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# Growth and Productivity of Elephant Foot Yam (*Amorphophallus paeoniifolius* (Dennst. Nicolson): an Overview

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## Abstract

In India, *Amorphophallus paeoniifolius* (Dennst. Nicolson), syn. *A. campanulatus* (Roxb.) BL. exDence (also elephant foot yam) is largely cultivated and consumed in the Philippines, Java, Indonesia, Sumatra, Malaysia, Bangladesh, India and China. In India, it is cultivated in Andhra Pradesh, West Bengal, Gujarat, Kerala, Tamil Nadu, Maharashtra, Uttar Pradesh, and Jarkhand. Sree Padma, Gajendra, Sree Athira (a hybrid), Bidhan Kusum and NDA-9 are some of the high yielding *Amorphophallus* varieties released for cultivation in India. The production potential of this crop is 50-80 t $ha^{-1}$ and net economic return is over 1 lakh rupees per ha. The plant growth and corm yield is influenced by size of planting material (corms / cormels / corm pieces), plant spacing and nutrient management. However, the production aspect of this crop is less understood as scanty research has been carried out in this crop. The available literature on growth and productivity of elephant foot yam is briefly described in this article.

Keywords: Elephant foot yam, growth, productivity

## Introduction

*Amorphophallus paeoniifolius* (Dennst.), syn. *A. campanulatus* (Roxb.) BL. exDence (also elephant foot yam) is a herbaceous, perennial $C_3$ crop. It is basically a crop of south eastern Asian origin. It serves as a source of protein as well as starch. It has long been used as a local staple food in many countries such as the Philippines, Java, Indonesia, Sumatra, Malaysia, Bangladesh, India, China and south eastern Asian countries (Chandra, 1984; Sugiyama and Santosa, 2008). It is commercially cultivated due to its production potential and popularity as a vegetable in various delicious Indian cuisines. In India, it is cultivated in Andhra Pradesh, West Bengal, Gujarat, Kerala, Tamil Nadu, Maharashtra, Uttar Pradesh, and Jarkhand whereas in northern and eastern states, wild, local cultivars grown are generally being used for making vegetable pickles and medicine preparations for various ailments. The crop is also cultivated as an intercrop along with turmeric (Fig. 1) and under coconut (Fig. 2) or banana. In recent years, farmers in Bihar and Uttar Pradesh have also started its cultivation. The production potential of this crop is 50-80 t $ha^{-1}$ and net economic return is over 1 lakh rupees per ha. This crop also offers export potential since it is not commercially cultivated in other countries (Misra and Shivalingaswamy, 1999; Misra et al., 2001). In India, Sree Padma, Gajendra, Sree Athira (a hybrid), Bidhan Kusum and NDA-9 are some of the high yielding *Amorphophallus* varieties released for cultivation (AICRP, 2006). The corms are usually eaten as vegetable after boiling or baking and are rich in calcium, (50 mg $g^{-1}$), phosphorus (34 mg $g^{-1}$) and vitamin A (260 IU $g^{-1}$). The leaves are used as a vegetable by local tribes in India because they contain high concentration of vitamin A (Rajyalakshmi et al., 2001). Elephant foot yam plants grow well in medium to light soils (coarse-textured sandy soils) with adequate amounts of organic matter because they prefer well-aerated soils. The crop can tolerate temporary flooding, but anaerobic waterlogging causes corm rot. In Kerala, elephant foot yam is planted in

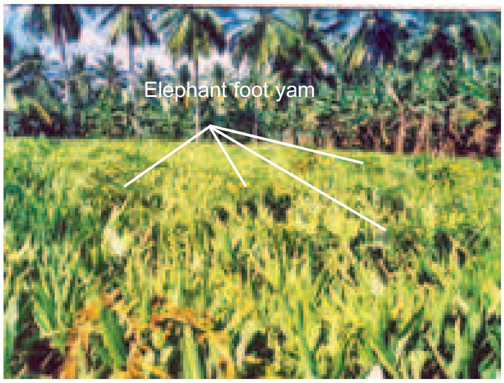



Fig 1. Elephant foot yam as an intercrop with turmeric

Fig 2. Elephant foot yam under coconut

February and harvested during November-December under rainfed conditions. In Andhra Pradesh, the crop is planted during September - October and harvested in June (*rabi* / winter season crop) or planted in June and harvested in January (*kharif* / rainy season crop) under irrigated conditions. In West Bengal, the crop is planted in October and harvested in June under irrigated conditions. This review summarizes the available literature on growth and productivity of elephant foot yam. However, biotic stress due to pests and diseases which may influence productivity of elephant foot yam is not dealt here.

