Theme of the paper: Ecology and Environmental concerns

Comparative study on growth pattern and above ground biomass produced by *Dendrocalamus asper* and *Bambusa* spp. in the mid Himalayan region of India

Anjuli Agarwal* & J P Purwar

GBPUA&T Agriculture Research Station, Majhera
Garampani (Nainital) 263 135 India
*email:anjulit@rediffmail.com

Abstract

Bamboos are fast growing plants and in nature, has a potential to increase the carbon stocks at a faster rate. In Siwalik hill range of Himalayas, a limited range of *Dendrocalamus* and *Bambusa* species occurs. Afforestation with faster growing species of bamboos has a potential for carbon sequestration along with providing livelihood to rural population. Plantation of *Dendrocalamus asper* and various *Bambusa* species was done in the mid Himalayan region of Uttarakhand state of India. Objective of the present study was to evaluate the above ground biomass accumulation, potential of carbon sequestration and enumerate the growth pattern. Growth pattern of various bamboo species in terms of per cent increase in height and number of culms in 6th year revealed highest per cent increase in height in *Bambusa bambos* (1075.34) and maximum increase in number of culms in *B. tulda* (742.11). Total increase in height and culm production in six years was lowest in *D. asper* as compared to *Bambusa* spp. Above ground biomass produced by *Bambusa bambos* (20.52 t ha^{-1}) and *B. nutans* (20.41 t ha^{-1}) was highest as compared to *D. asper* (12.92 t ha^{-1}). *B. tulda* (9.62 t ha^{-1}) produced the lowest above ground biomass.

Introduction

Bamboos are of great importance and gaining attention as an alternative forest crop with multiple uses and benefits (Bhatia 2003). India, China and Myanmar have 19.8 million hectares of bamboo reserves which is 80 per cent of the World's bamboo forests, out of which India's share is 45 per cent with nearly 130 species (Sharma 1980). India has the second largest bamboo resource after China. Additionally, India has promising opportunities for climate change mitigation due to large bamboo resource and has great potential for its cultivation and utilization (Dubey et al. 2008). Realizing the economic importance of bamboo, National Bamboo Mission Board has been established in India for promoting bamboo based industries. Bamboos can play an important role in carbon sequestration, especially as the extent of bamboo forests is increasing in some parts of the world (Zhou et al. 2011).

Biomass accumulation, carbon storage, net production and nutrient cycling in various species of bamboo have been reported by many groups in India ((Choudhury et al. 2015; Nath & Das 2011; Nath et al. 2009, 2008; Kumar et al. 2005; Shanmughavel & Francis 2001) and abroad (Yen 2016; Chen et al. 2009; Isagi et al, 1997). In mid Himalayan region, evaluation of above ground biomass produced by *Dendrocalamus asper* was studied on fresh and dry weight basis at two aspects (hill top and river bank) in two year old plantation (Agarwal & Purwar 2009). Other studies in the mid Himalayan region were also conducted on various bamboo species. Use of bamboo as an alternative resource in sustaining the Himalayan ecosystem (Agarwal 2014), evaluation of altitudinal variation in carbon sequestration by micropropagated *D. asper* in the mid Himalayan region of India (Agarwal & Purwar 2015), estimation of carbon in young micropropagated plants of *D. asper* (Agarwal & Purwar 2016) and carbon sequestration potential of important Bambusa spp., *Dendrocalamus strictus* and *Phyllostachys nigra* in the Uttarakhand state of India (Agarwal & Purwar 2012, 2017) has been reported.

