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Review paper

Crop physiology of elephant foot yam [*Amorphophallus paeoniifolius* (Dennst. Nicolson)]

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Abstract: ***Amorphophallus paeoniifolius*** **(Dennst. Nicolson), syn.** ***A. campanulatus*** **(Roxb.) BL. exDence (also elephant foot yam) is largely cultivated in the Philippines, Java, Indonesia, Sumatra, Malaysia, Bangladesh, India and China. In India, it is cultivated in the states of 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. The corm production potential of this crop is 50-80 t ha^{-1} and net economic return is about 2000 – 3000 US$ per ha. Plant growth and corm yield is influenced by the size of planting material (corms/cormels/corm pieces), plant spacing, nutrient management and water availability. Nevertheless, the production aspect of this crop is less understood as scanty research has been conducted in this crop. The available literature on growth and productivity of elephant foot yam is briefly described in this article.**

1. Introduction

Amorphophallus paeoniifolius (Dennst.), syn. *A. campanulatus* (Roxb.) BL. exDence (also elephant foot yam) is an herbaceous, perennial C_3 crop. It is basically a crop of southeastern 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 southeastern Asian countries (Chandra, 1984; Sugiyama and Santosa, 2008). It is commercially cultivated due to its production potential and popularity as a vegetable in various Indian cuisines. In India, it is cultivated in Andhra Pradesh, West Bengal, Gujarat, Kerala, Tamil Nadu, Maharashtra, Uttar Pradesh, and Jarkhand states whereas in northern and eastern states, the wild, local cultivars grown are generally 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 begun cultivation. Under improved cultural practices and high yielding varieties the production potential of this crop varies between 30 and 100 t ha^{-1} and the net profit (economic return) is about 2000 – 3000 US$ per ha (AICRP, 2004, 2005, 2006 a, b, 2007, 2008, 2009). This crop also offers export potential in India since it is not commercially cultivated in other

Fig. 1 - Elephant foot yam as an intercrop with turmeric. Arrows indicate elephant foot yam plants.

Fig. 2 - Elephant foot yam under coconut.

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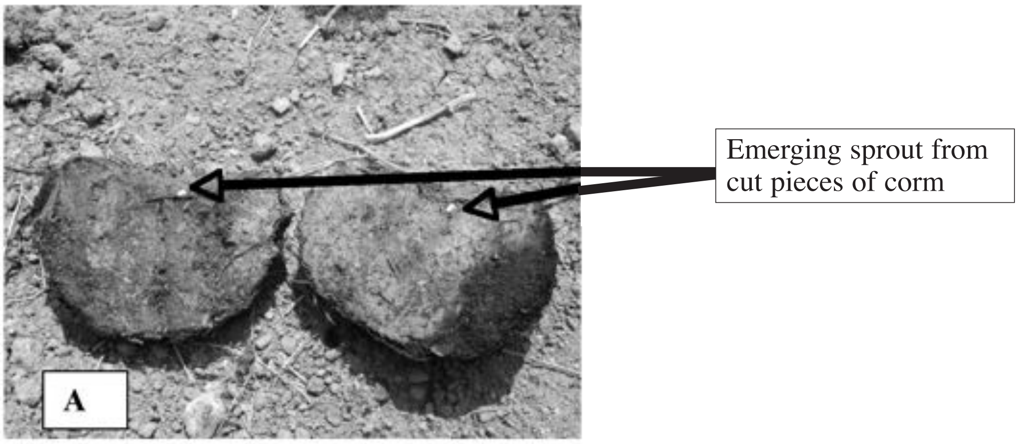
countries (Misra and Shivalingaswamy, 1999; Misra, 2000; Misra *et al*., 2001). In India, 'Sree Padma', 'Gajendra', 'Sree Athira' (a hybrid), 'Bidhan Kusum' and 'NDA-9' are some of the high yielding *Amorphophallus* varieties released for cultivation (AICRP, 2006 a). The corms are usually eaten as a 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 a high concentration of vitamin A (Rajalakshmi *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 water logging causes corm rot. In Kerala, elephant foot yam is planted in February and harvested during November-December under rainfed conditions. In Andhra Pradesh, the crop is planted during September-October and harvested in June (winter season crop) or planted in June and harvested in January (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.

2. Shoot characteristics

The new shoot (leaf) sprout emerges from the cut corm pieces or full corm used as planting material (Plate 1 A and B). The time of emergence (sprouting) of new shoots 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 or cut pieces of corm are planted. Leaves were found to emerge 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 planting. 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 shoots may be completed within 30 days (Plate 2 A to F). Leaves are basal, compound, pinnate, solitary and erect. Leaves are medium to very large in size. The plant develops leaves by using preserved carbohydrates in seed corms (planting material) and then daughter corms (new corms) enlarge by using



