Chapter VI

Biomass and productivity dynamics of cultivated bamboo species - *Bambusa pallida* and *B. tulda*

6.1 Introduction

Biomass is the total quantity of organic matter per unit area present in an ecosystem at a given time and may relate to a particular species, a group of species of a community as a whole. Primary producers in an ecosystem convert the solar energy into organic matter and accumulate it after respiratory utilization in the above and below ground parts (Golley and Leith, 1972; Odum, 1971). Such biomass studies are important to know the biological productivity and at times to know the economic productivity (Shanmughavel and Francis, 2001) and generally biomass is expressed on the basis of oven dry weight. The productivity of bamboo is assessed by the number of new culms produced annually. Production of new culms mostly depends on the degree of congestion, culm age and rainfall of the previous year (Shanmughavel *et al.*, 1997). Net primary productivity refers to the rate of organic matter storage in plant tissues in excess of the respiratory utilization during the measurement period. Accordingly, Egunjobi (1957) it may be considered as the rate of net primary production of organic matter left after respiration but including all the losses from litter fall, grazing etc. Productivity is one of the most important functional attributes of an ecosystem and this provides basic energy and matter for all the other biotic components of the ecosystem (Billore and Mall, 1977). It is also an index of fertility of an ecosystem for the organic matter production. Due to its fast growing nature, bamboo can accumulate maximum amount of biomass with higher productivity for which it may be considered as ideal species to establish carbon sink.

Bamboo is the only woody perennial grass, having the shortest gestation period and it plays a key role in carbon sequestration by fixing atmospheric carbon dioxide, which is one of the most important green house gasses (Pande, 2004). The biomass mainly depends on soil and climate of the area, topography, altitude, scientific cultivation and management of bamboo groves (Othman, 1992). Although
biomass and production is species specific, it also depends on the stock density and age (Banik 2000, Shanmughavel and Francis, 2001).

Moreover, short rotation of bamboo plantation couple with intensive management and rapid growth rates are also characterized by high rates of nutrient removal in the harvested biomass (Kumar et al., 2005). The associated high nutrient export potential especially with whole culm harvesting may deplete the nutrient capital in the system (Kumar et al., 1998). Estimating biomass and productivity can also help in the determination of nutrient removal through harvest and also in formulating suitable management strategy for sustainable production in natural stand as well in plantations.

Several studies were carried out on bamboo productivity in South East Asian Countries (Christanty et al., 1996, Isagi et al., 1993, Kao and Chang, 1989, Suzuki and Jakalne, 1986). In India, most studies are confined to exploration and distribution of bamboo species (Bahadur and Jain, 1983, Gadgil and Prasad, 1984, Haridasan et al., 2000, Beniwal and Haridasan, 1988, Biswas, 1988). In Arunachal Pradesh, there are about 57 bamboo species; some are highly exploited from the natural resources as well as from plantation gardens. On the other hand some species are planted and managed by the farmers in the homestead gardens (Haridasan et al., 1987, Sarkar and Sundryal, 2002) to meet their daily requirement as well as for selling them in the market. The present study, therefore, aims to determine the biomass and productivity of two species Bambusa tulda and B. pallida at different altitudes which were managed by the farmers themselves. These two species are predominated and widely distributed and popularly cultivated and utilized in and around the homestead gardens or in demarcated plot to fulfill the demand of bamboo culm in day to day life.

6.2 Materials and methods

This study was conducted in Sagalee, Toru, Kimin and Balijan circles of Papumpare district selecting bamboo garden of the same age group which are about 5 to 7 years old. The Biomass production of Bambusa pallida and B. tulda were measured at six months interval to evaluate the productivity (tonnes ha⁻¹Year⁻¹). Sampling was started during April 2007 at the above four circles and continued till April 2009 at six months interval over a period of two years.
Population density of *Bambusa pallida* and *B. tulda* of different compartments like < 1 year old, 1-2 years old and > 2 years old was also studied by counting the available stock from those earmarked clumps in permanent quadrats at each location.

