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INTEGRATED NUTRIENT MANAGEMENT FOR ARROW ROOT (*Maranta arundinacea* L.) UNDER PARTIAL SHADE

By

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DECLARATION

I hereby declare that this thesis entitled "**Integrated nutrient management for arrow root (*Maranta arundinacea* L.) under partial shade**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

Vellayani,

23-10-2000

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CERTIFICATE

Certified that this thesis entitled "**Integrated nutrient management for arrow root (*Maranta arundinacea* L.) under partial shade**" is a record of research work done independently by Ms. Veena Vidyadharan under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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My Parents

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

@	At the rate of
AMF	Arbuscular Mycorrhizal Fungus
ANOVA	Analysis of variance
BCR	Benefit-cost ratio
^{0}C	Degree Celsius
cv	Cultivar
CD	Critical difference
cm	Centimetre
CTCRI	Central Tuber Crops Research Institute
CCP	Composted coir pith
DAP	Days after planting
DMP	Dry matter production
FYM	Farmyard manure
Fig.	Figure
g	gram
ha	hectare
ha^{-1}	per hectare
K	Potassium
kg	kilogram
KAU	Kerala Agricultural University
LAI	Leaf area index
m	metre
mm	millimetre
MAP	Months after planting
%	per cent
N	Nitrogen
P	Phosphorus
RBD	Randomised Block Design
t	Tonnes
TNAU	Tamil Nadu Agricultural University
UI	Utilization index
VC	Vermi compost

INTRODUCTION

INTRODUCTION

Arrow root (*Maranta arundinacea* L.), commonly known as West Indian arrow root,is an unexploited minor tuber crop. The name arrow root appears to have been derived from the Carib word 'arunda' meaning mealy roots. Its use as an antidote for arrow poisoning as well as the pointed shape of the rhizomes contribute its name 'arrow root'. It is an erect herbaceous plant belonging to the family Marantaceae. It produces long, fleshy and cylindrical subterraneous rhizomes which taste like corn when boiled.

The economic part rhizome contains on an average 20 per cent starch (Raymond and Squires, 1959). It is valued as a foodstuff as well as a source of starch for the preparation of various bakery products, special glue and paste, as a base for face powder, as ice cream stabiliser and in carbonless paper used for computer print outs. In addition,it has some medicinal values. The starch possesses demulcent properties and is used in the treatment of intestinal disorders. It is employed in the preparation of barium meals. The fibrous material which remains after the extraction of starch is used as cattle feed or manure.

In India, arrow root is cultivated in Uttar Pradesh, Bihar, Orissa, West Bengal, Assam and Kerala. It is conventionally grown in the homesteads of Kerala. The area under the crop in Kerala is estimated to be about 200 ha (Vimala, 1994). The crop comes up well under shaded conditions in coconut garden. The coconut palm utilizes only 25 per cent of the land area and 30 cm surface soil is practically free of functional roots (Nair, 1979). Over 80 per cent of the active roots of the coconut are confined within an area of 2 m radius around the palm (Wahid *et al.*, 1993). Arrow root being a shallow rooted crop, can be grown successfully in the coconut garden without much competition for inputs. No serious pests and diseases are noted for the crop. Extraction of starch can be done even in households adopting a simple procedure. It serves as a raw material for cottage industries, providing employment for unemployed women and rural youth. Thus the necessity for the increased cultivation of the crop arises. Considering the need for producing more food, fodder, medicine and other basic necessities for rapidly increasing population, Nair (1984), Randhawa (1988) and Paroda (1988) emphasized the importance of popularizing potentially useful under exploited plant species.

The crop is generally grown with very little attention utilising the residual moisture and nutrients. But studies have shown that it responds well to application of nutrients (Kay, 1973 ; Ramesan, 1991 and Maheswarappa *et al*., 1997). There is great scope for increasing the yield of arrow root by adopting a suitable nutrient management schedule.

An integrated nutrient supply is important to maintain and sustain higher levels of soil fertility and crop productivity. The use of organic manure will help to correct marginal deficiencies of secondary and micronutrients and provide favourable physical and biological conditions in the soil. Among the organics, farmyard manure (FYM) is the most commonly used bulky organic manure. The conjunctive use of both organic and inorganic sources of nutrients will meet the nutritional deficiencies which are likely to occur due to continuous and intensive cultivation.

With this background the present investigation was taken up to study the efficacy of conjoint use of varying levels of organic manure and fertilizers for yield improvement of arrow root under partial shade and to work out the economics of cultivation.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Arrow root is cultivated as an intercrop under the partial shade of perennials with low levels of inputs and management. This crop is also free from any major pests and diseases. Hence there is great scope for extending its cultivation in India (Mohankumar *et al.*, 2000). The crop is very much suited as an intercrop in coconut garden. Also, it was found to respond well to nutrient application. Experimental evidences on nutrient requirement of this crop are meagre. The relevant literature on the effect of various levels of organic manure and fertilizers on growth characters, yield, quality of produce and nutrient uptake by the crop are reviewed in this chapter. Wherever information is lacking pertinent literature on other crops has been reviewed.

2.1 Effect of varying levels of nutrients

2.1.1 Growth characters

2.1.1.1 Nitrogen

Purseglove (1968) observed that N at higher rates increased plant height and number of leaves at all growth stages of arrow root. Kay (1973) reported an increase in growth characters due to increased dose of N application in arrow root. Ramesan (1991) also reported increase in growth characters of arrow root with incremental doses of N upto 150 kg ha^{-1} when grown as a pure crop.

In cassava intercropped in coconut garden, increased rates of N fertilization enhanced plant height, nodes per plant, functional leaves per plant and LAI (Nayar, 1986). Application of varying levels of N upto 80 kg ha^{-1} had significant effect in increasing plant height and LAI of taro (Mohankumar, 1986).

Nair (1964) and Pandey (1993) reported significant influence of N on plant height and number of suckers in turmeric. But they observed that N had no significant effect on number of leaves per plant. Tillering was enhanced by incremental doses of N application as observed by Rao (1973) and Saifudeen (1981). Application of 120 kg N ha^{-1} increased the plant height, number of leaves, tillers and leaf area in turmeric (Balashanmugham and Chezhiyan, 1986).

In ginger, an increasing trend in LAI with increasing N dose was reported by Randhawa and Nandpuri (1969). Application of N @ 100 kg ha^{-1} recorded maximum plant height and number of branches. According to Muralidharan *et al.* (1974) 70 kg N ha^{-1} significantly increased the number of tillers in ginger. There was progressive increase in plant height and number of tillers per plant with an increase in N applied upto 90 kg ha^{-1} as reported by Aclan and Quisumbing (1976). Johnson (1978) opined that higher levels of N had a significant effect on DMP in ginger. Lee *et al.* (1981) reported that N application significantly increased the number of third order shoots and fourth order rhizome branches in ginger.

2.1.1.2 Potassium

Purseglove (1968) and Kay (1973) reported increased plant height and leaf number with increased doses of K in arrow root. Positive influence of K upto 150 kg K_2O ha^{-1} on plant height, sucker number and LAI was noted by Ramesan (1991) in arrow root.

In colocasia, Premraj (1980) observed increase in plant height, stem girth, leaf number and leaf area with increasing levels of K. Ashokan and Nair (1984) noticed no significant influence of higher levels of K on plant height and number of leaves produced by taro. They also noticed that number of suckers per plant was maximum and significantly superior with 80 kg K_20 ha^{-1} compared to 40 and 120 kg K_2O ha^{-1}. Mohankumar and Sadanandan (1989) reported that potash application upto 100 kg ha^{-1} had significant effect in increasing plant height and LAI in taro.

Nayar (1986) observed that higher rates of K decreased plant height of cassava intercropped in coconut garden. But he noted an increase in LAI due to K application upto 100 kg K_2O ha^{-1}.

Potassium, when applied @ 70 kg ha^{-1} produced significant effect on plant height and number of suckers in turmeric (Nair, 1964 and Rao, 1973). According to Saifudeen (1981), tiller production in turmeric was influenced by incremental doses of K application, but number of leaves produced per tiller and height of plants were not affected. Application of higher levels of K @ 240 kg ha^{-1} recorded the highest plant height, tiller number, number of leaves and number of mother, primary and secondary rhizomes in turmeric

(Rathinavel, 1983). Rao and Swamy (1984) observed that when the rate of K was increased from 50 kg to 200 kg ha^{-1} the height of the turmeric plant also increased significantly. On the contrary, Muralidharan *et al.* (1974) noticed that a higher dose of K reduced the height of ginger plants.

2.1.1.3 Combined effects

Increasing trend in the growth characters of arrow root raised as pure crop was observed by Ramesan (1991) with increasing levels of fertilizers upto 150 kg each of N and K_2O ha^{-1}.

Geetha (1983) opined that 60 kg N and 120 kg K_2O along with 30 kg P_2O_5 ha^{-1} were sufficient to produce the highest dry matter yield in coleus.

Pushpakumari (1989) reported that leaf number and plant height of tannia and elephant foot yam intercropped in the coconut garden were not significantly influenced by the fertilizer levels but for greater yam there was significant increase in the plant height with increased fertilizer levels.

Different growth attributes of taro viz., plant height, leaf number and LAI were maximum when 60 kg N ha^{-1} and 160 kg K_2O ha^{-1} were applied in the open condition. Under intercropped situation 40 kg N ha^{-1} and 160 kg K_2O ha^{-1} recorded the maximum values of these characters (Rajasree, 1993).

An increasing trend in the number of tillers as well as leaf production with increasing levels of fertilizers applied upto 40: 40: 80 kg NPK ha^{-1} was observed in turmeric grown under shaded conditions. However NPK @

30:30:60 kg ha^{-1} recorded the maximum height in the shade and NPK @ 20:20:40 kg ha^{-1} in the open (KAU, 1983).

Ajithkumar (1999) observed that tillering, leaf number and LAI in ginger increased with increasing fertilizer levels.

2.1.2 Yield and yield components

2.1.2.1 Nitrogen

Purseglove (1968) stated that arrow root should receive 350-650 kg sulphate of ammonia per hectare for producing higher yield. A dose of 70 kg N ha^{-1} was sufficient for producing better yields in arrow root as observed by Kay (1973). Ramesan (1991) recommended a dose of 150 kg N ha^{-1} for arrow root when grown as a pure crop.

In turmeric, Nair (1964) reported that 82.5 lb N $acre^{-1}$ recorded the highest yield. Aiyadurai (1966) found that application of 100 kg ha^{-1} of ammonium sulphate doubled the yield in turmeric over that of unmanured crop. A dose of 100 kg N ha^{-1} was sufficient for the production of maximum yield in turmeric as observed by Muralidharan and Balakrishnan (1972). Shah and Muthuswamy (1981) recommended application of 140 kg N ha^{-1} along with 10 t ha^{-1} of FYM for maximum production of turmeric. Increase in N levels upto 120 kg ha^{-1} significantly increased the fresh rhizome yield in turmeric (Umate *et al.*, 1984; Balashanmugham and Chezhiyan, 1986). However Govind *et al.* (1990) noted that application of N @ 40 kg ha^{-1} produced significantly higher yield in turmeric. But Pandey (1993) obtained maximum yield of fresh rhizome in turmeric by the application of 160 kg N ha^{-1}.

Significant increase in the yield of ginger was reported by the application of 70 kg N ha^{-1} (Muralidharan *et al.*, 1974). The yield of ginger doubled when the N level was increased from 30 to 90 kg ha^{-1} (Aclan and Quisumbing, 1976). Sadanandan and Sasidharan (1979) found that the highest yield of ginger was recorded at 60 kg ha^{-1} and further increase in N levels decreased the yield.

2.1.2.2 Potassium

Purseglove (1968) reported that arrow root crop should receive 180 kg K_2O ha^{-1} for producing maximum yield. Kay (1973) recommended K application @ 126 kg ha^{-1} for producing better yields of arrow root. According to Ramesan (1991), arrow root require 150 kg K_2O ha^{-1} for producing maximum yield.

An increase in the number of cormels per plant was observed by Pillai (1967) at enhanced rate of K application in taro. Ashokan and Nair (1984) obtained positive response of yield and yield attributes with higher levels of K application in taro.

Nair (1964) opined that K played a major role in increasing the yield of turmeric than N and P and optimum level of K required for maximum yield was 160.5 lb $acre^{-1}$. Muralidharan and Balakrishnan (1972) observed that the yield of turmeric was influenced by incremental doses of K and that 200 kg K_2O ha^{-1} produced the maximum yield of rhizome. Similarly, Rao and Reddy (1977) obtained a linear response to higher doses of K and the highest yield was recorded by 237.5 kg K_2O ha^{-1}. But Saifudeen (1981) concluded that K had no significant influence on the rhizome yield of turmeric.

Rathinavel (1983) observed that application of K significantly increased the yield of turmeric and the highest level of K (240 kg K_2O ha^{-1}) recorded the highest yield. Rao and Swamy (1984) obtained maximum yield of fresh rhizome of turmeric from the plots receiving 200 kg K_2O ha^{-1}. Muthuvel *et al.* (1989) did not observe any significant effect due to varying levels of K on turmeric and suggested that 60 kg K_2O ha^{-1} was adequate. A dose of 90 kg K_2O ha^{-1} in four splits recorded higher yield of rhizomes in turmeric as reported by Thamburaj (1991).

Pawar and Patil (1987) obtained the highest yield in ginger with the application of 180 kg K_2O ha^{-1}. Maity *et al.* (1988) observed maximum yield of ginger from plots receiving 90 kg K_2O ha^{-1}.

2.1.2.3 Combined effects

Ramesan (1991) reported that maximum yield of a pure crop of arrow root (14 t ha^{-1}) was recorded when N, P_2O_5 and K_2O were applied @ 150, 75 and 150 kg ha^{-1} respectively. According to CTCRI (2000) the highest tuber yield of 13.34 t ha^{-1} could be obtained in arrow root under rainfed condition with the application of 50: 25: 75 kg NPK ha^{-1} in a coconut plantation.

Nayar (1986) and Ravindran (1997) observed that application of 50:50:100 kg NPK ha^{-1} was sufficient for the cassava variety Sree Visakham intercropped in coconut garden as against the recommended dose of 100 :100:100 kg NPK ha^{-1} for a pure crop.

Mohankumar *et al.* (1990) reported that in acid laterite soils of Kerala, a fertilizer dose of 80 kg N, 25 kg P_2O_5 and 100 kg K_2O per ha was found beneficial for higher yield of cormels in colocasia. According to Rajasree (1993), under open condition, the yield attributes of colocasia viz., number of cormels per plant and harvest index had maximum values when 60 kg N and 160 kg K were given per ha. In the intercropping situation the highest values were obtained when N and K were applied @ 40 and 160 kg ha^{-1} respectively.

In an experiment conducted to find out the optimum dose of fertilizers for yams and aroids grown under partial shade in coconut garden, greater yam recorded maximum yield with full dose of fertilizers, lesser yam with 75 per cent of the recommended dose and elephant foot yam with 50 per cent of the recommended dose of fertilizers for open situation (Pushpakumari and Sasidhar, 1992).

In turmeric, higher levels of fertilization resulted in increased yields of raw turmeric from 24 to 30 t ha^{-1} (Reddy and Rao, 1978). Singh and Lynarh (1991) suggested that application of 80 kg N and 80 kg K_2O ha^{-1} forms an optimum dose of fertilization in turmeric.

Saha (1989) obtained the highest yield of fresh ginger rhizomes with 90:60:90 kg NPK ha^{-1}. But Mohanty *et al.* (1992) obtained maximum yield of ginger with 125:70:150 kg NPK ha^{-1}. Significant increase in yield due to application of NPK in ginger was realised by Sadanandan and Hamza (1996). Among the different fertilizer levels tried for ginger intercropped in the coconut garden, Ajithkumar (1999) obtained maximum yield with 150:100:100 kg NPK ha^{-1}.

2.1.3 Quality characters

2.1.3.1 Nitrogen

According to Ramesan (1991), the quality characters like starch, protein and crude fibre contents of arrow root were increased by higher levels of N and 150 kg N ha^{-1} resulted in the maximum values.

Pillai (1967) reported that application of N significantly increased the starch content of corms in colocasia. Similarly Ashokan and Nair (1984) observed that starch content of colocasia cormels increased significantly with increase in N application.

Tsuno and Fujise (1965) suggested that N application should be moderate for producing tubers of high starch content in sweet potato. Knavel and Lasheen (1969) observed significant decline in both total sugars and starch content in sweet potato as a consequence of increased dose of N supply. In sweet potato, Mandal et al. (1971) observed maximum starch content at the N dose of 75 kg ha^{-1}.

Vijayan and Aiyer (1969) noted a decrease in starch content of cassava tubers with increase in N beyond 75 kg ha^{-1}. Obigbesan and Agboola (1973) found increase in starch content with higher dose of N in one variety of tapioca while it decreased in another variety. Prema *et al.* (1975) also obtained increase in starch content of cassava tubers with increase in N application. Ramanathan *et al.* (1980) reported that starch content was significantly increased in cassava tubers by applied N. But Nayar (1986) observed a depressing effect of higher levels of N on the starch content of tubers of cassava intercropped in coconut garden.

Patel and Mehta (1987) found that applied N increased the starch content in corms of elephant foot yam. Geetha and Nair (1993) observed no significant effect of N on the starch content of coleus, though a negative correlation was observed with increasing levels of N application.

Vijayan and Aiyer (1969) and Prema *et al.* (1975) found that protein content of cassava tubers increased with increase in N application. There was no significant influence of N in protein content of sweet potato as reported by Muthuswamy and Krishnamoorthy (1976). But Nambiar *et al.* (1976) found that in sweet potato protein content increased with increasing levels of applied N and was maximum in the treatment where 100 kg was applied. Mandal *et al.* (1982) observed that protein content of colocasia tuber increased with increase in the rates of N applied. Similar finding was reported by Geetha and Nair (1993) in coleus.

Aclan and Quisumbing (1976) reported that N has no influence on fibre content of ginger rhizome Similar result in ginger was also reported by Nair and Das (1982).

2.1.3.2 Potassium

Ramesan *et al.* (1996) reported that increasing K levels had a positive effect on starch and protein contents of arrow root but the fibre content showed a declining trend.

Application of K enhanced the starch content of cassava tubers (Mohankumar *et al.*, 1971; Muthuswamy and Rao, 1980; Mandardo *et al.*, 1984 and Nair and Aiyer, 1986). Ashokan and Sreedharan (1977) obtained maximum starch content of cassava tubers at 112.5 kg K_2O ha^{-1}.

Premraj (1980) found that K increased the starch content of colocasia tuber. Mohandas and Sethumadhavan (1980) reported that higher levels of K upto 150 kg ha^{-1} had a positive influence on starch content of taro tubers compared to 90 kg ha^{-1}. On the contrary Ashokan and Nair (1984) observed that dry matter percentage and starch content were not positively influenced by K levels in colocasia.

Ashokan and Sreedharan (1977) reported that there was gradual reduction in the crude protein content of cassava tubers with increased K levels. Similar result was reported by Shyu and Chang (1978) in *Dioscorea alata*.

Muthuswamy (1983) reported that increasing levels of K had no influence on crude protein content in elephant foot yam. But Sharafuddin and Voican (1984) found that protein content was increased with increasing levels of K in sweet potato. Corroboratory result has been reported by Geetha and Nair (1993) in coleus.

According to Muthuswamy (1983) increasing levels of K had no influence on crude fibre content in elephant foot yam. Nair and Aiyer (1985) recorded negative response of fibre content in cassava with increase in the levels of K upto 100 kg ha^{-1}.

2.1.3.3 Combined effects

Starch yield of arrow root rhizome was found to be influenced by the levels of N, P and K and it was maximum with 150 kg N, 75 kg P_2O_5 and 150 kg K_2O per ha^{-1}. (Ramesan, 1991).