### Corm dormancy

*Amorphophallus* corms exhibit dormancy for about 3 - 4 months after harvest. As a result of this, planting and harvesting are done at a particular time of the year. *Amorphophallus* is propagated by corms as such or by cut corm pieces having a part of apical meristem. Sprouting percentage was more (98%) with top cut portion of corm than the cut corms from lower half of the mother corm (Dhua et al., 1988; Nedunzhian and Mohankumar 1997; Mondal and Sen, 2004). The bottom portion of the corm is not used generally as planting material due to lower efficiency of sprouting (Dhua et al., 1988; Nedunzhian and Mohankumar, 1997; Mohankumar and Ravi, 2001). Therefore a greater portion of (about 25%) of the harvested produce is again lost as source of planting materials. Ethrel or ethephon was reported to induce early sprouting in *Amorphophallus* corm (Dhua et al., 1988; Bala Nambisan and Indira, 1992). Treating cut pieces of corms from lower half with chemicals significantly improved sprouting, subsequent growth and yield. Among the different chemicals used, thiourea, potassium nitrate and CCC were effective in promoting sprouting. Thiourea (200 ppm) and $KNO_3$ (1000 ppm) and kinetin (5 ppm) increased corm sprouting by 24.3 – 92.0, 17.8 and 13.4% respectively as compared to control (Table 4, Dhua et al., 1988; Kumar et al., 1998). However, mean corm weight was greater in plants from corms treated with thiourea (100 ppm), potassium nitrate ($KNO_3$) (500 ppm) and CCC (0.02 ml $l^{-1}$) yielding 722, 821 and 806 g per plant respectively (Dhua et al., 1988). However, corm yield per ha did not increase significantly in plants from corms treated with chemicals, as compared to plants from untreated corms. Exposing the whole corms to smoke for 6 h per day for 6 weeks increased sprouting by 58.3% as compared to untreated corms presumably due to ethrel in smoke. Similarly exposing the corms to 45°C for 6 h per day for 3 weeks increased sprouting by 83.3% as compared to untreated corms (Mohankumar and Ravi, 2001). Temperature (32°C) and thiourea had greater influence on breaking dormancy (Archana Mukherjee et al., 2009). This may be due to increase in availability of sugars due to increase in respiration at higher temperature. Compared to smoke and heat treatments, soaking corms in different chemicals [$KNO_3$, thiourea, ammonium sulphate ($NH_4SO_4$)] for a short period (20 - 30 minutes) had no significant effect on inducing early sprouting (Mohankumar and Ravi, 2001). However, treating the apical portion of corm (after removing the apical bud) with thiourea and subsequently wetting the apical portion for a period of 10 days induced early sprouting with more number of sprouts (Archana Mukherjee et al., 2009). Darkness had adverse effect on sprouting (Kumar et al., 1998). In *A. konjac*, abscisic acid (ABA) and ferulic acid were extracted from the dormant corms and exogenous application of ABA (10 mg $l^{-1}$) and ferulic acid (400 mg $l^{-1}$) inhibited sprouting and growth of the terminal buds of non-dormant corms suggesting that ABA and ferulic acid are inhibitors of sprouting of dormant corms (Sun et al., 1996). Corms are acrid before dormancy, but the acridity decreases after dormancy (Santosa et al., 2003).

### Shoot characteristics

The new shoot emerges from the corm used as the planting material. The time of emergence (sprouting) of new shoot depends on the dormancy status of the planting material. If the planting material has completed its dormancy before planting, then the new shoot sprout will emerge as soon as it is planted. Leaf emergence is delayed when the apical buds of seed corms are damaged. Leaves emerged earlier when whole corms were planted than when cut corms were planted irrespective of corm size (Sen et al., 1996). When whole corms, bud portions or upper half sections were planted, buds sprouted 2-3 weeks after plantation. However, buds started to sprout 4-7 weeks after planting when vertical 1/2, 1/4 and 1/8 corm sections and lower half corm sections were planted (Sugiyama and Santosa, 2008). Once the sprout is initiated further development of new shoot may be completed within 30 days (Plate 1. A to F). Leaves are basal, compound, pinnate, solitary and erect. Leaves are medium to very large sized. The plant develops leaves by using preserved carbohydrates in seed corms (planting material) and then daughter corms (new corms) enlarge by using assimilates synthesized by the leaves. In general, *Amorphophallus* corms have one apical bud, which exists inside the cavity in the head part of seed corms. Three or four small cataphylls existing in the head part of corms cover the apical bud in which the first leaf primordium has already differentiated at planting. The cataphylls elongate concomitantly with leaf development. Possibly, they protect a leaf from damage by soil impedance during development. Furthermore, subepidermal cells of cataphylls may contain needle-like crystals of calcium oxalate which presumably offer protection to a young leaf from damage by pests. Cataphyll size depends on corm size and plant age. The cataphylls wither after leaves become mature. Leaves are composed of a petiole (pseudostem) and three rachises with many leaflets. The number of leaves developing during the growing season is dependent on corm age. During a growing season upto 12 leaves may be produced successively. As such, more