Biomass determination is done by destructive sampling technique (Milner and Hughes, 1968) from 10 earmarked permanent quadrats of 10mx10m size in each location. The new culm production per hectare is also calculated from the permanent quadrats. From each location, 15 culms for each age group of <1 year, 1-2 years and >2 years were harvested, measured and weighed at field and then dry weight was taken after oven drying during April- 2007, Sept- 2007, April-2008, Sept-2008 and April-2009. The leaves (including culm sheath, if any) were oven dried at 60°C for 48 hours while branches and culms were dried at 105°C for 48 hours. Conversions of total fresh to dry weight were then calculated based on the methods used for the determination of moisture content (Suzuki and Jacalne, 1986). In this study, only the aerial bamboo biomass was considered as aboveground bamboo biomass. The aboveground primary productivity (t ha⁻¹ yr⁻¹) at different locations was determined by “Difference method” (Egunjobi, 1957 and Odum, 1971). Above ground net primary productivity at different location was computed by the method “Sum of positive increment in biomass plus mortality” as outlined by Singh and Yadava (1974). Thus for computing annual productivity the positive increment in 1 year old, 1-2 years old and more than 2 years old individual at successive sampling dates for one year period were summed up for respective locations. The data are recorded for six month intervals as well on annual basis for two consecutive years.

6.3 Results

6.3.1 Clump and Culm density at different sites

The prominently used bamboo species *B. pallida* and *B. tulda* are investigated for their density from each of the 10 earmarked 10 mx10 m quadrats from the respective locations and it is converted to per hectare area. The density of cultivated species *B. tulda* is recorded highest (210 clumps ha⁻¹) in Balijan among all the species followed by Kimin (170 clumps ha⁻¹) and Toru (160 clumps ha⁻¹) which can be attributed to its high value for local people (Table 6.1). Table also reveals that the clump density of *B. pallida* is the highest in Balijan (150 clumps ha⁻¹) followed by Kimin (130 clumps ha⁻¹) and Toru (120 Clumps ha⁻¹) and lowest in Sagalee (110
clumps ha$^{-1}$) circle. It also reveals that the number of clump per hectare decline with the increase of elevation for both the species. Simultaneously, total number of bamboo species per hectare are highest in Balijan circle (380 clumps ha$^{-1}$) followed by Kimin and Toru with equal number of clump (360 clumps ha$^{-1}$).

Table 6.2 reveals that total culm density of $B. tulda$ is significantly (F=63.445, P< 0.001) greater in Balijan i.e., 10060 culms ha$^{-1}$ in 2006 and increased to 11840 culms ha$^{-1}$ in 2007 and 13920 culms ha$^{-1}$ in 2008 along with years (F=59.716 , P< 0.001), which decline with the increase in elevation. The second highest bamboo culm density is observed in Kimin i.e., 6030 culms ha$^{-1}$ in 2006 which increased to 7670 culms ha$^{-1}$ in 2007 and 9570 culms ha$^{-1}$ in 2008. The third and fourth positions are occupied by Toru and Sagalee circle. It is also revealed that the culms increment (new culms production) per year are also highest in Balijan i.e., 1780 culms ha$^{-1}$ in 2007 and which increased to 2080 culms ha$^{-1}$ in 2008. On the other hand, the second position of culms increment is recorded in Kimin i.e., 1640 culms ha$^{-1}$ in 2007 which increased to 1900 culms ha$^{-1}$ in 2008. The lowest culms increment is observed in Sagalee (960 culms ha$^{-1}$ in 2007 and 1090 culms ha$^{-1}$ in 2008). It is also observed that the production of new culms per hectare is significantly different at the different study sites (F= 63.661, P< 0.001) and year (F= 77.730, P< 0.001) which declined with the increase in elevation.

