EVALUATION OF ESTABLISHMENT METHODS AND AMF APPLICATION ON GROWTH AND YIELD OF RICE

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DECLARATION

I hereby declare that this thesis entitled **"Evaluation of establishment methods and AMF application on growth and yield of rice"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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CERTIFICATE

Certified that this thesis entitled **"Evaluation of establishment methods and AMF application on growth and yield of rice"** is a record of research work done independently by Mr. Jayakiran K. (2002-11-05) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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LIST OF ABBREVIATIONS

%	-	Per cent
@	-	At the rate of
^0C	-	Degree celsius
AMF	-	Arbuscular Mycorrhizal Fungi
ANOVA	-	Analysis of variance
BCR	-	Benefit cost ratio
cm	-	Centimetre
cm^2	-	Square centimetre
DAT	-	Days after transplanting
DMP	-	Dry matter production
et al.	-	And others
Fig.	-	Figure
FYM	-	Farmyard manure
G	-	Gram
ha	-	Hectare
K	-	Potassium
K_2O	-	Potash
kg	-	Kilogram
kg ha^{-1}	-	Kilogram per hectare
LAI	-	Leaf area index
m	-	Metre
mg	-	Milligram
min.	-	Minute
ml	-	Millilitre
mm	-	Millimetre
MOP	-	Muriate of potash
N	-	Nitrogen
P	-	Phosphorous
P_2O_5	-	Phosphate
RH	-	Relative humidity
Rs	-	Rupees
t	-	Tonnes
TDMP	-	Total dry matter production
t ha^{-1}	-	Tonnes per hectare

INTRODUCTION

1. INTRODUCTION

Rice is a vital food for more than half of the Asian population and widely grown in 89 countries. Since, the availability of land for rice cultivation remains static or in many cases dwindling rapidly due to the use of cultivable areas for industrial purposes, every effort should be made to increase the productivity of rice per unit land area to feed the ever increasing population.

In Kerala rice is grown in an area of about 3.22 lakh ha with an annual production of about 7.04 lakh t (FIB, 2004). Manual transplanting is the main method followed in assured irrigated areas. Traditionally, rice is transplanted by contract labourers on daily wages. Usually the farmers are practicing random planting in rice cultivation. For targeted yield, maintenance of optimum plant population is necessary which is not possible under random planting. So line planting was introduced which requires more skilled labourers to maintain optimum population under such a system.

Increased industrialization has reduced the availability of farm labourers. Further, increased wage rates increased the cost of production, making the cultivation of rice uneconomical. Under such situation, a less expensive and labour saving method of rice planting without much loss of yield is the urgent need of the hour.

In Uttar Pradesh, a labour saving method of transplanting rice *i.e.*, by broadcasting seedlings has been successfully adopted (Varughese *et al.*, 1993). However this practice is not in vogue in Kerala.

In recent years, the area under rice crop is also decreasing year by year due to less profitability. To get maximum returns, the cost of cultivation has to be reduced through reduction in labour input.

Use of rice transplanter will also reduce the total cost of cultivation since, large areas can be transplanted within a very short period. The use of machines in agricultural production is one of the outstanding developments in agriculture across the globe. Through mechanization the burden and drudgery of farm work has been reduced and the efficiency of labour is increased. Reducing the labour requirements has been the principal motivating force in agricultural mechanization.

Mycorrhizal fungi are the key components of soil microbiota. A careful selection of functionally compatible host-fungus-substrate combination is essential for early establishment of arbuscular mycorrhizal fungi in nursery or in out planted fields of major horticultural crops. Mycorrhiza has the ability to mobilize nutritionally important elements from unavailable to available form through biological processes.

In recent years, biofertilizers have emerged as an important component of Integrated Nutrient Supply System (INSS) and hold a promise to improve nutrient supplies and crop yield. Among mycorrhizas, AMF (Arbuscular Mycorrhizal Fungi) has good potential in improving nutrient cycling. Inoculation of seedlings with mycorrhiza will increase the proliferation of roots which enhances the anchoraging capacity of the seedlings and improve the uptake of nutrients. The fungus-root relationship has importance from the point of availability of diffusion dependent elements (immobile in soil) like phosphorus and zinc etc.

Hence the present investigation is proposed to study the effect of different establishment methods and arbuscular mycorrhizal fungi (AMF) on growth and yield of rice and to compare the economics of rice cultivation by the adoption of different establishment methods.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Transplanting of rice seedlings in the traditional practice is a labour intensive and laborious task. The non-availability of labourers for transplanting at appropriate time leads to delay in planting, which results in poor yields. The major operations like nursery preparation and management, pulling out seedling, transportation and distribution of seedlings to main field and transplanting consumes 30–40 per cent of total cost of cultivation in transplanted rice. Increase in transplanting cost and declining profitability of rice production under puddled conditions forced many farmers to shift from transplanting to novel methods.

Inoculation of seedlings with mycorrhiza increases the proliferation of roots, which improves the anchoraging capacity of the seedlings and enhances the uptake of nutrients and increase the yield.

The present review is mainly confined to the studies made on different planting methods and AMF inoculation on growth and yield attributes of rice.

2.1 EFFECT OF THE DIFFERENT METHODS OF PLANTING IN RICE

Transplanting is the most common and expensive method for obtaining good economic yields. Mechanization in transplanting through rice transplanter using mat nursery reduces the cost of cultivation since large areas can be transplanted within a very short period.

Direct seeding and throwing of seedlings under puddled condition are the viable alternatives for transplanting (Matsushima, 1979).

Singh *et al.* (1997) reported that the grain and straw yield were maximum with transplanting compared to drill sowing and broadcast seeding in rice.

Ganesh (1999) observed that yields were high in puddled and ponded transplanted rice, followed by puddled and ponded broadcast rice. Padhi (1999) reported that different planting systems in rice affect the grain yield and expression of yield attributes.

Sanbagavalli *et al.* (1999) observed that the response of individual growth characters varied significantly with planting methods. The crop growth parameters *viz.*, plant height, root length, root volume and number of tillers m^{-2} at flowering and dry matter production at maturity stages were found to be more in different planting methods in rice.

Budhar and Tamilselvan (2002) reported that the yield attributes like productive tillers $hill^{-1}$, filled grains $panicle^{-1}$ and test weight were significantly higher by methods of planting viz. transplanting, throwing of seedlings, direct seeding by manual broadcasting and wet seeding by drum seeder. But direct seeding practices reduced the time for 50 per cent flowering by 7 – 9 days compared with transplanting and throwing of seedlings.

Hegde *et al.* (2000) noticed that the brown spot incidence in rice was minimum in row seeding using a drum seeder and line transplanting using a transplanter.

Ponnuswamy *et al.* (2000) noticed that the number of tillers was positively influenced by the method of planting in rice.

Highly significant differences were noticed for the effect of planting methods on the number of tillers m^{-2}, number of panicles m^{-2}, number of grains $panicle^{-1}$, panicle weight, 1000 grain weight, grain yield m^{-2}, grain and straw yields (El-Kasaby *et al.*, 2002).

Pillai *et al.* (2002) reported that different methods of sowing / transplanting had significant effect on plant population and number of panicles at harvest. But pre-germinated seeds mixed with cowdung, broadcast and dibbling recorded significant higher plant population than transplanting in rice under low land situation.

2.1.1 Seedling Throwing

In South East Asian countries, a method of rice crop establishment simply by throwing the rice seedlings into the puddled field has been developed to achieve better management and yield in rice cultivation (Matsushima, 1979).

In a study conducted at Rice Research Station, Kayamkulam, Kerala, Varughese *et al.* (1993) reported that broadcast planted crop produced higher number of panicles as a result of heavy tillering even though the number of hills m^{-2} was low in broadcast planted crop compared to transplanted crop.

Kandasamy *et al.* (1996) reported that due to yield maintenance and saving in planting labour cost, the B: C ratio was higher with seedling throwing methods, especially in kharif season.

Li *et al.* (1999) reported that seedling broadcast produced more yield due to increased number of tillers and spikes.

Jiang *et al.* (1999) observed that the technique of throwing rice seedlings into wet paddy field has been widely used to solve the problems of high labour intensity and late maturation.

At Coimbatore, studies revealed that there was a considerable saving in labour for transplanting due to seedling throwing in addition to increased grain yield (Shekinah *et al.*, 1999).

Yan *et al.* (1999) found that rice seedlings transplanted by throwing were distributed at random and were shallow rooted, and developed a good population structure. They also had a shorter lag phase, more tillers and higher yield.

2.1.2 Mechanical Transplanting

Mechanization enhances productivity, as it requires less time to complete the various cultivation/agricultural operations. Mechanization improves the efficiency and cost effectiveness in cultivation.

Studies conducted by various workers reported that sustained rice production can be achieved by the extensive adoption of mechanical transplanting (Khan and Gunkel, 1988; Varghese, 1995).

The improved IRRI six row paddy transplanter saved 75 per cent labour and 70 per cent cost in transplanting (KAU, 2002).

Islam and Ahmad (1998) observed that the work rate of machine transplanting was approximately nine times more than that of hand transplanting.

Pandiarajan *et al.* (1999) reported that transplanting with power transplanter has given best benefit cost ratio. Hegde *et al.* (2000) reported that the incidence of brown spot in rice was minimum by using a transplanter.

Ming *et al.* (2000) observed that mechanical transplanting stimulated early tillering, more number of panicle on earlier tillers, larger panicles, longer active leaf life and reduced the rate of loss of leaf area.

Manjappa and Kataraki (2002) found that the net returns were significantly higher with machine transplanting. El-Kasaby *et al.* (2002) observed that mechanical transplanting gave highest values for number of tiller m^{-2}, number of panicle m^{-2}, number of grains $panicle^{-1}$, panicle weight, thousand grain weight, grain yield m^{-2} and straw yield than that of manual broadcasting and drilling in dry soil.

2.1.3 Line Transplanting

Line transplanting ensures uniform crop stand and higher productivity but requires more labour than machine planting and seedling throwing. Chatterjee and Maiti (1989) stated that proper plant spacing is one of the important factors to obtain good yield in rice, particularly in transplanted condition.

Chandra (1992) reported that in line planting, there is an even distribution of light, moisture and nutrients among the rice plants in a unit area, leading to manifestation of ideal growth components.

Saikia *et al.* (1992) reported that improved practices of transplanting in lines with fertilizer application have higher grain yield (4.33 t ha^{-1}) and benefit cost ratio (2.11) over other methods of planting *i.e.*, direct seeding and random transplanting.

Anbumani *et al.* (1999) observed that line planting had the highest number of tillers m^{-2} and maximum leaf area index (LAI) and dry matter production (DMP) at harvest. Line planting also produced highest number of panicles m^{-2}, number of filed grains $panicle^{-1}$ and thus by increased the grain yield.

In Kerala, based on the results from experiments conducted in different agro-climatic regions, a spacing of 15 x 10 cm, 20 x 10cm and 20 x 15 cm are recommended for short, medium and long duration rice varieties respectively for general cultivation to get high rice yield (KAU, 2002).

2.2 COMPARISON OF DIFFERENT METHODS OF PLANTING IN RICE

2.2.1 Seedling Throwing Vs Line Planting

In a study to compare broadcast planting and conventional planting Lal *et al.* (1986) observed that broadcast planting resulted in considerable savings in labour costs as it required less number of labour and yielded similar to that of conventional transplanting.

Sanbagavalli *et al.* (1999) reported that throwing of seedling under wetland condition is simple, practically feasible and less labour intensive. Seedling throwing method produced 4.7 and 6.6 per cent more tillers than line planting during the rabi and kharif seasons respectively. Seedling throwing method registered the highest grain yield (6.35 t ha^{-1}) compared to that of line planting (6.15 t ha^{-1}). Seedling throwing method required only 30 and 31 women days ha^{-1} in rabi and kharif respectively, whereas line planting required maximum labour for transplanting *viz.*, 56 (rabi) and 54 (kharif). This method of planting is less labour intensive and less drudgerous, required only 55.5 per cent and 68.5 per cent of labourers used for line and random planting methods respectively over the two seasons. They also reported higher DMP in seedling throwing method in kharif season and line planting method in rabi season.

Ponnuswamy *et al.* (2000) in a study on various establishment methods on yield of rice observed that grain yield under line planting and seedling throwing were comparable.

Kathiresan and Narayanasamy (2001) reported that the labour saving in throwing paddy seedlings was 57 per cent over line planting.

Subbulakshmi and Pandian (2002) reported that high grain yield in both line transplanting and seedling broadcast was due to more number of productive tillers and filled grain $panicle^{-1}$.

2.2.2 Mechanical Transplanting Vs Manual Transplanting

Khan *et al.* (1988) concluded that manual labour was found to transplant only 68 per cent of the recommended plant population ha^{-1} than that was transplanted by a mechanical transplanter.

Transplanting by self-propelled transplanter produced significantly higher number of effective tillers m^{-2} than direct sowing both under dry and wet conditions and this was due to the higher number of seedlings $hill^{-1}$ planted through a mechanical transplanter (Garg *et al.*, 1997).

Budhar and Tamilselvan (2002) observed that filled grains panicle^{-1} and 1000-grain weight were maximum in the manual transplanting, followed closely by mechanical transplanting and both recorded significantly higher test weight than direct sowing. Similar trend was observed for grains and straw yields.

El-Kasaby *et al.* (2002) reported that mechanical transplanting produced highest values for number of tillers m^{-2}, number of panicles m^{-2}, number of grains panicle^{-1}, panicle weight, thousand grain weight, grain yield m^{-2} and straw yield than that of manual broadcasting and drilling in dry soil.

2.2.3 Mechanical Transplanting Vs Seedlings Throwing

Seedling throwing method reduces the labour requirement for planting. A better alternative to regular transplanting of rice in the context of scarcity of human labour, high cost and drudgery involved in transplanting would be the seedling throwing method since it reduced the labour requirement for planting. But use of rice transplanter will also reduce the total cost of cultivation since large areas can be transplanted within a very short period through the use of machine transplanting.

Ming *et al.* (2000) observed that when mechanical transplanting was compared to transplanting by broadcasting seedlings and hand transplanting methods, mechanical transplanting increased yield by 5.71 per cent and 3.80 per cent respectively.

2.3 EFFECT OF PLANTING METHODS ON GROWTH OF RICE

In a field experiment conducted at Rice Research Station, Kayamkulam, Kerala Varughese *et al.* (1993) reported that transplanting of seedlings caused a significant increase in hills m^{-2} while seedling broadcast resulted in heavy tillering and taller plants.

Field experiments conducted during kharif and rabi seasons to study the effect of different planting methods, Sanbagavalli *et al.* (1999) observed that profuse development of lateral roots with seedling thrown crop favoured tiller production at early stages. The tillers with seedling throwing method of planting was 4.7 per cent, 6.6 per cent more over line planting in rabi and kharif seasons respectively. The leaf area index recorded was comparable in line planting (5.70) and seedling throwing methods (5.53) in wet season. The dry matter accumulation was highest in line planting (rabi) and seedling throwing (kharif) methods of planting when compared to random planting.

Ponnuswamy *et al.* (2000) reported that seedling broadcasting had significant influence on number of tillers and was superior to random planting and line planting methods. He also reported that high tillering was possible because of shallow planting and less root damage. The maximum benefit cost ratio of 3.26 was realized under seedling broadcast method.

2.4 EFFECT OF PLANTING METHODS ON YIELD ATTRIBUTES AND YIELD OF RICE

Varughese *et al.* (1993) recorded higher number of panicles m^{-2} with seedling throwing method compared to transplanting. Anbumani *et al.* (1999) reported that line planting recorded the higher number of panicles m^{-2}, number of filled grains $panicle^{-1}$ and higher grain yield when compared to random planting and direct seeding. Line planting produced the highest grain yield of 4650 kg ha^{-1} and seedling throwing registered the grain yield of 4350 kg ha^{-1}. Sanbagavalli *et al.* (1999) observed that line planting method recorded more panicle m^{-2} (485) compared to seedling throwing (471) in rabi season. The reverse was true in the kharif season (483 and 459 $panicles^{-2}$) for seedling throwing and line planting methods respectively. Seedling throwing method recorded significantly more number of filled grains $panicle^{-1}$ (88.8) and was on par with line planted crop (86.0) in kharif season. Higher spikelet sterility was observed with seedling throwing method (16.7 and 19.0 per cent in rabi and kharif seasons respectively compared to line and random planting methods. Seedling throwing method produced grain yield of (5.61 t ha^{-1}) and on par with line planting method (5.84 t ha^{-1}) in rabi season. The random planting method recorded yield of 5.22 t ha^{-1} (rabi) and 5.71 t ha^{-1} (kharif).

2.5 ECONOMICS OF DIFFERENT PLANTING METHODS

Saikia *et al.* (1992) reported a higher benefit : cost ratio with row planting compared than random planting and direct seeding. Varughese *et al.* (1993) observed that seedling broadcasting was economic compared to ordinary transplanting. Sanbagavalli *et al* (1999) reported that seedling throwing method was more advantageous because of less labour requirement (44.5 per cent of labour saving compared to line planting) and resulted in higher benefit : cost ratio (2.85 and 3.14 for the rabi and kharif seasons) compared to line planting method(2.79 and 2.95 for rabi and kharif seasons Ponnuswamy *et al.* (2000) reported that the labour requirement in seedling broadcast method was only one third of line planting and seedling broadcast recorded highest benefit : cost ratio than straight row planting and random planting.

Manickasundaram and Gnanamurthy (2002) found that the labour saving in seedling throwing method over line planting was around 25 per cent. The net returns and benefit: cost ratio in seedling throwing method is higher than line planting. The B : C ratio is always higher with seedling throwing method compared to transplanting method. Sharma *et al.* (2002) observed that in comparison to manual transplanting, mechanical transplanting saved 93 per cent time and 65.87 per cent cost.

2.6 EFFECT OF PLANTING METHODS ON NUTRIENT UPTAKE

Sanbagavalli *et al.* (1999) observed that the development of profuse lateral roots in seedling thrown crop favoured better nutrient uptake. Subbulakshmi (2001) also reported that N, P and K uptake in seedling throwing method was significantly superior to line, random and wet seeding methods.

