STANDARDISATION OF PROPAGATION THROUGH BRANCH CUTTINGS IN SELECTED BAMBOO SPECIES OF KERALA

by

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(2014 - 17 - 113)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"STANDARDISATION OF PROPAGATION THROUGH BRANCH CUTTINGS IN SELECTED BAMBOO SPECIES OF KERALA"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"STANDARDISATION OF PROPAGATION THROUGH BRANCH CUTTINGS IN SELECTED BAMBOO SPECIES OF KERALA"** is a record of research work done independently by **Mr. Sreejith M M (2014-17-113)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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INTRODUCTION

INTRODUCTION

Bamboos are the versatile arborescent grasses belonging to family *Poaceae*, subfamily *Bambusoideae*, tribe *Bambuseae* with multiple uses. Bamboos form the valuable natural resource of India because of its adaptability to various site conditions leading to large species diversity, great role in poverty alleviation and improvement of rural and tribal livelihood, ever increasing number of uses and environmental benefits. Bamboo has been the integral part of socio economic and cultural part of human life from time immemorial due to its multifarious and versatile utility and it also plays a role in women empowerment. Value addition of bamboo has led to an extended diversity of products ranging from domestic household items to industrial applications and generates income and employment and contributes substantially to the ecological, economic and social development of the man. Due to its wood properties like hardness, lightness, flexibility, desirable appearance and tensile strength it can act as suitable substitute for timber in many applications including furniture and construction industries. Bamboo possesses variety of uses ranging from the conventional use in building construction, pulp and paper making, to cottage industries and household use. Nowadays, bamboo is attracting the farmers and it has become farm crop rather than being a major non-timber forest produce. Bamboo has been acting as the backbone of the rural life for many years and will continue to remain so with the population increase. For tribal and forest dwellers, 'bamboo for living' and 'living with bamboo' is still the norm and the plant offers an excellent entry point in increasing employment, income generation and improving the nutritional status of the rural poor. Bamboo endows vast, and as yet substantially untapped, potential.

The distribution of bamboos is uneven and based on geographical and climatic conditions. The records show that China has maximum number of genera and species of bamboo. India has the World's second largest bamboo resource and the largest area under bamboo plants, with 136 species, 23 genera covering 13.96 million hectares. Due to human interventions, and peculiar nature of gregarious flowering, followed by death of clumps after seed setting, there has been a steady decline in the species diversity and the extent of bamboo resources of the country. Industrial revolution induced heavy demand of bamboo for diverse purposes such as pulp for paper and rayon, laminated bamboo, parquet flooring, bamboo-ply, bamboo composites and bamboo charcoal along with the mechanization of traditional sectors like mat weaving, bamboo shoot processing, stick industries, and handicrafts. Over-exploitation coupled with the lack of efforts to replenish and replant natural bamboo areas and

establishing new plantations has resulted in dwindling resources. The dwindling bamboo resources and subsequent shortage and increase in the market price of bamboo caught the attention of scientists, forest managers and public alike, leading to concerted efforts for conservation and enhancement of resources. Earlier, natural forests were the major source of bamboo in the market. In order to ensure the sustained supply of bamboos for the extensive uses, for which they are employed, is to raise large scale in plantations. The growing awareness on deforestation and its negative effects on environment have also contributed to the promotion of bamboo as a wood substitute and eco-friendly material. Two missions *viz*. National Mission on Bamboo Applications (NMBA) and the National Bamboo Mission (NBM)) under Ministry of Science and Technology and Ministry of Agriculture and Co-operation respectively, were initiated by Government of India to focus on the integrated development of the bamboo sector. Hence, the bamboo resource enhancement is at pace in our country. Nowadays, bamboo has been an important component of agroforestry systems and more and more farmers are attracted to bamboo planting. In Kerala, bamboo cultivation is now gaining momentum because of the hurdles in profitable agriculture practices. Although Kerala possess a rich diversity of agricultural crops, profitability is constrained by high operational costs, land values and change in socio-economic status. Nowadays farmers attracted more towards the low-cost production strategies such as tree and bamboo cultivation because of lower input requirement. The early and continuous returns from the bamboo cultivation is the major attraction for the farmers. Cultivation of bamboo can provide a cost-effective return within a short period of 3-5 years. In the pursuit of meeting the objectives of greening the country and livelihood security, bamboo plays a prominent role and hence there is need to evolve appropriate technology for successfully raising bamboo plantations at economical costs. Although examples of successful attempts in producing bamboo in this way are available, they are mostly isolated attempts and technology standardization has not been achieved for most of the species.

Most of the research on bamboo has been concentrated on the production of quality planting stock and a common strategy for good quality planting stock production in bamboos is not yet available. The seed propagation is the cheapest among the propagation methods. However, in bamboo it is not dependable due to monocarpic nature, erratic flowering behavior, prolonged flowering cycle and poor viability of seeds, which give way to the conventional vegetative propagation methods such as offset planting, layering and rooting of culm cuttings and it has been successfully employed in many bamboo species. However, these methods are limited, by number of propagules and the propagation is destructive nature. The rooting of

branch cuttings is the least studied propagation method in bamboos which is very simple, easy and non-destructive. The present study focuses on the adventitious rhizogenesis in branch cuttings of three prominent bamboo species of economic and ecological relevance to Kerala *viz.*, *Bambusa balcooa* Roxb., *Dendrocalamus giganteus*Wall. Ex Munro and *Thyrsostachys oliveri* Gamble.

Studies on rooting of branch cuttings are scarce especially under humid tropics of Kerala. Literature indicated that the adventitious rhizogenesis of branch cuttings is influenced by season of collection, position of the cutting, type and concentration of growth regulators etc. Some studies indicated that the success of rooting is not as high as in culm cuttings. However, considering the availability in large numbers and ease in handling, even a moderate rooting percentage is enough as it is cost effective. With this back ground, the present study is proposed to standardize the vegetative propagation through branch cuttings in selected bamboo species of Kerala *viz. Bambusa balcooa*, *Dendrocalamus giganteus* and *Thyrsostachys oliveri*. The study focuses on influence of collection time, type and concentration of growth regulating substances and media on rooting of branch cuttings.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Bamboos are resourceful group of plants with multifarious utility which grows abundantly and occur as belt of vegetation in tropical, subtropical and temperate forests and homesteads (Hogarth and Belcher, 2013). Once, the bamboo was considered as resource in plenty, but the over exploitation especially through unscientific extraction with no efforts to replenish the resources had led to the dwindling resource base. With the reincarnation of interest on bamboos large scale plantation activities have been initiated worldwide. For the successful planting programme, we greatly depend on the quality planting material. Seed propagation is considered as the cheapest and easiest method for of planting stock production in bamboos (Banik, 1994). But the uncertainty of sporadic flowering and long flowering cycle decreases the availability of seeds and even the viability of some bamboo seeds is very short. Hence, vegetative propagation is the best option to multiply bamboo (Seethalakshmi *et al.*, 2008). Vegetative propagation methods in bamboo comprise of rhizome planting, offset planting, culm cuttings, branch cuttings and air layering (Adarsh Kumar, 1991; Seethalakshmi *et al.*, 2008).

2.1. Clump Morphology and Vegetative Growth

Bamboo occurs in different growth forms in nature like trees, shrubs and climbers (Prasad and Gadgil, 1981). Bamboo plants consist of roots, rhizome, culm (stem), branches, flowers and fruits. Roots are fibrous and form a dense network in the soil. Rhizome, the underground stem or the basal part of the stem has two parts viz., rhizome neck and rhizome proper. Two types of rhizomes are commonly observed in bamboos based on the branching pattern *viz.*, pachymorph which are seen in sympodial bamboo species that are clump forming and leptomorph seen in monopodial bamboos known as runner or walking bamboo (McClure, 1966, Stapleton, 1997). Pachymorph rhizomes are short and thick, with larger diameter than the culm formed from upward curved apex of it. Leptomorph types of rhizome are an underground stem, which is long, slender, and smaller in diameter than the culm originated from it. Amphimorph, mixed type exhibiting both pachymorph and leptomorph characters are also observed (Judziewicz *et al.*, 1999).

The rhizomes are connected to the aerial part known as culm which is cylindrical in form and consist of distinct nodes and internodes. The culm is depending completely on the rhizome for the nutrition (Liese, 1985). Culms consist of nodes, internodes, axillary buds,

leaves and in some of the basal nodes and root primordia. It is from the node, branch/leaf originates in the stem and hence the morphology of node is complex. Internodes, the region between two consecutive nodes, may be either solid (e.g. *Dendrocalamus strictus*) or hollow (e.g. *Bambusa bambos*). The length of internode varies among different species. With the onset of monsoon, new set of culms are formed in the clumps hence, the growth pattern in bamboos is known as exponential. The new set of culms complete their height growth within three to four months and the mature culms are due to the process of primary growth through which culm reaches maximum diameter, elongation of internode in a telescopic fashion and subsequent hardening through lignification (McClure, 1966).

Bamboo is reported as the fastest growing plant on earth due to rapid rate of growth of the new vegetative shoots. Ueda (1960) observed that the genus *Phyllostachys* in Japan grows more during the day time, whereas in the tropical areas, bamboos grow more during the night (Osmaston, 1918). Banik (2000) had described bamboo growth as "In bamboos the new culms are produced from the culms buds. When the young culm bud on an underground rhizomes or juvenile shoot begins to develop, a conical growth is seen protruding from the ground, covered with imbricating sheaths, often of a bright colour and furnished with blades. Gradually the cone lengthens, the sheaths separate, the nodes appear, and finally full-grown culm is developed". "Usually, one by one, the sheaths drop off, the buds on the culm nodes put out branches and these produce their leaves". Banik (1991) observed that in Bangladesh, new culm production starts generally either from May or June and continue up to 6-7 months.

2.2. Diversity and Distribution of Bamboos

Reports on diversity and number of species in bamboos keep on changing. All together 110 genera and 1500 species of bamboo are identified which are erratically distributed in various parts of the world (Subramaniam, 1998; Orhnberger and Goerrings, 1985., Ram *et al.*, 2010; Hogarth and Belcher, 2013). Dransfield and Widjaja (1995) reported that the maximum number of bamboo species (590) in 44 genera is distributed in Asia. Within Asia, India is the main bamboo producing country (almost 11.4 million hectares) second to China, which accounts for roughly half the total area of bamboo reported in Asia (Lobovikov *et al.*,2007). The latest compilation indicated 1662 bamboo species in 121 genera, of which 232 (14%) have been introduced beyond their native ranges in the world (Susan *et al.*, 2016).

Bamboo has as wide distribution throughout the world, Lobovikov *et al.* (2007) reported that the bamboo stands occupy an area of 36 million hectares (ha) equivalent to 3.2 per cent of the total forest area of the world. The estimates also pointed out that bamboo occupies over one per cent of the tropical and subtropical forest area, over 22 million ha. It is interesting to see that over 80 per cent of the total area covered by bamboo is located in Asia, 10 per cent each in Africa and America. Majority of bamboo species need a fairly warm climate, resulting their good growth in the tropical, subtropical and temperate regions of the world except Europe (Dransfield, 1992; Zhu *et al.*, 1994; Nguyen, 2006). Bamboos grow particularly well in the tropics and subtropics, but some taxa also thrive in the temperate climate of Japan, China, Chile and the USA (Grosser and Liese, 1971). Bamboo has a cosmopolitan distribution in nature, ranging from 46°N to 47°S latitude (Dransfield, 1992; McNeely, 1995), reaching elevation as high as 4000 m in the Himalayas and parts of China (McNeely, 1995). Generally, small sized bamboo species occur in high elevations or temperate latitudes, and the larger ones occur in the tropic and sub tropic areas (Lee *et al.*, 1994). Studies on distribution and conservation status of bamboo diversity in the Asia-Pacific region indicated that over 6.3 million km^2 of Asian forests contains large areas of bamboo, with highest densities indicated from North-Eastern India through Myanmar to southern China and through Sumatra to Borneo (Bystriakova *et al.*, 2003). There are many regions in the world which are to be explored for new bamboo species.

India is one of the leading countries of the world, second only to China in bamboo production with 0.323 million tonnes per year (Pathak, 1989). India houses a huge number of bamboo species and is considered as one of the largest reserves of bamboos in the world. Although bamboo occurs throughout the country, its richest biodiversity occurs in North East India, the Western Ghats, Eastern Himalaya and Andaman and Nicobar Islands (Kumar 2011). The bamboo forms an understorey component in several forest types. The natural habitats of bamboos include the tropical moist-deciduous and semi-evergreen forests of North-Eastern India (Appasamy and Ganapathi, 1992). In the context of number of species, Seethalakshmi and Kumar (1998) reported 128 bamboo species belonging to 18 genera which include 87 naturally occurring and others as introduced or under cultivation. Later, six more species were recorded as new from Southern India and Andaman Nicobar Islands. Bamboo is distributed throughout the states of India, from the tropical to the temperate regions and from the alluvial plains to the high mountains. Sharma and Nirmala (2015) reported that an approximately 148 species of bamboos in 29 genera are currently occurring in India (both wild and cultivated).

According to Dutt (2007) India has the largest bamboo forest in the world, and two-third of which was reported to be in Northern India. As per the report of Forest Survey of India (2011) Arunachal Pradesh is having largest bamboo bearing area (1.6 m ha) followed by Madhya Pradesh (1.3 m ha) Maharashtra (1.15 m ha) and Orissa (1.03 m ha). Of all the commonly occurring genera of bamboos, the genus *Bambusa* is the widely distributed one in India.

With the occurrence of 22 species of bamboos under seven genera, Kerala is one among the major diversity centers of bamboo in the country. This accounts for about 20 per cent of the total bamboos distributed all over the country and 95 per cent of the total species from Peninsular India (Kumar and Ramesh, 1999). Nearly, 13.61 million culms with a green weight was 0.331 million tonnes was reported as total standing stock of bamboo in homesteads of Kerala during 2004-2005 (Muraleedharan *et al.*, 2007). The bamboo resource in the forest areas was estimated as 2.63 million based on the satellite imagery 1997. In Kerala, bamboos are distributed right from the sea coast to the high ranges. *Bambusa bambos, Dendrocalamus strictus, Ochlandra travancorica, O. scriptoria* and *O. ebracteata* are seen associated with different forest types of the state. Among these, *B. bambos, D. strictus* and *O. travancorica* are economically important and commercially exploited bamboos (Mohanan, 1994). In Kerala, home-gardens form a predominant land use activity and bamboo is an important component (Kumar *et al.*, 1994; Kumar, 1997). The home-gardens are often considered as an important source of bamboo in Kerala. Different species of bamboos grow in areas which receive an annual rainfall of 700 to 4000 mm and where mean annual temperature ranges from 8 to 36^0C (Seethalakshmi *et al.*, 2008).

The principal bamboo genera occurring in India are *Arudinaria, Bambusa, Chimonobambusa, Dendrocalamus, Dinchloa, Gigantochoa* etc. Of which *Bambusa* and *Dendrocalamus* species occur in tropical conditions, whereas *Arundinaria* and its alias occur in the temperate region and are most commonly found on higher elevations. Bamboos are distributed across India and are socially and culturally linked to the life of the local people (Nath and Das 2008). Despite the wide distribution and multifarious uses, occurrence of bamboo is limited to farm boundaries, homesteads and marginal areas, making it a shrinking resource base. Bamboos occur extensively in the managed ecosystems of India - both as plantations (Chandrashekara, 1996) and in agroforestry (Kumar, 1997; Divakara *et al.*, 2001).

2.3. Bamboo – A resourceful crop

Bamboos earlier known as the "poor man's timber" is now being elevated to the "timber of the 21st century" due to its versatile and multifarious uses. The range of uses of bamboo for humans is outstanding and has tremendous versatility (Rai and Chauhan, 1998). Bamboos are the fast-growing short rotation multi-purpose species having more than 1500 documented uses like food, building and construction material, handicrafts and as a raw material for the paper and pulp industry (Khan *et al.*, 2007). "Up to 30th day bamboo shoots are used as food, between 6-9 months: for basketry, between 2-3 years: for laminates and boards and between 3-6 years for construction (Vyavahare, 2009).

Traditionally, bamboo culms are widely used as structural material for building purposes, as a raw material for pulp, paper and panel board industries. Bamboo skin can be used in cottage industries (Kabir *et al.*, 1993). In rural areas, fencing with branches of thorny bamboos is widely used and the culms are used as water pipes (Patel, 2005). Bamboos with thin culms having thick walls are used as umbrella handles, pluckers and fishing rods. Bamboo leaves are used as fodder for cattle and thatching the roof (Banik 2015). An analysis of the nutritive value of bamboo leaves revealed high nutrient contents (Negi, 1977; Khatta and Katoch, 1983). Bamboo roots, leaves, sprouts and grains are used in the Ayurvedic system of medicine for the treatment of many diseases. Also, the silicaceous deposit *Banslochan* found in the interior parts of the hollow culms is used for the treatment of asthma, cough, paralytic complaints and other debilitating diseases. Young bamboo shoots are a delicacy and offer good export opportunities in many Asian countries (Choudhury *et al.*, 2012; Pandey and Ojha, 2014). Goldsmiths prefer the charcoal made from bamboos. Different types of musical instruments, bows and arrows are made from bamboos. Bamboo rhizomes are used for decorative handicraft items. Bamboo roots are considered poisonous due to the presence of cyanogenic glucosides, but the burnt roots are used for the treatment of ring worm, bleeding gums, painful joints and wounds. The medicinal properties of bamboos have been reviewed in detail by Shukla *et al.* (2012). Divergent uses of bamboos include environmental protection, paper making, construction material, production of bamboo charcoal and activated charcoal, a raw material for gasification, beers, vinegar, perfumes, medicines, boards, plywood, strip boards, particleboards etc.

Rich bamboo diversity and culture of bamboo utilization in India (Biswas, 1989; Tewari, 1992; Seethalakshmi and Kumar, 1998) with greater potentials has initiated nationwide programs for economic and industrial development by the use of bamboo in a most eco-

friendly way. In India bamboo is used for a variety of purpose and the major consumption pattern is consolidated below (Table 1).

Table 1. Consumption pattern of bamboos in India (Tewari, 1992)

Sl. No.	Uses	Consumption (%)
1.	Pulp	35.0
2.	Housing	20.0
3.	Non-residential	5.0
4.	Rural uses	20.0
5.	Fuel (non-industrial)	8.5
6.	Packing including basket	5.0
7.	Wood based industries and transport	2.5
8.	Furniture	1.0
9.	Others including ladders, mats etc.	3.0

From the sobriquet 'Poor man's timber' to 'Green Gold' bamboo is endowed with lot of names due to its versatile uses. The number of uses of bamboo is increasing with the advent of time and many authors had attempted to review the uses of bamboos (Zhou *et al.*, 2005; Borah et al., 2008; Sharma *et al.*, 2016). Bamboo has great potential to improve life even more in the years ahead. Bamboo helps more than two billion people to meet their basic needs, and as a widespread, renewable, productive, versatile, low or no-cost, easily accessed environment enhancing resource especially in the villages and countryside of the developing world (Sastry, 2008).

The international trade in bamboo ranges between 5 to 10 billion US$. More than 2 million tons of bamboo shoots are consumed annually (Kleinhenz *et al.*, 2000) with approximately 1.3 million tons produced in China alone (Shi *et al.*, 1997). Total trade in bamboo products was estimated at around 4.5 billion US $ /year (Sastry, 1998). The range of uses of bamboo for mankind is remarkable, with an estimated annual use of 12 kg of bamboo products per capita in Asia (Recht and Wetterwald, 1988; Sastry, 1998). The value of international bamboo market was estimated to be around 10 billion US dollars (Borah *et al.*, 2006).

Latest estimates indicate that the current demand of bamboo for various purposes in India is at 26.69 million tons as against the supply of 13.47 million tons (Tripathi, *et al.*, 2008). Of the 13.47 million tons of bamboo, 3.4 billion are currently being consumed for scaffolding alone all over India (Rain Forest Research Institute, 2008). As per the Planning Commission,

the demand for timber is estimated to increase from 58 million cubic meters in 2005 to 153 million cubic meters in 2020 whereas its supply is projected to increase from 29 million cubic meters in 2000 to 60 million cubic meters in 2020 (Manoharan, 2011). This gap has led to rising timber prices, which thus presents an opportunity for bamboo products, widely seen as eco-friendlier due to the quick regeneration of bamboo as compared to timber

Although bamboo has been used from ancient times, in recent years there is a reincarnation of potential of bamboos; and it is being used not only for the subsistence but also for modern industry (van der Lugt *et al.* 2006). Demand for bamboo has increased both within the country and abroad as a raw material for furniture making, as panel boards substituting wood, as agricultural implements, house construction related uses and as a vegetable (Parsai, 2007). Further development in use includes the mat based composites, including flattened bamboo boards, bamboo-jute composite, corrugated roofing, shuttering material and mat-glass fibre composites (Pandey and Pandey, 2008).

The ecological functions of bamboo are innumerable (Zhou *et al.*, 2005). It includes their ability to efficiently recycle the nutrients, protect against soil erosion (Fu *et al.*, 2000) and the high nutritive value of its parts (Stapleton, 1996). Bamboo can tolerate soil conditions ranging from organically poor to mineral rich and moisture levels from those of drought to submergence which makes it valuable for reclaiming degraded land and drought proofing. Due to its efficacy as a good soil binder because of the fibrous root system and rhizome it has been successfully used in river bank stabilization (Bahadur *et al.,* 1980; Singh *et al.*, 2015). Its foliage shelter topsoil from the attack of tropical heavy showers while its leaf litters also cushions the soil from the impact of rain and eases the soil's absorption and retention of moisture. The soil under bamboo cover possesses a high capacity of water conservation, which is closely related the species (Zhou 2005). Bamboo preserves many exposed areas, providing micro-climate for forest regeneration and watershed protection (Zhou 2005). Bamboo has an extensive fine root system, which ramifies horizontally and vertically binding the particles together (Sujatha *et al.*, 2008). It grows on elevated grounds and river banks (Nath *et al.*, 2008) and can cope with temporal floods (Kaushik *et al.*, 2005). In many areas, bamboo is planted for tapping collapsed soil in ravines (Higake *et al.*, 2005). It has the ability to restore the degraded soil and can conserve soil and moisture. It cleans environment by carbon sequestration, lowers light intensity and offers protection against UV rays. The carbon sequestration studies in bamboos have shown that it is an efficient sequester of carbon

(Balagopalan *et al.*, 2000). Also, bamboos are excellent carbon sinks and may form part of clean development mechanism (CDM) projects in near future (Kumar, 2011).

2.4. Bamboos in Agroforestry

Bamboo is one of the plant components in Agroforestry. *Bambusa balcooa*, *B. bambos, B. vulgaris, Dendrocalamus strictus* and *D. hamiltonii* has been successfully incorporated into different agroforestry systems in Kerala and North-eastern states of India (Chandrashekara *et al.*, 1997, Gangawar and Ramakrishnan, 1989, Krishnankutty *et al.*, 1995; Krishnankutty, 1998). In Kerala, homegardens contributed 63 percent of the total supply of bamboo and the remaining 37 percent by forests (Krishnankutty, 1998). Intercropping with other species like soybean is found successful (Seshadri, 1985). Investigation on bamboo plantations intercropped with mango, cashew nut, jack fruit, kokum and rubber in the Konkan region of Karnataka indicated that the bamboo was the most profitable among the crops. (Waugh and Rajput, 1991). In Central India, seven agroforestry models with three bamboos (*B. bamboos, B. nutans* and *Dendrocalamus strictus*) were developed to restore degraded agricultural lands. (Behari, 2001) recommended intercropping of pigeon pea, soybean and turmeric in bamboo (*B. bambos*) plantations based on comparative growth and yield. While cultivated in mixed cropping homegardens in Kerala, bamboo (*B. bambos*) showed the second position in terms of profitability among the crop groups (Krishnankutty, 2004). The feasibility of bamboo (*D. brandisii*) in abandoned paddy fields in Coorg, Karnataka had shown that bamboo at 6 x 6 m spacing intercropped with ginger had the highest NPV (Net Present Value) and LEV (Land Expectation Value). The high B/C (benefit-cost) ratio of bamboo is due to low input costs associated with bamboo farming and higher market value of the produce over a longer period (Krishnankutty, 2004; Viswanath *et al.*, 2007).