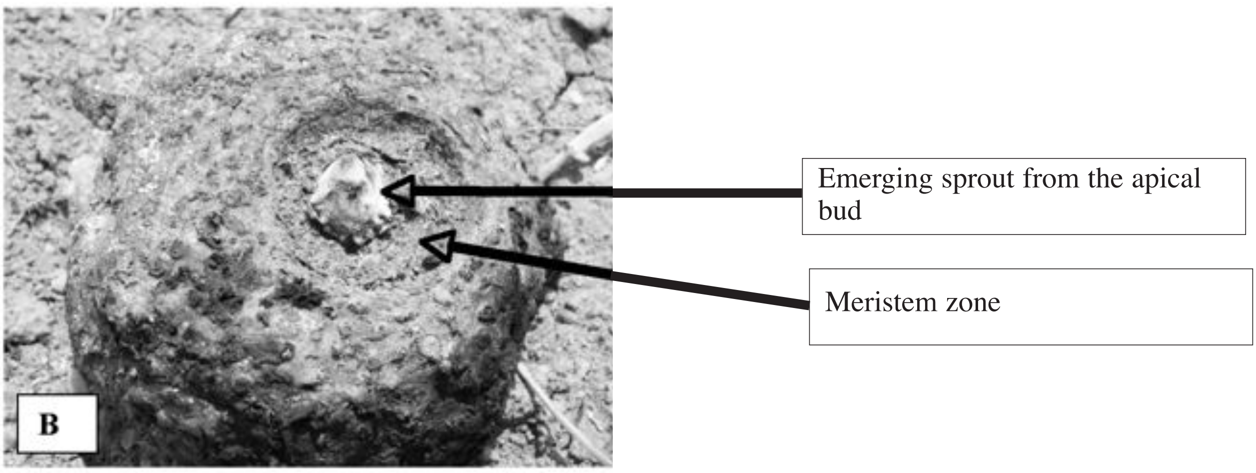
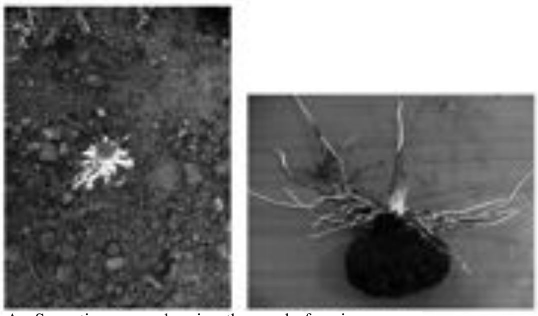
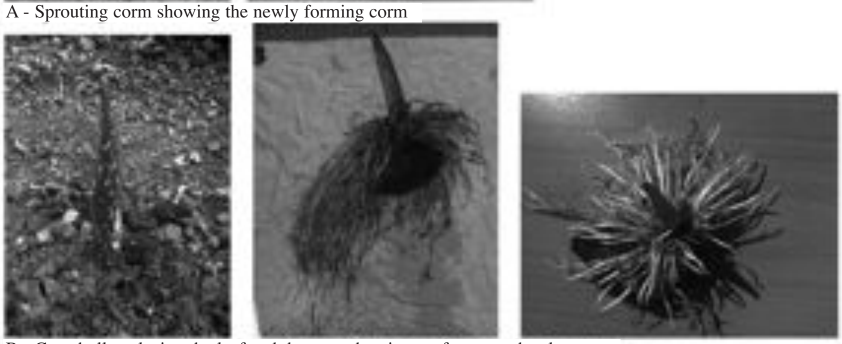


Plate 1 -New sprout emerging from cut corm pieces (A) and full corm (B) of elephant foot yam before planting.



A - Sprouting corm showing the newly forming corm

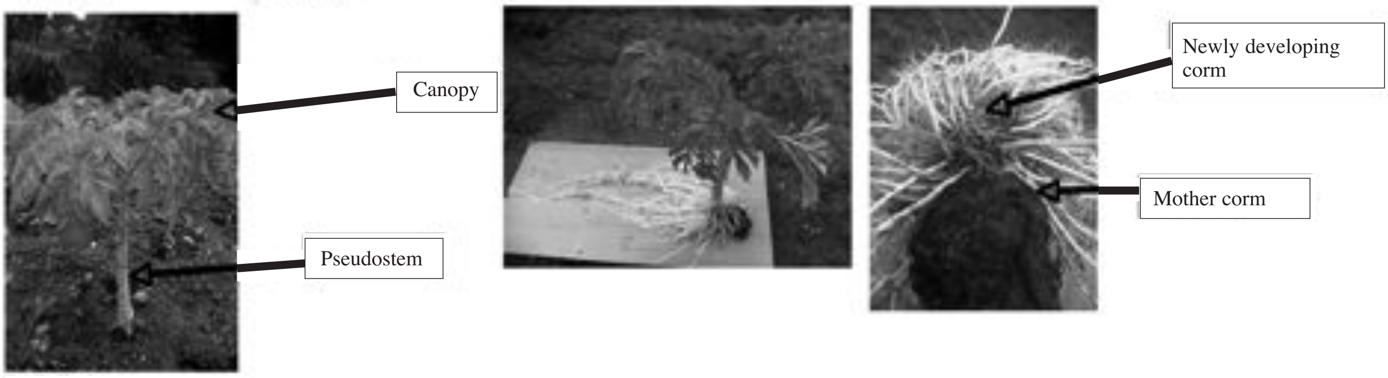


B - Cataphyll enclosing the leaf and the corn showing profuse root development

C - Early stage of leaf emerging out from the cataphyll

D - Leaf emerging out from the cataphyll

E - Spreading canopy



F - Full plant.