Dendocalamus asper, native of China is an important species which provides food, fiber and structural timber. The young shoots of *D. asper* are used as food in many countries (Singh et al. 2012). In clumping bamboos, one of the large genuses is *Bambusa* having many various species world-wide. *B. tulda* is sturdy, tall and quick growing species of tropics (Das &Pal 2005) whereas *B. nutans* grows best at altitudes between 500-1500 m and thrives well on moist hill slopes (Anonymous 2005). *Bambusa bambos* has thorny branches and grows densely in moist deciduous forests up to an altitude of 1000m. This is a promising species and planted for long fibred pulpwood production (Shanmughavel & Francis 1996)

For broadening the genetic base of the resource and to reduce disruption in supply caused by flowering, there is a need to introduce different potential species and evaluate their growth performance in various agro climatic zones (Alemayehu et al. 2015). In the foot hills and mid Himalayan region, a limited range of species occurs such as *Dendrocalamus strictus* and *Bambusa bambos*. At higher altitudes, bamboos in the genera *Arundinaria*, *Thamnocalamus* & *Himalayacalamus* are common. To broaden the range of species in the mid Himalayan region of India, plantation of different species was done at ARS, Majhera. The main objective of this study was to evaluate & compare the growth pattern of *Dendrocalamus asper* vs. *Bambusa* species and to estimate the above ground biomass produced by *D. asper, B. bambos, B. nutans* & *B. tulda* in the mid Himalayan region.

Material and Methods

Study site:

The present study was conducted at Agriculture Research Station, Majhera, situated at 905m (a.s.l) with latitude 29°30.137'and longitude 79°28.784' in Uttarakhand state of India. Average maximum & minimum temperature and maximum relative humidity of ARS, Majhera are 32.1°C, 4.83°C and 97.67 per cent, respectively. Texture of soil is sandy loam and pH is 6.0 ± 0.5.

Plantation of Bamboo species:

Plantation of *D. asper* and *Bambusa* spp. (*B. bambos, B. nutans* & *B. tulda*) was done at hill slope of Agriculture Research Station, Majhera in the year 2010. Standard agronomic practices for the plantation were followed. Spacing of plant to plant was maintained at a distance of 5 X 5m. Average height of the plants at the time of plantation was 50 cm. Each species was planted in an area of 100 sq. m. in a replicated manner. One plant was considered as one replication and nine replications were maintained.

Evaluation of growth pattern:

For the evaluation of growth pattern, data on length of culms and total number of culms in a clump was recorded one year after plantation i.e. year 2011. For the length measurements, average of three culms (With highest, lowest and medium length) in each clump was recorded. Further, measurements for the same parameters were made in the third and sixth year i.e. 2014 & 2017. Average of length and number of culms in all the nine replications of four species was used for calculations.

Estimation of above ground biomass (AGB):

For the non-destructive estimation of AGB(on dry weight basis), length and girth of culms at 1.0m & 1.5m was recorded along with total number of culms. In each clump, data of three culms was used for the estimation of above ground biomass (kg Pole^{-1}) through linear regression equations (Table 1).

Table 1: Linear relationship between AGB of different bamboo spp. (y kg culm^{-1}) and culm height (x_1, m), girth to height at 1m (x_2, m) and girth to height at 1.5 m (x_3, m) on dry weight basis

Bamboo species	Regression Equation	
D. asper	$Y=(-0.809)+(0.393)x_1+(-6.68)x_2+(18.43)x_3$	Agarwal & Purwar (2009)
Bambusa bambos	$Y=(5.17)+(-0.14)x_1+(-323.78)x_2+(363.98)x_3$	Agarwal & Purwar (2012)
Bambusa nutans	$Y=(-0.58)+(-0.20)x_1+131.59x_2+(-82.36)x_3$	Agarwal & Purwar (2017)
Bambusa tulda	$Y=(0.10)+(-0.07)x_1+(-24.48)x_2+59.75x_3$	

Total above ground biomass of the clump was obtained by multiplying the number of total culms to the average of biomass per pole. Carbon sequestration was estimated on the basis of fifty per cent of the total above ground biomass produced (Scurlock et al. 2000; Singh et al. 2009).

Growth pattern and fresh weight of newly emerged culms in the sixth year

In the 6th year (2017), one newly emerged culm of all the four species was harvested for the recording of fresh weight. Length, girth (at 1.0m & 1.5m) and number of nodes of these culms were also measured to monitor the growth pattern. New culm of maximum height in the clump was selected in three replications out of nine (to avoid destruction) and average of these was used.

