5.1 Assessment of bamboo shoot production potential in Jharkhand.

Bamboo shoot or ‘Karil’ as locally called are removed when emerged from ground during rainy season, July to mid-October in Jharkhand. Shoot dimension of 30 cm to 75 cm long of pahari or lathi bans (Dendrocalamus strictus) and 75 to 90 cm of ropa or dehati bans (Bambusa nutans) are usually sold in markets. The shoots are cut with axe or spade (hasua, kodali etc.) or a sharp knife beyond the rhizome neck after emergence from the ground and sold along with the culm sheaths attached or after peeling off the sheaths. The price is fixed according to the size when sold raw or by weight. Sometimes villagers sell raw karil by chopping off cross-sectional chips known as ‘Kardi’ and sold in khala, kheja or dona (container made of S. robusta, B. monosperma or Artocarpus lakoocha leaves). One khala full of kardi or sandhna weighs about 200 - 250 g.

Sheath removed karils are made into small pieces (gunda) with the help of samat or tuku (wooden country mortar-pestle or khal-musli) or traditional dheki (wooden grinder used for dehusking rice or making pressed rice or chira etc). These gunda karil are immersed in water for 3 to 8 days’ fermentation (best 3-4 days) and becomes sour giving rise to vinegar like smell. Otherwise shredded karils are kept in earthen pots for 4-7 days covering with Shorea robusta (sal or sakhua) or Butea monosperma (palash or parsera) leaves under almost airtight condition. After the fermentation is complete, the shredded shoots are removed and sold on weight basis or in khala, kheja or dona. The fermented product is mostly known as ‘Helta’ or ‘Sandhna’ (or ‘Sadhna’). The water left after fermentation is discarded and never allowed for drinking even to livestock for safety, as informed by villagers. In order to consume during off-season, chopped karils are fermented for 4 days and then dried either in shade (mostly under the thatched roof) or in the sun. Sometimes the sadhna is packed with sal leaves and dried in the sun. After drying, the sandhna become light flaky powder like substance and stored in earthen pots. The product is called ‘Harua’ (or ‘Handua’) and can be consumed even for a year or so.
Now a days, three different grade of sandhna are being marketed. i) The rough sandhna after crushing with samat, shal or shell ii) Hand cut - comparatively uniform in size and shape and iii) The machine cut uniform in size and shape as potato finger chips or French fry and it is the whitest of all.

5.1.1 Village survey for assessment of production, collection and market potential of edible bamboo shoot in Jharkhand

Bamboo as a renewable natural resource with its plethora of essential uses is gaining increasing importance worldwide. Bamboo shoots are being eaten by people of bamboo growing belts throughout India. In Jharkhand, bamboo shoots are used traditionally as food for hundreds of years with its adequate stock of edible shoot species. However, extent of shoot consumption, market linked productivity and future potentiality have not been explored so far. Since bamboo species are region specific and people of Jharkhand are ethnically, culturally and linguistically more closer to other people of the sub-continent, results of village and market survey could only be compared and discussed with similar studies conducted.

As most bamboo species produce edible shoots, people since time immemorial depends on the available bamboo species in their geographical region suited to that particular climatic or agro-climatic situation. Dendrocalamus strictus is the most widely distributed and dominant species of Jharkhand forest and it is also dominant next to Bambusa nutans in homesteads of the state. As such bamboo diversity in Jharkhand is limited and most of the potential and commercial bamboo species of the sub-continent except D. strictus and B. nutans is not found here or if present they are found in very limited area. Species like Bambusa balcooa and Bambusa tulda are such two species available in most of the north eastern states of India (Bhatt et. al., 2004, Jha, 2010) are traced in north eastern part of Jharkhand with few number of clumps (Nath et al., 2012, 2013).
Jharkhand with its 29% of recorded forest area has potential natural bamboos covering about 14.5% of total forest area. Besides natural forest, 1.55% of total non-forest area is covered by homestead bamboos. *Bambusa nutans* covering 84.58% of the village bamboo area is the dominant non-forest species of Jharkhand followed by *Dendrocalamus strictus* (11.92%) and *Bambusa bambos* (2.26%) (Nath et al., 2012, 2013). In spite of being not common in NE states of India, one of the 18 biodiversity hot spots of the world (Bhatt et al., 2003a), *D. strictus* is one of the species recommended by INBAR for development of bamboo shoot sector in India (Nath et al., 2008). Quite naturally along with those of *D. strictus*, shoots of *B. nutans* have been tasted in Jharkhand for edible purposes. Thus out of 16 districts covered during village survey on shoot collection, shoots of *B. nutans* are being collected, consumed and sold and their utilization had increased over time. Though shoots of *D. strictus* are preferred in rural Jharkhand, according to the personal communication, those who tasted shoots of *B. nutans* experienced the same taste. According to some other villagers of Khunti district, shoots of *Bambusa bambos* are tastier than both *D. strictus* and *B. nutans*. Few more villagers opined that pickles made of *D. strictus* shoots are better in taste while vegetables made of *D. strictus* and *B. nutans* are almost identical in taste. According to the vendors of Jharkhand, villagers while processing shoots for preparing *sandhana* from *B. nutans* and *D. strictus*, it hardly makes any difference in appearance, texture and taste. Shoot products of *B. nutans* are superior in physical appearance and are more profitable. Unless raw shoots are traded, the source of shoot species in *sandhana* and *harua* is hardly recognizable. In addition to *B. nutans* another species, *B. vulgaris* has been found to be consumed by villagers though very rarely. *B. nutans* is a potential species known for its edibility not only in central and eastern India (Chongtham et al., 2011, Pandey et al., 2012) but also in Manipur, Assam, Meghalaya and other north eastern states (Singh. et al., 2003, Bhatt et al, 2005b, Singh, 2006). However, it has not been treated as the dominant commercial shoot species in north east India as per observations by Bhatt et al. (2004), Rai (2007) and Salem and Deka (2007). Though cited by
the villagers for its taste, *B. bambos* had not been reported as being collected for consumption and sale in Jharkhand. Along with *B. vulgaris* and others species such as *B. bambos* or *B. arundinaceae* are very important and preferred species for edible purpose in south India (Shanmughavel, 2004). *B. vulgaris* and *B. arundinaceae* (*bambos*) have also been listed among others by Chongatham *et al.* (2011), Pandey *et al.* (2012).

For edible shoot collection, villagers particularly the tribal groups with their population of 22.5% in the state exploit the natural forest resource in Jharkhand for shoots of *D. strictus* and in some occasion, they utilize *B. nutans* shoots collected from homestead grown clumps. According to the present study, *B. nutans* contributes only 13.45% of the village collection as against 86.15% by *D. strictus*. The preference for *D. strictus* may be attributed to the fact that it is available in plenty, collection is almost uninterrupted except very little apprehension by the SFD people and people tasted it for generations as their natural choice. Moreover, villagers are unaware of the general growth behaviour of bamboo and they cannot accept harvesting shoot from their own homestead clumps of mainly *B. nutans* fearing damage to the clump. In spite of travelling for hours, poor tribals venture into forests for a paltry earning and to satisfy their desire to have the palatable item in their dishes. Had they opt for their own plantation in their homesteads with *B. nutans* and/or *B. bambos*, they could earn even more what they earn today through motivation and technological interventions. Further, shoots of *B. nutans* and *B. bambos* are larger in dimension than those of *D. strictus* (Singh, 2006).

Shoot season is a unique characteristic of each species (Midmore, 2009) and is governed largely by the geographical location and climatic condition. The season may be extended considerably with increased yield through irrigation (Malab *et al.*, 2009) and agronomic practices particularly soil work and mulching (Cao *et al.*, 1985). Under Indian situation, shoot season is associated with the onset of monsoon. In Jharkhand, normal shoot season for 45 to 55 days is coincides with the
peak rainy period from July to September. The extended shooting up to 75 days particularly in East Singhbhum, West Singhbhum, Khunti and Ranchi districts may be attributed to the available soil moisture regime. In comparison to north eastern states, shooting season in Jharkhand is much shorter. According to Bhatt et al. (2003b), shooting season begins at the onset of rainy season i.e., May to June of the calendar and continues up to September. In Mizoram, bamboo shoots are available from late June to early September every year and prior to June and after September, the availability remains at much lower levels (Jha, 2010). Shoot availability in markets of that region, on an average, are 84, 84, 53, 81, 76 and 42 days per year in Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland and Tripura respectively. In some pockets of Manipur, Nagaland and Tripura shoots are available even for 84 to 92 days (Bhatt et al., 2004). Thus it is not unusual in the collection of shoots for 75 or more days beyond the general average period of 45 to 55 days as in the case of Potka block of East Singhbhum where shoots are available from July to October for 75 days and shorter duration of 30 to 45 days in Koderma district. Shorter duration of shoot season might be attributable to the nature of the parent materials on which the soils have developed that facilitate higher infiltration rate and loss of soil moisture.