Fig 3. A heavily weed infested elephant foot yam field

than 2 leaves may coexist at the same time. The number of leaves is also determined by the size of planting materials. Plants originating from small corms (10 g) produce three to eight leaves, while large corms (500 g) usually produce one or two leaves during a growing season. Under weedy conditions leaves are submerged (Fig. 3) under weeds and the number of leaves, total leaf area, leaf thickness and fresh masses of corms decreases markedly (Santosa et al., 2006c). When preflowering and post flowering corms with similar fresh masses were planted both types of corms sprouted at about the same time; however, leaf sizes (length of petioles and rachis) were larger in preflowering corms than in postflowering corms (Sugiyama and Santosa, 2008). Upto 150-250 leaflets per leaf may be produced per leaf and it may vary among accessions. The leaf area of any 1 of the 3 lobes of *A. campanulatus* leaves showed a highly significant correlation (r = 0.93 to 0.97) with total leaf area (Patel and Mehta, 1987). The number of stomata in lower epidermis increased from 10.22 per unit area at 50 DAP to 17.78 per unit area at 150 DAP (Gopi et al., 2008). The stoma has 2 adjacent cells surrounded by 4 subsidiary cells (Plate 2. a and b). The leaf area index increased with time and reached a maximum (6.1) at 120 DAP at a planting density of 1,40,000 plants $ha^{-1}$ (Das et al., 1997). On the other hand the LAI reached 4.4 and 5.4 at a planting density of 1,00,000 and 1,20,000 plants $ha^{-1}$ respectively. Petioles (pseudostem) looks like the stems of normal plants and are cylindrical in morphology. In general, large petioles indicate that the corm is also large. The mean shoot length varied between 47.3 - 122.5 cm depending upon


Plate 1. A to F Stages in the development of shoot

the variety, plant spacing or size of planting material used (Mukhopadhyay and Sen, 1986; Ravindran and Kabeerathumma, 1991; Sen and Das, 1991; Goswami and Sen, 1992; James George and Nair 1993; Geetha, 2001; Suja et al., 2005, 2006). Increase in N application from 50 to 150 kg ha$^{-1}$ increased shoot length by 11%, (Mukhopadhyay and Sen, 1986) or did not increase shoot length and girth (Geetha, 2001). Increase in K application from 50 to 150 kg ha$^{-1}$ did not have any significant effect on shoot growth (Mukhopadhyay and Sen, 1986; Geetha 2001). Regardless of plant spacing, increase in size of planting material increased plant (pseudostem) height and plant height was maximum (84.6 cm) when 1 kg cut corm piece was used as planting material. Closer plant spacing (60 x 45 cm) increased plant height (53.8 cm) than wider plant spacing (90 x 90 cm) (James George and Nair, 1993). Plants produced from whole seed corms were taller than those produced from cut pieces of corm of the same size. This may be due to early sprouting and better root ramification (Sen and Das, 1991).

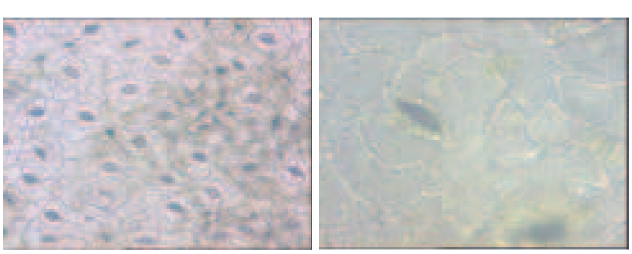
The canopy spread varied between 72.2 and 143.8 cm (Ravindran and Kabeerathumma, 1991; Sen and Das, 1991; Goswami and Sen, 1992; James George and Nair, 1993). Regardless of plant spacing, increase in size of planting material increased canopy spread and canopy spread was maximum (132.7 cm) when 1 kg cut corm piece was used as planting material at wider plant spacing (90 x 90 cm) (Sen and Das, 1991). The canopy spread was more in plants raised by planting whole seed corms than that in plants produced from cut pieces of corms of the same size. This was presumably due to early sprouting and better root ramification (Sen and Das, 1991).