2.7 CROP RESPONSE TO AMF

Arbuscular mycorrhizal fungi denote obligate symbiotic associations between certain zygomycetous soil fungi and higher plants in which the mycosymbiont is benefitted by obtaining its carbon requirements from the photosynthates of the host, which in turn function as additional absorbing surfaces of the host and supply less mobile nutrients, particularly phosphorus to the host plant with the help of extrametrical mycelium. The association is so prevalent in terrestrial plant community that non mycorrhizal plant is an exception rather than the rule.

AMF play an important role in the water economy of plants. It improves conductivity of roots, which contribute to better uptake of water (Levy and Krikun, 1980). Mycorrhizal fungi are the key components of soil microbiota. They are obligate symbionts and are not host specific (Bonfante-Fasolo, 1987).

Arbuscular mycorrhizae impart enormous benefits to the plant community both in the natural ecosystem and in the different agricultural situations. It has been widely used as a bio inoculant for sustaining the growth and health of cultivated crops (Rosendahl *et al.*, 1992).

The vesicular arbuscular mycorrhizal association increases the growth, nutrient uptake and resistance to root diseases in crop plants (Sivaprasad *et al.*, 1990).

Hegde and Dwivedi (1994) observed that the best strategy to utilize AMF fungi for crop production is to concentrate on crops normally grown in nursery beds where they can be easily inoculated with selected strains and then transplanted.

2.7.1 Nutrient Uptake and Transfer through Mycorrhiza

The symbiotic association between mycorrhizal fungi and plants is beneficial to the plant in terms of better nutrient uptake (Mosse, 1973) higher water potential (Sanchez-Dias and Honrubia, 1994) and lesser chances of root diseases (Newsham *et al.*, 1995), which led the plants more healthy and productive in comparison to non-mycorrhizal plants.

Inoculation of AMF is beneficial to crops by way of mobilizing nutrients especially P (Lambert *et al.*, 1980; Hayman, 1983; Bolan, 1991; Verma and Schuepp, 1995; Sekar *et al.*, 1997).

It has been well documented that AMF association can act as a channel for direct inter plant nutrient transfer of phosphorus (Heap and Newman, 1980), transfer of N (Kessel *et al.*, 1985) and carbon compounds (Greeves *et al.*, 1997) by AM hyphae.

Gangopadhyay and Das (1982) observed an increased nutrient uptake in AMF inoculated rice plants. Tinker (1975) reported the role of AMF in plant growth and nutrient uptake. Hayman (1983) observed that AM hyphae in organic connection with the root extend beyond the zone of phosphate depletion, which develops in phosphate deficient soils because the root absorbs phosphate ions faster than they can diffuse through soil to replenish the supply at the root surface. Bolan *et al.* (1984) observed that when the initial soil P concentration was very low, even a small addition of P tremendously increased colonization. In spite of this, when heavy dose of P was applied it reduced root volume and in consequence it decreased the surface area colonized by AMF (Smith, 1982; Thompson *et al.*, 1991).

Experimental results of Young *et al.* (1986) have indicated that AMF in association with plant roots increased phosphorus uptake.

Champawat (1992) reported enhanced shoot and root dry weight in chickpea due to mycorrhizal inoculations. Phosphorus content in shoot and root were significantly more in inoculated plants than non-inoculated plants.

In maize, Banerjee *et al.* (1999) reported that AMF generally enhances uptake and translocation of P and encourages plant growth and development in nutrient deficient soils.

Subramanian and Charest (1999) reported that mycorrhizal colonization significantly increased P status of maize regardless of soil moisture regime.

AMF benefit plants through the expansion of soil volume by which the nutrients are made more available. Availability of nutrients like phosphorus, nitrogen, zinc, copper, potassium, calcium and magnesium are enhanced in acidic soils (Clark and Zeto, 2000).

Gill *et al.* (2000) observed that AMF have an important effect on plant phosphorus uptake and availability of other elements like zinc, copper, potassium, sulphur, aluminium, manganese, magnesium, iron etc. Mycorrhiza inhabit roots of several crops and solubilize soil phosphates

AMF significantly stimulated growth, dry matter, nodulation, shoot and root length, shoot and root dry weight, and higher uptake in greengram (Hazarika *et al.*, 2000). Pare *et al.* (2000) reported that N recovery and mineralization from crop residues by maize was enhanced by inoculation with AMF fungi.

Devi and Sitaramaiah (2001) observed that blackgram inoculated with mycorrhizal fungi showed more root and shoot dry weight and chlorophyll content. The vegetative growth and chemical composition of nitrogen, phosphorus, potassium, calcium and magnesium increased with increasing inoculum density.

Khaliq *et al.* (2001) noticed that the symbiotic association of mycorrhizal fungi enhanced the mineral nutrients especially phosphorus, potassium and zinc acquisition of pepper mint.

Rea and Tullio (2001) concluded that AMF can be considered as biological fertilizers. They improve the host plant's water and nutritional conditions and are a valid help to chemical fertilizers in achieving yield and at the same time preserving the environment.

2.7.2 Effect of AMF on Growth, Yield Attributes, Yield and Nutrient Uptake in Rice

Gangopadhyay and Das (1982) reported that endogone type mycorrhizas were found in association with upland rice and both uptake and yield were increased in AMF inoculated plants.

Khan *et al.* (1988) found that mycorrhizal infection greatly improved the growth and nutrients (nitrogen, phosphorus and zinc) contents of rice plants.

In an experiment for monitoring the impact of AMF on rice plant under wetland ecosystem, conducted at College of Agriculture, Vellayani, Sivaprasad *et al.* (1993) observed that application of AMF inoculation as a top layer over the nursery bed was found to give more colonization as compared to mixing the inoculum in the nursery soil. They also observed that the growth and yield of mycorrhizal seedlings with nursery level inoculation and transplanting gave better results.

Solaiman and Hirata (1995) reported that .AMF establishment before flooding had a positive impact on AMF colonization and sporulation in wet land rice cultivation at the vegetative stage and AMF accelerate N and P transfer from shoots and/or soils to rice grains even under flooded conditions along with the tendency to increase the harvest index.

Solaiman and Hirata (1997a) observed that AMF inoculated rice seedling grew better than the uninoculated seedlings and had higher grain yield (+10 per cent). Shoot and root growth were effectively increased by AMF inoculation. In another green house experiment, Solaiman and Hirata (1997 b) reported that plants inoculated with AMF produced higher biomass at maturity, and grain yield was 14–21 per cent higher than that of un-inoculated plants.

Hernandez and Cuevas (1999) noticed that mycorohizal inoculation increased yields in rice.

Sinha *et al.* (2000) noticed that the dry weight and root colonization were higher in AMF treated transplanted rice cultivars than those without the treatment. Uptake of P was significantly higher with AMF and the plant growth was also better.

Purakayastha and Chhonkar (2001) reported that AMF inoculation in rice enhanced the root length, root weight, root volume and total uptake of zinc and increased grain and dry matter yields. The AMF colonized rice plants were more active in acquiring zinc from added or native sources than non-colonized plants.

In an experiment conducted at Central Rainfed Upland Rice Research Station, Hazaribag, mycorrhizal colonization enhanced the yield attributing characteristics like leaf area index, tiller number and panicle number in rice (Rana *et al.*, 2002). The total productivity of rice and pigeon pea was significantly and consistently higher than the other cropping systems but was on par with rice and groundnut system.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigation was carried out in the wetlands of the Instructional Farm, College of Agriculture, Vellayani from June 2003 to September 2003.

The details of materials used and methods adopted are presented in this chapter.

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 mean sea level.

3.1.1 Soil

The soil of the experimental site is sandy clay loam which belongs to the taxonomical order oxisol. The physicochemical properties of the soil of the experimental site are given in Table 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 the Appendix I and illustrated in Fig. 1.

3.1.3 Cropping History of the Field

The experimental area was kept under fallow prior to the lay out of the experiment.

3.1.4 Season

The field experiment was conducted during the first crop season kharif (June to September) of the year 2003.

Table.1.Soil characteristics of the experimental field

A.Mechanical composition			
Sl.No	Parameters	Content (%)	Methods used
1.	Coarse sand	47.56	Bouyoucos hydrometer method (Bouyoucos, 1962)
2.	Fine sand	10.84	
3.	Silt	8.42	
4.	Clay	33.18	
B.Chemical composition			
1.	Available N	282 kg ha^{-1} (Medium)	Alkaline permanganate method (Subbiah and Asija, 1956)
2.	Available P_2O_5	24.8 kg ha^{-1} (Medium)	Bray colorimeter method (Jackson, 1973)
3.	Available K_2O	180.96 kg ha^{-1} (Medium)	Ammonium acetate method (Jackson, 1973)
4.	Organic carbon	1.65 per cent (High)	Walkley and Black's rapid titration method (Jackson, 1973)
5.	Soil pH	5.50 (Acidic)	1 : 2.5 soil solution ratio using pH meter with glass electrode (Jackson, 1973)

3.2 MATERIALS

3.2.1 Seeds

The rice variety, selected for the experiment was 'Uma' (MO 16) released from Rice Research Station, Moncompu with duration of 135 days.

3.2.2 Mycorrhizal Inoculum

Mycorrhizal inoculum was obtained from the Department of Plant Pathology, College of Agriculture, Vellayani.

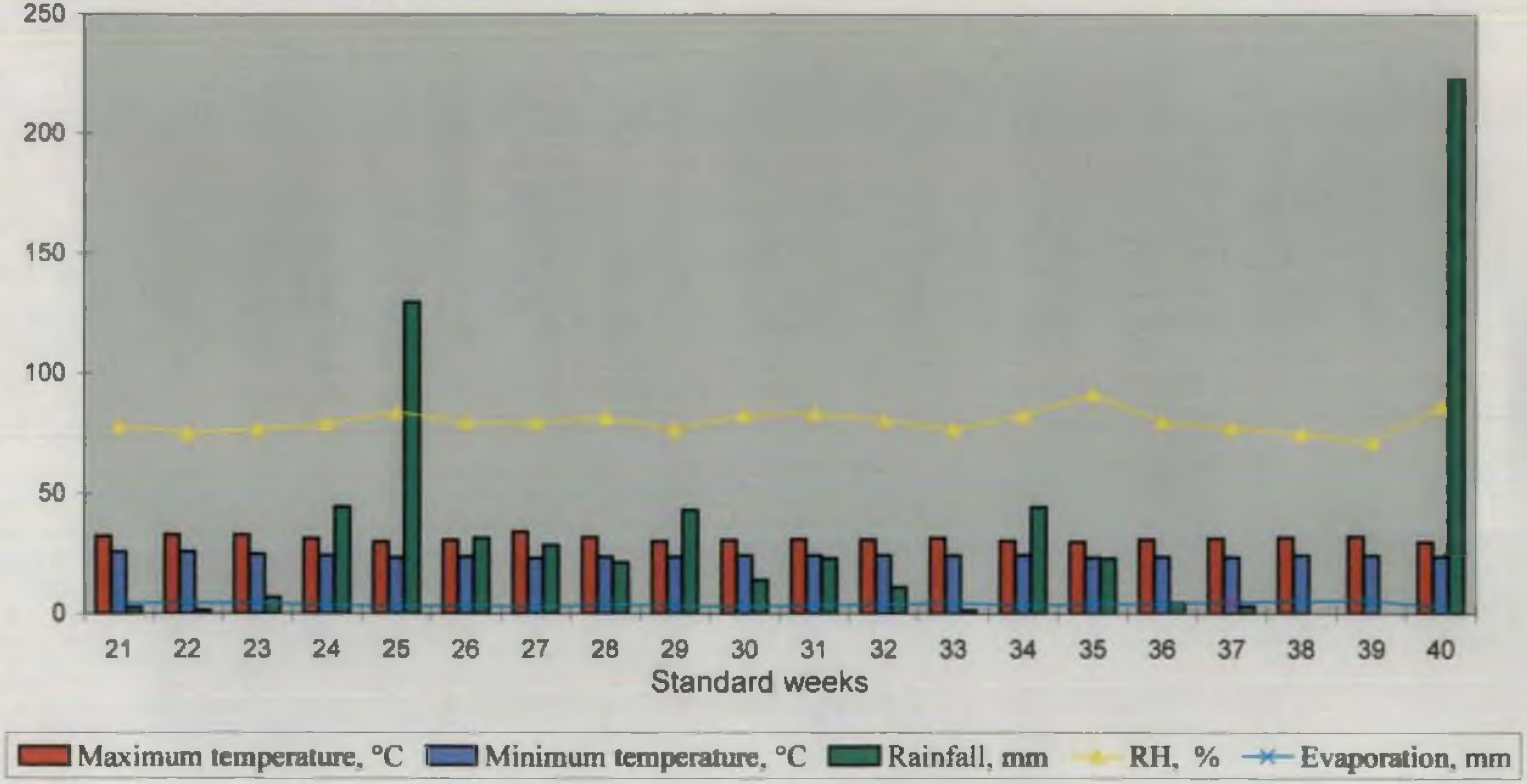

Fig. 1. Weather parameters during the cropping period (June to September 2003)

3.2.3 Manures and Fertilizers

FYM (0.35 per cent N) is used as organic source. Fertilizer sources like urea (46 per cent N), musooriephos (18 per cent P_2O_5) and muriate of potash (60 per cent K_2O) were used as the inorganic sources for the experiment.

3.3 METHODS

3.3.1 Design and Layout (Fig. 2)

General view of the experimental field is given in Plate 1.

Design	: Split plot design
Number of main plot treatments	: 3
Number of sub plot treatments	: 2
Number of replications	: 5
Gross plot size	: 6 x 3.6 m^2
Net plot size	: 5.6 x 3.4 m^2
Total number of plots	: 30

3.3.2 Treatments

Main plot : Method of planting

a. Throwing seedlings at random – M_1

Seedling throwing method is given in Plate 2.

b. Mechanical transplanting by transplanter – M_2.

Mechanical transplanting by transplanter is given in Plate 3

c. Line transplanting at 20 x 10 cm – M_3

Line transplanting is given in Plate 4.

Sub plot: AMF application in nursery

a. With AMF application in nursery – A_1

b. Without AMF application – A_0

Plate 1. General view of the experimental field

Plate 2. Seedling throwing method

Plate 3. Mechanical transplanting by transplanter

Plate 4. Line transplanting

M_1A_1	M_1A_0	M_3A_0	M_3A_1	M_2A_0	M_2A_1	R_1
M_2A_1	M_2A_0	M_3A_0	M_3A_1	M_1A_0	M_1A_1	R_2
M_3A_0	M_3A_1	M_1A_0	M_1A_1	M_2A_0	M_2A_1	R_3
M_3A_1	M_3A_0	M_2A_1	M_2A_0	M_1A_0	M_1A_1	R_4
M_1A_0	M_1A_1	M_3A_0	M_2A_1	M_1A_0	M_2A_1	R_5

M_1 – Throwing seedlings at random

M_2 – Mechanical transplanting by transplanter

M_3 – Line transplanting at 20 x 10 cm

A_0 – Without AMF application

A_1 – With AMF application

Fig. 2. Layout plan of the experiment

3.4 CROP HUSBANDRY

3.4.1 Nursery

3.4.1.1 Land Preparation

The experimental area for nursery was ploughed, puddled and levelled after removing the weeds and stubbles.

3.4.1.2 Seeds and Sowing

Pre-germinated seeds @ 65 kg ha^{-1} were broadcasted on the nursery area during the last week of May 2003. Healthy seedlings were pulled out from the nursery and transplanted in the main field. Mat nursery was also raised using @ 150 g seeds for a 60 x 30 cm mat and this was used in machine transplanting. Mycorrhizal inoculum was applied to mat nursery (@ 200 g m^{-2}) and conventional nursery.

3.4.2 Main Field

3.4.2.1 Land Preparation

The experimental area was ploughed, puddled and levelled using power tiller. Individual plots of size 6 x 3.6 m were laid out and were perfectly levelled before transplanting.

3.4.2.2 Transplanting

Transplanting was done with a thin film of water in the field. Seedlings were transplanted at a spacing of 20 x 10 cm using two seedlings $hill^{-1}$ in line transplanting method. Transplanter was used for transplanting the seedlings raised in the mat nursery. Seedlings were also planted by throwing seedlings at random.

3.4.2.3 Application of AMF

AMF inoculum applied to the nursery @ 200 g m^{-2}. It is placed as a layer on the soil surface. Seeds were sown on this layer.

3.4.2.4 Application of Manures and Fertilizers

FYM (5 t ha^{-1}) was incorporated at the time of first ploughing. Fertilizer @ 90 : 45 : 45 kg NPK ha^{-1} was applied to each plot as per POP recommendation of the Kerala Agricultural University after levelling the field (KAU, 2002). Full dose of P and half dose of N and K were applied as basal and the remaining half dose of N and K was applied as topdressing at panicle initiation stage.

3.4.2.5 Maintenance of the Crop

Maintained the water level at about 1.5 cm during transplanting. Thereafter increased it gradually to about five cm until maximum tillering stage. Two hand weedings were given at 20 and 45 days after transplanting. Drained water 13 days before harvest.

3.4.2.6 Plant Sampling

Samples were collected from the area left for sampling. Twelve hills were selected randomly from the net plot area to record biometric observations.

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 was harvested and the weight of grain and straw were recorded separately.

3.5 OBSERVATIONS

3.5.1 Biometric Observations

3.5.1.1 Establishment Count

It was taken after 15 days of transplanting. Number of plants m^{-2} in each plot was counted in a random manner using quadrate. Four quadrates each of 0.25 m^2 area were selected at random in each plot and number of seedlings established were counted at 15 DAT and expressed in hills m^{-2}

3.5.2 Root studies

Root studies were done at tillering, flowering and maturity stages.

3.5.2.1 Root Length

Sample hills were taken from each plot, roots were washed well and root length was taken from the base of the root to the tip of the longest root and expressed in cm.