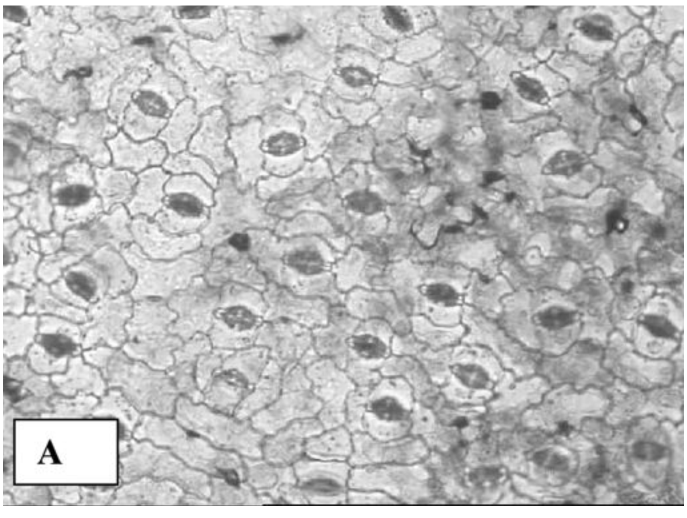
Plate 2 - Different stages (A-F) of leaf development from the sprout in elephant foot yam.

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 which develop during the growing season is dependent on corm age. During a growing season up to 12 leaves may be produced successively. As such, more than two 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 field conditions, weeds grow much before shoot development from planted corms because of corm dormancy and delay in sprouting. Under weedy conditions, leaves are submerged under weeds (Fig. 3) and the number of leaves, total leaf area, leaf thickness and fresh masses of corms decreases markedly (Santosa *et al*., 2006 c). 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). Up to 150-250 leaflets may be produced per leaf and this may vary among accessions.

Fig. 3 - A heavily weed-infested elephant foot yam field.

The leaf area of any one of the three 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 the lower epidermis increased from 10.22 per unit area at 50 days after planting (DAP) to 17.78 per unit area at 150 DAP (Gopi *et al*., 2008). A stoma has two adjacent cells surrounded by four subsidiary cells (Plate 3 A and B). The leaf area index increased with time and reached a maximum (6.1) at 120 DAP at a planting density of 140 x 10^3 plants ha^{-1} (Das *et al*., 1997). On the other hand, the LAI reached 4.4 and 5.4 at a planting density of 100 x 10^3 and 120 x 10^3 plants ha^{-1} respectively. Petioles (pseudostem) look like the stems of normal plants and are cylindrical in morphology. In general, large petioles indicate that the corm is also large. Depending upon the variety, plant spacing or size of planting material used, the mean shoot length varied between 47.3 and 122.5 cm (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; AICRP, 2004, 2005, 2006, 2007, 2008, 2009; Saraswati *et al*., 2008). Increases in N application from 50 to 150 kg ha^{-1} increased shoot length by 11%, (Mukhopadhayay and Sen, 1986) or did not increase shoot length and girth (Geetha, 2001), while increases in K application from 50 to 150 kg ha^{-1} did not have any significant effect on shoot growth (Mukhopadhayay and Sen, 1986; Geetha 2001). Regardless of plant spacing, an increase in size of planting material increased plant (pseudostem) height; 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) more than wider plant spacing (90 x 90 cm) (James 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).

Canopy spread was found to vary between 70.2 and 143.8 cm (Ravindran and Kabeerathumma, 1991; Sen and Das, 1991; Goswami and Sen, 1992; James and Nair, 1993; AICRP, 2004, 2005, 2006 a, b, 2007, 2008, 2009). Regardless of plant spacing, increases in the



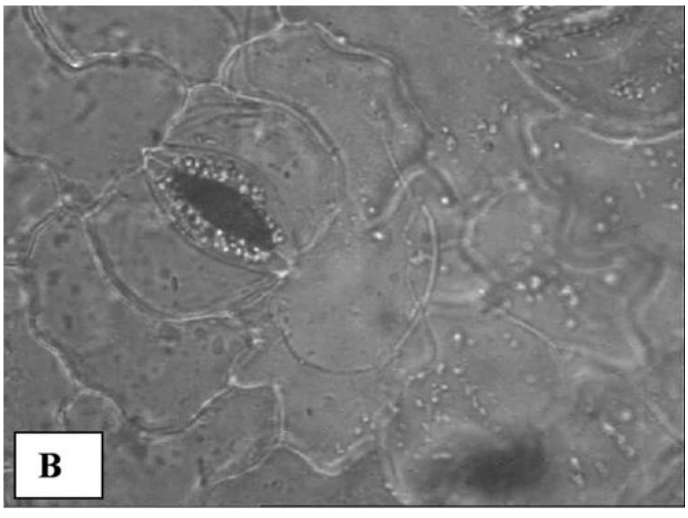


Plate 3 - A and B Stomata in elephant foot yam leaf. A) Stomata on the abaxial leaf surface (10x10). B) Single stoma with subsidiary cells (40x10).