Social aspects like man-hours spent per day or per trip for shoot collection, carrying, cleaning, sale, etc., distance covered by villagers in collection and other activities, number of families and persons involved in collection and also marketing, frequency of collection are very important in assessing the livelihood support through edible bamboo shoot. The distance, a collector has to travel for collection of shoot from forest is unique throughout the subcontinent as the sector is unorganized and no shoot purpose plantation has been raised. The dwindling forest cover is the main cause of long distance walking by the collectors. Travelling a distance of up to 6-7 km and spending 4 to 7 hours a day is a common feature of the collectors in north eastern states (Bhatt et al., 2004). It has been noted that in Arunachal Pradesh, Manipur, Nagaland and Tripura, primary
vendors use to travel $\geq 2.0, 1.6$ to $4.0, 1.5$ to $4.0$ and $3.7$ to $6.3$ km respectively for collection. In Meghalaya, Mizoram and Sikkim the corresponding range of distances are $0.4$ to $2.33, 0.05$ to $2.0$ and $1.5$ to $3.33$ km respectively. In Jharkhand, on the contrary, $82\%$ respondents travel distances up to $5.0$ km and the rest more than $5.0$ km. Similar trends have also been noted for distances covered by collectors for attending markets in Jharkhand. In Meghalaya, Mizoram and Sikkim, collectors have to travel maximum up to $10$ km to market with an average of $2.67, 1.70$ and $4.38$ km respectively. While in Jharkhand for sale, about $64.5\%$ of villagers use to travel up to $5.0$ km. They have also to travel more than $10$ km ($12.3\%$) besides a large number of collectors between $5$ and $10$ km ($23.2\%$).

The tribal livelihood earlier was forest based and they used to explore forest resources for their needs. They are very much accustomed to that environment and even today some tribes like Birhor meet most of their daily needs from forests. They spent the entire day travelling through forests collecting non-timber products required in their daily life. Bamboo shoot collection is part of their total collection and by selling this item they satisfy some of their precious purchase.

The mean daily shoot collection in Jharkhand is $6.22$ kg per collector and this figure is far less than the mean quantity collected by primary vendors of Arunachal Pradesh, Manipur, Nagaland, Meghalaya and Mizoram but comparable to that of Tripura and Sikkim as reported by Bhatt et al. (2003a, 2003b, 2004). The mean daily collection of vendors of Arunachal Pradesh, Manipur, Nagaland, Meghalaya and Mizoram has been found to be $21.1, 28.9, 9.8, 31.3$ and $27.6$ kg, respectively. Irrespective of states in north eastern India, primary vendors use to spend roughly $3.05$ to $6.5$ hrs for collection of shoots from forests and these figures are somewhat less after what the Jharkhand people are spending as has been communicated by the collectors during field survey.
A small quantity of shoot consumed and stored in comparison to those sold by the collectors reflects the socio-economic status of the villagers of the state. People have very little option and have no other alternative earnings. Further, if not consumed in time, there are chances for mass waste and loss. So they also have little option relating to the purchaser or secondary vendors. People who resides nearer the forest can visit daily as they in reality have to travel only once for both collection and sale and it is possible for them to collect shoots daily as observed among 27% of the collectors in the state. While collecting shoots from clumps of *B. nutans*, which is available nearby the villages or within their neighbourhoods, they usually harvest at larger gap i.e., monthly or so.

In Jharkhand, the total villagers engages in shoot collection have been projected is about 0.76% of the total population. This is an enormous figure while considering total man days involved in shoot collection though engaged for a shorter period or for few days. The projected collection of shoots to the tune of 27,349 metric tons is also unexpectedly high compared to the extent of collections from potential areas like north eastern states. According to Bhatt *et al.* (2004), the total young bamboo shoot harvest from 6 north eastern states excluding Assam accounted for 5,685 tons per year during 2002-2003. The state wise share was 1,979, 2,188,442,433, 442 and 201 tons for Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland and Tripura, respectively. In a similar study from Philippines (Rivera, 2009), volume of shoot sold in selected wet markets has been assessed from four prominently bamboo growing regions. It has been estimated that 27 tons of shoots were sold during 2005 there. The projected market value of 70.30 crores from the yearly shoot collected in Jharkhand is also very high while comparing the total earnings from north eastern states. The district and zone wise variation in shoot collection and market value is due to the variation in number of villagers involved in collection, quantity collected per trip and also on the forest coverage with potential bamboo stock within the near vicinity. As in case of Giridih, the
district having maximum number of villages and higher percentage of population engaged in shoot collection at higher frequency of collection and moderate price all have contributed to maximum collection of 6,236.27 tons and earning of 14.87 crores.

It is well understood that collection of bamboo shoots from natural resources may play a pivotal role in the rural economy as well as nutritional security of the tribal communities of Jharkhand. This may also reduce the waste of the shoots that are not supposed to be developed into full length culms and generate means of self-employment to a large extent if suitable processing, preservation, packaging and storage arrangements are made.

5.1.2 Market survey for assessment on sale of fresh bamboo shoot and shoot products in Jharkhand

In Jharkhand bamboo shoots are marketed in major three forms, the fresh, wet the fermented and fermented dry. The fresh shoots are sold as fresh whole karil or fresh cross-sectional discs known as kardi. The fermented shoots are available in two forms – one is crushed or chopped into very small pieces and then fermented and the other is machine cut into regular thin rectangular pieces or slice like French fry and then fermented. The third form is the dried sandhna which we may also term as crushed fermented dry. Unlike NE states of India, where roasted whole shoot and whole shoot boil as reported by Bhatt et al. (2005a) from Arunachal Pradesh and Sikkim respectively are not sold in the Jharkhand market.

Another dissimilarity with NE states relating to bamboo shoot market and sale is that in the entire NE region, there is a great diversity in the availability of bamboo shoot species. About 10 edible bamboo shoot species each from Meghalaya and Mizoram, 8 each from Manipur and Sikkim, 6 each from Nagaland and Tripura, 5 from Arunachal Pradesh have been reported by Bhatt et al. (2003b, 2004). The total species are about 25 covering entire NE region except Assam, out of these about 16 species have commercial importance. Altogether in Jharkhand, shoots of major two
species are marketed, *D. strictus* and *B. nutans* contributing about 86.15% and 13.45% respectively in terms of collection as described earlier. Another species *B. bambos* has the potentiality as a shoot species as it covers about 2.26% of total non-forest bamboos in the state.

The most preferred species of NE India are *Melocanna baccifera* in Mizoram, *Bambusa balcooa* and *Dendrocalamus hamiltonii* in Meghalaya, *D. hamiltonii* in Nagaland, *Bambusa tulda*, *B. balcooa* and *M. baccifera* in Tripura, *Chimnobambusa hookeriana* and *D. hamiltonii* in Sikkim, *B. balcooa*, *D. gigantea* and *D. hamiltonii* in Manipur and *D. hamiltonii* and *D. hookerii* in Arunachal Pradesh (Bhatt *et al.*, 2003b; Bhatt *et al.*, 2004). In Jharkhand, *D. strictus* is the most preferred species while this species is treated as shoot species only in Sikkim. Only the primary vendors in Jharkhand can identify the species which are being sold or consumed more as a fresh shoot and the crushed-fermented ones. The secondary vendors mostly remain indifferent about the source of the bamboo shoots and shoot products and thus, it becomes almost impossible to list the species wise sale in Jharkhand.

Assessment for total collection and sale of bamboo shoot and its products for the entire state is a difficult task due to various reasons. Vendors sell shoots along with other vegetables in most of the cases and are very reluctant to cooperate in fear of confiscation and apprehension from the SFD authorities. The actual number of markets of different size is also not available as there is mismatch in many instances between the number provided by the state authority and in reality. Smaller unorganized markets have not been taken into account. However, the total sale of bamboo shoot and fermented products has been projected as per the authorized list. In spite of difficulties, information gathered is very rare and interesting which was till recently unknown.

In general, bamboo shoot season in Jharkhand, on an average, is 45-55 day and this may be extended to 60 days in some pockets and exceptionally to 75 days from July to September as recorded during 2010 and 2011. During that period, shoots are available for a maximum duration of 60 days in markets of Jharkhand. On the contrary, in North Eastern Hill region, shoots are
available from first week of July to first week of September and generally fresh shoot remain in market for 2-4 months every year (Bhatt et al., 2003a; 2003b). In spite of availability of shoots, the vendors seldom attend markets daily and thus, the trade duration narrow down to maximum of 50 days. However, during 2012 shoot season, while selected markets are surveyed at regular intervals, the sale period of bamboo shoots has been found to be upto 60 days. Thus, under normal climatic condition, shoots can be available for at least two months. The exceptional extended period of 79 days from July to mid October of shoot market at East Singhbhum may be ascribed to some local factors. The region experienced comparatively less precipitation during 2012 and humidity and air temperature were more against the situations of 2010 and 2011. The annual rainfall was also spread over July to September with sudden low rainfall during October, favouring prolonged shoot emergence. As Kleinhenz et al. (2003) indicated formation of short events of over-wet soil condition which negatively affect shoot growth and yield.