Estimation of above ground biomass (AGB) due to new culms:

Increment in AGB due to newly emerged culms after 6 years of plantation was also estimated. For the non-destructive estimation of above ground biomass (on dry weight basis), length and girth of culms at 1.0m & 1.5m was recorded for all the newly emerged culms. Average of these values was used for the estimation of AGB (kg $Pole^{-1}$) through linear regression equations (Table 1). Total increment due to new culms was obtained by multiplying with the number of total newly emerged culms.

Results and Discussion

Growth Study:

Various growth parameters i.e. maximum gain of plant height and total number of culms produced by *D. asper* and *Bambusa* spp. are presented in table 2. Initial parameters on length and number of culms recorded in the year 2011 were considered as the reference point, one year after the plantation for all the four species. Increase in height and number of culms was evaluated on the basis of data recorded in the year 2014 & 2017. Comparative study revealed higher increase in height and number of culms in the 3rd year of plantation as compared to 6th year in all the species. Maximum per cent increase in height was observed in *B. bambos* (738.36) followed by *B. tulda* (545.83) in the third year of plantation in mid Himalayan region. But in the 6th year *B. nutans* gained highest height with 70.05 per cent increase. The present study was similar with earlier study that maximum height was attained by B. *nutans* (6.62m) followed by *B. balcooa* (6.44m) and *B. bambos* (4.12m) in the mid Himalayan region (Agarwal & Purwar 2016). After six years of plantation maximum per cent increase in height was observed in *B. bambos* (1075.34) followed by *B. tulda* (862.50) and *B. nutans* (830.32). However, lowest per cent increase in height was in *D. asper* (508.33). Total increase in height and culm production in six years was lowest in *D. asper* as compared to *Bambusa* spp. whereas total per cent increase in number of new culms was highest in *B. tulda* (742.11) in 6 years. Similar trend was also observed in *B. tulda* in the previous report (Agarwal & Purwar 2016). They reported highest per cent increase in number of culms (394.7) in *B. tulda* two years after plantation.

Table 2: Growth pattern of *D. asper* and *Bambusa* species in the mid Himalayan region

Name of species	**Per cent increase**					
	Plant height			**Total number of culms**		
	3rd year	**6th year**	**Total increase (up to 6th year)**	**3rd year**	**6th year**	**Total increase (up to 6th year)**
D. asper	483.33	4.28	508.33	37.25	8.57	49.02
B. bambos	738.36	40.20	1075.34	148.72	31.96	228.21
B. nutans	447.09	70.05	830.32	235.71	24.47	317.86
B. tulda	545.83	49.03	862.50	257.89	135.29	742.11

Growth pattern of new culms emerged in 6th year:

Fresh weight of new culm emerged in the 6th year was recorded highest (17.5 kg) in *B. nutans* having maximum height (15.5m) and girth at 1.0m followed by *B. bambos* (12.5m). Number of nodes in *B. nutans* and *B. bambos* were at par but fresh weight recorded in *B. bambos* was almost 50 per cent lower than *B. nutans* (Fig. 1). Though culm length of *B. tulda* (7.5 m) was at par with *D. asper* (7.2 m) but fresh weight of *D. asper* was three times more than *B. tulda*, indicating length is not the only factor in deciding the weight of the culm. However, girth at 1.5m was not significantly different than girth at 1.0m in all the four species.

