinetin and triacontanol due to greater retention of chlorophyll and protein content (Debata and Murthy, 1981). Predominant effect of kinetin were the stimulation of cell division, cell enlargement and delaying of senescence (Mooney and Vanstaden, 1986). Foliar spray of kinetin (20 ppm) at heading stage delayed leaf senescence in rice (Thangaraj and Sivasubramanyan, 1992). Dashora and Jain (1994) observed that foliar spray of kinetin significantly increased chlorophyll content in soyabean.

2.2.3.4 Yield and yield attributes

Kinetin spray at 25 ppm concentration increased the number of grains per panicle, per cent of filled grains, 1000 grain weight and yield in rice (Singh *et al.*, 1984). Anbazhagan *et al.* (1987) reported that foliar spray of kinetin brought early grain maturity, grain filling and increased yield in rice by increasing leaf longevity. Application of 17.5 kg potassium and kinetin spray (10 ppm) or 35 kg potassium and kinetin spray (10 ppm) at 10 DAF gave an yield of 5.65 and 5.56 t ha^{-1} respectively which was most profitable in rice (Sakeena and Salam, 1989). Thangaraj and Sivasubramaniyan (1992) reported that foliar spray of kinetin (20 ppm) at heading stage increased total dry matter, panicle number, grain filling and grain yield by delaying leaf senescence in rice.

Cytokinin possess the property of direct transport of metabolites from source to sink (Mothes and Engelbrecht, 1961) and increase the number and size of individual sinks in rice (Holmnes, 1974). Synthetic kinetins increased grain yield in barley (Williams and Cartwright, 1980). Kinetin increased the grain yield and yield components of rice (Biswas and Choudhari, 1981). Singh *et al.* (1984) reported that kinetin and IAA significantly increased the 1000 grain weight, number of grains panicle^{-1} and maximum accumulation of starch in the grain of rice. Kinetin as foliar spray applied to rice increased the grain number per panicle and grain density through delayed senescence of leaf (Samantasinhar and Sahu, 1990). The number of fertile tillers, number of spikelets and 1000 grain weight were also increased by treating the wheat plants with kinetin (Dhir *et al.*, 1991). Kinetin treatment increased yield compared to untreated control in wheat (Singh *et al.*, 1992). Effect of foliar spray with kinetin at tillering and heading stage on quality and grain yield of wheat revealed that there was an increase in the number of spikelets, seed weight and protein content (Hegazi *et al.*, 1995). Thousand grain weight and protein content were increased by kinetin treatment in wheat (Wierzbouska and Nowak, 1998).

2.2.3.5 Nutrient uptake

Dashora and Jain (1994) observed that foliar spray of kinetin significantly increased the uptake of N, P and K in soyabean. The application of kinetin induced a substantial increase in the measured parameters like growth characters, nitrate content and uptake of N and nitrate reductase activity in maize under saline conditions (Khan and Srivastava, 1998). Kinetin and auxin applied alone or together with urea increased N content in grain as well as in all vegetative organs by the intensification of nitrogen accumulation (Wierzbouska and Nowak, 1998).

2.2.4 Effect of Penshibao

Penshibao is a new generation high technology multi functional liquid containing nutrients such as N, P, K, Zn, B, Mg, Fe, Mo and some other physiologically active organic compounds. This product is manufactured by M/S Guangxi Penshibao group Co. Ltd.

Most of the works about the use of Penshibao on cereal plants associated with seed soaking. Research on foliar application of Penshibao is very limited. Elankavi (1999) reported that seed soaking with Azospirillum + Penshibao and foliar spray of Penshibao + triacontanol produced the maximum yield of 5.75 and 5.41 t ha^{-1} in first and second season respectively. The percentage yield increase of this combination compared with control was 50.52 and 59 per cent in first and second seasons respectively.

2.2.5 Effect of micro nutrients on growth and yield of rice

Muthuvel *et al.* (1981) noticed significant influence of foliar application of Zn on straw yield of rice IR-20. They also observed the highest straw yield with foliar application of $ZnSO_4$ at 0.75 per cent concentration. Misra and Reddy (1985) found that foliar application of 0.2 per cent $ZnSO_4$ as foliar spray at flowering stage increased grain yield. Ilangovan and Palaniyappan (1987) noticed that foliar application of $ZnSO_4$ increased grain yield by 20.5 per cent and 28.1 per cent over control in kharif and summer rice respectively.

Panda and Nayak (1974) reported that the plant height of rice cv. Jaya increased with increased levels of $ZnSO_4$ through both soil and foliage application. Thompson and Troch (1979) observed that zinc is needed for protein metabolism and it appears to be involved some how in the production of chlorophyll in rice. Muthuvel *et al.* (1981) reported that 1000 grain weight was significantly increased by Zn as foliar spray in rice. Kuppuswamy (1983) observed that LAI of both first and residual crop of rice was favorably influenced by Zn application. Many workers observed the significant influence of zinc on DMP of rice (Chatterjee *et al.*, 1976; Balakrishnan *et al*, 1985).

All trace elements B, Co, Mo, Zn, Mn and Cu along with NPK increased nutrient uptake at tillering, heading and maturity when it was given as seed treatment or folia spray in rice (Sheudzhen, 1990). He also stated that these treatments increased chlorophyll content. Rice plants treated with NPK and multi micronutrient as foliar spray mixture (Fe, Mn, Zn, Cu, B, Mg, Ca and S) an increase in grain yield was noticed by Tripathi *et al.* (1995). Foliar spray of Mn increased grain yield in wheat (Dhaliwal and Chaohal, 1996).

Materials and Methods

3. MATERIALS AND METHODS

A field experiment was conducted in the wetlands of the Instructional farm, College of Agriculture, Vellayani during Rabi season (August to December) of 2000 to study the effect of seed soaking and foliar spray of growth regulators on rice. The materials used and methods followed are presented below.

3.1 Experimental site

The experiment was conducted at the Instructional farm attached to the College of Agriculture, Vellayani, Kerala located at 8.5° N latitude and 76.9° E longitude at an altitude of 29 m above the mean sea level.

3.1.1 Soil

The soil of the experimental site was sandy clay loam which belongs to the taxonomical order oxisol. The physico-chemical properties of the soil of experimental site are given in Table 3.1.1.

3.1.2 Climate

The experimental site enjoys a humid tropical climate. The data on various weather parameters during the cropping period are given in Appendix I and illustrated in Fig. 1.

Table 3.1.1 Physico-chemical properties of the soil of the experimental site

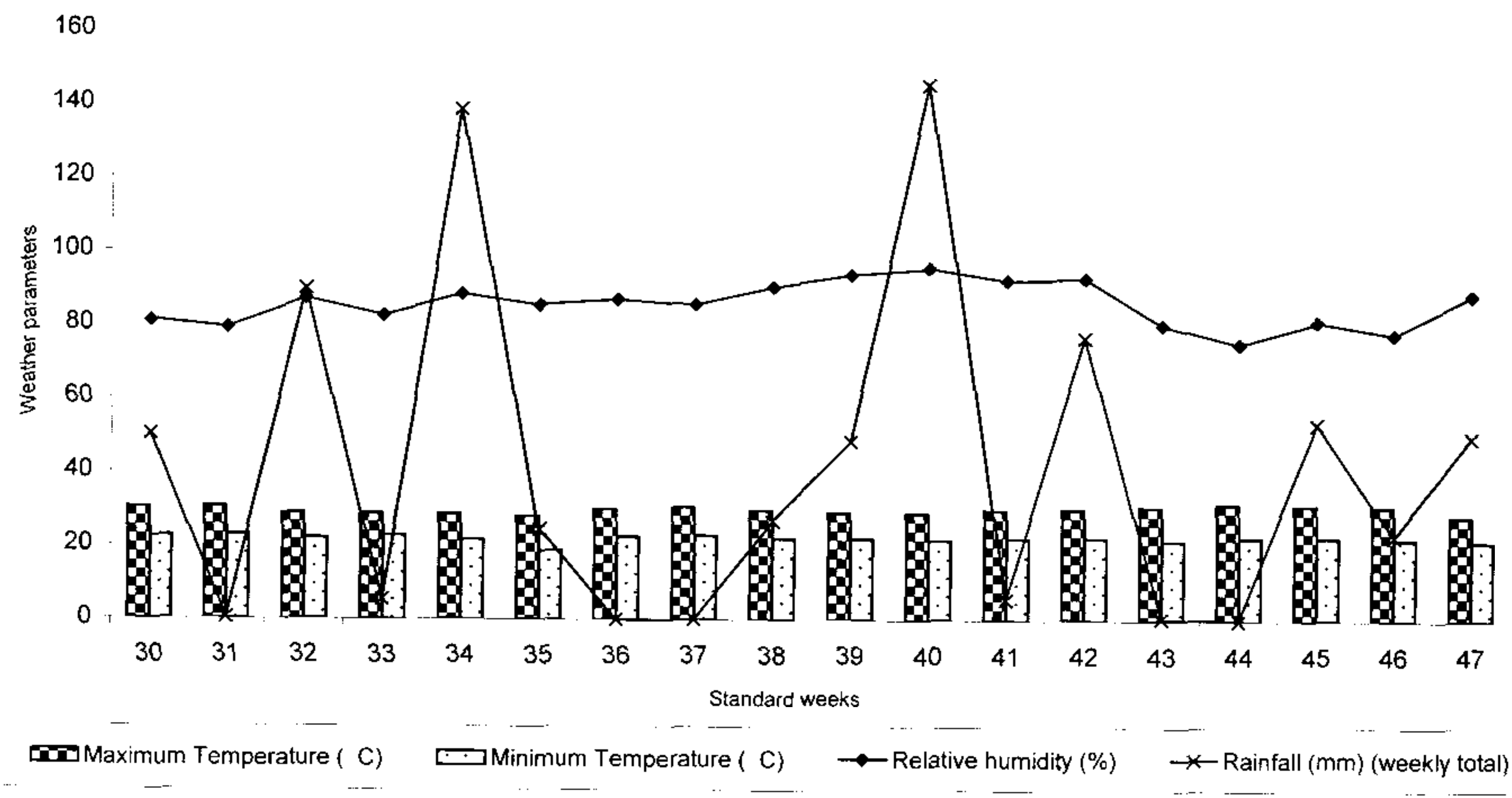
Mechanical composition

Sl. No.	Parameters	Content	Methods used
1.	Coarse sand	47.76%	Bouyoucos Hydrometer method (Bouyoucos, 1962)
2.	Fine sand	10.64%	
3.	Silt	8.60%	
4.	Clay	33.00%	

Chemical composition

Sl. No.	Parameters	Content	Methods used
1.	Available N (Kg ha^{-1})	311.38 (Medium)	Alkaline permagnate method (Subbiah and Asija, 1956)
2.	Available P_2O_5 (Kg ha^{-1})	28.64 (Medium)	Bray colorimetric method (Jackson, 1973)
3.	Available K_2O (Kg ha^{-1})	188.63 (Medium)	Ammonium acetate method (Jackson, 1973)
4.	Organic carbon (Per cent)	1.70 (High)	Walkley and Black rapid titration method (Jackson, 1973)
5.	Soil pH	5.40 (Acidic)	1:2.5 soil solution ratio using pH meter with glass electrode (Jackson, 1973)

Fig. 1 Weather parameters during the cropping period



3.1.3 Season

The field experiment was conducted during the early second crop (Rabi) season of the year 2000.

3.2 Materials

3.2.1 Seed

The rice variety selected for experiment was Aiswarya (PTB-52) released from Regional Agricultural Research Station, Pattambi with a duration of 120-125 days. The grains are red, long and bold. The variety is resistant to blast and blight diseases and brown plant hopper. The seeds were obtained from Cropping Systems Research Centre, Karamana, Thiruvananthapuram.

3.2.2 Manures and Fertilizers

Well decomposed and dried farmyard manure @ 5 t ha^{-1} was used for the experiment. Urea (46 percent N), Mussoriephos (20 percent P_2O_5) and Muriate of Potash (60 percent K_2O) were used @ 90:45:45 kg ha^{-1} for the experiment.

3.2.3 Materials used for seed soaking

3.2.3.1 Azospirillum

Azospirillum culture was manufactured and marketed by Agro industries Ltd., Kottayam.

3.2.3.2 Penshibao

This is manufactured by M/S Guangxi Penshibao Group Co Ltd., China and was obtained from Prithvi Biotech India Pvt. Ltd., Bangalore.

Penshibao is a multifunctional foliage nutrient which is highly nutritive to plants. This is non toxic and does not leave any residue on plants. It can be used either as seed soaking or as foliage spray at tillering stage, young ear differentiation stage and milk stage. This chemical is manufactured in China and is used all over the world for different crops. The chemical composition is given in Appendix II.

3.2.4 Materials used for foliar spray

3.2.4.1 Triacontanol

Triacontanol is available as "Vipul" marketed by Godrej Agrovet Ltd. This was obtained from Bahar Agrochem and Feeds Pvt. Ltd., Maharashtra. The chemical structure is given in Appendix III.

3.2.4.2 GA_3

GA_3 is available as gibberellic acid marketed by SISCO Research Laboratories Pvt. Ltd., Bombay. This was obtained from Chemical House, Pulimoodu, Thiruvananthapuram. The chemical structure is given in Appendix III.

3.2.4.3 Kinetin

Kinetin is marketed by SISCO Research laboratories Pvt. Ltd., Bombay. This was obtained from Chemical House, Pulimoodu, Thiruvananthapuram. The chemical structure is given in Appendix III.

3.2.4.4 Penshibao

The details regarding this chemical is explained in section 3.2.3.2 and Appendix II.

3.3 Methods

3.3.1 Nursery studies

3.3.1.1 Design and Layout

The experiment was laid out in completely randomized design with 4 treatments and was replicated four times. The lay out plan of the experiment is given in Fig. 2.

The details of experiment are given below

Design	:	CRD	
Treatments	:	T_1	Water soaking
		T_2	Soaking in Azospirillum (600 gha^{-1})
		T_3	Soaking in Penshibao (100ppm)
		T_4	Soaking in Azospirillum (600 gha^{-1}) + Pensibao (100ppm)
Replications	:	4	

Fig. 2 LAYOUT PLAN OF NURSERY

5 m
4 m

T_1	T_3	T_4	T_2
T_3	T_1	T_2	T_4
T_1	T_3	T_4	T_2
T_2	T_3	T_1	T_4

Details

Design : CRD

Treatments : 4

Replications : 4

T_1 – Water soaking
T_2 – Soaking in Azospirillum (600 g ha^{-1})
T_3 – Soaking in Penshibao (100 ppm)
T_4 – Soaking in Azospirillum (600 g ha^{-1}) + Penshibao (100 ppm)

3.3.2 Main field studies

3.3.2.1 Design of the experiment

The experiment was laid out in split–split plot design which comprised of forty treatment combination replicated three times. The layout plan is given in fig. 3. and the details of experiment are given below.

Design	Split – split plot design
Treatment combinations	40
Replications	3
Plot size	
Gross	5 x 4 m
Net	4.6 x 3.8 m
Spacing	20 x 10 cm
Total no. of plots	120
Variety	Aiswarya
Season	Rabi (2000)

3.3.2.1.1 Treatments

Main plot	Seed soaking
T_1	Water soaking
T_2	Soaking in Azospirillum (600 g ha^{-1})
T_3	Soaking in Penshibao (100 ppm)
T_4	Soaking in Azospirillum (600 g ha^{-1}) + Penshibao (100 ppm)

Fig. 3 LAYOUT PLAN OF THE EXPERIMENT – MAIN FIELD

N

Plot size: 5 m × 4 m

	$T_2F_3S_2$	$T_2F_3S_1$	$T_3F_1S_1$	$T_3F_1S_2$	$T_4F_4S_2$	$T_4F_4S_1$	$T_1F_4S_2$	$T_1F_4S_1$
	$T_2F_5S_2$	$T_2F_5S_1$	$T_3F_3S_2$	$T_3F_3S_1$	$T_4F_2S_1$	$T_4F_2S_2$	$T_1F_1S_1$	$T_1F_1S_2$
R I	$T_2F_1S_1$	$T_2F_1S_2$	$T_3F_5S_1$	$T_3F_5S_2$	$T_4F_5S_1$	$T_4F_5S_2$	$T_1F_3S_2$	$T_1F_3S_1$
	$T_2F_4S_1$	$T_2F_4S_2$	$T_3F_4S_1$	$T_3F_4S_2$	$T_4F_1S_2$	$T_4F_1S_1$	$T_1F_5S_2$	$T_1F_5S_1$
	$T_2F_2S_2$	$T_2F_3S_1$	$T_3F_2S_2$	$T_3F_2S_1$	$T_4F_3S_2$	$T_4F_3S_1$	$T_1F_2S_1$	$T_1F_2S_2$
	$T_4F_1S_2$	$T_4F_1S_1$	$T_2F_2S_2$	$T_2F_2S_1$	$T_1F_1S_1$	$T_1F_1S_2$	$T_3F_5S_1$	$T_3F_5S_2$
	$T_4F_5S_1$	$T_4F_5S_2$	$T_2F_4S_1$	$T_2F_4S_2$	$T_1F_3S_2$	$T_1F_3S_1$	$T_3F_2S_1$	$T_3F_2S_2$
R II	$T_4F_2S_1$	$T_4F_2S_2$	$T_2F_3S_2$	$T_2F_3S_1$	$T_1F_4S_1$	$T_1F_4S_2$	$T_3F_3S_1$	$T_3F_3S_2$
	$T_4F_4S_2$	$T_4F_4S_1$	$T_2F_5S_1$	$T_2F_5S_2$	$T_1F_2S_2$	$T_1F_2S_1$	$T_3F_1S_2$	$T_3F_1S_1$
	$T_4F_3S_1$	$T_4F_3S_2$	$T_2F_1S_1$	$T_2F_1S_2$	$T_1F_5S_2$	$T_1F_5S_1$	$T_3F_4S_1$	$T_3F_4S_2$
	$T_1F_1S_1$	$T_1F_1S_2$	$T_3F_4S_2$	$T_3F_4S_1$	$T_4F_5S_2$	$T_4F_5S_1$	$T_2F_2S_2$	$T_2F_2S_1$
	$T_1F_3S_2$	$T_1F_3S_1$	$T_3F_5S_1$	$T_3F_5S_2$	$T_4F_4S_2$	$T_4F_4S_1$	$T_2F_3S_1$	$T_2F_3S_2$
R III	$T_1F_4S_1$	$T_1F_4S_2$	$T_3F_2S_2$	$T_3F_2S_1$	$T_4F_1S_1$	$T_4F_1S_1$	$T_2F_5S_1$	$T_2F_5S_2$
	$T_1F_5S_2$	$T_1F_5S_1$	$T_3F_1S_1$	$T_3F_1S_2$	$T_4F_3S_2$	$T_4F_3S_2$	$T_2F_1S_1$	$T_2F_1S_2$
	$T_1F_2S_2$	$T_1F_2S_1$	$T_3F_3S_1$	$T_3F_3S_2$	$T_4F_2S_2$	$T_4F_2S_1$	$T_2F_4S_2$	$T_2F_4S_1$

Sub plot — Foliar spray of growth regulators

F_1	Triacontanol (500 ppm)
F_2	GA_3 (5 ppm)
F_3	Kinetin (5 ppm)
F_4	Penshibao (100 ppm)
F_5	Water spray

Sub sub plot — 2 stages of foliar application

S_1	Foliar spraying at 20 DAT
S_2	Foliar spraying at 20 DAT and 30 DAT

3.4 Crop Husbandry

3.4.1 Nursery

3.4.1.1 Land preparation

The experimental area for nursery was ploughed, puddled and levelled. Weeds and stubbles were removed by hand picking. Plots of size 5 x 4 m were laid out as per the design (CRD).

3.4.1.2 Seeds and sowing

Pre germinated seeds at the rate of 80 kg for planting one ha main field were soaked according to treatment and broadcasted on the nursery. After 22 days, healthy seedlings were pulled out from the nursery.

3.4.2 Main field

3.4.2.1 Land preparation

The experimental area was ploughed, puddled and levelled. Weeds and stubbles were removed by hand picking. Initial soil samples were taken for analysis. Individual plots of size 5 x 4 m were laid out and were perfectly levelled before transplanting.

3.4.2.2 Transplanting

Transplanting was done in a thin film of water in the field. Twenty two days old seedlings were used for transplanting.

3.4.2.3 Application of manures and fertilizers

Farm yard manure (FYM) was applied uniformly to all the plots and mixed well with the top soil. Nitrogen and potassium was applied in 2 equal split doses first as basal and second at 5 to 7 days prior to panicle initiation stage. Full dose of phosphorus was applied at the time of land preparation as basal.

3.4.2.4 Maintenance of the crop

Subsequently after transplanting the water level was raised to about 5 cm. Two hand weedings were given at 20 and 45 DAT. Nuvacron was sprayed twice against leaf folder and stem borer and one spraying with Malathion to control rice bug.

3.4.2.5 Foliar spray of growth regulators and Penshibao

The foliar spray was given in 2 stages i.e. at 20 DAT and 30 DAT.

3.4.2.5.1 Triacontanol

Aqueous solution of 500 ppm triacontanol was prepared and sprayed with knapsack sprayer as per the treatment. A total of 200 litre of solution was used per hectare.

3.4.2.5.2 Kinetin and GA_3

The spray (5 ppm) was prepared by dissolving 5 mg of hormone in a small quantity of ethanol and volume was made upto 1 l with water.

3.4.2.5.3 Penshibao

It was prepared by serial dilution of Penshibao to obtain 100 ppm.

3.4.2.6 Plant sampling

Samples were collected from the area left for sampling at 20,40, 60 DAT and at harvest. Five plants were selected randomly from the net plot area and tagged as observational plants. Two rows from all sides were left as border rows.

3.4.2.7 Harvest

The crop was harvested at full maturity. The border and sampling rows were harvested separately. Net plot area of individual plots were harvested, threshed and the weight of grain and straw were recorded.

3.5 Observations

3.5.1 Observations in nursery

3.5.1.1 Germination percentage

Four quadrate areas consisting of 0.25 m^2 were earmarked randomly in the sampling area in each treatment. Bunds were formed all around the sampling area and a known number of seeds soaked in respective materials were sown in the sampling area. From this randomly earmarked sampling areas observations on germination count were recorded on the fifth day after sowing and expressed as percentage.