2.5. Bamboo Propagation

Generally, both seed and vegetative methods are employed in the bamboos for planting stock production. Both methods have their own advantages and limitations. If seeds are available, natural and artificial regeneration are mainly through them. Propagation through seed is the cheapest and easiest method for production of planting stock (Banik, 1994). Due to the uncertainty of sporadic flowering and long flowering cycle, availability of seeds when required is not sure in bamboos. Additionally, viability of seeds is for a short period (3-6 months). Hence, the best option is to multiply the bamboos through vegetative propagation. Vegetative

propagation methods in bamboo comprise of rhizome planting, offset planting, rooting of culm and branch cuttings and air layering (Adarsh Kumar, 1991; Seethalakshmi *et al.*, 2008) among which, rhizome planting and culm cuttings are the most widely used methods. Different methods known for production of planting stock for each species of bamboo need to be used in combination to achieve maximum positive response (Seethalakshmi *et al.*, 2008). Mass propagation of bamboos for raising industrial and commercial plantations was an ever-existing major enigma world over, till the later years of 20th century (Adarsh Kumar, 2012).

Banik, in 1980 opined that a truly successful method for vegetative multiplication of bamboos has not been standardized. Successful propagules must develop sufficient roots and rhizomes in the field so as to ensure their survival after planting. The observations of earlier workers (Pathak, 1899; Lin, 1962; 1964; Chinte, 1965) were limited only to the rooting ability which does not necessarily indicate the success of rooted cuttings after transplanting in the field. Clones do not become field worthy unless rhizomes have been formed and new shoots start emerging (Hasan, 1980). The literature on bamboo propagation by different vegetative methods in different bamboo species especially macro-propagation is reviewed as follows. The micropropagation methods in bamboos are emerging however not reviewed as it is not directly relevant to the present study.

2.5.1. Vegetative propagation

In the absence of seeds the vegetative propagation is the only tool that can be resorted to obtain the planting stock of bamboos. Traditionally bamboo replanting is done by dividing clumps and their underground stems or cutting up the underground stems (rhizomes) of non-clumping species. The two potential advantages in using vegetative propagation are to reproduce the mother plant identically since they produce clones and refined techniques of vegetative propagation have been found to cut cost of production

The vegetative propagation methods in bamboo can be divided into macro and micro propagation techniques. Of which the macro propagation techniques are detailed in the following sections.

2.5.1.1. Macro-propagation Techniques in Bamboos

Studies on macro-propagation of bamboos are very old. For instance, Cabanday (1957) had compared the rooting performance of whole culms, two node cuttings, and single-node cuttings of bamboos. Results indicated that the single-node cuttings gave the greatest number of rooted shoots per culm used, although the success rate was not the highest. Abeels (1962) had reported the bamboo propagation by cutting and layering. McClure (1966) had narrated the features of a truly successful cutting as one which carries a bud that developed into a rhizome from which new rooted shoots had arisen. He used the term rhizome in a black and white sense which may have obscured the potential transition between partially rhizomatous shoot bases and true rhizomes. Similarly, Dai (1981) showed that whole culms partially severed between the nodes were more productive than uncut culms, although these culms still had the rhizomes attached.

2.5.1.2. Offset Method

Offset is an age-old method in bamboos propagation (Ahlawat *et al.*, 2002) and it is the lower part of a single culm with 3-5 nodes and with the rhizome axis basal to it and its roots. They are collected from the one to two-year-old culms. To prepare the offset, the culm is given a slanting cut and the rhizome to which it is attached is dug up and cut off to a suitable length to include well developed buds (Pandalai *et al.,* 2002). There are some limitations for offset planting like, offsets are bulky and heavy and are few in number (Seethalakshmi *et al.,* 2008). The excavation and transportation costs may be high and if more are excavated the regeneration of the parent clump can be affected. Survival of these which is theoretically 100 per cent, can be much lower. The method is unsuitable to develop planting stock in large quantity.

2.5.1.3. Rhizome cutting

Rhizomes are traditionally used to propagate non-clump-forming species with long and slender rhizomes: the leptomorph type (Banik, 1995) are rarely used to propagate clump-forming species. In order to ensure the successful propagation, rhizomes should be healthy and be "fresh" in color, 2-3 years old, not damaged and should possess roots. Rhizomes without culms are cut 50-60 cm long with about 10-15 nodes and with roots. February to March appears to be the best time for both collecting and transplanting. If the region has a cold climate the best planting time is April, if it is warm then it should be the cooler month (Seethalakshmi, 2015). Offset and rhizome planting are the most common methods applied in bamboos in the

absence of seed (Seethalakshmi *et al.*, 2008) and called as the traditional methods for bamboo propagation.

2.5.1.4. Culm Cuttings

Culm cuttings are segments of the culm (stem) with one to three nodes with buds or branches. The method is more suitable for clump-forming species rather than non-clump-forming. Generally, the culm selected for the cuttings should be not more than two years old and buds should be healthy. The method of preparation of cuttings is detailed in KFRI handbook (1990). Treatment with growth regulating substances (GRS) like Naphthyl acetic acid (NAA) and Indole butyric acid (IBA) enhanced the rooting response in bamboo. Generally, 50- 100 ml of growth regulator solution is used for bamboos like *Bambusa balcooa, B. bambos, Dendrocalamus brandisii*, etc. For large diameter bamboos like *D. giganteus* about 250 to 500 ml of the solution is required (Seethalakshmi *et al.,* 2008). The selection of the cuttings based on position of node and application of proper concentration of growth regulating substance can be resorted to ensure efficient rooting and cost-effective planting stock production (Jijeesh and Seethalakshmi, 2010; Raveendran*et al.*, 2010 a-b).

Rooting response of cuttings varied with species, cutting type, season of collection, growth regulator and its concentration etc. (Hartman *et al.*, 1993). The environmental conditions during collection like light, temperature, humidity, rainfall plays a significant role in root induction of cuttings (Hofferman, 1979; Bunce, 1984; Karaguzel, 1997). This may be related to endogenous plant growth regulator levels or carbohydrates (Day and Loveys, 1998). The seasonal influence was prominent during root induction in bamboos (Raveendran *et al.*, 2010 a-b). Surendran and Seethalakshmi (1985) reported that the application of the growth regulating substances *viz.,* IAA, IBA, NAA, Coumarin or Boric Acid enhanced the rooting and sprouting and the responses varied with species and collection time. The study conducted by Raveendran *et al.* (2010a) on adventitious root induction of culm cuttings in giant bamboo *Dendrocalamus giganteus* indicated that the maximum rooting can be obtained during summer season (February to May) only. Similar results were obtained in rooting of *Dendrocalamus brandisii* cuttings also (Raveendran *et al.* 2010b). Gulbaro *et al.* (2012) investigated the influence of season on the rooting behaviour of eight important bamboo species. The study revealed that in *Bambusa balcooa, B. nutans, B. vulgaris, D. hamiltonii* and *D. strictus*, cuttings collected during summer season showed maximum sprouting and rooting, whereas, *B. bambos, B. tulda* and *D. giganteus* had maximum rooting in spring. The type of culm cutting

also played an important role in the success of rooting. For instance, in Nepal, good success rate (60-80%) has been achieved from single node culm cuttings in *B. balcooa, B. nutans, D. hamiltonii, D. hookeni*, and *Oxytenanthera nigrociliata* (Das, 1988). Propagation studies in Sri Lanka showed that two-node culm cuttings of some major bamboo species are more satisfactory than split culm-cuttings (Vivekanandan, 1987). Reddy and Yekanthappa (1989) reported that, two node cuttings obtained from one-year old culm exhibited 90 per cent rooting in eight months' period in *Oxytenanthera stocksii.* The position of cuttings also played an important role in the propagation through culm cuttings (Raveendran *et al.*, 2010 a-b). There was difference in rooting efficacy of cuttings collected from basal, middle and top portion of the bamboos. In most cases, basal portions of the culm responded better than the top and middle ones (Mabayag, 1937; Chinte, 1965). In the propagation of *Thyrsostachys oliveri* using culm cuttings, especially cuttings from basal third of culms performed better than the other parts and the growth promoter NAA stimulated rooting responses quickly than IBA (Seethalakshmi, 1995). It was observed that horizontal planting of culm cuttings was significantly better over planting in slanting as well as vertical irrespective of size. Similarly planting of one or two noded cuttings horizontally was the best method over others. More than one noded culm cutting should be planted horizontally, because the vertical or slanting position methods not only reduce quality of plant but also number of rooted plants (Bhol and Nayak, 2012).

Treatment with growth regulating substances like NAA and IBA enhances rooting response in bamboo. Since NAA is cheaper than IBA, generally NAA is preferred. For bamboos with hollow internode (e.g. *Bambusa bambos*), GRS solution is poured into the cavity and for solid bamboos (e.g. *Dendrocalamus strictus*), dip method of treatment (the basal part is dipped in GRS solution overnight) is given (Seethalakshmi *et al.*, 2008). Growth regulating substances have been used to induce rooting in cuttings of many species in forestry as well as in agriculture (Nanda, 1970). These substances are known to influence various processes of development *viz.*, cell division, elongation, differentiation, mobilization of nutrients and activity of hydrolyzing enzymes. Uchimura (1977) found that, among the three growth regulators (IAA, IBA and NAA), cuttings treated with 100 ppm of IBA for 24 hours gave better rooting percent and formation of longer roots in *B. vulgaris*. In a similar study with *B. blumeana* using different concentrations of IAA, IBA and NAA, Bumarlong (1977) observed the highest dry weight and mean length of roots for cuttings treated with 600 mg/l of NAA while maximum number of roots per cutting was obtained with 200 mg/l^{-1} of NAA. Higher survival rate was recorded in the cuttings treated with IBA (13%) over control in *B. blumeana*, 5 per cent in *B.*

vulgaris and 6.5 per cent in *Dendrocalamus merrilianus* (Suzuki and Ordinario, 1977). However, normal concentrations of growth regulators have no effect on rooting of branch cuttings (White, 1947; Delgado 1949). Methods for vegetative propagation using culm cuttings by treating them with GRS were standardised for many commercially important bamboo species like *Bambusa balcooa, B. bambos, B. blumeana, B. pellicio, B. tulda, B. vulgaris. Dendrocalamus hamiltonii, D. strictus. Ochlandra scriptoria, O. travancorica* and *Teinostachyum dullooa* (Banik,1980; Seethalakshmi *et al.*, 1983; Surendran *et al.*, 1983; Surendran and Seethaiakshrni, 1985; Sharma, 1987; Nath *et al.* 1986; Adarshkumar *et al.*, 1988; Jayasree, 1989; Dhuria and Chadhar, 1990; Jijeesh and Seethalakshmi, 2010; Seethalakshmi and Jijeesh, 2011; Singh *et al.*, 2006; Chetri and Kumar, 2015; Sadd *et al.*, 2016).

2.5.1.5. Layering Methods

Layering is the method of bringing a culm or branch in contact with soil or other rooting medium so that rooting occurs. There are four types of layering namely ground or simple layering, stump layering, air layering or marcotting and seedling layering (Ahlawat *et al.,* 2002; Pandalai *et al.,* 2002). Whole bamboo layering method has been adopted to develop rooting and sprouting at each node. Serajuddoula (1987) described the propagation of *Bambusa vulgaris* and *Melocanna baccifera* by layering. Ground-layering and air-layering trials were conducted on *B. vulgaris* and *M. baccifera*. All the treated branches of *B. vulgaris* produced successful propagules in the air-layering experiment. The ground-layering of twelve culms of this species produced 23 rooted and rhizomed propagules. Initiation of rooting and rhizome appeared only in the branches of mid-culm zone in both of the layering experiments. *M. baccifera* did not respond to any of the layering methods. Layering is successfully employed in the propagation of *Guadua anguistifolia* (Verma *et al.,* 2013).

2.5.1.6. Branch Cutting

Propagation through branch cuttings is the simplest and easiest method of bamboo propagation due to the ease in handling but the success of rooting is not as high as in culm cuttings. However, considering the availability in large number and ease in handling, even 50 per cent rooting is sufficient if this method of propagation is successful. It is reported to be suitable for bamboo species with prominent primary branches from the base of the culm like

Bambusa balcooa, B. vulgaris, but very difficult in species like *Dendrocalamus giganteus* and *Thyrsostachys oliveri* (Seethalakshmi *et al.,* 2008).

Banik (2015) reported that in majority of the species viz. *B. balcooa, B. bambos, B. tulda, B. vulgaris* etc. exhibit branching from base to top, more or less throughout the culm. In some bamboo species, culms of progressively larger sizes (those approaching mature statures) have a progressively longer series of budless lower above-ground internodes. As for example, mature size culms from clumps of *B. cacharensis, B. polymorpha, D. asper, D. giganteus, D. hamiltonii, D. longispathus, Thyrsostachys oliveri, T. siamensis*, may lack buds and branches in the lower ½ to ⅔ or even ¾ of their length (Banik, 2015). Branching pattern vary in different bamboo species. Each bud or culm node can potentially produce a branch; however, in many species the primary branch remains dominant and stout. Whereas, in others the primary branch is indistinguishable from the other branches due to high branching e.g. *Schizostachyum* and *Melocanna baccifera* branches near the top of the culm (Seethalakshmi and Kumar, 1998). Many *Ochlandra* species also produce many branches towards the top region of culms. The major limitations of propagation through branch cutting are low rooting percentage of branches, availability of branches is scarce in species with branching only from top one-third of the culm, technology is not standardized for many species and synchronous flowering etc. (Seethalakshmi, 2015). The adventitious rhizogenesis in branch cuttings can be enhanced by the treatment with GRS. The treatment enhances rooting response in branch cuttings and dip method of treatment can be successfully used (Seethalakshmi *et al.*, 2008). The time taken for planting stock production is a constraint and the time taken for rooting may have about four to eight months and rhizome formation takes still longer periods of about a year (Seethalakshmi *et al.*, 2008). Preparing pre-rooted and pre-rhizomed branch cuttings can reduce the time taken for rooting and rhizome development in branch cuttings (Banik 1984). Natural aerial rooting and rhizome formation is seen in some species the collection of planting material from this region ensures more rooting success. Chopping off the top part of the culm and covering the nodal buds with moist medium like moss or coir can also induce pre-rooting (Seethalakshmi, 2015).

The efforts to root the branch cuttings were started as early as 20th century. White (1947) successfully propagated *Gigantoochloa verticillata* Munro and *Sinocalamus oldhami* (Munro) McClure through branch cuttings. Delgado (1949) and McClure and Durand (1951) also propagated bamboos using branch cuttings, which were slow to form roots. The success of

rooting in branch cuttings can be improved by the selection of pre-rooted cuttings. Banik (1984) successfully induced *in situ* rooting and rhizome at the branch bases of some thick-walled species of bamboos of Bangladesh. These "pre-rooted and pre- rhizomed branch cuttings" performed better than normal branch cuttings (Banik, 1987). The average rooting and rhizome formation of these types of cuttings were 67 per cent in *Bambusa balcooa*, 70 per cent in *B. nutans*, 93 per cent in *B. polymorpha* 90 per cent in *B. vulgaris* and 63 per cent in *D. giganteus* (Banik, 1984 & 1991).

Seethalakshmi *et al.* (1983) reported that, *B. balcooa* lateral branch cuttings and culm cuttings treated with growth promoting substances like coumarin, IAA, and NAA, as well as survival after transplanting in the field. NAA and mixture of coumarin and IAA gave the higher percentage of rooting. They were of the opinion that branch and culm cutting materials are more economical and convenient for large scale vegetative propagation of bamboos, than the conventionally used offset and rhizome material. Surendran and Seethalakshmi (1985) conducted the rooting trials with branch cuttings of *B. arundinacea* (*B. bambos)* and *B. balcooa*. Results indicated the possibility of root induction by treating with a suitable growth regulating substance. About 40 per cent (with IBA 100 ppm) rooting was obtained in branch cuttings of *B. arundinaceae*. In branch cuttings planted vertically as well as horizontally only the latter developed vigorous sprouts and roots occasionally from both the nodes. In *Bambusa balcooa* About 40 per cent rooting was obtained in branch cuttings treated with IAA or coumarin.

Venkatesh (1989) had attempted to root small sized bamboo propagules with the aid of growth regulators. Single noded lateral branch cuttings, two noded culm segments and single noded culm chips of *Bambusa balcooa* and *B. bambos* were used in the experiment. Results showed that lateral branch cuttings of bamboo culms can be effectively used for vegetative multiplication with the help of suitable growth regulators

Agnihotri and Ansari (2000) investigated the adventitious rhizogenesis in culm branch cuttings of *Bambusa vulgaris* var. striata and *Dendrocolamus strictus* as influenced by season, size of cuttings, IAA treatment and their all possible interactions. Results indicated that the adventitious rhizogenesis was dependent on season and cutting size and IAA treatment enhanced the rooting during warm season of the year. It was found that the cuttings collected in April treated with 100 ppm IAA with double/triple nodes (59.6%) and those in February treated with 100 ppm IAA with double nodal cuttings (30.3%) gave the better rooting

performance in *B vuulgaris* and *D. strictus*, respectively. Singh *et al.* (2002) studied the suitability of both culm and culm-branch cuttings for adventitious rooting under the influence of various auxin treatments in *Bambusa nutans*. It was observed that the adventitious rhizogenes is in both types of cuttings was higher during April than May. However, culm cuttings exhibited markedly better adventitious root formation and growth, compared to culm-branch cuttings.

Pattanaik *et al.* (2004) reported that the two noded branch cuttings with rhizomatous swelling, treated with 200 ppm IBA gave 66.7 per cent rooting in *Bambusa balcooa.* Moreover, 100 per cent rhizome formation and field survivals were also obtained after two years of field planting in these branch cuttings. However, field trial indicated that the culms produced were small sized and requires intensive management practices like fertilization, irrigation and regular soil working for faster establishment in the field. They opined that the possibility of combining macro-proliferation technology with branch cutting technique needs to be explored for fast and large-scale multiplication of the species. Somashekar *et al.* (2004) reported that, the leafy branch cuttings treated with IBA 2500 ppm (talcum based IBA powder) induced maximum (85%) rooting. Whereas, nodal cutting exhibited maximum (80%) rooting by pulse treatment with IBA 2500 ppm solution in case of *Guadua angustifolia.*

Oathman (2005) compared the performance of different type of planting stock produced through the branch cuttings. It was observed that the polybag branch cuttings gave the highest survival after one year of field planting, although nursery beds tended to provide better growing conditions for preparing planting materials. The use of commercial IBA 2000 ppm enhanced both survival and growth of polybag cuttings and was found to be more effective than other applications of IBA. The planting of *Gigantochloa levis* in the field showed that the polybag branch cuttings had a higher survival percentage (88.9%) than those of the bare root planting (41.7%) and the newly branch cutting planting (33.3%).

Hossain *et al.* (2005) studied the influence of different light regimes on rooting of untreated and treated (with 0.2% solution of rooting hormone IBA) branch cuttings of *Bambusa vulgaris* Schrad ex Wendl and the field performance of the rooted cuttings were assessed. Rooting and growth performance of cutting were significantly influenced by light intensity and IBA treatment. Maximum rooting (84%) was in cuttings treated with IBA rooted in the tree shade followed by untreated cuttings under the tree shade (73.3%) and the lowest (60%) was under the deep shade. Study also indicated that the highest survival percentage was 95.2 in

treated cuttings rooted in the open sun and the lowest was in case of deep shade without IBA treatment. Hossain *et al.* (2006) studied the rooting of *Bambusa vulgaris* Var. striata and the highest percentage of rooting (63.33%) was observed in the base cuttings (Rhizomatous) treated with 400 ppm IBA than in case of secondary branch cuttings. However, the highest rooting response was in samples treated with 2000 ppm IBA in *B. vulgaris*.

Nautyal *et al.* (2007) reported that the rooting of branch cuttings of *D. giganteus* was very promising. Study indicated that the highest rooting was observed in cuttings kept as control, followed by Boric acid 100 mg l^{-1} and IBA 100 mg l^{-1}. As the maximum rooting was initiated in the untreated cutting this species does not require any growth regulator treatment. They also opined that the application of growth regulators may be inhibiting the rooting of the cuttings in this species.

Bakshi and Prakesh (2008) studied the propagation of *Bambusa vulgaris* var. striata through culm branch cuttings using various growth promoting substances. Culms of current year's growth were extracted and treated with growth regulators. After 10-15 days of planting, bud burst and elongation of buds occurred. After 50- 60 days of planting, profuse rooting and sprouting was achieved. The best response as regards to survival (80%), rooting (75%) and sprouting (80%) was achieved in IBA 100 ppm treatment, whereas control depicted 50% survival, 40% rooting and 50% sprouting only.

Razvi and Nautiyal (2009) studied the rooting response of juvenile branch cuttings of *Bambusa vulgaris* (green). The rooting response of juvenile branch cuttings was very encouraging and the maximum rooting was observed in untreated cuttings that are control (55%) followed by IBA and IAA 500 ppm. Islam *et al.* (2011) observed that rooting of the branch cuttings was significantly enhanced by the application of rooting hormone IBA in the clonal propagation of *Bambusa vulgaris* by leafy branch cuttings. The highest rooting percentage was obtained in nodal leafy cuttings and the tip cuttings (56.67 and 51%, respectively) on treatment with 0.8 per cent IBA.

The rooting behaviour of primary and secondary branch cuttings of eight different bamboo species *viz.*, *Bambusa balcooa, B. bambos, B. nutans, B. tulda, B. vulgaris, Dendrocalamus asper, D. giganteus* and *D. hamiltonii* was studied by Kaushal *et al.* (2011). The primary branch cuttings were given 200 ppm IBA treatment for 8 hours and secondary branch cuttings were treated with 4000 ppm IBA for one minute. The study revealed that

application of IBA enhanced the rooting and sprouting parameters of primary branches and those varied with species. In secondary branch cuttings, all the species except *B. vulgaris* failed to produce root.

Singh *et al.* (2011) studied the influence of season, IBA and type of cuttings adventitious rhizogenesis in *Bambusa nutans* Wall. and *Bambusa tulda* Roxb. Rooting of cuttings was influenced much by season in *B. nutans* and by season, nature of cuttings and IBA treatment in *B. tulda.* The rooting performance of culm cuttings was superior over culm-branch cuttings in these species. Rooting of culm branch cuttings was observed to be feasible method for propagation of *B. nutans.* They recommended single node culm and culm-branch cuttings in *B. nutans* and culm cuttings in *B. tulda* treated can be used for mass multiplication during February to May on treating with with 2 mM IBA.

Bhol and Parida (2015) studied the influence of growth regulators on propagation of culm and branch cuttings of *Bambusa vulgaris.* It was observed from the effect of various growth regulator treatments on branch cuttings that IAA 100 ppm excelled over other treatments in propagation of the culm–branch cuttings of *B. vulgaris.* However, as regards to growth and quality parameters better performance was recorded in IAA and NAA 50 and 100 ppm.

Razvi *et al.* (2015) reported that in *Dendrocalamus giganteus* branch cuttings collected from mature clumps treated with different concentrations of IAA, IBA and NAA (100, 200 and 500 ppm) in spring, summer, autumn and winter that the maximum (63.33%) rooting was also recorded in untreated cuttings in rainy season while minimum (21.83%) rooting was recorded in the cuttings treated with NAA 200 ppm in autumn. As regards to rooting hormones the rooting behaviour was in the order: Control > IBA500 ppm > IBA200 ppm > IBA100 ppm > IAA100 ppm > IAA500 ppm > IAA200 ppm > NAA100 ppm> NAA200 ppm > NAA500 ppm.