3.5.2.2 Root-Shoot Ratio

Fresh weight of root was taken and then it is oven dried to constant weight and the ratio of dry weight to fresh weight is taken and expressed as root-shoot ratio.

3.5.2.3 Root Colonization Percentage of AMF

Plants were selected at random from respective plots and the roots were washed well in tap water to remove the dirt and clay particles. The mycorrhizal colonization in root was estimated following the procedure of Phillips and Hayman (1970). The well cleaned root samples were cut into one cm size bits and fixed in FAA (Formaldehyde-Acetic acid-Alcohol) in 5:5:90 proportion. The roots were hydrolysed in 10 per cent potassium hydroxide at 100^0C for 10-15 min. The alkalinity of the samples was then neutralized by washing in one per cent hydrochloric acid and the root bits were stained with 0.05 per cent trypan blue in lactophenol (lactic acid 20 ml, phenol 20 ml, glycerol 40 ml and distilled water 20 ml). The stained roots were arranged on a clean slide, pressed with another clear slide and observed under medium powder of the microscope for the presence of mycelium, vesicles and arbuscules. A minimum of 25 root bits from each sample were observed and the percentage infection was recorded in the three different methods of planting *viz.*, seedling throwing, machine planting and line planting methods.

$$\text{AMF colonisation (\%)} = \frac{\text{No.of root bits positive for AMF colonisation}}{\text{Total no. of root bits observed}} \times 100$$

3.5.2.4 Root Volume

The root volume was recorded by water displacement method as stated below. The roots of sample plants were washed free of adhering soil with water. The roots were immersed in 1000 ml measuring cylinder containing water and the rise in water level was recorded. Displacement of volume of water was taken as volume of the root and expressed in cm^3 $hill^{-1}$.

3.5.3 Observations on Growth Components

3.5.3.1 Height of Plant

Height of plants (cm) were recorded at tillering, flowering and at maturity stages. Height of plants were measured from the base of the plant to the tip of the longest leaf or to the tip of the longest ear head whichever was taller.

3.5.3.2 Tiller Number $Hill^{-1}$

Tiller number was counted at tillering, flowering and at maturity stages from sample hills, the mean values worked out and recorded.

3.5.3.3 Leaf Area Index

Leaf area at tillering, flowering and at maturity stages was calculated using the length width method suggested by Gomez (1972).

$$\text{Leaf area} = k \times l \times w$$

where k is an adjustment factor, l is the length and w is the maximum width.

LAI was worked out using the formula,

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

3.5.3.4 Dry Matter Production

Dry matter production at tillering, flowering and maturity stage were recorded. The sample plants were uprooted, washed, air dried and oven dried at 70°C for 72 hours to constant weight. Dry matter production was computed for each treatment and expressed in kg ha^{-1}.

3.5.4 Observations on Yield Components

3.5.4.1 Days to 50 per cent Flowering

Number of days from sowing till the date when approximately 50 per cent of the plants flowered were counted and recorded.

3.5.4.2 Number of Productive Tillers $Hill^{-1}$

Number of productive tillers in twelve sample hills were counted and expressed as number per hill at maturity stage.

3.5.4.3 Number of Panicles m^{-2}

In each plot, number of panicles with in a m^2 was recorded using a quadrate.

3.5.4.4 Number of Filled Grains $Panicle^{-1}$

From the random samples of panicle the total number of filled grains $panicle^{-1}$ was counted and expressed as filled grains $panicle^{-1}$

3.5.4.5 Thousand Grain Weight

One thousand grains were counted from the cleaned and dried produce from net plot area of each plot and the weight was expressed in gram.

3.5.4.6 Sterility Percentage

Number of spikelets and unfilled grains per panicle was counted and expressed as chaff percentage using the following formula :

$$\text{Sterility percentage} = \frac{\text{Number of unfilled grains per panicle}}{\text{Number of filled grains per panicle}} \times 100$$

3.5.4.7 Grain Yield

The grains harvested from each net plot were dried to constant weight, cleaned, weighed and expressed in kg ha^{-1}.

3.5.4.8 Straw Yield

The straw harvested from each net plot was dried to a constant weight under sun and the weight was expressed in kg ha^{-1}.

3.5.4.9 Harvest Index

Harvest index was calculated using the formula;

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}}$$

3.5.5 Labour Requirement

The labour requirement for different planting methods were worked out and expressed in man-days ha^{-1}.

3.5.6 Chemical Analysis

3.5.6.1 Plant Analysis

Sample plants collected from each plot at harvest were sun dried then, oven dried to a constant weight, ground the samples, digested and used for nutrient content analysis. The N content (modified microkjeldahl method), P content (Vanado-molybdo-phosphoric yellow colour method) and K content (Flame photometer method) were estimated for plant samples from each plot separately (Jackson, 1973). Plant nutrient uptake was calculated by multiplying the nutrient content of plant samples with the respective dry weights at harvest stage and expressed in kg ha^{-1}.

3.5.6.2 Soil Analysis

Samples collected before and after the experiment were dried in shade, sieved through 2 mm sieve and analysed to determine the available N content of the soil by alkaline permanganate method (Subbiah and Asija, 1956), available P by Bray's method and available K by ammonium acetate method (Jackson, 1973).

3.5.7 Economic Analysis

Economic analysis was done after taking into account the cost of cultivation and prevailing market price of rice and straw.

3.5.7.1 Net Returns

Net returns were calculated using the formula.

Net returns (Rs ha^{-1}) = Gross returns – Total expenditure (cost of cultivation)

3.5.7.2 Benefit : Cost Ratio (BCR)

Benefit : cost ratio was worked out using the formula.

$$BCR = \frac{\text{Gross return}}{\text{Cost of cultivation}}$$

3.5.8 Scoring of Major Pests like Rice Bug, Stem Borer and Leaf Roller and Diseases Like Sheath Blight, Blast and Bacterial Leaf Blight

The disease and pest incidences did not reached the threshold level and hence uniform score was given to all plots.

3.5.9 Statistical Analysis

The data generated for the characters studied under different treatments were subjected to analysis of variance (Panse and Sukhatme, 1978). Whenever the results were significant, the critical difference was worked out at five or one per cent probability.

RESULTS

4. RESULTS

A field experiment on medium duration rice variety Uma was conducted at the Instructional Farm attached to the College of Agriculture, Vellayani during kharif season (June - September, 2003). The present investigation was done to evaluate the efficiency of the different planting methods and AMF application on the growth and yield of rice. The experimental data collected were statistically analysed and results obtained are presented below.

4.1 BIOMETRIC OBSERVATIONS

4.1.1 Establishment Count

The average establishment count of seedlings as influenced by the treatments is presented in Table 2.

Establishment count was significantly influenced by methods of planting and AMF application.

Significantly higher establishment was noticed in line planting (48.81). It was followed by seedling throwing method (47.71). The lowest value was recorded in machine planting (32.34).

AMF inoculated seedling established better (43.52) than non-inoculated seedlings (42.38).

The interaction between planting methods and AMF application was not significant.

4.2 ROOT CHARACTERISTICS

4.2.1 Root Length

The average length of root at three stages of growth *viz.*, tillering, flowering and maturity stages are presented in Table 3.

Table 2. Effect of planting methods (M) and AMF application (A) on establishment count, m^{-2}

Treatments	A1	A0	Mean
M_1	48.24	47.18	47.71
M_2	38.83	31.84	32.34
M_3	49.48	48.13	48.81
Mean	43.52	42.38	

	M	A	MA
F	1429.81**	13.08**	0.126
SE	0.244	0.222	0.185
CD	0.794	0.684	NS

** Significant at 1 per cent level   NS - Non significant

Table 3. Effect of planting methods (M) and AMF application (A) on root length, cm

	Tillering stage			Flowering stage			Maturity stage		
Treatments	A_1	A_0	**Mean**	A_1	A_0	**Mean**	A_1	A_0	**Mean**
M_1	10.94	8.99	9.96	12.99	11.46	12.22	13.72	12.93	13.32
M_2	10.41	8.56	9.48	12.29	10.52	11.41	12.74	11.88	12.31
M_3	10.37	8.77	9.57	11.60	10.67	11.14	12.16	11.40	11.78
Mean	10.57	8.77		12.29	10.88		12.87	12.07	

	M	A	MA	M	A	MA	M	A	MA
F	5.58*	300.58**	0.98	10.44**	54.94**	1.70	34.32**	9.18**	0.01
SE	0.107	0.073	0.391	0.175	0.134	0.719	0.134	0.186	0.997
CD	0.350	0.226	NS	0.571	0.414	NS	0.436	0.575	NS

* Significant at 5 per cent level ** Significant at 1 per cent level NS - Non significant

At all stages of growth, root lengths varied significantly among the methods of planting and AMF application.

Superior root length was noticed for seedling throwing method at all stages. Line planting and machine planting registered more or less same root lengths which were on par. But at maturity stage lowest root length was produced by plants which were line transplanted.

AMF inoculated plants showed higher root length than non-inoculated plant at all stages.

The interaction between planting methods and AMF application was not significant.

4.2.2 Root Volume

The average volume of root at three stages of growth *viz.*, tillering, flowering and maturity stages are presented in Table 4.

At tillering and maturity stages, planting methods had no significant influence on root volume while effect of AMF application was significant.

At tillering stage, though statistically not significant, higher root volume was observed in seedling throwing method (2.93 cm^3). The lowest root volume was noticed in line planting (2.63 cm^3).

At flowering stage, both methods of planting and AMF application significantly influenced the root volume. Higher root volume was noticed in machine planting (9.86 cm^3). Seedling throwing method and line planting method recorded lesser root volume.

AMF inoculated seedling registered higher root volume than non-inoculated seedling at all stages of growth.

The interaction was not significant at any of the stages.

Table 4. Effect of planting methods (M) and AMF application (A) on root volume, cm^3

	Tillering stage			Flowering Stage			Maturity stage		
Treatment	**A_1**	**A_0**	**Mean**	**A_1**	**A_0**	**Mean**	**A_1**	**A_0**	**Mean**
M_1	3.15	2.71	2.93	9.12	7.62	8.37	9.55	8.70	9.12
M_2	3.27	2.52	2.89	11.13	8.59	9.86	8.55	7.98	8.26
M_3	2.91	2.36	2.63	9.30	7.39	8.34	8.38	7.91	8.15
Mean	3.11	2.53		9.85	7.86		8.83	8.19	

	M	A	MA	M	A	MA	M	A	MA
F	4.19	32.10**	0.79	29.32**	89.36**	2.08	2.79	7.67*	0.25
SE	0.079	0.072	0.124	0.16	0.148	0.257	0.320	0.162	0.280
CD	NS	0.222	NS	0.522	0.457	NS	NS	0.499	NS

* Significant at 5 per cent level ** Significant at 1 per cent level NS - Non significant

4.2.3 Root Shoot Ratio

The average root-shoot ratio at three stages of growth *viz.*, tillering, flowering and maturity stages are presented in Table 5.

Significant difference was noticed between the different planting methods and AMF application on root-shoot ratio at all stages of growth.

At tillering stage higher root-shoot ratio was observed in seedling throwing method. Line planting and machine planting recorded lesser root-shoot ratio and were on par. At flowering stage higher root-shoot ratio was registered in machine planting followed by line planting. Lowest root-shoot ratio was recorded in seedling throwing method. Line planting recorded superior root-shoot ratio at maturity stage. It was followed by seedling throwing method and the lowest value was recorded in machine planting.

AMF inoculated plant registered higher root-shoot ratio than non-inoculated plants at all stages of growth.

The interaction effect was significant only at flowering stage. At flowering stage machine planting with AMF inoculation followed by line planting with AMF inoculation recorded higher root-shoot ratio and they were on par. The lower values were recorded in non-inoculated seedlings in machine planting, seedling throwing, line planting and seedling throwing with AMF inoculation.

4.2.4 Root Colonization Percentage of AMF

The average root colonization percentage of AMF at nursery stage, two weeks after transplanting and four weeks after transplanting are presented in Table 6.

Out of the three methods tried, seedling throwing method was found to be the best for higher colonization of AMF. At nursery stage higher rate of colonization was noticed in mat nursery (54 per cent) used for mechanical transplanting. At 14 DAT and 28 DAT higher colonization

Table 5. Effect of planting methods (M) and AMF application (A) on root shoot ratio

Treatments	Tillering stage			Flowering stage			Maturity stage		
	A_1	A_0	**Mean**	A_1	A_0	**Mean**	A_1	A_0	**Mean**
M_1	0.58	0.47	0.53	0.33	0.30	0.31	0.34	0.28	0.31
M_2	0.52	0.42	0.48	0.43	0.33	0.38	0.31	0.28	0.30
M_3	0.53	0.44	0.49	0.41	0.32	0.36	0.35	0.30	0.33
Mean	0.54	0.44		0.39	0.31		0.33	0.29	

F	M	A	MA	M	A	MA	M	A	MA
	8.36*	160.43**	0.06	10.24**	82.06**	5.21*	13.36**	24.26**	0.73
SE	0.009	0.006	0.010	0.01	0.006	0.011	0.004	0.006	0.011
CD	0.030	0.017	NS	0.033	0.019	0.033	0.013	0.019	NS

* Significant at 5 per cent level ** Significant at 1 per cent level NS - Non significant

Table 6. AMF colonization at different stages, %

Treatments	Nursery stage*	14 DAT*	28 DAT*
M_1	48	68	76
M_2	54	62	70
M_3	46	60	65
Control	28	32	26

*Not statistically analysed

percentage was noticed in seedling throwing method (68 per cent and 76 per cent) respectively. In machine planting the percentage was 62 per cent and 70 per cent respectively. In line planting the colonization percentage was 60 per cent and 65 per cent respectively. In control plot, the root colonization per cent was 28, 32 and 26 respectively.

4.3 GROWTH CHARACTERS

4.3.1 Plant Height

The average plant height at three stages of growth *viz.*, tillering, flowering and maturity stages are presented in Table 7.

Plant height was significantly influenced by methods of planting and AMF application at all stages of growth. Significant interaction was noticed at flowering and maturity stages.

At tillering stage, maximum plant height was registered in line planting method (45.40 cm) and it was on par with seedling throwing method (43.05 cm). Machine planted seedling recorded significantly lower plant height (37.18 cm).

Seedling throwing method recorded higher plant height both at flowering (91.40 cm) and at maturity stages (99.86 cm) and it was followed by line planting (85.78 cm and 93.19 cm). The lowest plant height was observed in machine planting (77.27 cm and 86.66 cm).

AMF inoculated plants showed significantly higher plant height than non-inoculated plants at all stages of growth. At flowering stage maximum plant height was observed in seedling throwing method with AMF inoculation (100.93 cm). It was followed by line planting with AMF inoculated seedlings (90.66 cm). Machine planting and throwing seedlings without AMF inoculation and machine planting with AMF inoculation recorded more or less same plant height. The lowest plant height was observed in machine planting with non-inoculated seedlings (72.64 cm).

Table 7. Effect of planting methods (M) and AMF application (A) on plant height, cm

	Tillering stage			Flowering stage			Maturity stage		
Treatments	A_1	A_0	Mean	A_1	A_0	Mean	A_1	A_0	Mean
M_1	45.30	40.80	43.05	100.93	81.87	91.40	109.41	90.32	99.86
M_2	39.03	35.33	37.18	81.89	72.64	77.27	90.60	82.72	86.66
M_3	47.73	43.08	45.40	90.66	80.90	85.78	97.56	88.83	93.19
Mean	44.02	39.73		91.16	78.47		99.19	87.29	

	M	A	MA	M	A	MA	M	A	MA
F	24.14**	57.68**	0.27	48.37**	207.99**	13.12**	38.07**	200.51**	18.42**
SE	0.797	0..745	1.291	1.024	0.621	1.076	1.071	0.593	1.027
CD	2.600	2.297	3.979	3.336	1.917	3.320	3.488	1.831	3.171

** Significant at 1 per cent level NS - Non Significant

At maturity stage significantly higher plant height was observed in seedling throwing (109.41 cm) that was inoculated with AMF followed by line planting with AMF (97.56 cm). The lowest plant height was registered in non-inoculated machine planted seedlings (82.72 cm).

4.3.2 Number of Tillers

The average number of tillers at three stages of growth *viz.*, tillering, flowering and maturity stages is presented in Table 8.

Tiller count at tillering and flowering stages were significantly influenced by methods of planting. Mycorrhiza also proved to be effective as significantly higher tiller number was noticed in AMF inoculated seedlings at all stages.

At tillering and flowering stages maximum tiller count was observed in machine planting (10.51 and 11.35). Line planting and seedling throwing method registered lower tiller number and were on par at both the stages.

At maturity stage, methods of planting showed no significant influence on number of tillers whereas AMF inoculated plants recorded higher tiller number (9.73). Though statistically not significant, seedling throwing method recorded higher number of tillers (9.60) than machine planting (9.25) and line planting (8.82).

The interaction was not significant at any of the stages.

4.3.3 Leaf Area Index (LAI)

The average LAI at three stages of growth *viz.*, tillering, flowering and maturity stages are presented in Table 9.