The nature of vendors dealing with sale of fresh and fermented shoots in Jharkhand may not be similar to those of other parts. In Jharkhand markets, vendors are of both types’ retailers (79%) and wholesaler (21%) who attend markets at different frequencies – daily, thrice a week, biweekly and very rarely monthly. Most of the respondents (82.2%) collect the shoot directly from collectors and wholesalers together while only 17.8% are the primary vendors collecting shoots from the forest or homestead themselves.

Since the vendors of Jharkhand sell bamboo shoot along with other vegetables, their sale volume is generally low. Among the 152 respondents, 11 vendors sell less than 100 kg and 24 between 100 and 200 kg in a season. Again 16 of these respondents sell more than 1000 kg and 40 sell between 500 and 100 kg per season. On an average daily rate of the former group comes to less than 3.5 kg and for the latter group is more than 35 kg per day. The lower ranges of fresh and crushed fermented wet shoot sale per vendor has been found to be 2.8 to 5.5 kg and 1.5 to 10.5 kg, respectively for retailer and 5 to 65 kg of fresh shoot for the wholesaler. On the other hand, the
corresponding upper ranges are 4 to 25 kg and 5 to 45 kg for retailers and 75 to 100 kg of fresh shoot for wholesale. Wholesalers have been found to deal with mostly raw and fresh shoots. The present figures for the retailers are comparable to those of engaged in NE hill regions (Bhatt et al., 2003a; 2003b; 2004). During 2002-03, in Arunachal Pradesh, Mizoram, Manipur and Tripura, the daily sale by vendors on an average have been found to be 2.7 to 39.4 kg, 13.6 to 44.1 kg, 6.1 to 13.5 kg and 5.3 to 6.1 kg per day respectively. The mean daily sale by a vendor in Meghalaya, Mizoram and Sikkim was 31.33, 27.64 and 7.78 kg respectively. The state wise yearly sale has been estimated as 1979, 2188, 442, 443, 442, 201 and 26.7 tons in Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Tripura and Sikkim respectively during 2002-03. In Jharkhand total shoot sale has been projected to 1704.1 tons with market value of Rs. 59.06 million. It may be recalled that, total collection of shoot by villager has been projected as 27348.82 metric tons having market value of Rs. 703.02 million and this entire volume is thought to be consumed by the entire Jharkhand state. Out of this total volume of production 6.23% is being sold in the markets and the rest is consumed by the villagers collected by them and purchased locally. In comparison to the NE states, where consumption and market sale has been treated as the same volume, the sale of fermented shoots in Jharkhand is comparatively of lower volume than states like Arunachal Pradesh and Manipur but higher than the rest of the states. The price of Jharkhand bamboo shoot product may not be compared due to time span of about a decade.

In respect to employment generation through sale of shoot and its products in Jharkhand, it has been found that as per projection 6,713 people are entirely dependent for their livelihood. Based on the frequency of attendance, about 1, 79, 98 man days had been generated in the shoot sale market. According to the estimates of NE hill region, Arunachal Pradesh, Manipur, Meghalaya, Nagaland and Sikkim together provided employment to 1258 persons fully or partly for their livelihood through merchandising of fermented, roasted and boiled bamboo shoot products to the
tune of about 680 tons per year. However, it may be stated that the volume of these fermented products is about 13% of total shoot sale in these five states (Bhatt et al., 2005a).

As has been observed in 2012, that in most markets of Jharkhand, the number of vendors are usually higher in numbers during peak shoot season which almost coincides with the mid-season and the fermented shoot product has started dominating the sale volume during the second half of the season and its share as a whole on total volume of sale is found to be about 57%. The price also started diminishing from the mid-season. The sale price of the crushed fermented dry shoot or *harua* is Rs. 200 per kg and it does not change much in Jharkhand market. The similar product of NE states fetched about Rs. 322 a kg at Arunachal Pradesh during 2002-03 (Bhatt et al., 2005a).

The prices of bamboo shoots tend to increase during the lean seasons when supply is lower. Alternatively lower price is associated with the peak season as also observed in Philippines (Rivera, 2009). In Philippines, bamboo shoots are not often included in the standard restaurant menus, but only prepared on request. People requesting dishes incorporating shoots are of middle-to-high-income classes. The situation in our country is almost similar as in first-class and deluxe hotels or restaurants run by selected ethnic groups and also Chinese, Thai and Tibetans in metropolitan cities are serving shoot based dishes. In general in hotels, people ask for bamboo shoot items.

Bamboo shoot production, its collection and marketing have not been pursued adequately in India as a whole except in NE India and in Jharkhand in particular. Further, little hazard for its pre-processing treatment and availability of other vegetables at relatively low price affect the acceptability of this product. In spite of these, more and more people are consuming bamboo shoots with every passing season. The major hindrance in this respect is the unawareness and lack of motivation. Besides diverse ethnic groups of the sub-continent, few people are attached with this product. Further, it has not been appropriately documented both in terms of availability, marketing, economy as well as its health benefits as a nutraceuticals. Promotion of better
technologies awareness through information campaign and other extension strategies, generation of linkage through production-consumption chain are essential to address the sensory issues relating to bamboo shoots. Unless the market potential is analysed including vital information about demand and supply of raw materials and processed products, the shoot collectors or producer with an eye to improve livelihood and socio-economic level may not gain access to favourable markets in spite of availability of productivity enhancing technologies.

Taking the utilization of bamboo from the very beginning is of course the development of an industry based on bamboo shoots. In traditional Indian cuisine, bamboo shoots are also featured in various dishes. There is however, no attempt visible at growing bamboo for shoots on a large scale. Taking into account the volume of shoot collection and its unorganized market, the opportunity to promote the cultivation of bamboo shoots on a large scale for export oriented industry thus exists.

The silvics of managing cultivated stands in respect to factors affecting better performance or mortality of shoots and stems, phenology of shoot production, fertilization, planting design and harvesting intensities etc. are mostly understood. However, further studies are essential to address the local requirements in terms of suitable species and the emphasis must be given for the translation of the relevant technology into viable and economic ventures for rural development. In this respect the local or regional development authorities’ role and participation are of immense important. The other critical area to bear in mind involves harnessing and managing the raw material resource to the best advantage. It is feasible to consider exploiting marginal and fallow lands lying vacant with imposition of silvicultural management for the increased output of bamboo raw materials to sustain the production and processing linkage.
5.2. Field trials on improvement of shoot production, duration of shoot season and clump growth as influenced by organic and inorganic amendments of soils, mulching and clump management

The range of uses of bamboo is remarkable. Probably more than 2.0 million tons of bamboo shoots are consumed annually (Kleinhenz et al., 2000) with approximately 1.3 million tons produced in China (Shi et al., 1997). As per 2006 estimate, global bamboo shoot market has been estimated to the tune of 1.5 billion US$. With newer bamboo industries like modern laminated furniture, flooring and panels, the market demand may reach 16.8 billion US$ per annum from 2006 estimate of 6.8 billion US$ excluding markets for bamboos in paper/pulp production and raw bamboos for construction and other purposes (Smith et al., 2006). While supplying products for immediate use to humans, bamboo also serves multiple ecological functions such as soil and water conservation, erosion control (Fu and Banik, 1995). Bamboo is a significant net sink for global CO$_2$ (Jones et al., 1992).

There is a rising concern about acute scarcity of bamboo products in spite of vast land tracts in South and South East Asia are covered with bamboo. There is, therefore, a need to develop technologies so as to enhance output of edible shoots and timber through management practices for selected premium species.

Management factors that influence shoot production fall mainly under irrigation, fertilizer, mulch and thinning regimes (Kleinhenz and Midmore, 2001). In the present study attempts have been made to increase shoot production duration and yield through application of organic matter, inorganic fertilizers, mulch materials, clump density regimes and shoot harvest in *D. asper*, *B. nutans* and *D. strictus*. 
5.2.1. Effect of organic amendments and inorganic fertilization on emergence of shoot, survival of shoot, duration of emergence of shoot, culm length, and culm DBH in *D. asper*, *B. nutans* and *D. strictus* for the year 2010, 2011 and 2012.

Next to irrigation, fertilization and manuring is the primary and foremost means of maintaining the soil productivity for maximizing return from a land through cultivation. While the soil physical properties are to be addressed, incorporation of bulky organic matter (OM) is obligatory. However, nutrient availability can be managed comparatively easily through fertilization. Fertilization has dramatic impacts on bamboo productivity under poor site condition and under minimal management. Beneficial role of fertilizer application in bamboos has been recognized for improvement of growth and yield of its various products in India and abroad (Hong, 1987; Ahmad and Haron, 1994; Widjaja, 1991; Qiu *et al.*, 1992, Lakshmana 1994, Suzuki and Narita, 1975). Nutrient management must not only satisfy requirements for yield but also for quality of harvested parts.

The exceptionally rapid flush of growth of below ground shoots and above ground culms require net import of energy of nutrients. The greater part of nutrient ions originates via absorption from the soil during the shoot season. Nutrient application shortly before and during shoot season is vital and in the present trial, fertilization and manuring had been administered before the rainy season (May-June) each year and after mixing with the soil surrounding the clump base.