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). Canopy spread was greater in plants raised by planting whole seed corms than 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 shoots (leaf and pseudostem/petiole) increased up to 120 and 150 DAP respectively and declined thereafter, whereas corm dry weight and total dry matter production (TDMP) showed a steady increase up to maturity. The corm dry-matter production (CDMP) per ha increased with increases in planting material size or plant density and the highest CDMP (25.6 t ha^{-1} and 19.4 t ha^{-1} respectively) was observed at six months after planting (MAP) by using 250 g cut corm pieces as planting material or with high plant density (14 plants m^{-2}) (Das *et al.*, 1997). Crop growth rate (CGR) increased gradually up to 120-150 DAP and sharply declined at maturity as crop growth ceased. However, the relative growth rate (RGR) continued to decrease with crop age and was the highest at the early growth stage (Das *et al.*, 1997). The leaf area increased with increases in planting material size or plant density and the highest leaf-area index (5.4) was observed between 4 and 5 MAP by using 250 g cut corm pieces as planting material or with high plant density (14 plants m^{-2}) (Das *et al.*, 1997). Similary 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 the bottom portion of corm with growth regulators thiourea, KNO_3 and GA_3 effectively influenced the growth characters and GA_3 gave the maximum corm yield (Das *et al.*, 1997).

3. Plant growth regulators

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).

4. Root characteristics

Roots grow out from the surface of newly developing daughter corms at the base of the pseudostem through the remnants of the cataphylls concomitantly with leaf emergence. These roots extend horizontally and are densely distributed at a shallow depth of the top 15-30 cm 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 stellar portion with eight protoxylem points (Plate 4 A and B).

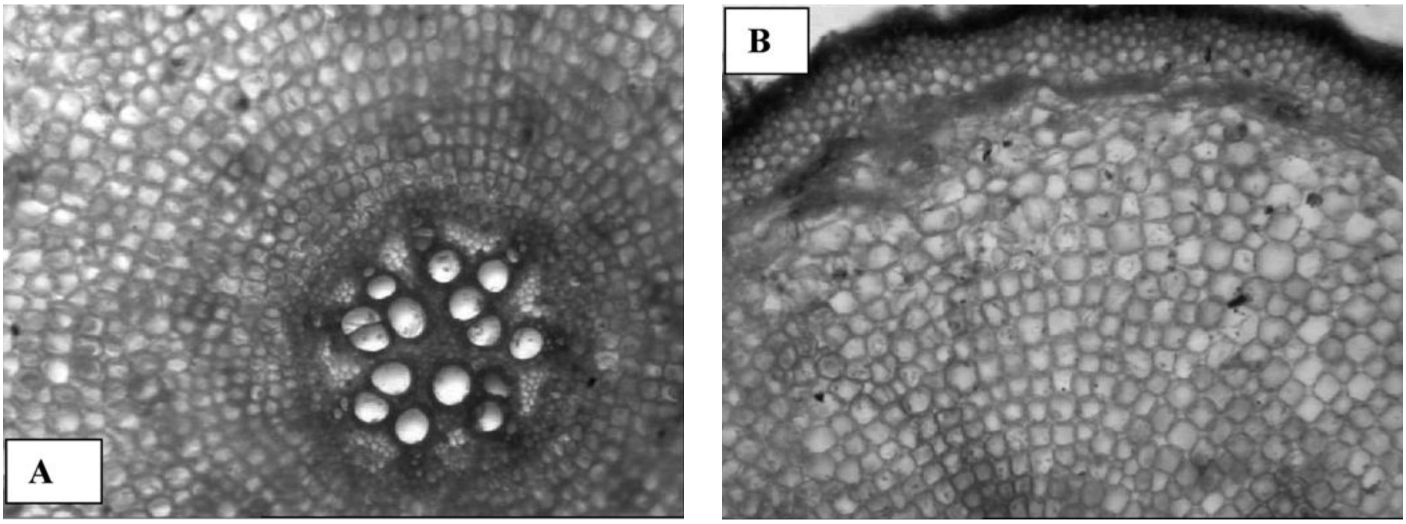


Plate 4 -A and B root anatomy of elephant foot yam (4x10). A) T.S. of root showing stele. B) T.S. of root showing cortex.

5. Corm development and yield

A new daughter corm is formed at the region between the petiole (pseudostem) and seed corm when a sprout grows out from the corm (Fig. 4). Then, roots appear from the surface of new corm and attain a maximum dry mass at 90 DAP. The daughter corm begins to enlarge after a leaf has fully expanded (one to two 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. After the corm has been initiated, it continuously grows and bulks as long as there is adequate moisture in the soil. Morphologically, the corm is a shortened stem with compressed nodes and internodes. 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 produces a larger number of cormels than other regions (Sugiyama and Santosa, 2008).