At all stages, LAI was significantly influenced by different methods of planting as well as AMF application. However, the interaction was significant only at flowering and maturity stages. At tillering, flowering and maturity stages maximum LAI was observed in

Table 8. Effect of planting methods (M) and AMF application (A) on number of tillers

Tillering stage				Flowering Stage			Maturity stage		
Treatment	A_1	A_0	Mean	A_1	A_0	Mean	A_1	A_0	Mean
M_1	9.16	7.70	8.43	11.97	9.72	10.84	10.39	8.81	9.60
M_2	11.37	9.66	10.51	12.03	10.68	11.35	9.63	8.88	9.25
M_3	8.73	8.06	8.40	10.53	9.07	9.80	9.18	8.46	8.82
Mean	9.75	8.47		11.51	9.82		9.73	8.72	

F	M	A	MA	M	A	MA	M	A	MA
	41.58**	38.19**	2.32	5.21*	52.62**	1.47	3.91	23.22**	1.74
SE	0.335	0.147	0.254	0.352	0.281	0.487	0.352	0.149	0.486
CD	1.148	0.866	0.784	1.130	0.506	1.501	NS	0.460	NS

* Significant at 5 per cent level ** Significant at 1 per cent level NS - Non Significant

Table 9. Effect of planting methods (M) and AMF application (A) on leaf area index

	Tillering stage			Flowering Stage			Maturity stage		
Treatment	A_1	A_0	Mean	A_1	A_0	Mean	A_1	A_0	Mean
M_1	1.69	1.47	1.58	6.03	5.66	5.84	4.38	3.73	4.05
M_2	1.17	0.91	1.04	4.65	4.10	4.37	3.14	2.77	2.95
M_3	1.65	1.34	1.49	5.46	4.45	4.95	3.77	3.19	3.48
Mean	1.50	1.24		5.38	4.74		3.76	3.23	

F	M	A	MA	M	A	MA	M	A	MA
	24.75**	20.79**	0.19	187.51**	246.05**	21.39**	299.62**	371.66**	9.01**
SE	0.058	0.041	0.069	0.054	0.029	0.050	0.032	0.019	0.034
CD	0.190	0.125	0.216	0.176	0.089	0.154	0.103	0.060	0.104

** Significant at 1 per cent level   NS - Non significant

seedling throwing method (1.58, 5.84 and 4.05) followed by line planting (1.49, 4.95 and 3.48). The lowest value for LAI was noticed in machine planting (1.04, 4.37 and 2.95).

AMF inoculated plants registered significantly higher LAI than non-inoculated plants.

At flowering stage, seedling throwing method with AMF inoculation recorded maximum LAI (6.03) and followed by seedling throwing method without AMF application (5.66). The lowest LAI was observed in machine planting without AMF inoculation.

At maturity stage significant interaction was observed between planting methods and AMF application. Higher LAI was noticed in seedling throwing with AMF inoculation (4.38). Line planting with AMF inoculation (3.77) and seedling throwing without AMF inoculation (3.73) recorded LAI that were on par. Line planting without AMF inoculation 3.19 and machine planting with AMF inoculation 3.14 recorded LAI that were on par. The lowest LAI was noticed in machine planting without AMF inoculation.

4.3.4 Dry Matter Production (DMP)

The DMP at three stages of growth viz. tillering, flowering and maturity stages are presented in Table 10.

DMP varied significantly between methods of planting and AMF application at all stages. However, significant interaction was noticed at flowering stage.

At all stages maximum DMP was noticed in seedling throwing method (679 kg ha^{-1}, 9124 kg ha^{-1} and 14039 kg ha^{-1}). It was followed by line planting (659 kg ha^{-1}, 8209 kg ha^{-1}, 13320 kg ha^{-1}). The lowest value was seen in machine planting (511 kg ha^{-1}, 6579 kg ha^{-1}, 11650 kg ha^{-1}).

Table 10. Effect of planting methods (M) and AMF application (A) on dry matter production, kg ha^{-1}

	Tillering stage			Flowering stage			Maturity stage		
Treatments	A_1	A_0	**Mean**	A_1	A_0	**Mean**	A_1	A_0	**Mean**
M_1	701	658	679	9811	8438	9124	14865	13214	14039
M_2	543	478	511	7269	5890	6579	12409	10892	11650
M_3	692	627	659	8543	7875	8209	14012	12627	13320
Mean	645	588		8541	7401		13762	12244	

	M	A	MA	M	A	MA	M	A	MA
F	283.8**	89.9**	1.5	1745.1**	1525.7**	65. 4**	714.1**	662.0**	1.7
SE	5.5	4.3	7.4	30.9	20.6	35.7	45.9	41.6	71.7
CD	17.8	13.2	22.9	100.6	63.6	1.10.2	149.6	128.5	222.6

** Significant at 1 per cent level NS - Non significant

AMF inoculated plants produced significantly higher DMP (645 kg ha^{-1}, 8541 kg ha^{-1}, 13762 kg ha^{-1}) than non-inoculated plants (588 kg ha^{-1}. 7401 kg ha^{-1}, 12244 kg ha^{-1}) respectively at all stages.

Different methods of planting and interaction with AMF application significantly influenced the DMP at flowering stage. Seedling throwing with AMF inoculation produced significantly high dry matter (9811 kg ha^{-1}) followed by line planting with AMF and throwing without AMF, which were on par. The lowest DMP was noticed in machine planting without AMF application.

4.4 YIELD AND YIELD ATTRIBUTING CHARACTERS

4.4.1 Days to 50 per cent Flowering

The average number of days taken for 50 per cent flowering is presented in Table 11.

Significant difference was noticed in number of days to 50 per cent flowering between the methods of planting and AMF application.

Seedling throwing method had taken more number of days to 50 per cent flowering (81 days). Line planting had taken 78 days while machine planting had taken 72 days. AMF inoculated seedlings had taken only 75 days to 50 per cent flowering where as non inoculated seedlings had taken more number of days (79) to 50 per cent flowering.

The interaction was not significant.

4.4.2 Productive Tillers

The average number productive tillers are presented in Table 12.

Significant variation was noticed in productive tiller count between methods of planting and AMF application.

Seedling throwing (7.98) and line planting (7.63) recorded higher number of productive tillers and were on par. Machine planting registered lowest number of productive tillers (6.97).

Table 11. Effect of planting methods (M) and AMF application (A) on days to 50 per cent flowering

Treatments	A_1	A_0	Mean
M_1	79	83	81
M_2	70	74	72
M_3	76	80	78
Mean	75	79	

	M	A	MA
F	243.01**	65.68**	0.075
SE	0.3	0.3	0.6
CD	1.0	1.1	NS

** Significant at 1 per cent level NS - Non significant

Table 12. Effect of planting methods (M) and AMF application (A) on productive tillers per hill

Treatments	A_1	A_0	Mean
M_1	8.87	7.09	7.98
M_2	7.11	6.82	6.97
M_3	8.12	7.15	7.63
Mean	8.03	7.02	

	M	A	MA
F	7.36*	42.28**	8.30*
SE	0.190	0.106	0.184
CD	0.620	0.328	0.569

Table 13. Effect of planting methods (M) and AMF application (A) on number of panicles m^{-2}

Treatments	A_1	A_0	Mean
M_1	529	476	502
M_2	418	367	392
M_3	442	376	409
Mean	476	463	

	M	A	MA
F	396.5**	564.5**	3.7
SE	3.0	1.7	2.9
CD	9.7	5.2	NS

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

NS - Non significant

AMF inoculated plants produced maximum number of productive tillers (8.03) when compared to non-inoculated plants (7.02).

Significant interaction was noticed between methods of planting and AMF inoculation. Highest numbers of productive tillers were noticed in seedling throwing method with AMF inoculation. It is followed by line planting with AMF inoculation.

4.4.3 Panicles m^{-2}

The average number of panicles m^{-2} is presented in Table 13.

Different methods of planting and AMF application significantly influenced the number of panicles m^{-2} but the interaction was not significant. Higher number of panicles m^{-2} was recorded in seedling throwing method (502). It was followed by line planting (409). Machine planting recorded lowest number of panicles m^{-2} (392).

AMF inoculated seedlings recorded higher number of panicles m^{-2} (463) when compared to non-inoculated seedlings (406).

4.4.4 Filled Grains Panicle^{-1}

The average number of filled grains panicle^{-1} is presented in Table 14.

Filled grains panicle^{-1} varied significantly among the methods of planting and AMF inoculation.

Maximum number of filled grains panicle^{-1} was observed in line planting method (90). It was followed by seedling throwing method (87) and the lowest value was recorded in machine planting (81).

AMF inoculated plants had produced significantly more filled grains panicle^{-1} (92) compared to non inoculated plants (80).

The interaction was not significant.

Table 14. Effect of planting methods (M) and AMF application (A) on filled grains panicle^{-1}

Treatments	A_1	A_0	Mean
M_1	94	81	87
M_2	85	77	81
M_3	98	82	90
Mean	92	80	

	M	A	MA
F	9.9**	19.2**	0.8
SE	1.4	2.0	3.5
CD	4.6	6.3	NS

Table 15. Effect of planting methods (M) and AMF application (A) on thousand grain weight, g

Treatments	A_1	A_0	Mean
M_1	26.09	24.22	25.15
M_2	24.31	22.34	23.32
M_3	26.04	24.24	25.14
Mean	25.48	23.60	

	M	A	MA
F	235.06**	414.98**	0.255
SE	0.069	0.065	0.113
CD	0.224	0.201	NS

** Significant at 1 per cent level NS - Non significant

4.4.5 Thousand Grain Weight

The average thousand grain weight is presented in Table 15.

Thousand grain weight varied significantly between the different methods of planting and AMF application however interaction effect was not significant. Seedling throwing method recorded significantly higher values of thousand grain weight (25.15 g) but was on par with line planting method (25.14 g). The lowest value was recorded in machine planting (23.32 g).

AMF inoculated plants recorded significantly higher values of thousand grain weight (25.48 g) than non-inoculated seedlings (23.60 g).

4.4.6 Sterility percentage

The average sterility percentage is presented in Table 16.

Sterility percentage was significantly influenced by different methods of planting. The highest sterility percentage was noticed in seedling throwing method (21.00). Line planting and machine planting recorded lower sterility percentages which were on par.

AMF had no significant influence on sterility and the interaction was also not significant.

4.4.7 Grain Yield

The average grain yield is presented in Table 17.

Significant difference was noticed between methods of planting and AMF application. The highest yield was noticed in seedling throwing (4436 kg ha^{-1}) which was on par with line planting (4421 kg ha^{-1}). The lowest yield was observed in machine planting (3447 kg ha^{-1}).

AMF inoculated plants produced higher yield (4392 kg ha^{-1}) than non-inoculated plants (3810 kg ha^{-1}).

Table 16. Effect of planting methods (M) and AMF application (A) on sterility percentage

Treatments	A_1	A_0	Mean
M_1	21.52	20.47	21.00
M_2	11.51	12.56	12.03
M_3	12.38	11.47	11.92
Mean	15.14	14.83	

	M	A	MA
F	69.38**	0.07	0.35
SE	0.626	0.812	1.407
CD	2.038	NS	NS

Table 17. Effect of planting methods (M) and AMF application (A) on grain yield, kg ha^{-1}

Treatments	A_1	A_0	Mean
M_1	4609	4264	4436
M_2	3880	3015	3447
M_3	4689	4153	4421
Mean	4392	3810	

	M	A	MA
F	402.2**	88. 7**	6.0*
SE	28.3	43.6	75.6
CD	92.1	134.7	233.3

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

NS - Non significant

The interaction between methods of planting and AMF application was significant. Line planting with AMF application (4689 kg ha^{-1}) and seedling throwing with AMF application (4609 kg ha^{-1}) recorded yields that were on par. Seedlings throwing without AMF application (4264 kg ha^{-1}), line planting without AMF application (4153 kg ha^{-1}), and machine planting with AMF application (3880 kg ha^{-1}) recorded lower yields. Machine planting without AMF application registered the lowest grain yield (3015 kg ha^{-1}).

4.4.8 Straw Yield

The average straw yield is presented in Table 18.

Significant difference was noticed in straw yield due to the different methods of planting and AMF inoculation. The interaction was also significant.

Significantly higher straw yield was noticed in seedling throwing method (9868 kg ha^{-1}) and it was followed by line planting (8951 kg ha^{-1}). The lowest yield was observed in machine planting (8100 kg ha^{-1}). Seedling throwing method with AMF inoculation recorded maximum straw production (10508 kg ha^{-1}) and it was followed by line planting with AMF application (9424 kg ha^{-1}). Seedling throwing without AMF (9229 kg ha^{-1}), machine planting with AMF (8555 kg ha^{-1}) and line planting without AMF (8478 kg ha^{-1}) recorded lower straw yield. The lowest straw yield was noticed in machine planting without AMF application (7644 kg ha^{-1}).

4.4.9 Harvest Index

The average harvest index is presented in Table 19.

Harvest index was significantly influenced by methods of planting and AMF application. Line planting recorded significantly higher harvest index (0.49). It was followed by seedling throwing (0.45). The lowest harvest index was noticed in machine planting (0.42).

Table 18. Effect of planting methods (M) and AMF application (A) on straw yield, kg ha^{-1}

Treatments	A_1	A_0	Mean
M_1	10508	9229	9868
M_2	8555	7644	8100
M_3	9424	8478	8951
Mean	9495	8450	

F	M	A	MA
	30.5**	28.1**	48.7**
SE	21.6	19.8	34.4
CD	70.3	61.2	106.1

Table 19. Effect of planting methods (M) and AMF application (A) on harvest index

Treatments	A_1	A_0	Mean
M_1	0.43	0.46	0.45
M_2	0.45	0.39	0.42
M_3	0.49	0.49	0.49
Mean	0.46	0.44	

F	M	A	MA
	100.81**	5.41*	14.76**
SE	0.003	0.004	0.007
CD	0.011	0.013	0.023

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

NS - Non significant

AMF inoculated plants have high harvest index (0.46) than non inoculated plants (0.44).

Interaction between methods of planting and AMF inoculation was significant. Line planting with and without mycorrhizal application recorded high harvest index (0.49). Machine planting with AMF application and throwing seedling without AMF application recorded more or less same harvest index. The lowest harvest index was noticed in machine planting without AMF inoculation.

4.5 UPTAKE

4.5.1 N Uptake

The average nitrogen uptake is presented in Table 20.

Planting methods and AMF inoculation had significantly influenced the nitrogen uptake of plants.

Significantly higher uptake was noticed in seedling throwing method (130.8 kg ha^{-1}). It was followed by line planting (119.7 kg ha^{-1}). The lowest value was recorded in machine planting (116.5 kg ha^{-1}).

AMF inoculated plants had better uptake (130.4 kg ha^{-1}) compared to non inoculated plants (114.3 kg ha^{-1}).

The interaction was not significant.

4.5.2 Phosphorus Uptake

The average phosphorus uptake is presented in Table 21.

It could be observed from the data that there was significant interaction among the treatments with respect to the uptake of P by the crop at harvest. The interaction was also significant.

Significantly superior uptake was noticed in seedling throwing method (37.7 kg ha^{-1}). It was followed by line planting (33.0 kg ha^{-1}). The lowest uptake was recorded in machine planting (29.9 kg ha^{-1}).

Table 20. Effect of planting methods (M) and AMF application (A) on nitrogen uptake kg ha^{-1}

Treatments	A_1	A_0	Mean
M_1	139.1	122.5	130.8
M_2	124.0	109.0	116.5
M_3	128.2	111.3	119.7
Mean	130.4	114.3	

	M	A	MA
F	62.76**	311.24**	0.47
SE	0.95	0.65	1.12
CD	3.09	1.99	NS

Table 21. Effect of planting methods (M) and AMF application (A) on phosphorus uptake (kg ha^{-1})

Treatments	A_1	A_0	Mean
M_1	44.6	30.8	37.7
M_2	36.0	23.7	29.9
M_3	36.0	30.1	33.0
Mean	38.9	28.2	

	M	A	MA
F	25.41**	81.81**	4.27*
SE	0.78	0.83	1.44
CD	2.54	2.57	4.45

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

NS - Non significant

AMF applied plots recorded maximum uptake (38.9 kg ha^{-1}) compared to non applied plots (28.2 kg ha^{-1}).

The highest uptake was found in seedling throwing method with AMF application (44.6 kg ha^{-1}). Line planting with AMF inoculation (36.0 kg ha^{-1}) and machine planting with AMF inoculation (36.0 kg ha^{-1}) recorded P uptake that were on par. Seedling throwing method and line planting method without AMF application recorded lower P uptake, 30.8 kg ha^{-1} and 30.1 kg ha^{-1} respectively. The lowest uptake was noticed in machine planting without AMF application (23.7 kg ha^{-1}).

4.5.3 Potassium Uptake

The average potassium uptake is presented in Table 22.

Significant difference was noticed among the methods of planting and AMF application in the K uptake by plants. The interaction was not significant.

The highest uptake was noticed in seedling throwing method (99.1 kg ha^{-1}). Line planting recorded uptake of 94.7 kg ha^{-1} and the lowest uptake was seen in machine planting (91.5 kg ha^{-1}).

AMF applied plants registered superior uptake (101.3 kg ha^{-1}) compared to non-inoculated plants (88.8 kg ha^{-1}).

4.6 SOIL ANALYSIS

4.6.1 Soil Nitrogen

The average soil nitrogen status after the harvest is presented in Table 23.

Between methods of planting, no significant variation was noticed in available nitrogen status. AMF application significantly influenced the soil nitrogen status but the interaction was not significant.

Nitrogen availability was less in AMF applied plots (255.7 kg ha^{-1}) than non applied plots (262.3 kg ha^{-1}).

Table 22. Effect of planting methods (M) and AMF application (A) on potassium uptake, kg ha^{-1}

Treatments	A_1	A_0	Mean
M_1	106.1	91.8	99.0
M_2	97.2	85.7	91.5
M_3	100.7	88.8	94.7
Mean	101.3	88.8	

	M	A	MA
F	51.54**	386.09**	1.83
SE	0.53	0.45	0.78
CD	1.71	1.39	NS

Table 23. Effect of planting methods (M) and AMF application (A) on nitrogen availability, kg ha^{-1}

Treatments	A_1	A_0	Mean
M_1	252.1	260.7	256.4
M_2	256.1	265.0	260.6
M_3	258.9	261.0	259.9
Mean	255.7	262.3	

	M	A	MA
F	1.90	21.14**	2.37
SE	4.38	1.01	1.27
CD	NS	3.12	NS

** Significant at 1 per cent level NS - Non significant

4.6.2 Soil Phosphorus

The average soil phosphorus status is presented in Table 24.

No significant variation was noticed between methods of planting in soil phosphorus availability. But AMF application enhanced the availability of phosphorus in soil. The interaction was also significant.

High P status was noticed in AMF received plots (36.9 kg ha^{-1}) than non received plots (34.1 kg ha^{-1}).