Razvi *et al.* (2017) attempted rooting from binodal bracnch cuttings of *Dendrocalamus giganteus* under natural conditions. The binodal cuttings were pre-treated with different concentrations of IAA, NAA and IBA and kept in open sun light. Maximum (40.42%) rooting percentage, were recorded in untreated cuttings that is control with (1.90) number of roots and (18.67 cm) root length followed by the cutting as treated with IBA 500 ppm with (37.71%), (1.79) number of roots and (19.45 cm) root length. Minimum (28.12%) rooting percentage were achieved in the cuttings treated with NAA 500 ppm with (1.76) number of roots and (18.32 cm) root length.

The review of the success of different vegetative propagation methods in Philippines as given by Lantican (2009) is given in the Table 2. The main method of propagation used in all bamboo species was culm cuttings. Branch cuttings also found to be successful although not suitable for all the species. The clump division and offsets give more success compared to other methods. Marcotting is limited to a few species only.

Table 2. Ranges in percentage rooting for different species and vegetative methods (based on the experiences of bamboo nursery operators in Laguna, Philippines) (Lantican, 2009)

Sl No	Scientific name	Stem cuttings	Branch cuttings	Clump division	Offsets	Marcot
1.	*Bambusa atra*	-	-	>90	>90	-
2.	*B. bambos*	50-70	50-70	-	-	-
3.	*B. blumeana*	50-70	50-70	-	-	-
4.	*B. dolichomerithalla*	50-70		>90	>90	>90
5.	*B. merrilliana*	40-50	50-60	-	-	-
6.	*B. multiplex*	25-40	-	70-80	70-80	-
7.	*B. multiplex f. variegata*	60-70	60-70	>90	>90	-
8.	*B. multiplex var. riviereorum*	<5	-	<85	<85	<5
9.	*B. oldhamii*	50-70	-	-	-	-
10	*B. philippinensis*	70-85	-	-	-	-
11	*B. sp. (pink bamboo)*	80-100	-	-	-	-
12	*B. sp. (Australian bamboo)*	50-70	-	-	-	-
13	*B. vulgaris*	70-85	70-85	-	-	-
14	*B. vulgaris var. vittata*	70-85	70-85	-	-	-
15	*B. vulgaris var. wamin*	50-70	50-70	-	-	-
16	*Dendrocalamus asper*	50-70	50-70	-	-	-
17	*D. latiflorus*	<10				<10
18	*D. strictus*	50-70	50-70	-	-	-
19	*Gigantochloa atter*	50-70	-	-	-	-
20	*Gigantochloa levis*	40-60	50-70	-	-	-
21	*Guadua angustifolia*	50-60	-	-	-	-
22	*Meloccana baccifera*	<10	-	-	<90	-
23	*Phyllostachys aurea*	-	-	-	>80	-
24	*Sasa fortune*	<10	<10	70-80	70-90	-
25	*Schizostachyum brachycladum*	50-60	-	-	<90	<5
26	*S. lima*	50-60	-	>70	<90	-
27	*S. lumampao*	50-60	-	-	75-90	-
28	*Thyrsostachys siamensis*	<5	-	-	<90	-

Synthesis

The literature review indicated that different vegetative propagation methods can be successfully employed in bamboo propagation. The propagation through branch cuttings in bamboos is gaining momentum and it is influenced by collection season, type of cuttings, growth regulators and their concentration. However, the literature on propagation through branch cuttings is limited especially under the humid tropical conditions of Kerala.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

3.1. STUDY AREA

The present study was conducted at the College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur district, Kerala located at latitude 10^0 32'N and longitude 76^0 26'E at an elevation of about 22 m above mean sea level. The study site experiences a warm and humid tropical climate with a distinct summer and rainy season.

3.2. MATERIALS

The details of the materials used in the present investigation are discussed in the following sections.

3.2.1. Bamboos under study

Three bamboo species *viz. Bambusa balcooa*, *Dendrocalamus giganteus* and *Thyrsostachys oliveri* (Plate. 1) were selected for the present study. These are among the priority species selected by National Mission on Bamboo Application for the popularization and large-scale cultivation in the country (NMBA, 2007). *B. balcooa* was selected for the study because of its large clump forming and non-thorny nature and is in high demand among the farmers. Moreover, the seed production in this bamboo species is not reported yet and the available reports indicate even the seeds are produced they are sterile. *D. giganteous* also is large clump forming bamboo and the largest among the Indian bamboos. The reports on flowering indicated the sporadic nature and low seed production. *T. oliveri* is a medium clump forming bamboo with multiple utility and preferred by most of the farmers of Kerala and which is not reported to flower more than 70 years in Kerala. The details of the bamboo species selected for the study is given in the following sections.

3.2.1.1. *Bambusa balcooa*

Bambusa balcooa is a tall non- thorny bamboo species forming dense clumps. The culms are 20–24 m long, 8–15 cm in diameter, thick walled (2–2.5 cm), nodes prominent with white ring above the node and internodes 30–45 cm long. It is a common homestead bamboo in North-East India and West Bengal. It also occurs in Bihar, Jharkhand, Uttaranchal, and Bangladesh (Seeethalakshmi and Kumar, 1998). It is a large clump forming bamboo with excellent strength properties similar to *B. bambos* and is introduced to Kerala due to non-thorny

Plate. 1. Species under study

Bambusa balcooa

Dendrocalamus giganteus

Thyrsostachys oliveri

nature. The most common use of this sturdy and strong bamboo is in construction, thatching, walling, roofing, handicrafts and for making novelty items. It is a good bamboo for scaffolding, making ladders and also for pulp, paper, rayon and agarbatti sticks. Its young shoots are edible. Flowering records indicated that, this species has a long flowering cycle of 55–60 years, after flowering the clump dies without setting seeds (Tewari, 1992). Other vegetative propagation methods like culm cuttings, offset planting and micro-propagation have been resorted for planting stock production.

3.2.1.2. *Dendrocalamus giganteus*

Dendrocalamus giganteus (Wall) Munroa large bamboo with green to dark bluish green culm. It is commonly known as the giant bamboo for its growth form, is the tallest of the sympodial bamboos with slender branches only on the top portions of the culm. It is a native of Myanmar, found in India, Indonesia and Sri Lanka. In India, it is cultivated in Arunachal Pradesh, Assam, Manipur, Nagaland and West Bengal. It grows well in humid tropical and sub-tropical regions, North East and Bihar. It is one among the twelve high yielding bamboos worth for plantings as a large-scale plantation. In North Eastern States of India, the culm is used for building purposes, boat masts, vases, buckets, and various other decorative purposes. Young shoots are used for the preparation of many delicacies in Manipur. Seeds are rare due to the unpredictable and long flowering cycle of 76 years. Unlike other bamboos, vegetative propagation is unprofitable and difficult in this species because of the large size.

3.2.1.3. *Thyrsostachys oliveri*

Thyrsostachys oliveri Gamble is a large tufted handsome, straight growing, moderate-sized bamboo with persistent culm-sheath and branching from node. It has bright green foliage with whitish silky surface when young, which turns dull green or yellowish on maturity. It is a native of Myanmar and cultivated in many parts of the country. Flowering occurs at an interval of 48-50 years (Varmah and Bahadur, 1980). However, long and irregular flowering intervals limit seed supply which is a major limitation for its growing on a large scale. Other propagation methods are also limited in this species. Culms of *T. oliveri* are in great demand for construction purposes, basket making, fishing rods, thatching the roof, javelins, reinforcement for concrete slabs, handicrafts, pulping and for use as poles. The young shoots are also edible. *T. oliveri* due to its small clump size, straight growth and branching only from top one-third of the culms is the most preferred species by farmers for growing in homesteads (Sharma *et al.*, 2004).

3.3. METHODS

The details of the methodology adopted for the present study is described in the following sections.

3.3.1. Experiment I

The first rooting trials were the main trials, which was carried out from October 2015 to September 2016. The primary branches of each species were collected during three periods *viz.* February to May, June to September and October to January. The branches were collected during the months of October, 2015, February 2016 and June 2016.

3.3.1.1. Collection and preparation branch cuttings

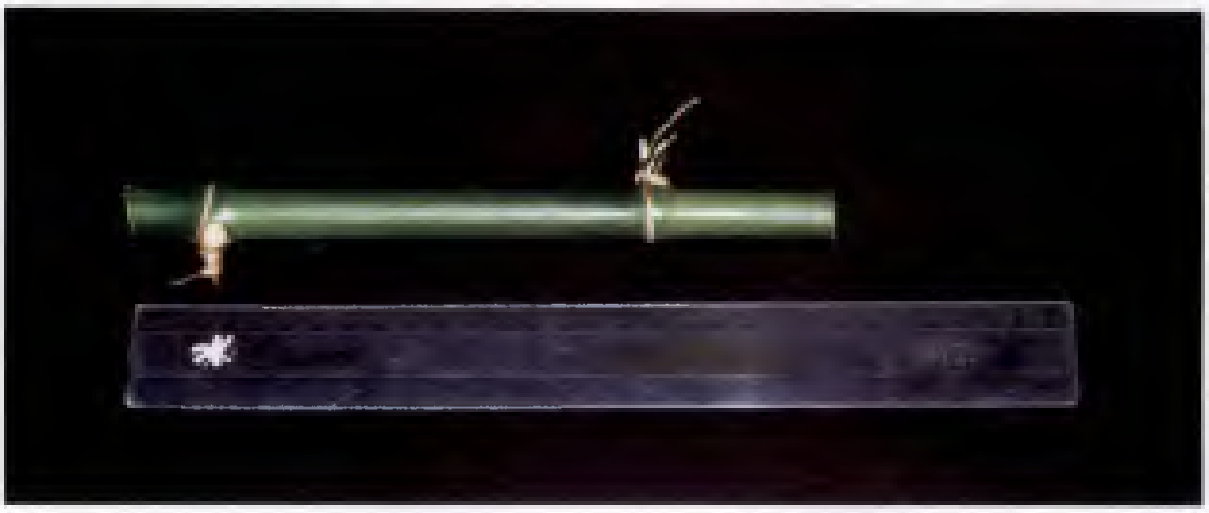
For the present study, primary branch cuttings of *B. balcooa*, *D. giganteus* and *T. oliveri* were collected from the bambusetum of Field Research Centre, Kerala Forest Research Institute, located at Vellupadam and KFRI main campus Peechi, Thrissur and from homesteads of Pattambi, Palakkad district of Kerala. The branches of *D. giganteus* cuttings were available for only two seasons as the synchronous flowering occurred in the bamboo clumps followed by the death of the clumps.

During each season, the primary branches of all three species were collected from two to three-year-old using secature and tree pruner (Plate. 2). The branches were severed close to the base of attachment the stem. The collected branches were immediately transported to the nursery by keeping in moistened gunny bags to avoid the moisture loss. From the primary branches, two-noded branch cuttings were prepared with secature after severing the top portion (top $1/3^{rd}$ portion). Average size of the cuttings collected from *B. balcooa* was, 20-25 cm in length and 1-2 cm in diameter, for *D. giganteus* the length was about 30-35 cm and the diameter was about 1-2 cm and for *T. oliveri,* 15-25 cm and 1-1.5cm for length and diameter respectively (Plate. 3). The secondary branches were trimmed without disturbing the buds. To prevent fungal attack, cuttings were treated with 0.05 % aqueous solution of Bavistin for 45 minutes.

The two-noded branch cuttings were treated with 0, 100, 250, 500, 1000 mg l^{-1} IBA (make- Merk) and NAA (make-SRL) solutions prepared as per the method suggested by KFRI (1990). After soaking the cuttings upright for 24 hours, they were planted in the two rooting mediums, positioning horizontally in the trays.

Plate. 2. Collection of cuttings

Plate. 3. Two noded branch cuttings



Bambusa balcooa

Dendrocalamus giganteus

Thyrsostachys oliveri

Two rooting media were used in the present study *viz.*, sand alone and sand, soil and cow dung in the ratio 1:1:1. The rooting media were filled in the plastic trays perforated at the base to facilitate drainage. The trays filled with medium were placed on the roof top of the College building. All together there were two growth regulators in four concentrations along with control planted in two rooting media. There were three replications of 25 branch cuttings (2x25 = 50 nodes) for each treatment combination. The treatment combinations for a single species are given in Table 3.

Table 3. The treatment combinations for a single bamboo species

Treatment no	Season	Rooting media	Growth regulator concentration (mg l^{-1})
1.	October to January	Sand	Control
2.			IBA 100
3.			IBA 250
4.			IBA 500
5.			IBA 1000
6.			Control
7.			NAA 100
8.			NAA 250
9.			NAA 500
10.			NAA 1000
11.		Soil, sand and Cowdung (1:1:1)	Control
12.			IBA 100
13.			IBA 250
14.			IBA 500
15.			IBA 1000
16.			Control
17.			NAA 100
18.			NAA 250
19.			NAA 500
20.			NAA 1000
21.	February to May	Sand	Control
22.			IBA 100
23.			IBA 250
24.			IBA 500
25.			IBA 1000
26.			Control
27.			NAA 100
28.			NAA 250
29.			NAA 500
30.			NAA 1000
31.		Soil, sand and Cowdung (1:1:1)	Control
32.			IBA 100
33.			IBA 250
34.			IBA 500

35.			IBA 1000
36.			Control
37.			NAA 100
38.			NAA 250
39.			NAA 500
40.			NAA 1000
41.	June to September	Sand	Control
42.			IBA 100
43.			IBA 250
44.			IBA 500
45.			IBA 1000
46.			Control
47.			NAA 100
48.			NAA 250
49.			NAA 500
50.			NAA 1000
51.		Soil, sand and Cowdung (1:1:1)	Control
52.			IBA 100
53.			IBA 250
54.			IBA 500
55.			IBA 1000
56.			Control
57.			NAA 100
58.			NAA 250
59.			NAA 500
60.			NAA 1000

For a single species, there were 2550 two-noded cuttings and the cuttings were planted in media horizontally and covered with thin layer of medium. The cuttings were irrigated twice a day for the first two weeks and once a day thereafter. The experiment was laid out in factorial completely randomized design (CRD) with 3 replications. The factors were season of collection, rooting media, growth regulator and concentrations. The observations on sprouting were recorded two weeks after planting of branch cuttings. The sprouted cuttings were uprooted after forty days and observations were made. Some of the sprouted cuttings were retained even after forty days but they eventually dried.

3.3.2. Experiment II

After the completion of the main experiment, the adventitious rhizogenesis was absent in the branch cuttings. Hence, another experiment was planned with the species *B. balcooa* and *T. oliveri*. *D. giganteus* cuttings were not available for the study due to gregarious flowering and death of the culms.

The Branch cuttings of mother plants were collected from a farmer's household at Pattambi, Palakkad district. The collections were made during November 2016. To prevent fungal attack, cuttings were treated with 0.05 % aqueous solution of Bavistin for 45 minutes. The two noded branch cuttings were prepared and soaked in plant growth regulators NAA and IBA in 0, 1000, 2000, 3000 mg l^{-1} for 24 hours. The cuttings were planted horizontally in the trays containing sand as the rooting media. There were three replications with each replication containing 15 branch cuttings. The treatment combinations are given below (Table 4).

Table 4. The treatment combinations for the rooting of branch cuttings

Treatment no	Growth regulator	Concentration (mg l^{-1})
1.	Control	0
2.	IBA	1000
3.	IBA	2000
4.	IBA	3000
5.	Control	0
6.	NAA	1000
7.	NAA	2000
8.	NAA	3000

3.3.3. Experiment III

Since the rooting was absent in the above experiment another trial was planned. In January 2017, *B. balcooa* and *T. oliveri* was treated with different concentrations of IBA and NAA *viz.*, 0, 1000, 1500 and 2500 mg l^{-1} prepared in talc by quick dip method. The cuttings were planted horizontally in the trays containing sand as the rooting media. There were three replications with each replication containing 15 branching cuttings. The treatment combinations are given below (Table 5).

Table 5. The treatment combinations for the rooting of branch cuttings.

Treatment no	Growth regulator	Concentration (mg l^{-1})
1.	Control	0
2.	IBA	1000
3.	IBA	1500
4.	IBA	2500
5.	Control	0
6.	NAA	1000
7.	NAA	1500
8.	NAA	2500

3.3.3.1. Preparation of talc-hormone mixture.

Three concentrations of IBA and NAA *viz.*, 1000, 1500 and 2500 mg l^{-1} were prepared by mixing with talcum powder using the instrument, mikro-dismembrator (B. BRAUN Mikro_dismembrator_ll S1_E57). Quantity of growth regulator mixture required is calculated using the formula;

Volume of Stock Solution = (Desired Hormone Concentration X Medium Volume) /Stock Solution Concentration.

The desired concentrations of NAA and IBA were prepared as shown in the Table 6.

Table 6. Quantity of IBA and NAA required for making different concentrations of IBA & NAA talc mixture.

Growth regulator concentration (mg l^{-1})	Quantity of NAA and IBA taken in 5 g talc
1000	0.005
1500	0.010
2500	0.015

3.3.4. Experiment IV

As a final trial, the branch cuttings of *Bambusa balcooa* were treated with different concentrations of IBA and NAA *viz.* 500, 1000, 1500, 2000 mg l^{-1} by overnight soaking in solution. The treated cuttings were planted horizontally in standard seed beds in trenches of one-inch depth (Plate. 4). The propagation bed was given 50 per cent shade using green nets. It was uniformly watered daily for the initial two weeks and then at an interval of two days. Drainage was provided so that water logging was completely avoided. Fifteen binodal branch

Plate. 4. Planting of treated branch cuttings in seed bed

Plate. 5. Sprouting's obtained

cuttings constituted a replication which was replicated thrice. The sprouted cuttings were uprooted after forty days and observations were made (Plate. 5).

3.5. Main items of observations

The cuttings were observed for sprout and root formation and the following observation were made.

3.5.1. Sprouting percentage

The sprouting percentage was calculated using the formula,

Percentage of sprouting = (Number of nodes sprouted / total number of nodes) x 100

3.5.2. Number of sprouts/ node

Number of sprouts produced by the nodal cuttings was recorded.

3.5.3. Sprout height

The height of sprout produced by the nodal cuttings was recorded in centimeters using a meter scale.

3.5.4. Rooting percentage

The rooting percentage was calculated using the formula,

Percentage of rooting = (Number of roots / total number of nodes) x 100

3.5.5. Root number

Number of roots produced by the nodal cuttings was recorded.

3.5.6. Root length

The length of root produced by the nodal cuttings was recorded in centimeters using a ruler

3.5.7. Statistical analysis

The first experiment was laid out in factorial completely randomized design (CRD) with 3 replications. Univariate analysis of variance was conducted taking season, rooting media, growth regulators and their concentration as the factor and the sprouting percentage, number of shoots and shoot length as the dependent variables. Two-way analysis of variance was conducted for the second to fourth experiments by taking the growth regulator as the first factor and its concentration as the second factor. The treatment means were compared with DMRT wherever necessary.

RESULTS

4. RESULTS

The results of the propagation trials through branch cuttings in three bamboo species *Bambusa balcooa, Dendrocalamus giganteus* and *Thyrsostachys oliveri* are presented in the following sections

4.1. Experiment I

The experiment I was the main trial to standardize the adventitious rhizogenesis in the selected bamboo species.

4.1.1. *Bambusa balcooa*

The performance of *B. balcooa* branch cuttings in response to season, rooting media and growth regulator and its concentrations has been studied in detail. However, rooting was not observed for any of the treatment combinations. The results of sprouting attributes are presented in Fig. 1-3 and Table 7.

During the first season (October 2015 to January 2016), the maximum sprouting (28.33%) was observed in treatment 2 (branch cuttings treated with IBA 100 mg l^{-1} which was kept in the sand medium) and the least sprouting (1.67%) was observed in treatment 14 (branch cuttings kept in the second medium treated with IBA 500 mg l^{-1}) (Fig. 1). The maximum number of sprouts produced per node (2.5±1.38) was the highest in branch cuttings treated with NAA 250 mgl^{-1} (Treatment No 14) and the lowest (1±0) was in those treated with IBA 100mgl^{-1} (Treatment 12) both kept in the second media. With regards to sprout height, the highest value (16.38±2.25 cm) was observed in treatment 14 (control for NAA kept in sand) and the lowest sprout height (12.48±2.77 cm) was in NAA 100 mg l^{-1} kept in the second media (Treatment 7).

In the second season (February 2016 to May 2016), the highest sprouting was observed in cuttings treated with NAA 250 mg l^{-1} (48.33%, treatment 28) which was kept in the sand and the least sprouting was in those treated with IBA 1000 mg l^{-1} (10.00%) which was kept in sand, soil and cow dung medium (Treatment 35) (Fig. 2). The cuttings kept as control also produced fairly good sprouting. The highest number of sprouts per node was recorded in those treated with IBA 100 mgl^{-1} (1.79±0.71) kept in sand (Treatment 22) and the lowest was in treatment 35 (1.00±0.00). The highest sprout height was observed in treatment 32 (15.64±2.17 cm) and the lowest was in treatment number 35 (11.57±4.57 cm).

In the third season (June to September, 2016), the maximum sprouting was observed in branch cuttings treated with IBA 100 mg l^{-1} (41.67%) and kept in the sand (Treatment 42). The least sprouting was recorded in treatments 48 and 54(11.67%) (Fig. 3). The sprouting of cuttings kept as control also was comparable to these. The number of sprouts produced per node was the highest in branch cuttings treated with NAA 1000 mgl^{-1}(1.75±0.62) which was kept in sand (Treatment 50) and the lowest was in those treated with IBA 100 mgl^{-1} (1.28±0.46) also kept in sand (Treatment 42). With regards to height of sprouts, the highest value (15.76±1.27 cm) was observed in cuttings treated with NAA 250 mgl^{-1}(Treatment 48) and the lowest sprout height was in NAA 500mgl^{-1}(11.46±2.36 cm) which was kept in the second media (Treatment 59).

Overall, the sprouting percentage was good in this species and the sprouting ranged from 1.67 to 48.33%. The highest sprouting was observed in branch cuttings collected during season II kept in the sand. The lowest sprouting was observed in branch cuttings collected during season I kept in the medium containing the mixture sand, soil and cow dung in the ratio 1:1:1, which was treated with IBA 500.

The analysis of variance did not reveal any significant difference in sprouting percentage of the cuttings due to interaction effect of Season* Media* Growth regulator* Concentration. With regards to sprouting percentage, the interaction effect of Season * Media * Growth regulator was significant at five percent level. The main effect of season and media was highly significant at one percent level. Similarly, the analysis of variance did not reveal any significant difference in number of sprouts from the nodes due to interaction effect of Season* Media* Growth regulator* Concentration. The interaction effect between media and growth regulator was significant at five percent level. Only the interaction effect between media and growth regulator was significant at five percent level in number of sprouts per node. The sprout height also did not vary due to interaction effect of Season* Media* Growth regulator* Concentration. Similar to number of sprouts, the sprout height also varied due to interaction effect between media and growth regulator at five percent significance level (Appendices I-III).