3.5.1.2 Seedling shoot length

Five seedlings were selected at random at 21 DAS and length of shoot was measured individually. The mean of five samples was expressed in centimetre.

3.5.1.3 Vigour index

Vigour index was computed on 21 DAS using the procedure suggested by Abdul Baki and Anderson (1973).

Vigour index = Germination percentage x Seedling shoot length

3.5.1.4 Speed of germination

From the samples in nursery, the number of seedlings emerged was recorded daily until the final count day (10 DAS). The speed of germination was then calculated by adding quotients of the daily count divided by the number of days for germination. (Agarwal, 1981).

3.5.1.5 Root biomass

Five seedlings were uprooted at random at 21 DAS and the roots were dried and weighed. The mean of five samples was expressed in gram.

3.5.2 Observations in Mainfield

3.5.2.1 Observations on growth characters

3.5.2.1.1 Height of plant

The mean value of the height of five randomly selected observational plants from the net plot area was computed at 20, 40, 60 DAS and at harvest and expressed in centimetre. The height was measured from the base to the tip of the topmost leaf. At harvest, the height was recorded from the base of the plant to the tip of the longest panicle and the mean height was computed and expressed in centimetre.

3.5.2.1.2 Tiller number per m^{-2}

Total number of tillers from unit area was recorded at 20.40,60 DAT and at harvest.

3.5.2.1.3 Dry matter production (DMP)

Dry matter production at 20, 40, 60 DAT and at harvest was recorded. The sample plants were dried at $70^{\circ}C$ for 48 hours, weighed and expressed in g m^{-2}.

3.5.2.1.4 Leaf area index

Leaf area index at tillering and flowering stages was recorded as per the method suggested by Gomez (1972).

Leaf area = L x W x K

where K - crop factor (0.75)

L - length of leaf

W - maximum width of leaf

$$LAI = \frac{\text{Leaf area}}{\text{Land area}}$$

3.5.2.1.5 Leaf Area Duration (LAD)

LAD at tillering and flowering stage was calculated using the formula suggested by Watson (1947)

$$LAD = \frac{Li + (Li + 1) \quad x \quad (t_2 - t_1)}{2}$$

Li - LAI at first stage

Li +1 - LAI at second stage

$t_2 - t_1$ - time interval between stages.

3.5.2.1.6 Crop Growth Rate (CGR)

CGR at tillering and flowering was computed by the formula suggested by Watson (1958) and expressed in g m^{-2} day^{-1}

$$CGR = \frac{W_2 - W_1}{P(t_2 - t_1)}$$

W_1 and W_2 are whole plant dry weight (g) at t_1 and t_2

$t_2 - t_1$ - time interval in days

P - Ground area (m^2) on which W_1 and W_2 have been estimated.

3.5.2.1.7 Relative Growth Rate (RGR)

RGR at tillering and flowering was determined based on the formula of Williams (1946) and expressed in mg g^{-1} day^{-1}.

$$RGR = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

where,

W_1 and W_2 - Plant dry weight (g) at time t_1 and t_2 respectively

t_2-t_1 - Time interval in days.

3.5.2.1.8 Net assimilation rate (NAR)

The method proposed by Williams (1946) was used for calculating the NAR on leaf dry weight basis and the values were expressed as mg cm^{-2} day^{-1}. NAR was recorded at tillering and flowering stages.

$$NAR = \frac{W_2 - W_1}{t_2 - t_1} x \frac{\log_e L_2 - \log_e L_1}{L_2 - L_1}$$

where

W_1 and W_2 - Plant dry weight (mg) at t_1 and t_2 respectively

L_1 and L_2 - Leaf area (cm^2) at t_1 and t_2 respectively

$t_2 - t_1$ - Time interval in days

3.4.2.2 Observations on yield and yield attributes

3.4.2.2.1 Number of panicles metre^{-2}

The number of panicles from five sample hills selected randomly from the sampling area were counted before harvest. The mean panicle number was then expressed as number of panicles metre^{-2}.

3.4.2.2.2 Filled grain percent

$$\text{Filled grain percent} = \frac{\text{No. of filled grains panicle}^{-1}}{\text{Total no. of grains panicle}^{-1}} x\ 100$$

3.4.2.2.3 Thousand grain weight

Thousand grain weight was calculated and adjusted to 13 per cent moisture using the formula suggested by Gomez (1972).

$$\text{1000 grain weight} = \frac{100 - M}{86} \frac{w}{f} x\ 1000$$

Where M – moisture content of filled grain

w – weight of unfilled grain in grams

F – No. of filled grain

3.4.2.2.4 Grain and straw yield

The grains harvested from each net plot area were dried to 13% moisture content, cleaned, weighed and expressed in tonnes ha^{-1}. The straw was sun dried properly and yield recorded in tonnes ha^{-1}.

3.4.2.2.5 Harvest Index (HI)

Harvest Index was calculated by using the formula

$$\text{Harvest Index, HI} = \frac{\text{Economic yield}}{\text{Biological yield}}$$

3.4.2.3 Chlorophyll estimation

Total chlorophyll content was estimated from the fully opened second leaf from the top at the tillering and panicle emergence stage by the method suggested by Arnon (1949).

Total chlorophyll, chlorophyll a and chlorophyll 'b' were estimated and expressed in mg g^{-1} of fresh weight leaf.

$$\text{Total chlorophyll} = 8.02\ A_{663} + 20.20\ A_{645} \times \frac{V}{1000 \times W}$$

$$\text{Chlorophyll a} = 12.70\ A_{663} - 2.69\ A_{645} \times \frac{V}{1000 \times W}$$

$$\text{Chlorophyll b} = 22.90\ A_{645} - 4.68\ A_{663} \times \frac{V}{1\,000 \times W}$$

Where A = Absorbance at specific wave lengths,

V = Final volume of chlorophyll extract in 80 per cent acetone

W = Fresh weight of tissue extracted in 80 per cent acetone

3.5.2.4 Nutrient uptake

Sample plants from each plot at 20, 40, 60 DAT and at harvest were collected, sun dried and oven dried to constant weight, ground, digested and nutrient content estimated. The N content (modified micro kjeldahl method), P content (Vanado-molybdo-phosphoric yellow colour method) and K content (Flame photometer method) were estimated. The nitrogen, phosphorus and potassium uptake by crop at 20, 40, 60 DAT and at harvest were worked out by multiplying the content of nutrients with respective dry weight and expressed in kg ha^{-1}.

3.5.2.5 Soil analysis

Composite soil samples collected before and after the experiment were analysed to determine the available nitrogen, available phosphorus and available potassium. The methods used are presented in Table 3.1.1.

3.5.2.6 Economic analysis

3.5.2.6.1 Benefit Cost ratio

The economics of cultivation was worked out considering the total cost of cultivation and the prevailing market price of the produce.

$$\text{Benefit – Cost ratio} = \frac{\text{Gross income}}{\text{Total expenditure}}$$

3.5.2.7 Statistical Analysis

The data generated were subjected to analysis of variance (Panse and Sukhatme, 1985). Wherever the results were significant, the critical difference was worked out at five or one percent probability.

Results

4. RESULTS

A field experiment was conducted at the Instructional Farm attached to the College of Agriculture, Vellayani during the Rabi season of 2000 to study the effect of seed soaking and foliar application of growth regulators on rice. The experimental results are presented below.

4.1 Nursery studies (Table 4.1)

4.1.1 Germination percentage

Seed soaking with Azospirillum and Penshibao significantly improved the germination percentage over control. But soaking in Azospirillum (T_2) alone (95.50 per cent) or Penshibao alone (T_3) (93.50 per cent) or its combinations (T_4) (95.00 per cent) did not show any significant difference in the germination percentage. The least germination percentage (91.75 per cent) was observed in control plots (T_1).

4.1.2 Seedling shoot length

Seed soaking treatments significantly improved the length of seedlings. Soaking in Azospirillum (T_2) recorded the tallest seedlings (38.46 cm) and was followed by T_4 (Azospirillum + Penshibao) which was on par with T_3 (Penshibao). The shoot length was only 26.43 cm in seedlings of the control plots.

Table 4.1 Effect of seed soaking on germination percentage, shoot length (cm), vigour index, speed of germination and root biomass (g)

Treatments	Germination percentage	Shoot length (cm)	Vigour index	Speed of germination	Root biomass (g)
T1	91.75	26.43	2423.38	27.91	0.014
T2	95.50	38.46	3672.90	29.82	0.035
T3	93.50	34.31	3114.92	29.20	0.039
T4	95.00	34.76	3306.76	29.77	0.026
$F_{3,12}$	3.72*	57.29**	67.03**	9.68**	39.7**
SE_d	1.429	1.087	104.300	0.468	0.132
CD	2.696	2.053	196.820	0.884	0.0171

* Significant at 5 per cent level
** Significant at 1 per cent level

4.1.3 Vigour index

Soaking in Azospirillum (T_2) recorded the highest vigour index (3672.90) followed by the T_4 (3306.76) which was on par with T_3 (3114.92). The vigour index under T_1 (control) was significantly low.

4.1.4 Speed of germination

Seed soaking treatment significantly influenced the speed of germination over control (T_1) but no significant difference was observed among the different soaking methods T_2, T_3 and T_4.The treatment T_2 recorded the highest index (29.82) for speed of germination.

4.1.5 Root biomass

Seed soaking significantly improved the root biomass over the control. But a combined application was found to be not effective. Soaking with Penshibao (T_3) recorded higher root biomass of 0.039 g which was comparable with the treatment T_2 (0.035 g) and T_4 (0.026 g).

4.2 Main field studies

4.2.1 Growth characters

4.2.1.1 Plant height (Tables 4.2.1.1a, 4.2.1.1b and 4.2.1.1c)

4.2.1.1.1 At 20 DAT

Plant height was significantly influenced by seed soaking (T) foliar spray (F) and time of application (S) as evident from the data.

At 20 DAT the treatment T_3 (soaking in Penshibao) recorded the highest plant height (50.33 cm) and was on par with T_2 (soaking in

Table 4.2.1.1a Effect of seed soaking, foliar spray and stage of application on plant height (cm)

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Seed soaking				
T_1	46.70	70.04	89.19	102.87
T_2	49.83	78.63	94.84	106.69
T_3	50.33	79.94	95.52	110.85
T_4	45.91	81.91	95.93	111.88
$F_{3,6}$	8.11*	72.13**	60.69**	36.16**
SE_d	0.780	0.394	0.405	0.687
CD	2.690	1.362	1.401	2.376
Foliar spray				
F_1	49.32	80.02	93.89	106.63
F_2	49.13	79.51	97.06	110.21
F_3	48.64	79.16	94.33	108.89
F_4	51.08	81.47	98.29	114.11
F_5	42.77	73.01	85.76	100.52
$F_{3,12}$	35.61**	48.96**	60.75**	37.99**
SE_d	0.530	0.467	0.628	0.185
CD	1.540	1.332	1.791	2.325
Stage of application				
S_1	47.61	78.36	92.33	106.43
S_2	48.76	78.91	94.91	109.72
$F_{1,40}$	5.38*	NS	39.03**	41.72**
SE_d	0.350	0.293	0.236	0.361
CD	1.002	-	0.674	1.031

* Significant at 5 per cent level
** Significant at 1 per cent level
NS Not significant

Seed soaking

T_1 Water soaking
T_2 Soaking in Azospirillum (600 g ha^{-1})
T_3 Soaking in Penshibao (100 ppm)
T_4 Soaking in Azospirillum (600 g ha^{-1}) + Penshibao (100 ppm)

Foliar spray

F_1 Triacontanol (500 ppm)
F_2 GA_3 (5 ppm)
F_3 Kinetin (5 ppm)
F_4 Penshibao (100 ppm)
F_5 Water spray

Stages of application

S_1 Foliar spraying at 20 DAT
S_2 Foliar spraying at 20 DAT and 30 DAT

Table 4.2.1.1b Interaction effect of seed soaking and foliar spray on plant height (cm)

Treatments	20 DAT	40 DAT	60 DAT	Harvest
T_1F_1	47.32	75.29	90.28	103.43
T_1F_2	47.43	74.85	89.13	102.21
T_1F_3	48.40	74.35	90.76	107.64
T_1F_4	48.65	77.63	92.98	108.29
T_1F_5	41.70	68.69	82.77	92.19
T_2F_1	53.82	81.06	94.29	106.27
T_2F_2	51.58	82.39	99.79	103.19
T_2F_3	50.23	77.31	95.27	107.03
T_2F_4	51.23	82.38	97.13	112.19
T_2F_5	42.32	70.04	87.70	104.76
T_3F_1	52.10	79.55	95.12	108.85
T_3F_2	53.08	79.67	98.77	115.68
T_3F_3	50.85	81.88	94.97	109.68
T_3F_4	53.02	82.25	101.71	118.25
T_3F_5	42.58	76.33	87.01	101.79
T_4F_1	44.07	84.17	95.91	107.98
T_4F_2	44.43	81.13	100.56	119.77
T_4F_3	45.10	83.10	96.33	111.19
T_4F_4	51.43	84.22	101.33	117.70
T_4F_5	44.50	76.95	85.55	102.73
$F_{12,32}$	4.94**	3.64**	NS	4.98**
SE_d	1.061	0.933	1.255	1.629
CD	3.028	2.644	-	4.650

** Significant at 1 per cent level
NS Not significant

4.2.1.1c Interaction effect of foliar spray and stage of application on plant height (cm)

Treatments	20DAT	40 DAT	60 DAT	Harvest
F_1S_1	50.03	80.87	92.42	104.57
F_1S_2	48.62	79.17	95.38	108.69
F_2S_1	49.52	79.45	96.41	109.81
F_2S_2	48.75	79.56	97.72	110.61
F_3S_1	47.90	78.45	93.28	106.47
F_3S_2	49.39	79.87	95.39	111.30
F_4S_1	49.36	81.85	97.37	111.96
F_4S_2	52.81	81.09	99.21	116.26
F_5S_1	41.28	71.17	84.67	99.31
F_5S_2	44.26	78.84	86.85	101.73
$F_{4, 40}$	3.871**	5.08**	NS	NS
SE_d	0.784	0.656	0.471	0.806
CD	2.240	1.874	-	-

** Significant at 1 per cent level
NS Not significant

Azospirillum). The lowest plant height was recorded by T_4 but it was on par with the treatment T_1 (control). Among the various foliar applications, spraying with Penshibao (F_4) produced the tallest plants (51.08 cm) which was significantly different from all other treatments. No significant difference in plant height was seen with F_1, F_2 and F_3. The smallest plant was observed in the control plots (42.78 cm). Plant height was significantly influenced by the stages of application. Two foliar sprays (20 and 30 DAT) registered an increase with plant height in comparison with spraying ones (20 DAT alone).

At 20 DAT significant interaction was observed between seed soaking and foliar spray. Treated seeds except control significantly resulted in increasing the plant height. No significant difference was observed with foliar spray treatments when the seeds were soaked in water. Under T_4, F_4 registered the highest value for plant height (51.43 cm) while F_1, F_2, F_3 and F_5 were on par. The interaction effect between foliar spray and stage of application was also significant. Foliar spray at two stages with F_4 resulted in an increase in plant height compared to others. The treatment combination T_2F_1 and F_4S_2 recorded the highest plant height.

4.2.1.1.2 At 40 DAT

At 40 DAT the treatment T_4 (soaking in Azospirillum + Penshibao) produced the tallest plants (81.91 cm). Among the various foliar sprays, spraying with Penshibao (F_4) recorded the highest plant height (81.47 cm).

The lowest height was observed in control plots, F_5 (73.01 cm). The impact of stage of application was found to be non-significant.

Among the interaction effects T x F (seed soaking x foliar spray) was found to be significant. All the treated plots recorded an increase in plant height. No significant difference was seen with F_1, F_2, F_3 and F_4 under T_1. The treatment F_3 was inferior to F_1, F_2 and F_4 under T_2 and under T_3, F_4, F_3 and F_2 were on par. The treatments F_1, F_3 and F_4 were equally effective under T_4. Among all the T x F interactions, T_4F_4 recorded the highest (84.22 cm) plant height and the smallest plants were produced by T_1F_5 (68.69 cm). Two stages of application of growth hormones did not result in any significant increase in plant height though the trend in response of foliar spray under S_1 and S_2 were not the same.

4.2.1.1.3 At 60 DAT

At 60 DAT, the treatment T_4 recorded the highest plant height, (95.93 cm) and was on par with T_3 (95.52 cm) and T_2 (94.84 cm). Spraying rice plants with Penshibao (F_4) recorded numerically the highest plant height (98.29 cm) and was on par with F_2 (spraying with GA_3). The lowest plant height was observed with F_5 (85.76 cm). The impact of stage of application was significant and the treatment S_2 (spraying at 20 and 30 DAT) produced the tallest plants. The interaction effect failed to exert any significant influence in plant height.

4.2.1.1.4 At harvest

At harvest the treatment T_4 produced the tallest (111.88 cm) plants and was on par with T_3 (110.85 cm). The least height was observed with T_1 (102.87 cm). Significant influence of foliar application was also noticed and the treatment F_4 recorded the tallest plants (114.11 cm) which was significantly superior to all other treatments. Spraying at 20 and 30 DAT (S_2) recorded the highest plant height (109.72 cm).

At harvest T x F interaction as found to be significant and the following results were observed. Under T_1, F_3 and F_4 were superior to F_2. The treatment F_4 (112.19 cm) was the best with T_2 while F_1, F_2, F_3 and F_5 were on par. The treatments F_2 and F_4 performed well under T_3 and T_4. Control plots were found to produce plants with less height.

4.2.1.2 Tiller number m^{-2} (Tables 4.2.1.2a and 4.2.1.2b)

Seed soaking, foliar application and stages of application and its interactions had significant influence on tiller number m^{-2}.

4.2.1.2.1 At 20 DAT

At 20 DAT soaking in Azospirillum + Penshibao (T_4) recorded the highest number of tillers m^{-2} (726.14) which was followed by T_2 and it was on par with T_3. The lowest tiller count was registered by T_1 (607.14). Among the foliar sprays, F_4 recorded the highest number of tillers m^{-2} (740.28) and was on par with F_2 (723.39). Spraying at 20 and 30 DAT (S_2) was significantly superior (705.11) to spraying at 20 DAT alone (646.43).

Table 4.2.1.2a Effect of seed soaking, foliar spray and stage of application on tiller number m^{-2}

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Seed soaking				
T_1	607.14	540.14	521.67	498.17
T_2	689.89	618.83	597.09	574.42
T_3	679.91	627.05	593.17	548.22
T_4	726.14	646.06	560.83	568.95
$F_{3,6}$	64.57**	102.46**	82.45**	82.91**
SE_d	6.208	4.445	5.140	10.326
CD	21.482	15.381	17.788	35.735
Foliar spray				
F_1	650.70	594.49	569.58	567.87
F_2	723.39	654.56	667.29	586.50
F_3	662.10	615.85	594.88	589.82
F_4	740.28	679.62	656.79	631.66
F_5	602.38	517.58	465.29	449.09
$F_{4,32}$	61.11**	74.25**	15.25**	84.69**
SE_d	7.188	9.410	6.095	11.414
CD	20.515	26.856	17.395	32.575
Stage of application				
S_1	646.43	589.33	524.17	512.23
S_2	705.11	616.71	602.17	586.15
$F_{1,40}$	159.13**	9.16**	NS	10.57**
SE_d	3.289	6.399	3.775	8.247
CD	9.401	18.288	-	23.57

** Significant at 1 per cent level
NS Not significant

Seed soaking

T_1 – Water soaking
T_2 – Soaking in Azospirillum (600 g)
T_3 – Soaking in Penshibao (100 ppm)
T_4 – Soaking in Azospirillum (600 g ha^{-1}) + Penshibao (100 ppm)

Foliar spray

F_1 – Triacontanol (500 ppm)
F_2 – GA_3 (5 ppm)
F_3 – Kinetin (5 ppm)
F_4 – Penshibao (100 ppm)
F_5 – Water spray

Stages of application

S_1 – Foliar spraying at 20 DAT
S_2 – Foliar spraying at 20 and 30 DAT

Table 4.2.1.2b Interaction effect of seed soaking and foliar spray on tiller number m^{-2}

Treatments	20 DAT	40 DAT	60 DAT	Harvest
T_1F_1	651.42	613.55	581.67	564.54
T_1F_2	632.34	628.02	526.66	511.52
T_1F_3	564.07	523.47	546.95	539.00
T_1F_4	571.58	474.83	538.33	512.50
T_1F_5	616.29	460.83	435.00	401.27
T_2F_1	600.09	582.35	524.16	520.18
T_2F_2	734.21	652.95	623.00	612.04
T_2F_3	741.17	659.58	635.85	603.94
T_2F_4	804.73	754.47	686.66	626.67
T_2F_5	569.30	444.80	448.33	421.25
T_3F_1	658.96	586.72	570.50	563.75
T_3F_2	736.90	649.08	633.33	630.50
T_3F_3	661.20	636.88	615.00	574.33
T_3F_4	773.30	727.58	651.66	634.75
T_3F_5	569.13	466.97	438.33	430.72
T_4F_1	692.35	605.33	590.00	567.00
T_4F_2	790.12	688.21	654.16	647.29
T_4F_3	681.98	628.46	595.12	572.02
T_4F_4	811.47	761.58	696.50	682.70
T_4F_5	654.48	546.71	492.50	435.13
$F_{12, 32}$	16.23**	11.56**	6.63**	7.34**
SE_d	14.377	18.821	12.190	22.829
CD	41.029	53.713	34.790	65.150

** Significant at 1 per cent level

At 20 DAT significant interaction observed between and soaking and foliar spray. With T_1, the foliar treatments F_1 and F_2 were the best. With T_2, F_4 (804.73) was the best. The treatments F_2 and F_4 were the best under T_3. When seeds were soaked under T_4, F_2 and F_4 as foliar sprays resulted in more number of tillers. The treatment combination T_4F_4 recorded the highest number (811.47) of tillers. Interaction effects of foliar spray and stage of application was also significant. Two applications resulted in an increase in tiller number under all foliar treatments. The foliar treatments F_2 and F_4 were superior under S_1 (one foliar spray at 20 DAT alone). With two applications (S_2), F_4 gave the best result.