Mazur and Dworakwoski (1979) found that increasing rates of NPK tended to decrease the starch content of potato tuber. Geetha (1983) obtained maximum starch content of coleus tubers with 30 kg N and 90 kg K_2O ha^{-1}.

The different levels of N, P and K failed to produce any significant variation in the starch content of mango ginger rhizome (Mridula, 1997). Higher levels of N and P enhanced the starch content of the rhizomes of ginger intercropped in the coconut garden (Ajithkumar, 1999).

According to Singh (1993) starch is composed of a linear molecular component, amylose and a branched chain component, amylopectin. The ratio of amylose to amylopectin in starch is characteristic of plant species and is under genetic control. But Paule (1977) stated that the same rice variety grown under different environment can fall into different amylose groups.

Moorthy (2000) has reported that the amylose content in different tuber crops ranges from 10-25 per cent and variation is observed among various environmental conditions and method used for amylose determination. High amylose is often related to low stickiness of starch and better film forming capacity. Various applicationsof starch depends on their film forming capacity.

Mandal *et al.* (1969) reported that crude protein content showed an increase upto 80 kg N and 40 kg K_2O ha^{-1} in *Dioscorea esculenta.* Carvenho *et al.* (1983) observed no significant effect of fertilizer on the protein content of sweet potato.

There was no significant effect of fertilizers on crude fibre content of sweet potato as reported by Carvenho *et al.* (1983). Similar results were reported by Sasidharan (1985) in lesser yam.

Aclan and Quisumbing (1976) stated that none of the 3 elements N, P and K influenced fibre content of ginger rhizome. The quality of ginger rhizome was not adversely affected by increased levels of fertilizers application (Ancy and Jayachandran, 1993). Mridula (1997) noticed that increasing levels of N and P increased the fibre content of rhizomes of mango ginger. But with higher dose of K, a low fibre content was observed.

2.1.4 Nutrient content and uptake

2.1.4.1 Nitrogen

Nair *et al.* (1976) realised that in sweet potato total N content increased with applied N. The total N in ginger shoots and rhizome increased with increasing N application (Lee *et al.*, 1981). Saifudeen (1981) found that varying levels of N did not significantly influence the N uptake in turmeric

According to Lynarh (1991) nitrogenous fertilizer application improved the vigour of turmeric plant and resulted in increased uptake and accumulation of other nutrients in the rhizome.

Muthuswamy and Krishnamoorthy (1976) reported that N applied had no significant influence on phosphorus content of sweet potato.

Varying levels of N did not influence the content of K or its uptake in the leaf, pseudostem and rhizome of turmeric (Saifudeen, 1981). He also observed that the total uptake of K was not significantly influenced by different levels of N.

Significant effect of N application on the uptake of N, P and K in taro was observed by Mohankumar (1986). Singh *et al.* (1992) found that application of 80 kg N ha^{-1} had better effect on N, P and K accumulation in the rhizomes of turmeric.

2.1.4.2 Potassium

Saifudeen (1981) reported that application of K at different levels did not influence the N contents of leaves, pseudostem and rhizome of turmeric.

Muthuswamy and Krishnamoorthy (1976) reported that phosphorus content was not affected by K application in sweet potato. Saifudeen (1981) observed that different levels of K did not influence P content in different parts of turmeric. But the uptake of P in the leaf was influenced by K application.

Application of K increased the K content as reported by Pena (1967) in taro leaves. Content and uptake of K in the leaf, pseudostem, rhizome and also total uptake by turmeric were significantly influenced by K levels (Saifudeen, 1981).

Singh *et al.* (1992) observed that application of K significantly increased N,P and K content in turmeric rhizome and the increase was more pronounced with increasing doses of K. In general, K exerts a balancing effect on the effect of both N and P, consequently it is especially important in multinutrient fertilizer use (Brady, 1996).

2.1.4.3 Combined effects

Uptake of N, P and K was influenced by the different levels of nutrients tried in arrow root and maximum values were recorded by the highest levels of nutrients (Ramesan, 1991).

Sharma and Grewal (1991) reported that N, P and K uptake by potato crop increased progressively with increase in their rates of application.

The uptake of N, P and K were found to be maximum with the highest level of applied fertilizers in ginger (Ancy, 1992). A corresponding increase in the uptake of nutrients with their application was observed in mango ginger by Mridula (1997). Similar result was recorded in ginger by Ajithkumar (1999).

2.2 Effect of organic manure

Arrow root is thought to be a heavy feeder and it usually thrives well in fertile sandy loam soil. Use of 10 t ha^{-1} FYM or compost is admirably suitable for arrow root cultivation (CTCRI, 1996; Mohankumar *et al.*, 2000).

While studying the effects of different organic manures on arrow root intercropped in coconut garden, Maheswarappa *et al.* (1997) found that FYM and vermicompost (VC) are better than composted coir pith (CCP). FYM at 13.5 to 15t ha^{-1} and VC at 13.9 to15-9 t ha^{-1} recorded significantly higher rhizome yield compared to CCP at 9.7 to 10.3 t ha^{-1} or application of NPK alone at 75:50:50 kg ha^{-1}.

Cassava responds to both bulky and concentrated organic manures (Thampan, 1979). Application of FYM @ 12.5 t ha^{-1} to cassava gave better response in terms of growth characters and yield (Ashokan and Sreedharan, 1977; KAU, 1996). Higher efficiency of FYM in producing higher yield and improving chemical properties of soil compared to castor oil cake and urea was revealed in a study conducted by Gomes *et al.* (1983). Studies conducted at CTCRI revealed that basal application of FYM at 12.5 t ha^{-1} and 5 t ha^{-1} to cassava and sweet potato respectively was beneficial in enhancing the yield and quality traits of tubers besides conserving soil moisture and maintaining soil fertility (Mohankumar *et al.*, 1976; Pillai *et al.*, 1987; Ravindran and Balanambisan, 1987).

Application of FYM alone resulted in higher yields in elephant foot yam (Patel and Mehta, 1987) and turmeric (Balashanmugham *et al.*, 1989).

2.3 Effect of integrated nutrient management

The organic manure adds to the soil those constituents needed for the healthy life of plants. The acids produced during the process of decomposition render unavailable nutrients in the soil available to the plants. Organic manures and the gases produced during the process of decomposition help to lighten the soil and keep its texture open. Among the various organic manures, FYM is the most commonly used one.

Maheswarappa *et al.* (1997) opined that combined application of FYM @ 20 t ha^{-1} and 75:50:50 kg NPK ha^{-1} recorded significantly higher rhizome yield of arrow root (17.1t ha^{-1}) intercropped in coconut garden. Reduction in the yield with FYM applied alone was 16.4 to 17.9 per cent, with NPK alone was 26.9 per cent and with control was 63.7 per cent compared to FYM + NPK treatment (Maheswarappa *et al.*, 1999). Application of FYM and NPK also produced significantly higher number and length of rhizomes and higher starch and crude protein contents.

Nutrient requirement studies on Amorphophallus conducted by Kabeerathumma and George (1992) revealed that maximum corm yield, highest DMP as well as highest nutrient uptake were recorded for the treatment NPK @ 100:50:150kg ha^{-1} + FYM @ 25 t ha^{-1} than lower levels of N, P and K with and without FYM.

The fertilizer dose as per the recommendation by KAU (1996) for taro is 12 t ha^{-1} of FYM and 80:50:100 kg NPK ha^{-1} and for elephant foot yam it is

24 to 30 t ha^{-1} of FYM and 80:60:100 kg NPK ha^{-1} . But there is no package of practices recommendation for arrowroot.

The highest tuber yield of cassava (27.1 t ha^{-1}) was obtained with 100 kg each of N, P_2O_5 and K_2O ha^{-1} along with 12.5 t ha^{-1} of FYM. Neither FYM nor any of the nutrients (N, P or K) applied individually could increase yield by more than 4 t ha^{-1} but the combined use of NPK + FYM produced a response four times higher (Mohankumar et al., 2000).

Increase in yield due to combined application of FYM and inorganic fertilizers has been reported in turmeric (Rao *et al.*, 1975) and ginger (Pawar and Patil, 1987). KAU (1996) recommends 30t ha^{-1} of FYM and 75:50:50 kg NPK ha^{-1} for ginger and 40 t ha^{-1} of FYM along with 30:30:60 kg NPK ha^{-1} for turmeric.

2.4 Soil fertility status as affected by nutrient application

2.4.1 Available N

Study conducted by Ramesan (1991) revealed that higher levels of N and P application (50 kg N and 75 kg P_2O_5 ha^{-1}) for arrow root significantly increased the available N content in the soil after the experiment. The effect of K was non-significant in increasing the N status of the soil.

According to Nayar (1986) the post harvest available N content of soil increased with the application of higher levels of N and K for cassava intercropped in coconut garden. But significant reduction in status was noticed due to enhanced P application.

The change in N status of soil when taro was grown was reported by Mohankumar and Sadanandan (1991). They noticed that the available N status of the soil after a crop of taro increased with increase in N level but it was unaffected by P and K levels.

Rajasree (1993) observed that available N status of the soil was not affected by N and K levels when taro was grown under open condition. However, available N increased with increased levels of N and K application for taro intercropped in the coconut garden.

Available N content increased with applied N as reported by Ajithkumar (1999) in a study conducted in ginger intercropped in the coconut garden.

Soil analysis data after five years of continuous cultivation of cassava revealed an increase in available N status due to combined application of FYM and fertilizers (Pillai *et al.*, 1987). Kabeerathumma *et al.* (1991) studied the effect of continuous application of manures (FYM and wood ash) and fertilizers on the chemical properties of acid laterite soils. After 12 years of study they observed that inclusion of FYM in the treatment increased the available N in the soil, the maximum being recorded by NPK + FYM treatment.

2.4.2 Available P

While studying the nutrient requirement of arrow root, Ramesan (1991) found that the post harvest available P status of the soil was maximum at lower dose of N and the highest level of P application. Application of K had no significant influence in increasing the soil P content after the experiment.

Nayar (1986) observed that the post harvest soil available P increased with increased rates of P application for cassava, while higher levels of N and K decreased the soil P content.

Mohankumar and Sadanandan (1991) reported increase in post harvest available P content of soil with increased levels of P application for taro. They also reported that different levels of N and K did not affect the soil P status. Similarly Rajasree (1993) noticed that soil available P status was not influenced by N and K application for taro both in the open and shaded conditions.

Ajithkumar (1999) found that higher rates of P application to ginger increased the available P status in the soil N and K had no effects.

Pillai *et al.* (1987) and Kabeerathumma *et al.* (1991) observed an increase in available P status in the soil due to combined application of FYM and fertilizers for cassava.

2.4.3 Available K

After the harvest of arrow root, the soil available K was maximum in the plot which received the highest level of K but N and P application did not have any significant influence on the post harvest soil available K (Ramesan, 1991).

Soil nutrient analysis after the experiment in cassava intercropped in coconut garden indicated that higher doses of K increased the K status of soil whereas application of N and P had no effects (Nayar, 1986). Similar result was reported in taro by Mohankumar and Sadanandan (1991).

Rajasree (1993) found that available K was maximum at the highest level of K application (160 kg K_2O ha^{-1}) for taro, both as pure crop and as inter crop. But available K in the soil was not influenced by N application for a pure crop of taro while it increased with increased level of N application for taro intercropped in the coconut garden.

The combined application of FYM and fertilizer for cassava increased the available K status of the soil as reported by Pillai *et al.* (1987). But Kabeerathumma *et al.* (1991) observed no appreciable increase in available K in the soil in NPK + FYM treatment.

From the review of literature it is seen that information on the nutrient requirement of arrow root is meagre. Ramesan (1991) studied the nutrient requirement of arrow root as a pure crop. Maheswarappa *et al.* (1997) studied the effect of different organic manures on yield and quality of arrow root intercropped in the coconut garden. But they did not study the effect of conjoint use of different levels of organic manure and fertilizers. A scan of literature on related crops also indicates the necessity for judicious use of organic manure and fertilizers for increasing yield and sustaining soil fertility. KAU (1996) recommends integrated use of organic manures and fertilizers for tuber crops like cassava, sweet potato, yams, aroids and coleus. However, there is no such recommendation for arrow root and hence the present study is undertaken.

MATERIALS AND METHODS

MATERIALS AND METHODS

The present study envisages to study the efficacy of conjoint use of varying levels of organic manure and fertilizers for yield improvement of arrow root under partial shade and also to work out the economics of cultivation. The materials used and methods adopted for the study are presented in this chapter.

3.1 Materials

3.1.1 Experimental site

The experiment was conducted in the Instructional Farm attached to the College of Agriculture, Vellayani, located at 8.5^0 N latitude and 76.9^0 E longitude at an altitude of 29 m above mean sea level.

3.1.2 Soil

The soil of the experimental site was laterite which comes under the order oxisol. The soil belongs to the family of loamy, skeletal, kaolinitic, isohyperthermic Rhodic Haplustox (Vellayani series). The data on important physical and chemical properties of the soil before the experiment are presented in Table 1.

The soil was sandy loam in texture and acidic with a pH of 5. It was low in organic carbon and available N and medium in available P_2O_5 and K_2O contents.

Table 1 Soil characteristics of the experimental site

Parameter	Unit	Mean value	Method
Mechanical composition			
Coarse sand	Per cent	50.00	International pipette method (Piper, 1966)
Fine sand	"	20.00	
Silt	"	19.00	
Clay	"	11.00	
Texture	-	Sandy loam	
pH	-	5.00	pH meter with glass electrode (Jackson, 1973)
Organic carbon	Per cent	0.27	Wet oxidation method (Walkley and Black, 1934)
Available nitrogen	kg ha^{-1}	156.80	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P_2O_5	"	36.48	Bray's colorimetric method using ascorbic acid (Bray and Kurtz, 1945)
Available K_2O	"	209.00	Neutral normal ammonium acetate method (Hanway and Heidal, 1952)

3.1.3 Cropping history of the experimental site

The crop was grown in the interspaces of middle aged (30 years) coconut palms of variety West Coast Tall. The interspace of coconut palms were occupied by mulberry bushes during the previous year.

3.1.4 Season

The experiment was conducted during June 1999 - March 2000. The crop was planted on 15th June 1999 and harvested on 4th March 2000.

3.1.5 Weather conditions

Vellayani enjoys a tropical humid climate. Data on maximum and minimum temperatures, relative humidity and rainfall during the entire crop season are collected and presented as monthly averages in Appendix I and Fig. 1.

3.1.6 Planting material

Rhizomes of uniform size were used for planting. The rhizomes were obtained from Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram.

3.1.7 Manures and fertilizers

The organic manure used was FYM analyzing 0.4 per cent N, 0.3 per cent P_2O_5 and 0.2 per cent K_2O. The fertilizers used were urea (46 per cent N), mussoriephos (20 per cent P_2O_5) and muriate of potash (60 per cent K_2O).

Fig. 1 Weather data for the cropping period (June 1999 - March 2000) – monthly averages

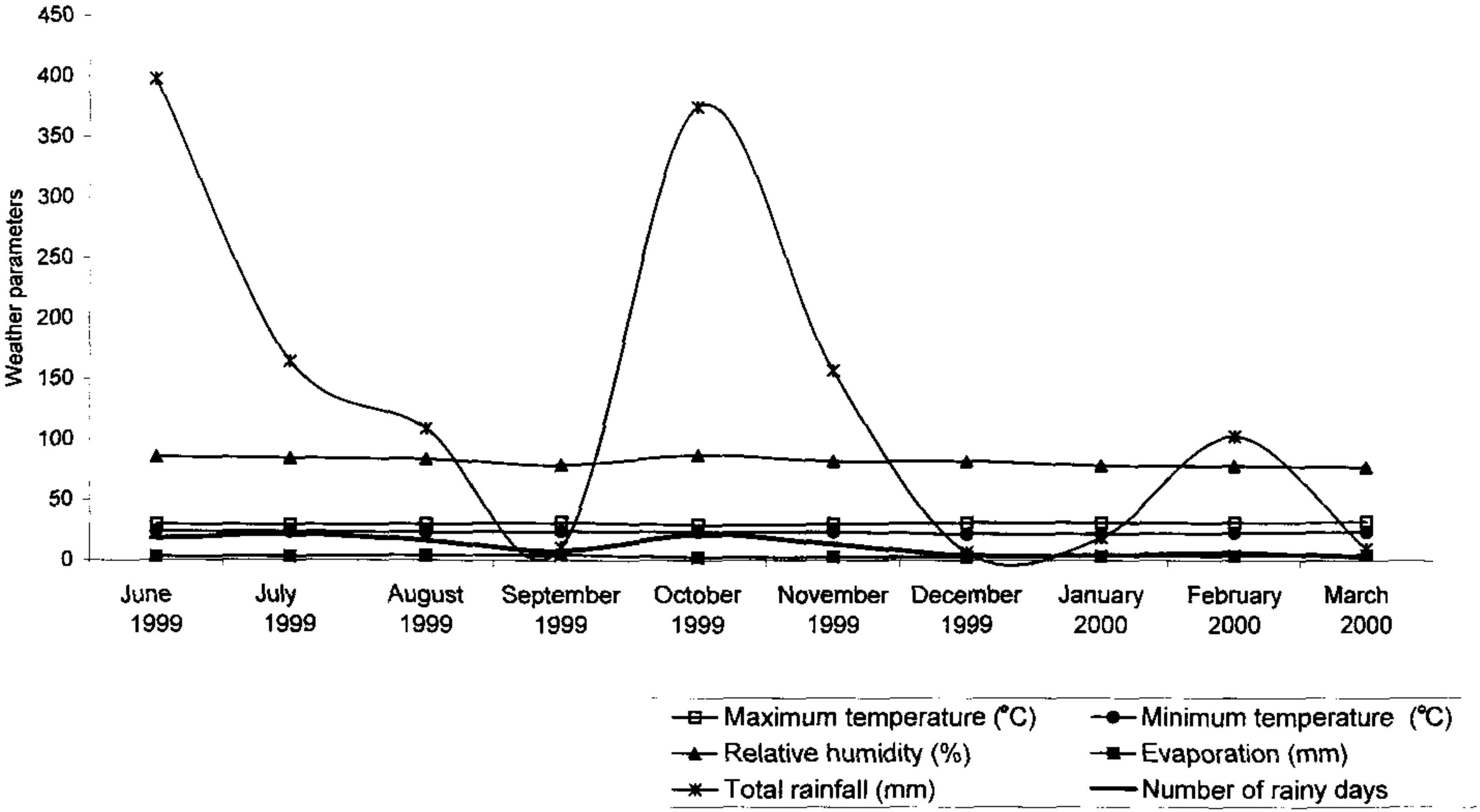


Fig. 2 Lay out of the experiment

N

	BLOCK 1			BLOCK 2			BLOCK 3		
Replication I	$m_1n_3k_2$	$m_1n_2k_3$	$m_1n_1k_1$	$m_1n_3k_3$	$m_3n_1k_3$	$m_2n_3k_2$	$m_1n_2k_2$	$m_2n_1k_2$	$m_3n_1k_1$
	$m_3n_3k_3$	$m_3n_2k_1$	$m_2n_2k_2$	$m_2n_2k_3$	$m_1n_2k_1$	$m_1n_1k_2$	$m_2n_2k_1$	$m_3n_2k_3$	$m_1n_3k_1$
	$m_3n_1k_2$	$m_2n_3k_1$	$m_2n_1k_3$	$m_2n_1k_1$	$m_3n_2k_2$	$m_3n_3k_1$	$m_3n_3k_2$	$m_1n_1k_3$	$m_2n_3k_3$
Replication II	$m_2n_1k_2$	$m_1n_1k_1$	$m_3n_3k_1$	$m_1n_3k_3$	$m_2n_1k_3$	$m_2n_2k_2$	$m_2n_1k_1$	$m_1n_2k_2$	$m_3n_1k_2$
	$m_2n_2k_1$	$m_1n_2k_3$	$m_2n_3k_3$	$m_3n_1k_1$	$m_2n_3k_1$	$m_1n_2k_1$	$m_3n_2k_1$	$m_2n_3k_2$	$m_3n_3k_3$
	$m_3n_1k_3$	$m_3n_2k_2$	$m_1n_3k_2$	$m_3n_2k_3$	$m_1n_1k_2$	$m_3n_3k_2$	$m_2n_2k_3$	$m_1n_1k_3$	$m_1n_3k_1$

3 m

3 m

Plate 1 General view of experimental field

3.2 Methods

3.2.1 Details of treatments

The treatments consisted of factorial combinations of three levels each of organic manure, nitrogen and potassium.