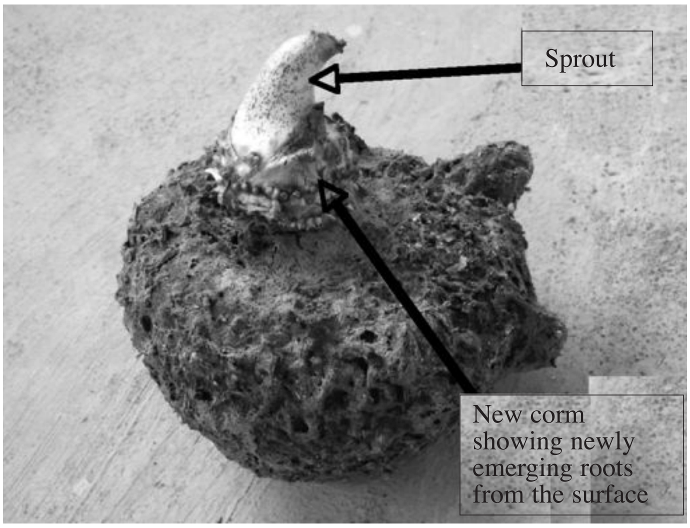


Fig. 4 - New corm formed at the base of the apical sprout before planting.

Corm growth rate (corm bulking rate) increased steadily between 1 and 5-6 MAP. Maximum corm bulking rate (7.2-8.2 g plant^{-1} day^{-1}) was observed during the fifth or sixth MAP (Mukhopadhayay and Sen, 1986; Nair *et al*., 1991). Corm bulking efficiency (final corm weight or size as compared to that planted) follows four rules of thumb: 1) at identical plant spacing, corm bulking efficiency decreases with increases in planting material size in both cut pieces and whole corm (Table 1); 2) at a given constant planting material size, corm bulking efficiency increases with increases in plant spacing (Table 2); 3) corm bulking efficiency is greater in the case of whole corm than cut pieces of corm used as planting material (Table 3); and 4) under rainfed conditions, using constant size of planting material, corms harvested from a particular field or a plot show gradient sizes (Table 4). Nevertheless, the proportion of gradient sizes may narrow under the best management and soil conditions. Thus, corms of desired size can be produced by using appropriate sized planting material and plant spacing. Production of full corms of 1 kg size is suitable for home consumption because cut corms may perish rapidly.

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

Table 1 - At identical plant spacings, corm bulking efficiency decreases with increase in planting material (cut pieces or full corm) size

Size of corm planted (g)	Plant spacing	Size of corm harvested (g)	Corm bulking efficiency	Reference
Cut pieces				
100	50 x 50 cm	513	5.1	Rajib *et al*., 2007
100	60 x 20 cm	500-700/1000	5-7/10	Nedunchezhiyan, 2006, James and Nair, 1993
200	50 x 50 cm	659	3.3	Rajib *et al*., 2007
250	60 x 45 cm	740	3.0	James and Nair, 1993
250	50 x 50 cm	840	3.4	Sen and Das, 1991
300	55 x 50 cm	810	2.7	Ghosh *et al*., 2008
500	60 x 45 cm	1063	2.1	James and Nair, 1990
500	50 x 50 cm	950	1.5	Sen and Das, 1991
500	55 x 50 cm	1320	2.6	Ghosh *et al*., 2008
750	60 x 45 cm	1017	1.4	James and Nair, 1990
750	50 x 50 cm	1230	1.6	Sen and Das, 1991
Full corm				
250	50 x 50 cm	1360	5.44	Sen and Das, 1991
500	50 x 50 cm	1480	3.0	
750	50 x 50 cm	1800	2.4	
1000	50 x 50 cm	2530	2.5	
400-500 g [(z)]	90 x 90 cm	3-4 kg	6-10	Nedunchezhiyan, 2006
1 kg [(z)]	1.2 x 1.2 m	5 kg	5	Ravindran (pers. comm.)
5 kg [(z)]	1.5 x 1.5 m	15 kg	3	Nedunchezhiyan (pers. comm.)

[(z)] Corm bulking efficiency in farmer's field under the best management practices.

Table 2 - At a given constant planting material size, corm bulking efficiency increases with increase in plant spacing

Size of corm planted (g)	Plant spacing (cm)	Size of corm harvested (g)	Corm bulking efficiency	Reference
100	50 x 30	279	2.8	Rajib *et al*., 2007
100	50 x 40	373	3.7	
100	50 x 50	513	5.1	
200	50 x 30	389	1.9	
200	50 x 40	510	2.6	
200	50 x 50	656	3.3	
250	60 x 45	740	3.0	James and Nair, 1993
250	90 x 45	927	3.7	
250	90 x 90	1143	4.6	
300	40 x 40	810	2.7	Ghosh *et al*., 2008
300	55 x 50	1005	3.4	
300	65 x 60	1265	4.2	
300	70 x 70	1450	4.8	
300	90 x 85	1585	5.3	
500	40 x 40	1170	2.3	Ghosh *et al*., 2008
500	55 x 50	1320	2.6	
500	65 x 60	1610	3.2	
500	70 x 70	1800	3.6	
500	90 x 85	1970	3.9	
500	60 x 45	1063	2.1	James and Nair, 1993
500	90 x 45	967	1.9	
500	90 x 90	1533	3.1	
750	60 x 45	1017	1.4	James and Nair, 1993
750	90 x 45	1290	1.7	
750	90 x 90	1880	2.5	