Seedling throwing and line planting methods with AMF inoculation and machine planting with and without AMF recorded more or less the same P status and were on par. Seedling throwing and line planting methods without AMF inoculation recorded the lowest soil P status.

4.6.3 Soil Potassium

The average soil potassium status is presented in Table 25.

Between planting methods, no significant variation was observed in soil potassium status. Significant influence of mycorrhiza was noticed.

Soil potassium status was low in AMF received plots (160.0 kg ha^{-1}) than non-inoculated plants (162.9 kg ha^{-1}).

4.7. LABOUR REQUIREMENT

The labour requirement for different methods of planting and percentage of labour saving over line planting were worked out and expressed in Table 26.

Machine planting required less number of labour of five man days ha^{-1} which accounts for 90.9 per cent labour saving over line planting. Seedling throwing required 20 women days ha^{-1} which accounts for 63.6 per cent labour saving over line planting. Line planting took maximum number of labour (55 women days ha^{-1}).

Table 24. Effect of planting methods (M) and AMF application (A) on phosphorus availability, kg ha^{-1}

Treatments	A_1	A_0	Mean
M_1	37.4	33.0	35.2
M_2	36.3	36.3	36.3
M_3	37.2	32.9	35.0
Mean	36.9	34.1	

	M	A	MA
F	2.96	35.62**	9.18**
SE	0.94	0.34	0.59
CD	NS	1.05	1.81

Table 25. Effect of planting methods (M) and AMF application (A) on potassium availability, kg ha^{-1}

Treatments	A_1	A_0	Mean
M_1	157.9	164.4	161.2
M_2	161.4	162.2	161.8
M_3	160.8	162.0	161.4
Mean	160.0	162.9	

	M	A	MA
F	0.17	5.37*	2.24
SE	0.84	0.87	0.79
CD	NS	2.68	NS

* Significant at 5 per cent level NS - Non significant

Table 26. Labour requirement (men / women days ha^{-1})

Establishment method	Labour requirement	Labour saving (%)
1. Seedling throwing	20	63.6 (L.P)*
2. Machine planting	5	90.9 (L.P)*
3. Line planting (L.P)	55	

*Compared to line planting

Table 27. Effect of planting methods and AMF application on B:C ratio

Treatments	A1	A0	Mean
M_1	2.99	2.72	2.86
M_2	3.11	2.53	2.82
M_3	2.08	1.85	1.97
Mean	2.73	2.37	

	M	A	MA
F	2009.20**	163.78**	15.57**
SE	0.011	0.020	0.034
CD	0.036	0.061	0.106

** Significant at 1 per cent level

4.8 ECONOMICS OF CULTIVATION

4.8.1 B : C Ratio

The B:C Ratio is presented in Table 27.

Significant difference was noticed as B:C ratio varied among methods of planting and AMF application. Seedling throwing methods and machine planting recorded high B:C ratios, 2.85 and 2.82 respectively. Line planting registered the lowest B:C ratio (1.97).

AMF inoculated plants registered high B:C ratio (2.73) than non-inoculated plants (2.37).

The interaction between methods of planting and AMF application was significant. The highest B:C ratio of 3.11 was found in seedling throwing method with AMF application. The lowest B:C ratio was obtained in line planting without AMF inoculation (1.85).

4.8.2 Gross Returns

Gross Returns is presented in Table 28.

Different planting methods significantly influenced the gross returns.

Higher gross returns were recorded in seedling throwing method (Rs.49965 ha^{-1}). It was followed by line planting method (Rs.45477 ha^{-1}). The lowest gross returns were registered in machine planting (Rs.37142 ha^{-1}).

AMF inoculated plants produced high yields and the gross return was high (Rs.46089 ha^{-1}) compared to non inoculated plants (Rs.40301 ha^{-1}).

4.8.3 Net Returns

Net Returns is presented in Table 29.

Table 28. Effect of planting methods (M) and AMF application (A) on gross return, Rs. ha^{-1}

Treatments	A_1	A_0	Mean
M_1	49176	44754	46965
M_2	40960	33324	37142
M_3	48130	42824	45477
Mean	46089	40301	

	M	A	MA
F	672.1**	155.6**	4.3
SE	204.5	327.6	567.4
CD	666.0	1011.0	NS

Table 29. Effect of planting methods and AMF application on net returns, Rs.ha^{-1}

Treatments	A1	A0	Mean
M_1	32731	28309	30520
M_2	27815	20179	23997
M_3	25085	19779	22432
Mean	28544	22756	

	M	A	MA
F	441.3**	155.6**	4.3
SE	201.4	327.56	567.4
CD	655.9	1011.00	NS

** Significant at 1 per cent level NS - Non significant

Net returns varied significantly due to AMF application and methods of planting.

Seedling throwing method registered higher net returns (Rs. 30520 ha^{-1}). It was followed by machine planting (Rs. 23997 ha^{-1}). The lowest net returns was observed in line planting (Rs. 22432 ha^{-1}).

AMF inoculated plants had higher net returns (Rs. 28544 ha^{-1}) when compared to non inoculated plants (Rs. 22756 ha^{-1}).

DISCUSSION

5. DISCUSSION

A field investigation was conducted during kharif season (June - September, 2003) at College of Agriculture, Vellayani to evaluate the efficiency of the different planting methods and AMF application on the growth and yield of rice. The results obtained are discussed below.

5.1. EFFECTS OF PLANTING METHODS AND AMF APPLICATION ON ESTABLISHMENT COUNT

Significant variation was observed between the different methods of planting (Fig. 3). Higher establishment was observed in line planting and seedling throwing method compared to machine planting. The wider row spacing in machine planting (30 x 10 cm) might have led to low seedling population than other methods. Seedling throwing was done at random which might have led to comparatively less population than line planting.

AMF inoculated plants had better establishment. This might be due to better root growth and root proliferation which made the establishment more effective. Similar results were reported by Purakayastha and Chhonkar (2001).

5.2 EFFECTS OF PLANTING METHODS AND AMF APPLICATION ON ROOT CHARACTERS

Seedling thrown crops had longer roots, more root volume and high root : shoot ratio compared to other methods. This might be due to zero depth of planting which resulted in more proliferation and growth of roots. Similar findings of increased root length, root volume and root activity in seedling thrown crop was reported by Sanbagavalli *et al.* (1999).

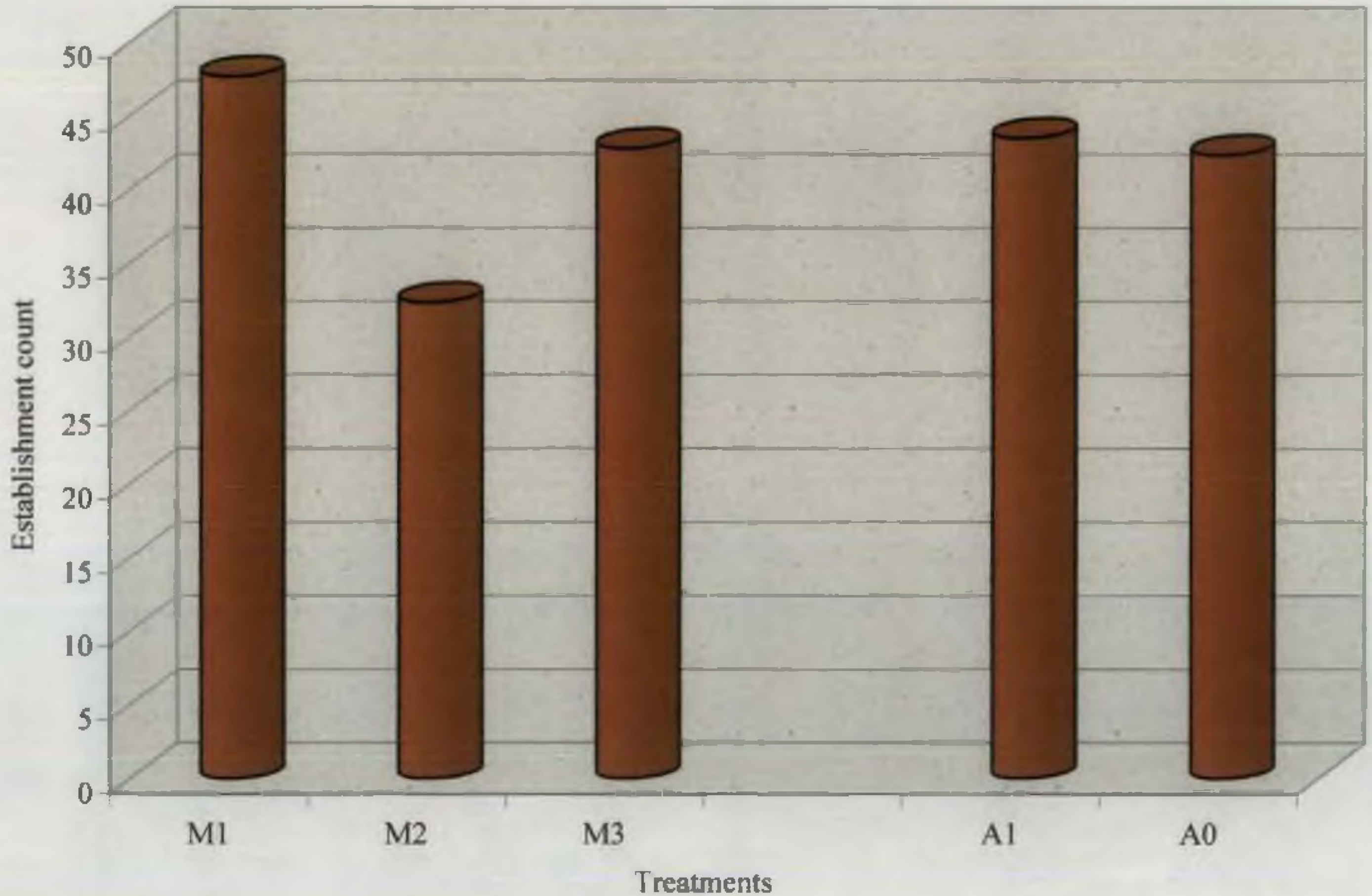

Fig. 3. Effect of planting methods and AMF application on establishment count

Increase in root length, root volume and root-shoot ratio was noticed in AMF inoculated seedlings during all the growth stages of the crop. Increased root and shoot dry weight was also noticed due to AMF application. This might be due to the enhanced root proliferation which resulted in more root volume. Purakayastha and Chhonkar (2001) also reported enhanced root length and root volume in AMF inoculated rice plants.

5.3 EFFECTS OF PLANTING METHODS ON GROWTH CHARACTERS OF RICE

The crop growth parameters viz. plant height, tillers, LAI and dry matter production at various growth stages were found to be very much responsive to different planting methods.

Higher plant height was observed in seedling throwing method at flowering and maturity stages. At tillering stage, plant height was comparable with line planting (Fig. 4). In seedling throwing method, due to zero depth of planting the proliferation of roots increased which help for more uptake of nutrients. This might have led to the increased height of the plant. Similar increase in plant height in seedling thrown crop was reported by Varughese *et al.* (1993) and Sanbagavalli (1999).

Data on tiller count revealed that at tillering and flowering stages machine planted seedlings recorded higher number of tillers. This can be attributed to the wider row spacing and higher number of seedling $hill^{-1}$ planted through mechanical transplanter. Similar results of increased tiller production in machine transplanting were reported by Garg *et al.* (1997) and Sharma *et al.* (2002). Wider row spacing in machine planting also led to the production of more number of tillers.

The LAI was higher in seedling throwing method at flowering and maturity stages but at tillering stage it was on par with line planting

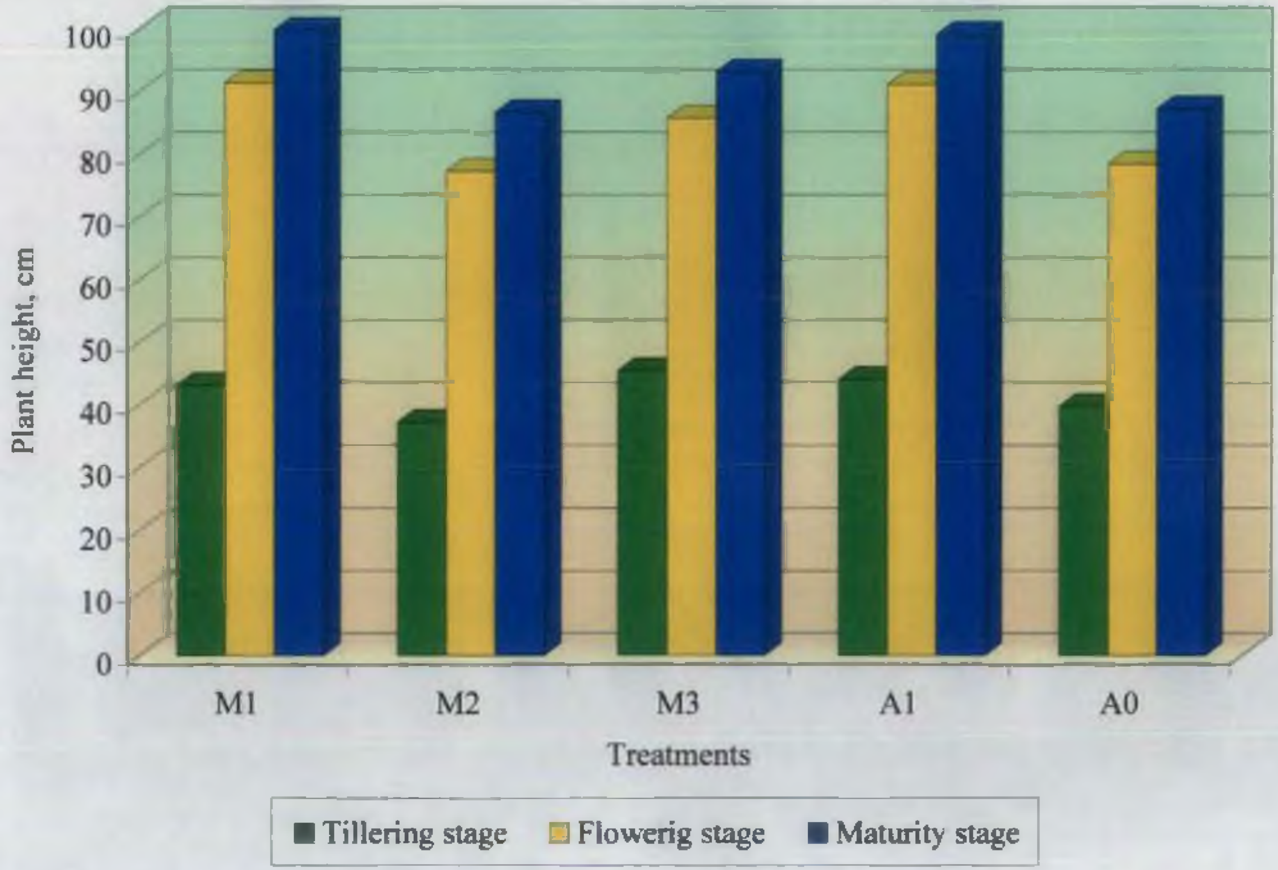

Fig. 4. Effect of planting methods and AMF application on plant height, cm

(Fig.5). This may be due to more number of leaves and tillers at these stages in seedling thrown crop compared to line transplanted crop. Lower LAI was noticed in machine transplanting. This was due to wider row spacing followed in machine planting method.

Dry matter production was higher under seedling throwing method compared to other methods at all stages of plant growth (Fig. 6). Greater accumulation of DMP under seedling throwing method could be due to favourable growth components as would be seen from increased plant height, LAI and higher plant population. Similar increase in DMP in seedling throwing method in kharif season was reported by Sanbagavalli *et al.* (1999) and Subbulakshmi (2001).

5.4 EFFECTS OF PLANTING METHODS ON YIELD ATTRIBUTING CHARACTERS OF RICE

Seedling throwing method had taken maximum number of days to 50 per cent flowering. This might be due to the more vegetative growth observed in this method.

Seedling throwing method recorded higher number of productive tillers m^{-2} than line planting and machine planting (Fig. 7). This was due to enhanced plant growth as evident from more LAI, root activity and better uptake of nutrients from soil. Sanbagavalli *et al.* (1997) also observed higher number of productive tillers m^{-2} in seedling throwing method.

More number of panicles m^{-2} was observed in seedling throwing method (Fig.8). This was due to more productive tillers $hill^{-1}$ in seedling throwing method. The lowest number of panicles m^{-2} was reported in machine planting. This was due to lower number of productive tillers.