(i) Organic manure (M)

m_1 - FYM 10 t ha^{-1}

m_2 - FYM 15 t ha^{-1}

m_3 - FYM 20 t ha^{-1}

(ii) Nitrogen levels (N)

n_1 - 40 kg N ha^{-1}

n_2 - 80 kg N ha^{-1}

n_3 - 120 kg N ha^{-1}

(iii) Potassium levels (K)

k_1 - 40 kg K_2O ha^{-1}

k_2 - 80 kg K_2O ha^{-1}

k_3 - 120 kg K_2O ha^{-1}

A uniform dose of 50 kg P_2O_5 ha^{-1} was applied to all plots.

Treatment combinations

$m_1 n_1 k_1$	$m_2 n_1 k_1$	$m_3 n_1 k_1$
$m_1 n_1 k_2$	$m_2 n_1 k_2$	$m_3 n_1 k_2$
$m_1 n_1 k_3$	$m_2 n_1 k_3$	$m_3 n_1 k_3$
$m_1 n_2 k_1$	$m_2 n_2 k_1$	$m_3 n_2 k_1$
$m_1 n_2 k_2$	$m_2 n_2 k_2$	$m_3 n_2 k_2$
$m_1 n_2 k_3$	$m_2 n_2 k_3$	$m_3 n_2 k_3$
$m_1 n_3 k_1$	$m_2 n_3 k_1$	$m_3 n_3 k_1$
$m_1 n_3 k_2$	$m_2 n_3 k_2$	$m_3 n_3 k_2$
$m_1 n_3 k_3$	$m_2 n_3 k_3$	$m_3 n_3 k_3$

3.2.2 Experimental design and lay out

The experiment was laid out in a 3^3 partially confounded factorial RBD confounding MNK in Replication I and M^2NK in Replication II.

The procedure followed for the allocation of various treatments to different plots was in accordance with Yates (1937). The lay out plan is depicted in Fig. 2.

The details of the lay out are furnished below.

Treatment combinations	:	27
Replications	:	2
Number of blocks per replication	:	3
Number of plots per block	:	9
Gross plot size	:	3.0 x 3.0 m
Net plot size	:	1.8 x 2.4 m
Variety	:	local
Spacing	:	30 x 30 cm

3.2.3 Details of cultivation

3.2.3.1 Field preparation

The experimental area was cleared off, dug twice and the stubbles were removed. Then the field was laid out into blocks and plots and raised beds were taken in each plot. Dried and powdered FYM was applied to the plots in appropriate quantities as per the treatment schedule and well incorporated into the soil.

3.2.3.2 Fertilizer application

Nitrogen, phosphorus and potassium were applied to the plots in the form of urea, mussoriephos and muriate of potash respectively in appropriate quantities according to the treatment schedule. Full dose of P and one third each of N and K were applied as basal dose. One-third each of N and K were applied on 60^{th} day after planting (DAP) and remaining one-third N and one third K were applied on 120^{th} DAP.

3.2.3.3 Seed rhizomes and planting

Seed rhizomes weighing 10-15 g each with atleast two viable healthy buds were used. The seed rhizomes were planted at a spacing of 30 cm between rows and 30 cm between plants and covered with a thin layer of soil.

3.2.3.4 After cultivation

Thinning and gap filling with seedlings of similar age were done 20 DAP. Hand weeding was done 60 and 120 DAP. A total of seven irrigations were given during periods of dry spell in September 1999 and from January 2000 till harvest.

3.2.3.5 Harvest

The crop was ready for harvest about nine months after planting (MAP). Harvesting was done by digging out the rhizomes carefully and the rhizomes were separated from the shoot. The border rows and observational plants were harvested separately from each plot. The rhizomes and shoot portions from the net plot were weighed separately and the weights were recorded.

3.3 Biometric observations

Single line of plants all round in each plot was left out as border row. A row of plants on the eastern side in each plot was set apart as destructive row for taking plant samples for the determination of leaf area and dry matter production (DMP). The subsequent row on that side was again left out as border row, thus making the net plot area to 1.8 x 2.4 m with six rows having eight plants per row. Five plants were selected randomly from the net plot as observational plants for recording biometric observations and for chemical analysis. Parameters considered and methods followed are briefly stated below.

3.3.1 Growth characters

3.3.1.1 Height of the plant

Height of the five observational plants from each plot was measured at six MAP and harvest. The height was measured from the ground level to the growing leaf bud. Mean plant height per plot was worked out and expressed in cm.

3.3.1.2 Number of suckers per hill

Number of suckers present on the observational plants were counted at six MAP and harvest and the average number per hill was taken.

3.3.1.3 Number of leaves per plant

The total number of functional leaves of the observational plants were recorded at six MAP and harvest. Average number of leaves per plant was worked out.

3.3.1.4 Leaf area index (LAI)

Five plants from the row kept for destructive sampling were uprooted during peak vegetative stage i.e., six MAP and the leaf area was determined by using LI-300 leaf area meter. From this, LAI was worked out using the following formula suggested by Watson (1952).

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

3.3.1.5 Dry matter production

Five sample plants uprooted at six MAP and observational plants uprooted at harvest were used for the determination of DMP. The samples were dried in a hot air oven at a temperature of 70^0 C to constant dry weights. The dry weights were expressed in kg ha^{-1}.

3.3.2 Yield and yield components

3.3.2.1 Number of rhizomes per plant

At harvest five observational plants were uprooted and the number of rhizomes were counted. The average number of rhizomes per plant was then worked out.

3.3.2.2 Length of rhizome

The average length of rhizomes was taken by measuring the length of ten rhizomes taken at random from the observational plants and expressed in cm.

3.3.2.3 Girth of rhizome

Girth measurements were recorded from the same rhizomes that were used for length measurements. Girth values were recorded at three portions, one in the middle and the others a quarter distance from both ends of each rhizome. The average of these three figures was designated as mean girth in cm.

3.3.2.4 Mean weight of rhizome per plant

The fresh weight of rhizome per plant was recorded in g from the sample plants uprooted at six MAP and harvest after removing the soil adhering to the rhizomes.

3.3.2.5 Rhizome yield

The weight of rhizomes from each net plot was converted to rhizome yield in t ha^{-1}.

3.3.2.6 Wet weight of plant at harvest

The fresh weight of shoot portion from the net plot was recorded at harvest and expressed in t ha^{-1}.

3.3.2.7 Utilization index (UI)

UI is the ratio of rhizome yield to top yield on fresh weight basis.

3.3.3 Quality characters of rhizome

Dried samples of the rhizomes from the observational plants were used for quality analysis.

3.3.3.1 Starch content

The starch content was estimated by using potassium ferricyanide method (Ward and Pigman, 1970). The values were expressed as percentage on dry matter basis.

3.3.3.1.1 Amylose content and amylose-amylopectin ratio

The percentage of amylose in starch was estimated colorimetrically (Mc Cready and Hassid, 1943). Amylopectin content was then calculated by subtracting the amylose content from the starch content and the ratio between the two starch fractions was worked out.

3.3.3.2 Protein content

The percentage of protein was calculated by multiplying the percentage of N in rhizome by the factor 6.25 (A.O.A.C., 1969).

3.3.3.3 Fibre content

Crude fibre content of the rhizomes in percentage was determined by the method of A.O.A.C. (1975).

3.4 Chemical analysis

3.4.1 Soil analysis

Soil samples were taken from the experimental area before and after the experiment. The composite sample from the experimental area before the experiment was analysed for physical and chemical properties as given in Table 1. After the experiment, composite samples were collected from each plot, air dried, powdered and passed through a 2 mm sieve and analysed for available N, P and K using the methods given in Table 1.

3.4.2 Plant analysis

The observational plants uprooted were used for the analysis of N, P and K contents at harvest. The rhizomes and the shoot portions were analysed separately. The samples were chopped and dried in an air oven at 70^0C separately till constant weights were obtained. Samples were then ground to pass through 0.5 mm mesh in a Willey mill.

The N content in plant was estimated by modified micro-kjeldahl method (Jackson, 1973). The P content in plants was estimated colorimetrically (Jackson, 1973) and K content by flame photometric method (Piper, 1966).

3.5 Uptake of nutrients

The total uptake of N, P and K were calculated based on the respective nutrient contents in rhizomes and shoot portions and their corresponding dry weights. The uptake was expressed in kg ha^{-1}.

3.6 Measurement of light intensity

The light intensity was measured in the open and in the coconut garden using a lux meter and the monthly averages are given in Appendix II. The middle aged coconut palms permitted on an average 19.3 per cent of the solar radiation to filter through the canopy which meant that arrow root was grown under 80.7 per cent shade.

3.7 Pest and disease incidence

No serious pests and diseases were noted for the crop.

3.8 Economics of cultivation

The economics of cultivation of the crop was worked out and net income and benefit – cost ratio (BCR) were calculated as follows.

Net income (Rs. ha^{-1}) = Gross income – Cost of cultivation.

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

3.9 Statistical analysis

The experimental data were analysed statistically by applying the technique of analysis of variance (ANOVA) for 3^3 partially confounded factorial experiment and the significance was tested by F test (Cochran and Cox, 1965). Wherever F test was significant in ANOVA, the critical difference (CD) is provided. The results and discussion are based on five per cent level of significance.

3.9.1 Response surface and standardization of response to applied nutrients

Response surface, $Y = b_0 + b_1M + b_2N + b_3K + b_{11}M^2 + b_{22}N^2 + b_{33}K^2 + b_{12}MN + b_{13}MK + b_{23}NK$ (Das and Giri, 1979) was fitted to estimate the relationship between rhizome yield and applied nutrients. The physical and economic doses of FYM, N and K for arrow root were estimated by solving the equation obtained by differentiating the above function with respect to M, N and K and then equating to zero or price ratio.

RESULTS

RESULTS

A field experiment was conducted in the Instructional Farm attached to the College of Agriculture, Vellayani from June 1999 to March 2000 to study the efficacy of conjoint use of varying levels of organic manure and fertilizers for yield improvement of arrow root under partial shade. The experimental data collected were statistically analysed and the results obtained are presented below.

4.1 Growth characters

4.1.1 Height of the plant

Plant height as influenced by varying levels of FYM, N and K at six MAP and harvest are presented in Table 2.

The data revealed that the plant height was significantly influenced by various FYM levels. Higher values of 122.54 cm and 123.89 cm were recorded at six MAP and harvest respectively at m_3 level which was significantly superior to m_2 and m_1 levels.

The plant height increased with increasing levels of N application. The treatment n_3 recorded higher values of 120.83 and 122.46 cm, at six MAP and harvest respectively. Levels n_2 and n_1 were on par at both stages.

Table 2 Effect of farmyard manure, nitrogen and potassium on plant height (cm)

Treatments	6MAP	Harvest
Farmyard manure (m)		
m_1	111.07	112.67
m_2	116.78	117.67
m_3	122.54	123.89
CD	4.05	4.25
Nitrogen (N)		
n_1	113.76	114.52
n_2	115.80	117.24
n_3	120.83	122.46
CD	4.05	4.25
Potassium (K)		
k_1	111.76	113.37
k_2	118.81	120.43
k_3	119.91	120.43
CD	4.05	4.25

Application of K significantly influenced the plant height. Higher values of 119.81 cm at six MAP and 120.43 cm at harvest were recorded by k_3 level but were on par with k_2 at both stages.

Interaction effects were found to have no significant effect on plant height.

4.1.2 Number of suckers per hill

Data showing the influence of FYM, N and K on the number of suckers per hill at six MAP and harvest are given in Table 3.

The number of suckers significantly increased with increasing levels of FYM, higher values of 3.65 and 3.7 being recorded at six MAP and harvest respectively.

N also had a significant influence on the number of suckers per plant. Significantly superior value of 3.52 was recorded by n_3 level both at six MAP and harvest. The n_2 and n_1 levels were on par at both stages.

K did not have any significant influence on the number of suckers per hill.

Interaction of treatments failed to express significant variation in the number of suckers at both the stages.

4.1.3. Number of leaves per plant

The mean value of number of leaves per plant at six MAP and harvest are presented in Table 4.

Table 3 Effect of farmyard manure, nitrogen and potassium on number of suckers per hill

Treatments	6MAP	Harvest
Farmyard manure (m)		
m_1	2.67	2.67
m_2	3.06	3.06
m_3	3.65	3.70
CD	0.34	0.33
Nitrogen (N)		
n_1	2.80	2.85
n_2	3.06	3.06
n_3	3.52	3.52
CD	0.34	0.33
Potassium (K)		
k_1	3.11	3.11
k_2	3.13	3.19
k_3	3.13	3.13
CD	-	-

Table 4 Effect of farmyard manure, nitrogen and potassium on number of leaves per plant

Treatments	6MAP	Harvest
Farmyard manure (m)		
m_1	25.89	6.56
m_2	26.15	7.26
m_3	33.09	7.04
CD	3.27	-
Nitrogen (N)		
n_1	27.67	6.63
n_2	27.76	7.31
n_3	29.76	6.91
CD	-	-
Potassium (K)		
k_1	27.50	6.72
k_2	28.47	6.70
k_3	29.15	7.43
CD	-	-

Levels of FYM had a profound influence on number of leaves per plant only at six MAP. Level m_3 recorded the highest number of leaves (33.09) at six MAP, which was significantly superior to m_2 and m_1 levels. At harvest the leaf number increased at m_2 over m_1 but it declined at m_3 level, though the effect of FYM was non significant.

The main effects of N and K were not significant with respect to leaf production. Higher number of leaves at six MAP was recorded by n_3 level while at harvest by n_2 level. Number of leaves per plant increased with increasing rates of K application at six MAP and harvest.

Interaction effects were found to be non significant with respect to this character.

4.1.4 Leaf Area Index

The influence of FYM, N and K and their second order interactions on LAI recorded at six MAP are furnished in Table 5 and the influence of third order interaction in Table 6.

A perusal of the data in Table 5 revealed that N levels alone had significant influence on LAI. Among the N levels, n_3 recorded the highest value (2.12) which was significantly higher than n_1 and n_2 levels.

FYM and K levels did not produce any marked difference in LAI, although LAI increased with increasing rates of FYM and K application.

The interaction effects of M x N and N x K were found to have significant influence on LAI. With regard to M x N interaction the treatment

Table 5 Effect of farmyard manure, nitrogen and potassium on LAI at 6 MAP

	m_1	m_2	m_3	Mean
n_1	1.82	1.50	2.16	1.83
n_2	1.86	1.72	1.89	1.82
n_3	1.78	2.54	2.06	2.12
k_1	1.69	1.69	2.02	1.80
k_2	1.99	1.91	1.87	1.92
k_3	1.79	2.16	2.22	2.06
Mean	1.82	1.92	2.04	

	n_1	n_2	n_3	Mean
k_1	1.59	1.96	1.86	1.80
k_2	2.04	1.47	2.26	1.92
k_3	1.86	2.05	2.26	2.96
Mean	1.83	1.82	2.12	

CD for marginal means 0.24
CD for combination 0.42

Table 6 Interaction effect of farmyard manure, nitrogen and potassium on LAI at 6 MAP

Treatments	6 MAP
$m_1n_1k_1$	1.57
$m_1n_1k_2$	2.10
$m_1n_1k_3$	1.81
$m_1n_2k_1$	1.50
$m_1n_2k_2$	1.92
$m_1n_2k_3$	2.17
$m_1n_3k_1$	2.00
$m_1n_3k_2$	1.95
$m_1n_3k_3$	1.39
$m_2n_1k_1$	1.27
$m_2n_1k_2$	1.53
$m_2n_1k_3$	1.73
$m_2n_2k_1$	2.10
$m_2n_2k_2$	1.26
$m_2n_2k_3$	1.79
$m_2n_3k_1$	1.70
$m_2n_3k_2$	2.96
$m_2n_3k_3$	2.96
$m_3n_1k_1$	1.92
$m_3n_1k_2$	2.50
$m_3n_1k_3$	2.06
$m_3n_2k_1$	2.27
$m_3n_2k_2$	1.22
$m_3n_2k_3$	2.19
$m_3n_3k_1$	1.88
$m_3n_3k_2$	1.88
$m_3n_3k_3$	2.42
CD	0.51

combination $m_3 n_1$ recorded the highest value which was on par with $m_3 n_2$. In the case of N x K interaction, all combinations were on par except $n_1 k_1$ and $n_2 k_2$.

The interaction effect of M x N x K significantly influenced the LAI (Table 6). The treatment combinations $m_2n_3k_2$ and $m_2n_3k_3$ produced the highest value of 2.96 which were superior to other combinations.

4.1.5 Dry matter production

Dry matter production as influenced by varying levels of FYM, N and K at six MAP and harvest are shown in Table 7 to 9.

The data revealed that varying levels of FYM and N had a profound influence on DMP at both stages (Table 7 and 8). FYM at m_3 level recorded the highest value of DMP at six MAP (1740.33 kg ha $^{-1}$) and harvest (6321.06 kg ha^{-1}) which was significantly superior to m_2 and m_1 levels. Among the N levels, n_3 recorded the highest value of 1581.27 kg ha^{-1} at six MAP whereas n_2 gave the highest value of 6083.37 kg ha^{-1} at the harvest stage, both being significantly superior to other levels.

The influence of K on DMP was significant only at the harvest stage. The level k_2 gave the highest value (5980. 94 kg ha $^{-1}$) which was on par with k_3 (5880.50 kg ha^{-1}) but significantly superior to k_1 level.