Precipitation affects distribution and limits growth of bamboo more than any other component of climate except temperature (Biswas, 1988). Supply of water to bamboo just before and during shoot season has been recognized as an enhancing factor for the onset and continued production of shoots (Midmore, 2009). Positive effects of greater availability of water on bamboo production are very common (Qiu *et al.*, 1992, Kigomo and Kamiri, 1985, Koyama and Uchimura, 1995, Lin, 1995). It is well known that wet summer increase shoot production of sympodial bamboo (Pearson *et al.*, 1994). The field trial plots after selecting clumps for maintaining respective
treatment schedule were irrigated during April and May each year at 15 days interval till the arrival of monsoon in order to maintain the soil moisture regime so that clumps may not be affected by water scarcity and nutrient absorption. Thus the effect of irrigation has not been studied separately. For all the trials, treated and untreated clumps received similar moisture condition. The irregular raining during monsoon as experienced several instances in the sub-continent and even with Jharkhand may not be compensated through irrigation due to economic feasibility point of view and as such the trial groves were left only to be rain fed for practical reason. It has also been observed that water-use efficiency of shoot production could be raised by 28% by omitting irrigation in Queensland, Australia (Midmore, 2009) and year-round irrigation has not found to be important for shoot production.

The early rains during June, though at lower level, in addition with the irrigation applied after the organic and for inorganic treatments, probably provided substantial moisture to the soil, which initiated early shoot emergence for *B. nutans* during 2012 supported up to 90 days of shoot duration.

In most of the cases, shoot emergence initiated during July for *B. nutans*, late July to early August for *D. strictus* and mid to late August to early September in *D. asper*. The shoot season is a characteristic unique to each species for reasons not known clearly (Midmore, 2009). Supporting this view the three species had shown differential behavior relating to their shoot season in Jharkhand. The onset of shooting of *D. asper* is late. Thus, through silvicultural intervention, in the present study shoot emerging duration in these species could be enhanced from mean duration of 33.3 days with the untreated control clumps to as high as 60 days in case of *D. asper*. The mean shoot season during 2010 to 2012 for *B. nutans* and *D. strictus* has been found to be 53 and 39 days, respectively in untreated clumps. The shooting period for these two species had extended maximum up to 90 days for *B. nutans* and 63 days for *D. strictus*. Further, the shoot initiation for these species have also been advanced for 10 to 22 days for *D. asper*, 14 to 32 days for *B. nutans*
216 and 16 to 30 days for *D. strictus* and most of the extended shooting periods are associated with clumps those received higher levels of organic amendment alone or in combination with inorganic fertilizers at both the levels. Thus under the present circumstances, onset of shoot season and its duration in the three species, though species specified, are governed not only by water availability but also affected largely by fertilization. It has also been seen that in the present study application of both OM and inorganic fertilizer individually or in combination favoured higher shoot emergence.

The present dose of organic manure and NPK fertilizer application jointly provide about 140 to 280 kg N per ha. At the higher level, these together with P and K supported 73% increase in production of *Phyllostachys pubescens* paper-pulp stands with average yield of 18,221 kg per ha in Anji and Yuhang County, China during 1985 (Shi et al., 1985)

Application of organic fertilizer, which has been a traditional one in our agriculture, can be used in bamboo stands for both culm and shoot production. Organic fertilizer like cow dung, human waste, farm yard manure, compost, vermicompost etc. contains the entire nutrient needed by plant i.e., it is complete fertilizer. Application of these can increase the humus in the soil, improve its physico-chemical properties, and increase the capacity in keeping it warm and preserving its moisture and fertility. The rhizomes can grow without any barrier and it is easy for shoots to grow up through soil (Qiou and Fu 1985). However, they recommend that both organic and commercial fertilizers should be used widely and N is the most one followed by P and K. As regards doses, 50 Kg per ha is better for N, if soil lacks P and K, mixed fertilizer at the proportion of N: P: K= 2:2:1. P and K are essential when N is applied at higher levels.

Organic manure may act as slow releasing fertilizer and with repeated application, it may add to the consistent improvement in the physical health of the soil which along with yearly doses of inorganic fertilizer might have resulted in further greater improvement of the clump growth, the
shooting intensity etc. This is in contrast to declined shoot yield in *P. Pubescens* with organic manure in Australia for slower availability of nutrients (Kleinhenz et al., 2003).

Virtucio and Roxcas (2003) have reported shoot emergence and its duration as a function of monthly rainfall. The present observation corroborates the findings of Malab et al. (2009) in that the advance cleaning and sanitation cuttings and application of complete fertilizers improved shoot production and omitting fertilizers and organic matter suppressed shoot production and production period for all the species in all three years as observed from emergence of lower number of shoots and shorter duration when clumps received less or nil OM and/or fertilizers.

Under the influence of higher dose of both OM and NPK fertilizers, The mean number of shoots emerged had been found to be 6.3, 8.7 and 10.0 in *D. asper*, 6.3, 13.3 and 15.7 in *B. nutans* and 6.0, 6.7 and 7.7 during 2010, 2011 and 2012, respectively *Bambusa blumeana* in one rehabilitated plantation maintained with optimum fertilization in Philippines had produced 5.9 to 9.0 new shoots (Malab et al., 2009) and the present values for *D. asper* and *D. strictus* are in accordance with that range but for *B. nutans*, the present figures are much higher. According to Kleinhenz and Midmore (2001), *D. asper* is not a prolific producer of shoots compared to other species. Gradual increase in shoot number with season is very common particularly for the growing clumps as in *B. nutans* which is yet to achieve their full vigour. In a well managed fertilized and mulched 7 year old *D. asper* plantation in Philippines, Decipulo et al. (2009) obtained average shoot production of 10.47 while one year earlier it was only 3.83 per clump.

The age of mother culms is also critical to shoot production. One year old mother culms produce significantly higher numbers of shoots every year than the older culms, regardless of treatments (Kleinhenz and Midmore, 2001, Decipulo, 2009, Malab et al., 2009). Lakshmana (1990) has shown that 1 year, 2 year and >2 year old standing culms contribute 77, 20 and 3% to annual production. For the present investigation, the survived culms of the previous year under the respective treatments were also higher in numbers. In spite of being young, *B. nutans* had
produced much more number of shoots than *D. asper*. This may be attributed to the better response of the former species to the applied treatments and also to the fact that it is indigenous and acclimatized in Jharkhand since long. Virtucio *et al.* (1990) showed that fertilizer application significantly increased shoot production in *B. blumeana var. Philippinensis* and Tiongco (1997) observed enhanced shoot number and yield in *B. bambusa* due to N-fertiliser application.

As outcome of the Australian Centre for International Agricultural Research (ACIAR) funded project titled ‘Improving and maintaining productivity of bamboo for quality timber and shoots in Australia and Philippines’ Midmore (2009) emphasized on application of N, P and K fertilizers and preferably nitrogenous one. Fertilizer application at the levels that ensure leaf N at close to 3.0% invariably allow clumps to achieve high shoot yields, consistently hastening not only the onset of shoot production but also rate of emergence and number of shoots as observed in Northern Territories (NT), Australia (Midmore, 2009, Traynor and Midmore, 2009). Withholding N fertilizer led to significantly smaller and unmarketable shoots in Queensland, Australia (Zhu *et al.*, 2009) and when N supply is reduced to one-quarter in NT, Australia, shoot number and yield decreased. However, the rates of N required to maintain % N at closer to 3.0% are uneconomic for shoot production and a lower dose of N is called for.

Hoanh (1992) studied impact of silvicultural treatment on culm properties particularly culm diameter and height in case of *Bambusa blumeana* at Mt. Makiling, Los Banos, Laguna. Highest mean of culm diameter was 68 mm at 300 g of complete fertilizer treatment. The study also showed that the application of appropriate amount of complete fertilizer have provided favourable condition for faster growth and development of bamboo. Similar results have been found in the present trial.

Abasolo (2011) studied effect of application of organic fertilizer on mechanical attributes of *Gigantochloa levis* and *Dendrocalamus asper*. As per the study mechanical properties of the
bamboo culms were affected by the organic fertilizers. However, such influence was only minimal. The study conforms to the result obtained in present trial.

The positive significant effect, on shoot emergence and clump growth, of fertilization in the present study may be highlighted from bamboo root system point of view. The dense root system of bamboo absorbs plant available ions from inorganic fertilizer effectively and immediately (Tripathi and Singh, 1996; Li et al., 1998) preventing nutrient loss through leaching. It is found that application of 130, 250 and 500 kg N per ha per year supported shoot yields to the tune of 6000, 8000-9000 and 11000-12000 kg per ha in *P. Pubescens*, revealing the great nutrient demand for bamboos.