4.2.1.2.2 At 40 DAT

The impact of seed soaking was significant at 40 DAT. T_4 (Azospirillum + Penshibao) recorded the highest number of tillers (646.06). Among the foliar sprays, spraying with Penshibao recorded the highest number of tillers (679.62) which was significantly superior to control and was on par with F_2 (spraying with GA_3). Spraying at 20 and 30 DAT was also found to be significantly superior to spraying at 20 DAT alone.

In two factor interactions, seed soaking and foliar spray (T x F) was found to be significant. Under water soaking methods (T_1), the highest tiller number was observed with F_2 (628.02) and was on par with F_1 (613.55). When seeds were soaked in T_2, T_3 and T_4, the highest tiller number was registered by the treatment F_4 for all the above seed soakings and was significantly superior to other foliar sprays. The treatment combination T_4F_4 produced the highest number of tillers (761.58).

4.2.1.2.3 At 60 DAT

At 60 DAT the highest number of tillers (597.07) was recorded by the treatment T_2 which was on par with T_3. The lowest tiller number was recorded by T_1 (521.67). Among the various foliar sprays F_2 recorded the highest numbers of tillers m^{-2} (667.29) and was on par with F_4. Stage of application failed to exert any significant influence.

The interaction effects at 60 DAT between seed soaking and foliar sprays (T x F) and foliar spray and stage of application (F x S) were observed to be significant. Number of tillers were in general less in control plots. The treatments F_1 and F_2 were the best treatments under T_1. F_4 and F_2 were superior to F_1, F_3 and F_5 under T_3. F_4 (686.66) was superior under T_2. F_4 was the best under T_4. The treatment combination T_4F_4 recorded the highest number of tillers.

4.2.1.2.4 At harvest

At harvest, the treatment T_2 recorded the highest number of tillers m^{-2} (574.42) and was on par with the treatment T_4 and T_3. The impact of foliar application was also significant and the treatment F_4 (spraying with Penshibao) recorded the highest number of tillers m^{-2} (631.66) and was significantly superior to other treatments. The stage of application was also significant and S_2 (spraying at 20 and 30 DAT) was found to be superior.

All the two factor interactions were significant except T x S at harvest. Number of tillers were in general less in control plots. The treatments F_1, F_2, F_3 and F_4 were on par under T_1. F_2, F_3 and F_4 were found to be superior to F_1 and F_5 under T_2. F_4 was superior under T_3 and T_4, but on par with F_2.

4.2.1.3 Drymatter production (Tables 4.2.1.3a, 4.2.1.3b and 4.2.1.3c)

DMP was significantly influenced by seed soaking, foliar spray and stage of application at 20, 40, 60 and at harvest.

4.2.1.3.1 At 20 DAT

At 20 DAT, soaking in Penshibao + Azospirillum (T_4) recorded the highest DMP (210.50 g m^{-2}). This was followed by T_3 which was on par with T_2. The least DMP (109.09 g m^{-2}) was recorded by the control plot. Among the various foliar sprays, spraying with kinetin (F_3) registered the highest DMP (177.10 g m^{-2}) which was followed by F_4 and F_2 which were on par. The least DMP was recorded by the control (F_5) which was on par with F_1. The influence of stages of application was not significant.

Under water soaking treatment (T_1), F_2 gave the best result. Under T_2 all foliar sprays were on par except F_2. With Penshibao seed soaking (T_3), the foliar spray with all chemicals were on par. With T_4, the treatment F_4 (221.55 g m^{-2}) performed well.

Table 4.2.1.3a Effect of seed soaking, foliar spray and stages of application on DMP (g m^{-2})

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Seed soaking				
T_1	109.09	428.89	492.20	962.60
T_2	177.01	489.06	565.83	1098.66
T_3	178.28	520.70	585.39	1102.62
T_4	210.50	565.26	627.88	1136.74
$F_{3,6}$	508.09**	57.19**	254.09**	34.83**
SE_d	1.893	7.581	3.425	13.04
CD	6.350	26.236	11.854	45.126
Foliar spray				
F_1	162.58	466.85	545.63	1041.98
F_2	171.14	556.77	620.15	1164.66
F_3	177.10	466.83	540.80	1066.19
F_4	171.34	624.69	687.57	1264.84
F_5	161.38	389.74	437.48	838.11
$F_{4,32}$	14.67**	250.23**	220.93**	184.05**
SE_d	1.724	5.752	6.318	11.734
CD	4.921	16.417	18.032	33.488
Stage of application				
S_1	169.34	473.41	527.66	1029.83
S_2	168.08	528.55	604.99	1120.48
$F_{1,40}$	NS	165.03**	628.51**	293.91**
SE_d	1.655	3.035	2.781	10.686
CD	-	8.674	6.235	293.906

** Significant at 1 per cent level
NS Not significant

Seed soaking
T_1 Water soaking
T_2 Soaking in Azospirillum (600 g ha^{-1})
T_3 Soaking in Penshibao (100 ppm)
T_4 Soaking in Azospirillum (600 g ha^{-1}) + Penshibao (100 ppm)

Foliar spray
F_1 Triacontanol (500 ppm)
F_2 GA_3 (5 ppm)
F_3 Kinetin (5 ppm)
F_4 Penshibao (100 ppm)
F_5 Water spray

Stages of application
S_1 Foliar spraying at 20 DAT
S_2 Foliar spraying at 20 DAT and 30 DAT

Table 4.2.1.3b Interaction effect of seed soaking and foliar spray on DMP (g m^{-2})

Treatments	20 DAT	40 DAT	60 DAT	Harvest
T_1F_1	99.33	411.72	493.78	926.93
T_1F_2	131.33	447.80	514.53	1067.50
T_1F_3	115.40	429.29	478.86	867.85
T_1F_4	98.29	492.93	575.56	1126.21
T_1F_5	101.14	362.72	398.29	824.53
T_2F_1	180.41	470.33	553.53	1056.49
T_2F_2	163.74	523.99	582.67	1257.99
T_2F_3	173.12	496.19	581.12	1084.31
T_2F_4	188.31	614.74	715.09	1309.52
T_2F_5	179.49	340.03	396.73	784.97
T_3F_1	175.21	495.50	596.63	1095.45
T_3F_2	182.65	570.54	657.24	1160.69
T_3F_3	179.78	488.99	570.62	1100.51
T_3F_4	177.20	626.18	660.18	1264.26
T_3F_5	176.23	422.31	442.31	892.16
T_4F_1	195.36	489.87	535.58	1089.05
T_4F_2	206.83	684.75	726.19	1172.47
T_4F_3	240.11	452.87	532.61	1212.08
T_4F_4	221.55	764.92	799.45	1359.37
T_4F_5	188.68	433.91	512.57	850.76
$F_{12,32}$	15.25**	19.46**	14.46**	7.00**
SE_d	3.449	11.505	12.637	23.468
CD	9.843	32.834	36.064	66.975

** Significant at 1 per cent level

Table 4.2.1.3 c Interaction effect of foliar spray and stage of application on DMP (g m^{-2})

Treatments	20DAT	40 DAT	60 DAT	Harvest
F_1S_1	160.68	440.19	507.23	992.12
F_1S_2	164.47	493.52	584.03	1091.83
F_2S_1	171.37	526.51	570.21	1119.24
F_2S_2	170.91	587.13	670.09	1210.09
F_3S_1	182.13	416.04	484.75	1000.75
F_3S_2	172.07	517.63	596.85	1131.63
F_4S_1	169.36	618.74	659.39	1235.24
F_4S_2	173.32	630.66	715.75	1294.45
F_5S_1	163.16	365.58	416.69	801.81
F_5S_2	159.61	413.91	438.25	874.40
$F_{4, 40}$	NS	11.14**	18.08**	5.38**
SE_d	3.700	6.786	4.878	8.361
CD	-	19.395	13.941	23.896

** Significant at 1 per cent level

NS Not significant

Among the treatment combinations the highest DMP m^{-2} was recorded in T_4F_3 (240.11 g m^{-2}) which was significantly superior to all other treatment combinations.

4.2.1.3.2 At 40 DAT

At 40 DAT, T_4 recorded the highest DMP (565.26 g m^{-2}) and was significantly superior to other treatments. The lowest DMP was observed with T_1 (428.89 g m^{-2}). The impact of foliar spray was also significant and spraying with Penshibao (F_4) recorded the highest DMP (624.69 g m^{-2}) and the lowest DMP (389.74 g m^{-2}) was produced by control. Stage of application was also significant and S_2 was found to be superior treatment.

Significant interaction was observed between seed soaking and foliar spray. The treatment F_4 was found to be the best with all seed soaking methods. The foliar application with F1, F_2 and F_3 were on par under T_1. F_2 was found to be on par with F_3 under T_2. The treatment F_4 was superior to F_1, F_2 and F_3 under T_3 and T_4.

Another two factor interaction F x S also was observed to be significant. With S_1 and S_2 (spraying at 20 DAT alone and 20 and 30 DAT), F_4 was found to be the best followed by F_2. Among the F x S treatment combinations, F_4S_1 (618.74 g m^{-2}) and F_4S_2 (630.66 g m^{-2}) were found to be on par and superior to all others. Among the T x F interactions, T_4F_4 combination (764.92 g m^{-2}) was found to be the best.

4.2.1.3.3 At 60 DAT

At 60 DAT the treatment T_4 registered the highest DMP (627.88 g m^{-2}) and was significantly superior to all other seed soaking methods. The lowest DMP (492.20 g m^{-2}) was recorded by T_1 (control). Among the foliar sprays, the treatment F_4 recorded the highest DMP (687.57 g m^{-2}) and was significantly superior to other treatments. The impact of stage of application was also evident and S_2 (spraying at 20 and 30 DAT) was significantly superior to S_1 (spraying at 20 DAT alone).

All the three two factor interactions were found to be significant, Under T x F interaction, the treatment combination T_4F_4 was observed to be the best one (799.45 g m^{-2}). The foliar spray with Penshibao (F_4) with different seed soaking methods was found to be good. But it was on par with F_2 under T_3.

Significant interaction was observed between F and S (foliar spray and stages of application). The foliar application of Penshibao (F_4) gave the best results with two foliar sprays. F_1, F_2 and F_3 were on par with F_4 when applied at 20 and 30 DAT. The best treatment combination was F_4S_2 (715.15 g m^{-2}).

4.2.1.3.4 At harvest

At harvest, soaking in Penshibao + Azospirillum (T_4) recorded numerically the highest DMP (1136.74 g m^{-2}) which was on par with T_3 and T_2. Among the foliar sprays, F_4 registered the highest DMP (1264.84 g m^{-2}) and was significantly superior to others. Spraying with water gave the lowest DMP (838.11 g m^{-2}). Stage of application also had a significant influence and S_2 (spraying at 20 and 30 DAT) was superior (1120.48 g m^{-2}) to S_1 (20 DAT alone).

Significant interaction was observed between seed soaking and foliar spray. Under T_1 (water soaking) there was significant influence with foliar spray of F_4 and F_2 but these were on par. Under T_2, the foliar application with F_2 was on par with F_3. Under T_3 and T_4 the treatment F_4 was the best. Best combination was T_4F_4 (1359.37 g m^{-2}) which was on par with T_2F_4.

Significant interaction was seen between foliar spray and stage of application. With either one or two sprays, F_4 was found to be the best one followed by F_2. But two sprays at 20 and 30 DAT gave the best result. The treatment combination F_4S_2 (1294.45 g m^{-2}) was found to be the best.

4.2.1.4 Leaf area index (Tables 4.2.1.4a, 4.2.1.4b and 4.2.1.4c)

Leaf area index (LAI) was significantly influenced by seed soaking, foliar spray, stage of application and its interactions.

4.2.1.4.1 At tillering stage

At tillering stage, T_4 (soaking in Penshibao + Azospirillum) recorded the highest LAI (3.17) and the least (1.45) was recorded by the treatment T_1 (control). Among the foliar sprays, the treatment F_4 (spraying with Penshibao) registered the highest LAI (2.69) followed by the treatment F_3 (spraying with kinetin) which was on par with F_2

Table 4.2.1.4a Effect of seed soaking, foliar spray and stage of application on LAI and LAD (days)

Treatments	Tillering stage		Flowering stage	
	LAI	LAD	LAI	LAD
Seed soaking				
T_1	1.45	48.02	3.31	33.48
T_2	2.10	62.82	4.16	42.91
T_3	3.06	66.5	3.86	40.47
T_4	3.17	69.04	4.63	47.30
$F_{3,6}$	970.75**	163.33**	39.07**	126.71**
SE_d	0.026	0.736	0.088	0.513
CD	0.091	2.547	0.305	1.777
Foliar spray				
F_1	2.45	63.73	3.85	40.38
F_2	2.46	67.83	4.42	45.15
F_3	2.50	64.21	4.19	43.62
F_4	2.69	71.93	5.08	51.07
F_5	2.12	40.27	2.42	24.99
$F_{4,32}$	18.78**	309.55**	177.19**	324.73**
SE_d	0.048	0.703	0.074	0.542
CD	0.137	2.006	0.212	1.547
Stage of application				
S_1	2.32	59.01	3.79	38.41
S_2	2.56	64.18	4.18	43.67
$F_{1,40}$	92.55**	152.10**	42.94**	263.33**
SE_d	0.020	0.296	0.041	0.654
CD	0.057	0.846	0.118	0.229

* Significant at 5 per cent level

** Significant at 1 per cent level

Seed soaking

T_1 Water soaking
T_2 Soaking in Azospirillum (600 g ha^{-1})
T_3 Soaking in Penshibao (100 ppm)
T_4 Soaking in Azospirillum (600 g ha^{-1}) + Penshibao (100 ppm)

Foliar spray

F_1 Triacontanol (500 ppm)
F_2 GA_3 (5 ppm)
F_3 Kinetin (5 ppm)
F_4 Penshibao (100 ppm)
F_5 Water spray

Stages of application

S_1 Foliar spraying at 20 DAT
S_2 Foliar spraying at 20 DAT and 30 DAT

Table 4.2.1.4b Interaction effect of seed soaking and foliar spray on LAI and LAD (days)

Treatments	Tillering stage		Flowering stage	
	LAI	LAD	LAI	LAD
T_1F_1	1.56	49.87	3.34	33.78
T_1F_2	1.49	51.82	3.63	36.32
T_1F_3	1.43	42.90	2.79	28.47
T_1F_4	1.42	59.87	4.59	45.75
T_1F_5	1.32	35.63	2.22	23.08
T_2F_1	1.80	62.75	4.24	44.05
T_2F_2	2.18	67.68	4.51	46.17
T_2F_3	2.14	67.80	4.57	46.76
T_2F_4	2.59	74.07	5.29	53.18
T_2F_5	1.79	41.82	2.19	24.4
T_3F_1	3.31	68.90	3.20	35.75
T_3F_2	2.94	76.15	4.55	48.38
T_3F_3	3.38	72.78	4.30	45.00
T_3F_4	3.26	77.06	4.89	49.22
T_3F_5	2.42	37.6	2.38	23.98
T_4F_1	3.13	73.42	4.61	47.92
T_4F_2	3.23	75.67	5.00	49.72
T_4F_3	3.05	73.35	5.11	54.23
T_4F_4	3.49	76.73	5.56	56.12
T_4F_5	2.93	46.02	2.88	28.52
$F_{12,32}$	5.35**	11.04**	6.15**	12.60**
SE_d	0.093	1.406	0.149	1.084
CD	0.273	4.013	0.424	3.095

** Significant at 1 per cent level

Table 4.2.1.4c Interaction effect of foliar spray and stage of application on LAI, LAD (days), CGR (g m^{-2} day^{-1}), RGR (mg g^{-1} day^{-1}) and NAR (mg cm^{-2} day^{-1})

Treatments	Tillering stage					Flowering stage				
	LAI	LAD	CGR	RGR	NAR	LAI	LAD	CGR	RGR	NAR
F_1S_1	2.44	60.88	13.91	45.74	5.89	3.63	37.39	3.09	5.01	3.22
F_1S_2	2.46	66.58	16.61	50.87	7.63	4.06	43.36	4.53	6.09	4.86
F_2S_1	2.34	64.69	22.59	55.17	9.73	4.20	42.03	3.33	6.57	6.61
F_2S_2	2.59	70.97	25.56	59.26	11.56	4.64	48.26	4.99	8.70	7.92
F_3S_1	2.47	61.96	13.67	42.29	7.83	3.94	40.03	2.60	5.47	4.37
F_3S_2	2.53	66.46	17.65	48.95	9.33	4.44	41.2	3.46	7.39	5.68
F_4S_1	2.46	70.14	23.29	59.66	9.94	4.93	48.58	3.64	7.75	6.25
F_4S_2	2.92	73.73	25.87	62.38	11.99	5.23	53.55	5.76	11.16	8.37
F_5S_1	1.91	37.39	11.20	29.21	3.44	2.29	24.03	1.80	3.40	2.13
F_5S_2	2.32	43.14	13.38	30.95	4.29	2.54	25.97	2.40	3.69	2.41
$F_{4,40}$	10.35**	NS	2.98*	NS	NS	NS	7.71**	8.01**	11.78**	6.69**
SE_d	0.044	0.662	0.278	0.899	0.168	0.093	0.512	0.152	0.238	0.159
CD	0.127	-	0.793	-	-	-	1.463	0.434	0.681	0.455

** Significant at 1 per cent level
NS Not significant

(spraying with GA_3). Stages of application also had significant influence on LAI. Spraying at 20 and 30 DAT (S_2) recorded the maximum LAI and was significantly superior to spraying at 20 DAT alone (S_1).

Significant interaction was observed between seed soaking and foliar spray. There was no significant difference in foliar treatments with growth regulators under T_1. In T_2 soaked seeds, LAI was significantly high with F_4 spray. When the seeds were soaked in T_3, LAI was high for F_1, F_3 and F_4 sprayed plants. Under T_4, F_4 sprayed plants registered the highest LAI and was on par with F_2. Among the treatment combinations, T_4F_4, T_3F_1, T_3F_3, T_3F_4 and T_4F_2 were observed to be superior and were on par. Interaction between foliar spray and stages of application was also found to be significant. For single application (20 DAT) no significant difference was observed with F_1, F_2, F_3 and F_4. But in spraying twice, F_4 sprayed plants recorded the highest LAI.

4.2.1.4.2 At flowering stage

At flowering stage, the highest LAI (4.63) was registered by T_4 (soaking in Azospirillum + Penshibao). Among the various foliar sprays, the highest LAI (5.08) was observed with the treatment F_4 (spraying with Penshibao). LAI was profoundly influenced by stages of application. The effect of spraying at 20 and 30 DAT (S_2) was superior to spraying at 20 DAT alone.

Significant interaction was observed between seed soaking and foliar spray. The treatment F_4 was found to be superior which resulted in high LAI in plants which were raised with T_1 and T_2 seed soaking. But with T_3, no significant difference was observed with F_2, F_3 and F_4 and while with T_4, F_4 was superior to others except F_3.

4.2.1.5 Leaf area duration (Tables 4.2.1.4a, 4.2.1.4b and 4.2.1.4c)

Leaf area duration (LAD) was significantly influenced by seed soaking, foliar spray, stage of application and its interaction.

4.2.1.5.1 At tillering stage

At tillering stage, the treatment T_4 (soaking in Penshibao + Azospirillum) recorded numerically the highest LAD (69.04 days) and was comparable with T_3 (soaking in Penshibao). The least LAD (48.02 days) was recorded by T_1 (control). Among the foliar sprays, the treatment F_4 (spraying with Penshibao) registered the highest LAD. Spraying at 20 and 30 DAT was found to be superior to spraying at 20 DAT alone.

Significant interaction was observed between seed soaking and foliar spray. Under T_1 and T_2, the highest LAD was recorded by F_4. No significant difference was seen with foliar sprays of F_1, F_2, F_3 and F_4 under T_3 and T_4 soaked seeds.

Interaction effect of seed soaking and stages of application was significant. Seed soaked in T_3 and T_4 did not show any significant difference in LAD when the plants received two sprays.

4.2.1.5.2 At flowering stage

At flowering stage the treatment T_4 (soaking in Penshibao + Azospirillum) recorded the highest LAD (47.30 days) which was significantly superior to all other seed soaking treatments. The lowest LAD (33.48 days) was observed with T_1 (control). Among the foliar sprays, the treatment F_4 (spraying with Penshibao) recorded the highest LAD (51.07 days) which was superior to other treatments. The lowest LAD (24.99 days) was observed with F_5 (control). The impact of stage of application was found to be significant and treatment S_2 (spraying 20 and 30 DAT) produced the highest LAD.

Significant interaction effect between seed soaking and foliar spray on LAD was observed. Foliar spray with Penshibao (F_4) was found to be effective which resulted in highest LAD in plants which were raised with T_1 and T_2 seed soaking. But with T_3, no significant difference was observed with F_2 and F_3 while with T_4, F_4 was found to be on par with F_3.

Another two factor interactions, F x S was also significant (foliar spray and stage of application). Under S_1 (spraying at 20 DAT alone), the highest LAD was recorded by F_4 and was significantly superior to other foliar sprays. Spraying twice (at 20 and 30 DAT) with F_4 produced the highest LAD (53.55 days) and was superior.

4.2.1.6 Crop growth rate (Tables 4.2.1.6a, 4.2.1.6b and 4.2.1.4c)

Crop growth rate (CGR) was significantly influenced by foliar spray, stage of application and its interaction.

4.2.1.6.1 At tillering stage

The different seed soaking methods did not influence the CGR at tillering. Among the foliar sprays, the treatment F_4 recorded the highest CGR (24.58 g m^{-2} day^{-1}) and was on par with F_2 (24.07 g m^{-2} day^{-1}). The lowest CGR (12.29 g m^{-2} day^{-1}) was observed with control (F_5) plants. Spraying at 20 and 30 DAT recorded the highest CGR (19.81 g m^{-2} day^{-1}).

Significant interaction was observed between foliar spray and stage of application. With one spray (at 20 DAT alone), F_1 and F_3 performed more or less in a same manner but F_2 and F_4 were on par. But with two sprays F_4 was found to be the best and was on par with F_2.

4.2.1.6.2 At flowering

The different seed soaking methods did not influence the CGR at flowering. Among the foliar sprays, the treatment F_4 (spraying with Penshibao) recorded the highest CGR (4.70 g m^{-2} day^{-1}) which was significantly different from the control. The impact of stage of application was also significant and spraying at 20 and 30 DAT (S_2) was found to be significantly superior to spraying at 20 DAT alone (S_1).