The interactions M x N, M x K and N x K had significant influence on DMP at both stages. Among M x N interaction, $m_3 n_2$ registered the highest DMP (1867.44 kg ha^{-1}) at six MAP which was on par with $m_3 n_1$ (Table 7). In the case of M x K interactions, $m_3 k_3$ produced the highest value (1837.32 kg ha^{-1})

Table 7 Effect of farmyard manure, nitrogen and potassium on total dry matter production (kg ha^{-1}) at 6 MAP

	m_1	m_2	m_3	Mean
n_1	1063.29	1466.02	1773.74	1434.35
n_2	1393.90	1369.29	1867.44	1543.54
n_3	1476.76	1687.22	1579.81	1581.27
k_1	1188.85	1632.68	1685.15	1502.23
k_2	1535.78	1261.47	1698.51	1498.59
k_3	1209.38	1628.38	1837.32	1558.34
Mean	1311.32	1507.51	1740.33	
	n_1	n_2	n_3	Mean
k_1	1461.56	1620.05	1425.07	1502.23
k_2	1248.47	1503.08	1744.22	1498.59
k_3	1593.02	1507.49	1574.51	1558.34
Mean	1434.35	1543.54	1581.27	

CD for marginal means 69.88
CD for combination 121.03

Table 8 Effect of farmyard manure, nitrogen and potassium on total dry matter production (kg ha^{-1}) at harvest

	m_1	m_2	m_3	Mean
n_1	5261.00	5423.21	5832.76	5505.66
n_2	6684.51	5693.28	5872.31	6083.37
n_3	5115.10	4175.37	7258.10	5516.19
k_1	4622.50	5447.46	5663.38	5243.78
k_2	6049.40	5379.21	6514.20	5980.94
k_3	6388.70	4467.20	6785.59	5880.50
Mean	5686.87	5097.29	6321.06	

	n_1	n_2	n_3	Mean
k_1	4827.40	5815.38	5088.57	5243.78
k_2	6600.47	5990.88	5351.45	5980.94
k_3	5089.10	6443.84	6108.55	5880.50
Mean	5505.66	683.37	5516.19	

CD for marginal means 420.56
CD for combination 728.43

Table 9 Interaction effect of farmyard manure, nitrogen and potassium on total dry matter production (kg ha^{-1}) at 6MAP and harvest

Treatments	6 MAP	Harvest
$m_1n_1k_1$	725.00	4468.47
$m_1n_1k_2$	1177.65	6885.86
$m_1n_1k_3$	1287.21	4428.68
$m_1n_2k_1$	1422.15	5563.21
$m_1n_2k_2$	1577.92	7038.87
$m_1n_2k_3$	1181.62	7451.44
$m_1n_3k_1$	1419.40	3835.81
$m_1n_3k_2$	1851.77	4223.47
$m_1n_3k_3$	1159.13	7286.01
$m_2n_1k_1$	1871.66	5907.27
$m_2n_1k_2$	835.66	6165.63
$m_2n_1k_3$	1690.74	4196.73
$m_2n_2k_1$	1621.06	5191.35
$m_2n_2k_2$	1108.45	5808.94
$m_2n_2k_3$	1378.36	6079.56
$m_2n_3k_1$	1405.32	5237.77
$m_2n_3k_2$	1840.30	4163.05
$m_2n_3k_3$	1816.05	3125.30
$m_3n_1k_1$	1788.02	4106.45
$m_3n_1k_2$	1732.09	6749.93
$m_3n_1k_3$	1801.12	6641.91
$m_3n_2k_1$	1816.95	6691.57
$m_3n_2k_2$	1822.86	5124.84
$m_3n_2k_3$	1962.50	5800.53
$m_3n_3k_1$	1450.50	6192.12
$m_3n_3k_2$	1540.59	7667.84
$m_3n_3k_3$	1748.35	7914.34
CD	148.23	892.14

which was superior to other combinations. With regard to N x K, n_3k_2 (1744.22 kg ha^{-1}) registered the highest DMP. At harvest (Table 8) m_3n_3, m_3k_3 and n_1k_2 gave higher values of 7258.10, 6785.59 and 6600.47 kg ha^{-1} respectively. But m_3n_3 was on par with m_1n_2, m_3k_3 with m_3k_2, m_1k_2 and m_1k_3 and n_1k_2 with n_2k_2, n_2k_3, n_3k_3 combinations.

The higher order interaction also gave significant response in terms of DMP at both stages (Table 9). The treatment $m_3n_2k_3$ recorded the highest value of 1962.5 kg ha^{-1} at six MAP, but was on par with $m_3n_2k_2$, $m_3n_2k_1$, $m_2n_3k_3$, $m_2n_3k_2$, $m_2n_1k_1$ and $m_1n_3k_2$. At harvest, the combination $m_3n_3k_3$ registered the highest value of 7914.34 kg ha^{-1} which was on par with $m_3n_3k_2$, $m_1n_3k_3$, $m_1n_2k_3$ and $m_1n_2k_2$.

4.2 Yield and yield components

4.2.1 Number of rhizome per plant

The data on number of rhizomes per plant taken at six MAP as influenced by FYM, N and K are presented in Table 10 and that recorded at harvest are given in Table 11. The M x N x K interaction effects of both stages are given in Table 15.

Number of rhizomes per plant was not significantly influenced by the application of FYM or N or K at six MAP (Table 10) but increase in rhizome number was noticed upto m_2, n_2 and k_2 levels individually.

The interaction M x N and M x K appreciably influenced the number of rhizomes per plant at six MAP (Table 10). The treatment combinations m_1n_1

Table 10 Effect of farmyard manure, nitrogen and potassium on number of rhizomes per plant at 6 MAP

	m_1	m_2	m_3	Mean
n_1	1.17	1.33	1.42	1.31
n_2	1.5	1.58	1.67	1.58
n_3	1.33	1.5	1.25	1.36
k_1	1.33	1.42	1.42	1.39
k_2	1.42	1.58	1.42	1.47
k_3	1.25	1.42	1.5	1.39
Mean	1.33	1.47	1.44	

	n_1	n_2	n_3	Mean
k_1	1.33	1.67	1.67	1.39
k_2	1.33	1.58	1.5	1.47
k_3	1.25	1.5	1.42	1.39
Mean	1.31	1.58	1.36	

CD for marginal means -
CD for combination 0.56

Table 11 Effect of farmyard manure, nitrogen and potassium on number of rhizomes per plant at harvest

	m_1	m_2	m_3	Mean
n_1	2.72	2.72	2.78	2.74
n_2	2.56	2.33	3.11	2.67
n_3	2.33	2.67	2.84	2.61
k_1	2.5	2.67	2.84	2.67
k_2	2.83	2.56	2.78	2.72
k_3	2.28	2.50	3.11	2.63
Mean	2.54	2.57	2.91	
	n_1	n_2	n_3	Mean
k_1	2.67	2.67	2.67	2.67
k_2	2.89	2.78	2.50	2.72
k_3	2.67	2.56	2.67	2.63
Mean	2.74	2.67	2.61	

CD for marginal means 0.21
CD for combination 0.36

and m_3n_2 among M x N interaction and m_2k_2 among M x K interaction recorded higher number of rhizomes of 2 and 1.88 respectively.

Application of FYM had a profound influence on the number of rhizomes per plant at harvest (Table 11). Level m_3 gave the highest number of rhizome per plant (2.91) which was significantly superior to m_2 and m_1 levels.

The main effects of N and K did not exert a significant influence on rhizome number per plant at harvest.

At harvest, M x N and M x K interactions also produced significant effect on rhizome number among which m_3n_2 (on par with m_3n_1 and m_3n_3) and m_3k_3 (on par with m_3k_1 and m_3k_2) gave the highest value of 3.11.

The interaction effect of M x N x K were also found to be significant only at six MAP and not at the harvest stage (Table 15) and treatment combinations $m_2n_3k_2$ and $m_3n_2k_1$ recorded the highest value of 2. These treatment combinations were closely followed by $m_1n_2k_2$, $m_2n_1k_2$, $m_2n_2k_3$, $m_3n_1k_2$ and $m_3n_3k_3$.

4.2.2 Length of rhizome

The data on length of rhizome as affected by FYM, N and K are presented in Table 12.

The main effects of M, N and K as well as their interactions failed to express any significant influence on the length of rhizome.

Table 12 Effect of farmyard manure, nitrogen and potassium on length and girth of rhizome (cm)

Treatments	Length	Girth
Farmyard manure (M)		
m_1	18.05	6.97
m_2	17.69	6.87
m_3	16.75	7.07
CD	-	-
Nitrogen (N)		
n_1	15.83	6.53
n_2	18.50	7.29
n_3	18.16	7.08
CD	-	-
Potassium (K)		
k_1	17.11	6.84
k_2	17.19	7.07
k_3	18.19	7.10
CD	-	-

4.2.3 Girth of rhizome

The mean values of rhizome girth as influenced by FYM, N and K and their interactions are given in Table 12 and 15 respectively.

The data revealed that the main effects of FYM, N and K on rhizome girth was non significant. However, the higher order interaction of $m_1n_2k_3$ had a significant influence on rhizome girth and produced the highest value of 9.34 cm which was on par with $m_3n_3k_3$ (8.64cm).

4.2.4 Mean weight of rhizome per plant

The mean value of rhizome weight per plant as influenced by FYM, N and K at six MAP and harvest are given in Table 13 and 14 respectively. The M x N x K interaction effects at both stages are given in Table 15.

The main effects of FYM, N and K were non significant with respect to rhizome weight per plant both at six MAP (Table 13) and harvest (Table 14).

The interactions M x N, M x K and N x K appreciably influenced the weight of rhizome per plant at both stages. The treatment combination m_3n_2 recorded the highest value of 16.5 g at six MAP but was on par with all combinations of M and N except m_1n_1, m_2n_2 and m_3n_3 (Table 13). Significantly superior value of 18.89 g was recorded at six MAP by m_1k_2 but was on par with m_2k_1, m_3k_1 and m_3k_3. The effects of the treatment combinations n_1k_1, n_1k_3 and n_3k_2 were on par with the highest value recorded by n_2k_1 (19.56 g).

Table 13 Effect of farmyard manure, nitrogen and potassium on weight of rhizomes (g) at 6 MAP

	m_1	m_2	m_3	Mean
n_1	11.67	16.17	14.72	14.18
n_2	15.67	12.22	16.5	14.80
n_3	15.95	14.17	8.06	12.72
k_1	13.06	18.33	15.11	15.50
k_2	18.89	10.56	9.45	12.96
k_3	11.34	13.67	14.72	13.24
Mean	14.43	14.19	13.09	
	n_1	n_2	n_3	Mean
k_1	16.11	19.56	10.83	15.50
k_2	10.28	12.50	16.11	12.96
k_3	16.17	12.34	11.22	13.24
Mean	14.18	14.80	12.72	

CD for marginal means -
CD for combination 4.20

Table 14 Effect of farmyard manure, nitrogen and potassium on weight of rhizomes (g) at harvest

	m_1	m_2	m_3	Mean
n_1	95.72	102.50	86.11	94.28
n_2	113.89	106.61	95.46	105.35
n_3	79.72	73.33	121.28	91.45
k_1	82.11	105.55	90.28	92.65
k_2	99.72	95.78	108.95	101.48
k_3	107.50	81.11	103.72	92.45
Mean	96.45	94.15	100.98	

	n_1	n_2	n_3	Mean
k_1	88.22	101.39	88.33	92.65
k_2	119.72	103.00	81.72	101.48
k_3	76.39	111.67	104.28	97.45
Mean	94.78	105.35	91.45	

CD for marginal means -
CD for combination 21.36

Table 15 Interaction effect of farmyard manure, nitrogen and potassium on yield components

Treatments	Number of rhizome per plant		Weight of rhizome per plant (g)		Girth of rhizome (cm)
	6 MAP	At harvest	6 MAP	At harvest	At harvest
$m_1n_1k_1$	1.00	2.50	4.17	98.00	6.47
$m_1n_1k_2$	1.00	3.00	10.83	118.34	6.50
$m_1n_1k_3$	1.50	2.67	20.00	70.84	5.95
$m_1n_2k_1$	1.50	2.50	20.00	95.84	6.00
$m_1n_2k_2$	1.75	3.17	18.34	123.34	6.56
$m_1n_2k_3$	1.25	2.00	8.67	122.50	9.34
$m_1n_3k_1$	1.50	2.50	15.00	52.50	7.75
$m_1n_3k_2$	1.50	2.34	27.5	57.50	7.50
$m_1n_3k_3$	1.00	2.17	5.34	129.17	6.67
$m_2n_1k_1$	1.75	2.84	25.00	108.33	5.84
$m_2n_1k_2$	1.25	2.84	7.50	124.17	6.73
$m_2n_1k_3$	1.00	2.50	16.00	75.00	7.11
$m_2n_2k_1$	1.50	2.33	16.67	95.83	7.34
$m_2n_2k_2$	1.50	2.34	11.67	107.34	7.53
$m_2n_2k_3$	1.75	2.34	8.34	116.67	7.25
$m_2n_3k_1$	1.00	2.83	13.34	112.5	7.17
$m_2n_3k_2$	2.00	2.50	12.5	55.84	6.71
$m_2n_3k_3$	1.50	2.67	16.67	51.67	6.17
$m_3n_1k_1$	1.25	2.67	19.17	58.34	6.84
$m_3n_1k_2$	1.75	2.84	12.50	16.67	7.50
$m_3n_1k_3$	1.25	2.84	12.50	83.34	5.92
$m_3n_2k_1$	2.00	3.17	22.00	112.5	7.70
$m_3n_2k_2$	1.50	2.84	7.50	78.34	7.96
$m_3n_2k_3$	1.50	3.33	20.00	95.84	5.96
$m_3n_3k_1$	1.00	2.67	4.17	100.00	6.50
$m_3n_3k_2$	1.00	2.67	8.34	131.84	6.63
$m_3n_3k_3$	1.75	3.17	11.67	132.00	8.64
CD	0.69	-	5.14	26.17	1.33

At harvest the treatment combination m_3n_3 produced the highest value of 121.28 g (Table 14) which was on par with m_1n_2, m_2n_1 and m_2n_2. The effects of all M and K combinations were on par except m_1k_1 and m_2k_3, the highest value (103.72 g) being produced by m_3k_2. Among N and K combinations, n_1k_2 recorded the highest value of 119.72 g which was on par with n_2k_1, n_2k_2, n_2k_3 and n_3k_3.

The combined effect of M, N and K showed significant influence on rhizome weight at both the stages (Table 15). The interactions $m_1n_3k_2$ recorded the highest value (27.5 g) at six MAP and $m_3n_3k_3$ produced the highest value (132 g) at harvest which was on par with $m_1n_3k_3$ and $m_3n_3k_2$.

4.2.5 Rhizome yield

The data pertaining to the yield of rhizome per ha as influenced by FYM, N and K are presented in Table 16 and 19.

Various levels of FYM, N and K had a profound influence on the rhizome yield (Table 16). The rhizome yield increased with increasing levels of FYM, the highest value being recorded at m_3 level (13.95 t ha^{-1}) which was significantly superior to m_1 but on par with m_2 (13.26 t ha^{-1}).

With regard to N, the level n_2 recorded the highest yield of 13.69 t ha^{-1} which was on par with n_3 level. Level n_1 was significantly inferior to n_2 and n_3 levels.

Table 16 Effect of farmyard manure, nitrogen and potassium on rhizome yield (t ha^{-1})

	m_1	m_2	m_3	Mean
n_1	11.75	12.42	12.81	12.33
n_2	12.51	13.88	14.69	13.69
n_3	12.55	13.50	14.34	13.46
k_1	11.14	13.00	12.69	12.27
k_2	13.39	13.80	14.55	13.91
k_3	12.28	12.99	14.61	13.29
Mean	12.27	13.26	13.95	
	n_1	n_2	n_3	Mean
k_1	10.10	13.96	12.76	12.27
k_2	13.43	13.72	14.60	13.91
k_3	13.44	13.40	13.03	13.29
Mean	12.33	13.69	13.46	

CD for marginal means 0.98
CD for combination -

Levels of K also appreciably influenced the rhizome yield, the highest value being recorded by k_2 (13.91 t ha^{-1}). This was on par with k_3 (13.29 t ha^{-1}) but significantly superior to k_1 level.

Although the effect of M x N x K interaction was not significant, the treatment combination $m_3n_1k_3$ and $m_3n_2k_2$ recorded higher rhizome yield of 15.36 and 15.35 t ha^{-1} respectively. These were closely followed by $m_3n_3k_2$ (15.28 t ha^{-1}) and $m_1n_3k_2$ (14.95 t ha^{-1}). Lower yields were recorded by the treatment combinations $m_1n_1k_1$ (10.28 t ha^{-1}), $m_2n_1k_1$ (10 t ha^{-1}) and $m_3n_1k_1$ (10.03 t ha^{-1}).

4.2.6 Wet weight of plant at harvest

Wet weight of plant at harvest (t ha^{-1}) as influenced by various levels of FYM, N and K and their interactions are given in Table 17 and 19.

Different levels of FYM, N and K failed to exhibit a significant variation in the wet weight of plant at harvest (Table 17). But higher values of wet weight of plant were recorded by the highest level of FYM (m_3) and N (n_3) and medium level of K (k_2).

The interactions M x N and N x K significantly influenced the wet weight of plant at harvest. Regarding M x N interaction, the combination m_3n_3 recorded significantly superior value of 15.36 t ha^{-1}. In the case of N x K interaction, the treatment combination n_1k_2 produced the highest value (14.4 t ha^{-1}) which was on par with n_3k_1 and n_3k_3.

Table 17 Effect of farmyard manure, nitrogen and potassium on wet weight of plant (t ha^{-1}) at harvest

	m_1	m_2	m_3	Mean
n_1	11.29	12.49	10.56	11.45
n_2	12.81	11.83	12.08	12.24
n_3	11.85	9.77	15.36	12.33
k_1	10.78	11.72	13.66	12.05
k_2	12.57	12.04	12.46	12.35
k_3	12.60	10.34	11.88	11.61
Mean	11.98	11.36	12.67	

	n_1	n_2	n_3	Mean
k_1	10.79	12.73	12.64	12.05
k_2	14.40	11.60	11.07	12.35
k_3	9.15	12.40	13.28	11.61
Mean	11.45	12.24	12.33	

CD for marginal means -
CD for combination 1.98

With regard to higher order interaction (Table 19) the treatment combination $m_2n_1k_2$ registered the highest value of 17.13 t ha^{-1} which was on par with $m_3n_2k_1$, $m_3n_3k_2$ and $m_3n_3k_3$.

4.2.7 Utilization index

The data on the effects of FYM, N and K on UI are presented in Table 18 and 19.

The data in Table 18 revealed significant influence of FYM and K on UI. Among the FYM levels the highest value of UI (1.26) was recorded by m_2 level which was significantly superior to m_1 level. UI declined at m_3 level though m_2 and m_3 were on par.

With regard to N levels, the highest value of UI (1.19) was registered by n_2 though the effect was non significant.

In the case of K levels, the effect of k_2 and k_3 levels were on par but superior to k_1, the highest value being recorded by k_2 level (1.22).

The interactions M x N and N x K had profound influence on UI. The effect of m_2n_3 and m_3n_2 were on par but superior to all other combinations of M and N. Among N and K combinations, n_1k_3 produced significantly higher UI which was on par with n_2k_2 and n_3k_2.

M x N x K interaction also had significant effect on UI (Table 19). The treatment combination $m_2n_3k_2$ registered the highest value of 1.93 which was on par with $m_2n_1k_3$, $m_3n_1k_3$ and $m_3n_2k_2$.

Table 18 Effect of farmyard manure, nitrogen and potassium on utilization index

	m_1	m_2	m_3	Mean
n_1	1.05	1.09	1.18	1.11
n_2	1.00	1.20	1.35	1.19
n_3	1.09	1.48	0.93	1.17
k_1	1.04	1.15	0.90	1.03
k_2	1.10	1.30	1.25	1.29
k_3	1.00	1.31	1.33	1.21
Mean	1.05	1.26	1.16	

	n_1	n_2	n_3	Mean
k_1	0.90	1.15	1.04	1.03
k_2	0.95	1.26	1.44	1.29
k_3	1.48	1.14	1.02	1.21
Mean	1.11	1.19	1.17	

CD for marginal means 0.15
CD for combination 0.27

Table 19 Interaction effect of farmyard manure, nitrogen and potassium on yield (t ha^{-1})

Treatments	Rhizome yield (t ha^{-1})	Wet weight of plant at harvest (t ha^{-1})	Utilization index
$m_1n_1k_1$	10.28	10.88	0.95
$m_1n_1k_2$	13.54	13.14	1.04
$m_1n_1k_3$	11.42	9.86	1.17
$m_1n_2k_1$	12.59	10.64	1.19
$m_1n_2k_2$	11.68	14.19	0.83
$m_1n_2k_3$	13.28	13.60	0.99
$m_1n_3k_1$	10.54	10.83	0.98
$m_1n_3k_2$	14.95	10.38	1.44
$m_1n_3k_3$	12.15	14.34	0.85
$m_2n_1k_1$	10.00	12.03	0.85
$m_2n_1k_2$	13.72	17.13	0.80
$m_2n_1k_3$	13.54	8.33	1.63
$m_2n_2k_1$	14.61	10.64	1.39
$m_2n_2k_2$	14.13	11.91	1.19
$m_2n_2k_3$	12.89	12.95	1.02
$m_2n_3k_1$	14.39	12.49	1.22
$m_2n_3k_2$	13.56	7.09	1.93
$m_2n_3k_3$	12.53	9.74	1.29
$m_3n_1k_1$	10.03	9.48	0.90
$m_3n_1k_2$	13.04	12.95	1.00
$m_3n_1k_3$	15.36	9.25	1.66
$m_3n_2k_1$	14.69	16.91	0.87
$m_3n_2k_2$	15.35	8.70	1.78
$m_3n_2k_3$	14.04	10.64	1.42
$m_3n_3k_1$	13.34	14.60	0.92
$m_3n_3k_2$	15.28	15.73	0.97
$m_3n_3k_3$	14.41	15.76	0.91
CD	-	2.43	0.33

4.3 Quality characters of rhizome

4.3.1 Starch content

The data pertaining to the starch content of the rhizome are furnished in Table 20 and 25.