Biomass production of shoot (leaf and pseudostem/petiole) increased up to 120 days after planting (DAP) and 150 DAP respectively and declined thereafter whereas the corm dry weight and total dry matter production (TDMP) showed a steady increase up to the maturity. The corm dry – matter production (CDMP) per ha increased with increase in planting material size or plant density and highest CDMP (25.6 t $ha^{-1}$ and 19.4 t $ha^{-1}$ respectively) was observed at 6 MAP by using 250 g cut corm pieces as planting material or with high plant density (14 plants $m^{-2}$) (Das et al., 1997). The crop growth rate (CGR) increased gradually up to 120-150 DAP and sharply declined at maturity as the crop growth ceased. However, the relative growth rate (RGR) continued to decrease with crop age and was the highest at early growth stage (Das et al., 1997). The leaf area increased with increase in planting material size or plant density and highest leaf-area index (5.4) was observed between 4 and 5 months after planting by using 250 g cut corm pieces as planting material or with high plant density (14 plants $m^{-2}$) (Das et al., 1997). Similarly CGR increased with increase in planting material size or plant density and highest CGR (25.3-32.2 g $m^{-2}$ $day^{-1}$) was observed at 5 months by using 250 g cut corm piece as planting material. The CGR was 22. 4 g $m^{-2}$ $day^{-1}$ at a plant density of 14 plants $m^{-2}$ (Das et al., 1997). Treating corm pieces from bottom portion of corm with growth regulators viz., thiourea, $KNO_3$ and $GA_3$ effectively influenced the growth characters and $GA_3$ gave maximum corm yield (Das et al., 1997).

Application of triazole compounds (systemic fungicides) triadimefon (TDM), paclobutrazole (PBZ) and propiconazole (PCZ) through soil drenching increased total root length (by 8.85 - 75.92%), dry weight of whole plant (by 71.44 – 84.91%), intercellular $CO_2$ concentration (by 25.12 – 27.91%), leaf thickness, number of spongy and palisade cells, number of chloroplasts per cell, net photosynthetic rate ($P_N$) (by 15.7 – 28.92%) and water use efficiency (WUE) (by 56.81 – 87.9%) as compared to untreated control plants. In contrast, total leaf area, transpiration rate ($T_R$) and stomatal conductance decreased (Gopi et al., 2005, 2008, 2009).

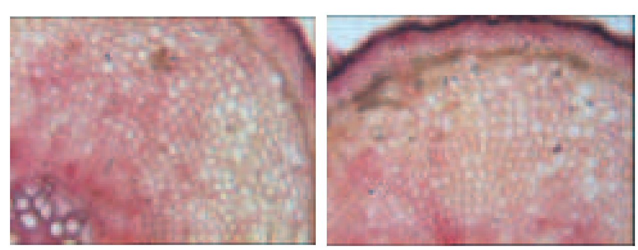
### Root characteristics

Roots grow out from the surface of newly developing daughter corms at the base of the pseudostem through the remanants of the cataphylls concomitantly with leaf emergence. These roots extend horizontally and are densely distributed at a shallow depth of top 15-30 cm

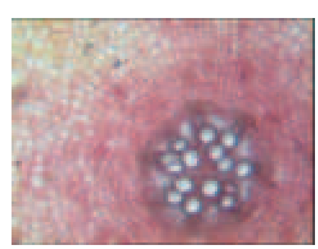


A-Stomata on the abaxial leaf surface (10 x 10) B-Single stoma with subsidiary cells (40 x 10)

Plate 2. A, B. Stomata in elephant foot yam leaf



A-Root T.S. B-Root T.S. showing cortex



B-Root T.S. showing stele

Plate 3. A-C. Root anatomy of elephant foot yam (4 x 10)

soil depth. The roots are cylindrical and 2 to 5 mm thick. Roots grow more than 1 m in length under adequate soil moisture conditions or under adequate rain and are known as "rain roots". Under dry soil conditions, the root length decreases to less than 30 cm length. The transverse section (T.S.) of root shows about 25 layers of thin walled parenchymatous cortex cells surrounding a central stelar portion with 8 protoxylem points (Plate 3 a, b and c).

#### Corm development and yield

A new daughter corm is formed at the region between the petiole (pseudostem) and seed corm when a leaf grows out from the cataphylls (sheathing leaves). Then, roots appear from the new corms and attain a maximum dry mass at 90 DAP. The daughter corm begins to enlarge after a leaf has fully expanded (1 to 2 months) and remarkable enlargement occurs later. The dry mass of seed corms (planting material) decreases gradually, finally decomposing within three months after the new shoot sprouts and develops and the new corm initiates with profuse roots at the base of the emerging new shoot (sprout). After the corm has been initiated, it continuously grows and bulks as long as there is adequate moisture in the soil. There are many small lateral buds (about 1 mm in height) and one large lateral bud (5-15 mm in height) arranged in a definite pattern in concentric nodes of corms. The number of lateral buds per node ranges from 13.0 to 43.3. The number of lateral buds is larger in the middle region of corms than in the head and bottom regions. About 20% of visible lateral buds develop into cormels in the head and middle regions of corms, while about 8% of visible buds develop into cormels in the bottom region. Therefore, the middle region of corms produce a large number of cormels than other regions (Sugiyama and Santosa, 2008). The corm growth rate (corm bulking rate) increased steadily between 1 and 5 to 6 months after planting. Maximum corm bulking rate (7.2 – 8.2 g plant$^{-1}$ day$^{-1}$) was observed during 5 or 6$^{th}$ month after planting (Mukhopadhyay and Sen, 1986; Nair et al. 1991). Increasing the level of N from 100 to 200 kg ha$^{-1}$ or $K_2O$ from 75 to 150 kg ha$^{-1}$ increased the plant height and corm bulking rate (Sen et al., 1996). Increase in N application from 50 to 150 kg ha$^{-1}$ increased corm growth (corm bulking rate) by 10.6-27.6% during the six month's growth period (Mukhopadhyay and Sen, 1986). The effect of N was more pronounced during initial growth period than during later growth period. The increase in corm bulking rate due to increase in N application from 50 to 150 kg ha$^{-1}$ was maximum (27.6%) during the 4 month's growth period but declined to 15.3% and 10.6% during 5$^{th}$ and 6$^{th}$ month after planting respectively. The mean corm weight per plant increased by 21.3% with increase in N application from 50 to 150 kg ha$^{-1}$. The corm yield per ha increased by 20% with increase in N application. The corm yield was 84.6 and 102.3 t ha$^{-1}$ with N @ 50 and 150 kg ha$^{-1}$ application respectively. Increase in K