Table 7. Sprouting attributes of *Bambusa balcooa* branch cuttings as influenced by season, rooting media and growth regulators

No	Season	Rooting media	Growth regulator concentration (mg l^{-1})	No of sprouts/node	Sprout height (cm)
1.	October to January	Sand	Control	1.18±0.40	14.89±3.61
2.			IBA 100	1.53±0.45	13.59±2.88
3.			IBA 250	1.54±0.51	14.50±2.13
4.			IBA 500	1.25±0.88	15.01±2.03
5.			IBA 1000	1.17±0.46	14.08±2.81
6.			Control	1.4±0.55	16.38±2.25
7.			NAA 100	1.38±0.39	12.48±2.77
8.			NAA 250	1.57±0.52	13.70±3.68
9.			NAA 500	1.29±0.79	13.94±1.81
10.			NAA 1000	1.17±0.49	13.19±2.42
11.		Soil, sand and Cowdung (1:1:1)	Control	1.67±0.58	15.87±2.08
12.			IBA 100	1.00±0.00	16.18±3.66
13.			IBA 250	1.67± 0.58	14.60±1.55
14.			IBA 500	2.00±0.00	14.25±0
15.			IBA 1000	1.50±0.55	14.51±3.80
16.			Control	1.44±0.53	14.17±5.60
17.			NAA 100	1.38±0.52	14.49±2.69
18.			NAA 250	2.5±1.38	12.98±2.84
19.			NAA 500	1.29±.49	15.43±2.40
20.			NAA 1000	1.33±0.52	15.07±4.43
21.	February to May	Sand	Control	1.42±0.65	13.62±2.65
22.			IBA 100	1.79±0.71	12.80±2.10
23.			IBA 250	1.58±0.61	14.56±1.80
24.			IBA 500	1.63±0.71	14.03±2.33
25.			IBA 1000	1.35±0.61	14.64±2.23
26.			Control	1.13±0.34	13.85±3.89
27.			NAA 100	1.38±0.65	14.37±2.42
28.			NAA 250	1.31±0.47	14.40±2.52
29.			NAA 500	1.17±0.38	14.31±2.18
30.			NAA 1000	1.38±0.50	13.83±2.72
31.		Soil, sand and Cowdung (1:1:1)	Control	1.6±0.63	14.44±1.94
32.			IBA 100	1.30±0.48	15.64±2.17
33.			IBA 250	1.12±0.49	14.15±1.74
34.			IBA 500	1.20±0.42	13.89±2.75
35.			IBA 1000	1.00±0.00	11.57±4.57
36.			Control	1.22±0.44	13.98±3.25
37.			NAA 100	1.20±0.41	14.57±2.11
38.			NAA 250	1.25±0.45	14.15±2.64
39.			NAA 500	1.50±0.93	13.58±2.13
40.			NAA 1000	1.58±0.90	15.37±1.91
41.		Sand	Control	1.55±0.53	14.5±2.30
42.			IBA 100	1.28±0.46	13.84±2.54

43.	June to September		IBA 250	1.33±0.48	14.85±2.26
44.			IBA 500	1.35±0.49	14.32±2.24
45.			IBA 1000	1.38±0.52	14.52±2.34
46.			Control	1.44±0.53	13.38±2.46
47.			NAA 100	1.63±0.74	14.49±2.54
48.			NAA 250	1.57±0.53	15.76±1.27
49.			NAA 500	1.46±0.52	13.78±1.86
50.			NAA 1000	1.75±0.62	14.77±2.09
51.		Soil, sand and Cowdung (1:1:1)	Control	1.67±0.71	14.64±2.82
52.			IBA 100	1.50±0.71	13.28±3.32
53.			IBA 250	1.38±0.52	13.45±3.17
54.			IBA 500	1.57±0.53	13.76±1.60
55.			IBA 1000	1.45±0.52	15.07±1.63
56.			Control	1.50±0.52	13.65±3.98
57.			NAA 100	1.42±0.51	12.78±2.17
58.			NAA 250	1.44±0.53	12.49±3.09
59.			NAA 500	1.50±0.52	11.46±2.36
60.			NAA 1000	1.50±0.67	12.43±2.50

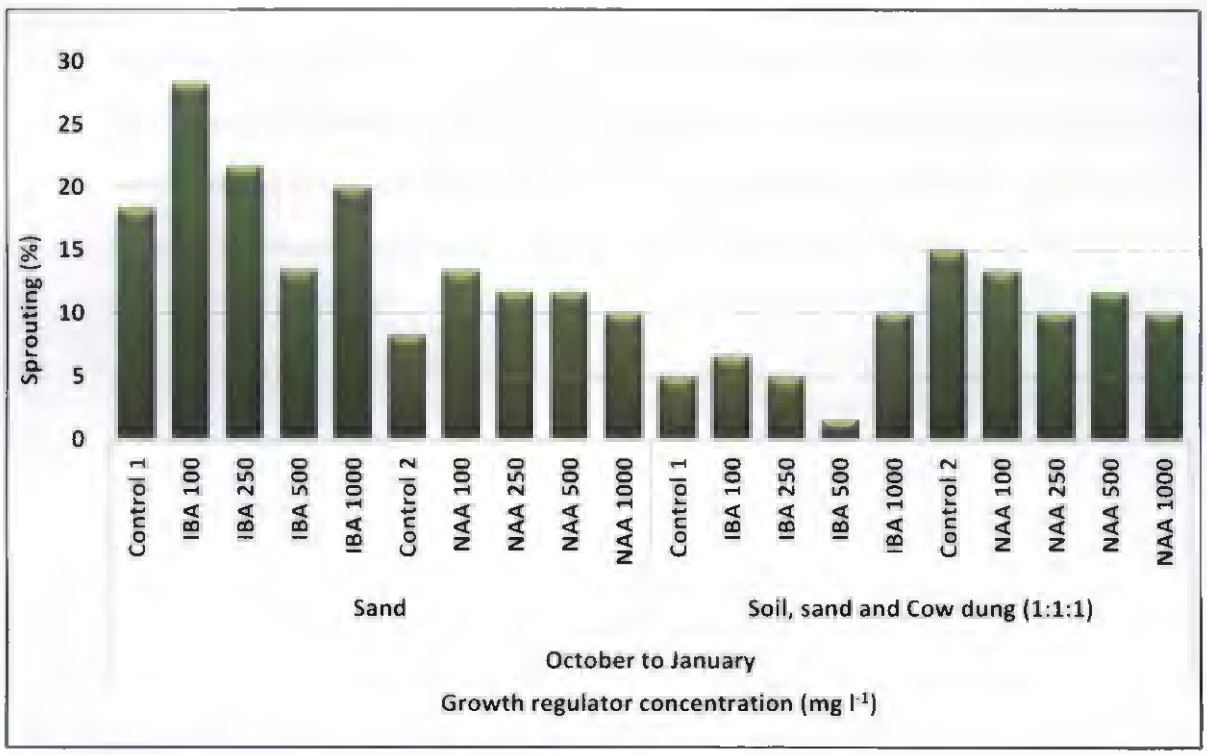


Fig 1. Sprouting percentage of *Bambusa balcooa* branch cuttings as influenced by rooting media and growth regulator during first season

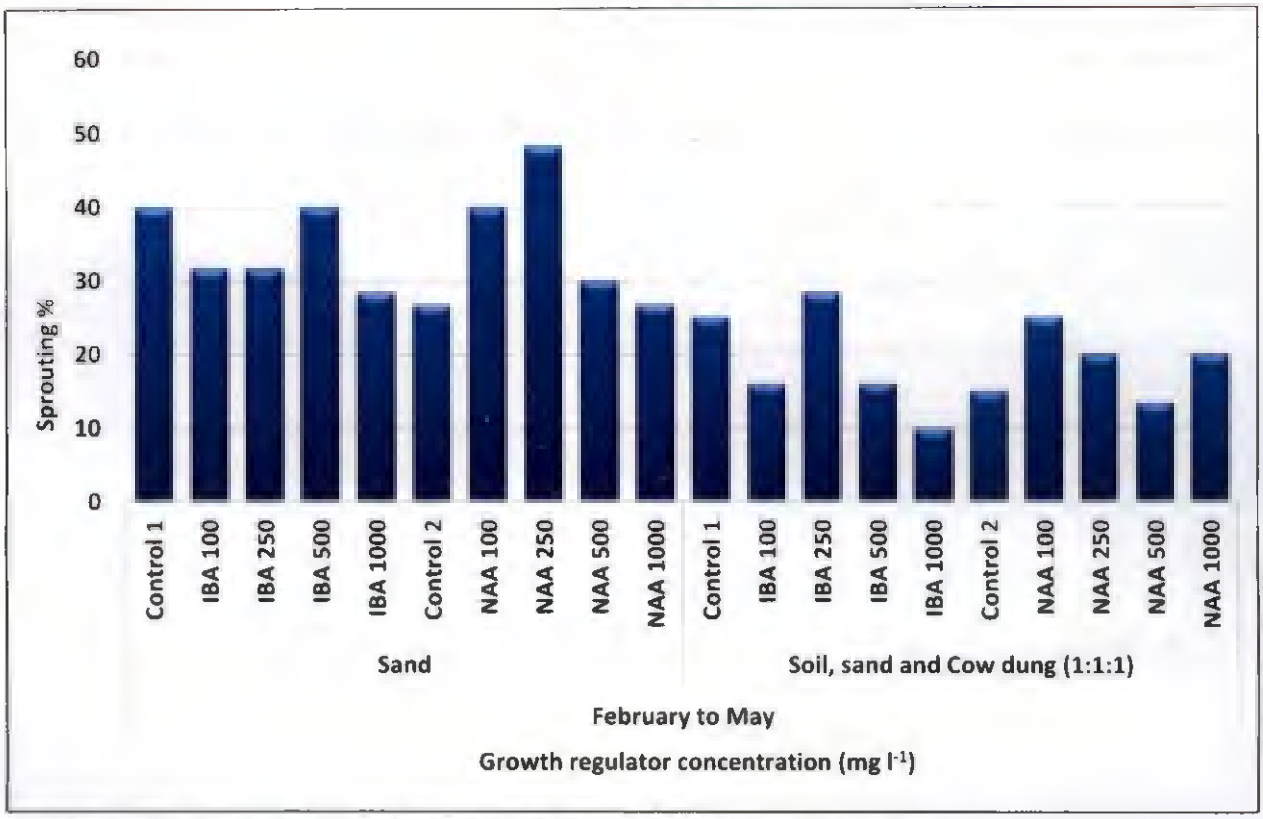


Fig 2. Sprouting percentage of *Bambusa balcooa* branch cuttings as influenced by rooting media and growth regulators during second season

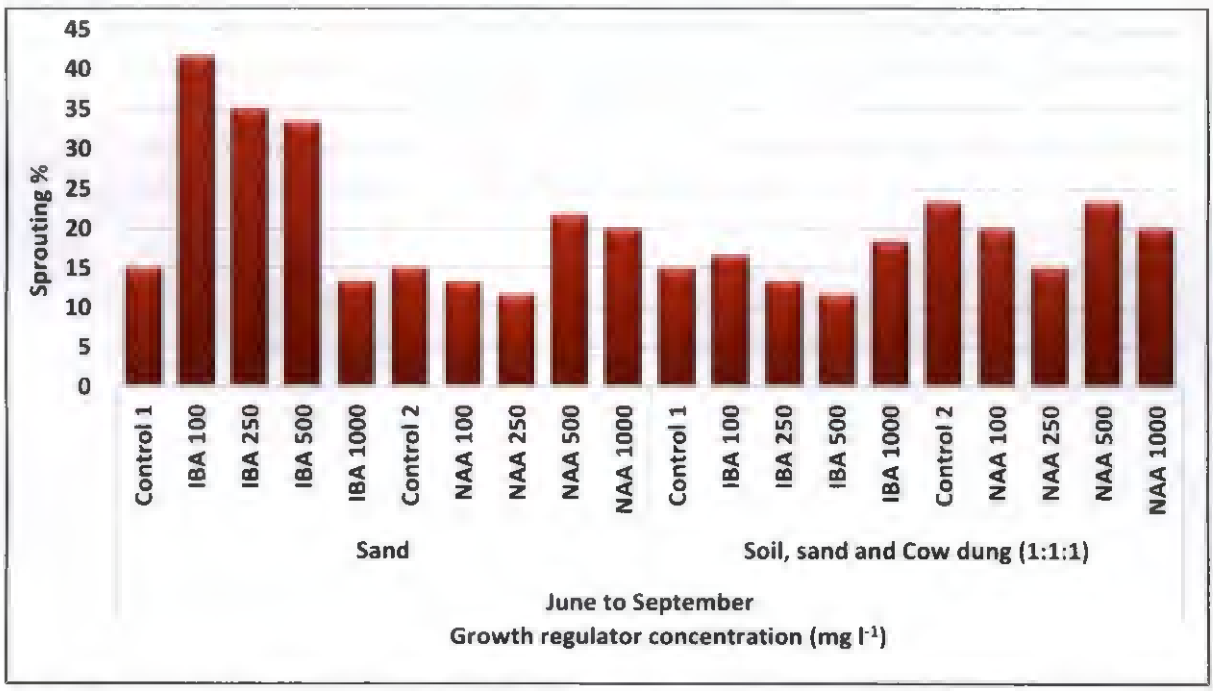


Fig 3. Sprouting percentage of *Bambusa balcooa* branch cuttings as influenced by rooting media and growth regulators during third season

4.1.2. *Dendrocalamus giganteus*

The performance of *Dendrocalamus giganteus* branch cuttings in response to season, rooting media and growth regulator and its concentrations has been studied in detail. However, rooting was not observed for any of the treatment combinations. The results of sprouting attributes are presented in Fig. 4-5 and table 8. In the first season, the maximum sprouting was observed in treatment 3(26.67%) and the least was in treatment 11 and 18 (8.33%) (Fig. 4). The number of sprouts per node was highest (1.67±0.82) in branch cuttings treated with IBA 1000 mgl^{-1} and NAA 1000 mgl^{-1} (Treatments 15 and 20 respectively) and the lowest was in the treatments 11 and 17 (1.20±0.45). Regarding the sprout height, the highest value was observed in treatment 14 those treated with IBA 500 mgl^{-1} (25.03±2.43 cm) and the lowest was in treatment 12, IBA 100 mgl^{-1} (18.43±4.29 cm), both planted in the second media.

During the second season, the maximum sprouting was observed in cuttings treated with NAA 500 mg l^{-1} (43.33%) which was kept in the second media (Treatment 39) and the least was in those in control of NAA (5.00%) which was kept in sand (Treatment 26) (Fig. 5). The cuttings kept as control also produced fairly good sprouting. The number of sprouts per node was the highest in those treated with IBA 1000 mg l^{-1} (2.50±1.38) and the lowest was in those treated with NAA 1000 mg l^{-1} (1.00±0.00) both kept in second media (Treatments 35 and 40 respectively). With regards to sprout height, the highest value was observed in those treated with IBA 100 mg l^{-1} (24.25±2.39 cm, treatment 22) and the lowest was in NAA 1000 mg l^{-1} (12.75±3.91 cm) which were kept in the sand (Treatment 30).

The results indicated that the sprouting in *D. giganteus* branch cutting was poor and ranged from 5.0 to 43.3%. Among all seasons the highest sprouting percentage was observed in cuttings treated with NAA 500 mg l^{-1} kept in the second media least was in those in control of NAA (5.00%) during second season.

Analysis of variance did not reveal any significant difference in sprouting per cent, number of sprouts per node or sprout height of branch cuttings due to interaction effect of season, media, growth regulator and concentration. .The interaction effect of season, growth regulator and concentration was significant at five percent level in sprouting percentage. The only interaction significant in the case of number of sprouts per node was season, media and concentration ($p=0.01$). With regards to sprout height the next highest interaction significant was season, growth regulator and concentration (Appendices IV-VI).

Table 8. Sprouting attributes of *Dendrocalamus giganteus* branch cuttings as influenced by season, rooting media and growth regulators

Treatment no	Season	Rooting media	Growth regulator concentration (mg l^{-1})	No of sprouts/node	Sprout height (cm)
1.	October to January	Sand	Control	1.60±0.70	20.75±4.94
2.			IBA 100	1.57±0.53	23.14±1.33
3.			IBA 250	1.44±0.63	23.12±1.91
4.			IBA 500	1.50±0.53	23.85±1.02
5.			IBA 1000	1.33±0.49	24.31±1.85
6.			Control	1.43±0.53	20.66±2.45
7.			NAA 100	1.50±0.53	24.17±1.74
8.			NAA 250	1.63±0.52	24.38±1.84
9.			NAA 500	1.50±0.52	20.95±3.74
10.			NAA 1000	1.38±0.52	20.45±2.69
11.		Soil, sand and Cowdung (1:1:1)	Control	1.2±0.45	19.82±3.42
12.			IBA 100	1.40±0.55	18.43±4.29
13.			IBA 250	1.50±0.53	20.34±4.18
14.			IBA 500	1.33±0.52	25.03±2.43
15.			IBA 1000	1.67±0.71	22.15±4.28
16.			Control	1.5±0.53	23.40±2.76
17.			NAA 100	1.20±0.45	19.82±3.42
18.			NAA 250	1.29±0.49	21.86±2.88
19.			NAA 500	1.33±0.52	23.56±2.37
20.			NAA 1000	1.67±0.82	22.66±2.81
21.	February to May	Sand	Control	1.28±0.48	15.43±2.40
22.			IBA 100	1.29±0.49	24.25±2.39
23.			IBA 250	2.00±0.71	21.51±1.87
24.			IBA 500	1.42±0.51	19.04±5.93
25.			IBA 1000	2.50±1.38	12.98±2.84
26.			Control	1.66±0.57	14.28±0.53
27.			NAA 100	1.33±0.52	15.07±4.43
28.			NAA 250	1.44±0.53	14.18±5.60
29.			NAA 500	1.15±0.38	13.99±2.08
30.			NAA 1000	1.00±0.00	12.75±3.91
31.		Soil, sand and Cowdung (1:1:1)	Control	1.38±0.51	14.68±2.41
32.			IBA 100	1.38±0.59	14.61±2.17
33.			IBA 250	1.38±0.52	14.36±2.41
34.			IBA 500	1.27±0.59	13.70±2.22
35.			IBA 1000	2.00±1.26	15.30±2.50
36.			Control	1.6±0.84	13.38±2.38
37.			NAA 100	1.44±0.63	13.73±2.61
38.			NAA 250	1.47±0.64	14.23±1.82
39.			NAA 500	1.77±0.65	14.28±2.27
40.			NAA 1000	1.33±0.49	14.19±1.65

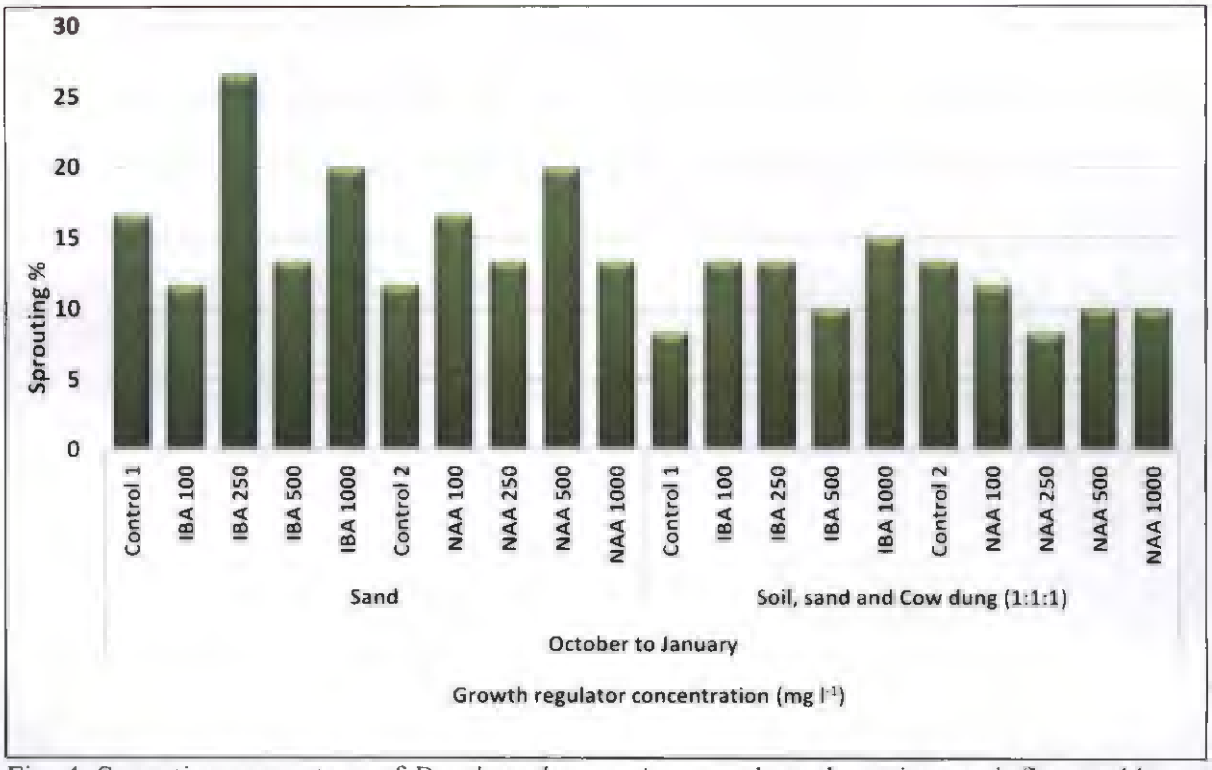


Fig. 4. Sprouting percentage of *Dendrocalamus giganteus* branch cuttings as influenced by rooting media and growth regulators during first season

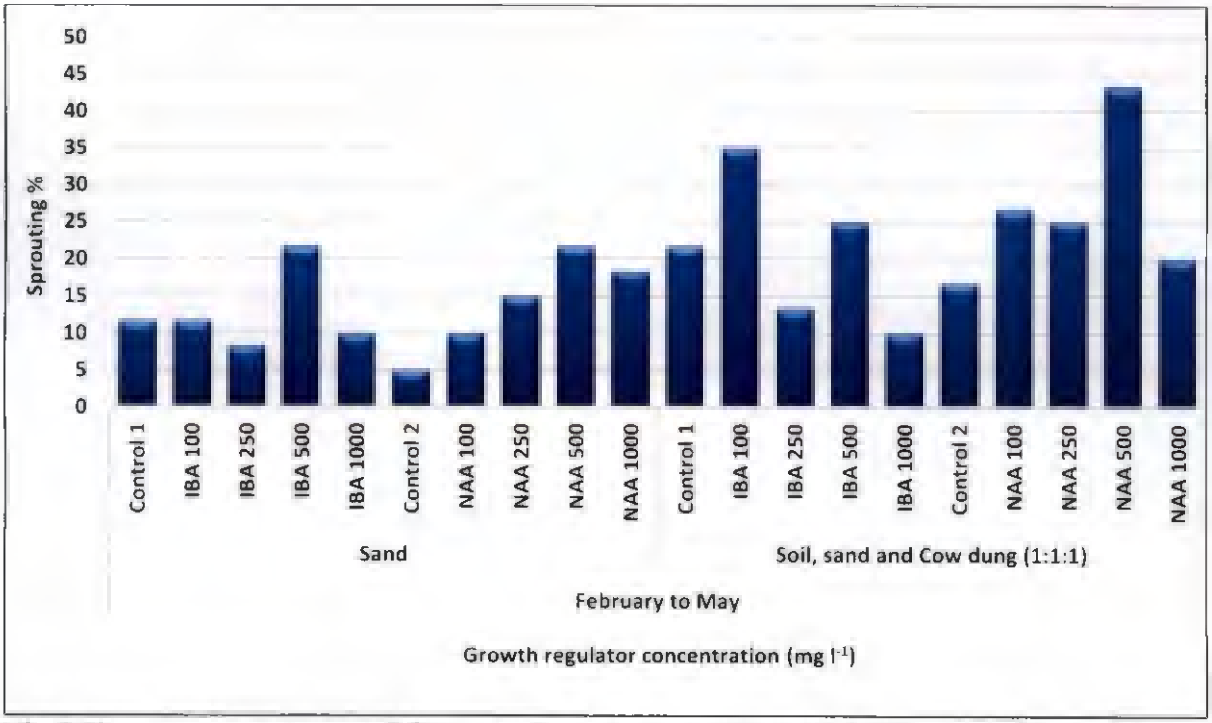


Fig.5. Sprouting percentage of *Dendrocalamus giganteus* branch cuttings as influenced by rooting media and growth regulators during second season

4.1.3. *Thyrsostachys oliveri*

Rooting was absent in all the treatment combinations tried. The sprouting attributes of *T. oliveri* branch cuttings as influenced by season, rooting media, growth regulator and its concentrations given in fig. 6-8 and table 9. Overall, the sprouting percentage was lower in this species and it ranged from 0 to 23.33%. The highest sprouting was observed in branch cuttings collected during season II kept in the medium containing sand, soil and cow dung in the ratio 1:1:1 without any growth regulator treatment.