Different levels of FYM and N failed to express any significant influence on the starch content (Table 20). However, K had a profound influence on starch content and the highest value of 76.4 per cent was noticed at k_3 level which was significantly superior to k_2 and k_1 levels.

The interactions M x N and M x K appreciably influenced the starch content. The combinations m_2n_2 and m_3k_3 recorded higher values of 75.84 and 77.52 per cent respectively. But m_2n_2 was on par with m_1n_1, m_2n_3, m_3n_1, m_3n_2 and m_3n_3 and m_3k_3 with m_1k_3. N x K interaction was found to be non significant.

M x N x K interaction also had a profound influence on the starch content (Table 25). The highest value of 77.81 per cent was recorded by $m_1n_1k_3$, $m_3n_1k_3$ and $m_3n_3k_3$. The next higher value of 76.95 per cent was recorded by $m_1n_3k_3$, $m_2n_2k_2$, $m_2n_2k_3$ and $m_3n_2k_2$.

4.3.1.1 Amylose content and amylose-amylopectin ratio

The data on the main effects of FYM, N and K on amylose content in starch is given in Table 21 and the interaction effect in Table 25. The ratio between amylose and amylopectin contents is given in Table 22 and 25.

Table 20 Effect of farmyard manure, nitrogen and potassium on starch content (%) of rhizome

	m_1	m_2	m_3	Mean
n_1	74.80	72.21	74.56	73.81
n_2	73.65	75.84	74.54	74.68
n_3	73.21	74.72	75.29	74.41
k_1	71.63	72.88	72.35	72.28
k_2	73.66	74.52	74.47	74.22
k_3	76.40	75.28	77.52	76.40
Mean	73.88	74.23	74.78	
	n_1	n_2	n_3	Mean
k_1	71.59	72.62	72.63	72.28
k_2	73.42	75.31	73.93	74.22
k_3	76.42	76.11	76.67	76.40
Mean	73.81	74.68	74.41	

CD for marginal means 0.77
CD for combination 1.33

Table 21 Effect of farmyard manure, nitrogen and potassium on amylose content (%) in starch

Treatments	Amylose (%)
Farmyard manure (m)	
m_1	19.99
m_2	19.64
m_3	20.53
CD	0.69
Nitrogen (N)	
n_1	19.44
n_2	20.61
n_3	20.11
CD	0.69
Potassium (K)	
k_1	19.64
k_2	20.00
k_3	20.52
CD	0.69

Table 22 Effect of farmyard manure, nitrogen and potassium on amylose–amylopectin ratio

	m_1	m_2	m_3	Mean
n_1	0.36	0.36	0.36	0.36
n_2	0.39	0.37	0.40	0.39
n_3	0.36	0.37	0.38	0.37
k_1	0.38	0.35	0.39	0.37
k_2	0.35	0.39	0.38	0.37
k_3	0.38	0.35	0.37	0.38
Mean	0.37	0.37	0.38	

	n_1	n_2	n_3	Mean
k_1	0.38	0.35	0.39	0.37
k_2	0.35	0.39	0.38	0.37
k_3	0.38	0.35	0.37	0.38
Mean	0.36	0.39	0.37	

CD for marginal means 0.02
CD for combination 0.03

Application of FYM, N and K had significant influence on the amylose content of the rhizome (Table 21). Regarding FYM, m_3 level registered the highest value of 20.53 which was superior to m_1 and m_2 levels. Application of N at n_2 level recorded the highest value (20.61) which was on par with n_3 level. Amylose content increased with increasing levels of K application. The highest value of 20.52 was produced by k_3 level which was on par with k_2 but superior to k_1 level.

The interaction effect was not significant with respect to this character (Table 25) but the highest value of 21.39 was produced by $m_2n_2k_2$.

The data in Table 22 revealed that the ratio was significantly influenced by N application. The highest value of 0.39 was recorded by n_2 level which was on par with n_3 but superior to n_1 level. The main effects of FYM and K were found to be non-significant.

The interaction M x K was also found to the significant and the combinations m_2k_2 and m_3k_1 registered the highest value 0.39 which was on par with m_1k_1, m_1k_3, m_3k_2 and m_3k_3.

The higher order interaction M x N x K did not have any significant influence on amylose-amylopectin ratio (Table 25).

4.3.2 Protein content

Protein content of the rhizome as influenced by various treatments are shown in Table 23 and 25.

Table 23 **Effect of farmyard manure, nitrogen and potassium on protein content (%) of rhizome**

	m_1	m_2	m_3	Mean
n_1	3.84	3.61	5.74	4.40
n_2	4.66	4.61	5.67	4.98
n_3	4.32	6.11	6.05	5.49
k_1	4.54	4.77	5.79	5.04
k_2	4.38	4.37	6.06	4.93
k_3	3.90	5.19	5.61	4.90
Mean	4.27	4.78	5.82	

	n_1	n_2	n_3	Mean
k_1	4.62	5.18	5.31	5.04
k_2	4.49	4.81	5.50	4.93
k_3	4.07	4.95	5.67	4.90
Mean	4.40	4.98	5.49	

CD for marginal means 0.31
CD for combination 0.54

Different levels of FYM and N significantly influenced the protein content (Table 23). The protein content significantly increased with increasing levels of FYM and N. Levels m_3 and n_3 recorded the highest protein content of 5.82 per cent. But K levels failed to exert significant influence on protein content.

M x N and M x K interactions had a profound influence on the protein content of the rhizome. Regarding M x N interaction, the combination m_2n_3 recorded the highest value of 6.11 but was on par with m_3n_1, m_3n_2 and m_3n_3. In the case of M x K interaction the combination m_3k_2 produced the highest protein content (6.06). But the effect of m_3k_2, m_3k_1 and m_3k_3 were found to be on par. N x K interaction was found to be non significant with regard to this quality.

The higher order interaction M x N x K also had a significant influence on protein content (Table 25). The highest value of 6.48 was noticed at $m_2n_3k_1$ which was on par with $m_1n_2k_1$ and $m_3n_1k_1$.

4.3. 3 Crude fibre content

The mean values of crude fibre content of the rhizome are summarised in Table 24.

The data revealed that FYM, N and K levels had significant influence on fibre content of the rhizome. The fibre content increased with increasing levels of FYM and N application. Lower values of fibre content were recorded by m_1 (1.19) and n_1 (1.14) levels but were on par with m_2 (1.21) and n_2 (1.19) levels respectively.

Table 24 Effect of farmyard manure, nitrogen and potassium on crude fibre content (%) of rhizome

	m_1	m_2	m_3	Mean
n_1	1.16	1.06	1.20	1.14
n_2	1.12	1.22	1.22	1.19
n_3	1.29	1.36	1.44	1.36
k_1	1.16	1.30	1.41	1.29
k_2	1.17	1.25	1.27	1.23
k_3	1.24	1.08	1.19	1.17
Mean	1.19	1.21	1.29	

	n_1	n_2	n_3	Mean
k_1	1.15	1.28	1.45	1.29
k_2	1.17	1.19	1.34	1.23
k_3	1.10	1.10	1.30	1.17
Mean	1.14	1.19	1.36	

CD for marginal means 0.08
CD for combination 0.13

Table 25 Interaction effect of farmyard manure, nitrogen and potassium on quality characters

Treatments	Starch (%)	Amylose (%)	Amylose-Amylopectin ratio	Protein (%)	Crude fibre (%)
$m_1n_1k_1$	71.33	19.04	0.36	4.38	1.18
$m_1n_1k_2$	75.26	19.18	0.34	4.03	1.13
$m_1n_1k_3$	77.81	20.96	0.37	3.12	1.18
$m_1n_2k_1$	72.88	21.02	0.41	5.93	1.05
$m_1n_2k_2$	73.64	20.15	0.38	4.03	113
$m_1n_2k_3$	74.43	21.16	0.40	4.03	1.18
$m_1n_3k_1$	70.60	19.55	0.39	3.33	1.26
$m_1n_3k_2$	72.09	18.41	0.35	5.08	1.26
$m_1n_3k_3$	76.95	20.46	0.36	4.55	1.36
$m_2n_1k_1$	71.36	17.85	0.36	3.29	1.05
$m_2n_1k_2$	71.36	19.43	0.37	3.50	1.16
$m_2n_1k_3$	73.64	18.84	0.35	4.03	0.97
$m_2n_2k_1$	73.64	18.40	0.33	4.55	1.38
$m_2n_2k_2$	76.95	21.39	0.43	4.20	1.23
$m_2n_2k_3$	76.95	20.05	0.35	5.08	1.05
$m_2n_3k_1$	73.64	20.38	0.37	6.48	1.48
$m_2n_3k_2$	75.26	20.32	0.37	5.40	1.36
$m_2n_3k_3$	75.26	20.14	0.37	6.47	1.23
$m_3n_1k_1$	72.09	18.61	0.35	6.20	1.22
$m_3n_1k_2$	73.64	19.96	0.37	5.95	1.23
$m_3n_1k_3$	77.81	21.11	0.39	5.08	1.16
$m_3n_2k_1$	71.33	21.21	0.42	5.05	1.40
$m_3n_2k_2$	75.33	21.06	0.39	6.20	1.20
$m_3n_2k_3$	76.95	21.02	0.38	5.75	1.08
$m_3n_3k_1$	73.64	20.70	0.39	6.13	1.60
$m_3n_3k_2$	74.43	20.15	0.37	6.02	1.40
$m_3n_3k_3$	77.81	20.94	0.37	6.00	1.32
CD	1.63	-	-	0.66	-

The fibre content showed a declining trend with increase in the rates of K application. The minimum fibre content was recorded by k_3 level which was on par with k_2 level. But k_2 level was found to be on par with k_1 level.

Among the two factor interactions, M x K interaction alone had a significant influence on fibre content. The treatment combination m_1k_3 recorded the lowest value of 1.10 which was on par with m_1k_1, m_1k_2, m_2k_2 and m_2k_3.

The higher order interaction did not exert a significant influence on this parameter.

4.4 Uptake of nutrients

4.4.1 Uptake of nitrogen

The mean values of N uptake at harvest are summarised in Table 26 and 29.

A perusal of the data in Table 26 revealed that different levels of FYM and N had significant effect on N uptake. Among FYM levels the highest uptake of N was noticed at m_3 level (52.83 kg ha^{-1}). Application of N enhanced N uptake but the effects of n_2 and n_3 levels were almost equal registering 45.61 and 45.33 kg ha^{-1} of N uptake respectively.

Levels of K did not show any significant influence on N uptake though an increasing trend was noticed upto k_3 level.

The interactions M x N, M x K and N x K appreciably influenced the N uptake. Higher values of 65.30, 59.35 and 52.02 kg ha^{-1} were recorded by the

Table 26 Effect of farmyard manure, nitrogen and potassium on N uptake (kg ha^{-1}) at harvest

	m_1	m_2	m_3	Mean
n_1	33.18	30.38	44.29	35.95
n_2	48.38	39.73	48.91	45.67
n_3	33.04	37.64	65.30	45.33
k_1	36.20	39.02	44.59	39.94
k_2	37.54	35.52	54.55	42.54
k_3	40.86	33.21	59.35	44.47
Mean	38.20	35.92	52.83	
	n_1	n_2	n_3	Mean
k_1	33.46	44.70	41.66	39.94
k_2	42.12	40.29	45.19	42.54
k_3	32.27	52.02	49.14	44.47
Mean	35.95	54.67	45.33	

CD for marginal means 3.83
CD for combination 6.63

combinations m_3n_3, m_3k_3 (on par with m_3k_1 and m_3k_2) and n_2k_3 (on par with n_3k_3) respectively.

The three factor interaction M x N x K was also found to be significant (Table 29). The combination $m_3n_3k_2$ registered the highest uptake of 72.56 kg ha^{-1} on par with $m_3n_3k_3$ and superior to other combinations.

4.4.2 Uptake of phosphorus

The data pertaining to P uptake as influenced by various treatments are furnished in Table 27 and 29.

Uptake of P increased significantly with increasing levels of FYM, the highest value of 13.37 kg ha^{-1} being recorded by m_3 level (Table 27). The influence of K on P uptake was found to be significant at k_2 level recording uptake of 11.45 kg ha^{-1} which was superior to k_1 and k_3 levels. Uptake of P was not significantly influenced by N levels.

The two factor interactions M x N, M x K and N x K had profound influence on P uptake. The treatment combinations m_3n_3 (15.17 kg ha^{-1}) and n_1k_2 (13.03 kg ha^{-1}) gave higher values among M x N and N x K interactions respectively which was significantly superior to other combinations. Among M x K interaction, m_3k_1 recorded the highest value of 13.50 kg ha^{-1} which was on par with m_3k_2 and m_3k_3.

The higher order interaction significantly influenced the P uptake (Table 29). The treatment combination $m_3n_3k_3$ registered the highest P uptake of 17.22 kg ha^{-1} which was on par with $m_3n_3k_2$.

Table 27 Effect of farmyard manure, nitrogen and potassium on P uptake (kg ha^{-1}) at harvest

	m_1	m_2	m_3	Mean
n_1	8.38	10.64	13.61	10.88
n_2	9.73	12.20	11.33	11.08
n_3	8.05	7.59	15.17	10.27
k_1	7.69	10.05	13.50	10.41
k_2	9.20	11.73	13.42	11.45
k_3	9.27	8.65	13.19	10.37
Mean	8.72	10.14	13.37	
	n_1	n_2	N_3	Mean
k_1	11.02	10.56	9.66	10.41
k_2	13.03	11.08	10.25	11.45
k_3	8.58	11.62	10.91	10.37
Mean	10.88	11.08	10.27	

CD for marginal means 0.87
CD for combination 1.51

4.4.3 Uptake of potassium

The influence of FYM, N and K levels and their interactions on K uptake are given in Table 28 and 29.

FYM at m_3 level recorded the highest K uptake (157.97 kg ha^{-1}) which was significantly superior to other levels (Table 28). Uptake of K increased significantly with increasing levels of K, the highest value (156.49 kg ha^{-1}) being recorded by k_3 level. The effect of N levels was found to be non significant.

The interactions M x N, M x K and N x K were found to have significant effect on K uptake. Among M x N interactions, m_3n_3 recorded the highest value (175.18 kg ha^{-1}) which was on par with m_1n_2. In the case of M x K interaction, the combinations m_3k_3 and m_1k_3 were found to be on par registering values of 186.96 and 171.37 kg ha^{-1} respectively. Regarding N x K interaction, the highest value was recorded by n_2k_3 (175.69 kg ha^{-1}) but was on par with n_3k_3.

The combined effect of three factors viz., M, N and K showed a profound influence on K uptake (Table 29). The highest K uptake of 224.65 kg ha^{-1} was noticed at $m_3n_3k_3$ level which was on par with $m_1n_2k_3$ and superior to other treatment combinations.

Table 28 Effect of farmyard manure, nitrogen and potassium on K uptake (kg ha^{-1}) at harvest

	m_1	m_2	m_3	Mean
n_1	114.23	125.17	153.73	131.04
n_2	160.58	113.88	145.02	139.82
n_3	115.43	102.00	175.18	130.87
k_1	97.23	113.24	120.32	110.26
k_2	121.63	116.66	166.65	134.98
k_3	171.37	111.15	186.96	156.49
Mean	130.08	113.68	157.97	
	n_1	n_2	n_3	Mean
k_1	109.66	109.58	111.55	110.26
k_2	153.89	134.21	116.84	134.98
k_3	129.57	175.69	164.21	156.49
Mean	131.04	139.82	130.87	

CD for marginal means 10.39
CD for combination 17.99

Table 29 Interaction effect of farmyard manure, nitrogen and potassium on uptake of nutrients (kg ha[-1]) at harvest

Treatments	N uptake	P uptake	K uptake
$m_1n_1k_1$	37.39	7.30	85.46
$m_1n_1k_2$	40.05	10.90	137.38
$m_1n_1k_3$	22.11	6.94	119.84
$m_1n_2k_1$	50.97	8.75	110.43
$m_1n_2k_2$	42.61	9.64	149.93
$m_1n_2k_3$	51.56	10.81	221.38
$m_1n_3k_1$	20.26	7.02	95.82
$m_1n_3k_2$	29.97	7.09	77.59
$m_1n_3k_3$	48.91	10.06	172.89
$m_2n_1k_1$	29.92	10.96	144.01
$m_2n_1k_2$	33.95	12.89	139.18
$m_2n_1k_3$	27.28	8.06	92.31
$m_2n_2k_1$	34.30	9.24	73.43
$m_2n_2k_2$	39.56	14.93	122.2
$m_2n_2k_3$	45.32	12.42	146.02
$m_2n_3k_1$	52.84	9.94	122.27
$m_2n_3k_2$	33.06	7.39	88.61
$m_2n_3k_3$	27.04	5.46	95.11
$m_3n_1k_1$	33.06	14.81	99.51
$m_3n_1k_2$	52.37	15.31	185.12
$m_3n_1k_3$	47.43	10.73	176.58
$m_3n_2k_1$	48.83	13.68	144.89
$m_3n_2k_2$	38.72	8.68	130.51
$m_3n_2k_3$	59.17	11.63	159.66
$m_3n_3k_1$	51.88	12.01	116.57
$m_3n_3k_2$	72.56	16.29	184.32
$m_3n_3k_3$	71.46	17.22	224.65
CD	8.12	1.84	22.03

4.5 Soil nutrient status after the experiment

4.5.1 Available nitrogen

The data showing the effect of FYM, N and K levels on available N content in the soil after the experiment are presented in Table 30.

The data revealed that various levels of FYM had a significant influence on available N status of the soil. Level m_3 recorded the highest value of 216.47 kg ha^{-1} which was on par with m_2 and significantly superior to m_1.

Levels of N failed to produce any significant variation on available N content in the soil. However an increasing trend was noticed upto n_3 level.

The different K levels appreciably influenced the soil available N status. The highest value of 218.81 kg ha^{-1} was noticed at k_3 level which was superior to k_2 and k_1 levels.

The effect of interactions failed to express any significant variation in available N status after the experiment.

4.5.2 Available phosphorus

The mean values of available P content in soil after the experiment are summarised in Table 31 and 32.