In spite of advocating application of higher N levels for higher shoot production, Midmore (2009) also observed that organic fertilizer even showed a small but consistently positive response. Corroborating these views, in the present study, with a very few exceptions, inorganic treatments with N, P and K influenced significantly in increasing the number of shoots, their survival, shooting period and length and diameter growth of *D. asper*, *B. nutans*, and *D. strictus* for three consecutive years. At the same time, organic amendments with vermicompost has supported significant role in enhancing the shoot emergence and clump growth of these species in many instances. It is thought that organic matter has key role in improving the soil texture, structure, bulk density, air and water movement, moisture holding capacity and other non-chemical properties of soils which influence bamboo growth. It has been noted that many bamboo growing sites of China and Korea, soil texture is one of the most important parameters explaining variations in yield of *Phyllostachys pubescens*. Culm yield of the species has found to be negatively correlated with the percentage of < 0.1 mm soil particles (He and Ye, 1987) and clay content (Hong, 1994). This indicated that soils, which are rich in small soil particles such as heavy clay soils, are less suitable for bamboo production. This can be explained by their effect on growth of underground plant parts of bamboo. Soils rich in smaller-size soil particles have greater
bulk density which restricts rhizome and root growth (Wu and Li, 1984). Thus under Jharkhand situation, where soil is lateritic in nature with usual truncated surface horizon due to erosion and exposure of sub-surface soil rich in argillans or eluviated clays, improving of the soil physical health with incorporation of bulky organic manure is obligatory to ensure better bamboo production and more essential for shoot cultivation. Further, soils of Jharkhand are also characteristically deficient in organic matter, acidic, low in plant nutrients like N and P and also deficient in some micro-nutrients like zinc and manganese. So a combination of both organic and inorganic amendments for such type of soil would definitely improve the bamboo product quality and quantitatively provided other environmental condition like soil moisture regime is maintained.

5.2.2. Effect of mulching and organic manure (OM) on emergence of shoots, survival of shoots, duration of emergence of shoots, culm length and culm DBH in *D. asper*, *B. nutans* and *D. strictus* during the year 2010, 2011 and 2012

For centuries, mulching has been recognized as a beneficial practice in agronomic system where it is often enhance growth and yield of annual and perennial crops (Traux and Grangnon, 1993; Robinson 1988; Tarara, 2000). Materials used as mulches vary depending on number of factors. Mulch is usually but not exclusively organic in nature. The enhancement in growth and yield has been attributed to the reduction in vegetative competition in the rooting zone (Davis, 1994; Adams, 1997) and increases in the availability of key soil resources such as N and water (Truax and Gragnon, 1993; Wien et al., 1993, McDonald et al., 2004). Mulching has also been shown to accelerate early root growth and nutrient uptake (Robinson, 1988; McDonald and Helgerson, 1990; Wien et al., 1993).

More recently, the utility of mulching has been assessed in various forestry applications including the establishment of hardwood and conifer plantations, short rotation woody crop plantation and in reforestation efforts (McDonald and Helgerson, 1990; McDonald et al., 1994). Mulching confers a large benefit in forestry applications on poorer sites under conditions of greater
The positive influence of mulches, both natural and synthetic may be ascribed to multifarious factors. Plastic mulches, while compared to other mulches, are completely impermeable to water, thus prevent direct evaporation of moisture from the soil and thus limit water loss. Plastic mulches can reduce the loss of plant nutrient through leaching, provide a barrier to soil pathogens, prevent germination of weeds, repel certain insects and even maintain a warm temperature during night time enabling in establishment of strong root growth system. Above all, plastic mulches have exceptionally high soil solarization effect and thus control soil borne plant pathogens including those of fungi, bacteria, nematodes and also insect and mite pests along with weed seed (Ahmed et al., 2013). Mulching can significantly modify the micro-climate around the plants. Furthermore, poly mulch decreases the degree of soil kneading (Siwek et al., 2007). Lower quality, well-drained soils as associated with present investigation, tend to have inherently lower thermal insulation (McDonald and Helgerson, 1990; Tarara, 2000) and the high radiation loads and/or surface wind velocities imposed on soil may result in high evaporation water loss in shallow regions from where bamboo shoots procure most of their moisture. Additionally, soil temperature in such low quality soil is always higher than the high quality site under same condition and obviously the former may reflect a greater vulnerability to moisture stress. Thus the use of poly mulch in low quality soil may provide an attractive management option (Green et al., 2003). As short rotation woody crop systems, bamboo for shoot cultivation requires high input of fertilizers as well as repeated mechanical cultivation (Kleinhenz and Midmore, 2001), mulching may offer a particularly effective management alternative to reduce both costs and environmental impacts (Green et al., 2003).

Cao et al. (1995a, 1995b) observed that mulching increased the soil temperature, made the shoots emerge earlier, prolonged the shooting period and raised the yield and value of the shoots. The comprehensive evaluation of the results showed that rice chaff has been the best among the mulches tested. Compared to the control plots, rice chaff increased the shoots yield by 29.4%, the
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shoot production value by 270.3% and the stands economic benefit by 310.2%. The average soil
temperature at 10cm, 20cm and 25cm depth was increased by 5.33, 3.83 and 1.75°C by rice stalk,
rice chaff and bamboo leaves respectively and temperature rise has been notable during
December and January. All mulching treatments made the shoots emerge earlier and prolonged
the shooting period. Rice chaff and bamboo leaves in particular were very effective in that they
advanced the shooting time by 41 and 96 days and prolonged the shooting period by 40 and 97
days, respectively.

The soil temperature increased in underlying soil might have boosted the physiological activity of
the bamboo plants and stimulated the sprouting of shoots (Cao et al., 1995a, 1995b). Mulch
materials are also found to insulate the soil against heat loss during cold winter night’s thereby
boosting physiological activity of bamboo plants facilitating early and prolonged shoot
development and improving total yields. Whether under tropical or temperate condition, natural
covers and particularly bamboo leaves (Joshi et al., 1991), rice straw and rice hull are preferable
as their decomposition by microorganisms provide extra heat energy that many promote early
shoot growth. It has been noted that, on an average, due to the influence of the mulching
materials, the shoot duration have been increased from 37.0 days in the control clumps to a
maximum of 75.7 days in D. asper from 70.7 to 104.3 days in B. nutans and from 17.0 to 69.7
days in D. strictus during 2011. Further, in individual clumps, the shoot period had advance
universally for all the species in three years of study due to the mulching effect. In D. asper, the
shoot emergence has commenced at least 6 to 17 days, 6 to 26 days and 5 to 19 days earlier during
2010, 2011 and 2012, respectively. In B. nutans, seasonal shoot appearance had been advanced by
16 to 35 days, 18 to 31 days and 10 to 20 days during 2010, 2011 and 2012. For D. strictus, the
corresponding advancements are upto 16, 37 and 18 days during 2010, 2011 and 2012
respectively in spite of some minor exceptions. Kleinhenz et al. (2003) opined that water supply
has a major effect on bamboo growth and shoot yield. As already stated, mulches conserve soil
moisture by reducing evaporation (Thanarak, 1996) and enhance other soil properties including reduction in bulk density, improvement of water holding capacity, cation exchange capacity, weed control, erosion control, reduced surface water runoff and maintenance of soil organic matter. In one hand, the organic mulch materials, as administered in the present study, might have influenced the shoot emergence behaviour of the species under study through mineralization and subsequent absorption. The repeated application of OM along with mulch might also have some residual effect in improving the nutrient pool in addition to improvement of soil physical properties.

Christanty et al. (1997) described the development of a profuse system of fine and small roots by bamboo within the mulch layers and the mineral soil surface providing for efficient nutrient absorption. This may explain why mulching in combination with OM addition significantly improved shoot emergence in the three species. Though bamboos, designated for shoot production responds well with inorganic form of fertilizers and combined with higher irrigation rate (Kleinhenz et al., 2003) under the present situation, OM is combined with mulches support encouraging effect but the interaction is insignificant. In Bnkidnon, Philippines, where standing culm density of *D. asper*, maintained at 6-6 i.e., 6 culms each of 1 and 2 year old, increased shoot emergence have been recorded for three years from 2002 to 2005 in response to either inorganic fertilizer or mulch individually but no extra response to both combined (Decipulo et al., 2009). The present trends of shoot emergence, their duration and also the enhancement of culm length and diameter improvements corroborates the findings of Malab et al., (2009) who observed suppression of shoot production in Philippines with *Bambusa blumeana* due to omission of fertilizer, mulch and organic matter.

On an average, *B. nutans* favours production of less number of shoots as compared to *D. asper*. The species differed in their response to the imposed treatments may be because of their genetic makeup, as supported from lesser shoots in *D. strictus* than the other two, but also because of their
relative ages. The *D. asper* clumps were of 7 year old those of at the onset of the study while both
*B. nutans* and *D. strictus* were 4 years in age.