Table 1. Effect of *Azotobacter* on corm yield

| Treatments | Mean corm yield (t ha$^{-1}$) |
|---|---|
| N @ 75 kg ha$^{-1}$ | 42.9 |
| N @ 75 kg ha$^{-1}$ + *Azotobacter* (2%) solution applied to the seed corm before planting | 54.3 |
| N @ 75 kg ha$^{-1}$ + *Azotobacter* applied in soil (@ 9 kg ha$^{-1}$) at 35 days after planting | 51.3 |
| N @ 100 kg ha$^{-1}$ | 50.7 |
| N @ 100 kg ha$^{-1}$ + *Azotobacter* (2%) solution applied to the seed corm before planting | 55.8 |
| N @ 100 kg ha$^{-1}$ + *Azotobacter* applied in soil (@ 9 kg ha$^{-1}$) at 35 days after planting | 52.4 |
| N @ 112.5 kg ha$^{-1}$ | 52.3 |
| N @ 112.5 kg ha$^{-1}$ + *Azotobacter* (2%) solution applied to the seed corm before planting | 57.5 |
| N @ 112.5 kg ha$^{-1}$ + *Azotobacter* applied in soil (@ 9 kg ha$^{-1}$) at 35 days after planting | 54.7 |
| N @ 150 kg ha$^{-1}$ | 58.9 |
| N @ 150 kg ha$^{-1}$ + *Azotobacter* (2%) solution) applied to the seed corm before planting | 54.9 |
| N @ 150 kg ha$^{-1}$ + *Azotobacter* applied in soil (@ 9 kg ha$^{-1}$) at 35 days after planting | 62.2 |
| CD (0.05) | 6.6 |

(Source: Mukhopadhyay and Sen, 1999)

application did not significantly increase corm growth (corm bulking rate), mean corm weight per plant and corm yield per ha. However, N and K had significant interactive effect on corm growth (corm bulking rate), mean corm weight per plant and corm yield per ha and this appears to be mainly due to N (Mukhopadhyay and Sen, 1986). Shoot height, basal shoot (pseudo-stem) girth, dry matter accumulation in shoot increased and reached a peak at 120 days after planting (DAP). Corm and total (shoot and corm) dry matter increased up to

Table 2. Effect of seed corm size on shoot length, canopy spread, mean corm weight and corm yield

| Seed corm size (g) | Shoot length (cm) | Canopy spread (cm) | Mean corm weight (kg) | Corm yield (t $ha^{-1}$) |
|---|---|---|---|---|
| Cut corm piece (g) | | | | |
| 250 | 62.6 | 85.8 | 0.84 | 37.4 |
| 500 | 72.3 | 89.0 | 0.95 | 42.2 |
| 750 | 81.0 | 114.8 | 1.23 | 54.7 |
| 1000 | 84.6 | 132.7 | 1.74 | 77.3 |
| Whole corm (g) | | | | |
| 250 | 69.1 | 88.6 | 1.36 | 60.5 |
| 500 | 75.4 | 99.7 | 1.48 | 65.8 |
| 750 | 88.8 | 117.9 | 1.8 | 80.0 |
| 1000 | 96.8 | 134.9 | 2.53 | 112.4 |
| CD (0.05) | 0.8 | 0.8 | 0.06 | 2.7 |

(Source: Sen and Das, 1990)

Table 3. Effect of seed corm size on shoot length, canopy spread, mean corm weight and corm yield

| Seed corm size (g) | Shoot length (cm) | Canopy spread (cm) | Mean corm weight (kg) | Corm yield (t $ha^{-1}$) |
|---|---|---|---|---|
| 250 | 36.5 | 99.8 | 1.14 | 14.1 |
| 500 | 40.4 | 97.1 | 1.53 | 18.9 |
| 750 | 48.7 | 114.4 | 1.88 | 23.2 |