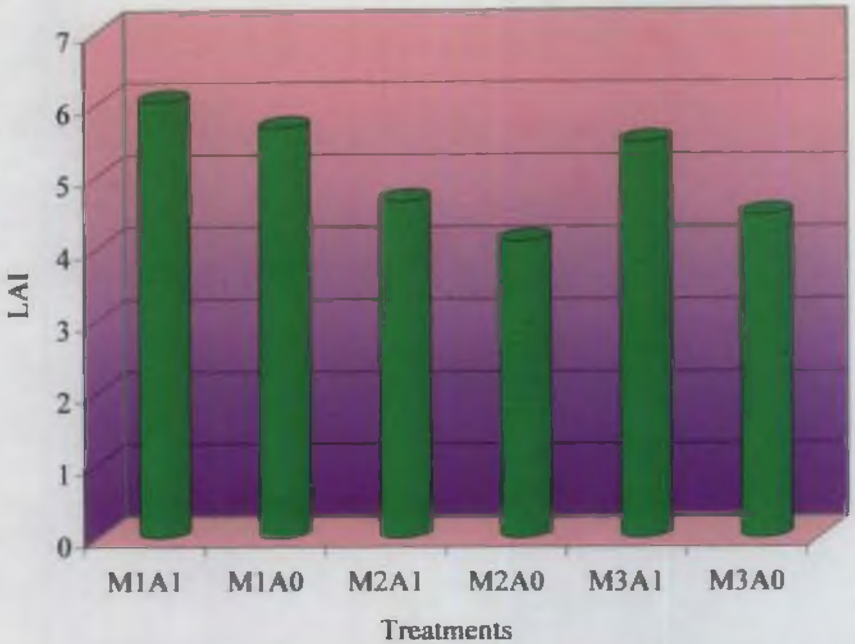

Fig. 5a Interaction effect of planting methods and AMF application on LAI at flowering

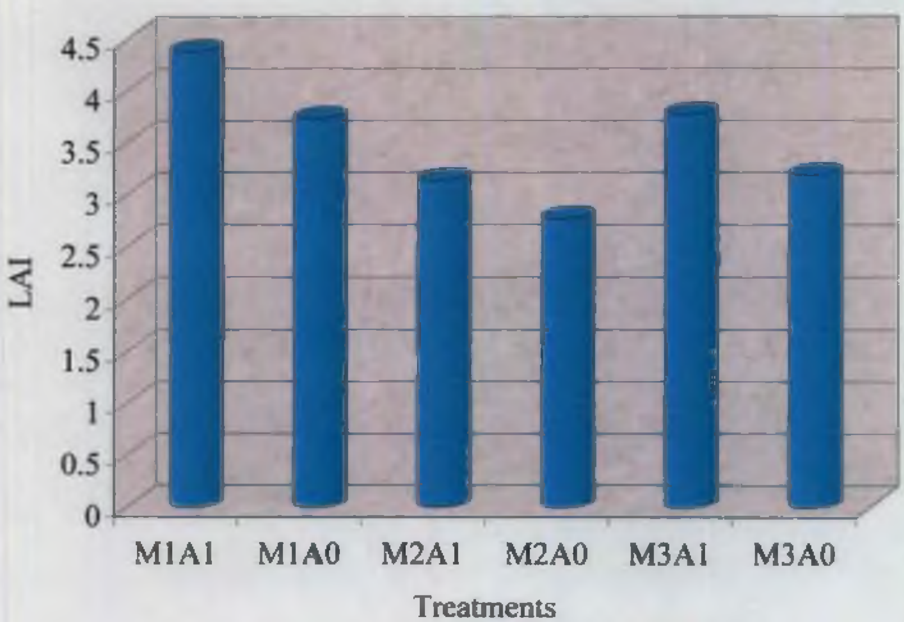

Fig. 5b Interaction effect of planting methods and AMF application on LAI at maturity stage

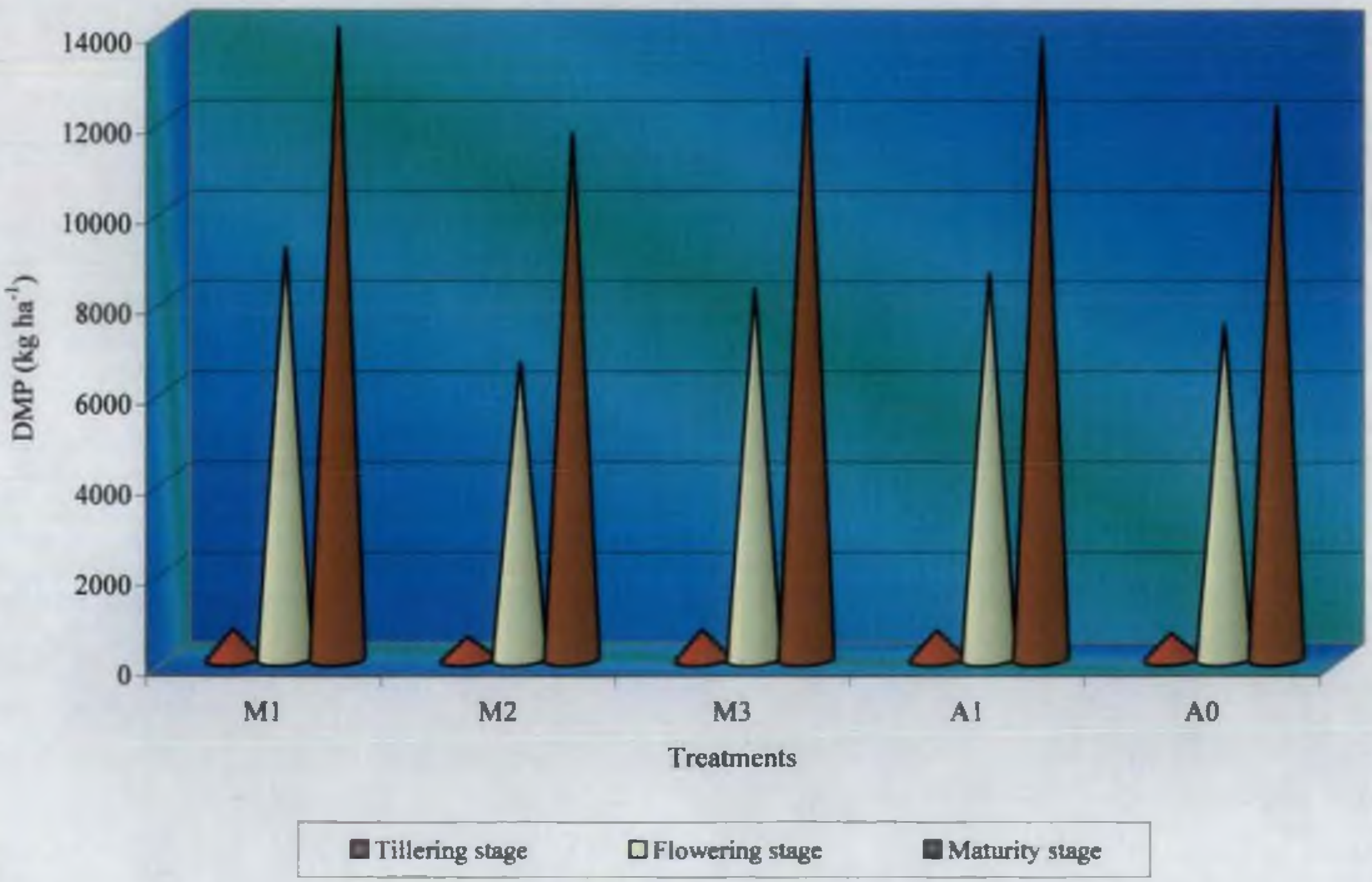

Fig. 6 Effect of planting methods and AMF application on dry matter prodcution, kg ha^{-1}

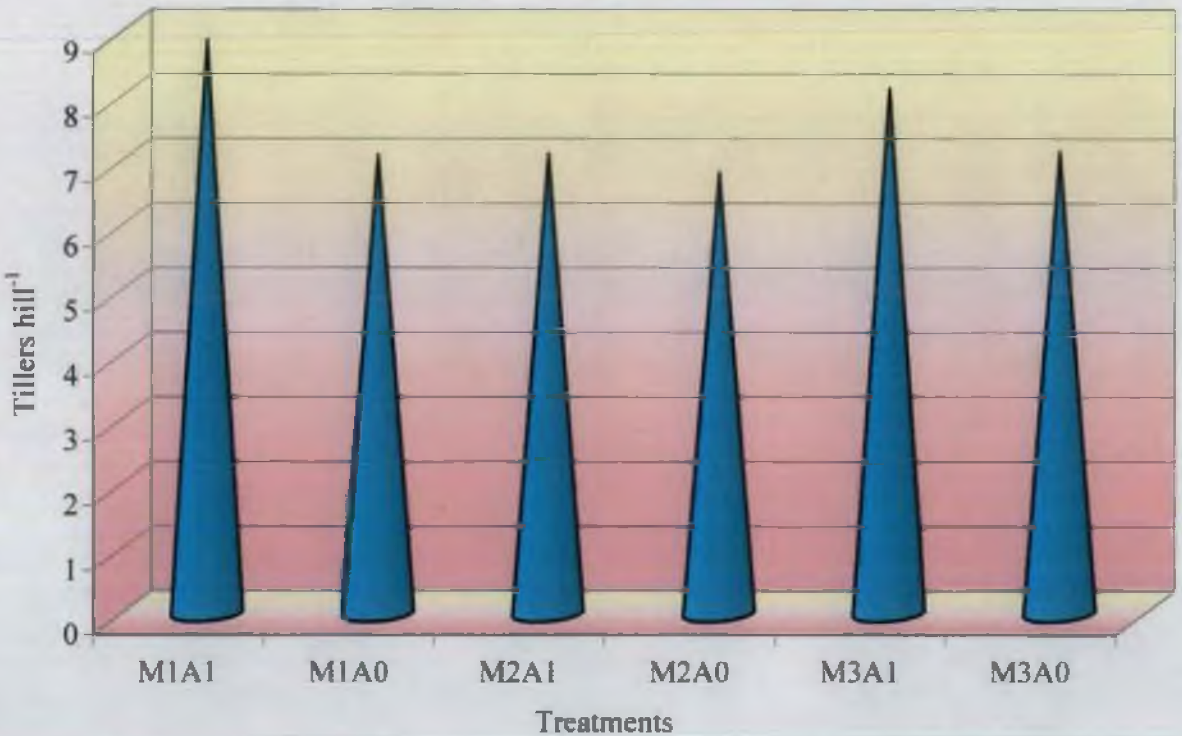

Fig. 7 Interaction effect of planting methods and AMF application on productive tillers hill^{-1}

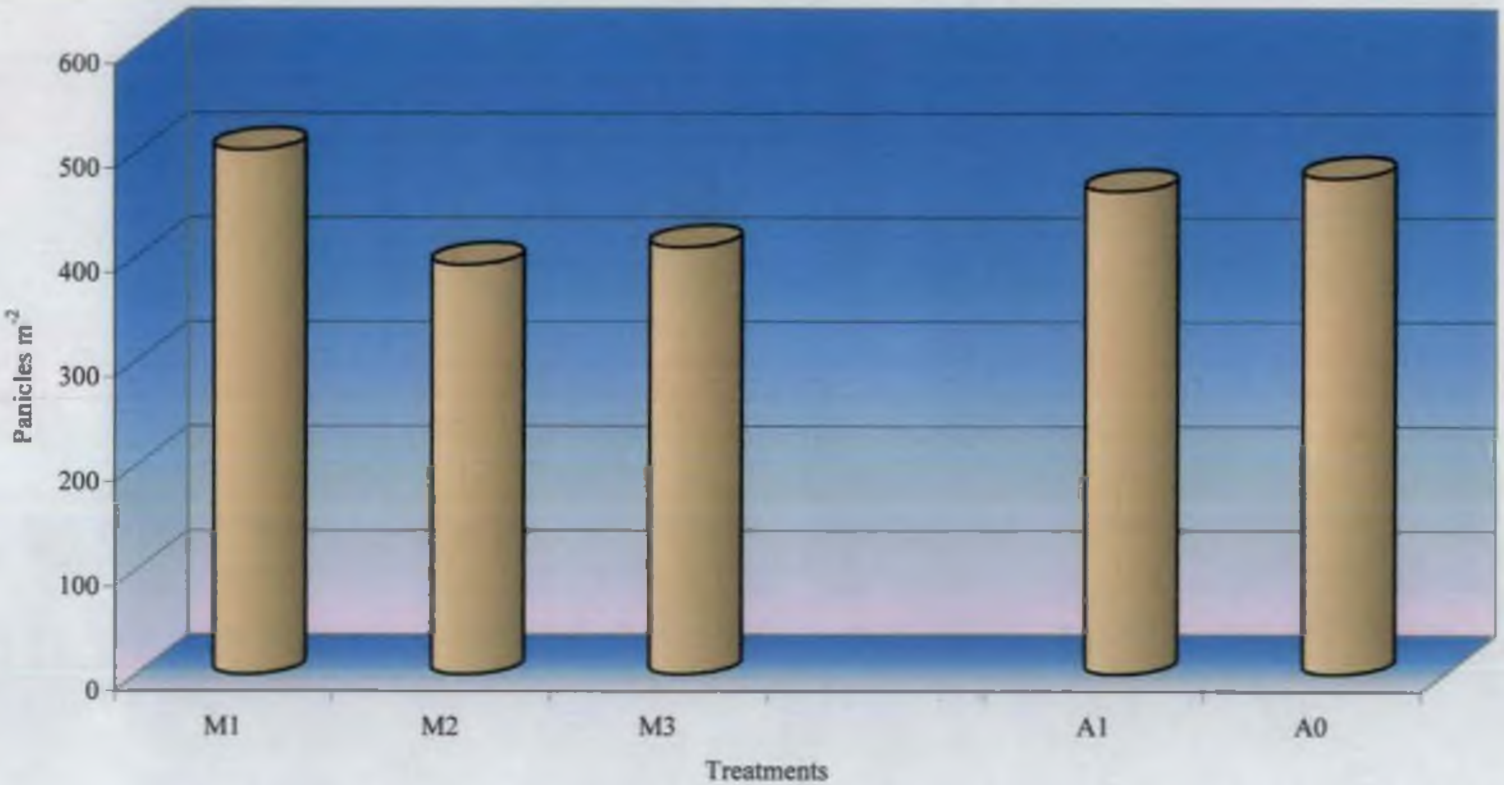

Fig. 8. Effect of planting methods and AMF application on number of panicles m^{-2}

Filled grains panicle^{-1} (Fig.9) and thousand grain weight were higher under line planting and seedling throwing methods. More LAI, consequent increase in photosynthesis and translocation of photosynthates might have enhanced these yield attributing characters in line planting and seedling throwing method. This is in line with the findings of Singh *et al.* (1997).

Increased sterility was noticed in seedling throwing methods. Increased vegetative growth expressed as height (Table 7), LAI (Table 9) and the erratic spatial arrangement of the seedlings due to the seedling throwing method might be the reason for the increased sterility percentage. Similar findings of increased spikelet sterility in seedling throwing method were reported by Sanbagavalli *et al.* (1999) and Shekinah *et al.* (1999).

5.5 EFFECT OF PLANTING METHODS ON YIELD

Line planting and seedling throwing produced higher grain yield (Fig. 10). The increased yield in line planting method is attributed to the more production of filled grains panicle^{-1} and low sterility percentage. Seedling throwing method also produced comparable yield with line planting method. This might be due to the increased number of productive tillers hill^{-1} and more number of panicles m^{-2} and higher thousand grain weight.

Line planting and seedling throwing produced 28.24 and 28.68 per cent more grain yield than machine transplanting respectively. Lesser grain yield was recorded in machine planting due to the production of lesser number of productive tillers, number of panicles hill^{-1}, filled grains panicle^{-1} and thousand grain weight.

Higher straw yield was produced by seedling throwing method (Fig.11). Seedling throwing method has produced 10.25 per cent and

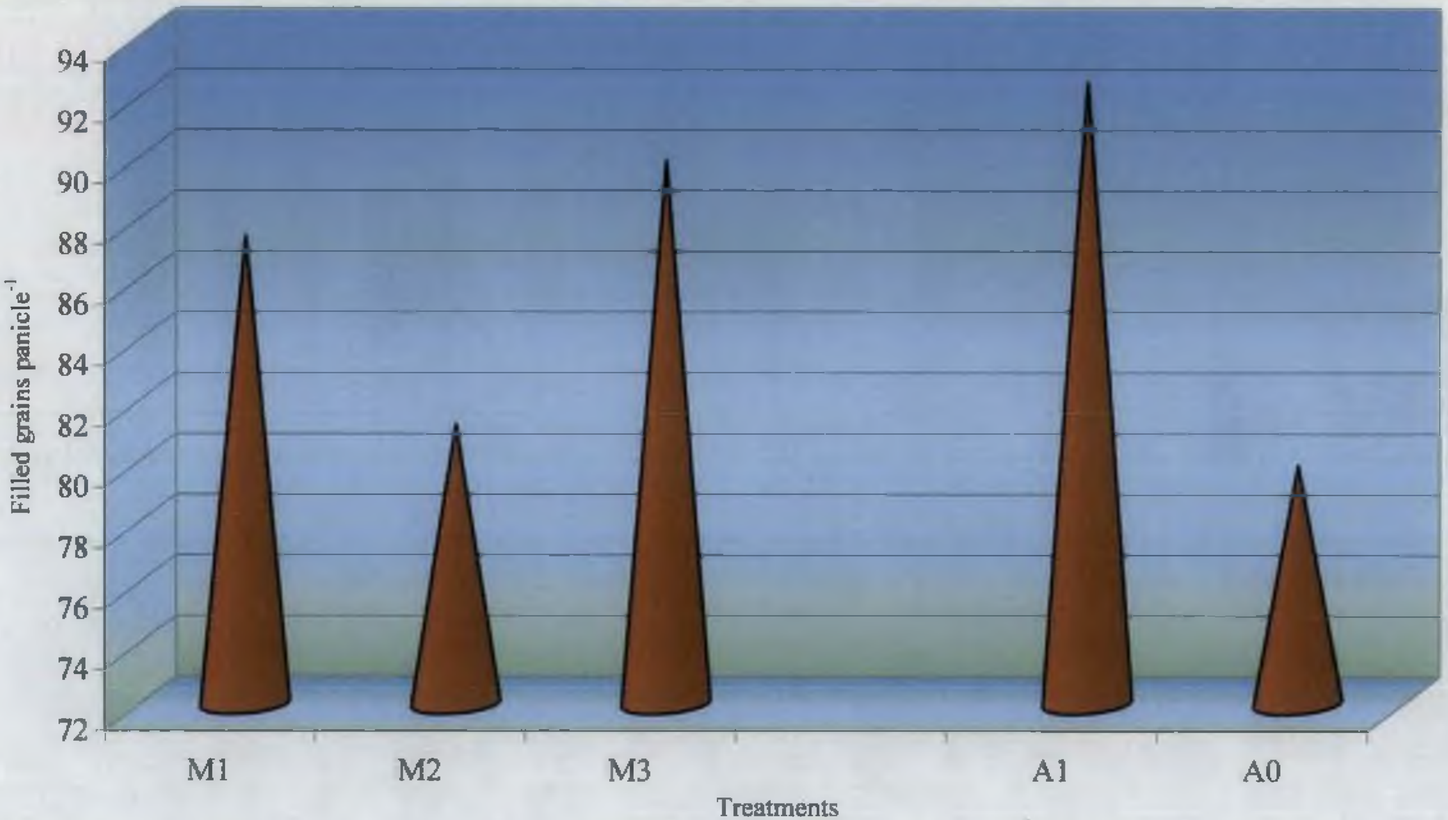

Fig. 9. Effect of planting methods and AMF application on filled grains panicle^{-1}