Similar trend is observed for $B. pallida$ also (Table 6.3). Statistical analysis reveals that the total number of culm per hectare is significantly different at the study sites (F= 20.803, P< 0.001) in different years (F= 64.492, P< 0.001) and it declined with the increase in elevation. In $B. pallida$, total culms density is recorded to be highest in Balijan i.e., 7630 culms ha$^{-1}$ in 2006 which increase to 9340 culms ha$^{-1}$ in 2007 and 11370 culms ha$^{-1}$ in 2008. The second highest bamboo culms density is observed in Kimin i.e., 6060 culms ha$^{-1}$ in 2006 and increased to 7480 culms ha$^{-1}$ in 2007 and 9080 culms ha$^{-1}$ in 2008. The third and fourth position are occupied by Toru and Sagalee circle. It also reveals that the culms increment (new culms production) per year is also maximum in Balijan i.e., 1710 culms ha$^{-1}$ in 2007 and 2030culm ha$^{-1}$ in 2008. The second position of culms increment is recorded in Kimin i.e., 1420 culms ha$^{-1}$ in 2007 and 1600 culms ha$^{-1}$ in 2008. The lowest culms increment is observed in Sagalee (940 culms ha$^{-1}$ in 2007 and 1100 culms ha$^{-1}$ in 2008). Like in $B. tulda$, the production of new culms of $B. pallida$ per hectare is significantly different.
at the study sites (F= 17.854, P< 0.001) in different years (F= 45.490, P< 0.05) and it declined with the increase in elevation. So, new culms production pattern per hectare area is noticed to be the highest at the lower elevation site in Balijan circle which decreased slowly with the increase in elevation. As the young (new) shoots are produced during June –July the highest population of <1 year old individuals to be observed during Sept compared to the previous years.

6.3.2 Above ground biomass production

Tables 6.4, 6.5, 6.6, 6.7, 6.8, 6.9 depict the above ground dry biomass production of two popular bamboo species in the four study sites. It is recorded that with the increase in age of the individual culms of B. tulda and B pallida, the dry weight also increase (Table 6.4 & 6.5) significantly (F = 2381.69, P< 0.001 & F = 515.75 , P< 0.001 respectively) as well as the dry weight of individual culms also decreased along with the increase of altitude of the area.

The biomass production of individual culm of Bambusa tulda is significantly different among the four elevation sites (F = 181.095, P< 0.001 for new culm, F = 467.846, P< 0.001 for 1-2 years old culm and F = 445.5824, P< 0.001 for >2 years old culm). Statistical analysis also reveals that the biomass production in individual culm significantly different in new culm at different seasons (F =8951.497, P< 0.001) and 1-2 years old culm (F =1086.554, P< 0.001) whereas, there is no significant difference in > 2 years old culm among the sampling periods or seasons, although, the standing crop increased considerably with age at all the four elevation sites. The highest dry weight of < 1 year, 1-2 years and > 2 years of individual culm of B tulda are observed in Balijan in different seasons, which is followed by Kimin (Table 6.4). The lowest dry weight of the culms of each age group is observed in Sagalee circle.

Similar pattern of dry weight of individual culm is recorded in B. pallida also. The highest total dry weight of culm of this bamboo species is recorded in Balijan which is followed by Kimin and the lowest is observed in Sagalee which is significantly different among the four study sites (F = 166.10, P< 0.001 for new culm, F = 70.00607, P< 0.001 for 1-2 years old culm and F = 71.21036, P< 0.001 for >2 years old culm) and seasons (F = 10345.28, P< 0.001 for new culm, F = 67.34100, P< 0.001 for 1-2 years old culm and F = 7.28938, P< 0.001 for >2 years old culm) in Bambusa pallida.
Overall, the above ground biomass of each age group is higher in *B. tulda* as compared to *B. pallida*. In the present study, >2 years old culm contribute maximum biomass to total standing of above ground biomass. There appears to be significant difference in biomass partitioning in different age group of both the species. However, among the age group of both the species, the total aboveground biomass is in the ascending order of <1 year old, 1-2 years old and >2 years old bamboo culm.

Statistical analysis reveals that the total biomass production of *B. tulda* in per hectar area is significantly different among the study sites (F =89.87392, P< 0.001 whereas, there is no significant difference among the sampling periods or seasons. The calculated value of above ground biomass production of *B. tulda* (Table 6.6 & 6.7) is significantly highest in Balijan circle (1.21 tones clump\(^{-1}\) ± 0.11 & 12.14 t ha\(^{-1}\) ±1.10) followed by Kimin (0.77 tones clump\(^{-1}\) ±0.05 & 7.66 tones ha\(^{-1}\) ±0.50) during the month of April, 2007. While lowest above ground biomass is recorded in Sagalee i.e., 0.42 tonnes clump\(^{-1}\) ±0.06 and 4.19 t/ha ± 0.58 during the month of April, 2007. Similarly, at the end of the sampling months i.e., April, 2009, the calculated value of above ground biomass production is highest in Balijan (1.72 tonnes clump\(^{-1}\) ±0.12 and 17.22 t ha\(^{-1}\)±1.23) followed by Kimin (1.26 tones clump\(^{-1}\) ±0. 07 and 12.63 t ha\(^{-1}\) ± 0.67) and lowest in Sagalee (0.71 tonnes clump\(^{-1}\) ±0.07 and 7.11 t ha\(^{-1}\) ± 0.67).