Estimation of AGB:

Above ground biomass on dry weight basis and carbon sequestration potential of *D. asper* and *Bambusa* spp. in a growth period of 6 years is presented in table 3. The data indicated that AGB and potential of carbon sequestration of *B. bambos* was at par with *B. nutans*. Though AGB of *B. nutans* estimated on per culm basis was more than *B. bambos* but due to more number of culms/clump, more biomass was estimated in *B. bambos*. Biomass estimated through regression equations was 20.52 and 20.41 t ha^{-1} for *B. bambos* and *B. nutans*, respectively. Lowest AGB was observed in *B. tulda* (9.62 t ha^{-1}) among all the four species in 6 years. For all the species 400 clumps ha^{-1} were considered for the estimation of t ha^{-1} biomass. As per the previous report (Agarwal & Purwar 2017) AGB produced by *B. tulda* was 4.9 t ha^{-1} in four years. An increase in AGB of 100 per cent was observed in two years by *B. tulda*. In Thrissur, India, above ground biomass of *B. bambos* clumps averaged 2417 kg $clump^{-1}$ with an average accumulation of 241.7 Mg ha^{-1} (Kumar et al. 2005). Carbon sequestration of *B. nutans* was evaluated in

Assam, North-East region of India at a rate of 88.95 t ha^{-1} through above ground biomass and 96.46 t ha^{-1} through total biomass in four years (Choudhury et al. 2015). Whereas, in the present report above ground biomass estimated in *B. bambos* and *B. nutans* was much lower in the agroclimatic zone of Majhera.

Table 3: Estimation of above ground biomass and carbon sequestration potential of *D. asper* and *Bambusa* spp. in the mid Himalayan region

Name of species	**Biomass (kg $pole^{-1}$)**	**Biomass (kg $plant^{-1}$)**	**Biomass (t ha^{-1})**	**Carbon sequestered (t ha^{-1})**
D. asper	1.93	32.29	12.92	6.46
B. bambos	3.22	51.30	20.52	10.26
B. nutans	4.13	51.02	20.41	10.20
B. tulda	1.43	24.04	9.62	4.81

Dendrocalamus asper gained 12.92 t ha^{-1} AGB in 6^{th} year which was more than *B. tulda* but less than *B. bambos* and *B. nutans*. Data of AGB in the present study was lower as compared to previous study. Earlier, *D. asper* plantation done at the hill top of ARS Majhera in the year 2006-07 showed gain of 24.34 t ha^{-1}AGB on dry weight basis after seven years of plantation (Agarwal & Purwar 2015). AGB in the present study was also estimated seven years after plantation in *D. asper* but plantation was done at the hill slope at ARS, Majhera. Kao & Chang (1989) reported the maximum net annual production (41.4 t ha^{-1}) during the 8^{th} year in *D. asper* plantation in Taiwan. Plantation showing higher AGB after 7 years was located at the top of the hill whereas, plantation representing lower AGB presented in this study was located at the slope.

Estimation of AGB due to new culms:

Increment in AGB on dry weight basis was estimated due to new culms emerged in 6^{th} year in all the four species (Fig. 2). Highest AGB was recorded in *B. bambos* (24.53 kg $plant^{-1}$) and lowest in *B. tulda* (9.31 kg $plant^{-1}$). It was observed that total AGB increment due to new culms in *D. asper* (16.28 kg $plant^{-1}$) was more than *B. tulda* but less than *B. bambos* and *B. nutans* (12.66 kg $plant^{-1}$). The increment in AGB represents the trend in annual potential of carbon sequestration of various species of bamboo.

Conclusion:

It can be concluded from this study that for biomass generation and environment purification through carbon sequestration, *B. bambos* and *B. nutans* are superior as compared to *D. asper* in the mid Himalayan region. But even better performance of *D. asper* makes it suitable for cultivation for various end uses like human food, animal feed and other various applications.

Acknowledgement

Authors are thankful to Department of Science & Technology, Govt. of India, New Delhi, India for financial assistance and Director Experiment Station, Govind Ballabh Pant University of Ag. & Tech, Pantnagar, India for providing the necessary facilities.

References

Agarwal, A.; Purwar, J.P. 2017. Carbon sequestration and above ground biomass by *Bambusa* spp. in the mid Himalayan region of Uttarakhand India. Indian Forester, 143(4), 303-306.