During first season, the maximum sprouting was observed in cuttings treated with NAA 250 mg l^{-1} (16.67%) kept in the sand (Treatment 8) and the sprouting was absent in cuttings treated with IBA 100 mg l^{-1} and IBA 250 mg l^{-1} kept in mixture of sand, soil and cow dung (Treatments 11 and 12 respectively) (Fig. 6). The number of sprouts per node was the highest in those treated with IBA 250 mg l^{-1} (2.00±1.41) which was kept in sand (Treatment 3) and the lowest was in those treated with NAA 250 mg l^{-1} (1.20±0.45), which was kept in the second media (Treatment18). The sprout height was seen highest in branch cuttings treated with NAA 1000 mg l^{-1}(14.01±2.83 cm) which was kept in sand (Treatment10) and the lowest was in control for IBA (10.37±1.36 cm) which was kept in the sand (Treatment5).

With regard the second season, maximum sprouting was observed in cuttings treated with IBA 100 mg l^{-1} (21.67%) kept in the sand (Treatment 22) and the least (0.00%) was in control for IBA (Treatment 21) (Fig. 7). In the case of number of sprouts per node, the highest number was observed in those treated with NAA 250 mg l^{-1} (2.25±1.16) and the lowest value was in those treated with IBA 100 mg l^{-1}(1.00±0.00) both kept in second media (Treatments38 and 32 respectively). With regards to sprout height, the highest value was observed in those treated with NAA 100 mgl^{-1}(13.74±1.72 cm) which was kept in sand (Treatment 27) and the lowest was in NAA 500 mgl^{-1}(11.18±2.86 cm) which was kept in the second media (Treatment 39).

During the third season, the maximum sprouting was observed in cuttings treated with IBA 100 mg l^{-1} (41.67%) kept in the sand (Treatment 42) and the least was in those treated with NAA 250 mg l^{-1} (0%) kept in second media (Treatment 58) (Fig. 8). The maximum number of sprouts per node was highest in those treated with NAA 1000 mg l^{-1}(2.38±0.52) which was kept in sand (Treatment 50) and the lowest was in those treated with IBA 250 mg l^{-1} (1.33±0.58) which was kept in second media (Treatment 53). With regards to sprout height, the highest was

observed in cuttings treated with NAA 500 mg l^{-1} (13.49±1.85 cm) and the lowest was in NAA 100 mg l^{-1}(10.47±2.49 cm) which was kept in sand (Treatments 49 and 47 respectively).

The statistical analysis variance did not reveal any significant difference in sprouting percentage of the cuttings due to interaction effect of Season* Media* Growth regulator* Concentration. The interaction effects between Season * Growth Regulator * Concentration and Media * Growth regulator * Concentration was significant in the case of sprouting percentage (p=0.05). The main effect of season and media also was highly significant at one percent level. The analysis of variance did not reveal any significant difference in number of sprouts per node due to interaction effect of Season* Media* Growth regulator* Concentration. Only the main effect of growth regulator was significant at five percent level. The interaction effect of media and growth regulator was significant at five percent level in the case of sprout height (Appendices VII-IX).

Table 9. Sprouting attributes of *Thyrsostachys oliveri* branch cuttings as influenced by season, rooting media and growth regulators

Treatment no	Season	Rooting media	Growth regulator concentration (mg l^{-1})	No of sprouts/node	Sprout height (cm)
1.	October to January	Sand	Control	1.33±0.58	10.37±1.36
2.			IBA 100	1.40±0.55	12.10±0.76
3.			IBA 250	2.00±1.41	12.41±0.93
4.			IBA 500	1.50±0.55	12.05±1.37
5.			IBA 1000	1.40±0.55	12.59±0.87
6.			Control	1.5±0.70	12.22±0.46
7.			NAA 100	1.33±0.50	11.99±1.92
8.			NAA 250	1.40±0.52	11.91±2.15
9.			NAA 500	1.33±0.58	12.43±1.62
10.			NAA 1000	1.50±0.58	12.04±2.27
11.		Soil, sand and Cowdung (1:1:1)	Control	1.33±0.52	12.62±0.77
12.			IBA 100	0.00±0.00	0.00±0.00
13.			IBA 250	0.00±0.00	0.00±0.00
14.			IBA 500	1.75±0.50	11.70±1.01
15.			IBA 1000	1.50±.055	12.84±0.63
16.			Control	1.5±1	11.94±2.26
17.			NAA 100	1.33±0.58	12.68±1.26
18.			NAA 250	1.20±0.45	14.00±1.10
19.			NAA 500	1.33±0.58	12.50±1.42
20.			NAA 1000	1.50±58	14.01±2.83
21.	February to May	Sand	Control	0.00±0.00	0.00±0.00
22.			IBA 100	1.38±0.51	13.71±1.69
23.			IBA 250	1.63±0.92	13.12±2.30
24.			IBA 500	1.13±0.35	14.29±2.81
25.			IBA 1000	1.44±0.73	13.08±1.53
26.			Control	1.33±0.65	13.16±2.78
27.			NAA 100	1.11±0.33	13.74±1.72
28.			NAA 250	1.10±0.32	13.36±2.82
29.			NAA 500	1.25±0.50	12.89±1.98
30.			NAA 1000	1.14±0.38	13.45±2.58
31.		Soil, sand and Cowdung (1:1:1)	Control	1.63±0.67	12.80±1.81
32.			IBA 100	1.00±0.00	13.70±2.95
33.			IBA 250	1.45±0.52	13.54±2.61
34.			IBA 500	1.63±0.92	12.74±2.13
35.			IBA 1000	1.67±0.71	12.99±0.92
36.			Control	1.42±0.75	12.71±2.35
37.			NAA 100	1.33±0.71	11.97±2.84
38.			NAA 250	2.25±1.16	12.97±1.49
39.			NAA 500	1.33±0.58	11.18±2.86
40.			NAA 1000	1.60±0.89	13.58±1.16
41.	June to September	Sand	Control	2.16±1.17	12.91±1.73
42.			IBA 100	1.84±0.90	12.30±2.61
43.			IBA 250	1.50±0.71	12.40±1.24
44.			IBA 500	1.67±0.71	12.77±0.91
45.			IBA 1000	1.56±0.73	11.57±2.37
46.			Control 2	1.83±0.85	11.83±2.96
47.			NAA 100	1.83±0.75	10.47±2.49
48.			NAA 250	1.50±0.73	13.09±1.49

49.			NAA 500	1.69±0.75	13.49±1.85
50.			NAA 1000	2.38±0.52	11.85±1.14
51.		Soil, sand and Cowdung (1:1:1)	Control	2.00±0.92	11.45±1.72
52.			IBA 100	2.00±0.76	12.07±1.36
53.			IBA 250	1.33±0.58	11.72±3.55
54.			IBA 500	1.75±0.46	11.16±0.92
55.			IBA 1000	2.17±0.41	12.12±1.91
56.			Control	2.11±0.78	10.52±1.87
57.			NAA 100	1.86±0.69	12.20±1.76
58.			NAA 250	0.00±0.00	0.00±0.00
59.			NAA 500	1.75±0.71	12.26±2.35
60.			NAA 1000	2.14±0.38	11.78±1.33

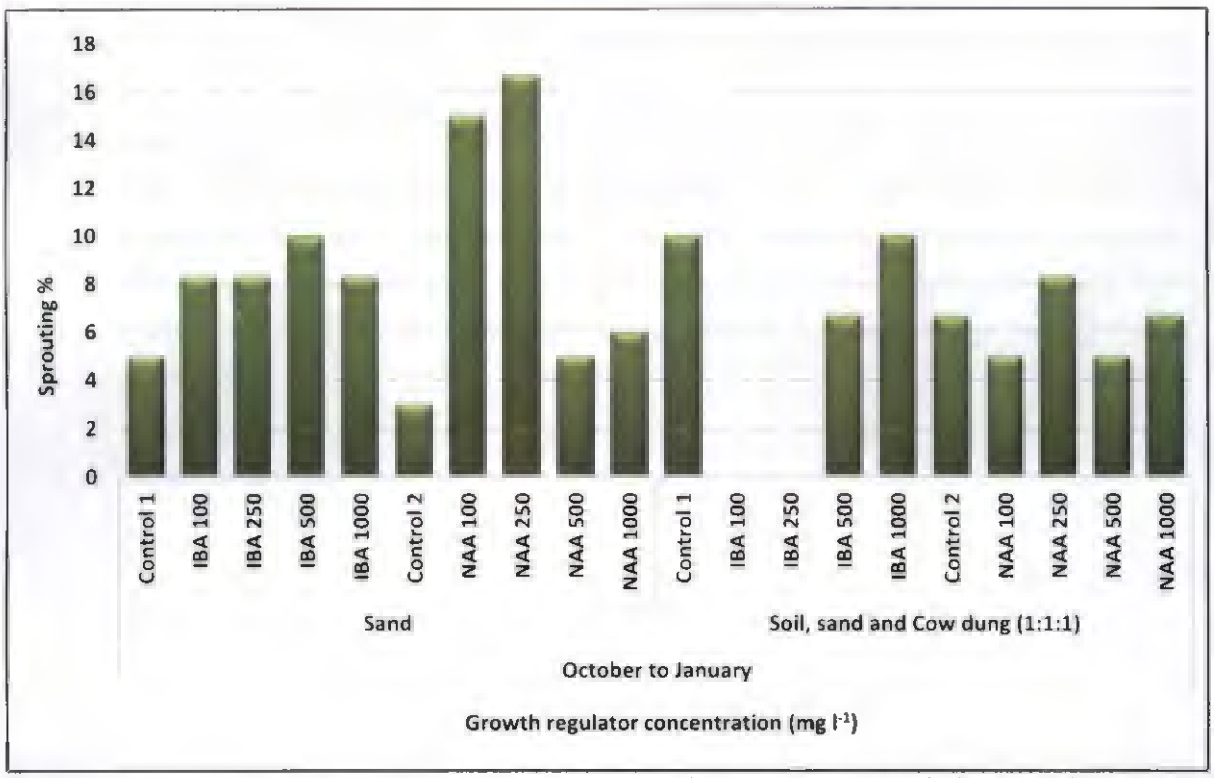


Fig.6. Sprouting percentage of *Thyrsostachys oliveri* branch cuttings as influenced by rooting media and growth regulators during first season

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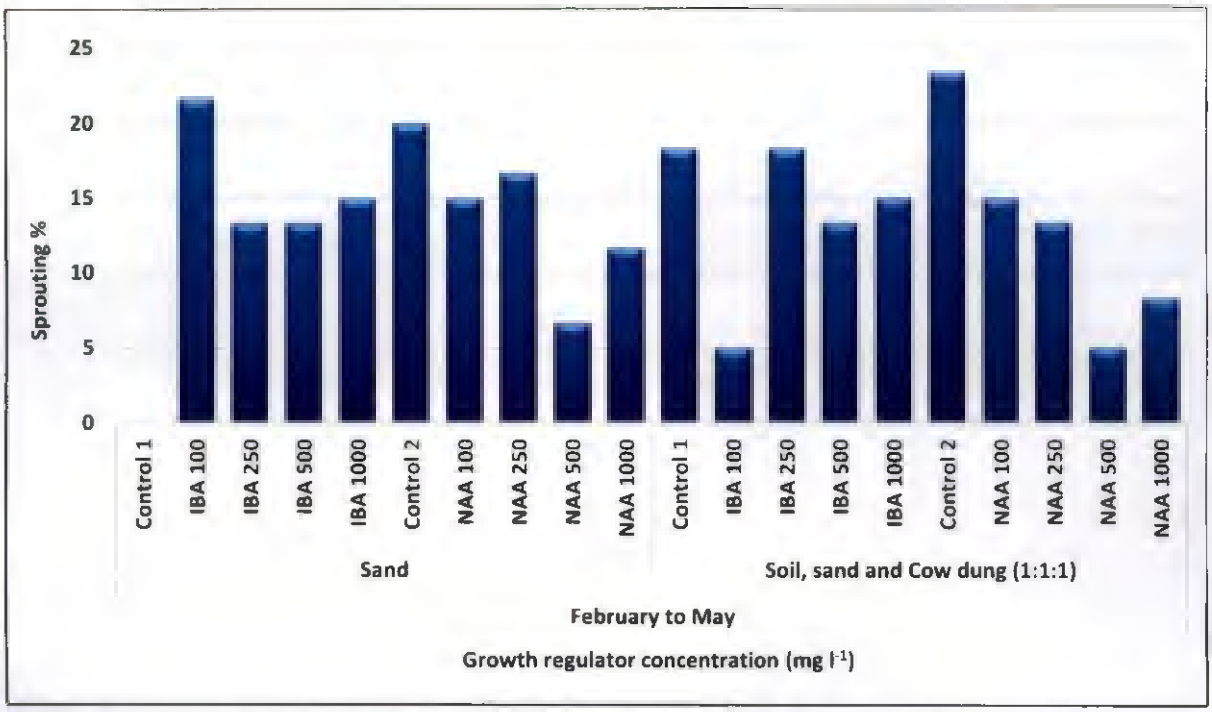

Fig. 7. Sprouting percentage of *Thyrsostachys oliveri* branch cuttings as influenced by rooting media and growth regulators during second season

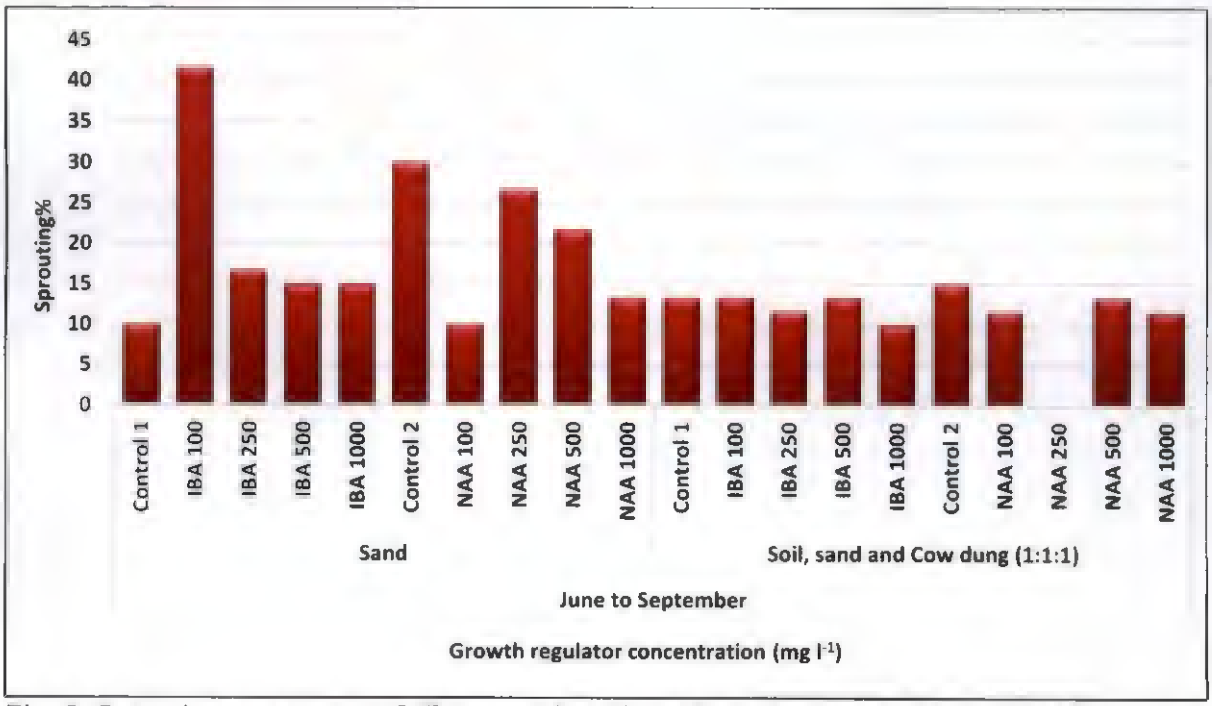

Fig. 8. Sprouting percentage of *Thyrsostachys oliveri* branch cuttings as influenced by rooting media and growth regulators during third season

4.2. Experiment II

Due to the absence of rooting in the first trail, one more experiment was conducted in both *B. balcooa* and *T. oliveri* with higher concentrations of growth regulators and the results are given below.

4.2.1. *Bambusa balcooa*

The results of the experiment on rooting of *B. balcooa* cuttings using the higher concentrations of growth regulator solutions are given in Fig. 9 and Table 10. Inspite of expected better sprouting and rooting of branch cuttings at higher concentrations, the rooting responses were non existant among the various treatment combinations. The maximum sprouting was observed in cuttings treated with IBA 1000 mg l^{-1} (36.66%) and the least was in those treated with NAA 1000 mg l^{-1} (10.00%). The cuttings kept as control also produced fairly good sprouting. There was decrease in sprouting with increase in concentration of growth regulators. The number of sprouts per node was highest in control (1.57±0.65) and the lowest was in those treated with NAA 3000 mgl^{-1}(1.00). Number of sprouts also decreased with increasing growth regulator concentration. With regards to sprout height, the highest was observed in those treated with NAA1000 mgl^{-1} (15.30±3.36 cm) and the lowest was in control (12.50±2.97 cm).

Analysis of variance did not reveal any significant difference in the sprouting attributes due to growth regulator or its various concentrations (Appendix X-XII).

Table 10. Sprouting attributes of *Bambusa balcooa* branch cuttings as influenced by growth regulator and its concentration

Treatment no	Growth regulator concentration (mg l^{-1})	No of sprouts/node	Sprout height (cm)
1.	Control	1.57±0.65	12.50±2.97
2.	IBA 1000	1.55±0.69	14.68±2.16
3.	IBA 2000	1.20±0.42	14.54±2.29
4.	IBA 3000	1.40±0.55	13.79±1.85
5.	NAA 1000	1.33±0.58	15.30±3.36
6.	NAA 2000	1.13±0.35	14.70±2.78
7.	NAA 3000	1.00±0.00	14.22±3.44

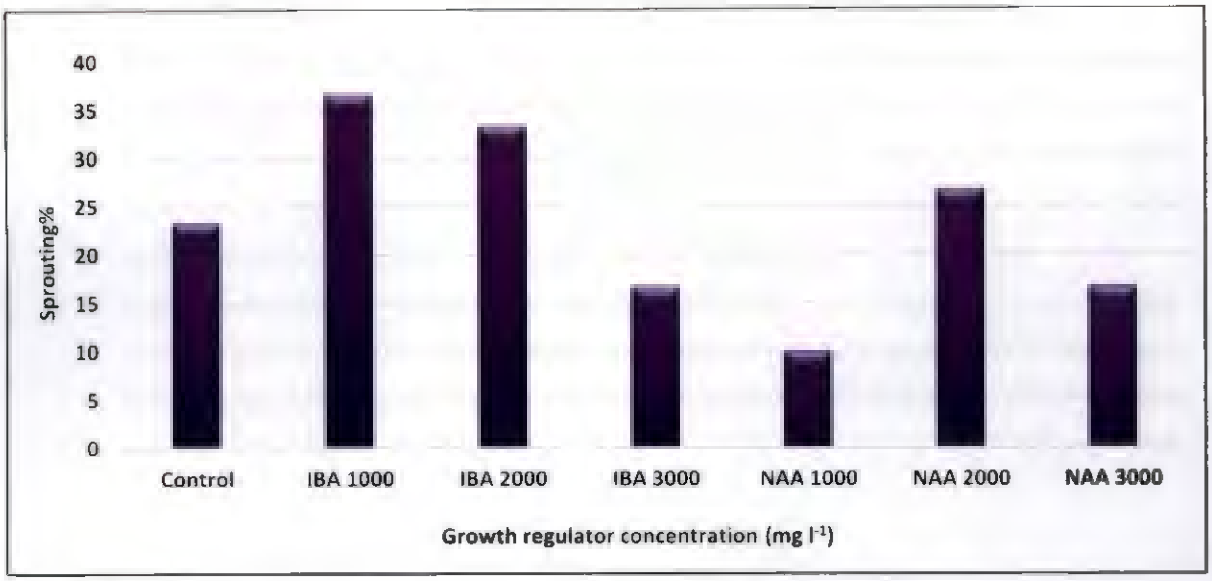

Fig. 9. Sprouting percentage of *Bambusa balcooa* branch cuttings as influenced by growth regulator

4.2.2. *Thyrsostachys oliveri*

Perusal of data on sprouting of *T. oliveri* branch cuttings revealed that the variation in sprouting parameters of the cuttings treated with growth regulators (Fig. 10 and Table 11). Of the different concentrations of IBA and NAA used, highest sprouting was observed in cuttings treated with IBA 1000 mg l^{-1} (26.66%) and those treated with IBA 3000 mg l^{-1} recorded the lowest sprouting percentage (10.00%). Here also with some exceptions the sprouting decreased with increase in growth regulator concentration indicating an inhibitory effect. The number of sprouts ranged from 2.50±1.00 to 1.33±0.82 and the highest was in cuttings treated with IBA 2000 mg l^{-1} and the lowest in IBA 3000 mg l^{-1}. Average sprout height was seen highest in cuttings kept as control (13.71±2.82 cm) and the lowest was recorded in the cuttings treated with IBA 1000 mg l-1 (11.52±1.55 cm).

Analysis of variance did not reveal any significant difference in the sprouting percentage or sprout height due to growth regulator or its various concentrations. The interaction effect of growth regulator and concentration was significant in the case of number of sprouts per node (Appendices XII-XV).

Table 11. Sprouting attributes of *Thyrsostachys oliveri* branch cuttings as influenced by growth regulator and its concentration

Treatment no	Growth regulator concentration (mg l^{-1})	No of sprouts/node	Sprout height (cm)
1.	Control	1.55±0.52	13.71±2.82
2.	IBA 1000	1.67±0.58	11.52±1.55
3.	IBA 2000	1.63±0.74	13.29±1.74
4.	IBA 3000	1.33±0.58	12.48±3.76
5.	NAA 1000	1.33±0.82	11.71±2.64
6.	NAA 2000	2.00±1.41	13.43±1.36
7.	NAA 3000	2.50±1.00	12.51±1.66

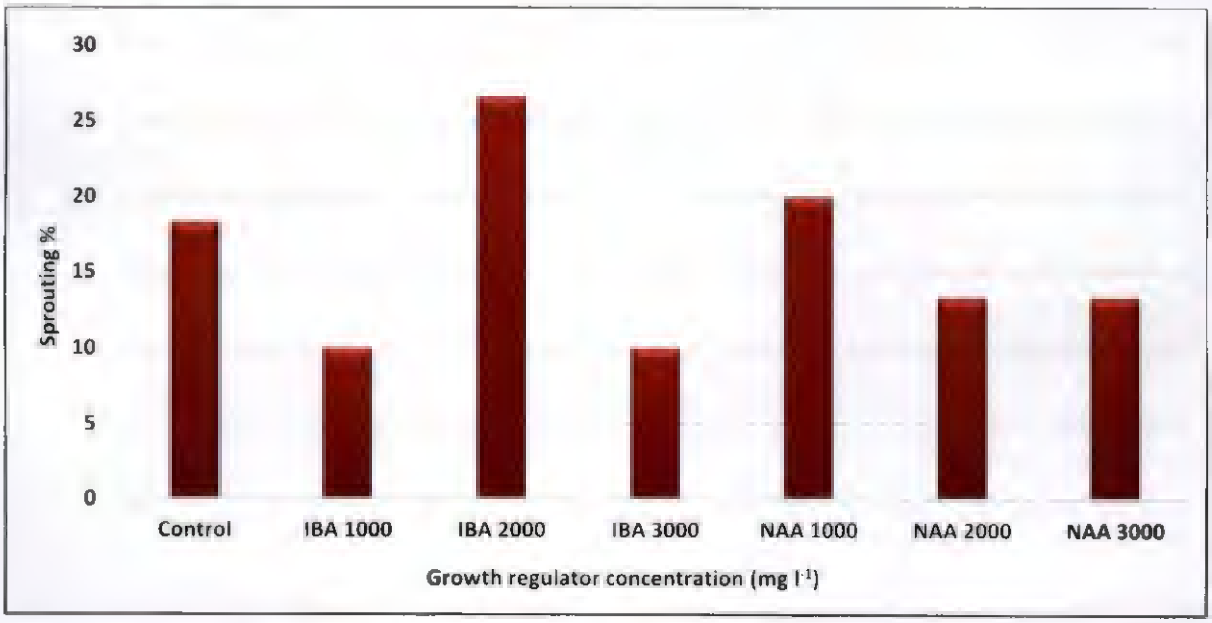

Fig.10. Sprouting percentage of *Thyrsostachys oliveri* branch cuttings as influenced by growth regulators

4.3. Experiment III

Another trial on rooting of both *B. balcooa* and *T. oliveri* was conducted in with higher concentrations of growth regulators by quick dip method and the results are given below.