Table 3 - Corm bulking efficiency is greater in the case of whole corm than the cut pieces of corm used as a planting material (Sen and Das, 1191)

Size of corm planted (cut pieces) (g)	Size of corm harvested (g)	Multiplication ratio	Size of whole corm planted (g)	Size of corm harvested (g)	Corm bulking efficiency
250	840	3.4	250	1360	5.4
500	950	1.5	500	1480	3.0
750	1230	1.6	750	1800	2.4
1000	1740	1.7	1000	2530	2.5

and corm bulking rate (Sen *et al*., 1996). Increases 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 growth period (Mukhopadhayay and Sen, 1986). The effect of N was more pronounced during the initial growth period than during the later growth period. The increase in corm bulking rate due to increase in N application from 50 to 150 kg ha^{-1} was highest (27.6%) during the four month growth period but declined to 15.3% and

Table 4 - Under rainfed conditions, with use of constant size of planting material, corms harvested from a particular field or a plot shows gradient sizes

Size of harvested corms	Proportion (%)
2-2.5 kg	1-2
1.5-2.0 kg	5
1.0-1.5 kg	5
900 g	5-6
700 g	6-7
600 g	7-8
500 g	15
400 g	12
300 g	10
200 g	10
100 g	10
50 g	10

10.6% during the fifth and sixth MAP respectively. The increase in N application from 50 to 150 kg ha^{-1} increased the mean corm weight per plant by 21.3%. The corm yield per ha increased by 20% with an increase in N application. The corm yield was 84.6 and 102.3 t ha^{-1} with N at 50 and 150 kg ha^{-1} application respectively. Increases in K application did not significantly increase corm growth, mean corm weight per plant and corm yield per ha. However, N and K had significant interactive effects 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 (Mukhopadhayay and Sen, 1986). Shoot height, basal shoot (pseudo-stem) girth, and dry matter accumulation in shoot increased and reached a peak at 120 DAP. Corm and total (shoot and corm) dry matter increased up to 150 days and declined thereafter. Maximum shoot height (85.2 cm), shoot girth (16.4 cm), 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) (Mukhopadhayay 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 (Mukhopadhayay and Sen, 1986; Nair *et al*., 1991; Ravindran and Kabeerathumma, 1991; Goswami and Sen, 1992; James and Nair, 1993; Kundu *et al*., 1998; Geetha, 2001; Suja *et al*., 2005, 2006, 2007, Suja and Sundaresan, 2008 a, b). Corm yields 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 (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 at 150 kg ha^{-1} increased yield by 6.5% (Patel and Mehta, 1984). Kabeerathumma *et al*. (1987) reported that 100 kg ha^{-1} N, 38 kg ha^{-1} of $^{P}2^{O}5$ 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 at 35 t ha^{-1} + green manuring with cowpea to generate 2 0-2 5 t ha^{-1} of green matter + neem cake at 1 t $ha^{-1}$and ash at 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 at 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 a, b, 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). Increasing the size of planting material from 2 50 g to 1 kg increased mean corm weight per plant from 0.75 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 and Nair, 1993; Das *et al*., 1995). Comparatively more corm yield was obtained by planting whole seed corms: about 45% greater than the corm yield obtained from cut pieces of corms of the same size (Table 5 and 6). This was presumably due to early sprouting and better root ramification (Sen and Das, 1991). Nevertheless, a seed corm size of 400 - 500 g at 90 x 90 cm spacing would be ideal for economic cultivation of elephant foot yam (James and Nair, 1993; Yadav *et al*., 2008). 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 *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 min and surface dried under shade for 24 hr before planting. Biofertilizers and other beneficial microorganisms may be added to the cow dung slurry for high productivity (Nedunchezhiyan *et al*. 2006). It was found that planting depth affected plant growth and yield (Santosa *et al*. 2004 a). 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 it is desirable to have corms at a depth of 10 cm below the soil surface (Sugiyama and Santosa, 2008). The multiplication ratio in *Amorphophallus* could be enhanced to 1:15, from the conventional 1:4, by adopt-

Table 5 - 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	

Source: Sen and Das, 1991.

Table 6 - 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 and Nair, 1993.

ing the minisett technique developed in CTCRI (James *et al*., 2004). Minisetts produced corms in the range 600 g to 1.5 kg. Treating setts of corm pieces from the bottom portion of corm with GA_3 (200 ppm) resulted in maximum corm yield (Das *et al*., 1997). Various integrated nutrient management practices (combination of inorganic fertilizers, organic manures and biofertilizers) and weed management practices enhanced plant height, canopy spread, corm size, and corm yield per ha (AICRP, 2004, 2005, 2006 a, b, 2007, 2008, 2009).