The main effects of FYM, N and K had a significant influence on post harvest available P content in soil (Table 31). Higher values of 88.60, 79.02, and 82.40 kg ha^{-1} of available P content were noticed at m_3, n_3 and k_1 levels

Table 30 Effect of farmyard manure, nitrogen and potassium on available N content in soil (kg ha^{-1}) after the experiment

Treatments	Available N (kg ha^{-1})
Farmyard manure (m)	
m_1	197.93
m_2	215.81
m_3	216.47
CD	11.00
Nitrogen (N)	
n_1	205.19
n_2	208.03
n_3	217.00
CD	-
Potassium (K)	
k_1	204.46
k_2	206.95
k_3	218.81
CD	11.00

Table 31 Effect of farmyard manure, nitrogen and potassium on available P_2O_5 content in soil ($kg\ ha^{-1}$) after the experiment

	m_1	m_2	m_3	Mean
n_1	68.21	60.80	80.44	69.81
n_2	62.66	47.52	89.65	66.61
n_3	63.84	77.51	95.73	79.02
k_1	78.53	76.00	92.69	82.40
k_2	55.04	65.38	83.04	69.49
k_3	61.14	44.45	85.09	63.56
Mean	64.90	61.94	88.60	
	n_1	n_2	n_3	Mean
k_1	73.97	91.17	82.08	82.40
k_2	80.62	53.37	74.47	69.49
k_3	54.86	55.29	80.53	63.56
Mean	69.81	66.61	79.02	

CD for marginal means 8.13
CD for combination 14.08

Table 32 Interaction effect of farmyard manure, nitrogen and potassium on available P_2O_5 content in soil (kg ha^{-1}) after the experiment

Treatments	Available P_2O_5
$m_1n_1k_1$	71.42
$m_1n_1k_2$	77.99
$m_1n_1k_3$	59.23
$m_1n_2k_1$	91.20
$m_1n_2k_2$	41.55
$m_1n_2k_3$	55.23
$m_1n_3k_1$	72.96
$m_1n_3k_2$	45.60
$m_1n_3k_3$	72.96
$m_2n_1k_1$	63.84
$m_2n_1k_2$	72.96
$m_2n_1k_3$	45.60
$m_2n_2k_1$	86.64
$m_2n_2k_2$	31.92
$m_2n_2k_3$	24.00
$m_2n_3k_1$	77.52
$m_2n_3k_2$	91.26
$m_2n_3k_3$	63.74
$m_3n_1k_1$	86.64
$m_3n_1k_2$	90.93
$m_3n_1k_3$	63.74
$m_3n_2k_1$	95.67
$m_3n_2k_2$	86.64
$m_3n_2k_3$	86.64
$m_3n_3k_1$	95.76
$m_3n_3k_2$	86.55
$m_3n_3k_3$	104.88
CD	17.25

respectively which were significantly superior to the corresponding other levels.

The M x N, M x K and N x K interactions exerted a significant influence on available P content. In the case of M x N interaction, the effect of the treatment combinations m_3n_3 and m_3n_2 were on par but superior to other combinations. With regard to M x K interaction, the treatment combinations m_3k_1, m_3k_2 and m_3k_3 were on par but superior to other combinations. With respect to N x K interaction, n_2k_1 recorded the highest value but was on par with n_1k_2, n_3k_1 and n_3k_3.

Regarding the effect of M x N x K interaction given in Table 32, the treatment combination $m_2n_3k_3$ recorded the highest value of 104.88 kg ha^{-1} which was significantly superior to all other combinations except $m_3n_3k_1$, $m_3n_2k_1$, $m_2n_3k_2$, $m_1n_2k_1$ and $m_3n_1k_2$.

4.5.3 Available potassium

The data on post harvest available K content in the soil as influenced by various treatments are given in Table 33.

The main effects of FYM, N and K had a profound influence on soil available K status. Among the FYM levels, m_3 recorded the highest value of 212.10 kg ha^{-1} which was significantly superior to m_1 and m_2 levels. In the case of N, levels n_1 and n_3 were on par but superior to n_2. Among K levels, k_3 produced the highest value of 228.12 kg ha^{-1} which was significantly superior to k_1 and k_2 levels which were on par.

Table 33 Effect of farmyard manure, nitrogen and potassium on available K_2O content in soil (kg ha^{-1}) after the experiment

	m_1	m_2	m_3	Mean
n_1	202.46	154.69	228.71	195.29
n_2	156.52	189.70	176.40	174.20
n_3	187.87	191.09	231.40	203.39
k_1	175.15	154.48	169.68	166.44
k_2	151.76	160.31	222.88	178.32
k_3	219.93	220.69	243.75	228.12
Mean	182.28	178.49	212.10	
	n_1	n_2	n_3	Mean
k_1	150.39	156.16	192.77	166.44
k_2	190.53	164.64	179.77	178.32
k_3	244.95	201.82	237.61	228.12
Mean	195.29	174.20	203.39	

CD for marginal means 18.94
CD for combination 32.81

M x N and M x K interactions also produced significant effect on soil available K status. The treatment combinations m_3n_3 and m_3k_3 recorded higher values of 231.20 and 243.75 kg ha^{-1} respectively. But m_3n_3 was found to be on par with m_1n_1 and m_3n_1 whereas m_3k_3 was on par with m_1k_3, m_2k_3 and m_3k_2.

No significant variation in available K status after the experiment was noticed due to the effect of M x N x K interaction.

4.6 Response surface and standardization of response to applied nutrients

The fitted quadratic response surface is as follows :

$$Y = -4.8954 + 0.2033\,M + 0.1189\,N + 0.1496\,K - 0.0062\,M^2 - 0.0005\,N^2 - 0.0007\,K^2 + 0.0009\,MN + 0.0010\,MK - 0.0005\,NK$$

F for regression = 3.3875** $R^2 = 0.4093$

The physical and economic optimum doses estimated are given in Table 34.

4.7 Economics of cultivation as influenced by nutrient application

The economics of cultivation as influenced by the combined application of nutrients is presented in Table 35. Cost of cultivation included the cost of labour, seed material and 50 kg P_2O_5 applied uniformly to all the plots and the additional cost due to treatments i.e., levels of FYM, N and K applied. Net income and BCR were calculated from the gross income and the cost of cultivation.

It is evident from the Table 35 that the treatment combination $m_1n_3k_2$ produced the highest net income of Rs. 34116.80 followed by $m_3n_1k_3$, $m_2n_2k_1$ and $m_3n_2k_2$. The highest BCR (1.84) was recorded by the treatment combination $m_1n_3k_2$ followed by $m_2n_2k_1$, $m_3n_1k_3$ and $m_3n_2k_2$.

Table 34 Optimum doses of farmyard manure, nitrogen and potassium for arrow root

Items	Price (Rs.)	Physical optimum dose (ha^{-1})	Economic optimum dose (ha^{-1})
Rhizome	5000 t^{-1}	-	-
FYM	375 t^{-1}	31.20 t	24.81 t
N	9.13 kg^{-1}	100.32 kg	97.27 kg
K_2O	6.67 kg^{-1}	93.31 kg	90.13 kg

Table 35 Economics of cultivation as influenced by nutrient application

Treatments			Additional cost due to treatments (Rs ha^{-1})	Cost of cultivation (Rs ha^{-1})	Rhizome yield (t ha^{-1})	Gross income (Rs ha^{-1})	Net income (Rs ha^{-1})	BCR
FYM (t ha^{-1})	N (kg ha^{-1})	K_2O (kg ha^{-1})						
10	40	40	4382.00	39632.00	10.28	51407.50	11775.50	1.30
10	40	80	4648.80	39898.80	13.54	67707.50	27808.70	1.70
10	40	120	4915.60	40165.60	11.42	57075.00	16909.40	1.42
10	80	40	4747.20	39997.20	12.59	62935.00	22937.80	1.57
10	80	80	5014.00	40264.00	11.68	58377.50	18113.50	1.45
10	80	120	5280.80	40530.80	13.28	66407.50	25876.70	1.65
10	120	40	5112.40	40362.40	10.54	52692.50	12330.10	1.31
10	120	80	5379.20	40629.20	14.95	74746.00	34116.80	1.84
10	120	120	5646.00	40896.00	12.15	60760.00	19864.00	1.49
15	40	40	6257.00	41507.00	10.00	50000.00	8493.00	1.20
15	40	80	6523.80	41773.80	13.72	68577.50	26803.70	1.64
15	40	120	6790.60	42040.60	13.54	67710.00	25669.40	1.61
15	80	40	6622.20	41872.20	14.61	73070.00	31197.80	1.75
15	80	80	6889.00	42139.00	14.13	70632.50	28493.50	1.68
15	80	120	7155.80	42405.80	12.89	64450.00	22044.20	1.52
15	120	40	6987.40	42237.40	14.39	71960.00	29722.60	1.71
15	120	80	7254.20	42504.20	13.56	67795.00	25290.80	1.60
15	120	120	7521.00	42771.00	12.54	62672.50	19901.50	1.47
20	40	40	8132.00	43382.00	10.03	50130.00	6748.00	1.16
20	40	80	8398.80	43648.80	13.04	65200.00	21551.20	1.50
20	40	120	8665.60	43915.60	15.36	76820.00	32904.40	1.75
20	80	40	8497.20	43747.20	14.69	73445.00	29607.80	1.68
20	80	80	8764.00	44014.00	15.35	76732.50	32718.50	1.75
20	80	120	9030.80	44280.80	14.04	70207.50	25926.70	1.59
20	120	40	8862.40	44112.40	13.34	66707.50	22595.10	1.52
20	120	80	9129.20	44379.20	15.28	76390.00	32010.80	1.72
20	120	120	9396.00	44646.00	14.41	72062.50	27416.50	1.62

Cost of cultivation per ha
excluding the treatments = Rs. 35250
Cost of 1 t FYM = Rs. 375
Cost of 1 kg N = Rs. 9.13
Cost of 1 kg K_2O = Rs. 6.67
Price of 1 kg rhizome = Rs. 5.00

DISCUSSION

DISCUSSION

The results of the experiment conducted to study the efficacy of conjoint use of varying levels of organic manure and fertilizers for yield improvement of arrow root under partial shade are discussed in this chapter.

5.1 Growth characters

Results of the study indicated a significant positive influence of FYM, N and K levels on the height of arrow root at six MAP and harvest (Table 2). Among the varying levels of FYM, N and K, higher values of plant height were recorded at their highest levels at both stages. Influence of N in promoting vegetative growth is a well established fact. N encourages plant height through its effect on rapid meristematic activity. It is well known that K also promotes the growth of meristematic tissue (Tisdale *et al.*, 1995). The present result on the height of plant is in agreement with the findings of Purseglove (1968) and Ramesan (1991) in arrow root.

A linear trend on number of suckers per hill was noticed with increasing levels of FYM and N at six MAP and harvest (Table 3). Positive influence of N on tillering was reported by Rao (1973), Saifudeen (1981), Balashanmugham and Chezhiyan (1986) in turmeric. Application of K did not exert any significant effect on sucker number.

The influence of FYM on leaf number was significant only at six MAP as seen from Table 4. Levels N and K did not have any significant effect on leaf number at both stages. Similar results regarding the influence of N was noticed by Nair (1964) and Pandey (1993) in turmeric. Saifudeen (1981) observed that K had no influence on the number of leaves in turmeric.

Pushpakumari (1989) also did not observe any significant effect of fertilizer levels on the leaf number of tannia grown in the coconut garden.

A close scrutiny of the data presented in Table 2 reveals that the increase in height from six MAP to harvest stage was only meagre. Similar trend can be seen in the case of number of suckers (Table 3). This might be due to the fact that photosynthates are diverted for tuber bulking. Leaf number was also drastically reduced at the harvest stage as evident from Table 4. This might be due to leaf shedding and senescence.

The results on plant height, sucker number and leaf number clearly indicate the positive effect of FYM levels. Higher values were obtained at the highest level of application. This emphasizes the role of FYM in promoting the growth characters of arrow root. Growth promoting effect of FYM has been stated in cassava by Ashokan and Sreedharan (1977) and Thampan (1979).

Different levels of FYM and K had no significant influence on LAI at six MAP (Table 5). But the N levels had a profound influence on LAI, the highest value being recorded by 120 kg N ha^{-1}. For many crops, the amount of leaf area available for photosynthesis is roughly proportional to the amount of N supplied (Russel, 1973). Significant increase in LAI due to N application was reported in coleus (Geetha, 1983), turmeric (Balashanmugaham and Chezhiyan, 1986) and mango ginger (Mridula, 1997). Negative relation between LAI and K has been observed in colocasia by Pillai (1967).

The data given in Table 7 and 8 indicate that varying levels of FYM, N and K significantly influenced DMP at six MAP and harvest. FYM at m_3

level (20 t ha^{-1}) recorded the highest value of DMP at both the stages which indicates the favourable effect of FYM on growth and yield of arrow root.

Among the N levels, 80 kg N ha^{-1} was found sufficient for higher DMP in arrow root. According to Russel (1973) as the N supply increases the extra protein produced allows the plant leaves to grow larger and hence to have more surface area available for photosynthesis, which results in better nitrogen use efficiency of plant and enhanced growth. This might have led to increased assimilation, high productivity and increased DMP. Comparable results were reported by Johnson (1978) in ginger, Ramesan (1991) in arrow root and Mridula (1997) in mango ginger.

The influence of K on DMP was significant only at the harvest stage. Level k_2 (80 kg K_2O ha^{-1}) registered significantly higher DMP which indicates that 80 kg K_2O ha^{-1} is optimum for arrow root. The role of K in tuber bulking might have contributed to the higher DMP at the harvest stage.

The interaction M x N, M x K and N x K had significant influence on DMP at both stages. The higher order interactions also gave significant response in terms of DMP at both stages (Table 9). The additive effect of the individual nutrients had resulted in the significant effects of the interactions. Increase in DMP in amorphophallus due to combined application of FYM and NPK has been reported by Kabeerathumma and George (1992).

5.2 Yield and yield components

It is evident from Table 10 that the levels of FYM, N and K did not have any significant influence on the number of rhizomes at six MAP. At harvest, the FYM levels had significant influence on number of rhizomes (Table 11). FYM @ 20 t ha^{-1} recorded the highest number of rhizomes. This might be due the increased availability of nutrients in the plots receiving higher level of FYM. After the initial six months, the vegetative growth might have ceased giving way to tuber initiation and bulking at the later stages.

Interaction effects of M x N and M x K (Table 10 and 11) as well as M x N x K (Table 15) had significant influence on the number of rhizomes at both stages indicating the increased efficiency of nutrients in the presence of FYM. Maheswarappa *et al.* (1997) also reported significantly higher rhizome number in arrow root due to combined application of FYM and NPK.

The influence of FYM, N and K was non significant on the length and girth of the rhizome (Table 12). But there was an increase in the length of rhizome when N level was increased from 40 to 80 kg ha^{-1}. Incremental doses of K increased the length and girth of the rhizome. Increase in number and size of storage cells might have contributed towards the better size rhizome at higher levels of K (Nayar, 1986). The higher order interaction of M x N x K had a profound influence on the rhizome girth as seen from Table 15. The highest value was obtained by the application of 10t of FYM + 80 kg N + 120 kg K_2O ha^{-1} ($m_1n_2k_3$).

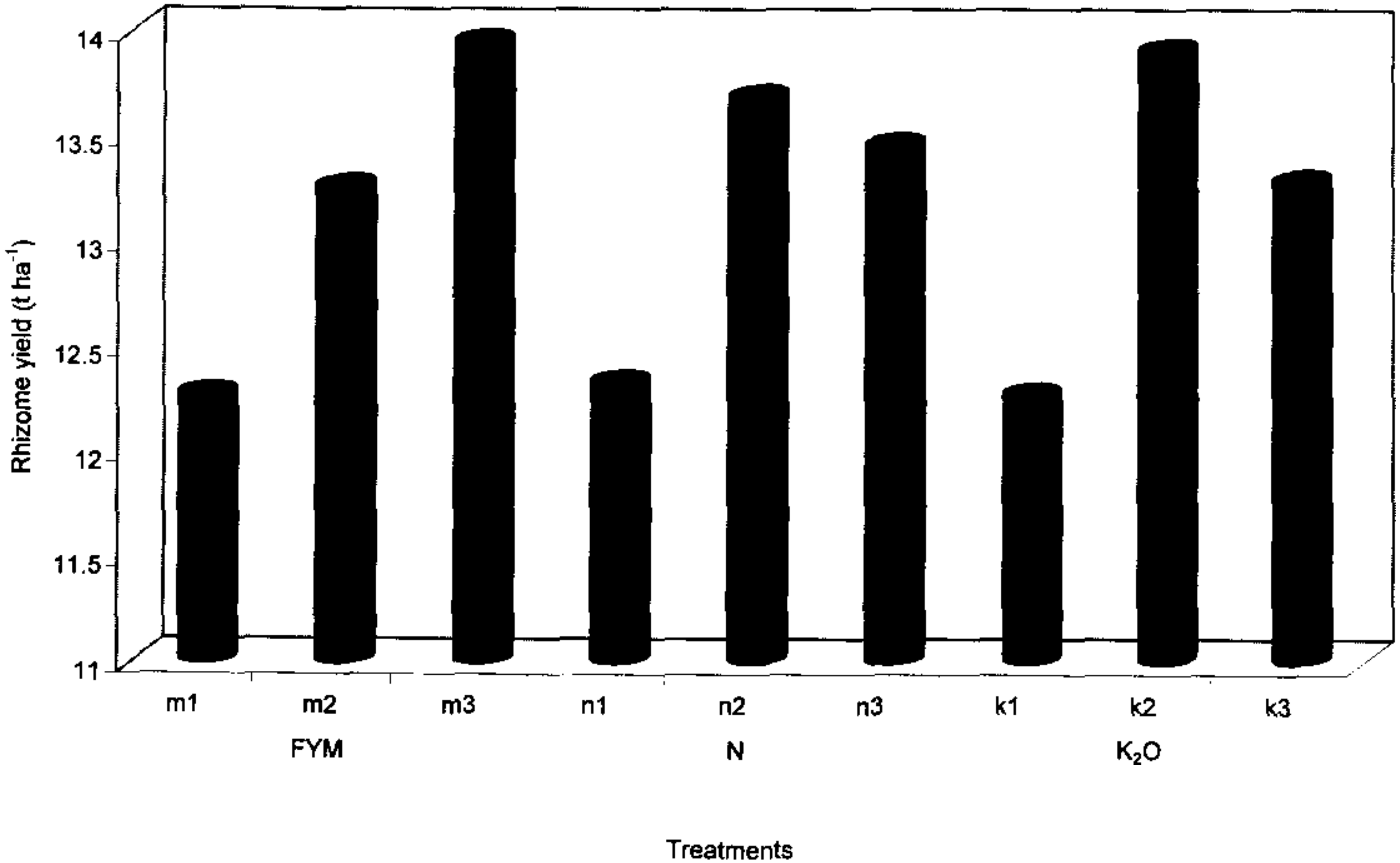
The mean weight of rhizome per plant was not significantly influenced by the main effects of treatments either at six MAP or at harvest. But the interaction effects of M x N, M x K, N x K and M x N x K (Table 13,14 and 15) were found to be significant at both stages. The result indicated the need for combined application of FYM and NPK for producing higher weights of rhizome per plant. The treatment combination $m_1n_3k_2$ (10 t FYM + 120 kg N + 80 kg K_2O ha^{-1}) produced the highest value at six MAP while $m_1n_3k_3$ (10 t FYM + 120 kg each of N and K_2O ha^{-1}) produced higher value at harvest.

The results of the study clearly indicated the significant influence of FYM, N and K on rhizome yield (Table 16). Among the three levels each of FYM, N and K tried, higher yields were realised at the medium levels of FYM (15 t ha^{-1}), N (80 kg ha^{-1}) and K (80 kg K_2O ha^{-1}) as depicted in Fig. 3. The effects of medium levels were found to be on par with the respective higher levels but superior to their lower levels. Application of 15 t ha^{-1} of FYM produced an yield increase of 1 t ha^{-1} over that produced by 10 t ha^{-1}. Similarly application of medium levels of N and K (80 kg each of N and K_2O ha^{-1}) produced yield increases of 1.36 and 1.94 t ha^{-1} respectively over that produced by 40 kg each of N and K_2O ha^{-1}.

Ramesan (1991) suggested 150: 75: 150 kg NPK ha^{-1} for maximum yield (14 t ha^{-1}) of a pure crop of arrow root. But for arrow root grown as an intercrop in coconut garden, CTCRI (2000) recommends a lower dose of nutrients, 50 : 25 : 75 kg NPK ha^{-1} for realizing an average yield of 13.34 t ha^{-1}.