Similarly, the total biomass production of *Bambusa pallida* in per hectar area is significantly different among the four elevation sites (F = 39.556, P< 0.001). The Tables 6.8 and Table 6.9 also depicts that the above ground biomass production of *B. pallida* at the beginning of the sampling month April, 2007 is recorded to be the highest in Balijan (0.56 tonnes clump\(^{-1}\) ±0.04 and 5.65 t ha\(^{-1}\) ±0.37) followed by Kimin (0.47 tonnes clump\(^{-1}\) ±0.04 and 4.71 t ha\(^{-1}\) ±0.44) and lowest in Sagalee (0.34 tonnes clump\(^{-1}\) ±0.03 and 3.42 t ha\(^{-1}\) ±0.28). Likewise, the above ground biomass production at the end of the sampling month April, 2009 is highest in Balijan (0.85 tonnes clump\(^{-1}\) ±0.05 and 8.50 t ha\(^{-1}\) ±0.49) and lowest in Sagalee (0.51 tonnes clump\(^{-1}\) ±0.04 and 5.12 t ha\(^{-1}\) ±0.40).

### 6.3.4 Above ground biomass productivity (t ha\(^{-1}\)year\(^{-1}\)) of *B. tulda* and *B. pallida*

The aboveground dry biomass productivity (tonnes ha\(^{-1}\)year\(^{-1}\)) of two popular bamboo species in the study sites is presented in Tables 6.10 & 6.11. The dry matter variation at six months interval is measured to know the seasonal variation and later
on variation in both the intervals. These are summed up to calculate the annual productivity of dry matter. Ultimately the mean annual productivity is worked out from both the years.

Table 6.10 reveals that the variation of dry matter production is more in Sept to April as compared to April to September of the sampling year. The total annual productivity of B. tulda is greater in Balijan circle i.e., 49.37 t ha\(^{-1}\)year\(^{-1}\) ± 0.12 and 57.48 tonnes ha\(^{-1}\)year\(^{-1}\)±0.10 followed by Kimin i.e., 39.66 t ha\(^{-1}\)year\(^{-1}\)± 0.11 and 44.76 tha\(^{-1}\)year\(^{-1}\)± 0.11 during 2007-08 and 2008-09, respectively. The lowest annual productivity is recorded at Sagalee circle i.e., 20.33 tha\(^{-1}\) years\(^{-1}\) ± 0.06 and 23.41 t ha\(^{-1}\)year\(^{-1}\) ±0.06 during 2007-08 and 2008-09, respectively.

On the other hand, the productivity of B. pallida is found to be less as compared to B. tulda. Maximum annual productivity of B. pallida is recorded at Balijan circle i.e., 19.523 t ha\(^{-1}\)year\(^{-1}\) ±0.09 and 23.23 t ha\(^{-1}\)year\(^{-1}\) ±0.08 during 2007-08 and 2008-09, respectively along with mean annual productivity of 21.38 t ha\(^{-1}\)year\(^{-1}\)± 0.06. The second highest annual productivity is recorded at Kimin i.e., 14.89 t ha\(^{-1}\)year\(^{-1}\) ±0.10 and 16.95 t ha\(^{-1}\)year\(^{-1}\) ±0.09 during the year 2007-2008 and 2008-2009, respectively, along with mean annual productivity of 15.92 tha\(^{-1}\)year\(^{-1}\)±0.06. The lowest annual productivity is at Sagalee circle 8.60 tha\(^{-1}\)year\(^{-1}\) ±0.06 and 10.07 tha\(^{-1}\) years\(^{-1}\) ± 0.06 during 2007-2008 and 2008-2009, respectively, with annual mean productivity of 9.34 tha\(^{-1}\)year\(^{-1}\) ±0.04.