(Source: James George and Nair, 1993)

Table 4. Effect of chemicals on sprouting of corm, mean corm weight and corm yield

| Treatments | Sprouting (%) | Mean corm weight(g) | Total corm yield (t $ha^{-1}$) |
|---|---|---|---|
| Thiourea (100 ppm) | 73.3 | 721.6 | 28.5 |
| Thiourea (200 ppm) | 91.1 | 488.0 | 31.3 |
| $KNO_3$ (500 ppm) | 82.2 | 820.6 | 30.9 |
| $KNO_3$ (1000 ppm) | 86.6 | 528.6 | 28.9 |
| Ethrel (0.025 ml $l^{-1}$) | 75.5 | 434.3 | 18.9 |
| Ethrel (0.125 ml $l^{-1}$) | 73.3 | 679.6 | 29.3 |
| Kinetin (5 ppm) | 82.2 | 390.0 | 24.5 |
| Kinetin (10 ppm) | 75.5 | 410.6 | 16.7 |
| CCC (0.02 ml $l^{-1}$) | 84.4 | 806.3 | 32.4 |
| CCC (0.1 ml $l^{-1}$) | 68.8 | 563.6 | 19.7 |
| Control (soaked in water) | 68.8 | 587.3 | 30.9 |
| Control (unsoaked) | 66.6 | 540.6 | 22.2 |
| Top cut portion | 97.7 | 722.6 | 36.7 |
| CD (0.05) | 16.7 | 218.3 | 11.6 |

(Source: Dhua et al., 1988)

Table 5. Yield of *Amorphophallus* as affected by NPK

| Nutrients (kg $ha^{-1}$) | Yield (t $ha^{-1}$) | Source | Nutrients (kg $ha^{-1}$) | Yield (t $ha^{-1}$) | Source |
|---|---|---|---|---|---|
| $N_{150}$ | 102.3 | Mukhopadhyay and Sen (1986) | $N_{40}$ | 30.2 | Geetha (2001) |
| $K_{50}$ | 96.7 | | $N_{80}$ | 33.5 | |
| $N_{100}$ $K_{50}$ | 91.8 | | $N_{120}$ | 34.8 | |
| $N_{100}$ $K_{100}$ | 90.5 | | $K_{0}$ | 31.1 | |
| $N_{100}$ $K_{150}$ | 91.1 | | $K_{90}$ | 33.1 | |
| $N_{150}$ $K_{100}$ | 102.2 | | $N_{80}K_{90}$ | 37.2 | |
| $N_{150}$ $K_{150}$ | 94.4 | | $N_{120}K_{0}$ | 39.2 | |
| $N_{50}$ | 64.4 | Kundu et al. (1998) | $N_{120}K_{90}$ | 39.8 | |
| $N_{100}$ | 65.5 | | | | |
| $N_{150}$ | 65.5 | | | | |
| $N_{200}$ | 75.1 | | | | |
| $P_{50}$ | 62.1 | | | | |
| $P_{100}$ | 65.5 | | | | |
| $P_{150}$ | 64.4 | | | | |
| $K_{50}$ | 62.2 | | | | |
| $K_{100}$ | 65.5 | | | | |
| $K_{150}$ | 63.9 | | | | |
| $N_{100}$ $P_{100}$ $K_{100}$ | 65.5 | | | | |
| $N_{150}$ $P_{100}$ $K_{100}$ | 67.4 | | | | |
| $N_{200}$ $P_{100}$ $K_{100}$ | 75.1 | | | | |
| $N_{100}$ $P_{25}$ $K_{125}$ | 32.5 | Nair et al. (1991) | | | |
| $N_{100}$ $P_{50}$ $K_{150}$ | 43.0 | | | | |
| $N_{150}$ $P_{25}$ $K_{150}$ | 36.3 | | | | |
| $N_{150}$ $P_{50}$ $K_{150}$ | 35.5 | | | | |

150 days and declined thereafter. Maximum shoot height (85.2 cm), shoot girth (16.4 cm) and shoot dry matter (6.63 t $ha^{-1}$) and corm yield (67.83 t $ha^{-1}$) were obtained with the application of 150 kg $ha^{-1}$ N and K in two splits (Verma et al., 1995). Treating planting material (corms) with 2% *Azotobacter* solution at the time of planting and application of 9.0 kg $ha^{-1}$ of culture mixed with 40 kg of soil at the root zone of the crop along with 150 kg N $ha^{-1}$ resulted in high corm yield (64.9 and 62.2 t $ha^{-1}$ respectively) (Table 1, Mukhopadhyay and Sen, 1999).