Several studies conducted in related crops also reveal that a lower dose of nutrients is sufficient for a crop grown as an intercrop. Pushpakumari and

Fig. 3 Effect of farmyard manure, nitrogen and potassium on rhizome yield



Sasidhar (1992) reported that lesser yam and elephant foot yam recorded maximum yields with 75 and 50 per cent of the recommended doses respectively when intercropped in the coconut garden. Rajasree (1993) also observed that a lower dose of N (40 kg ha^{-1}) was sufficient for realizing higher values of yield attributes of colocasia intercropped in the coconut garden than for a pure crop of colocasia. Lower doses of N and P were found to be sufficient for the cassava var. Sree Visakham intercropped in the coconut garden as against the recommended dose for a pure crop (Nayar, 1986 and Ravindran, 1997).

Integrated use of FYM @ 20 t ha^{-1} and 40 kg N and 120 kg K_2O ha^{-1} ($m_3n_1k_3$) or 20 t FYM with 80 kg each of N and K_2O ha $^{-1}$ ($m_3n_2k_2$) could produce higher rhizome yields of 15.36 and 15.35 t ha^{-1} respectively (Table 19). Another notable result is that lower yields (10.28, 10 and 10.03 t ha^{-1}) were produced by different levels of FYM (10, 15 and 20 t ha^{-1}) along with the lowest levels (40 kg each) of N and K_2O ha^{-1}. However FYM @ 10t + 120 kg N and 80 kg K_2O ha^{-1} ($m_1n_3k_2$) could produce substantially higher yields of 14.95 t ha^{-1}. It can be seen from Table 15 that FYM @ 10t + 120 kg N + 80 kg K_2O ha^{-1} produced the maximum weight of rhizome per plant at six MAP while FYM @ 10 t + 120 kg N + 120 kg K_2O ha^{-1} produced the maximum rhizome weight at harvest. Maheswarappa *et al.* (1997) also could obtain higher rhizome yield of arrow root intercropped in the coconut garden by the combined application of FYM @ 20 t ha^{-1} and 75 : 50 : 50 kg NPK ha^{-1}.

The influence of FYM, N and K on wet weight of plant at harvest was found to be non significant (Table 17). But there was an increasing trend in top yield with higher levels of N application. Plant height and LAI which are the contributing factors for top yield increased at higher rates of N in the present study (Table 2 and 5). Among the K levels, the highest top yield was recorded at the k_2 level (80 kg K_2O ha^{-1}). There was a reduction in the top yield at the highest level of K (120 kg K_2O ha^{-1}). This may be due to the role of K in the translocation of carbohydrates to the rhizomes favouring tuber bulking. Pushpakumari (1989) also observed non-significant influence of fertilizer levels on the top yield of lesser yam grown in the coconut garden.

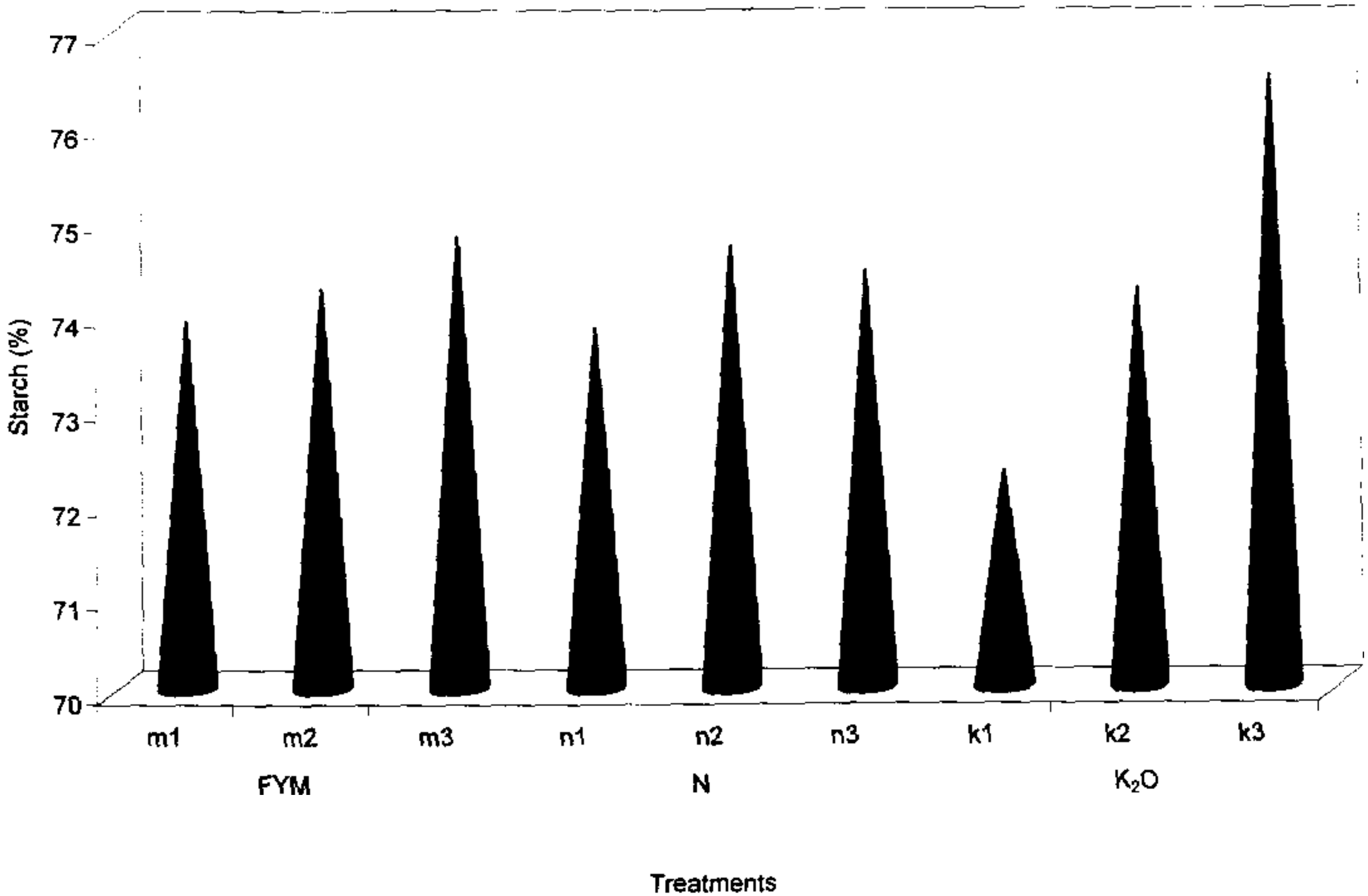
The treatment combination, 20 t FYM + 120 kg N ha^{-1} produced higher top yield in the case of M x N interaction while 40 kg N + 80 kg K_2O ha^{-1} resulted in higher top yield among N x K interaction. The higher order interaction also had a significant influence on the wet weight of plant at harvest (Table 19). This may be due to the additive effects of the nutrients.

It is seen from the data in Table 18 that FYM at 15 t ha^{-1} and K at 80 kg K_2O ha^{-1} were sufficient to produce higher value of UI. N at 80 kg ha^{-1} produced higher UI, though the effect was non significant. The interactions, M x N and N x K also had significant influence on UI. The combination m_2n_3 (on par with m_3n_2) and n_1k_3 (on par with n_2k_2 and n_3k_2) recorded higher values of UI. The effect of M x N x K interaction was also significant as seen from Table 19. The highest value of 1.93 was registered by $m_2n_3k_2$ but was on par with $m_3n_1k_3$ and $m_3n_2k_2$ which produced higher rhizome yield.

5.3 Quality characters of rhizome

The results revealed that the starch content of the rhizome was positively influenced by the levels of K whereas FYM and N had no significant impact on the starch content (Table 20 and Fig. 4). The significant

Fig. 4 Effect of farmyard manure, nitrogen and potassium on starch content of rhizome



influence of K on starch content might be due to the role of K in starch synthesis and translocation. The starch content in coleus was also not significantly influenced by N level as reported by Geetha and Nair (1993). Significant influence of K on starch content was reported by Premraj (1980) in colocasia and Ramesan *et al.* (1996) in arrow root. Mohandas and Sethumadhavan (1980) observed that K upto 150 kg K_2O ha^{-1} had a positive influence on starch content of taro tuber. In the present study also the highest starch content was obtained at the highest level of K (120 kg K_2O ha^{-1}) which was significantly superior to other levels.

The interactions M x N and M x K (Table 20) as well as M x N x K (Table 25) were significant indicating the need for combined application of FYM and fertilizers for increased starch production, Maheswarappa *et al.* (1997) also obtained high starch content of arrow root by the combined application of FYM and fertilizers.

The content of the starch fraction, amylose was determined and the ratio between the two fractions, amylose and amylopectin was worked out. Higher amylose content is desirable as it is related to lower stickiness and better film forming capacity of the starch on which depends the uses of starch. In the present study the amylose content of arrow root starch varied from 17.85 to 21.39 per cent (Table 25) which is in agreement with the findings of Moorthy (2000). The variation in amylose content was due to the significant influence of FYM, N and K applied (Table 21). The amylose content increased with increasing levels of FYM and K while medium level of N (80 kg ha^{-1}) was sufficient for producing higher content of amylose.

Regarding the ratio between amylose and amylopectin contents presented in Table 22, N had significant influence on the ratio, but medium level of N (80 kg ha^{-1}) produced the highest value of 0.39. Although the main effects of FYM and K were non-significant, the interactions M x K had significant effect on the ratio between the starch fractions.

It is evident from Table 23 that the protein content of the rhizome was significantly influenced by FYM and N levels. Higher protein contents were recorded by FYM @ 20 t ha^{-1} and N @ 120 kg ha^{-1}. Application of higher doses of FYM and N resulted in increased N uptake (Table 26) which was converted into proteins. Increase in protein content with increase in N application was reported by Vijayan and Aiyer (1969) and Prema *et al.* (1975) in cassava, Nambiar *et al.* (1976) in sweet potato and Geetha (1983) in coleus. Non-significant influence of K on protein content as observed in the present study was also reported by Muthuswamy (1983) in elephant foot yam.

The two factor interactions, M x N and M x K (Table 23) and also the three factor interaction M x N x K (Table 25) were found to have significant influence on the protein content of the rhizome. Maheswarappa *et al.* (1997) also reported higher crude protein content of rhizome by the combined application of FYM and NPK for arrow root.

The varying levels of M, N and K had a profound influence on the fibre content of the rhizome (Table 24). An increasing trend in fibre content was observed with increasing levels of FYM and N. But with increasing rates of K applied, the fibre content showed a declining trend. Similar effect of K on crude fibre content was reported by Nair and Aiyer (1985) in cassava and Mridula (1997) in mango ginger.

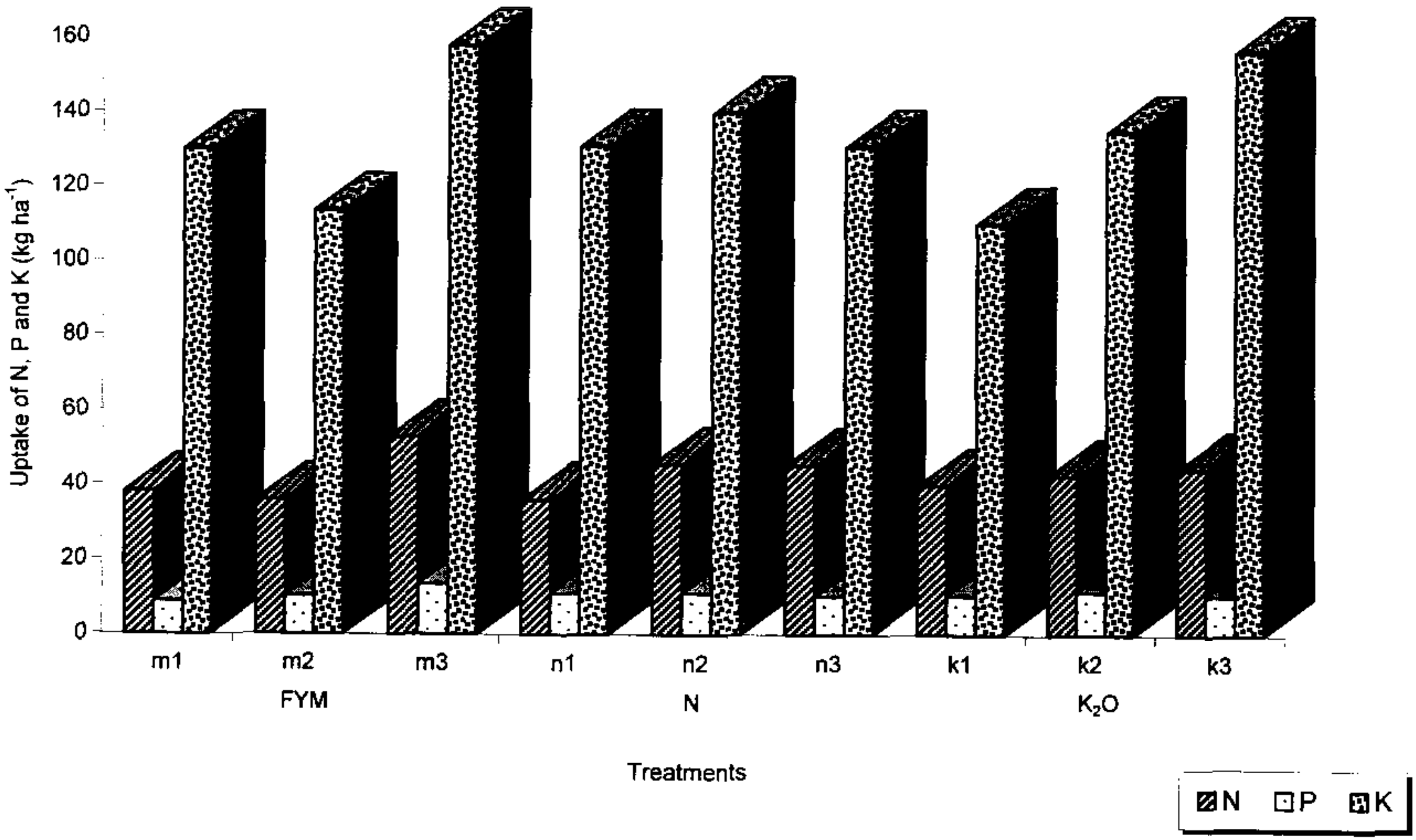
5.4 Uptake of nutrients

The data presented in Table 26 revealed significant effects of different levels of FYM, N and K on N uptake. The highest uptake of N was noticed of the highest level of FYM (Fig. 5). The effects of 80 kg and 120 kg N ha^{-1} were on par. From the data furnished in Table 7and 8, it is evident that FYM @ 20 t ha^{-1} recorded the highest DMP at six MAP and harvest. In the case of N, 120 kg ha^{-1} registered the highest DMP at six MAP whereas 80 kg ha^{-1} gave the highest value at the harvest stage. Increased DMP at higher rates of application might have resulted in increased N uptake. Similar results were reported in ginger (Nair *et al.*, 1976), turmeric (Lynarh, 1991) and coleus (Geetha, 1983). Levels of K did not show any significant influence on N uptake though an increasing trend was noticed upto the highest level of application.

Uptake of P increased significantly with increasing levels of FYM, the highest value being recorded by 20 t ha^{-1} (Table 27 and Fig. 5). Higher levels of FYM resulted in higher DMP which in turn increased the P uptake. N levels failed to exert significant influence on P uptake. Muthuswamy and Krishnamoorthy (1976) documented similar result in sweet potato. But the influence of K levels on P uptake was found to be significant and the medium level (80 kg K_2O ha^{-1}) gave the maximum P uptake. Reduced rate of P uptake due to higher levels of K application was also reported by Thampan (1979) in cassava.

Application of FYM at higher levels (20 t ha^{-1}) significantly enhanced K uptake (Table 28 and Fig. 5) which might be due to the increased availability of the nutrient in the presence of FYM. However, N levels did

Fig. 5 Effect of farmyard manure, nitrogen and potassium on uptake of nutrients



not affect the K uptake by arrow root. Saifudeen (1981) reported similar result in turmeric. Incremental doses of K upto k_3 level (120 kg ha^{-1}) significantly increased the K uptake. This is in agreement with the findings of Saifudeen (1981) and Singh *et al.* (1992) in turmeric.

The two factor and three factor interactions had positive influence on the uptake of nutrients as evident from Table 26 to 29 which might be due to the cumulative effects of the nutrients applied. The highest nutrient uptake in amorphophallus was also recorded for the combination FYM + NPK as reported by Kabeerathumma and George (1992).

5.5 Soil nutrient status after the experiment

Available N content of the soil increased by the application of higher levels of FYM upto 20 t ha^{-1}(Table 30). It may be noted that application of higher levels of FYM not only increased the uptake of N (Table 26) but also increased the available N in the soil after the experiment. An increasing trend in available N content of the soil was noticed upto the highest level of N applied. But the effect was found to be non-significant which could be due to increased uptake of N with increasing levels of N as evident from Table 26. Increased rates of K application significantly enhanced the available N content. Similar results were reported under intercropped situation with cassava (Nayar,1986) and taro (Rajasree, 1993). An increase in available N in the soil due to combined application of FYM and fertilizers to cassava has been reported by Pillai *et al.* (1987) and Kabeerathumma *et al.* (1991).

Application of higher levels of FYM (20 t ha^{-1}) and N (120 kg ha^{-1}) significantly increased the post harvest available P status in the soil as seen from Table 31. But the significant influence of K was found only at 40 kg K_2O ha^{-1}. The interactions were also found to have significant effect on available P (Table 31 and 32) which indicate the need for combined application of FYM and fertilizers to maintain the available P status in the soil. Corroboratory results have been reported by Pillai *et al.* (1987) and Kabeerathumma *et al.* (1991).

Although the uptake of K was the highest at the highest level of FYM applied (Table 28), the available K in the soil after the experiment was also highest at the highest level of FYM (Table 33). This indicates that FYM not only enhanced the availability of K to the crop but also maintained the soil status. However application of a lower dose of N (40 kg ha^{-1}) was found sufficient to maintain the soil available K status. This is in agreement with the findings of Nayar (1986) and Mohankumar and Sadanandan (1991). The uptake as well as post harvest soil nutrient status of K increased with increasing levels of K applied. Ramesan (1991), Nayar (1986), Mohankumar and Sadanandan (1991) and Rajasree (1993) observed increase in available K status of the soil with increasing levels of K application for different tuber crops as pure crop or intercrop in the coconut garden. Pillai *et al.* (1987) reported increased status of available K in the soil due to combined application of FYM and fertilizers for cassava.

5.6 Response surface and standardization of response to applied nutrients

The relationship between applied nutrients and rhizome yield was estimated by fitting a quadratic response surface. The fitted response surface was found to be significant. The coefficient of determination or predictability

171813

(R^2) indicated that about 41 per cent of variation in yield could be explained due to the effect of applied nutrients.

From the response surface, the physical optimum doses of FYM, N and K for arrow root were estimated which are given in Table 34. The economic doses were estimated by computing the price of rhizome and cost of FYM, N and K. It can be seen from Table 34 that the physical and economic optimum doses estimated are equivalent in the case of N and K but for FYM the economic optimum is lower than the physical optimum. Generally we expect a lower dose for economic optimum compared to physical optimum.