The mean starch content of *Amorphophallus* corm varied between 9.2 and 23.8% and the increase in N or K application did not have a significant effect on starch content (Mukhopadhayay 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 a, b). The starch content was found to range 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). Little variation was noted in the average size of starch granules (9-13 μm) and amylase content (22-24%) among different accessions (Moorthy, 2002).

6. Corm dormancy

Amorphophallus corms exhibit dormancy for about three to five months after harvest. As a result, 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 greater (98%) with top cut portion of corm than the cut corms from the lower half of the mother corm (Dhua *et al*., 1988; Nedunzhyan and Mohankumar, 1997; Mondal and Sen, 2004; Santosa *et al*., 2006 b). The bottom portion of the corm is not generally used as planting material due to its lower sprouting efficiency (Dhua *et al*., 1988; Nedunzhian and Mohankumar, 1997; Mohankumar and Ravi, 2001). Therefore, a greater portion (about 25%) of the harvested produce is again lost as source of planting materials. Also, the apical bud from the corm can be excised and used as planting material. Removal of the apical bud results in development of one or two adjacent buds within two weeks which also can be excised and used as planting material (Fig. 5). Ethrel or ethephon was reported to induce early sprouting in *Amorphophallus* corm (Dhua *et al*., 1988; Bala and Indira, 1992). Treating cut pieces of corms from the 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 7) (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 six weeks increased sprouting by 58.3% as compared to untreated corms presumably due to ethrel in smoke. Similarly exposing the corms to high temperature (32-45°C) increased sprouting by 83.3% as compared to untreated corms (Mohankumar and Ravi, 2001; Archana *et al*., 2009). Pre-harvest, foliar application of potassium nitrate (2%) and thiourea (1%) had greater influence on breaking dormancy and inducing early sprouting (Bhagavan *et al*., 2008). This may be due to an increase in the availability of sugars as a result of an 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 min) for 1-2 hr 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 sprouts (Archana *et al*., 2009). Darkness had an adverse

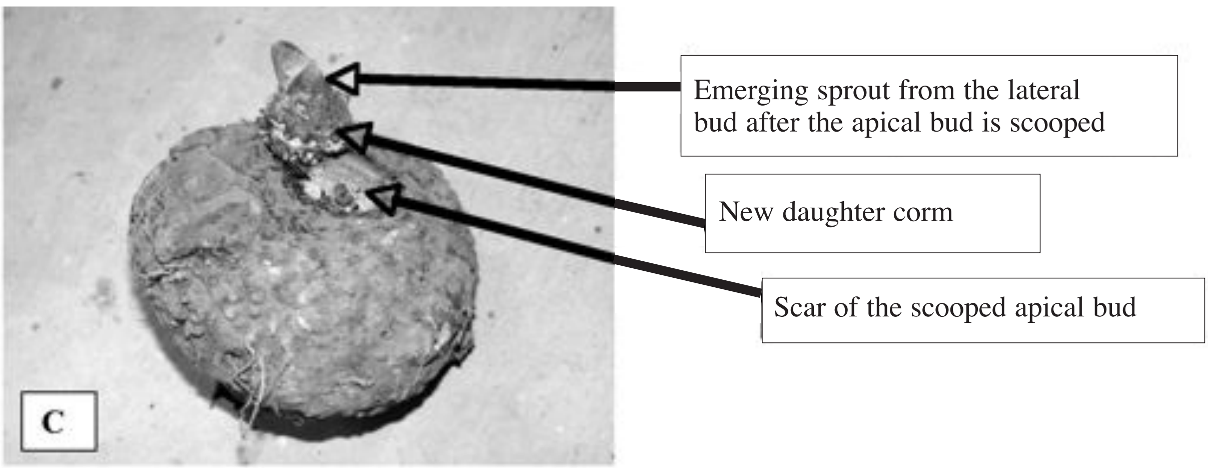


Fig. 5 - Emerging sprout from the lateral bud after the apical bud is scooped.

Table 7 - 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)

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 it decreases after dormancy (Santosa *et al*., 2003).

7. Ecological requirements

Elephant foot yam grows well under tropical, warm, humid conditions with maximum day-time temperature ranging between 25 and 35°C, minimum night-time temperature ranging between 20 and 25°C and annual rainfall ranging between 1000 and 3000 mm spread over a period of about six to eight months. It grows well in sandy loam or sandy clay loam soil with good drainage and pH of 6.0 to 7.0. It can also be grown in laterite soil (with about 40-50% gravel) but heavy clay soil is not suitable for this crop. Soil with high organic matter favours good crop growth and corm yield. Planting material (whole or cut pieces of corm) is planted shallow in pits of 60 x 60 x 45 cm size dug out in well-ploughed soil. The top soil dug out is then mixed with farm yard manure or compost (2.0-2.5 kg per pit) and the mixture is put back into the pit prior to placing the planting material over it. The planting material is placed vertically in the pits and is then covered with soil and compacted lightly.