All the interaction were found to be significant. Under T x F interaction, the best combination was T_4F_4 which recorded the highest CGR (6.06 g m^{-2} day^{-1}). Under all seed soaking methods, there was no significant difference between the foliar sprays F_1, F_2 and F_4 except under T_4.

There was significant interaction between foliar spray and stage of application. When spraying was done once (20 DAT alone), F_4 sprayed

Table 4.2.1.6a Effect of seed soaking, foliar spray and stage of application on CGR (g m^{-2} day^{-1}), RGR (mg g^{-1} day^{-1}) and NAR (mg cm^{-2} day^{-1})

Treatments	Tillering stage			Flowering stage		
	RGR	CGR	NAR	RGR	CGR	NAR
Seed soaking						
T_1	48.49	18.02	8.05	5.93	3.33	4.76
T_2	49.17	18.19	8.13	6.44	3.53	5.45
T_3	49.72	18.78	8.24	7.01	3.73	5.36
T_4	46.42	18.51	8.23	6.7	3.62	5.32
$F_{3,6}$	6.47*	NS	NS	NS	NS	6.72*
SE_d	0.567	0.234	0.104	0.306	0.123	0.121
CD	1.963	-	-	-	-	0.420
Foliar spray						
F_1	48.31	15.26	6.76	5.55	3.81	4.04
F_2	57.22	24.07	10.65	7.63	4.17	7.27
F_3	45.62	15.66	8.58	6.43	3.03	5.03
F_4	61.02	24.58	10.96	9.43	4.7	7.49
F_5	30.08	12.29	3.86	3.55	2.11	2.27
$F_{4,32}$	316.01**	230.14**	237.98**	99.96**	32.86**	108.29**
SE_d	0.678	0.369	0.191	0.221	0.177	0.606
CD	1.934	1.052	0.544	0.630	0.506	0.212
Stage of application						
S_1	46.41	16.93	7.37	5.64	2.89	4.59
S_2	50.48	19.81	8.96	7.39	4.23	5.85
$F_{1,40}$	51.21**	268.85**	225.67**	136.05**	192.16**	156.39**
SE_d	0.402	0.124	0.075	0.107	0.068	0.071
CD	1.149	0.355	0.214	0.305	0.194	0.204

* Significant at 5 per cent level
** Significant at 1 per cent level
NS Not significant

Seed soaking
- T_1 Water soaking
- T_2 Soaking in Azospirillum (600 g ha^{-1})
- T_3 Soaking in Penshibao (100 ppm)
- T_4 Soaking in Azospirillum (600 g ha^{-1}) + Penshibao (100 ppm)

Foliar spray
- F_1 Triacontanol (500 ppm)
- F_2 GA_3 (5 ppm)
- F_3 Kinetin (5 ppm)
- F_4 Penshibao (100 ppm)
- F_5 Water spray

Stages of application
- S_1 Foliar spraying at 20 DAT
- S_2 Foliar spraying at 20 DAT and 30 DAT

4.2.1.6b Interaction effect of seed soaking and foliar spray on CGR (g m^{-2} day^{-1}), RGR (mg g^{-1} day^{-1}) and NAR (mg cm^{-2} day^{-1})

Treatments	Tillering			Flowering		
	CGR	RGR	NAR	CGR	RGR	NAR
T_1F_1	15.63	48.72	7.01	4.11	5.39	3.32
T_1F_2	23.16	56.02	10.11	3.99	7.18	1.64
T_1F_3	14.87	49.10	8.38	2.48	5.57	4.42
T_1F_4	23.71	58.80	10.62	4.13	8.29	7.14
T_1F_5	12.75	28.79	4.13	1.94	3.23	2.26
T_2F_1	14.49	47.77	6.03	4.17	5.31	4.07
T_2F_2	24.18	57.34	10.99	4.10	7.09	7.64
T_2F_3	16.15	52.26	8.29	3.25	6.83	5.40
T_2F_4	23.65	59.88	10.95	4.35	7.27	7.65
T_2F_5	12.53	28.59	4.41	2.00	3.68	2.48
T_3F_1	15.85	51.65	7.45	4.52	5.95	4.26
T_3F_2	24.89	56.39	10.24	4.50	8.15	7.89
T_3F_3	16.14	46.76	9.03	3.42	6.65	4.78
T_3F_4	25.32	62.59	10.99	4.26	10.79	7.63
T_3F_5	11.63	31.17	3.46	1.95	3.47	2.22
T_4F_1	15.08	45.08	6.56	2.45	5.52	4.51
T_4F_2	24.07	59.10	11.24	4.07	8.13	6.90
T_4F_3	15.47	34.36	8.63	2.99	6.69	5.50
T_4F_4	25.65	61.79	11.28	6.06	9.37	7.58
T_4F_5	12.07	31.76	3.46	2.52	3.80	2.13
$F_{12,32}$	NS	8.84**	NS	3.65**	NS	NS
SE_d	0.737	1.355	0.381	0.355	0.442	0.424
CD	-	3.868	-	1.012	-	-

** Significant at 1 per cent level

NS Not significant

plants recorded at the highest CGR and was on par with F_2. While two sprays were given, F_4 recorded a significantly higher CGR.

4.2.1.7 Relative growth rate (Table 4.2.1.6a, 4.2.1.6b and 4.2.1.4c)

Relative growth rate (RGR) was significantly influenced by the main plot, sub plot and sub sub plot factors and its interaction.

4.2.1.7.1 At tillering stage

At tillering stage, the treatment T_3 (soaking in Penshibao) recorded numerically the highest RGR (49.72 mg g^{-1} day^{-1}) and was comparable with T_2 (49.17 mg g^{-1} day^{-1}) and T_1 (48.49 mg g^{-1} day^{-1}). The lowest RGR was observed with T_4 (soaking in Azospirillum + Penshibao). Among the foliar sprays, the treatment F_4 (spraying with Penshibao) recorded the highest RGR (61.02 mg g^{-1} day^{-1}) and was significantly superior to other treatment. Spraying at 20 and 30 DAT had a significant (50.48 mg g^{-1} day^{-1}) effect over spraying at 20 DAT alone.

Interaction between seed soaking and foliar spray had significant effect. The treatment F_4 produced a high value for RGR but was on par with F_2 under T_1, T_2 and T_4. Under T_3, the treatment F_4 (62.59 mg g^{-1} day^{-1}) was significantly superior to other treatments.

4.2.1.7.2 At flowering stage

RGR was influenced by foliar spray and stage of application. Among foliar sprays the treatment F_4 (spraying with Penshibao) recorded the highest RGR (9.43 mg g^{-1} day^{-1}) which was significantly superior to all other treatments. The lowest RGR (3.55 mg g^{-1} day^{-1}) was recorded by F_5 (control). S_2 (spraying 20 and 30 DAT) was also significantly superior to S_1 (spraying at 20 DAT alone).

Significant interaction was observed between foliar spray and stage of application. With S_1 and S_2 (one and two sprays) F_4 was found to be the best which was followed by F_2.

4.2.1.8 Net assimilation rate (Table 4.2.1.6a, 4.2.1.6b and 4.2.1.4c)

Sub plot and sub sub plot factors showed a significant influence on net assimilation rate (NAR).

4.2.1.8.1 At tillering

The effect of seed soaking was not significant on NAR at tillering stage. Among the foliar sprays the treatment F_4 (spraying with Penshibao) recorded numerically the highest NAR (10.96 mg cm^{-2} day^{-1}) which was comparable with F_2 (10.65 mg cm^{-2} day^{-1}). The impact of stage of application was significant and the treatment S_2 (spraying at 20 and 30 DAT) recorded the highest NAR of 8.96 mg cm^{-2} day^{-1}. The interactions failed to express any influence on NAR.

4.2.1.8.2 At flowering

At flowering, T_2 (soaking with Azospirillum) produced the highest NAR (5.45 mg cm^{-2} day^{-1}) and was on par with the treatments T_3 (5.36 mg cm^{-2} day^{-1}) and T_4 (5.32 mg cm^{-2} day^{-1}). Among the foliar sprays, spraying with Penshibao recorded numerically the highest NAR (7.49 mg cm^{-2} day^{-1}) which was on par with the treatment F_2 (7.27 mg cm^{-2} day^{-1}). The impact of stage of application at this stage was same as that at tillering stage.

Significant interaction was observed between foliar spray and stage of application. Under S_1 (foliar spray at 20 DAT) the highest NAR (6.25 mg cm^{-2} day^{-1}) was observed with F_4 (Penshibao) and was on par with F_2 (GA_3). When the plants were sprayed twice at 20 and 30 DAT (S_2) with F_4 (Penshibao), the NAR recorded was highest (8.37 mg cm^{-2} day^{-1}) which was significantly superior to all other treatments. The best treatment combination was F_4S_2.

4.2.2 Yield attributes and yield

4.2.2.1 Number of panicles m^{-2} (Tables 4.2.2a, 4.2.2b and 4.2.2c)

Number of panicles m^{-2} was significantly influenced by main plot, sub plot and sub sub plot factors and its interactions.

Soaking in Penshibao (T_3) recorded numerically the highest number of panicle m^{-2} (480.50) and was on par with T_2 (soaking in Azospirillum). The lowest number of panicle was recorded by control plants (301.14). Among the foliar sprays, the treatment F_4 (spraying with Penshibao) recorded the highest number of panicles m^{-2} (562.76), followed by F_1 (triacontanol) and was on par with the treatments F_2 (GA_3) and F_3 (kinetin). The impact of stage of application was significant and S_2 (spraying at 20 and 30 DAT) recorded the highest number of panicles m^{-2} (438.77).

Table 4.2.2a Effect of seed soaking, foliar spray and stage of application on number of panicle m^{-2}, filled grain percentage and 1000 grain weight (g)

Treatments	Panicle/m^2	Filled grain percentage	1000 grain weight
Seed soaking			
T_1	301.14	85.39	28.98
T_2	472.59	86.63	29.20
T_3	480.50	87.24	29.43
T_4	427.41	88.17	29.83
$F_{3,6}$	41.71**	37.33**	NS
SE_d	12.834	0.190	0.135
CD	44.413	0.658	-
Foliar spray			
F_1	443.58	86.43	28.94
F_2	440.39	90.09	30.34
F_3	431.76	88.16	29.57
F_4	562.76	90.58	30.92
F_5	223.55	79.05	26.61
$F_{4,32}$	350.33**	202.63**	134.38**
SE_d	6.548	0.328	0.144
CD	18.687	0.936	0.411
Stage of application			
S_1	402.05	85.85	28.88
S_2	438.77	87.86	29.68
$F_{1,40}$	22.45**	49.18**	55.58**
SE_d	5.479	0.203	0.075
CD	15.661	0.580	0.215

** Significant at 1 per cent level
NS Not significant

Seed soaking
T_1 Water soaking
T_2 Soaking in Azospirillum (600 g ha^{-1})
T_3 Soaking in Penshibao (100 ppm)
T_4 Soaking in Azospirillum (600 g ha^{-1}) + Penshibao (100 ppm)

Foliar spray
F_1 Triacontanol (500 ppm)
F_2 GA_3 (5 ppm)
F_3 Kinetin (5 ppm)
F_4 Penshibao (100 ppm)
F_5 Water spray

Stages of application
S_1 Foliar spraying at 20 DAT
S_2 Foliar spraying at 20 DAT and 30 DAT

Table 4.2.2b Interaction effect of seed soaking and foliar application on panicle m^{-2}, filled grain percent and 1000 grain weight (g)

Treatments	No. of panicles / m^2	Filled grain percent	1000 grain weight
T_1F_1	323.25	85.74	28.39
T_1F_2	290.63	86.73	30.46
T_1F_3	293.67	88.89	29.51
T_1F_4	408.50	86.96	30.65
T_1F_5	189.67	78.68	25.91
T_2F_1	523.25	85.39	28.42
T_2F_2	487.17	91.09	30.19
T_2F_3	541.71	85.88	29.78
T_2F_4	587.42	89.23	30.93
T_2F_5	223.42	81.58	26.69
T_3F_1	487.33	87.19	29.81
T_3F_2	550.83	91.81	30.21
T_3F_3	492.83	88.84	29.47
T_3F_4	641.25	92.45	30.73
T_3F_5	230.25	75.91	26.95
T_4F_1	440.50	87.39	29.15
T_4F_2	432.92	90.7	30.50
T_4F_3	398.85	89.05	29.53
T_4F_4	613.88	93.67	31.38
T_4F_5	250.88	80.03	26.91
$F_{12,32}$	13.45**	9.85**	NS
SE_d	13.096	0.656	0.144
CD	37.374	1.871	-

** Significant at 1 per cent level

NS Not significant

Table 4.2.2c Interaction effect of foliar spray and stage of application on panicle number m^{-2}, filled grain per cent and 1000 gram weight (g)

Treatments	Panicle No./ m^2	Filled grain per cent	1000 grain weight
F_1S_1	414.38	84.36	28.74
F_1S_2	472.79	88.49	29.14
F_2S_1	432.42	89.40	30.07
F_2S_2	448.35	90.77	30.60
F_3S_1	414.68	85.39	28.77
F_3S_2	448.64	90.93	30.38
F_4S_1	524.44	90.32	30.35
F_4S_2	601.09	90.84	31.49
F_5S_1	224.33	79.80	26.47
F_5S_2	222.77	78.29	26.76
$F_{4,40}$	3.31*	19.37**	5.61**
SE_d	12.252	0.454	0.168
CD	35.019	1.297	0.481

* Significant at 5 per cent level
** Significant at 1 per cent level

The interaction effects between seed soaking and foliar sprays, foliar spray and stage of application were found to be significant. Whatever be the type of seed soaking, F_4 was found to be the best foliar spray. When F_1 was used for spraying, T_2 recorded the best result. If with F_2 spray T_3 appeared to be good. When F_3 was sprayed, the best result was observed with T_2. With F_4 both T_3 and T_4 were on par, but T_3 was superior to T_1 and T_2. The treatment combination T_3F_4 (641.25) was found to be the best one.

In F x S interaction, F_1 and F_2 which when given twice, gave the best results. But with F_2 and F_3 no significant difference was observed with either one or two sprays. The lowest value was recorded by F_5 with both S_1 and S_2. The treatment combination F_4S_2 (601.09) produced the highest number of panicles m^{-2}.

4.2.2.2 Filled grain per cent (Tables 4.2.2a, 4.2.2b and 4.2.2c)

Seed soaking, foliar spray and stage of application significantly influenced the filled grain percentage. Soaking in Penshibao + Azospirillum (T_4) was significantly superior (88.17 %) followed by the treatment T_3 and its effect was comparable with the effect of treatment T_2. Control plants recorded the least filled grain percentage of 85.39.

Among the foliar sprays, the treatment F_4 (Penshibao) recorded numerically the highest filled grain percentage (90.58 %) and was on par with the treatment F_2 (GA_3). The lowest filled grain percentage was noticed in the control plot. Spraying at 20 and 30 DAT (S_2) was found to be significantly superior to spraying at 20 DAT alone.

Significant interaction was observed between seed soaking and foliar spray. All the treatments were effective. With T_1 seed soaking, F_3 spray resulted in good results. With T_2 and T_3 seed soaking both F_2 (91.09 % and 91.81 %) and F_4 (89.23 % and 92.45 %) performed well. With T_4 seed soaking, F_4 gave the best results. The treatment combination T_4F_4 recorded the highest filled grain percent (93.67 %) which was on par with T_3F_4 (92.45 %).

Significant interaction was observed between foliar spray and stage of application. With one spray (20 DAT alone), F_2 and F_4 performed well while, with two sprays (20 and 30 DAT), F_2, F_3 and F_4 were on par and gave good results.

4.2.2.3 Thousand grain weight (Tables 4.2.2a, 4.2.2b and 4.2.2c)

The seed soaking treatment did not show any significant influence on 1000 grain weight. The effect of foliar spray, stage of applications and its interactions influenced 1000 grain weight. The treatment F_4 (spraying with Penshibao) recorded significantly the highest test weight (30.92 g). The lowest weight (26.61 g) was recorded by the control plots. Similarly the treatment S_2 registered the highest test weight of 29.68 g.

The interaction between foliar spray and stage of application was found to be significant. Thousand grain weight was high in F_2 and F_4 when one spray was given. But with two sprays, F_4 (31.49 g) performed well.

4.2.2.4 Grain yield (Tables 4.2.2d, 4.2.2e and 4.2.2f)

Significant variation was observed among the factors seed soaking, foliar spray and stage of application and their interaction. The treatment, T_4 (soaking in Penshibao + Azospirillum) recorded the highest grain yield of 5.74 t ha^{-1} followed by the treatments T_3 (5.59 t ha^{-1}) and T_2 (5.55 t ha^{-1}). However, the effect of T_2 and T_3 were comparable. The least yield (5.26 t ha^{-1}) was recorded with the control (T_1). Among the foliar sprays tested, F_4 (spraying with Penshibao) recorded the highest grain yield of 6.34 t ha^{-1} which was significantly superior to the treatment F_2 (GA_3), F_1 (triacontanol) and F_3 (kinetin). The effect of stages of application was found to be significant and the treatment S_2 (spraying at 20 and 30 DAT) recorded the highest yield of 5.65 t ha^{-1}.

Among the interactions, T x F was significant. With T_2, T_3 and T_4 seed soaking methods, the highest grain yield was recorded by F_4 spray which was on par with F_2. But with T_1, F_2 was on par with F_3. The treatment combinations T_4F_4 registered the highest grain yield of 6.49 t ha^{-1}. The lowest yield (3.84 t ha^{-1}) was recorded by T_1F_5 (control).

4.2.2.5 Straw yield (Tables 4.2.2d, 4.2.2e and 4.2.2f)

Straw yield was significantly influenced by seed soaking, foliar spray, stage of application and their interactions. Among the seed soaking treatments, the treatment T_4 (soaking in Penshibao + Azospirillum) registered numerically the highest straw yield (8.37 t ha^{-1}) and was comparable with treatment T_3 (Soaking in Penshibao). The least straw yield (7.45 t ha^{-1}) was

Table 4.2.2d Effect of seed soaking, foliar spray and stage of application on grain yield (t ha^{-1}), straw yield (t ha^{-1}) and harvest index

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index
Seed soaking			
T_1	5.26	7.45	0.408
T_2	5.55	7.47	0.423
T_3	5.59	8.18	0.412
T_4	5.74	8.37	0.409
$F_{3,6}$	14.03**	76.57**	10.82**
SE_d	0.054	0.055	0.002
CD	0.186	0.189	0.007
Foliar spray			
F_1	5.56	7.39	0.428
F_2	6.14	8.72	0.418
F_3	5.34	7.74	0.399
F_4	6.34	9.23	0.412
F_5	4.32	6.28	0.408
$F_{4,32}$	181.31**	169.71**	9.73**
SE_d	0.059	0.088	0.003
CD	0.169	0.252	0.010
Stage of application			
S_1	5.43	7.61	0.415
S_2	5.65	8.13	0.412
$F_{1,40}$	19.47**	52.21**	NS
SE_d	0.035	0.051	0.002
CD	0.100	0.145	-

** Significant at 1 per cent level
NS Not significant

Seed soaking

T_1 Water soaking
T_2 Soaking in Azospirillum (600 g ha^{-1})
T_3 Soaking in Penshibao (100 ppm)
T_4 Soaking in Azospirillum (600 g ha^{-1}) + Penshibao (100 ppm)

Foliar spray

F_1 Triacontanol (500 ppm)
F_2 GA_3 (5 ppm)
F_3 Kinetin (5 ppm)
F_4 Penshibao (100 ppm)
F_5 Water spray

Stages of application

S_1 Foliar spraying at 20 DAT
S_2 Foliar spraying at 20 DAT and 30 DAT

Table 4.2.2e Interaction effect of seed soaking and foliar spray on grain yield (t ha^{-1}), straw yield (t ha^{-1}) and harvest index

Treatments	Grain yield	Straw yield	Harvest index
T_1F_1	5.35	7.10	0.430
T_1F_2	5.73	7.95	0.417
T_1F_3	5.42	7.36	0.390
T_1F_4	5.97	8.32	0.427
T_1F_5	3.84	6.62	0.377
T_2F_1	5.46	7.00	0.442
T_2F_2	6.44	7.82	0.448
T_2F_3	5.01	7.24	0.395
T_2F_4	6.47	8.89	0.420
T_2F_5	4.38	6.29	0.408
T_3F_1	5.66	7.95	0.405
T_3F_2	6.12	9.21	0.420
T_3F_3	5.56	7.78	0.427
T_3F_4	6.43	9.67	0.402
T_3F_5	4.21	6.28	0.405
T_4F_1	5.76	7.50	0.433
T_4F_2	6.27	9.88	0.387
T_4F_3	5.35	8.55	0.386
T_4F_4	6.49	9.99	0.398
T_4F_5	4.84	5.93	0.443
$F_{12,32}$	3.84**	8.38**	10.71**
SE_d	0.118	0.177	0.007
CD	0.338	0.505	0.019

** Significant at 1 per cent level

Table 4.2.2f Interaction effect of foliar spray and stage of application on grain yield (t ha^{-1}), straw yield (t ha^{-1}) and harvest index

Treatments	Grain yield	Straw yield	Harvest index
F_1S_1	5.54	7.14	0.434
F_1S_2	5.58	7.64	0.421
F_2S_1	5.99	8.41	0.426
F_2S_2	6.29	9.02	0.410
F_3S_1	5.15	7.53	0.386
F_3S_2	5.52	7.94	0.413
F_4S_1	6.21	8.88	0.418
F_4S_2	6.47	9.56	0.406
F_5S_1	4.25	6.09	0.409
F_5S_2	4.38	6.47	0.408
$F_{4,40}$	NS	NS	7.43**
SE_d	0.079	0.113	0.005
CD	-	-	0.013

** Significant at 1 per cent level
NS Not significant

observed with T_1 (control) and was on par with T_2 (Azospirillum). Among the various foliar sprays, F_4 (spraying with Penshibao) recorded the highest straw yield (9.23 t ha^{-1}) followed by F_2 (spraying with GA_3). The lowest straw yield (6.28 t ha^{-1}) was noticed in the control (F_5). Foliar spray at 20 and 30 DAT (S_2) recorded the highest yield (8.13 t ha^{-1}).