Corm yield varied between 30.9 and 85.4 t $ha^{-1}$ depending upon the variety, cultural practices particularly plant spacing and manurial practices (Mukhopadhyay and Sen, 1986; Nair et al. 1991; Ravindran and Kabeerathumma, 1991; Goswami and Sen, 1992; James George and Nair 1993; Kundu et al., 1998; Geetha 2001; Suja et al., 2005, 2006, 2007, Suja and Sundaresan, 2008). Corm yield between 39.6 and 98.9 t $ha^{-1}$ were obtained due to application of 100 - 200 kg N and 100 – 150 kg $K_2O_5$ each per ha (Table 5, Nair et al., 1991; Sen and Das, 1991; Kundu et al., 1998). Application of farmyard manure at a rate of 30 t $ha^{-1}$ increased the fresh mass or corms by 15%, while application of N @ 150 kg $ha^{-1}$ increased yield by 6.5% (Patel and Mehta, 1984). Kabeerathumma reported that 100 kg $ha^{-1}$ N, 38 kg $ha^{-1}$ of $P_2O_5$ and 267 kg ha $^{-1}$ of $K_2O$ were removed from the field every year when 33 t $ha^{-1}$ of corms were produced. Organic farming (FYM @ 35 t $ha^{-1}$ + green manuring with cowpea to generate 20-25 t $ha^{-1}$ of green matter + neem cake @ 1 t $ha^{-1}$and ash @ 3 t ha $^{-1}$) increased corm yield by 25.37% (62.67 t $ha^{-1}$) as compared to traditional method (farmer's practice, FYM 25-30 t $ha^{-1}$ + and ash @ 3 t $ha^{-1}$) (49.99 t $ha^{-1}$) and by 19.21% as compared to conventional method (FYM 25 t $ha^{-1}$ + NPK @ 100: 50: 150 kg $ha^{-1}$) of cultivation (52.57 t $ha^{-1}$) (Suja et al., 2005, 2006, 2007, Suja and Sundaresan, 2008, 2009).

The corm yield was significantly influenced by the size of seed corm and higher yields were recorded from planting materials of 1 kg size (Sen et al., 1984; Asokan, 1984; Sen and Das, 1991). Increase in size of planting material from 250 g to 1 kg increased mean corm weight per plant from 0.75 kg to 1.74 kg whereas the corm yield per ha increased from 21.6 to 77.34 t (Sen et al., 1984; Asokan, 1984; Sen and Das, 1991; James George, and Nair, 1993; Das et al., 1995). Comparatively more corm yield was obtained by planting whole seed corms which was about 45% greater than the corm yield obtained from cut pieces of corms of the same size (Table 2 and 3, Sen and Das, 1991). This was presumably due to early sprouting and better root ramification (Sen and Das, 1991). Nevertheless, a seed corm size of 500 g at 90 x 90 cm spacing would be ideal for economic cultivation of elephant foot yam (James George and Nair, 1993). For production of small size (< 1 kg) corms for home use, planting materials of 100 – 300 g may be used (Das et al., 1995; Mondal and Sen 2004; Rajib Nath et al., 2007). To prevent decay after planting due to the presence of several soil borne pathogens, cut corm pieces are dipped in cow dung slurry mixed with mancozeb (0.2%) + monocrotophos (0.05%) for 10 minutes and surface dried under shade for 24 h before planting. Biofertilizers and other beneficial microorganisms may be added to the cow dung slurry for high productivity (Nedunchezhiyan et al. 2006). The planting depth affected plant growth and yield (Santosa et al. 2004a). Deeper planting of seed corms led to deformation in daughter corms. At a depth of 30 cm, most corms were elongated or became pyriform. Therefore corms at a depth of 10 cm below the soil surface is desirable (Sugiyama and Santosa, 2008). Multiplication ratio in *Amorphophallus* could be enhanced to 1:15 from the conventional 1:4 by adopting minisett technique developed in CTCRI (James et al., 2004). Minisetts produced corms in the range of 600 g to 1.5 kg. Treating setts of corm pieces from bottom portion of corm with $GA_3$ (200 ppm) gave maximum corm yield (Das et al., 1997).

The mean starch content of *Amorphophallus* corm varied between 9.2 and 23.6% and increase in N or K application did not have significant effect on starch content (Mukhopadhyay and Sen, 1986; Geetha, 2001). Organic practices favoured starch content of elephant foot yam corm (Suja et al., 2005, 2006, 2007; Suja and Sundaresan, 2008). The starch content ranges from 3.6% to 11.5% on a fresh mass basis in Indonesian accessions (Santosa et al., 2002), and from 7.0 % to 14.3% in Indian accessions (Moorthy et al., 1994). There is little variation in the average size of starch granules (9-13 μm) and amylase content (22-24%) among different accessions (Moorthy, 2002).