The results on the effect of mulches together with OM on the three bamboo species also revealed
a general attrition of the mulching benefits during 2012. This may be associated with lower range
of precipitation during that year compared to the previous two years as reflected from the
meteorological information presented in Fig. 3a and 3b. Some ambiguity may be due to poor soil
condition or some other factors as an overriding effect. The benefits of mulch have been reported
to be much less than fertilizer probably because the major role of mulch is to conserve soil water
against evaporation and under the local condition mulch might have prevented light rainfall
during 2012 from entering the soil and the root zone. Otherwise minor beneficial effects of mulch
may be associated with the cycling of nutrients. ABSTRACT

A field study has been conducted to investigate the decomposition of various mulching materials
including bamboo leaves (C/N ratio 20) and rice straw (C/N 49) on *Phyllostachys praecox* forests
located in Lin’an, Zhejiang Province, China (Zhang et al., 2003). The results showed that bamboo
leaves and rice straw have been decomposed by 79.30 and 67.54%, respectively. The C content
from these decreased by 14.80 and 15.32% and N content increased by 15.77 and 173.26% with
concurrent decrease in C: N ration by 26.36 and 67.50%, respectively. It is also found that mulch
treatment enhanced soil respiration rate. The residual materials had a significantly higher alkyl C
to O-alkyl C ratio, but lower aromaticity than those in the original materials. The soil beneath the
mulches rapidly built up organic C, which was dominated by O-alkyl C with reduced aromaticity.
Thus, application of heavy mulch in a *Phyllostachys praecox* may enhance sequestration of soil C.
However, the relatively low aromatic C character would indicate that it is likely to be labile. The
labile C makes up a fraction of total C pool, breaks down relatively quickly and an active source
vegetative competition and for genotypes poorly suited to site conditions (Davies, 1988b, Adams 1997; McDonald and Helgerson, 1990).

The main purpose of using covers and mulches in bamboo stands is to protect rhizomes, roots and new shoots from excessively warm or cold temperatures and from solar radiation (Chaturvedi; 1988; Fu and Banik, 1995; Zhang et al., 2003).

Organic residues like grass clippings, straw, rice hull or rice chaff, leaf or foliage of different origin, pine needles, corn leaves, stalks and cobs, are being widely used, for improvement of bamboo growth and shoot and culm yield (Cao et al., 1995a, 1995b; Marquez, 2009; Decipulo et al., 2009; Malab et al., 2009). To avoid loss in quality of fresh edible bamboo shoots e.g., by greening, early aging and deterioration of taste, Lin (1995) and Thanarak (1996) recommended covering of the growing area with soil, mulch and/or plastic materials. Black polyethylene sheeting (poly mulch) has become the most commonly used material in agriculture because of its specifically thermal and optical properties considered to be particularly beneficial (Flint and Childs 1987; Walker and McLaughlin, 1989, Tarara, 2000). Organic mulches decay over time and are temporary. The way particular organic mulch decomposes and reacts to wetting by rain and dew affects its usefulness.

In the present investigation, significant influence in enhancing number of shoot emergence and their survival has been noted with all the mulching materials with and without organic amendments with very few exceptions. The duration of shoot period for all the species have also increased to a considerable extent due to the said treatments though statistically non-significant. The role of poly sheet mulch is more prominent in these respect, though in some instances, role of rice straw and bamboo leaf mulches surpass that of poly sheet as in case of shoot emergence duration for *D. asper* during 2011 and 2012, for *B. nutans* during 2010 and for *D. strictus* in all the three years.
of nutrition. It is an indicator of change in the soil. Liable C is also the major source for soil microbes. The size and quality of the labile C pool influences the decomposition rate.

5.2.3. Effect of clump management/thinning on emergence of shoots, survival of shoots, duration of emergence of shoots, culm length and culm DBH in *D. asper, B. nutans,* and *D. strictus* during the year 2010, 2011 and 2012

Manipulation of culm growth in bamboo involves the removal (i.e., harvesting) of culms of different age. Bamboo may be grown solely for one or more products at the same time. Thus, culm management aims to maximize the yield of one product, or alternatively to optimize yield of individual products to increase their combined monetary output. Since, bamboo is a perennial, all culm management practices must also aim to sustain long-term productivity of the stand (Virtucio, 2009). The intensity of removal dictates the total number of culms per unit area remaining, and the choice of culms harvested based upon maturity status governs the age structure of culms i.e., the relation between younger culms and older culms.

Culm age is tremendously important for quality of harvested bamboo products. They are harvested just prior to or shortly after emergence. For pulping and papermaking, 1-year-old bamboo culms are harvested when fiber quality is superior to that of older culms (Fu and Banik, 1995). Culms of most species mature after 3-4 years when they attain their maximum static bending and compression strength (Liese and Weiner, 1995) are ready for harvest. One of the most important quality parameters in fresh bamboo shoots and culms for timber is diameter. There is an inverse relationship between yield and diameter of shoots and culms, which is determined by standing-culm density or SCD (Sagwal, 1987).

Inappropriate or inadequate culm management jeopardizes bamboo resources worldwide (Yao, 1994; Fu and Banik, 1995; Perez et al., 1999). Congestion of clumps stresses bamboo plants to the extent that they may flower and finally die. Even simple management practices such as removal of dead and dying culms found to have increased productivity of congested clumps (Sharma, 1980; Lakshmana, 1994). If bamboo stands are left undisturbed, biomass production
increases until aboveground and belowground competition results in decreasing annual rates of biomass gain.

Optimum SCD varies with bamboo species and is usually much higher for smaller diameter species than for medium and bigger-diameter species (Kleinhenz and Midmore, 2001), and for individual species it also vary with growing conditions. In commercial bamboo forests of *P. pubescens* and *P. makinoi* in Taiwan, growers maintain greater standing-culm densities under ‘poorer’ conditions to promote higher culm yields and lower standing-culm densities under ‘richer’ conditions to promote greater culm diameter. Siddiqui (1994) and Shi *et al.* (1993) recommended standing-culm densities of 1,700 – 1,900 culms/ha under standard conditions but Patil *et al.* (1994) suggested a standing-culm density of 15,000 – 21,000 culms/ha on marginal land.

Appropriate densities vary dramatically depending on the product(s) for which bamboo is cultivated. These average 7,400, 9,100, and 13,300 standing-culms per hectare for shoot-only, shoot and timber and timber-only bamboo stand, respectively. Variations from these averages are due to species differences (higher density for species with thinner culms), yield (higher density for greater total yields), shoot and culm quality (lower density for thicker shoots and culms) and production sites (higher density to maximize yield in ‘poorer’ sites and lower density to maximize quality in ‘richer’ sites).

Age structure of standing culms is not a growth-limiting factor or a major consideration when the stand age is young. Young plants have a low leaf area index and total leaf area is the growth-limiting factor. Thus, a greater number of culms increases total leaf area, capture of solar radiation, and productivity in stands without full canopy closure. For maximum biomass production of a young stand, Thanarak (1996), and Tuncharearn and Suwajittanon (1996) recommended not to harvest culms in *D. asper* till a stand attains 4 years in age. In older plantations, ground cover by canopies is complete, and the photosynthetic capacity of leaves and
the ability of culms to transport assimilates and nutrients limits growth. In sympodial bamboo, younger culms contain relatively younger and more productive leaves and their transporting tissues are more effective than older culms.

The age structure of a bamboo stand can be modified by felling culm when they have reached a specific age. If culms are removed according to a short felling cycle, as has been administered in the present study, there will be a greater proportion of younger culms in a stand and, therefore, the age structure of the stand is younger.

All the thinning operations that actually prescribed for the removal of all or most of the older culms have supported better emergence of shoots, their survival and also duration of shoot emergence. At the outset of the trial, clumps were cleaned and all culms of more than 4 year old have been removed before assigning the designated thinning schedule. The older culms left after the thinning operation might have physically supported the clumps which have facilitated better shoot emergence and culm growth. Removal of 50% culms of more than 2 year old has supported maximum shoot emergence followed by either 100% removal of more than 2 year old culms or 100% removal of more than 3 year old culms.

It is well known that annual yield of a bamboo clump depends on the number of new culms produced each year. Young culms contribute greatly to the health of the clump through photosynthesis in their new leaves. The foods they synthesize are partly consumed by leaves but the greater proportion is transported to the rhizomes, stored as energy and is converted into next year’s new shoots (Zhaohua and Yang, 2004). Thus, a ‘too old’ or ‘too young’ age structure of a stand may constrain stand productivity through decreases in the photosynthetic capacity of the canopy or in the photosynthetic active leaf area, respectively (Kleinhenz and Midmore, 2001). Lakshmana (1990) showed that 1 year old standing culms contributed 77% to annual production of new culms in *B. arundinacea* while 2-year old culms 20% and culms of above 2 year old only 3%.
It is apparent that younger culms contribute disproportionally in favour of production. In ancient China overharvesting of 1-year-old culms for paper making harmed bamboo populations (Fu and Banik, 1995), while harvesting of 2-year-old culms resulted in depleted bamboo stands in Indonesia (Sutiyono, 1988). For many sympodial bamboo species in India, Chaturvedi (1988), however, concluded that culms >2 years old contribute only little to growth of new culms. It appears that 1-2-year-old culms are required to maintain productivity of bamboo stands; culms younger than 2 years must be left to reach productive age, while older culms could be harvested since they contribute little to stand productivity.