Significant interaction between seed soaking and foliar spray was observed. The treatments F_2 and F_4 produced more or less the same results when seeds were soaked in T_1 or T_3 or T_4 except in T_2. Among the interaction effects, the treatment combination T_4F_4 (seed soaking in Azospirillum + Penshibao spraying with Penshibao) recorded numerically the highest straw yield of 9.99 t ha^{-1} and was comparable with T_3F_4 (soaking in Penshibao x spraying with Penshibao) and T_4F_2 (soaking in Azospirillum + Penshibao x spraying with GA_3).

4.2.2.6 Harvest index (Tables 4.2.2d, 4.2.2e and 4.2.2f)

Harvest index (HI) was significantly influenced by seed soaking, foliar spray, time of applications and their interactions.

The treatment T_2 (soaking in Azospirillum) recorded the highest HI (0.423). The lowest HI (0.408) was observed with the control plants and was comparable with the treatment $T_4$and T_3.

Among the foliar sprays, the treatment F_1 (spraying with triacontanol) produced numerically the highest HI (0.428) and was on par with all other treatments. The impact of stage of application was found to be non significant.

Significant interactions between seed soaking and foliar spray was observed. HI was on par at different foliar treatment under T_1 and T_2 (F_1, F_2 and F_4). F_3 was inferior with T_1 and T_2. Under T_3, the foliar spray F_3 performed well which was on par with F_2. The treatment F_2, F_3 and F_4 were on par with T_4 while F_1 was on par with F_5.

Significant interaction was observed between foliar spray and stage of application. With one spray (20 DAT alone) F_1 and F_2 gave higher values for HI, but HI was on par at different levels of F when two sprays are applied. The best treatment combination which produced the highest harvest index were T_2F_2 (soaking in Azospirillum x foliar spray of GA_3), F_2S_2 (seed soaking with Azospirillum at 20 and 30 DAT) and F_1S_1 (foliar spray of triacontanol at 20 DAT alone).

4.2.3 Chlorophyll content

4.2.3.1 Chlorophyll a (Tables 4.2.3a, 4.2.3b and 4.2.3c)

4.2.3.1.1 At tillering stage

At tillering stage, chlorophyll a was significantly influenced by main plot, subplot and sub sub plot treatments and their interactions. The treatment T_4 (seed soaking in Azospirillum + Penshibao) recorded numerically the highest content of chlorophyll a (0.84 mg g^{-1}) and was comparable with the treatment T_3 (spraying with Penshibao) and T_2 (spraying with Azospirillum). Among the foliar sprays, spraying with Penshibao (F_4) registered numerically the highest chlorophyll a (0.80 mg g^{-1}) and was on par with the treatments F_2 (GA_3) and F_3 (Kinetin). Spraying at

Table 4.2.3a Effect of seed soaking, foliar spray and stage of application on Chlorophyll a, Chlorophyll b and Total Chlorophyll (mg g^{-1} fresh weight)

Treatments	Tillering			Flowering		
	Chl. a	Chl. b	Total Chl.	Chl. a	Chl. b	Total Chl.
Seed soaking						
T_1	0.62	0.37	0.99	1.19	0.81	1.99
T_2	0.74	0.38	1.14	1.50	0.95	2.32
T_3	0.81	0.41	1.18	1.41	0.81	2.30
T_4	0.84	0.48	1.31	1.41	0.76	2.25
$F_{3,6}$	7.58*	5.39*	20.16**	1615.09**	12.91**	19.98**
SE_d	0.034	0.021	0.029	0.003	0.023	0.034
CD	0.118	0.074	0.102	0.011	0.08	0.118
Foliar spray						
F_1	0.77	0.42	1.14	1.35	0.81	2.15
F_2	0.79	0.44	1.23	1.59	0.85	2.52
F_3	0.77	0.37	1.16	1.45	0.87	2.22
F_4	0.80	0.47	1.27	1.61	0.99	2.67
F_5	0.63	0.33	0.98	0.89	0.64	1.52
$F_{4,32}$	26.89**	12.11**	22.21**	118.92**	12.45**	200.63**
SE_d	0.013	0.016	0.023	0.027	0.037	0.031
CD	0.038	0.046	0.67	0. 077	0.106	0.089
Stage of application						
S_1	0.73	0.39	1.12	1.38	0.80	2.14
S_2	0.78	0.42	1.19	1.38	0.86	2.29
$F_{1,40}$	43.85**	11.69**	154.81**	NS	7.51**	83.53**
SE_d	0.005	0.005	0.004	0.021	0.016	0.012
CD	0.016	0.013	0.013	-	0.046	0.033

* Significant at 5 per cent level
** Significant at 1 per cent level
NS Not significant

Seed soaking
T_1 Water soaking
T_2 Soaking in Azospirillum (600 g ha^{-1})
T_3 Soaking in Penshibao (100 ppm)
T_4 Soaking in Azospirillum (600 g ha^{-1}) + Penshibao (100 ppm)

Foliar spray
F_1 Triacontanol (500 ppm)
F_2 GA_3 (5 ppm)
F_3 Kinetin (5 ppm)
F_4 Penshibao (100 ppm)
F_5 Water spray

Stages of application
S_1 Foliar spraying at 20 DAT
S_2 Foliar spraying at 20 DAT and 30 DAT

4.2.3b Interaction effect of seed soaking and foliar spray on Chlorophyll a, Chlorophyll b and Total Chlorophyll (mg g^{-1} fresh weight)

Treatments	Tillering			Flowering		
	Chl a	Chl b	Total	Chl a	Chl b	Total
T_1F_1	0.63	0.39	1.03	1.22	0.91	2.10
T_1F_2	0.67	0.42	1.09	1.29	0.79	2.08
T_1F_3	0.64	0.31	0.95	1.30	0.84	2.14
T_1F_4	0.76	0.38	1.13	1.42	0.82	2.24
T_1F_5	0.42	0.34	0.76	0.73	0.67	1.14
T_2F_1	0.77	0.43	1.17	1.36	0.83	2.14
T_2F_2	0.82	0.38	1.22	1.78	0.99	2.78
T_2F_3	0.73	0.37	1.77	1.59	1.07	2.28
T_2F_4	0.84	0.42	1.26	1.74	1.28	2.78
T_2F_5	0.54	0.27	0.89	1.104	0.58	1.63
T_3F_1	0.77	0.36	0.97	1.21	0.78	2.04
T_3F_2	0.79	0.49	1.29	1.57	0.77	2.59
T_3F_3	0.89	0.34	1.23	1.58	0.95	2.44
T_3F_4	0.81	0.51	1.32	1.79	0.88	2.87
T_3F_5	0.76	0.34	1.10	0.92	0.66	1.59
T_4F_1	0.89	0.49	1.38	1.605	0.70	2.32
T_4F_2	0.88	0.45	1.33	1.76	0.85	2.62
T_4F_3	0.83	0.46	1.29	1.34	0.63	2.02
T_4F_4	0.80	0.59	1.37	1.47	1.01	2.81
T_4F_5	0.79	0.38	1.19	0.86	0.63	1.47
$F_{12,32}$	6.98**	2.15*	3.33**	6.37**	2.89**	7.72**
SE_d	0.076	0.032	0.047	0.054	0.74	0.063
CD	0.027	0.091	0.133	0.154	0.212	0.179

* Significant at 5 per cent level

** Significant at 1 per cent level

Table 4.2.3c Interaction effect of foliar spray and stage of application on Chlorophyll a, Chlorophyll b and Total Chlorophyll ($mg\ g^{-1}$ fresh weight)

Treatments	Tillering stage			Flowering stage		
	Chl a	Chl b	Total Chl.	Chl a	Chl b	Total Chl.
F_1S_1	0.74	0.42	1.10	1.36	0.77	2.07
F_1S_2	0.79	0.43	1.17	1.34	0.85	2.23
F_2S_1	0.76	0.42	1.18	1.65	0.78	2.43
F_2S_2	0.82	0.45	1.29	1.55	0.43	2.61
F_3S_1	0.74	0.36	1.12	1.43	0.82	2.11
F_3S_2	0.80	0.39	1.19	1.48	0.92	2.33
F_4S_1	0.78	0.45	1.22	1.56	0.99	2.55
F_4S_2	0.83	0.49	1.31	1.65	1.00	2.79
F_5S_1	0.62	0.34	0.96	0.91	0.65	1.55
F_5S_2	0.64	0.33	1.004	0.87	0.62	1.49
$F_{4,40}$	NS	3.09**	3.78*	NS	NS	11.02**
SE_d	0.012	0.029	0.010	0.048	-	0.020
CD	-	0.010	0.028	-	-	0.074

* Significant at 5 per cent level
** Significant at 1 per cent level
NS Not significant

20 and 30 DAT (S_2) was significantly superior to S_1 (spraying at 20 DAT alone).

Significant interaction between seed soaking and foliar spray was observed. Under T_1 (water soaking) the highest chlorophyll a (0.76 mg g^{-1}) was given by F_4. Under T_2, F_2 and F_4 were the best and on par. Under T_3, F_3 was the best treatment and F_1, F_2 and F_4 were on par. Under T_4, F_1 gave best result, but on par with F_1, F_2 and F_3.

4.2.3.1.2 At flowering stage

At flowering stage, chlorophyll a was increased by the effect of seed soaking, foliar spray, stage of application and their interactions. Seed soaking treatment T_2 (soaking in Azospirillum) registered the highest chlorophyll a (1.50 mg g^{-1}) content. Foliar spray of Penshibao (F_4) recorded numerically the highest (1.61 mg g^{-1}) chlorophyll a and was on par with GA3 (F_2). The effect of stage of application was not significant.

Among the various two factor and three factor interactions, T x F interaction (seed soaking foliar spray) had significant influence on chlorophyll a at the flowering stage. The treatment combination T_3F_4 (soaking in Penshibao and spraying with Penshibao) recorded significantly the highest chlorophyll a content of 1.79 mg g^{-1} fresh weight. The treatment F_4 was the best and was on par with F_2 and F_3 under T_1. The treatment F_2 and F_4 were on par under T_2. F_4 was found to be superior under T_3 while F_2 was superior under T_4.

4.2.3.2 Chlorophyll b (Tables 4.2.3a, 4.2.3b and 4.2.3c)

The effect of seed soaking, foliar spray and stage of application and its interactions significantly influenced the chlorophyll b content.

4.2.3.2.1 At tillering stage

At tillering stage, the treatment T_4 recorded significantly the highest value of chlorophyll b (0.48 mg g^{-1}) and was on par with treatment T_3. Foliar application with Penshibao (F_4) registered numerically the highest content of chlorophyll b (0.47 mg g^{-1}) and was on par with the treatments F_2 and F_1. The treatment S_2 recorded the highest content of chlorophyll b.

The interaction between T and F was significant. Under T_1, all foliar treatments were on par. Under T_2, F_1 to F_4 were on par but F_2 and F_4 gave best results under T_3. Under T_4, F_4 was found to be the best one. The other two factor interaction F x S was also significant. Two sprays resulted in high chlorophyll b. With two sprays F_4 sprayed plants registered high chlorophyll b. Among the interaction effects, the treatment combinations T_4F_4 (0.59 mg g^{-1}) and F_4S_2 (0.49 mg g^{-1}) recorded the highest value.

4.2.3.2.2 At flowering stage

At flowering stage, the content of chlorophyll b was increased significantly and the treatment T_2 (0.95 mg g^{-1}), F_4 (0.99 mg g^{-1}) and S_2 (0.86 mg g^{-1}) recorded the highest chlorophyll b values. The interaction effects of T x F (seed soaking x foliar spray) had significant influence on chlorophyll b. The treatment combinations, T_2F_4 (1.28 mg g^{-1}) was found to have the highest content compared to other treatment combinations. No significant difference in F_1, F_2, F_3 and F_4 was observed under T_1 and T_3. The treatment F_3 and F_4 were the best under T_2 while F_2 and F_4 were the best under T_4.

4.2.3.3 Total chlorophyll content (Tables 4.2.3a, 4.2.3b and 4.2.3c)

Total chlorophyll content was significantly influenced by seed soaking, foliar spray and stage of application.

4.2.3.3.1 At tillering stage

At tillering stage, T_4 (soaking in Azospirillum + Penshibao) recorded the highest chlorophyll content (1.31 mg g^{-1}) and T_1 recorded the least content of 0.99 mg g^{-1}. Among the various foliar sprays, F_4 (spraying with Penshibao) recorded numerically the highest (1.27 mg g^{-1}) chlorophyll content and was on par with F_2 (spraying with GA_3). The lowest chlorophyll content was recorded in the control plots (0.98 mg g^{-1}). Foliar spray at 20 and 30 DAT (S_2) registered significantly higher total chlorophyll content than S_1 (spraying at 20 DAT alone).

At tillering stage, interaction between seed soaking and foliar spray was found to be significant. No significant difference in foliar sprays with F_1, F_2, F_3 and F_4 under T_1 and T_2 and T_4. The treatments F_2 and F_4 were on par with T_3. Significant interaction between F x S was also found. Two sprays gave the best result. The treatment F_4 was found to be the best (1.31 mg g^{-1}) which was on par with F_2 when applied twice.

4.2.3.3.2 At flowering stage

At flowering stage, the total chlorophyll content increased significantly due to the effect of seed soaking, foliar spray and stages of application. The treatment T_2 (Azospirillum) recorded the highest value of chlorophyll (2.32 mg g^{-1}) and was on par with T_3 (soaking in Penshibao) and T_4 (combination). Among the foliar sprays, F_4 (spraying with Penshibao) registered the highest chlorophyll content (2.67 mg g^{-1}). The lowest value was recorded by F_5 (1.52 mg g^{-1}), i.e., control plants. Spraying at 20 and 30 DAT (S_2) was found to be significantly superior to that of spraying at 20 DAT alone (S_1).

Significant interaction was observed between seed soaking and foliar spray. No significant difference was noticed in F_1, F_3 and F_4 under the seed soaking treatments T_1 and T_2. The treatment F_4 gave the best results under T_3 (2.87 mg g^{-1}) and T_4 (2.81 mg g^{-1}). Significant interaction between foliar spray and stages of application was also observed. Plant sprayed twice with F_4 registered the highest total chlorophyll content (2.79 mg g^{-1}). Even with one spray, F_4 was found to be the best. The best treatment combination was F_4S_2.

4.2.4 Nutrient uptake

4.2.4.1 Nitrogen uptake (Tables 4.2.4.1a, 4.2.4.1b and 4.2.4.1c)

Nitrogen (N) uptake by rice plants was significantly influenced by the treatments seed soaking, foliar spray and stage of application individually and in combinations.

4.2.4.1.1 At 20 DAT

At 20 DAT, the data revealed that the treatment T_4 recorded the highest N uptake (52.35 kg ha^{-1}) which was significantly different from others. Among the foliar sprays, foliar application with Penshibao (F_4) registered the highest uptake of N (48.74 kg ha^{-1}). Spraying at 20 and 30 DAT (S_2) recorded the higher N uptake (41.47 kg ha^{-1}) than other treatment and was significantly superior. For all these main effects, the control plot gave the lowest N uptake.

Significant interaction was observed between seed soaking and foliar spray. All the treated plots recorded significantly high N uptake. Under T_1, the treatments F_2, F_3 and F_4 were on par while F_1 was on par with F_5. Under T_2, F_4 sprayed plots registered high N uptake. Under T_3, F_2 and F_4 were on par while under T_4, F_3 and F_4 were on par and superior to others.

4.2.4.1.2 At 40 DAT

At 40 DAT the N uptake was increased and the main effects gave a similar trend as in the 20 DAT.

Significant interaction between seed soaking and foliar spray was observed. All the treated plots registered high N uptake values. Among F_1, F_2, F_3 and F_4, the treatment F_1 gave the lowest values. F_4 treated plots recorded high N uptake under different seed soaking treatments. The foliar spray with F_2 and F_3 were on par under T_1 and T_2 but under T_3 and T_4, F_2 performed better than F_3. Significant interaction was observed

Table 4.2.4.1a Effect of seed soaking, foliar spray and stage of application on N uptake (kg ha^{-1})

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Seed soaking				
T_1	21.40	73.27	74.16	126.07
T_2	41.07	108.15	88.57	152.95
T_3	41.66	116.34	99.13	157.99
T_4	52.34	137.94	103.79	161.90
$F_{3,6}$	171.71**	109.51**	26.55**	49.69**
SE_D	0.984	2.569	2.552	2.297
CD	3.406	8.891	8.831	7.949
Foliar spray				
F_1	34.74	89.51	88.23	141.58
F_2	41.30	129.42	106.22	181.39
F_3	42.07	108.94	83.73	145.43
F_4	48.74	159.33	131.26	196.62
F_5	28.75	57.43	52.52	83.62
$F_{4,32}$	172.15*	182.12**	141.66**	229.53**
SE_D	0.581	2.867	2.465	2.380
CD	1.659	8.183	7.04	8.241
Stage of application				
S_1	36.76	93.90	79.14	134.75
S_2	41.47	123.95	103.68	164.71
$F_{1,40}$	51.01**	157.81**	142.23**	223.31**
SE_d	0.466	1.692	1.455	1.420
CD	1.331	4.835	4.158	4.059

* Significant at 5 per cent level

** Significant at 1 per cent level

Seed soaking

- T_1 Water soaking
- T_2 Soaking in Azospirillum (600 g ha^{-1})
- T_3 Soaking in Penshibao (100 ppm)
- T_4 Soaking in Azospirillum (600 g ha^{-1}) + Penshibao (100 ppm)

Foliar spray

- F_1 Triacontanol (500 ppm)
- F_2 GA_3 (5 ppm)
- F_3 Kinetin (5 ppm)
- F_4 Penshibao (100 ppm)
- F_5 Water spray

Stages of application

- S_1 Foliar spraying at 20 DAT
- S_2 Foliar spraying at 20 DAT and 30 DAT

Table 4.2.4.1b Interaction effect of seed soaking and foliar spray on N uptake (kg ha^{-1})

Treatments	20 DAT	40 DAT	60 DAT	Harvest
T_1F_1	16.31	57.72	62.14	113.79
T_1F_2	26.19	76.92	83.65	152.86
T_1F_3	24.68	78.47	67.87	106.32
T_1F_4	23.99	106.69	104.77	175.96
T_1F_5	15.83	46.57	52.31	81.44
T_2F_1	35.71	92.29	90.39	152.16
T_2F_2	43.02	139.16	78.98	185.88
T_2F_3	42.24	121.48	95.06	155.31
T_2F_4	54.32	156.30	132.61	191.65
T_2F_5	30.04	47.52	45.78	79.75
T_3F_1	40.32	95.82	110.33	172.36
T_3F_2	49.01	153.61	118.99	193.81
T_3F_3	41.19	108.49	89.84	148.92
T_3F_4	48.14	171.84	122.44	182.86
T_3F_5	29.35	51.94	54.07	92.02
T_4F_1	46.60	112.21	70.46	128.05
T_4F_2	46.98	163.98	143.25	193.03
T_4F_3	59.87	127.32	82.17	171.18
T_4F_4	68.48	202.50	165.24	236.02
T_4F_5	39.79	83.69	54.85	81.28
$F_{12,32}$	17.51**	6.25**	13.77**	9.49**
SE_d	1.163	5.735	4.931	5.776
CD	3.318	16.366	14.072	16.483

** Significant at 1 per cent level

Table 4.2.4.1c Interaction effect of foliar spray and stage of application on N uptake (kg ha^{-1})

Treatments	20 DAT	40 DAT	60 DAT	Harvest
F_1S_1	31.90	77.79	70.96	126.29
F_1S_2	37.57	101.03	95.69	156.88
F_2S_1	38.99	111.47	94.09	168.93
F_2S_2	43.61	147.37	118.34	193.85
F_3S_1	40.33	87.94	64.92	123.35
F_3S_2	43.81	129.94	102.55	167.51
F_4S_1	45.60	143.41	120.39	180.19
F_4S_2	51.87	175.25	142.13	213.06
F_5S_1	26.99	48.69	45.35	75.04
F_5S_2	30.51	66.18	59.69	92.21
$F_{4,40}$	NS	3.38*	3.35*	4.95**
SE_d	1.04	3.783	3.253	3.176
CD	-	10.811	9.298	9.076

* Significant at 5 per cent level
** Significant at 1 per cent level
NS Not significant

between foliar spray and stage of application. The treatment F_4 recorded a higher N uptake values under both S_1 and S_2 followed by F_2. The treatment combination T_4F_4 and F_4S_2 recorded the highest N uptake which were significantly different from other combinations.

4.2.4.1.3 At 60 DAT

At 60 DAT, soaking in Azospirillum + Penshibao (T_4) registered a numerically higher N uptake which was on par with T_3 (soaking in Penshibao). Among the other factors, F_4 (spraying with Penshibao) and S_2 (spraying at 20 and 30 DAT) registered the highest N uptake of 131.26 kg ha^{-1} and 103.68 kg ha^{-1} which were significantly the superior one.

Significant interaction between foliar spray and seed soaking was observed. The treatment F_4 registered high N uptake values under all seed soaking treatments. Under T_3, the treatment F_4 was on par with F_2. The control plot gave the lowest values under all seed soakings. Significant interaction between foliar spray and stage of application was also observed. The treatment F_4 was the best while F_1 and F_3 were on par under S_1 and S_2. N uptake was high in F_4 treated plants when two sprayings were given.

4.2.4.1.4 At harvest

At harvest, treatment T_4 registered numerically the highest N uptake (161.91 kg ha^{-1}) which was on par with T_3 (157.99) and was significantly superior to other treatments. Among the various foliar sprays, the treatment F_4 gave the highest N uptake (196.62 kg ha^{-1}).

Spraying at 20 and 30 DAT (S_1) also resulted in a higher N uptake (164.71 kg ha^{-1}).

Significant interaction between foliar spray and seed soaking was observed. Under T_1 and T_4, the highest N uptake was recorded by spraying with Penshibao (175.96 kg ha^{-1} and 236.62 kg ha^{-1}) while under T_2 and T_3 the treatment F_2 was on par with F_4.

Significant interaction between seed soaking and stage of application was also observed. N uptake was not significantly different under F_1 and F_3 which were sprayed once. But N uptake measured from plots receiving two sprays revealed that F_4 recorded a high value followed by F_2. Among the various treatment combinations, T_4F_4 and F_4S_2 recorded the highest N uptake and were significantly superior to all other combinations.