4.3.1. *Bambusa balcooa*

The sprouting attributes of the *B. balcooa* branch cuttings varied among the growth regulators and their concentrations (Fig 11 and Table 12). In general, sprouting percentage was as low as 30.00%. The highest sprouting was recorded in the cuttings treated with NAA 1000 mg l^{-1} and the lowest was in those treated with IBA 2500 mg l^{-1} (6.00%). Application of IBA and NAA at higher concentrations reduced the sprouting per cent. Untreated cuttings also recorded fair sprouting. With regards to number of sprouts per node, the highest value was recorded for those treated with IBA 1500 mg l^{-1} (3.25±0.96) followed by NAA 1500 mg l^{-1} (2.20±1.10). The highest sprout height was observed in cuttings treated with IBA 2500 mg l^{-1} (15.33±1.70 cm) followed by NAA 2500 mg l^{-1} (15.45±1.06 cm) and the least was in cuttings treated with IBA 1500 mg l^{-1} (11.75±2.65 cm).

Statistical analysis of the data indicated that the sprouting percentage and sprout height of the branch cuttings did not vary significantly due to growth regulator its concentrations. The number of sprouts varied only with the type of growth regulator at one per cent significance level (appendices XVI-XVII).

Table 12. Sprouting attributes of *Bambusa balcooa* cuttings as influenced by the application of growth regulators by quick dip method

Treatment no	Growth regulator concentration (mg l^{-1})	No of sprouts/node	Sprout height (cm)
1.	Control	1.23±0.44	14.72±4.02
2.	IBA 1000	1.40±0.55	12.80±1.00
3.	IBA 1500	3.25±0.96	11.75±2.65
4.	IBA 2500	1.00±0.00	15.45±1.06
5.	NAA 1000	1.22±0.44	14.64±2.48
6.	NAA 1500	2.20±1.10	13.77±1.99
7.	NAA 2500	1.17±0.41	15.33±1.70

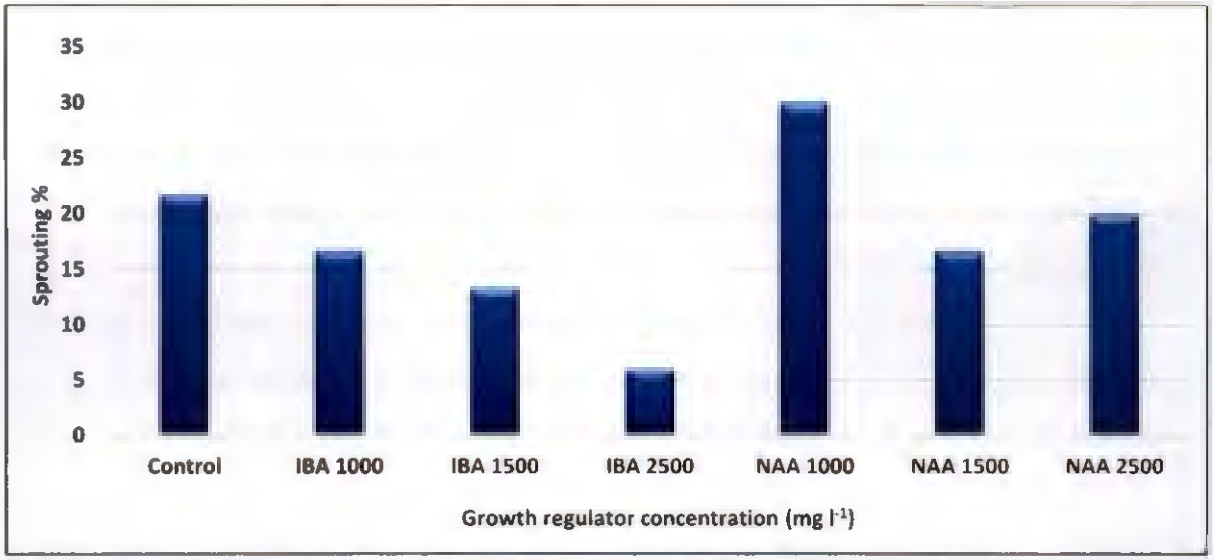

Fig. 11. Sprouting percentage of *Bambusa balcooa* cuttings as influenced by the application of growth regulators by quick dip method

4.3.2. *Thyrsostachys oliveri*

The rooting trial with quick dip method was conducted in *T. oliveri* also (Fig. 12 and Table 13). The highest sprouting was observed in cuttings treated with IBA 1000 mg l^{-1} (33.33%) followed by IBA 1500 mg l^{-1} (23.33%). the least sprouting was observed in cuttings treated with NAA 2500 mg l^{-1} (13.33%) followed by control (15.00%). The decrease in sprouting with increase in concentration of growth regulator was observed here also. The highest number of sprouts per node was observed in cuttings treated with IBA 2500 mg l^{-1} (3.00±0.82) followed by NAA 1000 mg l^{-1} (2.00±0.89). The lowest number of sprouts per node was observed in those treated with IBA 2500 mg l^{-1} and NAA 1500 mg l^{-1} (1.00±0.00). With regards to sprout height, the highest was observed in cuttings treated with IBA 2500 mg l^{-1} (13.62±1.37 cm) followed by control (13.43±1.11 cm) and the least was in cuttings treated with NAA 1500 mg l^{-1} (12.07±2.84 cm).

Analysis of variance indicated that the sprouting percentage and sprout height of the branch cuttings did not vary significantly due to growth regulator or its concentrations. The number of sprouts varied with the concentration of the growth regulators at one per cent significance level (Appendices XIX- XXI).

Table 13. Sprouting attributes of *Thyrsostachys oliveri* branch cuttings as influenced by the application of growth regulators by quick dip method

Treatment no	Growth regulator concentration (mg l^{-1})	No of sprouts/node	Sprout height (cm)
1.	Control	1.44±0.73	13.43±1.11
2.	IBA 1000	1.40±0.52	13.49±1.52
3.	IBA 1500	1.71±0.95	12.78±2.26
4.	IBA 2500	1.00±0.00	13.62±1.37
5.	NAA 1000	2.00±0.89	13.36±2.19
6.	NAA 1500	1.00±0.00	12.07±2.84
7.	NAA 2500	3.00±0.82	12.99±0.54

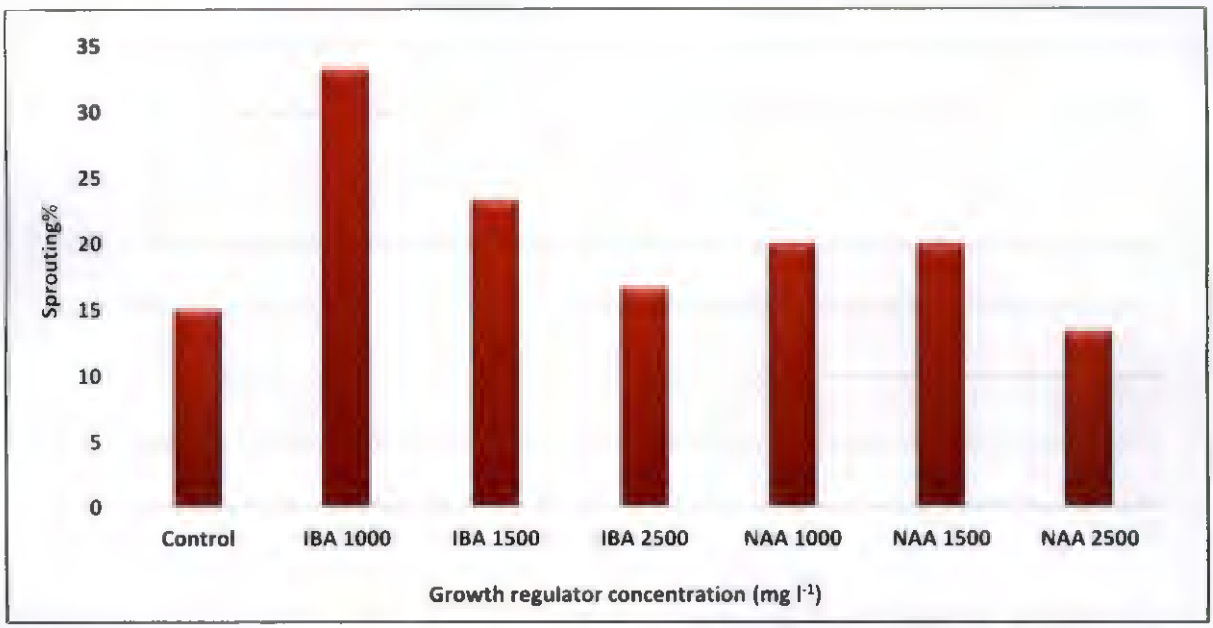

Fig. 12. Sprouting percentage of *Thyrsostachys oliveri* branch cuttings as influenced by the application of growth regulators by quick dip method

4. Experiment IV

In this experiment, rooting trial was conducted only for *Bambusa balcooa*. Observations are given in table. 14. The sprouting of cuttings in the different concentrations of growth regulators varied. Analysis of variance indicated that the sprouting percentage and sprout height of the branch cuttings did not vary significantly due to growth regular or its concentrations. The number of sprouts varied with the interaction effect of growth regulator and its concentration at five per cent significance level (Appendices XXII-XXIV). The lowest sprouting percentage was observed in cuttings treated with NAA 2000 mg l^{-1} (20.00%) and the highest sprouting was in cuttings treated with IBA 500 and IBA 1000 mg l^{-1} (40.00%) (Fig. 13). Irrespective of growth regulator, the increase in concentration decreased the sprouting of cuttings. Highest number of tillers per cutting was observed in the cuttings treated with IBA

2000 mg l^{-1} (2.14±1.35) followed by NAA 500 mg l^{-1} (2.00±1.15). However, highest sprout height (12.66±1.56 cm) was observed in cuttings treated with NAA 2000 mg l^{-1} followed by the IBA 500 mg l^{-1} (12.58±5.24 cm). Growth regulators, IBA and NAA recorded higher number of sprouts at high concentrations. Sprout height was observed highest in cuttings kept as control and those cuttings treated with NAA at higher concentrations.

Table 14. Sprouting attributes of *Bambusa balcooa* cuttings as influenced by growth regulator and its concentration.

Treatment no	Growth regulator concentration (mg l^{-1})	No of sprouts/node	Sprout height (cm)
1.	Control	1.40±0.63	12.53±3.35
2.	IBA 500	1.92±1.00	12.58±5.24
3.	IBA 1000	1.92±0.90	7.02±2.35
4.	IBA 1500	2.11±0.78	9.81±3.12
5.	IBA 2000	2.14±1.35	7.25±1.55
6.	NAA 500	2.00±1.15	9.27±3.79
7.	NAA 1000	1.50±0.76	12.13±5.19
8.	NAA 1500	1.25±0.46	12.01±3.66
9.	NAA 2000	2.00±0.89	12.66±1.56

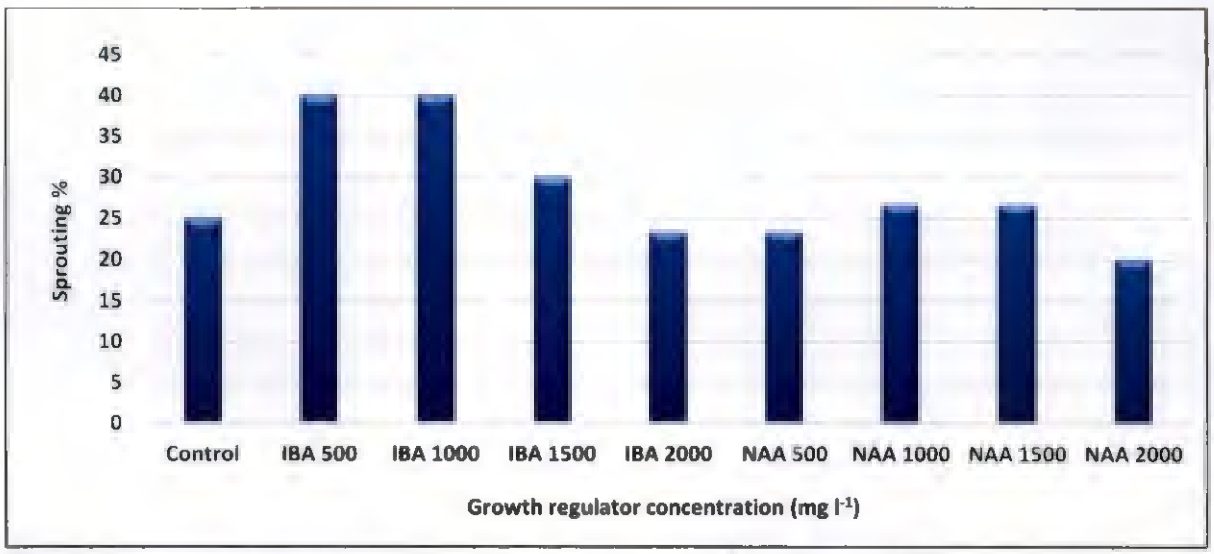

Fig.13. Sprouting percentage of *Bambusa balcooa* branch cuttings as influenced by the application of growth regulators by solution method

DISCUSSION

5. DISCUSSION

The present study focuses on the influence of collection season, rooting media, growth regulating substances and concentration on root induction of branch cuttings of the species *Bambusa balcooa, Dendrocalamus giganteus, Thyrsostachys oliveri.* The results of the study are discussed here.

Bambusa balcooa is a sturdy non-thorny bamboo species with multifarious utility preferred by farmers of Kerala. The rooting trials in this species were conducted during October 2015 to June 2016. The main trial was to find out the rooting response of branch cuttings to the collection seasons, rooting media and growth regulator application. There were two media sand and mixture of sand, soil and cow dung (1:1:1), two growth regulators IBA and NAA in concentrations 0-1000 mg l^{-1}. The rooting trials were conducted in three seasons. Although, the cuttings produced sufficient number of sprouts in all the seasons, rooting was absent in all the treatment combinations. During the trial, it was observed that branch cutting subjected to different treatment combinations started sprouting after first week and within one month the sprouts died without producing the roots. In *B. balcooa*, the untreated cuttings also produced fairly good sprouting. The branch cuttings treated during the Season II (February to May) retained the sprouts for more time, nearly four months but finally they failed to root and died. The interaction effects of season x media x growth regulator x concentration were not significant in sprouting parameters of this species. Hence, the individual effect of season, media, growth regulator and concentration is given in the Fig. 14 - 17

The sprouting of branch cuttings in this species was highest during the season II (February to May) followed by season III and the least was recorded during season I. The season II (February to May) is considered as the good season for propagation of the bamboo species (Raveendran *et al.*, 2010 a). Gulabaro *et al.* (2012) reported that the bamboo species exhibited differential rhizogenesis behavior in different seasons. In *B. balcooa* spring season emerged as best with regard to sprouting and rooting parameters. The environmental conditions during collection like light, temperature, humidity, rainfall plays a significant role in root induction of cuttings (Bunce, 1984; Karaguzel, 1997) which may be related to endogenous plant growth regulator levels or carbohydrates (Day and Loveys, 1998). Harrison-Murraya (1991) indicated the importance of seasonal timing, or the period of the year in which cuttings are taken in rooting of cutting. Blazich (1987) reported that time of year when cuttings are taken is an important factor influencing rooting of woody plants from stem cuttings and the influence is

attributed to the changes in the temperature, light and humidity conditions, which prevail at the time of collection and planting of cuttings. The media containing mixture of sand, soil and cowdung in the ratio 1:1:1 emerged as the better media for sprouting of branch cuttings and NAA was better in sprouting performance compared to IBA. The physiology of auxin action had indicated that auxin was involved in plant activities such as stem growth, adventitious root formation (Went, 1934; Haissig and Davis, 1994). Zimmerman and Wilcoxon (1935) showed that the synthetic auxins like IBA and NAA were more effective than the naturally occurring or synthetic IAA for rooting. Nowadays, IBA and NAA are the most widely used auxins for rooting stem cuttings. It has been confirmed that auxin is required for adventitious root initiation on stems, and indeed, it has been shown that divisions of the first root initial cells are dependent upon either applied or endogenous auxins (Stromquist and Hansen, 1980; Gaspar and Hofinger, 1988).

Among the different concentrations, sprouting was the highest in lower concentrations of growth regulating substances and decreased with increasing concentrations. However, there was slight increase in the sprouting per cent at 1000 mg l^{-1} (Fig. 17). With regards to sprouting, it was observed that the cuttings treated with higher concentrations of growth regulating substances produced lesser per cent of sprouts. In most of the seasons and in different rooting media there was an increase in the sprouting percentage from control to medium concentration but at higher concentrations like 1000 mgl^{-1} the sprouting was nominal. This can be attributed to the inhibitory effect of auxins at higher concentrations. The high auxin application is reported to produce toxicity and NAA is more toxic than IBA (Zeng and Lu 1988).

The first trial revealed that the sprouting percentage was fairly good in this species. The sprouting ranged from 1.67 to 48.33% and the highest sprouting was observed in branch cuttings collected during season II kept in the sand. The lowest sprouting was observed in branch cuttings collected during season I kept in the medium containing the mixture of sand, soil and cow dung in the ratio 1:1:1, which was treated with IBA 500. The season I coincides with the South west monsoon in Kerala and the sprouting and rooting of cuttings is mostly poor in this season.

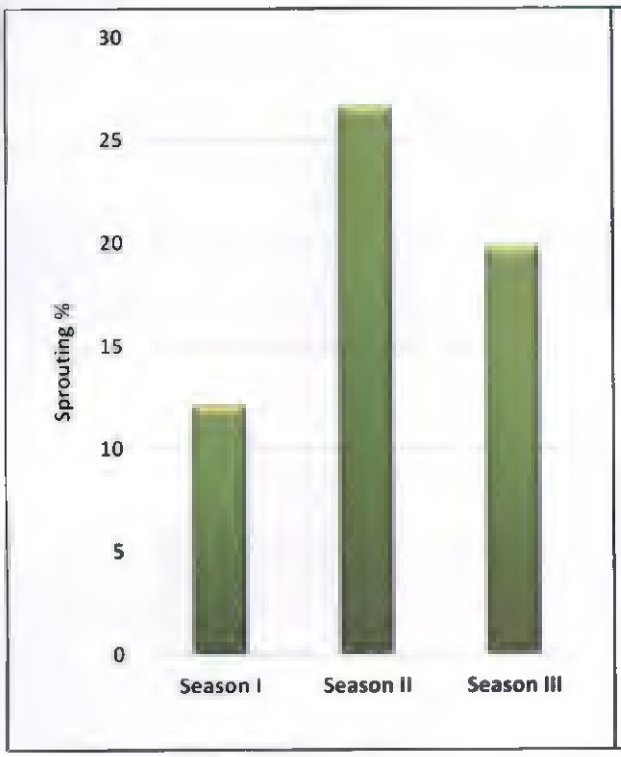

Fig. 14. Effect of season on sprouting per cent of *Bambusa balcooa*

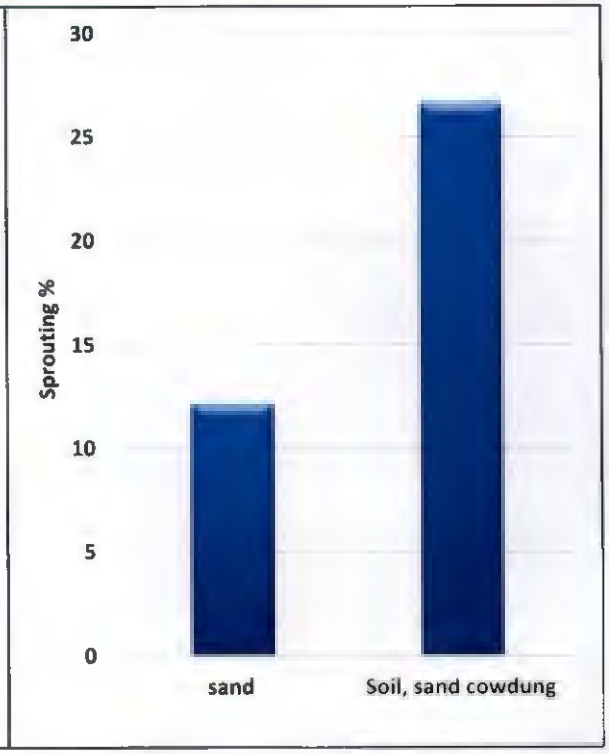

Fig. 15. Effect of rooting media on sprouting per cent of *Bambusa balcooa*

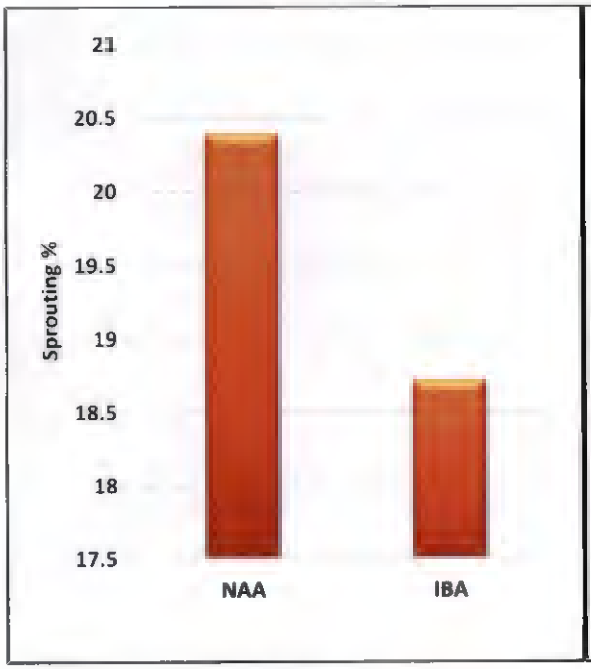

Fig. 16. Effect of growth regulators on sprouting per cent of *Bambusa balcooa*

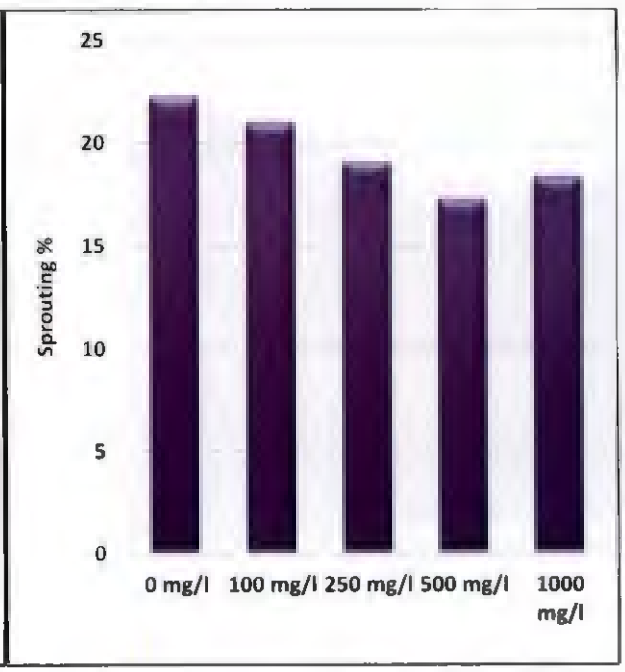

Fig. 17. Effect of concentrations on sprouting per cent of *Bambusa balcooa*

Seethalakshmi *et al.* (2008) had reported that be bamboo species with prominent primary branches from the base of the culm like *Bambusa balcooa*, *B. vulgaris* are more suitable for the propagation through branch cuttings. However, the studies on rooting of *B. balcooa* branch cuttings are scarce. Most of them are confined to easy rooting species *B. vulgaris* (Razvi and Nautiyal, 2009; Islam *et al.*, 2011; Bhol and Parida, 2015). Surendran and Seethalakshmi (1985) had reported a rooting of around 40 per cent in *B. balcooa* branch cuttings and horizontal planting of the cuttings had given better results but the detailed methodology is lacking in this report. Pattanaik *et al.* (2004) also tried rooting of two noded branch cuttings of *Bambusa balcooa* with rhizomatous swelling, treated with 200 ppm indole-3-butyric acid, gave 66.7% success in rooting and rhizome formation. However, in the present study this type of cuttings was not present. Inducing rhizomatous cuttings could have improved the rooting performance in the present study.