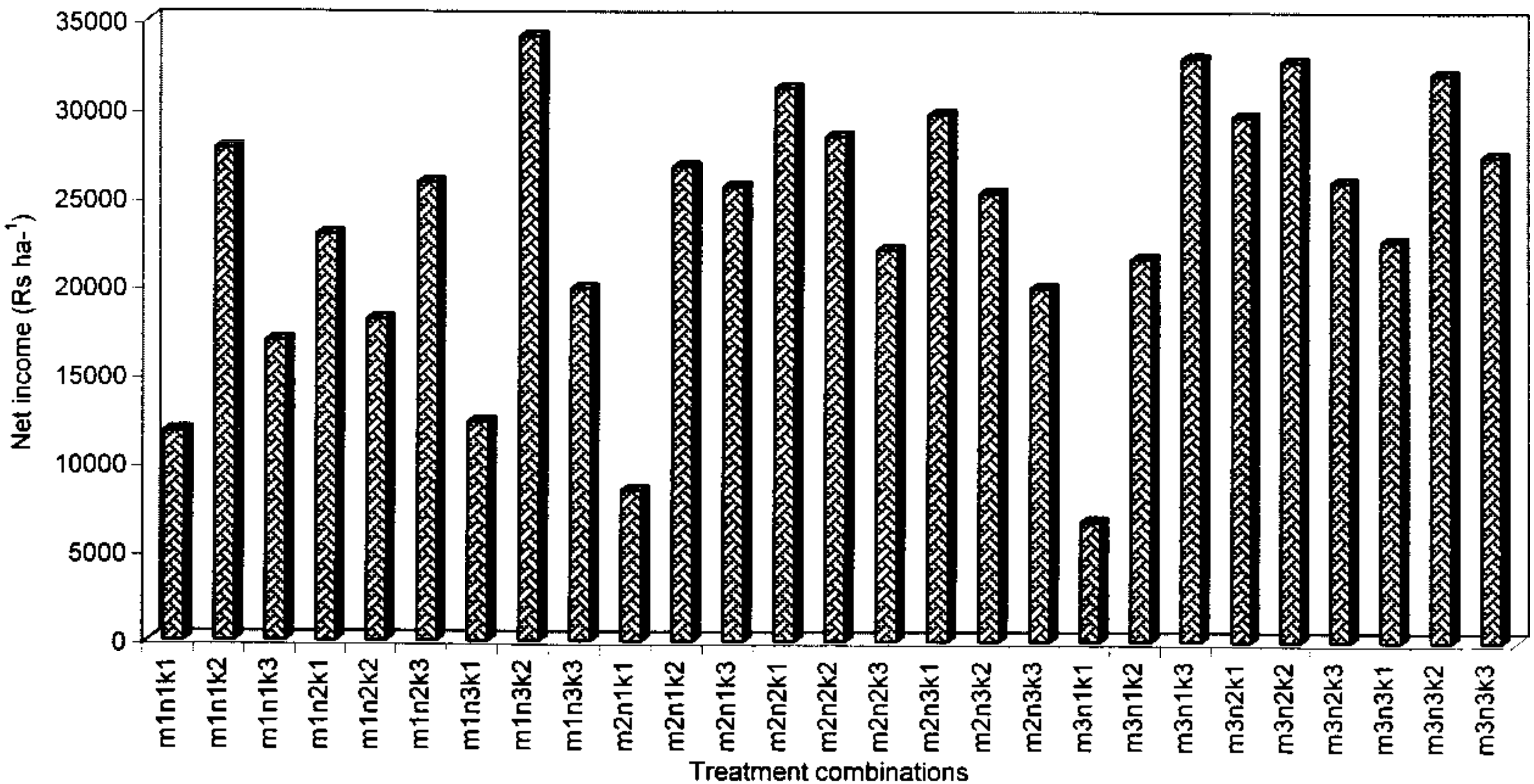
The economic optimum doses estimated were 24.81 t FYM, 97.27 kg N and 90.13kg K_2O ha^{-1}. In this context, it is worthwhile to note that application of 20 t FYM + 80 kg N + 80 kg K_2O ha^{-1} or 10 t FYM + 120 kg N + 80 kg K_2O ha^{-1} could produce higher rhizome yields as evident from Table 19.

5.7 Economics of cultivation as influenced by nutrient application

The data in Table 35 revealed that the combined application of 10 t FYM, 120 kg N and 80 kg K_2O ha^{-1} ($m_1n_3k_2$) produced the highest net income (Rs 34116.80) and BCR of 1.84 (Fig. 6 and 7). This was followed by 20 t FYM + 40 kg N + 120 kg K_2O ha^{-1} ($m_3n_1k_3$) which produced a net income of Rs. 32904.40. Application of 20 t FYM + 80 kg each of N and K_2O ha^{-1} ($m_3n_2k_2$) produced a net income of Rs 32718.50. Although BCR ~~ratio~~ of 1.75 could be registered by the treatment combinations $m_3n_1k_3$, $m_3n_2k_2$ and $m_2n_2k_1$ the net income was higher with $m_3n_1k_3$ closely followed by $m_3n_2k_2$.

Higher rhizome yields of 15.36, 15.35 and 15.28 t ha^{-1} could be produced by the treatment combinations, $m_3n_1k_3$, $m_3n_2k_2$ and $m_3n_3k_2$

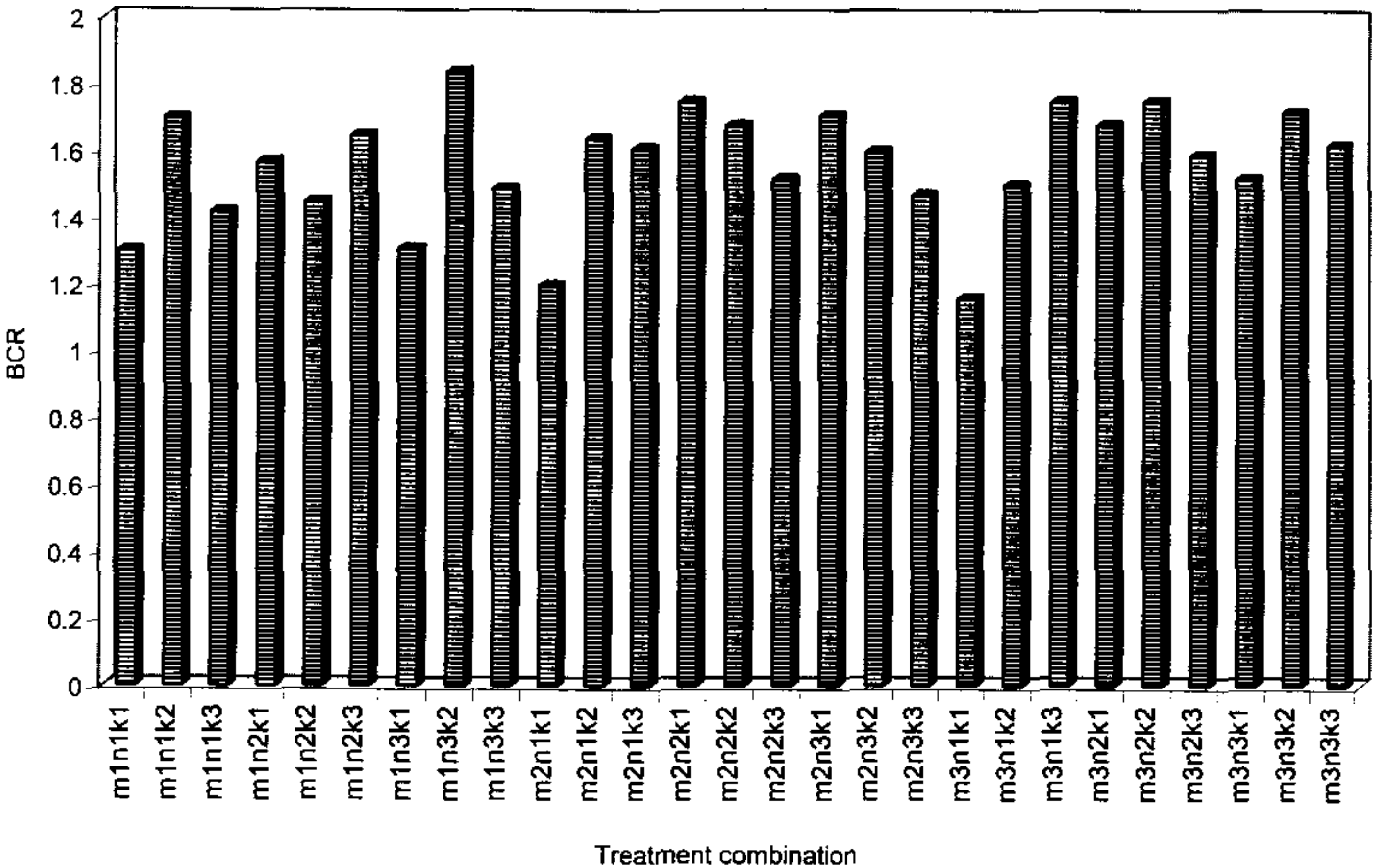
Fig. 6 Effect of treatment combinations on net income



respectively closely followed by $m_1n_3k_2$. (14.95 t ha^{-1}) as evident from Table 19. The economics of cultivation has clearly shown that the treatment combination $m_1n_3k_2$ is the economic dose for obtaining higher yields.

From these results, it can be concluded that combined application of 10 t FYM, 120 kg N and 80 kg K_2O along with 50 kg P_2O_5 ha^{-1} is the most advantageous fertilizer dose for arrow root intercropped in the coconut garden in the laterite soils of Vellayani.

Fig. 7 Effect of treatment combinations on BCR



SUMMARY

SUMMARY

A field experiment was conducted in the Instructional Farm attached to the College of Agriculture, Vellayani from June 1999 to March 2000 to study the efficacy of conjoint use of varying levels of organic manure (FYM at 10, 15 and 20 t ha^{-1}) and fertilizers (N and K_2O each at 40, 80 and 120 kg ha^{-1}) for yield improvement of arrow root under partial shade. The trial was conducted as a 3^3 partially confounded factorial experiment with two replications. The higher order interactions MNK and M^2NK were confounded in replication I and II respectively. A uniform dose of 50 kg P_2O_5 ha^{-1} was applied to all the plots. The results of the study are summarised below.

1. The height of the plant was significantly influenced by the application of FYM, N and K at six MAP and harvest, the maximum values being recorded by their highest levels (20 t ha^{-1} of FYM, 120 kg ha^{-1} N and 120 kg K_2O ha^{-1}).

2. A linear trend on number of suckers per hill was noticed with increasing doses of FYM and N at six MAP and harvest. Application of K did not have any significant influence on sucker number.

3. The influence of FYM on the number of leaves per plant was found to be significant only at six MAP with the highest level (20 t ha^{-1}) registering the highest number. N and K failed to express their effects on leaf number at six MAP or at harvest.

4. Application of N had a profound influence on LAI at six MAP, the highest value being recorded by 120 kg ha^{-1}. Though the effects of

FYM and K were non-significant LAI increased with increasing rates of application.

5. Varying levels of FYM and N significantly influenced DMP at six MAP and harvest. FYM at 20 t ha^{-1} recorded the highest value at both the stages. Among the N levels, 80 kg N ha^{-1} was optimum for higher DMP at both the stages. The effect of K was significant only at the harvest stage. For higher DMP, K at 80 kg K_2O ha^{-1} was found to be sufficient.

6. Number of rhizomes per plant was not significantly influenced by the application of FYM or N or K at six MAP. But FYM had a profound influence on the number of rhizomes per plant at harvest, the highest number being recorded by 20 t ha^{-1}.

7. The main effects of FYM, N and K and their interactions failed to express any significant influence on the length and girth of rhizome. However the combined applications of 10 t FYM, 80 kg N and 120 kg K_2O ha^{-1} had a positive ~~a positive~~ influence on the girth of rhizome.

8. The main effect of FYM, N and K were non-significant with respect to rhizome weight per plant both at six MAP and harvest. However all the two factor and three factor interactions had a significant influence on the rhizome weight at both the stages. The treatment combinations $m_1n_3k_2$ (FYM @ 10 t ha^{-1} + 120 kg N + 80 kg K_2O ha^{-1}) and $m_1n_3k_3$ (FYM @ 10 t ha^{-1} + 120 kg each of N and K_2O ha^{-1}) produced higher values at six MAP and harvest respectively.

9. FYM, N and K had a profound influence on rhizome yield. Among the three levels each of FYM, N and K tried, higher yields were realised at the medium levels of FYM (15 t ha^{-1}), N (80 kg ha^{-1}) and K (80 kg K_2O ha^{-1}). The effects of these levels of FYM, N and K were on par with the respective higher levels but superior to their lower levels. Regarding the interaction effects, higher yields were produced by the treatment combinations $m_3n_1k_3$ and $m_3n_2k_2$ closely followed by $m_1n_3k_2$.

10. The main effect of FYM, N and K did not have any influence on the wet weight of plant at harvest. But M x N, N x K and M x N x K interactions had a positive influence on this character. Higher top yields were recorded by higher levels of nutrients.

11. FYM @ 15 t ha^{-1} and K at 80 kg K_2O ha^{-1} produced significantly higher UI. N at 80 kg ha^{-1} produced the highest UI though the effect was non-significant. The interaction effects were significant with respect to this character.

12. The starch content of the rhizome significantly increased with higher levels of K, the highest value being obtained at 120 kg K_2O ha^{-1}. FYM and N had no significant effect. The interaction effects of M x N, M x K as well as M x N x K were found to be significant.

13. Amylose was significantly influenced by FYM, N and K. FYM @ 20 t ha^{-1} and N and K at medium levels (80 kg each of N and K_2O ha^{-1}) significantly influenced the amylose content in starch. The ratio between amylose and amylopectin was significantly influenced by the application of 80 kg N ha^{-1}.

14. The protein content of the rhizome showed an increasing trend with increasing levels of FYM and N while K failed to exert any significant influence. Interaction effects were also found to have significant influence on the protein content.

15. The lowest crude fibre content was recorded at the lowest levels of FYM (10 t ha^{-1}), N (40 kg ha^{-1}) and the highest level of K (120 kg K_2O ha^{-1}).

16. Significantly higher values of N uptake were noticed at the highest levels of FYM (20 t ha^{-1}) and the medium level of N (80 kg N ha^{-1}). Levels of K did not show any significant influence on N uptake while the interactions were found to be significant.

17. Uptake of P was significantly increased by the application of the highest level of FYM (20 t ha^{-1}) and medium level of K (80 kg K_2O ha^{-1}).

18. Uptake of K was highest at the highest levels of FYM and K while the levels of N had no significant impact on K uptake. The interaction effects had a significant influence on K uptake.

19. The available N content in the soil after the experiment was enhanced by the application of the highest levels of FYM and K tried.

20. Application of higher levels of FYM (20 t ha^{-1}) and N (120 kg ha^{-1}) significantly increased the post harvest available P in the soil. The significant effect of K was observed at 40 kg K_2O ha^{-1}. The interaction effects were also significant in this regard.

21. The post-harvest available K status of the soil was enhanced by the application of the highest levels of FYM (20 t ha^{-1}) and K (120 kg K_2O ha^{-1}) and the medium level of N (80 kg ha^{-1}).

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22. Quadratic response surface was found to be significant to define the relationship between the applied nutrients and rhizome yield. The physical and economic optimum doses of FYM, N and K were worked out. The economic optimum doses were 24.81 t of FYM, 97.27 kg N and 90.13 kg K_2O ha^{-1}.

23. The economics of cultivation showed that the highest net income (Rs. 34116.80) and BCR (1.84) were obtained by the combined application of 10 t FYM, 120 kg N, 80 kg K_2O ha^{-1} along with 50 kg P_2O_5 ha^{-1}.

The present investigation indicated that the combined application of 10 t FYM, 120 kg N and 80 kg K_2O along with 50 kg P_2O_5 ha^{-1} is most advantageous for arrow root intercropped in coconut garden in the laterite soils of Vellayani .

Future line of work

In the present study, FYM is tried as the organic source. Combinations of different levels of other organic sources and fertilizers may be tried to fix the optimum doses of various organic manures and fertilizers. Biofertilizers like phosphobacteria and AMF may also be included in the study. Nutrient requirement under different shade intensities may be worked out. Nutrient requirement of arrow root intercropped with banana, cassava and other crops may be assessed. Studies may be initiated to fix the critical stages for fertilizer application.

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* Original not seen

APPENDICES

APPENDIX – I

Weather data for the cropping period (June 1999 - March 2000) – monthly averages

Sl. No.	Period	Temperature (°C)		Relative humidity (%)	Evaporation (mm)	Total Rainfall (mm)	Number of rainy days
		Max.	Min.				
1.	June 1999	29.48	23.91	85.25	2.92	397.4	18
2.	July 1999	29.00	23.45	84.09	3.06	164.2	21
3.	Aug 1999	29.69	22.95	83.23	3.76	108.4	16
4.	Sept 1999	31.12	23.89	78.58	4.49	10.6	4
5.	Oct 1999	28.96	23.26	86.60	2.32	374.9	21
6.	Nov. 1999	29.79	23.17	81.78	2.84	156.8	13
7.	Dec. 1999	30.71	21.67	81.77	2.79	6.6	2
8	Jan. 2000	30.92	21.71	77.95	3.34	18.4	4
9.	Feb. 2000	30.88	22.69	77.84	3.96	102.2	6
10.	March 2000	32.02	23.41	76.66	4.53	9.4	3

APPENDIX – II

Light intensity in the open field and in the coconut garden

Period	Light intensity		Shade (%)
	Open field	Coconut garden	
June 1999	390	78	80.0
July 1999	430	81	81.2
Aug 1999	670	130	80.6
Sept 1999	648	125	80.7
Oct 1999	680	135	80.1
Nov. 1999	550	105	80.9
Dec. 1999	565	110	80.5
Jan. 2000	570	105	81.6
Feb. 2000	574	108	81.2
March 2000	538	105	80.5
Average			80.7

INTEGRATED NUTRIENT MANAGEMENT FOR ARROW ROOT (*Maranta arundinacea* L.) UNDER PARTIAL SHADE

By

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ABSTRACT OF THE THESIS
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ABSTRACT

A field experiment was conducted in the Instructional Farm, College of Agriculture, Vellayani from June 1999 to March 2000 to study the efficacy of conjoint use of varying levels of organic manure and fertilizers for yield improvement of arrow root under partial shade. The treatments included three levels each of FYM (10, 15 and 20 t ha^{-1}), N and K (40, 80 and 120 kg each of N and K_2O ha^{-1}). A uniform dose of 50 kg P_2O_5 ha^{-1} was applied to all the plots. The experiment was laid out in a 3^3 partially confounded RBD confounding MNK in replication I and M^2NK in replication II.

Application of FYM had profound influence on growth characters like plant height, sucker number, leaf number and dry matter production. Nitrogen also exerted significant influence on growth characters like plant height, sucker number, leaf area index and dry matter production. The effect of K was significant on dry matter production at the harvest stage and 80 kg K_2O ha^{-1} was found sufficient for higher dry matter production.

Number of rhizomes per plant at harvest showed an increasing trend with increasing levels of FYM. Girth of rhizome and weight of rhizome per plant were influenced by the combined application of FYM and fertilizers. Higher rhizome yields were realised at the medium levels of FYM (15 t ha^{-1}), N (80 kg ha^{-1}) and K (80 kg K_2O ha^{-1}). The combined application of 20 t FYM, 40 kg N and 120 kg K_2O ha^{-1} or 20 t FYM and 80 kg each of N and K_2O ha^{-1} produced higher yields closely followed by 10 t FYM + 120 kg N +

80 kg K_2O ha^{-1}. FYM @ 15 t ha^{-1}, N @ 80 kg ha^{-1} and K @ 80 kg K_2O ha^{-1} produced higher utilization index.

The highest starch content and the lowest crude fibre content of the rhizome were recorded by the highest level of K (120 kg K_2O ha^{-1}) tried while the highest protein content was recorded by the highest level of FYM (20 t ha^{-1}) and N (120 kg ha^{-1}) applied.

Application of FYM @ 20 t ha^{-1} enhanced the uptake of N, P and K as well as the post-harvest soil nutrient status. For higher N uptake, application of 80 kg N ha^{-1} was found sufficient. Uptake of K as well as available K in the soil after the experiment showed an increasing trend with increasing levels of K application.

The study indicated that combined application of 10 t FYM, 120 kg N and 80 kg K_2O ha^{1} along with 50 kg P_2O_5 ha^{-1} is most advantageous for arrow root intercropped in coconut garden which resulted in the highest net income and benefit-cost ratio in the laterite soils of Vellayani.