4.2.4.2 Phosphorus uptake (Tables 4.2.4.2a, 4.2.4.2b and 4.2.4.2c)

Phosphorus (P) uptake significantly influenced by the treatments and their combinations.

4.2.4.2.1 At 20 DAT

At 20 DAT, the treatment T_2 (soaking in Azospirillum) recorded the highest P uptake and was on par with T_4 (soaking in Azospirillum + Penshibao) and T_3 (soaking in Penshibao). Among the foliar sprays, F_2 (spraying with GA_3) recorded numerically the highest P uptake and was comparable with F_4 (spraying with Penshibao). The stages of application failed to exert its effect on P uptake.

Table 4.2.4.2a Effect of seed soaking, foliar spray and stage of application on P uptake (kg ha^{-1})

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Seed soaking				
T_1	2.47	5.01	11.67	18.14
T_2	3.52	7.56	14.13	19.96
T_3	3.39	7.68	14.23	20.01
T_4	3.52	10.05	15.34	19.19
$F_{3,6}$	51.95**	252.97**	71.96**	5.01*
SE_d	0.07	0.129	0.182	0.392
CD	0.243	0.448	0.63	1.357
Foliar spray				
F_1	3.17	7.52	13.48	19.27
F_2	3.44	7.26	14.09	20.34
F_3	3.18	7.49	13.82	18.98
F_4	3.27	8.02	13.90	21.03
F_5	3.06	7.58	13.93	17.01
$F_{4,32}$	4.49**	4.14**	NS	7.51
SE_d	0.066	0.139	0.205	0.560
CD	0.189	0.396	-	1.599
Stage of application				
S_1	3.24	7.63	13.87	18.54
S_2	3.20	7.52	13.81	20.11
$F_{1,40}$	NS	NS	NS	19.70**
SE_d	0.033	0.110	0.129	0.249
CD	-	-	-	0.713

* Significant at 5 per cent level
** Significant at 1 per cent level
NS Not significant

Seed soaking

- T_1 Water soaking
- T_2 Soaking in Azospirillum (600 g ha^{-1})
- T_3 Soaking in Penshibao (100 ppm)
- T_4 Soaking in Azospirillum (600 g ha^{-1}) + Penshibao (100 ppm)

Foliar spray

- F_1 Triacontanol (500 ppm)
- F_2 GA_3 (5 ppm)
- F_3 Kinetin (5 ppm)
- F_4 Penshibao (100 ppm)
- F_5 Water spray

Stages of application

- S_1 Foliar spraying at 20 DAT
- S_2 Foliar spraying at 20 DAT and 30 DAT

Table 4.2.4.2b Interaction effect of seed soaking and foliar spray on P uptake ($kg\ ha^{-1}$)

Treatments	20 DAT	40 DAT	60 DAT	Harvest
T_1F_1	2.29	4.79	11.67	19.56
T_1F_2	2.82	4.67	11.39	17.70
T_1F_3	2.37	5.06	11.84	17.09
T_1F_4	2.59	5.19	11.62	19.89
T_1F_5	2.28	5.33	11.88	16.44
T_2F_1	3.39	7.65	13.59	18.96
T_2F_2	3.65	7.08	14.95	22.57
T_2F_3	3.50	7.51	13.67	19.69
T_2F_4	3.44	8.32	13.97	21.77
T_2F_5	3.62	7.23	14.49	16.82
T_3F_1	3.45	7.91	13.91	19.34
T_3F_2	3.60	7.36	14.33	19.52
T_3F_3	3.22	7.78	14.14	20.59
T_3F_4	3.48	7.61	14.33	22.66
T_3F_5	3.19	7.72	14.45	17.96
T_4F_1	3.55	9.71	14.75	19.22
T_4F_2	3.69	9.92	15.73	21.57
T_4F_3	3.61	9.59	15.62	18.54
T_4F_4	3.55	10.99	15.69	19.82
T_4F_5	3.17	10.04	14.91	16.82
$F_{12,32}$	NS	N.S	NS	NS
SE_d	0.132	0.277	0.410	1.121
CD	-	-	-	-

NS Not significant

Table 4.2.4.2c Interaction effect of foliar spray and stage of application on P uptake (kg ha^{-1})

Treatments	20 DAT	40 DAT	60 DAT	Harvest
F_1S_1	3.11	7.59	13.57	18.75
F_1S_2	3.24	7.44	13.38	19.79
F_2S_1	3.49	7.63	13.89	19.32
F_2S_2	3.39	6.88	14.30	21.36
F_3S_1	3.08	7.35	14.22	18.46
F_3S_2	3.27	7.63	13.42	19.49
F_4S_1	3.27	7.95	13.75	19.14
F_4S_2	3.26	8.14	14.06	22.93
F_5S_1	3.25	7.64	13.93	17.05
F_5S_2	2.88	7.52	13.93	16.97
$F_{4,40}$	4.40**	NS	NS	3.39*
SE_d	0.075	0.246	0.288	0.558
CD	0.213	-	-	1.594

* Significant at 5 per cent level
** Significant at 1 per cent level
NS Not significant

Among the interactions, F x S interaction (foliar spray and stage of application) was found to be significant and F_2 (foliar spray of GA_3) recorded the highest uptake of P under S_1. No significant difference in F_1, F_2, F_3 and F_4 under S_2.

4.2.4.2.2 At 40 DAT

At 40 DAT, the treatment T_4 (soaking in Azospirillum + Penshibao) registered highest P uptake. Among the foliar sprays, spraying with Penshibao (F_4) recorded numerically the highest P uptake which was on par with all other foliar treatments except F_2. The treatment S (stages of applications) and all interactions failed to show any influence on P uptake.

4.2.4.2.3 At 60 DAT

At 60 DAT, the seed soaking treatments followed same trend as in the 40 DAT. The other treatments and interactions were found to be non-significant at this stage.

4.2.4.2.4 At harvest

At harvest stage, T_3 (soaking in Penshibao) recorded the highest P uptake and was on par with T_2 (soaking in Azospirillum) and T_4 (soaking in Azospirillum + Penshibao). Among the foliar sprays, F_4 (spraying with Penshibao) registered the highest P uptake and was on par with the treatments F_2 and F_1 (spraying with GA_3 and triacontanol). The impact of stage of application was also significant and S_2 was superior (spraying at 20 and 30 DAT) to S_1 (spraying at 20 DAT alone).

Significant interaction between foliar spray and stage of application was observed. No significant difference in P uptake values under F_1, F_2, F_3 and F_4 with S_1. Under S_2, F_4 sprayed plots registered higher values in comparison with F_1 and F_3.

4.2.4.3 Potassium uptake (Tables 4.2.4.3a, 4.2.4.3b and 4.2.4.3c)

Potassium (K) uptake was also significantly influenced by all the treatments and their combinations.

4.2.4.3.1 At 20 DAT

At 20 DAT, the treatment T_4 recorded the highest K uptake of 28.11 kg ha^{-1} which was followed by T_3 and was on par with T_2. The lowest K uptake (12.59 kg ha^{-1}) was recorded by T_1. Among the foliar sprays, the highest K uptake (24.22 kg ha^{-1}) was registered by F_4 (Penshibao) and was on par with F_3 (kinetin). The control plot recorded the lowest K uptake of 18.18 kg ha^{-1}. Spraying at 20 and 30 DAT (S_2) recorded the highest K uptake of 22.53 kg ha^{-1} over S_1.

Significant interaction between seed soaking and foliar spray was observed. Under T_1, F_2 and F_3 were on par and registered high values than F_1 and F_4. At T_2, F_1, F_2 and F_3 were on par. Under T_3, F_2, F_3 and F_4 were on par. All the treated plots registered high values compared to control. Under T_2 and T_4, F_4 treated plots recorded high values and under T_4, F_4 was on par with F_3. The treatment combination T_4F_3 gave the highest value of K uptake and was significantly superior to other combinations.

Table 4.2.4.3a Effect of seed soaking, foliar spray and stage of application on K uptake (kg ha^{-1})

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Seed soaking				
T_1	12.59	55.68	66.77	121.62
T_2	22.62	67.44	82.65	149.37
T_3	23.18	72.51	85.49	146.20
T_4	28.11	81.40	99.08	169.16
$F_{3,6}$	242.35**	107.35**	302.73**	76.19**
SE_d	0.418	1.036	0.702	2.234
CD	1.446	3.586	2.638	7.732
Foliar spray				
F_1	20.04	60.57	75.99	135.55
F_2	22.37	82.51	95.14	165.54
F_3	23.34	64.61	77.08	147.20
F_4	24.22	94.05	114.75	185.65
F_5	18.18	44.54	54.54	98.99
$F_{4, 32}$	51.19**	322.33**	367.28**	287.66**
SE_d	0.347	1.078	1.181	1.927
CD	0.990	3.077	3.37	5.499
Stage of application				
S_1	20.72	62.16	73.61	133.02
S_2	22.53	76.36	93.39	160.16
$F_{1,40}$	22.59**	434.76**	845.61**	359.89**
SE_d	0.270	0.481	0.481	1.012
CD	0.770	1.376	1.374	2.892

** Significant at 1 per cent level

Seed soaking

T_1 Water soaking
T_2 Soaking in Azospirillum (600 g ha^{-1})
T_3 Soaking in Penshibao (100 ppm)
T_4 Soaking in Azospirillum (600 g ha^{-1}) + Penshibao (100 ppm)

Foliar spray

F_1 Triacontanol (500 ppm)
F_2 GA_3 (5 ppm)
F_3 Kinetin (5 ppm)
F_4 Penshibao (100 ppm)
F_5 Water spray

Stages of application

S_1 Foliar spraying at 20 DAT
S_2 Foliar spraying at 20 DAT and 30 DAT

Table 4.2.4.3b Interaction effect of seed soaking and foliar spray on K uptake (kg ha^{-1})

Treatments	20 DAT	40 DAT	60 DAT	Harvest
T_1F_1	10.93	51.99	66.36	116.56
T_1F_2	15.33	60.28	71.69	144.56
T_1F_3	13.81	58.04	66.33	109.79
T_1F_4	12.83	69.58	82.52	141.20
T_1F_5	10.10	38.49	46.93	95.98
T_2F_1	22.94	61.22	77.29	136.21
T_2F_2	21.85	78.45	90.88	178.13
T_2F_3	22.69	66.64	83.18	140.85
T_2F_4	26.35	92.86	113.89	198.66
T_2F_5	19.25	38.04	48.02	92.99
T_3F_1	21.28	61.65	79.22	131.54
T_3F_2	24.19	85.02	97.49	160.58
T_3F_3	23.84	68.02	81.59	148.53
T_3F_4	25.42	97.18	108.94	186.48
T_3F_5	21.19	50.66	66.24	103.86
T_4F_1	25.00	67.41	81.08	157.89
T_4F_2	28.09	106.32	120.49	178.91
T_4F_3	33.01	65.74	77.22	189.64
T_4F_4	32.28	116.59	153.67	216.23
T_4F_5	22.17	50.95	62.95	103.12
$F_{12,32}$	7.96*	14.57**	25.01**	13.38**
SE	0.694	2.157	2.362	3.854
CD	1.980	6.155	6.741	10.999

* Significant at 5 per cent level
** Significant at 1 per cent level

Table 4.2.4.3c Interaction effect of foliar spray and stage of application on K uptake (kg ha^{-1})

Treatments	20 DAT	40 DAT	60 DAT	Harvest
F_1S_1	18.95	53.59	65.39	121.79
F_1S_2	21.13	67.56	86.58	149.31
F_2S_1	21.17	73.45	82.35	150.05
F_2S_2	23.56	91.58	107.94	181.04
F_3S_1	22.89	54.97	65.45	134.60
F_3S_2	23.79	74.26	88.70	159.8
F_4S_1	22.68	87.74	103.85	168.61
F_4S_2	25.75	100.37	125.66	202.69
F_5S_1	17.90	41.05	51.03	90.01
F_5S_2	18.45	48.03	58.04	107.97
$F_{4,40}$	NS	10.34**	23.26**	3.69*
SE_d	0.603	1.071	1.075	2.263
CD	-	3.077	3.072	6.467

* Significant at 5 per cent level
** Significant at 1 per cent level
NS Not significant

4.2.4.3.2 At 40 DAT

At 40 DAT, among the various treatments T_4, F_4 and S_2 recorded the highest K uptake (81.40 kg ha^{-1}, 94.05 kg ha^{-1} and 76.36 kg ha^{-1} respectively) and were significantly superior to other treatments. Control plot recorded the lowest K uptake for seed soaking and foliar spray treatments.

Significant interaction was observed between seed soaking and foliar sprays. The treatment F_4 registered high values under all seed soaking treatments followed F_2. The results on F x S interaction had shown that it was significantly different. Under S_1, the treatments F_1 and F_3 were on par and inferior to F_4 and F_2. Under both S_1 and S_2, F_4 plots registered higher values. The treatment combinations T_4F_4 and F_4S_2 recorded the highest K uptake.

4.2.4.3.3 At 60 DAT

The treatments T_4 (99.08 kg ha^{-1}), F_4 (114.75 kg ha^{-1}) and S_2 (93.39 kg ha^{-1}) recorded the highest values of K uptake and were significantly superior to other treatments.

Significant interaction between seed soaking and foliar spray was seen. Under all seed soaking treatments F_4 plots registered high values, followed by F_2. The treatments F_1 and F_3 were on par under T_2, T_3 and T_4. Significant interaction between F x S was also observed. Under both S_1 and S_2, F_4 registered high values followed by F_2 and the treatments F_1

and F_3 were on par. The treatment combinations, T_4F_4 and F_4S_2 recorded the highest K uptake.

4.2.4.3.4 At harvest

The treatments T_4 (169.16 kg ha^{-1}), F_4 (185.65 kg ha^{-1}) and S_2 (160.16 kg ha^{-1}) recorded the highest K uptake at harvest in main plot, sub plot and sub sub plot respectively.

There was significant interaction between seed soaking and foliar spray at harvest. Under all seed soaking methods, F_4 treated plots registered high values followed by the treatment F_2. The treatments F_1 and F_3 were on par. The interaction between F x S was significant. Even with one or two sprays, F_4 recorded high values followed by F_2.

4.2.5 Soil analysis

Main effects of treatment and their interactions had no significant influence on available nitrogen (N), available phosphorus (P_2O_5) and available potassium (K_2O).

4.2.6 Economic analysis

4.2.6.1 Benefit cost ratio (Tables 4.2.5.1a, 4.2.5.1b and 4.2.5.1c)

Benefit cost ratio (BCR) was significantly influenced by main plot, sub plot and sub sub plot treatments and their interactions. Soaking in Azospirillum and Penshibao (T_4) recorded numerically the highest BCR (1.16) and was comparable with the treatment T_3 (1.14). The lowest BCR (1.07) was recorded with the control plot. However, it was comparable

Table 4.2.5.1a Effect of seed soaking, foliar spray and stage of application on BCR

Treatments	B.C. ratio
Seed soaking	
T_1	1.07
T_2	1.08
T_3	1.14
T_4	1.16
$F_{3,6}$	57.76**
SE_d	0.02
CD	0.02
Foliar spray	
F_1	1.12
F_2	1.24
F_3	1.01
F_4	1.29
F_5	0.90
$F_{4,32}$	222.58**
SE_d	0.011
CD	0.03
Stage of application	
S_1	1.09
S_2	1.13
$F_{1,40}$	24.20**
SE_d	0.006
CD	0.017

** Significant at 1 per cent level

Seed soaking

T_1 Water soaking
T_2 Soaking in Azospirillum (600 g ha^{-1})
T_3 Soaking in Penshibao (100 ppm)
T_4 Soaking in Azospirillum (600 g ha^{-1}) + Penshibao (100 ppm)

Foliar spray

F_1 Triacontanol (500 ppm)
F_2 GA_3 (5 ppm)
F_3 Kinetin (5 ppm)
F_4 Penshibao (100 ppm)
F_5 Water spray

Stages of application

S_1 Foliar spraying at 20 DAT
S_2 Foliar spraying at 20 DAT and 30 DAT

Table 4.2.5.1b Effect of seed soaking and foliar application on BCR

Treatments	20 DAT
T_1F_1	1.06
T_1F_2	1.19
T_1F_3	1.06
T_1F_4	1.21
T_1F_5	0.84
T_2F_1	1.10
T_2F_2	1.18
T_2F_3	0.93
T_2F_4	1.26
T_2F_5	0.91
T_3F_1	1.16
T_3F_2	1.28
T_3F_3	1.03
T_3F_4	1.33
T_3F_5	0.89
T_4F_1	1.17
T_4F_2	1.31
T_4F_3	1.03
T_4F_4	1.34
T_4F_5	0.95
$F_{12,32}$	3.34**
SE_d	0.021
CD	0.061

** Significant at 1 per cent level

Table 4.2.5.1c Interaction effects of foliar spray and stage of application on BCR

Treatments	BCR
F_1S_1	1.11
F_1S_2	1.13
F_2S_1	1.18
F_2S_2	1.29
F_3S_1	1.02
F_3S_2	1.01
F_4S_1	1.27
F_4S_2	1.30
F_5S_1	0.88
F_5S_2	0.92
$F_{4,40}$	6.64**
SE_d	0.013
CD	0.037

with soaking in Azospirillum (T_2). Among the foliar sprays, the treatment F_4 recorded the highest BCR (1.29) and was significantly superior to all the treatments. The lowest BCR was observed with control plots (F_5). Foliar spray at 20 and 30 DAT (S_2) was found to be significantly superior to foliar spray at 20 DAT alone.

Significant interaction between seed soaking and foliar application was observed. Under T_1, T_3 and T_4 the treatment F_4 registered high BC ratio and was on par with F_2. Under T_2 soaking F_4 was found to be best while F_3 was on par with F_5. Under all seed soaking method, F_5 recorded the least BCR. Significant interaction between foliar spray and stages of application was also seen. Even with one or two sprays, F_4 recorded high values followed by F_2. But under S_2, F_4 was on par with F_2. Among the T x F treatment combinations, T_4F_4, T_3F_4, T_4F_2 and T_3F_2 were superior to other combination and were on par. Among the F x S treatment combinations, F_4S_2 and F_4S_1 gave highest BCR and were on par.

Discussion

5. DISCUSSION

A field experiment was conducted during Rabi 2000 to study the effect of seed soaking and foliar application of growth regulators on rice. A critical analysis of the result of the experiment revealed a marked response of the crop to various treatments which are discussed below.

5.1 Nursery studies

5.1.1 Germination and seedling characters

The results clearly revealed that seed soaking treatments like use of Azospirillum and Penshibao alone and in combination significantly improved the germination percentage, seedling shoot length, vigour index, speed of germination and root biomass. Seed treatment with Azospirillum increased the amylase activity during germination. Production of gibberellins by Azospirillum and its subsequent hydrolysis result in enhanced seedling vigour, shoot length, dry weight and speed of germination (Ramamoorthy *et al.*, 2000). Similar results were also reported by Rao (1981), Okon (1985), Boddey and Doberener (1988), Sahu *et al.* (1997), Natarajan and Kuppaswamy (1998) and Pradhan *et al.* (1998).

Seed treatment with Penshibao had a significant impact on seed germination and other nursery characters. Penshibao contains micronutrients like Zn, B, Mo, Mn and this might have increased the enzyme activity. The essentiality of zinc in metabolic activities viz., enzymatic activities, RNA and ribosome functions has already been established (Lindsay, 1974).

Kalyanasundaram (1999) also observed an increase in germination percentage of rice by seed treatment with Penshibao. Individual as well as the additive effect of Penshibao and Azospirillum were comparable. Remarkable increase in growth characters by combined seed soaking was also reported by Babu (1998) and Elankavi (1999).

5.2 Main field studies

Result of the study conducted to evaluate the influence of seed soaking, foliar spray and stage of application of growth regulators in rice revealed a positive influence of these treatments on growth and yield of rice. The significant influences are discussed below.