It can also be observed from the Table that the annual productivity of both the bamboo species have increased significantly from first year to second year (F = 15.849, P< 0.001 for B. tulda & F = 49.191, P< 0.001 for B pallida) in all the study sites (F = 52.360, for B. tulda & F = 11.579, P< 0.001 for B pallida ) of Papumpare district of Arunachal Pradesh.

5.3.5 Discussion

Arunachal Pradesh is known for bamboo diversity and the tribal communities of the region use this potential resource for various purposes. The Nyishi people of Papumpare district are using and cultivating two most popular bamboo species (e.g., B. tulda and B. pallida) in their homestead garden as well in bamboo garden. There is no land legislation and land revenue system in Arunachal Pradesh. They are just
occupying a large area from ancient times constituting forest plots, agricultural land and home gardens with a definite demarcated border which are totally hilly in nature except in Balijan and Kimin. Hence, the bamboo growers are also planting in the hilly slopes by maintaining a high spacing to obtain and fulfill their daily requirement of bamboos. The density of bamboo clumps and culms depend on altitude and areas available for each bamboo growers (Banik, 2000, Shanmughavel and Francis, 2001). In the present study also it has been observed that the number of bamboo clumps and culms per unit area in the plantation bamboo garden are significantly different among the study sites and years. Number of bamboo clumps per unit area is significantly highest in the lowest altitude (107m asl) region i.e., in Balijan circle for both the popular species (210 clumps ha$^{-1}$ for B. tulda and 150 clumps ha$^{-1}$ for B. pallida) followed by Kimin circle ( 170 clumps ha$^{-1}$ for B tulda & 130 clumps ha$^{-1}$ for B. pallida). The lowest bamboo clump per unit area is observed to be in highest altitude circle (900m asl) Sagalee (150 clumps ha$^{-1}$ for B. tulda and 110 clumps ha$^{-1}$ for B. pallida). The reason for lower density of bamboo clumps is due to the difficulty of management of the bamboo groves at sloppy land which compels the farmers to place the groves at higher spacing rate as compared to plain area. The different studies conducted by different scientists also revealed that the production of new culms also depends on altitude, degree of culms congestion, culms age and rainfall of the previous year. Accordingly, in the present study also it has been observed that the emergence of new culms per clump and per unit area are significantly more in lowest altitude circle i.e., Balijan followed by Kimin & Toru and lowest in Sagalee circle for both the species i.e., B. pallida and B. tulda.

Production of biomass depends on number of culms available in the unit area. Production of new culms, age of culms in between 1-2 years, and >2 years old culm are significantly more observed in B. tulda and hence, biomass production of this bamboo species is more as compared to B. pallida. The estimated biomass production also varied significantly at different study locations may be due to different soil and climatic condition of the area, stock density, age of culm & clump, topography, altitude, scientific cultivation and management of bamboo groves (Othman, 1992, Banik, 2000, Shanmughavel and Francis, 2001). The bamboo species found in tropical lowland areas are usually larger in size and possess more standing biomass as compared to those of high altitude. Joshi (1984) reported the influence of
topographical features (slope inclination on altitudes) on different growth attributes of *D. strictus* who reported negative correlation between bamboo growth and the topographic features. In tropical region higher rate of culm elongation takes place during night (Osmaston, 1918), while in temperate region, it takes place during day time (Ueda, 1960). Due to these reasons the biomass production may be more in Balijan and Kimin circle as compared to Sagalee and Toru circle of Papumpare district of Arunachal Pradesh.

Significant increase in culm weight as the age increases is observed in both the species studied (Chua *et al.*, 1996, Liese and Weiner, 1995) opined that in bamboo maximum growth takes place within one year of emergence of Culm. Nevertheless, ageing of culms is associated with significant chemical and structural changes in parenchyma and fiber tissues that decrease the fiber content (Espilosy, 1994, Sattar *et al.*, 1994) as well as cell wall thickening (Liese, 1995). This could explain the increasing above ground biomass in < 1 years, 1-2 years and ≥2 years old culms of the bamboo species studied. Culms of all bamboo species may complete their growth within 2-3 months after the emergence of sprouts from the ground, but their diameter and height do not increase after the growth is completed (Mc Clure, 1966, Banik 1980, Udea, 1981, Shanmughavel and Francis, 1996). But their biomass accumulation is more after this period.