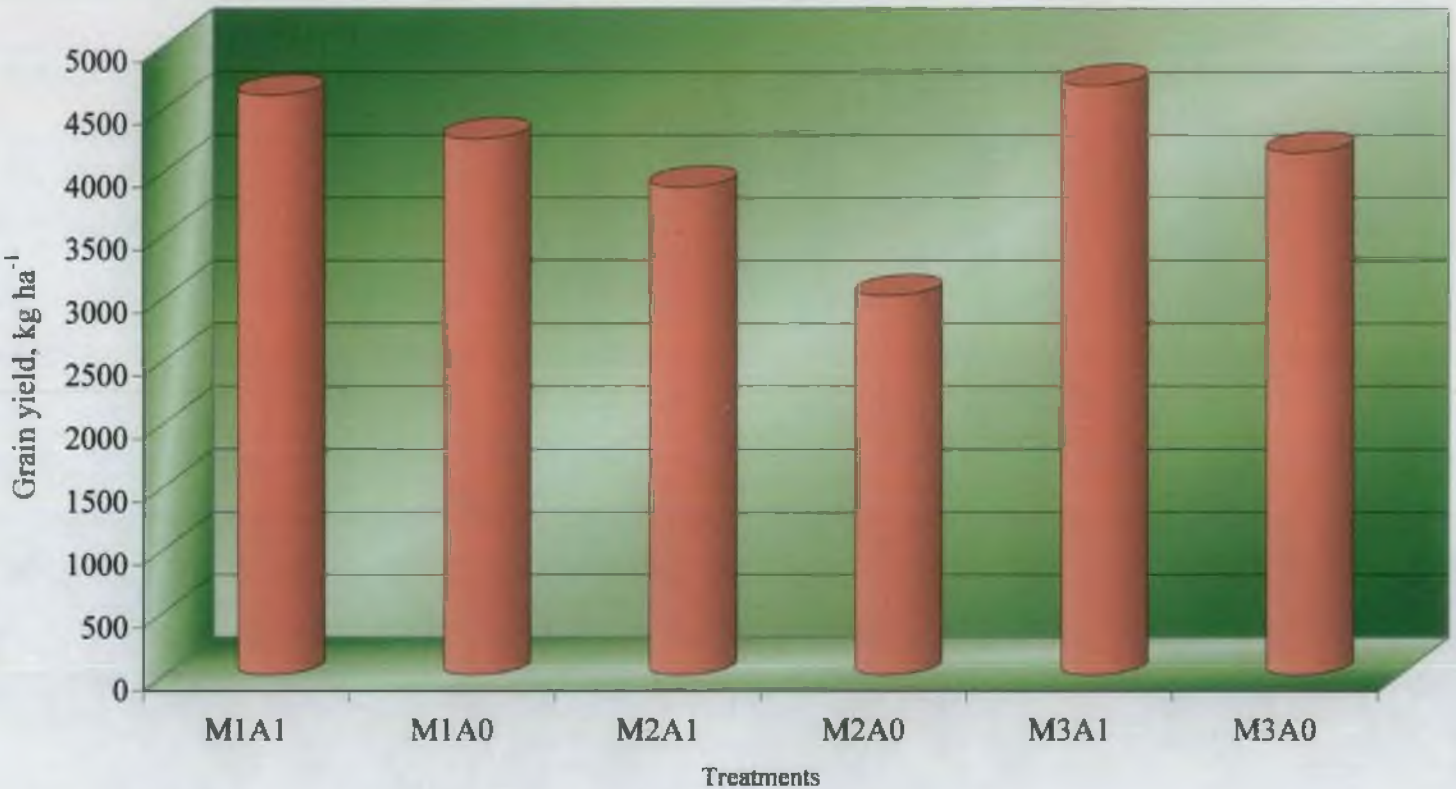

Fig. 10. Interaction effect of planting methods and AMF application on grain yield, kg ha^{-1}

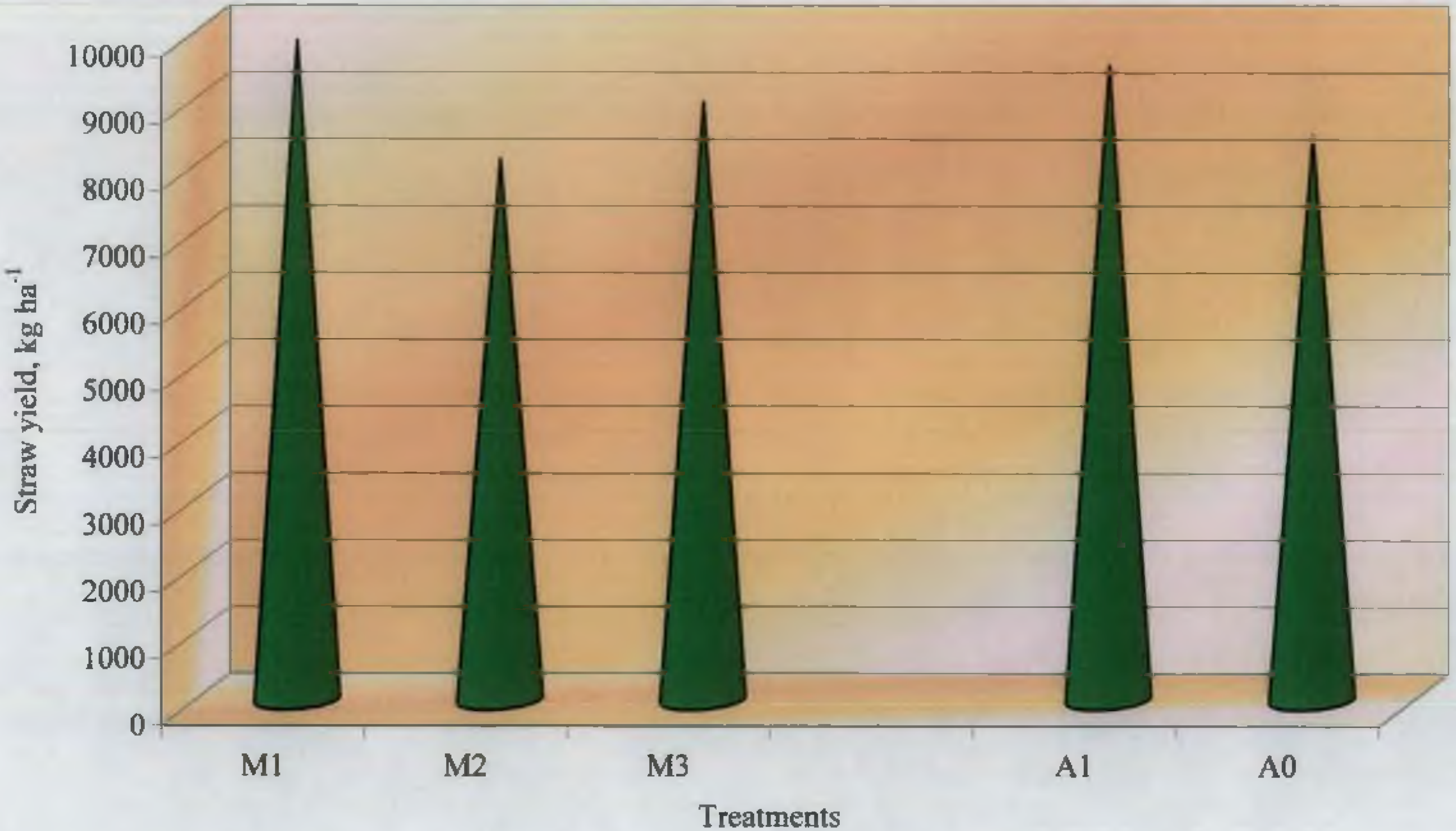

Fig. 11. Effect of planting methods and AMF application on straw yield, kg ha^{-1}

21.83 per cent more straw yield than line transplanting and machine transplanting respectively. The better straw yield noticed may be due to the direct reflection of the positive response of growth attributes like plant height, tiller number, leaf area index and dry matter production.

5.6 EFFECT OF PLANTING METHODS ON HARVEST INDEX

Harvest index represents the energy conversion efficiency of a plant. It is influenced by the amount of assimilates translocated to the earhead during grain filling, which in turn depends on the yield capacity. Line planting recorded the highest and mechanical transplanting recorded the lowest harvest index. Line planting recorded the highest harvest index as the biological yield of this method was less compared to that of seedling throwing method. In seedling throwing method, though the grain yield was high, the harvest index was low due to high biological yield. In machine planting, the grain yield was low and it resulted in a low harvest index.

5.7 EFFECT OF PLANTING METHODS ON NUTRIENT UPTAKE

Nutrient uptake was significantly high under seedling throwing method (Fig.12, 13 and 14). The enhanced root proliferation, more vegetative growth along with enhanced total dry matter production (TDMP) might have resulted in increased uptake of nitrogen, phosphorus and potassium. But in machine transplanted crop, the short stature and reduced vegetative growth resulted in lower nutrient content.

5.8 EFFECT OF PLANTING METHODS ON LABOUR USE EFFICIENCY

Machine transplanting saved 90.9 per cent labour and seedling throwing method saved 63.6 per cent labour over line planting respectively (Fig. 15). In machine planting, mat nursery is used which is

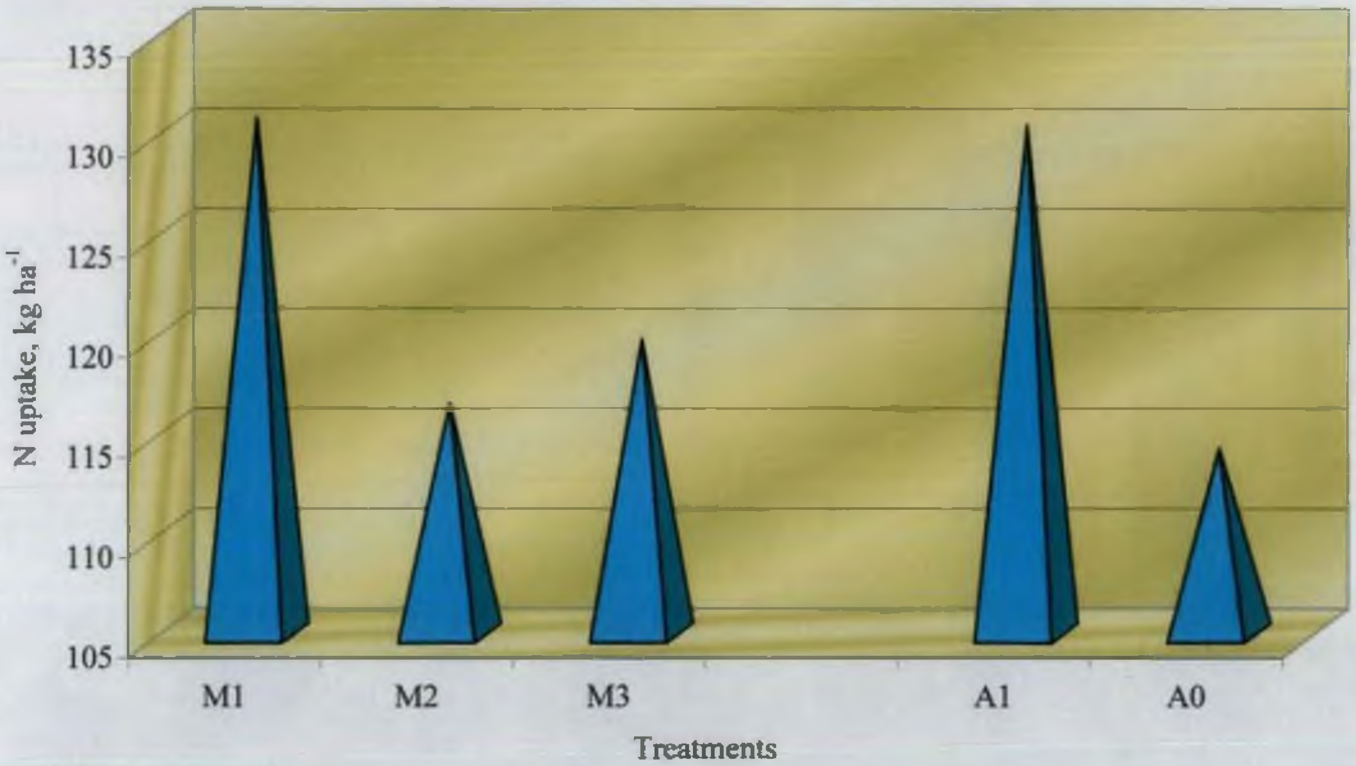

Fig. 12 Effect of planting methods and AMFapplication on nitrogen uptake (kg ha^{-1})

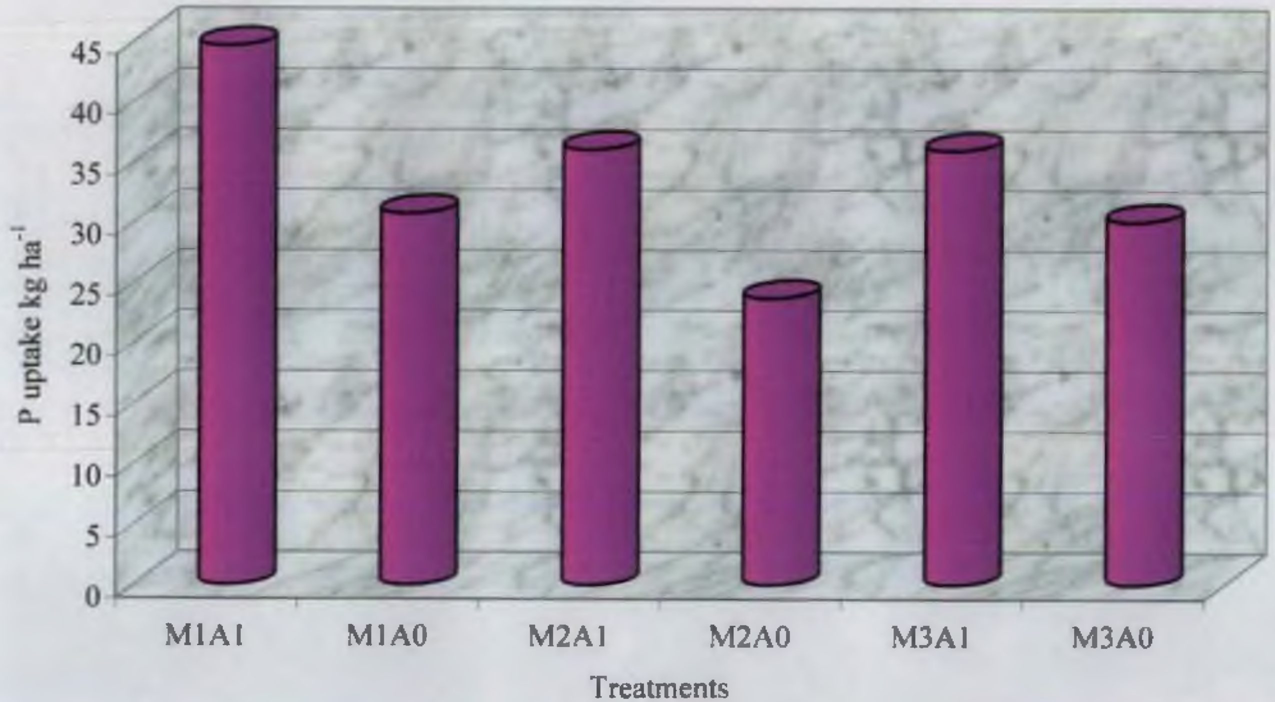

Fig. 13 Interaction effect of planting methods and AMF application on phosphorus uptake, kg ha^{-1}

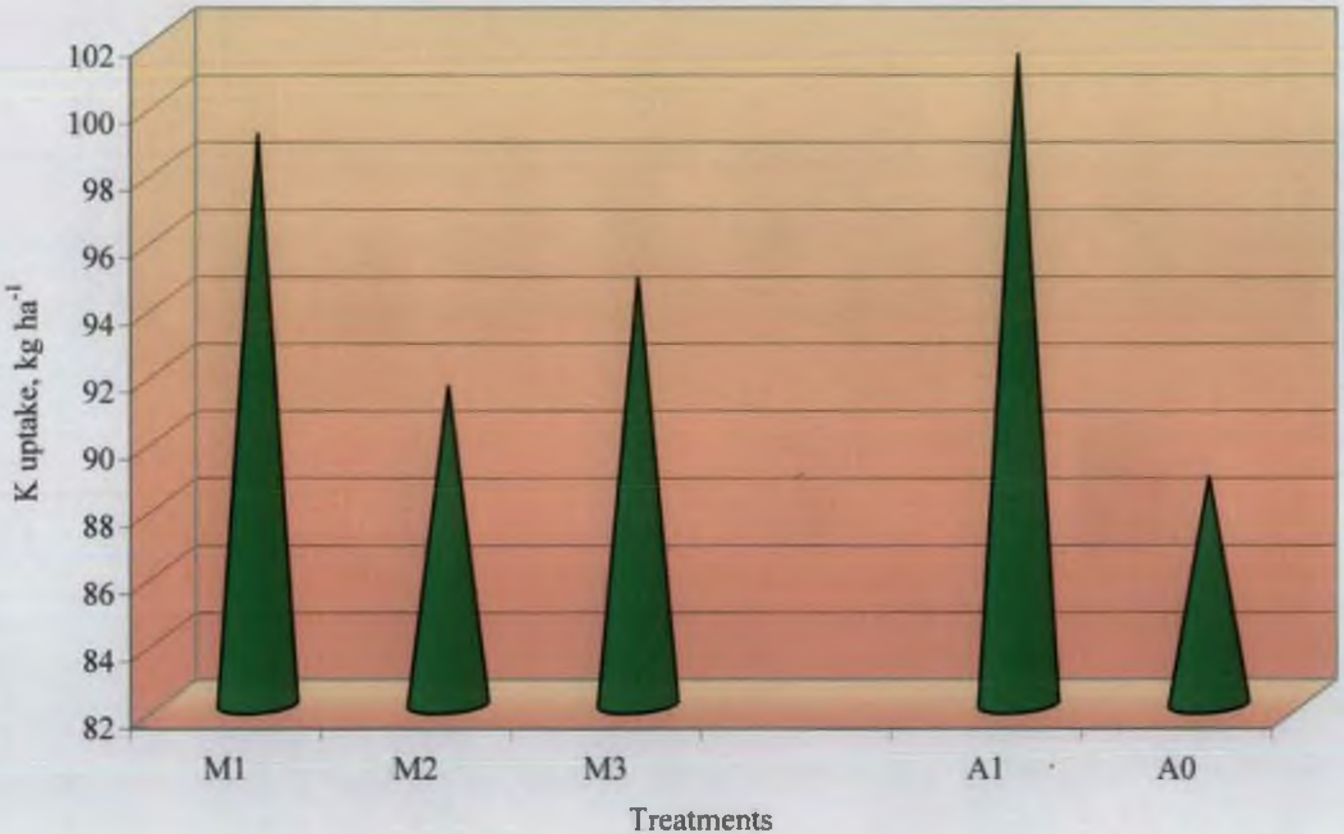

Fig. 14 Effect of planting methods and AMF application on potassium uptake, kg ha^{-1}