5.2.1 Effect of seed soaking (Fig. 4, 5, 6 and 7)

Seed soaking methods had a significant effect on growth characters of rice. At all stages of growth, except at 20 DAT T_4 (Azospirillum + Penshibao) recorded the highest plant height and tiller number. At harvest T_4 was comparable with T_3. In the case of DMP (Fig. 4) also T_4 was the best treatment (1136.74 g m^{-2}) at harvest and it was comparable with T_3 (Penshibao) and T_2 (Azospirillum). The positive influence of Azospirillum in enhancing plant height and tiller number in cereals and

Fig. 4 Effect of seed soaking (T), foliar spray (F) and stages of *application* (S) on DMP at harvest ($g\ m^{-2}$)

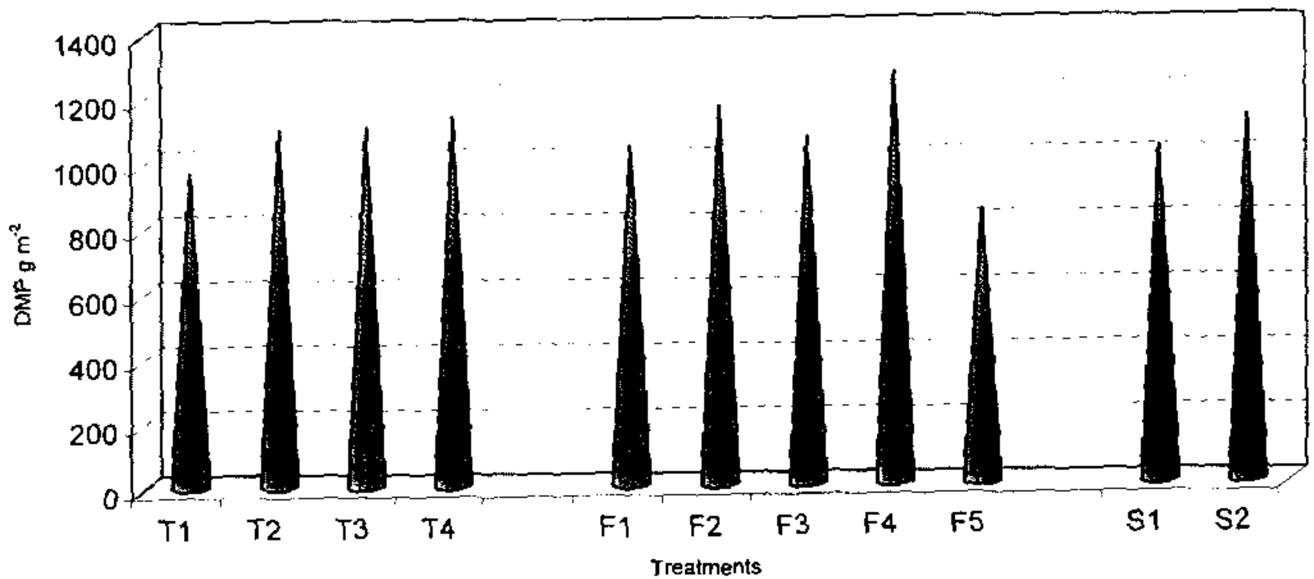
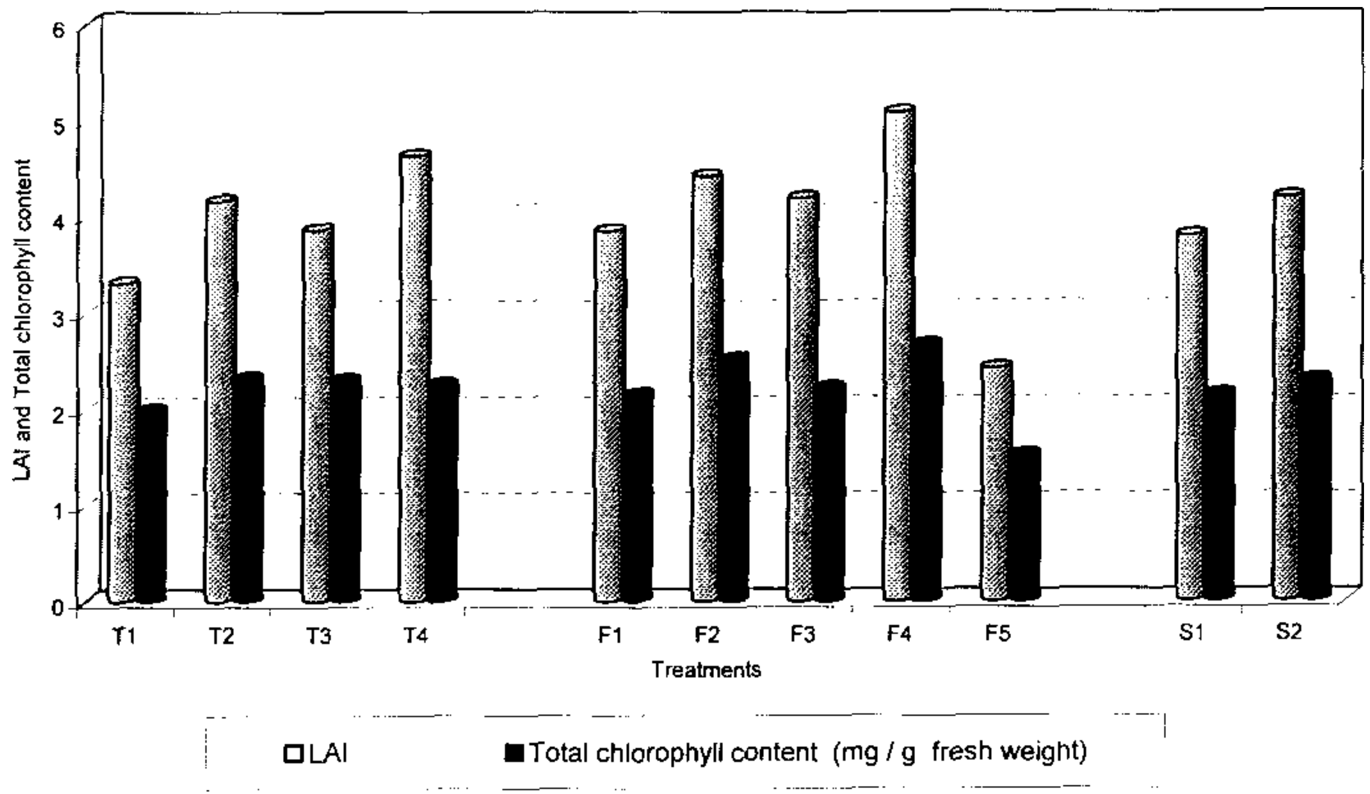


Fig. 5 Effect of seed soaking (T), foliar spray (F) and stages of application (S) on LAI and total chlorophyll (mg g^{-1} fresh weight) at flowering stage



non cereals was earlier reported by Okon (1985), Sahu *et al.* (1997) and Pradhan *et al.* (1998). Shivraj (1981) and Karthikeyan (1981) observed an increase in DMP of rice by Azospirillum inoculation.

The presence of Zn, B and other micronutrients in Penshibao might have satisfied the micronutrient need of rice which might have helped in improving the growth characters like plant height, tiller number and DMP. The favourable influence of seed soaking wtih Zn on growth characters of rice was earlier reported by Gukoua *et al.* (1985) and Baskar (1986) (Plant height). Srinivasan, (1984), Ilangovan and Palaniyappan (1987) (DMP). Azospirillum seed inoculation enhanced the root biomass production (evident from nursery studies). These influences in turn improved the nutrient uptake values (Table 4.2.4.1a, 4.2.4.2 a and 4.2.4.3a). Moreover, N fixed by the Azospirillum also might have favourably influenced on the growth parameters of rice. Similar improvements on tiller numbers and plant height was earlier reported by Okon *et al.* (1985) and Boddey and Doberener (1998).

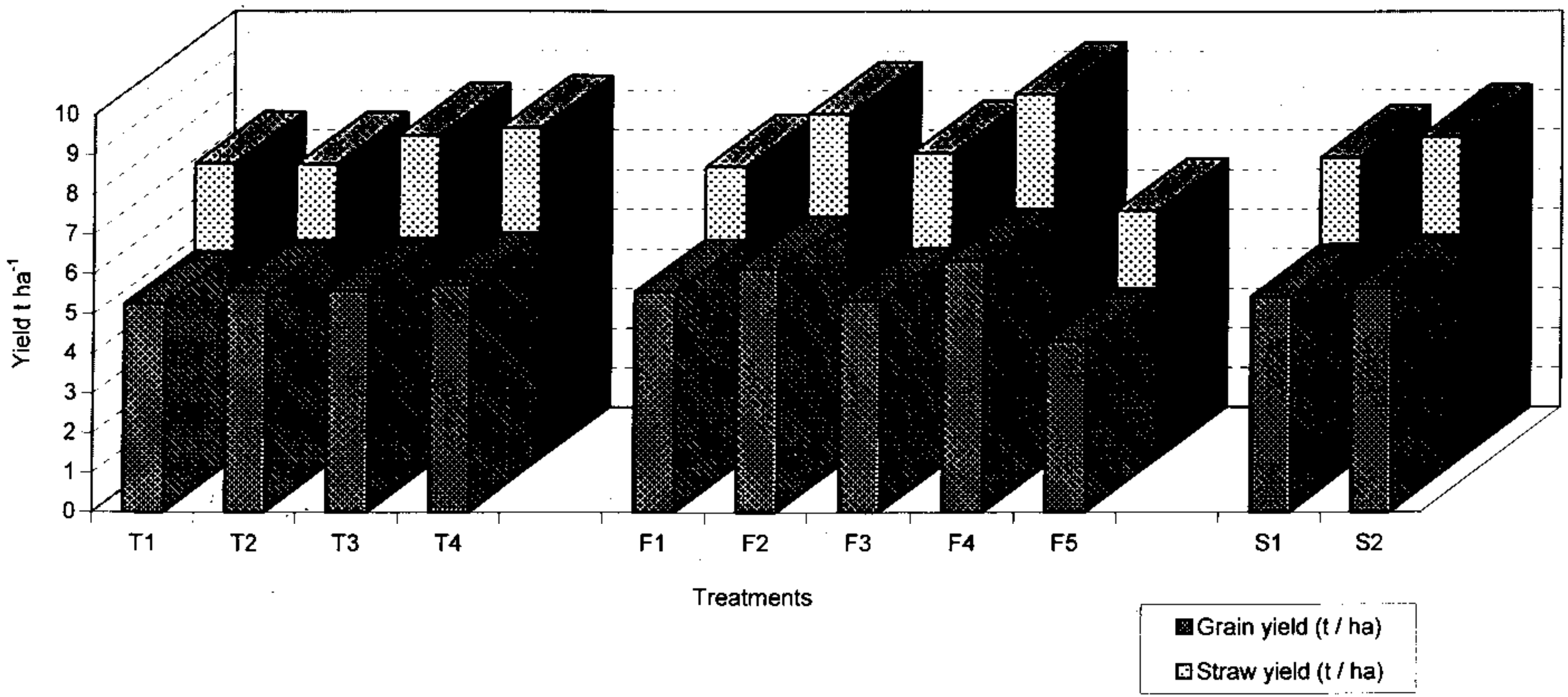
At all stages of growth, T_4 recorded its superiority on growth characters. The complementary effect of Penshibao and Azospirillum had resulted in a favourable response on growth characters as evident from Table (4.2.1.1a, 4.2.1.2a and 4.2.1.3a). This was in agreement with the findings of Babu (1998) who also observed an increase in plant height, tiller number and DMP by seed soaking with Azospirillum, Penshibao and

Phosphobacteria. Ilangovan and Palaniyappan (1987) and Elankavi (1999) also observed similar results.

In general the yield attributing characters were positively influenced by seed soaking treatments. Use of Penshibao or Azospirillum for seed soaking recorded the higher number of panicle m^{-2} whereas, the combined application of these two gave a significant improvement in filled grain percentage. The influence of Azospirillum in promoting tillering led to an increase in panicle number per unit area. So also seed soaking in Penshibao - a multi functional foliar liquid with different organic and inorganic compounds led to an increase in tiller count and subsequently the panicle number m^{-2}. The favourable influence of Penshibao in enhancing the panicle count per m^{-2} was also reported by Babu (1998). The complementary effect of Penshibao + Azospirillum combination in enhancing the filled grain percentage might be attributed to the complementary action of Penshibao and Azospirillum.

The grain yield presented in Table 4.2.2d and Fig. 6 clearly indicated that seed soaking treatments significantly improved both grain and straw yields. Soaking rice seeds in Penshibao-Azospirillum combination recorded the highest grain yield (5.74 t ha^{-1}). The improvement in plant growth by seed soaking with Penshibao and Azospirillum as evident from growth characters, growth analysis parameters like LAI, LAD and Chlorophyll content at tillering stage (Table 4.2.1.4a, 4.2.1.6a and 4.2.3a) must have helped in yield

Fig. 6 Effect of seed soaking (T), foliar spray (F) and stages of application (S) on grain and straw yield of rice (t ha^{-1})

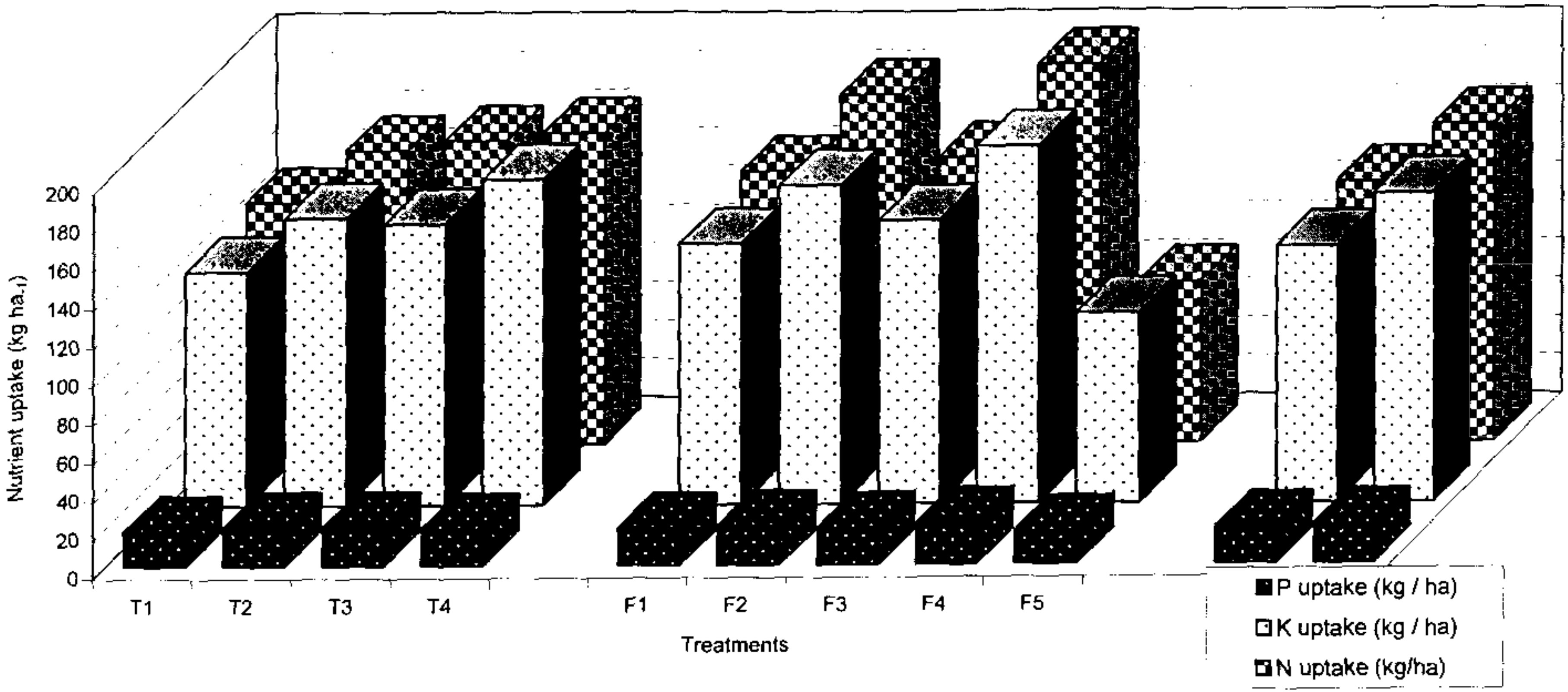


improvement. The nutrient uptake by the crop was also higher in this treatment (Table 4.2.4a, 4.2.4b and 4.2.4c) which in turn had stimulated the crop growth and filled grain percentage. An yield increase of 9.13 per cent over control was observed by seed soaking with Penshibao and Azospirillum. All seed soaking methods were superior to control and the increase is in the tune of 5.51 per cent (Azospirillum), 6.27 per cent (Penshibao) and 9.13 per cent (Azospirillum + Penshibao). Babu (1998) and Elankavi (1999) reported that seed soaking with Azospirillum + Penshibao increased the yield by improving the yield attributes. Kalyanasundaram (1999) also reported similar results.

In the case of straw yield (Fig. 6) also the treatment T_4 recorded the highest yield and was on par with T_3. Seed soaking in Penshibao alone or with Azospirillum increased the plant height and tiller number (Table 4.2.1.1a and 4.2.1.2a). The data presented in Tables 4.2.4.1a, 4.2.4.2a and 4.2.4.3a also showed an improvement in N, P and K uptake by seed soaking which enhanced the growth characters and straw yield.

The result of uptake studies revealed (Tables 4.2.4.1a, 4.2.4.2a, 4.2.4.3a and Fig. 7) that N, P and K uptake was significantly influenced by different seed soaking methods. All seed soaking methods improved the nutrient uptake which had a reflection on grain and straw yield of rice. In general combined use of Azospirillum and Penshibao for seed soaking enhanced the N, P and K uptake by different stages. Better uptake of nutrients by soaking rice seeds in Azospirillum was due to its capacity to

Fig. 7 Effect of seed soaking (T), foliar spray (F) and stages of application (S) on nutrient uptake at harvest (kg ha^{-1})



fix atmospheric N and also to absorb more nutrients due to better root biomass production (Rao, 1981). Penshibao contain major nutrients like N, P and K and use of this for seed soaking might have helped in increasing the content of major nutrients in plants. Combined application of these two had a complementary effect on the uptake of nutrient by rice (Babu, 1998).

5.2.2 Effect of foliar spray (Fig. 4, 5, 6 and 7)

Foliar application of growth regulators resulted in an improvement in growth characters.

In general, foliar spray with Penshibao (F_4) registered the highest value for all characters. However at 60 DAT, F_2 (spraying of GA_3) was observed to be comparable with Penshibao application (F_4). In the case of tiller number also F_4 was comparable with F_2 at all stages except at harvest. Several workers observed the significance of foliar application of Zn on DMP of rice (Balakrishnan *et al.*, 1985 and Chatterjee *et al.*, 1976). Panda and Nayak (1974) reported an increase in plant height in rice var. Jaya which was due to the increased levels of $ZnSO_4$ through both soil and foliage. The favourable effect of Penshibao foliar spray in improving the growth characters of rice could be attributed to the positive influence of Zn and other micronutrients present in the multifunctional foliar liquid.

At 40 and 60 DAT, application of GA_3 was found to be on par with Penshibao application for most of the growth characters especially plant height. Application of GA_3 was next to Penshibao application in improving growth characters. This might be due to the enhanced cell elongation and growth of second leaf sheath by the capacity of GA_3 to increase the cell wall extensibility (Matsukura *et al.*, 1998) and increased growth was also due to more mobilization of photosynthates from source to sink (Singh, 1996). Thirthalinguppa and Reddy (1999) also reported about the growth increase in rice by GA_3 application.

Results of the study clearly revealed that foliar application of growth regulators and Penshibao exerted a positive influence on the yield attributing characters and yield. Penshibao recorded the highest number of panicle m^{-2}, filled grain percentage and test weight followed by GA_3. Foliar application of growth regulators in general led to a significant improvement on yield attributing characters and yield. The influence of Penshibao and other growth regulators in promoting the tiller number, LAD, LAI (Fig. 5), CGR, RGR and NAR led to an increased filling of grain and yield. This was earlier reported by many workers (Paraye *et al.*, 1995 and Ponnuswamy *et al.*, 1998). Penshibao and other growth regulators increased the chlorophyll content (Fig. 5) at tillering and flowering stages (Table 4.2.3a) compared to water spray (control). This increased the photosynthetic rate of the plant which in turn increased the translocation of photosynthates from source to sink and resulting in an improvement in filled grain percentage and 1000 seed weight. Similar observations were already made by Debata and Murthy (1981), Ramamoorthy *et al.* (1990) and Singh *et al.* (1992). The effect of Penshibao on the yield attributes was mainly due to the presence of organic and inorganic nutrients which increased the growth characters which in turn increase various yield attributing characters (Elankavi, 1999).

The grain yield presented in Table 4.2.2d and Fig. 6 indicated that foliar application significantly improved the grain and straw yield. Penshibao recorded the highest grain yield, followed by GA_3. All growth regulators increased the grain and straw yield over control. Foliar application of Penshibao enhanced the physiological parameters like LAI (Fig. 5), LAD and chlorophyll content (Fig. 5) i.e., improvement in source. When the LAI and LAD were increased, the total photosynthates produced also increased. It helped the plant to produce and translocate more photosynthates to sink which resulted in an improvement in yield attributing characters and yield. This was earlier reported by Singh (1996). The NPK uptake (Table 4.2.4.1a, 4.2.4.2a, 4.2.4.3a and Fig. 8) was also maximum in growth regulators applied plot compared to control. An yield increase of 46.76 per cent over control was observed by foliar spray with Penshibao. All foliar sprays were superior to control and yield increase is in the tune of 28.84 per cent (F_1), 42.13 per cent (F_2) and 23.61 per cent (F_3). The nutrient uptake and subsequent yield increase in rice by foliar application with Penshibao and growth regulators was studied by Dashora and Jain (1994), Aldesuquy (1998), Elankavi (1999) and Bull *et* *al*. (2000). The yield improvement by the application of growth regulators like GA_3, kinetin and triacontanol was also due to the above factors which was explained by Katayama and Akita (1989), Baruah (1990) and Singh (1996).

Foliar spraying of Penshibao recorded the highest straw yield (Fig. 6) followed by GA_3. Both growth regulators were superior to water spray. The improvement brought about by foliar application of growth regulators was to the tune of 17.68 per cent for triacontanol, 30.85 per cent for GA_3, 23.25 per cent for kinetin and 46.82 per cent for Penshibao. This might be due to the increased growth characters like plant height, tiller number and DMP.

5.2.3 Effect of stages of application (Fig. 4, 5, 6 and 7)

Foliar application of growth regulators and Penshibao at various stages gave a positive response on growth characters (height, tiller number and DMP), yield attributing characters, yield and nutrient uptake of rice. Improvement in rice growth characters by the application of growth regulators at 20 DAT was reported by Chatterjee *et al*. (1976). Biswas and Choudari (1981) observed that foliar spray of growth regulators applied at the vegetative stage of rice increased the chlorophyll content and thus photosynthetic efficiency which led to more filling of grains. This was in agreement with the result of present study.