On an average, maximum shoot emergence and subsequent survival have been recorded in *D. strictus* followed by *B. nutans*. However, the emergence in *D. asper* was much less than the other two species. This may be due to the age difference between the species. *B. nutans* and *D. strictus* are plantations of 15 year old while that of *D. asper* only 7 year when treatments were assigned. Further, the standing culms at the outset of the trial were also maximum in *D. strictus* followed by *B. nutans* and the least in *D. asper*. According to Kleinhenz and Midmore (2011), compared to other species, *D. asper* is not found to be a prolific shoot producer. Like total and above ground biomass, shoot biomass may also vary substantially within individual species, even when cultivated at the same site. Due to high genetic variability, shoot production may vary enormously. Kiang *et al.* (1976) measured yields of edible shoots ranging from 7.4 to 20.3 kg/clump/yr i.e., 0.74 to 2.03 t/ha/yr with 100 clumps/ha in different strains of *D. latiflorus* growing in one site. Although *D. latiflorus* may have a yield potential up to 41 t/ha of edible shoots per year.

For systematic management to ensure maximum quantity and volume, field study on the effects of NPK (15:15:15) fertilizer and felling of mature culms at intensities of 0, 40, 60 and 80% have been practiced on *Gigantochloa scortechinii* natural stands, an important species for industrial uses in Peninsular Malaysia over 2 year period (Azmy, 1995). Only culms of ≥ 3 year have been
felled as per the assigned treatments. After 1 year of felling, the mean number of shoots showed significant increase at the felling intensity of 80% though not for fertilizer application and their interactions. Harvesting intensities of 0 and 40% showed significant difference in their respective values. Fertilizer application, however, showed no substantial effect but various felling intensities did show notable effects on bamboo clumps. There was no notable effect for fertilizer. Though 2 kg of NPK 15:15:15 applied to every clump resulted in a 30% increase in the sprouting of the shoots.

Fu and Banik (1995) emphasized on the culm density regimes based on intended end use. For the planned end product of large sized monopodial species such as *P. pubescens* is 7/8 year old culms, the recommended age structure is in the ratio of 3:3:3:1 for 1 - 2, 3 - 4, 5 - 6 and more than 7 years old culms. For shoot stand, the reasonable density should be 2,225 culms per ha for large sized monopodial species and 9,000 to 12,000 culms (1 to 3 year old) for medium and small sized ones. In case of sympodial species each clump can have 6 to 8 culms of 1 to 2 years of age. A few 3 year old culms may be retained. For young bamboo stands, early thinning within the first 2 years of establishment may negatively affect the bamboo growth. However, greater number of older culms reduces the size of the new culms (Midmore *et al.*, 1998).

In the Northern Territory of Australia, by thinning of 3.5 to 4.5 year old *D. asper* and *D. latiflorus* clumps and retaining higher percentage of 1 year and 2 year old standing culm density (SCD), maketable shoot yield have been increased (Traynor and Midmore, 2009). Higher SCD may result in the development of more rhizome axes and a greater shoot yield potential from the growing points of these axes. It was found that 1 and 2 year old culms can produce 90% of new shoots. A productive thinning strategy for shoot production would maintain only 1 and 2 year old culms or their higher percentage and apply a SCD that encourages strong rhizome development. Possible thinning scheme focusing on shoot production might be 4-4-2 or 4-4. If both shoots and mature 3-year-old timber culms are to be
Discussion

harvested, then 4-4-4 would be a better schedule. Before the first thinning operation of young bamboo plants, it is important to encourage a well-developed and branching rhizome. Culm yield has been found to be the reflection of the number of culm harvested. Culm yield ranged from 3.5 to 3.7 to 6.8 t/ha/year for the treatments with SCD of 4-2-2, 2-2-2 and 4-4-4, respectively.

Malab et al (2009) obtained significant differences with number of shoots produced in 2 year old mother culms within clumps under the SCD regimes of 4-4-4-4 and when all 3 year old culms are removed. They have recorded negatively affected shoot production where no shoots or culms were harvested. The potential number of shoots was also higher in the 4-4-4 and 4-4-4-4 SCD regimes than 3-3-3 culm density per clump. Decipulo et al. (2009) also observed enhanced shoot production from clumps with higher numbers of 1 and 2 year old culms of D. asper. They have noted higher shoot production as well as healthy culm numbers with SCD of 10-10, 6-6-6 and when all 3 year old culms were harvested. The tallest and thickest D. asper culms have been harvested from assigned harvesting strategy of 10-10 SCD.

Hoanh (1992) studied impact of silvicultural treatment on culm properties particularly culm diameter and height in case of Bambusa blumeana at Mt. Makiling, Los Banos, Laguna. Highest means of culm diameter was 68 mm at 300 g of complete fertilizer treatment. The study also showed that silviculture treatment such as thinning and pruning have provided favourable condition for faster growth and development of bamboo. Thinning the small culms and lower branches provided more sunlight and space at the base of the clump for the growth and development of new bamboo shoots into the culm.

For improving the productivity of the young bamboo plantations as in our experiment at Ranchi, the management option is the fertilization with N, P and K as per site requirement and leaving culms and harvesting 3-year old culms that may result in highest growth and yield of plantation. This may hold true if the objective is to produce culms only. On the other hand, if the objective is to produce edible shoots and timber, 4-4 combination coupled with the application of fertilizer,
mulch and irrigation would result in significantly longer duration of shoot emergence and yield as observed by Marquez (2009) while improving and maintaining productivity of *B. blumeana* in Capiz, Philippines.

**5.2.4. Effect of bamboo shoot harvest on emergence of shoots, survival of shoots, duration of emergence of shoots, culm length and culm DBH in *D. asper*, *B. nutans*, and *D. strictus* during the year 2010, 2011 and 2012.**

In order to maintain bamboo plantations and maximize yield on sustainable way for both shoot and timber, shoot harvest during the early season of emergence is another option. Shoot harvest during the shoot season is also mandatory for maintaining the prescribed SCD for sustainable yield of either timber i.e., culms or edible bamboo shoots. Culinary bamboo shoots are immature culms harvested just prior to or shortly after emergence. Shoot emerged during initial shoot season may give rise to new shoots at the later phase of the same season under high rainfall condition as observed in Northern Territories, Australia (Traynor and Midmore, 2009). Thus, it is also possible in Jharkhand for enhanced shoot production if arrangements for irrigation, at least one month in advance and during the shoot season are assured.

For the present study, across the treatments where shoots are removed during early shoot season support higher shoot emergence and their survival significantly. The increase in shoot number with age or clump development of a young plantation is a natural phenomenon and that has been manipulated through shoot harvest at the very early stage of growth season. This may be explained from ‘conservation of energy’ point of view.

For growth and production, it is of particular importance to understand the sources of energy and nutrients that sustain the rapid accumulation of biomass in young culms. Since, shoots at very early stage and subsequent young culms have no photosynthetic leaf area to provide energy and sustain their growth, there should be a net-import of energy for the early sustenance (Pearson et al., 1994; Liese, 1995). Li *et al.* (1998b) estimated that during the rhizome growth stage only
26% of the total non-structural carbohydrates in *P. pubescens* are located in rhizomes whereas culms contain 44%. Both Uchimura (1980) and Li *et al.* (1999) measured decreases in concentration of carbohydrates in rhizomes during new culm and rhizome growth in the same species and the decrease in carbohydrate content of rhizomes could provide no more than 20% of the carbohydrates required for the accumulation of biomass in new and non-photosynthesizing culms. The remaining 80% most likely originates from current photosynthesis and stored photosynthates in older (≥ 1-year-old) culms. Sulthoni (1995) studied seasonal variations in starch contents of bamboo culms of *B. vulgaris, Dendrocalamus asper, Gigantochloa apus*, and *G. atter* and the starch contents in these species are comparatively high before the shoot season i.e., the period when shoots extend through the soil surface, but are non-existent after completion of culm expansion (Sulthoni, 1995). That starch is not stored in those culms thereafter until just prior to the next shoot season and this suggests that photosynthesis by culms ≥1 year old after the shoot season does not contribute to the storage of non-structural carbohydrates in readiness for the following shoot season but rather to development of new rhizome and root biomass.

It may be argued that harvesting of shoots during early shoot season perhaps divert the energy reserved for shoot elongation of the removed shoots towards the new rhizome-buds for flushing their growth within the same season with cumulative increase in shoot number. Midmore (2009) has reported a weak negative relationship between the number of shoots removed during the shoot season and the culm biomass production. The energy and nutrient elements which are, otherwise, supposed to facilitate growth of newly emerged shoots are acting as stimulating agent for development of most viable rhizome bud in this respect in favour of numerical preponderance of emerged shoots within the same shoot season.
In spite of the fact that there is no ‘true’ storage of photosynthates in bamboo (Kleinhenz and Midmore, 2001), assimilation products are temporarily stored in culm tissues (i.e., parenchyma cells) to be remobilized and translocated to rapidly growing new culms (and other plant parts) as needed. The primary role of (pseudo-) rhizome tissues in bamboo is transport rather than storage, i.e., to connect young culms dependent upon imported carbohydrates to older culm sources.