### Responce to shade

Elephant foot yam tolerates shade conditions. Therefore, it can be intercropped between young trees. Corm yield decreased by 66% when the light intensity is reduced to 25% of full sunlight (Pushpakumari and Sasidhar, 1992). In contrary, Santosa et al., (2006) reported that the fresh biomass of corms increased with a decrease in light intensity; 75% shading produced the largest corms and 0% shading produced the smallest corms. Under full sunlight necrosis and curling at either the edge or the tips of leaflets occurred causing 25% loss of the crop. No damage was observed in the 25, 50 and 75% shading. However, the shading treatments significantly decreased the leaf number. The short life span of leaves might enhance the production of new leaves resulting in a larger number of leaves under full sunlight. Shading treatments significantly affect the length of petioles and rachis. Plants developed the shortest petioles under full sunlight but the longest under 75% shading.

### Effect of water deficit stress

Little research work has been done on the response of *Amorphophallus* to water deficit stress. Soil moisture status does not influence sprouting but further development of new shoot depends on adequate soil moisture. Elephant foot yam plants produce large corms when the water supply is adequate. About 1000-1500 mm of rainfall per year is optimum for the crop (Jansen et al., 1996). Many plants enter dormancy earlier than usual when the rainy season is shorter than 4 months and supplementary irrigation is necessary for high productivity when the rainy season is shorter than 4 months. Plants produced a larger number of leaves under frequent watering (1-, 3- and 5 day intervals) than under 7- and 15-day intervals; the third leaves were produced in treatments up to 7-day intervals, but neither the second nor the third leaves were produced in 15-day intervals. Furthermore, frequent watering produced large leaves and extended their life span compared with less frequent watering (Santosa et al., 2004b). A decreas in the dry mass of seed corms was more evident with frequent watering, suggesting that reserved carbohydrates in seed corms are not easily metabolized under a limited water supply. The ratios of dry mass of daughter corms to that of seed corms are 6.1, 1.1, 0.6, 0.4 and 0.2 at 1-, 3-, 5-, 7-, and 15-day intervals, respectively. The high ratio of dry mass of daughter corms to that of seed corms under frequent watering treatments could be ascribed to the fact that the soil water availability affects not only the utilization of dry matter in seed corms but also the production and translocation of photoassimilates into daughter corms (Sugiyama and Santosa, 2008). The roots dried earlier than usual when the soil water content decreased to less than 40% of field capacity (Santosa et al., 2004b). The crop tolerates water deficit stress conditions for about 30-60 days but prolonged stress may affect corm yield (Santosa et al., 2004b). In green-house conditions, plant growth was not affected when plants were watered at 1, 3 or 5 day intervals. Nevertheless, infrequent watering (watering at 7 or 15 days intervals) reduced corm yield and forced the corms to enter into dormancy. Soil moisture conservation methods like mulching induced higher percentage of early sprouting, greater canopy spread, plant height, greater mean corm weight and corm yield (Mohankumar et al., 1973). The corm yield of elephant foot yam was greater under surface irrigation (40.0 t $ha^{-1}$) and microirrigation @ 80% CPE (37.0 t $ha^{-1}$) than under rainfed conditions (25.2 t $ha^{-1}$) (M. Nedunchezhiyan, personal communication).

### Seed dormancy

Successful seed production has been reported in *Amorphophallus* (Arakeri, 1950). Seed dormancy of 5-6 months has been reported in this crop (Arakeri, 1956). Exposing seeds to running water for 6 days resulted in highest sprouting (55.5%) as compared to control (2.7%). However, exposing seeds to water for more than 6 days resulted in lower percentage of sprouting (Rajendran and Hrishi, 1976).

### Future thrust

Heavy weed infestation has been shown to strongly compete with elephant foot yam for light, water and nutrition and significantly reduce leaf production and corm biomass (Santosa et al., 2006c). However, critical period of elephant foot yam-weed competition and weed management practices to be followed are little understood and warrants investigation. Since the whole corm and cut corm pieces are used as planting material, a larger portion of harvested produce is used for propagation. Therefore, the development of plantlets through *invitro* culture of lateral buds (Irawati et al., 1986; Archana Mukherjee et al., 2009; Unnikrishnan and Mohan, 2009) has to be further refined and exploited for planting material production. Besides, the physiological aspects of growth and productivity of *Amorphophallus* is little understood. This warrants detailed investigation on the following aspects:

(a) leaf area development, crop growth rate, stomatal characteristics, photosynthetic rate, root development and rooting pattern, corm development and corm bulking rate, light interception, dry matter production and partitioning (harvest index), varietal variation in these aspects and physiological factors limiting corm yield.

(b) effect of exogenous application of growth regulators such as benzyl adenine and other such growth promoters on maximizing corm yield.

(c) *Amorphophallus* needs a long duration (8 months) for maximum corm yield. Hence, studies on factors controlling corm bulking will reveal physiological basis for developing fast bulking, short duration varieties in this crop.

(d) studies to determine water, light and thermal degree days requirement and effect of water deficit stress and shade on growth and productivity of this crop.

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