As the rooting was absent in the main trial, further experiment was conducted with higher concentrations (0, 1000, 2000 and 3000 mg l^{-1}) of growth regulator (NAA and IBA) and the application method was soaking in the solution for 24 hours. The rationales for selecting higher concentrations was to seek the possibility of rooting at higher concentrations. Although at higher concentrations the sprouting decreased, still there was possibility of rooting. The maximum sprouting was observed in cuttings treated with IBA 1000 mg l^{-1} (36.66%) and the least sprouting was in those treated with NAA 1000 mg l^{-1} (10.00%). The cuttings kept as control also produced fairly good sprouting. There was decrease in sprouting with increase in concentration of growth regulators. Hence, it can be concluded that the increasing growth regulator concentrations have a negative effect on sprouting these species. Due to failure in rooting another trial was conducted with IBA and NAA by quick dip method, the concentrations were 0, 1000, 1500 and 2500 mg l^{-1}. The quick dip method is found to be more effective in rooting of cuttings. The sprouting percentage was as low (30.00%) in this trial compared to other trials. The highest sprouting was recorded in the cuttings treated with NAA 1000 mg l^{-1} and the lowest was in those treated with IBA 2500 mg l^{-1} (6.00%). IBA at higher concentration decreased the sprouting whereas NAA 2500 mg l^{-1} produced fairly good sprouting.

Final trials on *B. balcooa* branch cuttings with IBA and NAA solutions of different concentrations (0, 500, 1000, 1500 and 2000 mg l^{-1}) in the seedbed also do not produce roots. The lowest sprouting percentage was observed in cuttings treated with NAA 2000 mg l^{-1} (20.00

%) and the highest sprouting was in cuttings treated with IBA 500 and IBA 1000 mg l^{-1} (40.00 %). Irrespective of growth regulator, the increase in concentration decreased the sprouting of cuttings.

The rooting trial of *D. giganteus* was constrained by the availability of branch cuttings and hence the trials were conducted for two seasons only. Flowering of *D. giganteus* is reported for the first time from Kerala by Seethalakshmi *et al.* (2010) in Kottayam. The synchronous flowering in other cohorts also occurred during the study period. The study indicated that the sprouting in *D. giganteus* branch cutting was poor and ranged from 5.00 to 43.3%. The highest sprouting percentage was observed in cuttings treated with NAA 500 mg l^{-1} kept in the second media. From the estimated marginal means it was obvious that Season II was the best to induce sprouting, the media containing sand, soil and cow dung was superior over sand, IBA was slightly more effective compared to NAA and there was increase in the sprouting with increasing in concentration of growth regulator up to 250 mg l^{-1} and higher concentrations reduced sprouting (Fig.18-21)

Seethalakshmi *et al.* (2008) had reported that the rooting of branch cuttings is difficult in species which produce branches in top portion. However recent studies indicated success of rooting in branch cuttings of *D. giganteus*. Nautyal *et al.* (2007) reported that the rooting response of untreated branch cuttings of *D. giganteus* was 80 per cent indicating this species does not require any growth regulator treatment. Razvi *et al.* (2015) reported maximum of 63.33 per cent rooting recorded in untreated cuttings in rainy season. Razvi *et al.,* (2017) also attempted rooting of *Dendrocalamus giganteus* under natural conditions. Maximum (40.42%) rooting percentage was recorded in untreated cuttings that is control with (1.90) number of roots and (18.67 cm) root height followed by the cutting as treated with IBA 500 ppm with (37.71%), (1.79) number of roots and (19.45 cm) root height. However, in the present study the cuttings did not root even those kept as control.

Thyrsostachys oliveri is an elegant bamboo species preferred by the most of the farmers in Kerala (Sharma *et al.*, 2004). It did not respond positively to most of the vegetative propagation method. Here, in this trial also the rooting was absent in branch cuttings. In the main trial, the sprouting percentage was lower in this species and it ranged from 0 to 23.33%. The highest sprouting was observed in branch cuttings collected during season II kept in the medium containing sand, soil and cow dung in the ratio 1:1:1 without any growth regulator treatment. From the estimated marginal means it was clear that season III was superior to other

seasons, sand was the better media, NAA was better compared to IBA and increase in the concentration of the growth regulator decreased the sprouting. In a study conducted by Ray and Ali (2016) in *B. balcooa*, coarse sand was shown to be the most economic and easily accessible bedding material for macro propagation followed by the mixture of coarse sand: soil. Similarly, BTSG KFRI (2014) also reports that sand is considered to be the best medium to be filled up in raised beds for getting maximum rooting from culm or branch cuttings in the North-eastern region of India. There was not much variation in the number and height of the sprouts produced by different treatment combination.

As first rooting trial does not yield any rooting in branch cuttings, another trial was conducted with higher concentrations *viz.* 0, 1000, 2000 and 3000 mg l^{-1} of NAA and IBA and application method was soaking in the solution for 24 hours. Of the different concentrations of IBA and NAA used highest sprouting was observed in cuttings treated with IBA 1000 mg l^{-1} (26.66%) and those treated with IBA 3000 mg l^{-1} recorded the lowest sprouting percentage (10.00%). Here also with some exceptions the sprouting decreased with increase in growth regulator concentration indicating an inhibitory effect on sprouting. Adventitious root formation was absent in this trial also. Due to failure in rooting another trial was conducted with IBA and NAA by quick dip method, the concentrations were 0, 1000, 1500 and 2500 mg. l^{-1}. The highest sprouting was observed in cuttings treated with IBA 1000 mg l^{-1} (33.33 %) followed by IBA 1500 mg l^{-1} (23.33 %) and the least sprouting was observed in cuttings treated with NAA 2500 mg l^{-1} (13.33 %) followed by control (15.00%). The decrease in sprouting with increase in concentration of growth regulator was obvious here also. Studies on rooting of *T. oliveri* by branch cuttings are scarce and even other methods also did not yield root. Seethalakshmi (1998) had reported the rooting in the culm cuttings of this species.

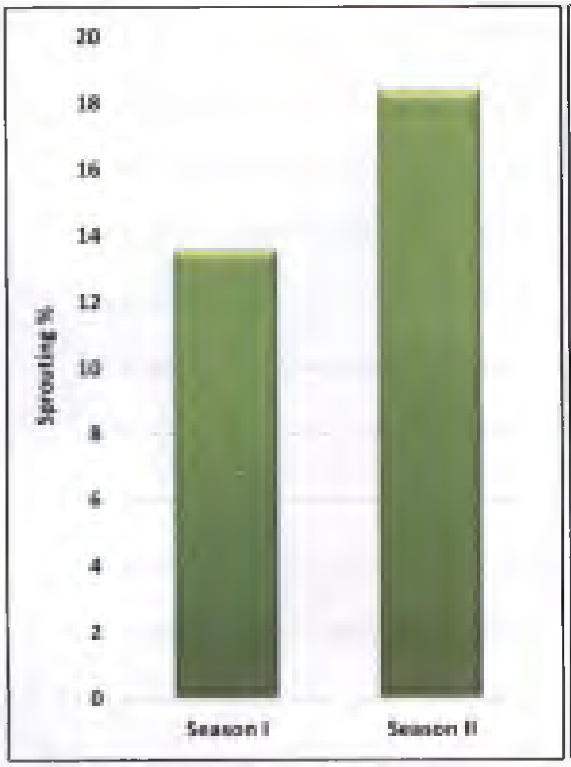

Fig. 18. Effect of season on sprouting per cent of *Dendrocalamus giganteus*

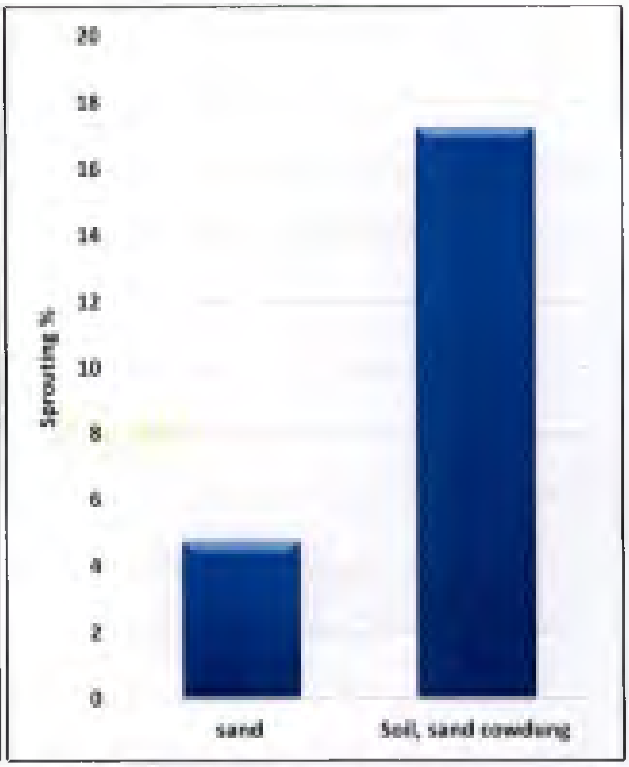

Fig. 19. Effect of growing media on sprouting per cent of *Dendrocalamus giganteus*

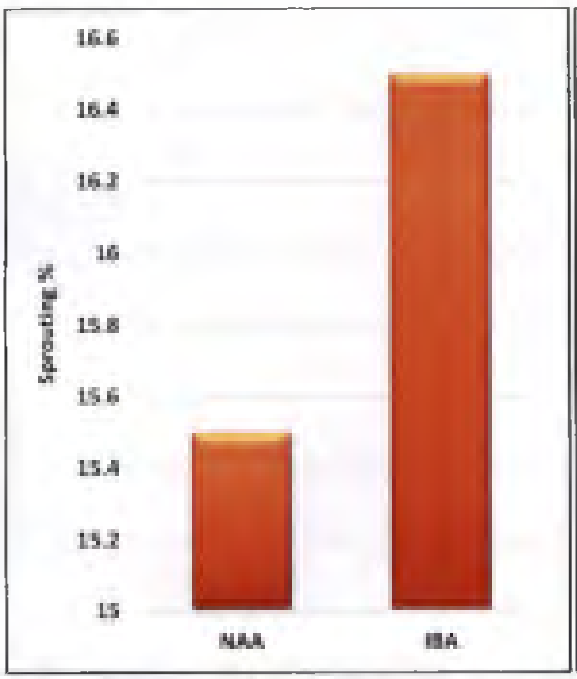

Fig.20. Effect of growth regulators on sprouting per cent of *Dendrocalamus giganteus*

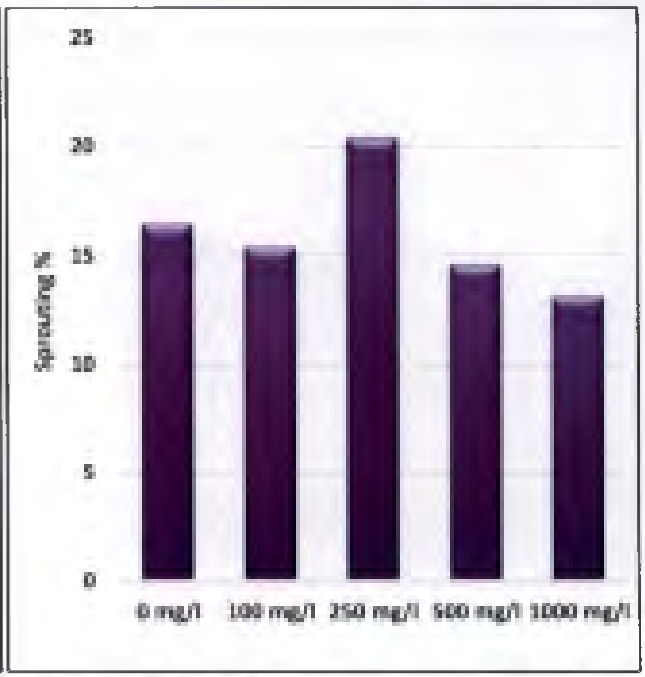

Fig. 21. Effect of concentrations on sprouting per cent of *Dendrocalamus giganteus*

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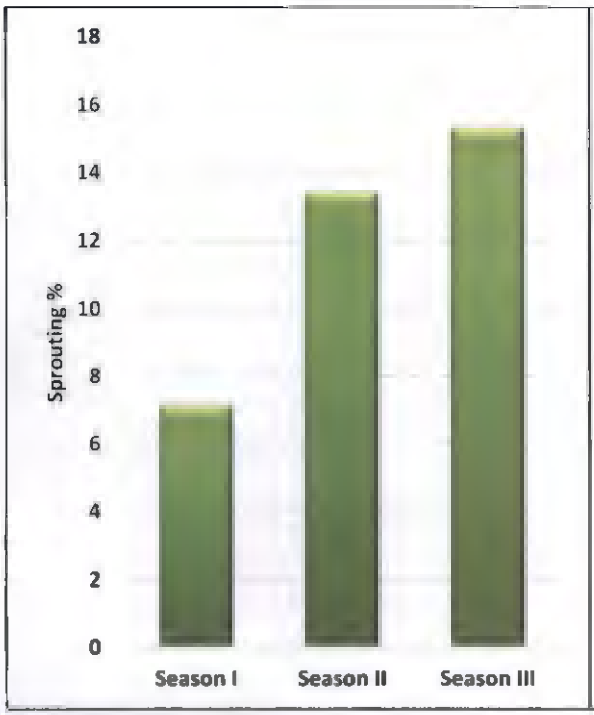

Fig.22. Effect of season on sprouting per cent of *Thyrsostachys oliveri*

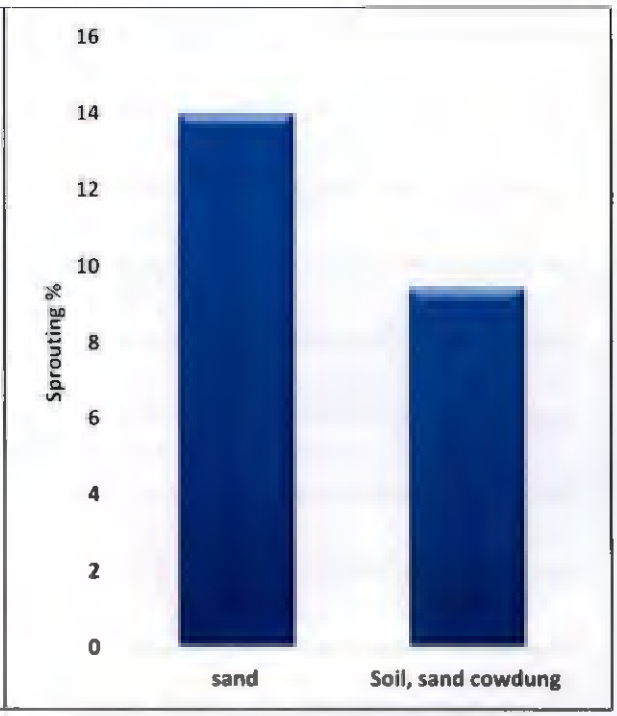

Fig.23. Effect of rooting media on sprouting per cent of *Thyrsostachys oliveri*

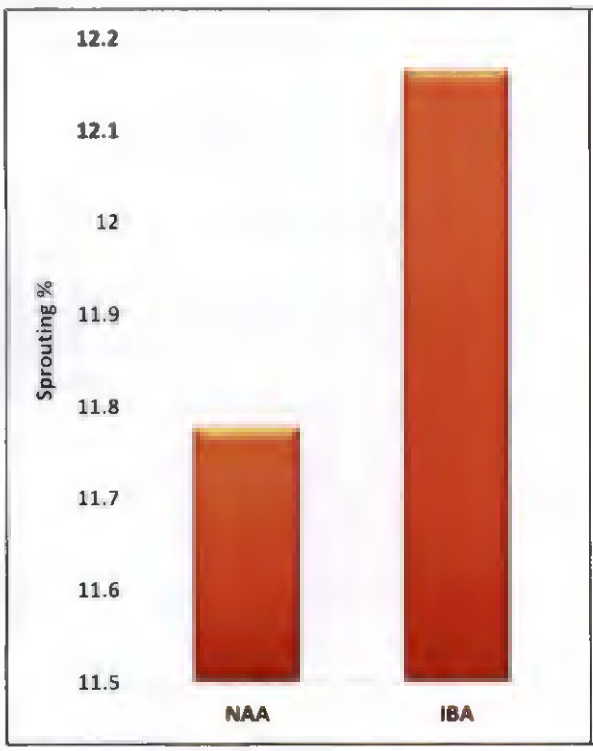

Fig.24. Effect of growth regulators on sprouting per cent of *Thyrsostachys oliveri*

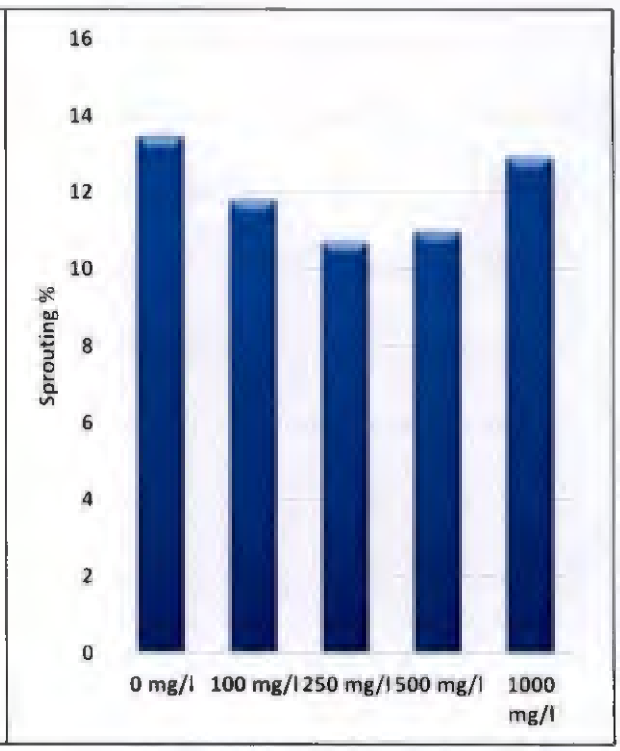

Fig. 25. Effect of concentration on sprouting per cent of *Thyrsostachys oliveri*

From the main trials on rooting of branch cuttings it can be observed that season II was the best to obtain a greater sprouting in *B. balcooa* and *D. giganteus* whereas the sprouting was higher during season III in *T. oliveri*. The medium containing, sand soil and cow dung was the best for sprouting in the *B. balcooa* and *D. giganteus* whereas sand alone was the better in sprouting of *T. oliveri* branch cuttings. NAA was effective in sprouting of *B. balcooa* whereas IBA was more effective in sprouting of *D. giganteus* and *T. oliveri*. In general, the sprouting of cuttings decreased with increasing concentration in all bamboo species.

The present study was unsuccessful in inducing adventitious rhizogenesis in the three selected bamboo species. The attempt was to produce the planting stock through branch cuttings under natural conditions. There are only a few studies on branch propagation conducted under natural condition for example Razvi *et al.,* (2017). Other studies were either conducted in green houses or mist chambers in order to get maximum rooting and the attempts were made in open conditions so that it may become a farmer friendly way to propagate bamboos and cost effective. Hence, further trials need to be conducted at more controlled conditions. The season of collection also played a role in the sprouting of cuttings. But the monthly variation in sprouting and rooting of cuttings needs to be recorded for all species. Although species specific variations are obvious, standardization at monthly intervals will be more effective. Further, the selection of cuttings plays great role in the successful vegetative propagation (Kaushal *et al.*, 2011). In the present study, the primary branches were selected for root induction. However, there are many factors to be considered while selecting the cuttings like the age of the clumps, in our study the primary branches were collected from the over mature as well as mature culms. Although the collection of branch cuttings was restricted to 2-3-year-old culms in our study the other aged culms need to be tried. The studies on the influence of clump age need to be under taken in future. The rhizomatous cuttings are reported to perform better in most of the studies hence the possibility of uses of the rooted branches is to be considered. There is dare need to standardize the diameter of the branch cuttings which vary with age of the clump. In our study, due to shortage of material, the branch cuttings of several diameter were used. In the present study, the thick branches produced sprouts with a higher height. The position of the branch cuttings can also play an important role in the success of rooting and hence the branches from different culm positions like base, middle and top need to be tested for rooting efficacy. The availability of cuttings from the nearest sources was one of the constraints in our study. Although cuttings were carefully taken to college with most care

without losing moisture content by keeping in gunny bags availability of fresh cuttings might have enhanced the rooting.

In the present study, different concentrations of growth regulating substances were tried in solution and quick dip method. But the rooting was not obtained. There are reports on rooting of the cuttings even in untreated cuttings which were superior to treated cuttings. Although we tried rooting trials at lower concentrations the study at different lower concentrations like 50, 100, 150, 200 mg l^{-1} can be carried out.

SUMMARY

6. SUMMARY

Present study entitled "Standardization of propagation through branch cuttings in selected bamboo species of Kerala" was conducted at College of Forestry, Kerala Agricultural University, Thrissur, Kerala. The species selected for the present study were *Bambusa balcooa, Dendrocalamus giganteus and Thyrsostachys oliveri*. The primary branches of each species were collected during three periods *viz.* October to January, February to May and June to September from bamboo plantations located in Thrissur. The two noded branch cuttings were prepared out of this and subjected to growth regulator treatment at different concentrations and planted horizontally in two media *viz.* sand and mixture of sand, soil and cow dung in the ration 1:1:1. As the rooting was absent in the main trial other trials with branch cuttings also were conducted. The salient findings of the study are as follows.

Rooting trial of *B. balcooa* branch cuttings in response to season, rooting media and growth regulator and its concentrations indicated that root induction was not possible in this species with the present frame work of study. However, sprouting attributes of the species varied due to treatment combinations. The sprouting percentage was good in this species and it ranged from 1.67 to 48.33%. The highest sprouting was observed in branch cuttings collected during season II (February to May) treated with NAA 250 mg l^{-1} kept in the sand. The lowest sprouting was observed in branch cuttings collected during October to January kept in the medium containing the mixture sand, soil and cow dung in the ratio 1:1:1, which was treated with IBA 500 mg l^{-1}. There was no definite trend in variation with regards to number and height of sprouts due to treatments.