Although bamboo rhizomes may contain large quantities of nutrients (Li et al., 1998b), their ability to remobilize and translocate these to new culms (and other plant parts) is questionable. Li et al. (1999) noted no decrease in nitrogen content in rhizomes over the shoot season, indicating that N supply of new culms from N stored in rhizomes is insignificant or that export of stored N from rhizomes is adequately replaced by N from other plant parts or from the soil. In the same study, the authors calculated that translocation of nutrients from re-mobilized reserves in other plant parts (e.g., senescing leaves) is only of minor significance (e.g., 7% of N required). They, therefore, concluded that required nutrients to sustain the rapid growth of culms are mainly absorbed directly from the soil.

It is noted that 50 per cent shoot harvest during early shoot season favoured maximum increase in total number of shoot emergence and their survival for all the species in three consecutive years with very few exceptions. These results are in agreement with those of Jha (2010) in most occasions. Jha (2010) harvested young shoots at 25, 50 and 75% intensity from natural habitats of *M. baccifera, D. hamiltonii, D. longispathus* and *D. tulda* in Mizoram to study the impact of shoot removal during early season on total shoot emergence within the same shoot season and growth of the shoot species. For *D. longispathus*, 50% juvenile shoot removal during early shoot season has supported maximum percent increase in shoot and culm numbers. Average culm lengths and diameter for three years of study. In *D. hamiltonii* both shoot emergence and culm diameter have increased more with 50% harvest intensity and 70% shoot harvest favoured maximum culm length immediately followed by 50% harvest. In *B. tulda* 50% removal of shoots
also maintained higher per cent increase in number of shoot emergence, their survival, culm length and culm diameter during all the three years of study except maximum shoot number during the second year with 75% shoot removal.

5.3. **Proximate analysis, nutritional and anti-nutritional constituents of bamboo shoot due to effect of mulching and organic amendments in *Dendrocalamus asper*, *Bambusa nutans* and *Dendrocalamus strictus***

Bamboo shoot is becoming one of the most favourite food items among people all over the world with every passing day. Edible shoots are harvested within 7 – 10 days of emergence above the soil surface. If they are allowed to grow well above the surface, they become tough and woody and lose their delicate taste and aroma.

As already stated, juvenile bamboo shoots have a long history of utilization as food for its characteristic taste, nutritive and medicinal values and more than 500 bamboo species can produce edible shoots. The shape and dimension of shoots and also the shoot season vary from species to species and also from place to place. The characteristics for which bamboo shoots are preferred may be stated as low in calorie, low in fat, high in dietary fibre and rich in various nutrients. The main nutrients in bamboo shoots are protein, carbohydrates, amino acids, minerals, fibre and inorganic salts. Fresh shoots have a good profile of minerals, consisting mainly of potassium, calcium, manganese, zinc, chromium, copper, iron, phosphorus and selenium, ‘the miracle life element’. Fresh shoots are a good source of thiamin, niacin, vitamin A, vitamin B₆ and vitamin E along with some bioactive compounds referred to as ‘phytochemicals’ like phenols, phytosterols etc. (Chongtham *et al.*, 2007 and 2011; Shi and Yang, 1992; Visuphaka, 1985; Xia, 1989). In spite of having nutritive and health enhancing attributes, shoots contain cyanogenic glyeocide, called taxiphyllin (Hunter and Yang, 2002). Potential toxicity of cyanogenic glyeocide results in cyanide poisoning in humans and other life-forms including live-stocks.
However, cyanide content may be substantially decreased following harvest (Chongtham et al., 2007); chopping, fermentation (Bhatt et al., 2005) and cooking in boiling water (Ferreira, 1995). The variation in concentration of these nutritive and anti-nutritive values is also common among bamboo species and from one place to another and also between fresh and processed shoot products (Singh, 2006; Bhatt. et al., 2005b; Chongthamn et al., 2011, Choudhury et al., 2010; Pandey et al., 2012).

The recommended length of young shoots for harvesting is generally upto 45 or 50 cm (Choudhury et al., 2010), in the present study, shoots of all the species have attained the length from 50 cm to 80 cm with mean of about 65 cm. This length is comparatively larger than recorded by Marquez (2009) from Capiz, Philippines with *Bambusa blumeana*. He reported length, diameter and average weight of *Bambusa blumeana* shoots as 27 to 30 cm, 8 to 12 cm and 950 to 2800 g, respectively. The basal diameter of *D. asper*, *B. nutans* and *D. strictus* shoots as harvested for this study at Ranchi are 6.4 to 8.0 cm, 6.0 to 9.4 cm and 4.1 to 6.0 cm weighing fresh from 916.7 to 1535.0 g, 828.1 to 1771.1 g and 425.5 to 1172.0 g, respectively. Midmore (2009) from Australia have reported the average weight of *D. asper* shoots upto 4.50 kg. The shape, size and weight of shoots depend considerably upon the species, location, depth and nutritional status of the soil, irrigation, fertilization and clump management strategies. In general, for temperate zone, winter shoots are smaller while the summer shoots are larger.

Bhatt et al., (2004) have reported diverse shape of edible shoot harvested from NE states. Shoots of most species, there are cylindrical either thick or narrow, some are conical, short and stout (*B. balcooa, D. hamiltonii, Gigantochloa rostrata*) or bullet shaped, short, thick (*D. sikkimensis*). The length of the shoots also varies significantly species to species. *D. giganteus* are found to be longest and thickest with dimension of 34.6 cm in length and 13.11 cm in diameter and *Teinostachyum wightii*, the shortest and thinnest 13.0 cm in length and 0.8 cm in diameter.
Shoot weight of edible part is found to be maximum for *D. giganteus* (1.86 kg/shoot) followed by *B. balcooa* (1.6 kg/shoot), *D. sikkimensis* (1.4 kg/shoot) and *G. rostrata* (1.2 kg/shoot). The lower levels of shoot weight have been recorded with *Melocanna baccifera* (0.17 kg/shoot), *Phyllostachys bambusoides* (0.13 kg/shoot), *B. wightii* (0.13 kg/shoot) and *Schizostachyum dullooa* (0.05 kg/shoot). The mean edible shoot weight of *Chimonobambusa hookeriana* and *D. hamiltonii* from Sikkim has been found to be 0.334 and 0.850 kg respectively (Bhatt et al., 2003a; 2004). For the present study, the mean weight range of edible part of the shoots of *D. asper*, *B. nutans* and *D. strictus* have been recorded as 0.505 to 1.107 kg, 0.543 to 1.236 kg and 0.237 to 0.745 kg with mean moisture content of 79.6, 78.6 and 80.7%, respectively. The present values of moisture content in shoot is not in conformity with the shoot moisture contents as reported by Choudhury et al., (2010) with a number of species including *D. strictus* and also by Singh (2006). They observed more than 89% moisture in the edible part of the most of the species of shoots they studied except in *D. strictus* shoots which contains 86% moisture. However, the percent edible part in *B. nutans* recorded at Ranchi is in agreement with the values obtained (63.1 to 74.0%) by Singh (2006) with the same species. The ranges of edible parts for the *D. asper* and *D. strictus* in the present investigation are 52.9 to 66.5 and 52.4 to 71.8%, respectively.

The results, concerning the nutritive and anti-nutritive values have failed to manifest any remarkable trends for the treatments assigned to *D. asper*, *B. nutans* and *D. strictus* clumps. Some inter species variations and variations due to shoot parts have been recorded. Nevertheless, the information is of immense value for popularizing shoots of other species than *D. strictus* which is universally accepted for its juvenile shoots throughout the Central and Eastern part of our country.

Although cyanogenic glycosides or HCN is unknown as a problem in the Chinese bamboo shoot food industry, there are several reports elsewhere of bamboo species containing significant, potentially very toxic amount of HCN in their shoots (Hunter and Yang, 2006). However,
elimination of cyanide can be accomplished reasonably easily (Ferreira et al., 1995). The mean HCN content in *D. asper*, *B. nutans* and *D. strictus* studied at Ranchi varies from 0.0907 to 0.1035%. This range is much higher than what Bhatt et al., (2005b) reported (0.009 to 0.02%) which is much less as reported from various sources (Poulton, 1983; Tewari, 1992; Tripathi 1998; Choudhury et al., 2010) reported 0.017 to 0.242% HCN in the tips of some commonly edible shoot species from NE Indian states. The higher concentration of cyanide in the tip part than the mid-part in the present study is in conformity with all the previous studies made HCN content in bamboo shoots. The present level of HCN test may encourage the shoot processors and consumers to prefer Jharkhand shoots than from other places.

Carbohydrate and sugar content for the species in the present study vary from 10.0 to 13.9 and 3.03 to 3.22%, respectively on an average. These values are on the higher side in comparison to those observed by Bhatt et al., (2005b) and Choudhury et al., (2010). Values to the tune of 16.7 to 21.1% of protein on dry matter basis are in conformity with those reported by Singh (2006) as 2.67 to 3.41% N on dry shoot mass is not very uncommon.

The ranges of P, K, Ca, Mg, Na and Fe concentration in bamboo shoots as observed with *D. asper*, *B. nutans* and *D. strictus* are nearer to the values reported by Singh (2006), Bhatt et al., (2005a), Chongtham et al., (2011) with diverse bamboo sp