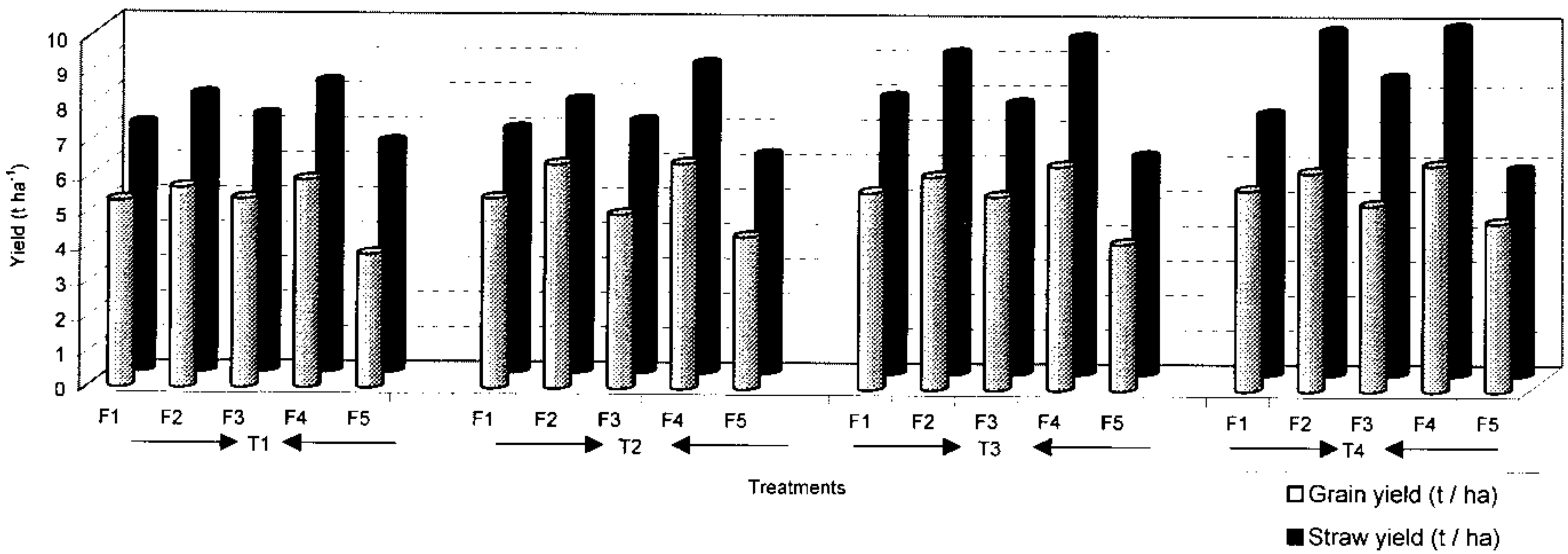
Application twice at 20 and 30 DAT was found to be superior to single application at 20 DAT alone. This might be due to the additive effect and increased availability of growth promoters at critical stages. Application at two stages increased the chlorophyll content, LAI (Fig. 5), LAD and other growth analysis parameters (NAR, RGR and CGR) and the subsequent maintenance of high chlorophyll content and leaf area for a longer period which in turn might have enhanced the longevity of flag leaf and thus the rate of photosynthesis and translocation (Thangaraj and Sivasubramaniyan, 1992; Debata and Murthy, 1981). Application at two times enhanced the yield (Fig. 6) significantly compared to application at one single stage. This enhancement could be attributed to the enhanced growth characters like LAI, LAD (growth analysis parameters) and nutrient uptake of plants receiving foliar sprays at two growth stages.

5.3 Interaction effects (Fig. 8)

A critical review of the interaction effects revealed that the interaction between seed soaking and foliar spray (T x F) foliar spray and stage of application (F x S) and seed soaking and stage of application (T x S) showed a positive influence on growth characters, yield and yield attributes. These are discussed below.

In general, soaking of rice seeds in Azospirillum-Penshibao (T_4) combination and spraying plants with Penshibao (F_4) was found superior to other combination in DMP and tiller number at harvest. Though T_4F_2

Fig. 8 Interaction effect of seed soaking (T) and foliar spray (F) on grain and straw yield (t ha^{-1})



recorded the highest value for plant height (119.77 cm) at harvest, it was comparable with T_3F_2, T_3F_4 and T_4F_4. The interaction between foliar spray and stages of application was also significant. Foliar application of Penshibao at two stages (F_4S_2) recorded the highest value for tiller count (634.6) and DMP (1294.45 g m^{-2}) at harvest stages.

Review of results (Table 4.2.1.1b, 4.2.1.2b and 4.2.1.3b) revealed that the combined effect of seed soaking and foliar spray was much pronounced in improving the growth characters of rice than their individual effect. When compared to seed soaking of Penshibao and Azospirillum alone their combination was found superior (discussed earlier). This superior combination along with foliar application of Penshibao might have enhanced the availability of micronutrients at active growth stages of the crops which resulted in an additive response. Similar improvement in plant growth characters by the combination of seed soaking (Azospirillum + Penshibao) and foliar application (Penshibao) was earlier reported by Elankavi (1999).

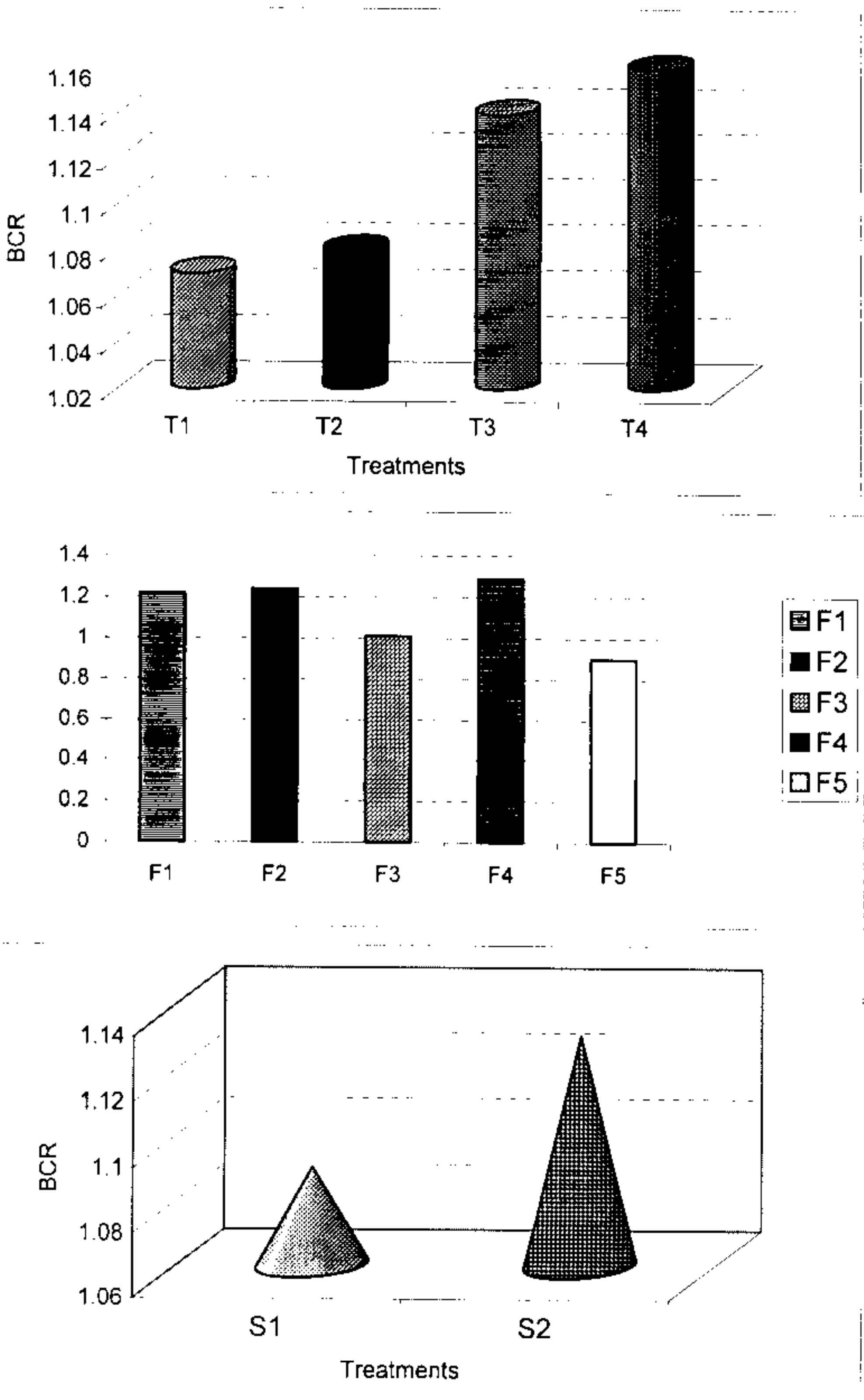
The interaction effect of seed soaking and foliar spray significantly influenced the yield attributes and yield. In general, soaking rice seeds in Azospirillum and Penshibao or Penshibao alone and spraying with Penshibao (F_4) was found superior to other treatments in improving the yield attributes like panicle m^{-2} and filled grain percentage. In grain and straw yield also, T x F (seed soaking x foliar spray) interaction was found to be significant. The T_4F_4 combination recorded the highest grain (6.49 t ha^{-1})

and straw yield (9.99 t ha^{-1}) which was on par with T_4F_2 and T_3F_4 in grain yield and T_2F_2 and T_2F_4 in straw yield. When seed soaking was combined with foliar spray the favourable effect of seed soaking and foliar spray (discussed earlier) might have resulted in a complementary effect of these two resulting in an overall improvement in growth and their yield. Other attributes like LAD, LAI and chlorophyll content which have a direct impact on enhancing the photosynthetic activity of the crop were also improved by combining seed soaking with foliar spray. The results clearly indicate soaking of rice seeds in Penshibao alone or with Azospirillum followed by foliar spray of Penshibao or GA_3 is ideal for yield improvement in rice. Similar yield improvement in rice by seed soaking with Azospirillum + Penshibao and a foliar spray of Penshibao and triacontanol was also observed by Babu (1998) and Elankavi (1999).

5.4 Economic analysis (Fig. 9)

Analysis of the results presented in Table 4.2.5.1a and Fig. 9 revealed that all the treatments significantly influenced the BC ratio. Among seed soaking treatments, T_4 (Azospirillum-Penshibao combination) recorded the highest BCR (1.16) which was on par with seed soaking on Penshibao alone. The water soaking recorded the lowest value of 1.07. The most profitable foliar treatment was F_4 (Penshibao spray) which registered a BCR of 1.29 whereas water spray (control) recorded the lowest BCR (0.09). Application of chemicals at two stages increased the BCR over application at one stages. The use of Azospirillum and

Fig. 9 Effect of seed soaking (T), foliar spray (F) and stages of application (S) on BCR



Penshibao for seed soaking and giving foliar spray of Penshibao enhanced the plant growth characters resulting in high grain and straw yield (Table 28) which in turn enhanced the total income. Though the cost of cultivation was slightly increased by these treatments, the yield improvement was maximum to compensate this excess cost and to increase the profit. So also application of these chemicals twice did not cause any reduction in BCR as the increased availability of these chemical at the critical growth stages of the crop resulted in yield improvement and thereby enhanced total income.

Among the interaction, the T x F interaction was found significant and the combination T_4F_4 recorded a higher BCR of 1.34. Seed soaking in water and water spray combination registered the lowest values of 0.84. In F x S interactions, foliar spray of Penshibao at 20 DAT (F_4S_1) and at 20 and 30 DAT (F_4S_2) were observed to be on par and superior to other.

Summary

6. SUMMARY

A field experiment was conducted at the Instructional Farm attached to College of Agriculture, Vellayani during the Rabi 2000 to study the effect of seed soaking and foliar application of growth regulators on the growth and yield of rice. The soil of the experimental site was sandy clay loam and acidic in reaction. A nursery study was conducted in CRD with four replications. The treatments consisted of four seed soaking methods like water soaking, soaking in Azospirillum, soaking in Penshibao and soaking in Azospirillum + Penshibao. Observations on germination percentage and seedling characters were taken. The main field experiment was laid out in split split plot design with four seed soaking methods (T_1 - water soaking, T_2 - soaking in Azospirillum, T_3- soaking in Penshibao, T_4 - soaking a Penshibao + Azospirillum) in the main plot, five foliar sprays (F_1 - triacontanol, F_2- GA_3, F_3- kinetin, F_4- Penshibao and F_5- water) in the subplots and two stages of application (S_1- spraying at 20 DAT, S_2 spraying at 20 and 30 DAT) in the sub sub plot with three replications. Observations on growth characters, growth analysis parameters, yield attributing characters, yield, nutrient uptake and economics of the treatments were recorded and analysed statistically. The results of the study are summarized below.

1. The results from nursery studies revealed that seed soaking had a positive influence on germination percentage and seedlings

characters. Among the treatments, soaking in Azospirillum was found to be the best followed by Azospirillum + Penshibao soaking.

2. The treatments tried led to an increase in plant height at different growth stages of crop. The treatment T_4 (soaking in Penshibao + Azospirillum), F_4 (spraying with Penshibao) and S_2 (spraying at 20 and 30 DAT) recorded the highest plant height over other treatments at harvest. The combinations of T_4F_2, T_3F_2, T_4F_4 and T_3F_4 were found to be on par and superior to all other combinations.

3. Seed soaking and spraying of growth regulators increased the tiller count. The highest tiller count was recorded by the treatments T_2 (which was on par with T_4 and T_3), F_4 and S_2. In general, the treatment combinations T_4F_4 and T_3F_4, F_4S_2 and F_4S_1 recorded the highest number of tillers m^{-2} at various stages.

4. The influence of T_4, T_3 and T_2 was found comparable in DMP of rice at harvest. The foliar spray with Penshibao and spraying at 20 and 30 DAT recorded the highest DMP. The treatment combination T_4F_4, F_4S_2 and T_3S_2 registered the highest DMP at harvest.

5. The LAI and LAD recorded at flowering stage were observed to be the highest for T_4, F_4 and S_2.

6. Other growth analysis parameters were positively influenced by the treatments and the individual effects of F_4 and S_2 were found to be

superior. The highest value for all growth analysis parameters was recorded by the treatment combination T_4F_4, F_4S_2 and T_4S_2.

7. In the case of total chlorophyll, seed soaking with Azospirillum recorded the highest value which was on par with Penshibao and Penshibao + Azospirillum. Among the foliar sprays, F_4 was found to be the best while application at two stages was found superior to single stage application. The treatment combination T_3F_4, T_4F_4, T_3F_2 and T_2F_4 were found to be on par and superior. Among F x S interaction, the treatment combination F_4S_2 was found to be the best one.

8. Yield attributes like panicle number m^{-2}, filled grain percentage and 1000 grain weight was significantly influenced by the factors T, F and S. In general, the individual effect of T_4, F_4 and S_2 was superior. The treatment combinations T_3F_4, T_4F_4, F_4S_2, F_3S_2 and F_4S_1 recorded the highest values over other combinations.

9. Seed soaking with T4 (Penshibao + Azospirillum), foliar spray with Penshibao (F_4) and S_2 (spraying at 20 and 30 DAT) registered the highest grain yield and were significantly superior to other treatments. The treatment combination which produced the highest grain yield was T_4F_4 and was on par with T_4F_2, T_3F_4, T_2F_2 and T_2F_4.

10. Straw yield was found to be the highest for the treatments T_4 and was on par with T_3. Among the foliar sprays, F_4 registered the highest straw yield when applied at two stages. The treatment

combinations T_4F_4, T_3F_4 and T_4F_2 were on par and significantly superior to other combinations.

11. N uptake was favourably influenced by all the three factors (T, F and S) studied. Seed soaking with Penshibao + Azospirillum recorded the highest value which was on par with soaking in Penshibao alone. T_3 registered the highest P uptake and was on par with T_2 and T_4. Foliar spray with Penshibao (F_4) and spraying at 20 and 30 DAT (S_2) recorded the highest N and P uptake at harvest. In K uptake also, the individuals effects of T_4, F_4 and S_2 registered the highest value. The treatment combination T_4F_4, F_4S_2 and T_4S_2 recorded the highest N and K uptake.

12. The data on economic analysis showed a significant influence of the factors T,F and S on BCR. The treatment T_4 recorded the highest BCR which was on par with T_3 while foliar application with Penshibao (F_4) and S_2 (spraying at 20 and 30 DAT) recorded the highest BCR. Among the T x F interactions, T_4F_4 recorded the highest BCR which was on par with T_3F_4, T_4F_2 and T_3F_2. Among the F x S interactions, the treatment combination F_4S_2 was observed to be the most profitable one.

It is evident from the study that soaking of rice seeds in Penshibao + Azospirillum followed by foliar application of Penshibao at 20 and 30 DAT is advantageous for yield improvement and economic returns.

Future line of work

- ⇒ Yield improvement using multi functional foliar applicators needs further investigation in other cereals, pulses and vegetables.
- ⇒ Standardisation of optimum dose and correct stage of application needs refinement.
- ⇒ Seed hardening studies using these chemicals has to be undertaken for improving productivity in rainfed areas.
- ⇒ Educating the farmers on the correct use of these chemicals should be undertaken through demonstrations and farm trials.

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*Original not seen

Appendices

APPENDIX - I

Data on weather parameters during cropping period

Standard week	Relative humidity (%)	Temperature (°C)		Rainfall (mm) (weekly total)
		Maximum	Minimum	
30	80.93	30.34	22.44	50.20
31	79.14	30.33	22.89	0.40
32	86.93	28.50	21.86	89.60
33	82.50	28.56	22.76	5.40
34	88.29	28.39	21.53	138.60
35	85.36	27.93	18.59	24.20
36	86.86	29.81	22.37	-
37	85.43	30.43	22.71	-
38	90.29	29.60	21.96	26.60
39	93.64	28.80	21.94	48.20
40	95.43	28.89	21.50	145.40
41	92.21	29.69	22.09	5.60
42	92.71	29.90	22.14	76.60
43	80.21	30.63	21.57	0.60
44	75.00	31.37	22.31	-
45	81.00	31.14	22.23	53.30
46	77.57	30.73	21.97	22.70
47	88.14	28.03	21.30	49.60

APPENDIX - II

Chemical composition of Penshibao

Citric acid and aminoacid	-	30%
Zinc (Zn) as Sulphate	-	0.3%
Boron (B) as borate	-	1%
Nitrogen (N) as Urea	-	1.4%
Phosphorus (P) as water soluble phosphate	-	2.3%
Potassium (K) as phosphate	-	2.3%
Dissolving agent	-	30%
Maximum Biuret	-	0.05%

Balance as added water to make it 100%

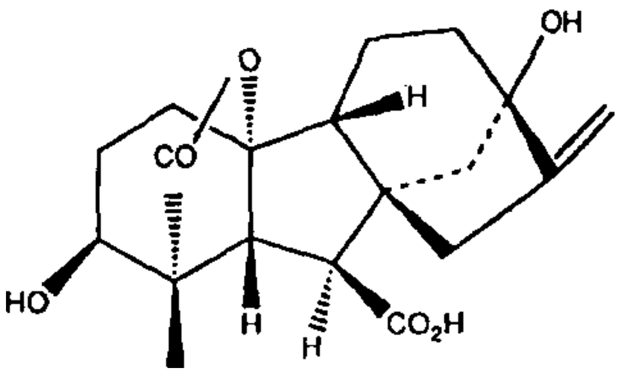
APPENDIX- III

Chemical structures of growth regulators

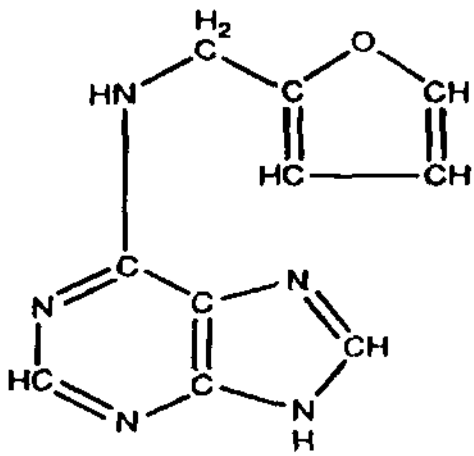
(Halmann, 1985)

(1) Triacontanol - A straight chain alcohol, $C_{30} H_{61} OH$

(2) GA_3 - Gibberelic acid



(3) KINETIN - N^6 – furfuryl aminopurine



EFFECT OF SEED SOAKING AND FOLIAR SPRAY OF GROWTH REGULATORS ON RICE (*Oryza sativa* L.)

By

POORNIMA YADAV. P.I.

ABSTRACT OF THE THESIS
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THIRUVANANTHAPURAM

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ABSTRACT

A field experiment was conducted at the Instructional Farm, College of Agriculture, Vellayani during the Rabi 2000, to study the effect of seed soaking and foliar spray of growth regulators on the growth and yield of rice.

To assess the influence of different seed soaking chemicals on seed germination and seedling characters, a nursery study was conducted in CRD with four treatments and four replications (T_1- water soaking, T_2 – soaking in Azospirillum, T_3 – soaking in Penshibao, T_4 – soaking in Azospirillum + Penshibao). The main field experiment was laid out in split split plot design with three replications. The treatments included four types of seed soaking (T_1-water soaking, T_2 – soaking in Azospirillum, T_3 – soaking in Penshibao, T_4 – soaking in Azospirillum + Penshibao) in the main plots, five types of growth regulators as foliar spray (F_1-triacontanol, F_2-GA_3, F_3-kinetin, F_4-Penshibao and F_5-water spray) in sub plots and two stages of application (S_1-20 DAT and S_2-20 and 30 DAT) in sub sub plots.

Observations on nursery study revealed that soaking rice seeds in Azospirillum or Penshibao alone or in combination improved the germination percentage and all other seedling characters.

Results of the main field experiment indicated that seed soaking, foliar spray, stages of application and their combinations had a significant influence on most of the growth characters, growth analysis parameters, yield attributing characters, yield, nutrient uptake and BCR. Soaking seeds in Penshibao + Azospirillum (T_4), foliar spray with Penshibao (F_4) and spraying

at 20 and 30 DAT (S_2) improved almost all growth characters, growth analysis parameters and chlorophyll content. These treatments also recorded the highest grain yield while straw yield was comparable for soaking in Penshibao alone and its combination with Azospirillum. Among the foliar sprays, Penshibao registered the highest grain and straw yield when applied at two stages compared to single application. In treatment combinations, soaking seeds in Azospirillum and Penshibao followed by foliar spray of Penshibao, soaking seeds in Penshibao followed by its foliar spray and soaking in Penshibao and Azospirillum followed by foliar spray of GA_3 were found to be on par and significantly superior to other combinations. Nutrient uptake was also influenced by the three factors studied (seed soaking, foliar spray and stage of application). Nitrogen uptake was the highest for soaking seeds in Penshibao and Azospirillum and it was on par with soaking in Penshibao alone. Similarly foliar spray with Penshibao at 20 and 30 DAT registered the highest N uptake at harvest. The different chemicals used for seed soaking were found to have a comparable effect and superior to water soaking on P uptake. Among the combinations, soaking in Penshibao and Azospirillum with foliar spray of Penshibao at 20 and 30 DAT registered the highest values for N, P and K uptake.

The economic analysis showed that the individual effect of combined soaking in Azospirillum (600 g ha^{-1}) and Penshibao (100 ppm), foliar spray of Penshibao (100 ppm) and spraying at 20 and 30 DAT were superior to other treatments. Among the interactions, the treatment combination of soaking seeds in Penshibao + Azospirillum followed by foliar application of Penshibao at 20 and 30 DAT, recorded the highest BCR.