Three more trials were conducted in *B. balcooa* to check the possibility of rooting in branch cuttings. One trial was with higher concentrations (0, 1000, 2000 and 3000 mg l^{-1}) of growth regulators (NAA and IBA) and the method of application was soaking the branch cuttings in the solution for 24 hours and the medium used was the sand. The maximum sprouting was observed in cuttings treated with IBA 1000 mg l^{-1} (36.66%) and the least was in those treated with NAA 1000 mg l^{-1} (10.00%). The number of sprouts produced per node was the highest in control (1.57±0.65%) and the lowest was in those treated with NAA 3000 mgl^{-1}(1.00). The highest sprout height was observed in those treated with NAA1000 mgl^{-1}(15.30±3.36cm) and the lowest sprout height was in control (12.50±2.97). Another trial was conducted with IBA and NAA by quick dip method, the concentrations used were 0, 1000, 1500 and 2500 mg l^{-1} and the cuttings were planted in sand medium. sprouting percentage was

as low as 30.00 per cent. The highest sprouting was recorded in the cuttings treated with NAA 1000 mg l^{-1} and the lowest was in those treated with IBA 2500 mg l^{-1} (6.00%). The highest number of sprouts per node was recorded for branch cuttings treated with IBA 1500 mg l^{-1} (3.25±0.96) followed by NAA 1500 mg l^{-1} (2.20±1.10). A higher sprout height was observed in cuttings treated with IBA 2500 mg l^{-1} (15.33±1.70 cm) followed by NAA 2500 mg l^{-1} (15.45±1.06 cm) and the least was in cuttings treated with IBA 1500 mg l^{-1} (11.75±2.65 cm). The last experiment was conducted on standard nursery beds with IBA and NAA solutions of different concentrations (0, 500, 1000, 1500 and 2000 mg l^{-1}) and here also the cuttings failed to initiate rooting. The lowest sprouting percentage was observed in cuttings treated with NAA 2000 mg l^{-1} (20.00 %) and the highest sprouting was in cuttings treated with IBA 500 and IBA 1000 mg l^{-1} (40 %). Highest number of sprouts per node was observed in the cuttings treated with IBA 2000 mg l^{-1} (2.14±1.35) followed by NAA 500 mg l^{-1}(2.00±1.15). However, highest sprout height (12.66±1.56 cm) was observed in cuttings treated with NAA 2000 mg l^{-1} followed by the IBA 500 mg l^{-1}(12.58±5.24 cm).

Studies on adventitious root induction in *Dendrocalamus giganteus* branch cuttings in response to season, rooting media and growth regulator and its concentrations also indicated that rooting was absent in this species. Sprouting in the branch cuttings in different treatments ranged from 5.00 to 43.3%. The highest sprouting percentage was observed in cuttings treated with NAA 500 mg l^{-1} kept in the second media and the least was in those in control of NAA (5.00%) which was kept in sand. The number and height of sprouts did not show any definite trend in variation due to treatments.

The experiment to initiate rooting in *Thyrsostachys oliveri* cuttings in different seasons, rooting media and growth regulator concentrations also was a failure. The maximum sprouting was observed in cuttings treated with IBA 100 mg l^{-1} third season (41.67%) kept in the sand and the least was in those treated with NAA 250 mg l^{-1} (0.00%). The number and height of the sprouts produced did not show any trend with regards to different treatments. In the treatment with higher growth regulator solution, highest sprouting was observed in cuttings treated with IBA 1000 mg l^{-1} (26.66%) and those treated with IBA 3000 mg l^{-1} recorded the lowest sprouting percentage (10%).The number of sprouts ranged from 2.50±1.00 to 1.33±0.82 and the highest was in cuttings treated with IBA 2000 mg l^{-1} and the lowest in IBA 3000 mg l^{-1}. Average sprout height was the highest in cuttings kept as control (13.71±2.82 cm) and the lowest was recorded in the cuttings treated with IBA 1000 mg l^{-1} (11.52±1.55 cm). Whereas, in the treatment of

growth regulators with quick dip method highest sprouting was observed in cuttings treated with IBA 1000 mg l^{-1} (33.33 %) followed by IBA 1500 mg l^{-1} (23.33 %). the least sprouting was observed in cuttings treated with NAA 2500 mg l^{-1} (13.33 %) followed by control (15%). The number of sprouts per node was highest in cuttings treated with IBA 2500 mg l^{-1} (3.00±0.82) followed by NAA 1000 mg l^{-1} (2.00±0.89). The lowest number of sprouts was observed in those treated with IBA 2500 mg l^{-1} and NAA 1500 mg l^{-1} (1.00±0.00). With regards to height of sprouts, the highest height was observed in cuttings treated with IBA 2500 mg l^{-1} (13.62±1.37 cm) followed by control (13.43±1.11cm) and the least was in cuttings treated with NAA 1500 mg l^{-1} (12.07±2.84 cm).

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APPENDIX

Appendix I

Abstracts of ANOVA for the sprouting percentage of *Bambusa balcooa* branch cuttings as influenced by season, rooting media, growth regulator and concentration

Source	df	Mean Square	F	Sig.
Season	2	3157.22	28.74	0.00
Media	1	3555.56	32.36	0.00
Growth regulator	1	125.00	1.14	0.29
Concentration	4	147.01	1.34	0.26
Season * Media	2	493.89	4.50	0.01
Season * Growthregulator	2	26.67	0.24	0.79
Season * Concentration	8	93.68	0.85	0.56
Media * Growth regulator	1	1227.22	11.17	0.00
Media * Concentration	4	130.90	1.19	0.32
Growth regulator * Concentration	4	28.82	0.26	0.90
Season * Media * Growth regulator	2	348.89	3.18	0.05
Season * Media * Concentration	8	33.82	0.31	0.96
Season * Growth Regulator * Concentration	8	210.69	1.92	0.06
Media * Growth Regulator * Concentration	4	67.15	0.61	0.66
Season * Media * Growth regulator * Concentration	8	133.61	1.22	0.30
Error	120	109.86		

Appendix II

Abstracts of ANOVA for the number of sprouts of *Bambusa balcooa* branch cuttings as influenced by season, rooting media, growth regulator and concentration

Source	df	Mean Square	F	Sig.
Season	2	0.49	1.85	0.16
Media	1	0.24	0.92	0.34
Growth regulator	1	0.67	2.51	0.12
Concentration	4	0.11	0.40	0.81
Season * Media	2	0.23	0.85	0.43
Season * Growth regulator	2	0.15	0.55	0.58
Season * Concentration	8	0.31	1.18	0.31
Media * Growth regulator	1	1.50	5.66	0.02
Media * Concentration	4	0.14	0.52	0.72
Growth regulator * Concentration	4	0.40	1.52	0.20
Season * Media * Growth regulator	2	0.68	2.55	0.08
Season * Media * Concentration	8	0.23	0.85	0.56
Season * Growth Regulator * Concentration	8	0.21	0.79	0.61
Media * Growth Regulator * Concentration	4	0.06	0.23	0.92
Season * Media * Growth regulator * Concentration	8	0.25	0.96	0.47
Error	120	0.27		

Appendix III

Abstracts of ANOVA for the sprout length of *Bambusa balcooa* branch cuttings as influenced by season, rooting media, growth regulator and concentration

Source	df	Mean Square	F	Sig.
Season	2	10.97	0.57	0.57
Media	1	40.27	2.09	0.15
Growth regulator	1	41.53	2.16	0.14
Concentration	4	18.02	0.94	0.45
Season * Media	2	11.73	0.61	0.55
Season * Growth regulator	2	10.25	0.53	0.59
Season * Concentration	8	25.84	1.34	0.23
Media * Growth regulator	1	118.23	6.15	0.02
Media * Concentration	4	22.88	1.19	0.32
Growth regulator * Concentration	4	6.33	0.33	0.86
Season * Media * Growth regulator	2	43.87	2.28	0.11
Season * Media * Concentration	8	22.96	1.19	0.31
Season * Growth Regulator * Concentration	8	9.44	0.49	0.86
Media * Growth Regulator * Concentration	4	3.70	0.19	0.94
Season * Media * Growth regulator * Concentration	8	25.74	1.34	0.23
Error	120	19.23		

Appendix IV

Abstracts of ANOVA for the sprouting percentage of *Dendrocalamus giganteus* branch cuttings as influenced by season, rooting media, growth regulator and concentration

Source	df	Mean Square	F	Sig.
Season	1	700.83	9.92	0.00
Media	1	187.50	2.66	0.11
Growth regulator	1	30.00	0.43	0.52
Concentration	4	181.98	2.58	0.04
Season * Media	1	1920.00	27.19	0.00
Season * Growth regulator	1	187.50	2.66	0.11
Season * Concentration	4	243.02	3.44	0.01
Media * Growth regulator	1	67.50	0.96	0.33
Media * Concentration	4	90.10	1.28	0.29
Growth regulator * Concentration	4	76.35	1.08	0.37
Season * Media * Growth regulator	1	3.33	0.05	0.83
Season * Media * Concentration	4	77.81	1.10	0.36
Season * Growth Regulator * Concentration	4	224.48	3.18	0.02
Media * Growth Regulator * Concentration	4	29.48	0.42	0.80
Season * Media * Growth regulator * Concentration	4	60.10	0.85	0.50
Error	80	70.63		

Appendix V

Abstracts of ANOVA for the number of sprouts per node of *Dendrocalamus giganteus* branch cuttings as influenced by season, rooting media, growth regulator and concentration

Source	df	Mean Square	F	Sig.
Season	1	0.07	0.29	0.59
Media	1	0.01	0.03	0.86
Growth regulator	1	0.12	0.49	0.49
Concentration	4	0.33	1.36	0.26
Season * Media	1	0.16	0.64	0.43
Season * Growth regulator	1	1.29	5.33	0.02
Season * Concentration	4	0.24	1.00	0.42
Media * Growth regulator	1	0.61	2.51	0.12
Media * Concentration	4	0.21	0.86	0.49
Growth regulator * Concentration	4	0.39	1.61	0.18
Season * Media * Growth regulator	1	0.52	2.17	0.15
Season * Media * Concentration	4	0.84	3.46	0.01
Season * Growth Regulator * Concentration	4	0.40	1.66	0.17
Media * Growth Regulator * Concentration	4	0.37	1.54	0.20
Season * Media * Growth regulator * Concentration	4	0.20	0.83	0.51
Error	80	0.24		

Appendix VI

Abstracts of ANOVA for the sprout length of *Dendrocalamus giganteus* branch cuttings as influenced by season, rooting media, growth regulator and concentration

Source	df	Mean Square	F	Sig.
Season	1	1157.17	58.93	0.00
Media	1	29.44	1.50	0.22
Growth regulator	1	5.30	0.27	0.61
Concentration	4	50.48	2.57	0.04
Season * Media	1	2.52	0.13	0.72
Season * Growth regulator	1	377.58	19.23	0.00
Season * Concentration	4	26.93	1.37	0.25
Media * Growth regulator	1	109.79	5.59	0.02
Media * Concentration	4	38.37	1.95	0.11
Growth regulator * Concentration	4	17.07	0.87	0.49
Season * Media * Growth regulator	1	79.41	4.04	0.05
Season * Media * Concentration	4	39.50	2.01	0.10
Season * Growth Regulator * Concentration	4	67.40	3.43	0.01
Media * Growth Regulator * Concentration	4	16.26	0.83	0.51
Season * Media * Growth regulator * Concentration	4	20.82	1.06	0.38
Error	80	19.64		

Appendix VII

Abstracts of ANOVA for the sprouting percentage of *Thyrsostachys oliveri* branch cuttings as influenced by season, rooting media, growth regulator and concentration

Source	df	Mean Square	F	Sig.
Season	2	1094.31	13.90	0.00
Media	1	740.14	9.40	0.00
Growth regulator	1	6.81	0.09	0.77
Concentration	4	52.22	0.66	0.62
Season * Media	2	350.97	4.46	0.01
Season * Growth regulator	2	4.31	0.06	0.95
Season * Concentration	8	68.26	0.87	0.55
Media * Growth regulator	1	23.47	0.30	0.59
Media * Concentration	4	281.11	3.57	0.01
Growth regulator * Concentration	4	176.94	2.25	0.07
Season * Media * Growth regulator	2	2.64	0.03	0.97
Season * Media * Concentration	8	52.36	0.67	0.72
Season * Growth Regulator * Concentration	8	197.36	2.51	0.02
Media * Growth Regulator * Concentration	4	238.06	3.02	0.02
Season * Media * Growth regulator * Concentration	8	76.60	0.97	0.46
Error	120	78.75		

Appendix VIII

Abstracts of ANOVA for the number of sprouts per node of *Thyrsostachys oliveri* branch cuttings as influenced by season, rooting media, growth regulator and concentration

Source	df	Mean Square	F
Season	2	33.99	1.72
Media	1	32.74	1.66
Growth regulator	1	0.37	0.02
Concentration	4	4.57	0.23
Season * Media	2	95.57	4.84
Season * Growth regulator	2	17.00	0.86
Season * Concentration	8	49.39	2.50
Media * Growth regulator	1	17.63	0.89
Media * Concentration	4	103.50	5.25
Growth regulator * Concentration	4	46.80	2.37
Season * Media * Growth regulator	2	25.67	1.30
Season * Media * Concentration	8	31.60	1.60
Season * Growth Regulator * Concentration	8	41.97	2.13
Media * Growth Regulator * Concentration	4	38.73	1.96
Season * Media * Growth regulator * Concentration	8	32.09	1.63
Error	120	19.73	

Appendix IX

Abstracts of ANOVA for the sprout length of *Thyrsostachys oliveri* branch cuttings as influenced by season, rooting media, growth regulator and concentration

Source	df	Mean Square	F
Season	2	6.69	16.62
Media	1	0.16	0.39
Growth regulator	1	0.01	0.02
Concentration	4	0.63	1.57
Season * Media	2	2.60	6.45
Season * Growth regulator	2	0.02	0.04
Season * Concentration	8	1.39	3.45
Media * Growth regulator	1	0.17	0.42
Media * Concentration	4	1.66	4.11
Growth regulator * Concentration	4	1.13	2.81
Season * Media * Growth regulator	2	0.37	0.92
Season * Media * Concentration	8	0.82	2.03
Season * Growth Regulator * Concentration	8	0.77	1.91
Media * Growth Regulator * Concentration	4	0.88	2.18
Season * Media * Growth regulator * Concentration	8	0.50	1.25
Error	120	0.40	

Appendix X

Abstracts of ANOVA for the sprouting percentage of *Bambusa balcooa* branch cuttings as influenced by growth regulator and concentration

Source	df	Mean Square	F	Sig.
Growth regulator	2	270.83	0.74	0.49
Concentration	2	27.78	0.08	0.93
Growth regulator * Concentration	1	33.33	0.09	0.77
Error	15	364.44		

Appendix XI

Abstracts of ANOVA for the number of sprouts per node of *Bambusa balcooa* branch cuttings as influenced by growth regulator and concentration

Source	df	Mean Square	F	Sig.
Growth regulator	2	0.81	2.09	0.16
Concentration	2	0.25	0.65	0.54
Growth regulator * Concentration	1	0.10	0.26	0.62
Error	15	0.39		

Appendix XII

Abstracts of ANOVA for the sprout length of *Bambusa balcooa* branch cuttings as influenced by growth regulator and concentration

Source	df	Mean Square	F	Sig.
Growth regulator	2	89.73	2.82	0.09
Concentration	2	13.66	0.43	0.66
Growth regulator * Concentration	1	17.77	0.56	0.47
Error	15	31.80		

Appendix XIII

Abstracts of ANOVA for the sprouting percentage of *Thyrsostachys oliveri* branch cuttings as influenced by growth regulator and concentration

Source	df	Mean Square	F	Sig.
Growth regulator	2	133.33	0.59	0.57
Concentration	2	116.67	0.52	0.61
Growth regulator * Concentration	1	0.00	0.00	1.00
Error	15	226.67		

Appendix XIV

Abstracts of ANOVA for the number of sprouts per node of *Thyrsostachys oliveri* branch cuttings as influenced by growth regulator and concentration

Source	df	Mean Square	F	Sig.
Growth regulator	2	1.78	3.44	0.06
Concentration	2	2.36	4.56	0.03
Growth regulator * Concentration	1	5.01	9.67	0.01
Error	15	0.52		

Appendix XV

Abstracts of ANOVA for the sprout length of *Thyrsostachys oliveri* branch cuttings as influenced by growth regulator and concentration

Source	df	Mean Square	F	Sig.
Growth regulator	2	47.86	1.91	0.18
Concentration	2	57.76	2.31	0.13
Growth regulator * Concentration	1	0.03	0.00	0.97
Error	15	25.04		

Appendix XVI

Abstracts of ANOVA for the sprouting percentage of *Bambusa balcooa* branch cuttings as influenced by growth regulator and concentration in quick dip method

Source	df	Mean Square	F	Sig.
Growth regulator	2	208.33	1.79	0.20
Concentration	2	129.17	1.11	0.36
Growth regulator * Concentration	1	75.00	0.64	0.44
Error	15	116.67		

Appendix XVII

Abstracts of ANOVA for the number of sprouts per node of *Bambusa balcooa* branch cuttings as influenced by growth regulator and concentration in quick dip method

Source	df	Mean Square	F	Sig.
Growth regulator	2	6.39	10.41	0.00
Concentration	2	0.07	0.12	0.89
Growth regulator * Concentration	1	1.33	2.17	0.16
Error	15	0.61		

Appendix XVIII

Abstracts of ANOVA for the sprout length of *Bambusa balcooa* branch cuttings as influenced by growth regulator and concentration in quick dip method

Source	df	Mean Square	F	Sig.
Growth regulator	2	22.44	0.84	0.45
Concentration	2	57.08	2.14	0.15
Growth regulator * Concentration	1	50.06	1.88	0.19
Error	15	26.66		

Appendix XIX

Abstracts of ANOVA for the sprouting percentage of *Thyrsostachys oliveri* branch cuttings as influenced by growth regulator and concentration in quick dip method

Source	df	Mean Square	F	Sig.
Growth regulator	2	133.33	0.59	0.57
Concentration	2	116.67	0.52	0.61
Growth regulator * Concentration	1	0.00	0.00	1.00
Error	15	226.67		

Appendix XX

Abstracts of ANOVA for the number of sprouts per node of *Thyrsostachys oliveri* branch cuttings as influenced by growth regulator and concentration in quick dip method

Source	df	Mean Square	F	Sig.
Growth regulator	2	1.78	3.44	0.06
Concentration	2	2.36	4.56	0.03
Growth regulator * Concentration	1	5.01	9.67	0.01
Error	15	0.52		

Appendix XXI

Abstracts of ANOVA for the sprout length of *Thyrsostachys oliveri* branch cuttings as influenced by growth regulator and concentration in quick dip method

Source	df	Mean Square	F	Sig.
Growth regulator	2	47.86	1.91	0.18
Concentration	2	57.76	2.31	0.13
Growth regulator * Concentration	1	0.03	0.00	0.97
Error	15	25.04		

Appendix XXII

Abstracts of ANOVA for the sprouting percentage of *Bambusa balcooa* branch cuttings as influenced by growth regulator and concentration

Source	df	Mean Square	F	Sig.
Growth regulator	2	321.53	1.85	0.19
Concentration	3	159.72	0.92	0.45
Growth regulator * Concentration	3	70.83	0.41	0.75
Error	18	174.07		

Appendix XXIII

Abstracts of ANOVA for the number of sprouts per node of *Bambusa balcooa* branch cuttings as influenced by growth regulator and concentration

Source	df	Mean Square	F	Sig.
Growth regulator	2	0.91	2.92	0.08
Concentration	3	0.12	0.38	0.77
Growth regulator * Concentration	3	0.25	0.81	0.51
Error	18	0.31		

Appendix XXIV

Abstracts of ANOVA for the sprout length of *Bambusa balcooa* branch cuttings as influenced by growth regulator and concentration

Source	df	Mean Square	F	Sig.
Growth regulator	2	33.09	4.80	0.02
Concentration	3	4.80	0.70	0.57
Growth regulator * Concentration	3	24.49	3.55	0.04
Error	18	6.90		

STANDARDISATION OF PROPAGATION THROUGH BRANCH CUTTINGS IN SELECTED BAMBOO SPECIES OF KERALA

By

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ABSTRACT OF THE THESIS

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ABSTRACT

The present study attempted root induction in the branch cuttings of three commercially important bamboo species namely; *Bambusa balcooa, Dendrocalamus giganteus* and *Thyrsostachys oliveri*. The primary branches of each species were collected during three seasons *viz*. October to January (Season I), February to May (Season II) and June to September (Season III). Two noded branch cuttings were prepared out of the primary branches and subjected to soaking in growth regulator solutions of IBA and NAA at different concentrations of 0 (control), 100, 250, 500 and 1000 mg l^{-1} for 24 hours and planted horizontally in two media *viz*. sand alone and mixture of sand, soil and cow dung (1:1:1) filled in plastic trays.

Results indicated that sprouting attributes of bamboo species varied among different treatments. In *B. balcooa*, sprouting percentage varied from 1.67 (branch cuttings of season I treated with IBA 250 mg l^{-1} kept in second medium) to 48.33% (branch cuttings of season II treated with NAA 250 mg l^{-1} kept in the sand). In *D. giganteus,* sprouting in the branch cuttings ranged from 5.00 to 43.3%. The highest sprouting was observed during season II in cuttings treated with NAA 500 mg l^{-1} kept in the second media and the least was in control of NAA kept in sand in the same season. Meanwhile, in *T. oliveri*, maximum sprouting was observed in cuttings treated with IBA 100 mg l^{-1} (41.67%) in third season kept in sand, while sprouting was absent in some treatment combinations along with the control. However, sprouted cuttings failed to initiate rooting in any of treatment combinations in three bamboo species.

Further trials were conducted with higher concentrations (0, 1000, 2000 and 3000 mg l^{-1}) of growth regulators in sand medium. Maximum sprouting in *B. balcooa*, was observed in cuttings treated with IBA 1000 mg l^{-1} (36.66%) while, the least was in those treated with NAA 1000 mg l^{-1} (10.00%). Branch cuttings treated with IBA 1000 mg l^{-1} recorded the highest sprouting (26.66%) and those treated with IBA 3000 mg l^{-1} recorded the lowest value (10.00%) in *T. oliveri*. Here also, the expected rooting of cuttings was not observed. Hence, another trial with the application of NAA and IBA by quick dip method at concentrations 0(control), 1000, 1500 and 2500 mg l^{-1} was carried out. In *B. balcooa*, the highest sprouting was in the cuttings treated with NAA 1000 mg l^{-1} (30%) and the lowest was in those treated with IBA 2500 mg l^{-1} (6.00%). Whereas, in *T. oliveri* highest sprouting was observed in cuttings treated with IBA 1000 mg l^{-1} (33.33%) followed by IBA 1500 mg l^{-1} (23.33%). The least sprouting was observed in cuttings treated with NAA 2500 mg l^{-1} (13.33 %) followed by control (15%). Here also, the rooting was absent in different treatments. In the last experiment, *B. balcooa* branch cuttings

were treated with IBA and NAA solutions 0, 500, 1000, 1500 and 2000 mg l^{-1} concentration and planted in standard nursery beds. The lowest sprouting percentage was observed in cuttings treated with NAA 2000 mg l^{-1} (20.00 %) and the highest sprouting was in cuttings treated with IBA 500 and 1000 mg l^{-1} (40 %) but the sprouted cuttings did not produce any root. As the present study did not give the expected results, further trials are needed for the standardization of propagation through branch cuttings in the selected bamboo species.