The productivity of bamboo is assessed by the number of new culms produced annually as well as biomass increment in older culm. The crowded and congested condition creates a scarcity of room for the new emerging culms and it also increases competition among them for survival (Kondas, 1981 and Banik, 1993). For production of new culms proper management of bamboo groves is very much essential which provides the space for emergence of new culms, its proper growth and development in the clumps. Clump and culm density *i.e.*, closer spacing, high new culm production per unit area, adoption of proper row direction, proper management of bamboo groves and adoption of scientific harvesting methods are observed to be highest in Balijan circle as compared to other circles. Removal of dry culms increased the productivity of bamboo (Singh, 2002). Patil and Patil (1990) observed that close spacing produced higher dry matter as compared to the wider ones at the early stage, which is also observed in the present study. Weeding also plays an important role to reduce the competition between bamboo and weeds for nutrient uptake. Extent of adoption score
of scientific bamboo cultivation technique is observed to be highest in Balijan followed by Kimin. The lowest is also observed in Sagalee. Hence, the production of biomass and annual productivity in both the species is found to have increased significantly from first year to second year in Balijan followed by Kimin. The lowest biomass and annual productivity in both the species are recorded in Sagalee area.

The increase in biomass production per culm and per unit area in the study site may be the result of availability of nutrients and water in the soil for proper growth and biomass production of bamboo (Anonymous, 1961, Adamson et al., 1978, Hussain, 1980, Shi et al., 1987 and Patil and Patil 1990, Uchimura, 1980, Kinhal 1985, Huang, 1987). Earthing up and mulching at the base of the bamboo groves and manuring by applying Farm Yard Manure during planting time and later during the course of bamboo growth period may supply the plant nutrient for production of new culm as well as its growth and development irrespective of age to a certain period of time. Bamboo requires sufficient moisture for luxuriant growth and scarcity of moisture adversely affect the growth particularly during winter months. The mulching practice reduces loss of moisture through evaporation from root zone of clump and conserve the moisture in the root zone of bamboo groves. The increase in biomass production at different locations may also be the result of closer (Singh, 2002) spacing of bamboo, which increased the number of new bamboo culms per unit area. Singh (2000) also reported that production of total biomass is highest under closer spacing of 6mX6m in B. pallida in 12 years old bamboo as compared to low density (Singh, 2002). The length of culm is also more under closer spacing. Pruning and cleaning of clump helps in removing the dead and dying culms from the clump that facilitate proper growth of new shoots (Kumar and Seethalakshmi, 2006).

Mineral availability may be one of the important factors for increase in biomass production. The Mineral accumulation (N, P, K, Ca, Mg, Cu, Zn, Fe, Mn) was highest at closer spacing than in wider spacing (Singh, 2002). According to Nath et al., (2008) the culm density of Bambusa cacharensis in bamboo stand was increasing in succeeding years. He also reported that in farmer managed village bamboo grove in Assam, total above ground standing biomass of the grove was observed to be more in 2006 as compared to 2003. Similar study was also conducted by different scientists. Compared with biomass measurement the annual yield of air dried bamboo per ha of 3-4 year old plantation was found to be 6-7 t ha$^{-1}$ for Bambusa vulgaris and
Gigantochloa aspera Chinte, (1965). The above ground biomass of Gigantochloa scortechnii from Malaysia was 71.9 t/ha-1 in natural stand and 36.36 t/ha in a 3 year old plantation (Othman, 1992). This is lower than three years old plantation stand (47.48t/ha) of Kallipatty, Tamilnadu, India (Shanmughavel, 1995). Shanmughavel and Francis (2001) reported that B. bambos a tropical bamboo can accumulate larger quantity of dry matter with 52 -72 kg individual\(^1\) during the first year. On the other hand subtropical bamboo species like Phyllostachys glauca, P. nigrahexonis and P. viridis could accumulate only 1.82, 1.67 and 2.16 kg individual\(^1\) (Othman and Shamsuddin, 2002) and P. heteroclada could accumulate only 1.03 kg individual\(^1\) (Sun et al., 1987). Same trend was also observed in the present study. Accumulation of biomass per individual in both the species was found to be increasing with decreasing altitude from mean sea level.