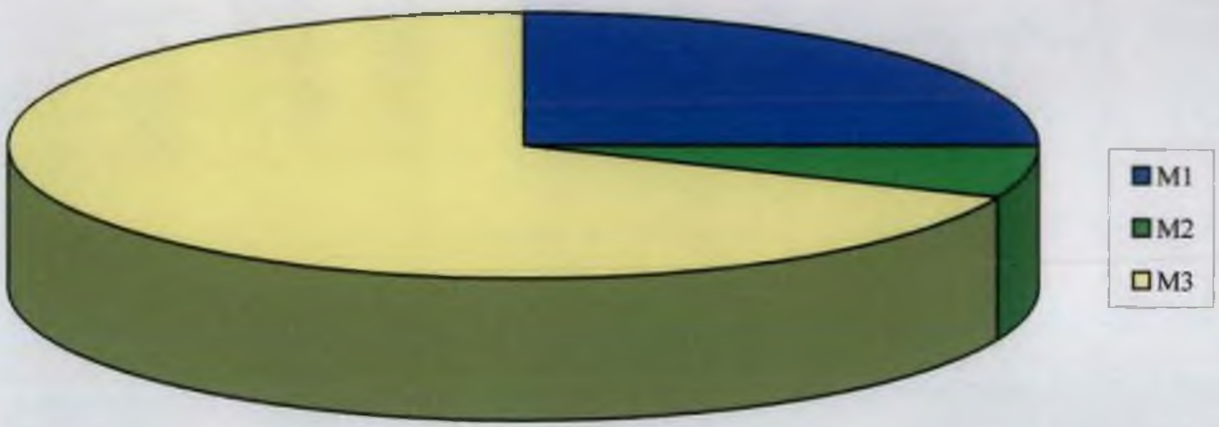

Fig.15. Labour requirement for transplanting, men/women days ha^{-1}

cheap. So the labour required for raising a conventional nursery and pulling of seedling for transplanting can be avoided and more area can be transplanted within a short period of time. Similar findings of labour saving through the use of mechanical transplanter were reported earlier (KAU, 2002). Similarly, Lal *et al.* (1986) and Kathiresan and Narayanasamy (2001) observed that seedling throwing resulted in considerable labour saving over conventional transplanting.

5.9 EFFECTS OF PLANTING METHODS AND AMF APPLICATION ON ECONOMICS OF CULTIVATION

B: C ratio was high in seedling throwing and machine planting methods (Fig.16). This was due to low labour requirement in these methods compared to line planting method.

In line planting, grain production was high but straw production was low when compared to seedling throwing method, which resulted in reduced gross returns in line planting. In seedling throwing method, transplanting cost accounts to only one third of that required in line planting. This increased the net returns in seedling throwing method compared to line planting. Cost of cultivation was low in seedling throwing method because of low labour requirement in transplanting and the ease and quickness of transplanting. Though the gross return in machine planting was low, it registered a higher net returns because of the low cost incurred in transplanting and nursery preparation. This is in conformity with the findings of Manjappa and Kataraki (2002).

5.10 EFFECT OF AMF ON GROWTH CHARACTERS OF RICE

Inoculation of AMF favoured the growth of rice plant than non inoculated plants. This can be possibly explained through the relative values of various growth components *viz.*, plant height, LAI, number of tillers produced, DMP and root characters.

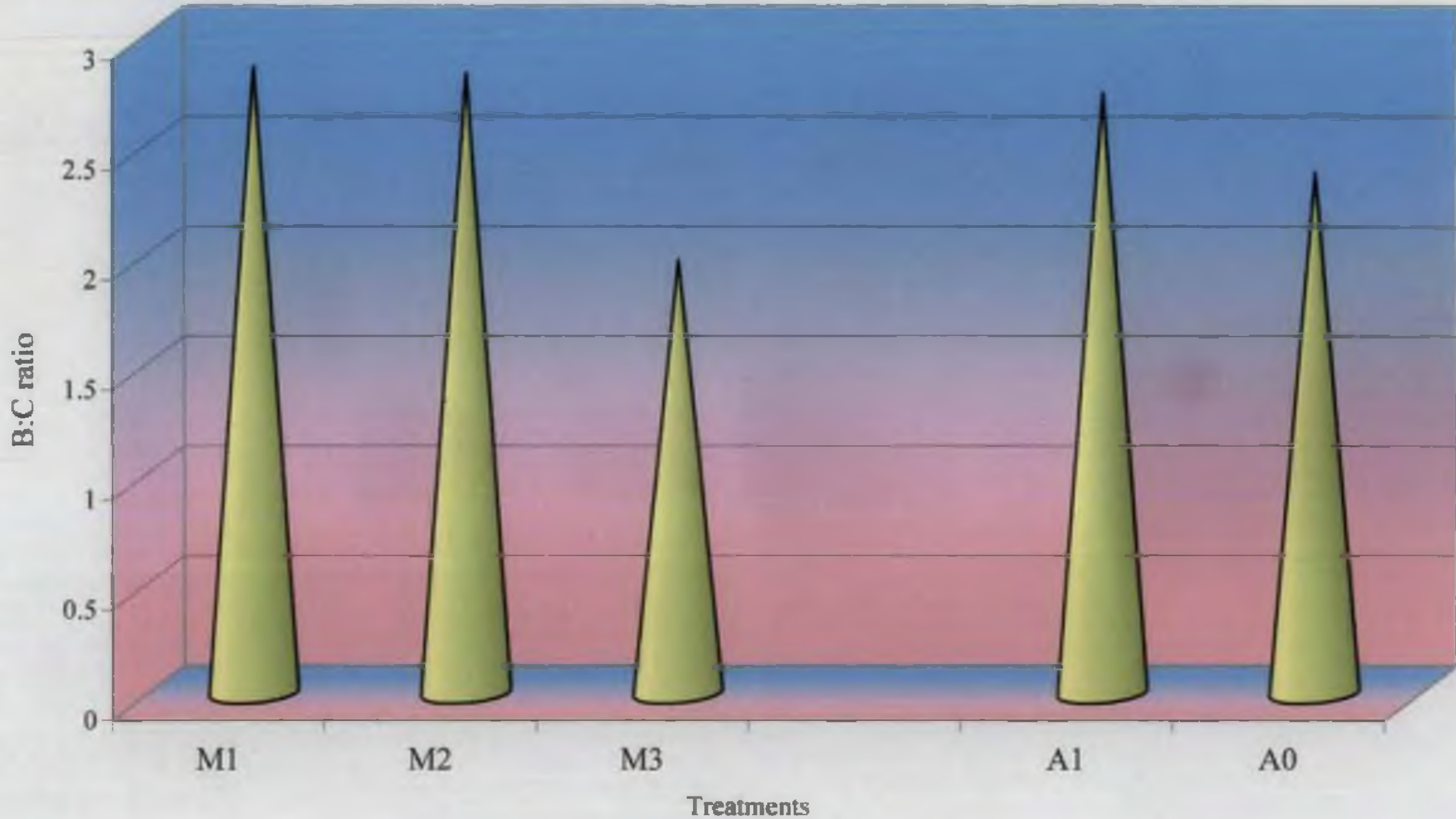

Fig. 16. Effect of planting methods and AMF application on B:C ratio

AMF inoculated seedlings produced more number of tillers, high LAI, dry matter production, productive tillers etc. The higher trend in these characters was due to enhanced root conductivity which led to better uptake of water and nutrients. This is in conformity with the findings of Levy and Kirkun (1980) and Khan *et al.* (1983).

High LAI was noticed in AMF inoculated plants. Effective utilization of resources led to more shoot growth, producing more leaves and tillers resulting in higher LAI. This result is in conformity with the findings of Rana *et al.* (2002).

AMF inoculated plants produced higher DMP at all stages than non inoculated plants. Effective AMF colonization and higher uptake of nutrients resulted in higher dry matter production. This is in accordance with the findings of Singh *et al.* (1997), Khan *et al.* (1988) and Sinha (2000).

5.11 EFFECT OF AMF ON YIELD ATTRIBUTES OF RICE

Yield attributes like number of productive tillers m^{-2}, panicles m^{-2}, 1000 grain weight and number of filled grain panicle^{-1} were higher in AMF inoculated seedlings. Increased uptake of water and nutrients, enhanced translocation of metabolites might have contributed to increased production of productive tillers m^{-2}, panicles m^{-2}, thousand grain weight, number of filled grains panicle^{-1}. This was in line with the findings of Rana *et al.* (2002).

5.12 EFFECT OF AMF ON GRAIN AND STRAW YIELD

Grain and straw yield were higher in AMF inoculated plants. The increase in grain and straw yield in AMF inoculated plants were 15.27 and 11.18 per cent respectively. Higher straw yield in AMF inoculated plants may be resulted from enhanced plant growth and dry matter accumulation. Increased grain yield was due to improved yield attributes *viz.* increased production of productive tillers m^{-2}, panicles m^{-2}, thousand grain weight, number of filled grains $panicle^{-1}$. Higher grain yield in AMF inoculated rice was also reported by Solaiman and Hirata (1997a), Solaiman and Hirata (1997a) and Purakayastha and Chhonkar (2001).

5.13 EFFECT OF AMF INOCULATION ON NUTRIENT UPTAKE

Root conductivity and root activity was more in AMF inoculated plants. The enhanced root proliferation and better nutrient assimilation along with higher total dry matter production might have resulted in increased uptake of nitrogen, phosphorus and potassium in AMF inoculated plants. Similar results were also reported by Khan *et al.* (1988) and Sinha (2000).

5.14 EFFECT OF AMF ON ECONOMICS OF CULTIVATION

B : C ratio, gross income and net return were high in AMF inoculated plants and this may be due to higher grain yield and straw yield compared to non-inoculated plants.

5.15 EFFECT OF PLANTING METHODS AND AMF INOCULATION ON SOIL NUTRIENT STATUS

The planting methods had no significant influence on nutrient status of soil while there was significant influence of AMF on available nutrient status of soil as evident from the data presented in Table 23, 24 and 25. The inoculation of AMF has registered the minimum content of available nitrogen, potassium and maximum available phosphorus status of soil.

The lowest values of available soil nitrogen and potassium might be due to the increased uptake of these nutrients by AMF. In addition to P solubilization, this microorganism could mineralize organic phosphorus into soluble form. Thus microbes rendered more phosphorus into soil solution than that is required for their own growth and metabolism. This might be the reason for increased soil P in AMF received plots.

Similar result of mineralization of phosphorus through the production of organic acids was reported by Levy and Kirkun (1980). Hegde and Dwivedi (1994) also reported enhanced availability of diffusion dependent nutrient like phosphorus by AMF.

SUMMARY

6. SUMMARY

A field investigation was conducted during kharif season (June-September 2003) at College of Agriculture, Vellayani to evaluate the efficiency of different planting methods and AMF application on establishment, growth and yield attributes of rice. .The findings of the investigation are summarised below.

Maximum establishment count was noticed in line planting followed by seedling throwing method. AMF inoculated seedlings established better than non inoculated seedlings.

Higher root length was observed in seedling throwing at all stages. AMF inoculated seedlings have higher root length than non-inoculated plants.

Machine planting recorded higher root volume at flowering stage. AMF inoculated seedlings have higher root volume than non-inoculated stage at all stages.

Seedling throwing recorded higher root-shoot ratio at tillering stage; at flowering stage, higher root-shoot ratio was recorded in machine planting following by line planting. Line planting recorded the highest root-shoot ratio at harvest stage. AMF inoculated plants had higher root-shoot ratio at all stages of growth. The interaction effect was significant at flowering stage; machine planting with AMF inoculation followed by line planting with AMF inoculation recorded higher root shoot ratio.

Higher rate of root colonization was observed in mat nursery. At field level, higher colonization percentage was noticed in seedling throwing method at 14 days and 28 days after transplanting.

Seedling throwing and line planting produced higher number of productive tillers. AMF inoculated plants produced more tillers than non-inoculated seedlings.

Higher number of panicles m^{-2} was observed in seedling throwing method. AMF inoculated plants also produced more number of panicles m^{-2}.

Seedling throwing and line planting methods recorded higher 1000 grain weight. AMF inoculated plants also recorded higher 1000 grain weigh.

Sterility percentage was low in line planting and machine planting but high in seedling throwing method.

Higher grain yield was obtained in seedling throwing method and line planting methods. AMF inoculated plants produced higher grain yield than non-inoculated plants.

Higher straw yield was noticed in seedling throwing and line planting methods. AMF inoculated plants produced more straw than non-inoculated.

Line planting registered higher harvest index followed by seedling throwing method. AMF inoculated plants had higher harvest index than non-inoculated plants.

Uptake of nitrogen, phosphorus and potassium was higher in seedling throwing method followed by line planting method. AMF inoculated plants had higher nitrogen, phosphorus and potassium uptake than non-inoculated plants.

Nitrogen and potassium availability was low in seedling throwing method and AMF applied plots. Higher P status was noticed in AMF applied plots.

Seedling throwing and machine planting recorded higher B:C ratio. AMF inoculated plants also recorded higher B:C ratio.

Higher gross returns were observed in seedling throwing method followed by line planting method. AMF inoculated plants recorded higher gross returns.

Seedling throwing method registered higher net returns by machine planting. AMF inoculated plants also recorded higher net returns.

Future line of work

Potential of AMF in improving the growth and yield parameters in rice should be studied in detail. Practicability of labour saving methods should be analysed for improving the profitability and returns in rice cultivation under Kerala condition.

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EVALUATION OF ESTABLISHMENT METHODS AND AMF APPLICATION ON GROWTH AND YIELD OF RICE

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ABSTRACT

An experiment was conducted at College of Agriculture, Vellayani during kharif season (June – September 2003) to evaluate the efficiency of different planting methods and AMF application on the establishment, growth and yield attributes of rice. The experiment was laid out in split plot design with five replications. The main treatments were seedling throwing, machine planting and line transplanting methods. The subplot treatments consisted of AMF application and without AMF application.

Maximum establishment as noticed in line planting. More root activity, plant height, leaf area index, dry matter production and tillers were observed in seedling throwing method.

Days to 50 per cent flowering was minimum in machine planting. Higher number of filled grains per panicle was observed in line planting. Higher number of productive tillers, panicles m^{-2} and straw yield was observed in seedling throwing method. Higher grain yield was observed in seedling throwing and line planting methods. Maximum harvest index was noticed in line planting. Higher uptake was noticed in seedling throwing method.

AMF inoculated plants showed superior trends in establishment count, plant height, leaf area index, drymatter production, number of tillers, productive tillers, panicles m^{-2}, filled grains $panicle^{-1}$, 1000 grain weight, grain yield and straw yield.

Higher gross return and net return was observed in seedling throwing method. In machine planting and seedling throwing there was high labour saving compared to line planting. High B : C ratio, gross return and net return were observed in AMF inoculated plants.

Machine planting of seedlings raised in AMF inoculated mat nursery, at a spacing of 30 x 10 cm followed by seedling throwing of AMF inoculated seedlings recorded higher B : C ratio.

APPENDIX

APPENDIX I

Weather parameters during the cropping period
(May 22nd 2003 to September 5th 2003)

Standard weeks	Maximum temperature, °C	Minimum temperature, °C	Rainfall, mm	RH, %	Evaporation, mm
21	32.30	25.80	2.6	78.1	4.5
22	33.00	25.90	1.4	75.4	4.5
23	33.00	25.00	6.8	76.8	4.6
24	31.40	24.30	44.6	79.3	3.6
25	30.20	23.40	129.8	84.1	3.1
26	30.80	23.80	31.6	79.7	3.6
27	34.20	23.20	28.7	79.7	2.7
28	32.00	23.70	21.4	81.6	3.8
29	30.30	23.70	43.2	77.0	3.3
30	30.80	24.30	14.1	82.9	3.0
31	31.00	24.30	23.1	83.6	3.6
32	30.90	24.50	11.0	80.6	3.8
33	31.60	24.40	1.4	77.1	4.4
34	30.40	24.50	44.5	82.7	3.6
35	30.10	23.40	23.1	91.6	4.0
36	30.90	23.70	4.6	80.0	4.2
37	31.30	23.60	3.1	77.5	4.7
38	31.80	24.30	0	75.0	5.2
39	32.20	24.30	0	71.8	5.2
40	29.90	23.80	222.8	86.6	3.0