8. Response to shade

Elephant foot yam tolerates shade conditions. Therefore, it can be intercropped between young trees. Corm yield decreased by 66 % when light intensity was reduced to 2 5% of full sunlight (Pushpakumari and Sasidhar, 1992). On the contrary, Santosa *et al*. (2006 a) 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. 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, 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.

9. 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 and yield more when the water supply is adequate (AICRP, 2008). About 1000-1500 mm of rainfall per year is optimum for the crop. Many plants enter dormancy earlier than usual when the rainy season is shorter than four months and supplementary irrigation is necessary for high productivity under the same conditions. Plants produced a larger number of leaves under frequent watering (one-, three- and five-day intervals) than under seven- and 15-day intervals; the third leaves were produced in treatments up to seven-day intervals, but neither the second nor the third leaves were produced with 15-day intervals. Furthermore, frequent watering produced large leaves and extended their life span compared to less frequent watering (Santosa *et al*., 2004 b). A decrease 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 one-, three-, five-, seven-, and 15-day intervals, respectively. The high ratios 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*., 2004 b) and the crop tolerates water deficit stress conditions for about 30-60 days but prolonged stress may affect corm yield (Santosa *et al*., 2004 b). In green-house conditions, plant growth was not affected when plants were watered at one-, three- or five-ay intervals. Nevertheless, infrequent watering (watering at seven- or 15-day intervals) reduced corm yield and forced the corms to enter into dormancy. Soil moisture conservation methods like mulching induced a higher percentage of early sprouting, greater canopy spread, plant height, greater mean corm weight and corm yield (Mohankumar *et al*., 1973). In India, mulching the field with paddy straw resulted in maximum plant height (78.2 and 88.2 cm respectively), girth (14.1 and 14.4 cm respectively) and corm yield (47.44 and 56.74 t ha^{-1} respectively) as compared to control (AICRP, 2004, 2006 a, b). Also cowpea live mulch produced greater yield (41.72 t ha^{-1}) than control (AICRP, 2006 a, b). Maximum corm yield was also obtained by black polythene mulching (82.48 t ha^{-1}) and straw mulch (64.82 t ha^{-1}) ranked second (AICRP, 2004). Although the corm yield and net return in the straw mulch treatment was lower than polythene mulch, the cost:benefit ratio of straw mulch (1:3.18) was greater than polythene mulch and other treatments (AICRP, 2004). Mulching with sesame leaves also resulted in better corm yield (41.8 t ha^{-1}) than straw and black polythene mulch (AICRP, 2004, 2006 a, b). Paddy straw mulch also resulted in greater corm yield (13.8 t ha^{-1}) than control (AICRP, 2004, 2006 a, b). When considering mulching with straw, black polythene or cowpea, corm yield was significantly greater only in the first two cases (11.69-14.12 t ha^{-1}) whereas live cowpea mulching significantly reduced corm yield (5.68 t ha^{-1}) compared to control (7.98 t ha^{-1}) (AICRP, 2004, 2006 a, b). Maximum corm yield (44.3 t ha^{-1}) was recorded with the application of 100% recommended dose of fertilizer (RDF) along with flood irrigation and the yield (43.5 t ha^{-1}) was on par with the application of 100% RDF plus irrigation at 100% CPE (AICRP, 2009). Corm yield was significantly reduced when irrigation was less than 100% CPE (AICRP, 2009). Finally, the corm yield of elephant foot yam was greater (37.3 t ha^{-1}) under micro-irrigation (drip-irrigation) at 60% CPE daily for the first 15 days and then on alternate days for the next 15 days, at 80% CPE between two and six months and then at 60% CPE between seven and eight months, than under surface irrigation (26.4t ha^{-1}) (Nedunchezhiyan *et al*., 2008).

10. Seed dormancy

Successful seed production has been reported in *Amorphophallus* (Arakeri, 1950). A seed dormancy of five to six months has been reported in this crop (Arakeri, 1956). Exposing seeds to running water for six days resulted in greater sprouting (55.5%) than in control (2.7%). However, exposing seeds to water for more than six days led to a lower percentage of sprouting (Rajendran and Hrishi, 1976).

11. Future thrust

Since the whole corm and cut corm pieces are used as planting material, a large portion of harvested produce is used for propagation. Therefore, the development of plantlets through *in vitro* culture of apical/lateral buds (Irawati *et al*., 1986; Archana *et al*., 2009; Unnikrishnan and Mohan, 2009) should be further refined and exploited for planting material production.

Furthermore, more detailed investigation of the physiological aspects of growth and productivity of Amorphophallus needs to be developed in the following areas:

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

Effect of exogenous application of growth regulators such as benzyl adenine and other such growth promoters on maximizing corm yield.

Since *Amorphophallus* needs a long duration (8 months growing period) for maximum corm yield, studies on factors controlling corm bulking could reveal the physiological basis for developing rapid bulking, short duration varieties.

Studies to determine water, light and thermal degree-day requirements and the effect of water deficit stress, high temperature (>35°C) (heat stress), salinity and shade on growth and productivity.

Factors controlling corm dormancy, breaking of dormancy and sprouting and related gene expression.

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