Agarwal, A. 2014. Bamboo : An alternative resource in sustaining the Himalayan ecosystem. IN: Environmental and Biodiversity N. Gupta and D. K. Gupta (eds.). Narendra Publishing House, Delhi, India. 73-85.

Agarwal, A.; Purwar, J.P. 2009. Evaluation of above ground biomass produced by *Dendrocalamus asper* in North Western Himalayan region of India. In: Proceedings of VIII World Bamboo Congress, 4, 91-96.

Agarwal, A.; Purwar, J.P. 2012. Biomass production and carbon sequestration potential of various bamboo species in the Mid Himalayan region of India. In: Proceedings of IX World Bamboo Congress, 142-147.

Agarwal, A.; Purwar, J.P. 2015. Altitudinal variation in carbon sequestration potential of micropropagated *Dendrocalamus asper* in the Mid Himalayan region of India. In: Proceedings of X World Bamboo Congress.

Agarwal, A.; Purwar, J.P. 2016. Growth pattern of *Bambusa* spp. and carbon estimation of micropropagated *Dendrocalamus asper* (schult.) Backer in the mid Himalayan region. J. Env. Bio-sci., 30(1), 9-12.

Alemayehu, A; Mulatu, Y;Eshete, N; Melkamu, T. 2015. Growth performance and biomass accumulation of four introduced bamboo species in south-western Ethiopia. In: Proceedings of X World Bamboo Congress.

Anonymous 2005.Field guide the bamboo book Vol II. National Mission on Bamboo Applications, New Delhi, 70p.

Bhatia, V. 2003. Bamboo shoots as an option for Agroforestry, Proceedings of National Seminar on Forest resource management, 15-17 Nov, 2003. Department of Forestry, CSAU&A, Kanpur, India: 93-104.

Chen, X.; Zhang, X.; Zhang, Y.; Booth, T.; He, X. 2009. Changes of carbon stocks in bamboo stands in china during 100 years. For Ecol and Manage, 258,1489-1496.

Choudhury, H.; Kalita, P.; Das, R.; Goswami, R.K.; Saikia, L.; Medhi, T. 2015. Carbon sequestration potential of mokal bamboo (*Bambusa nutans)*. Crop Res., 50, 117-120.

Das, M.; Pal, A. 2005. Clonal propagation and production of genetically uniform regenerants from axillary meristems of adult bamboo. J. Plant Biochem. & Biotech. 14, 185-188.

Dubey, R.M.; Das, P.S.; Choudhury, R. 2008. An investigation into macroproliferation of some selected bamboo species of Assam. Indian Forester, 134(3), 367-378.

Isagi, Y.; Kawahara, T.; Kamo, K.; Ito, H. 1997. Net production and carbon cycling in a bamboo *Phyllostachys pucescens* stand. Plant Ecol., 130,41-52.

Kao, Y.P.; Chang, T.Y. 1989. The growth and biomass production of *Dendrocalamus asper* plantation. Bulletin-of-the-Taiwan-Forestry-Research-Institute., 4(1), 31-41.

Kumar, B.M.; Rajesh, G.; Sudheesh, K.G. 2005. Aboveground biomass production and nutrient uptake of thorny bamboo [*Bambusa bambos* (L.) Voss] in the homegardens of Thrissur, Kerala. J Tropical Agric., 43(1-2), 51-56.

Nath, A.J.; Das, G; Das, A.K. 2008. Above ground standing biomass, production and carbon sequestration in farmer managed village bamboo grove in Assam, North East India. Bamboo Science and Culture: The Journal of the American Bamboo society 21(1), 32-40.

Nath, A.J.; Das, A.K. 2011. Carbon storage and sequestration in bamboo-based smallholder homegardens of Barak Valley, Assam. Curr. Sci.,100(2), 229-233.

Nath, A.J.; Das, G.; Das, A.K. 2009. Above ground standing biomass and carbon storage in village bamboos in North East India. Biomass Bioenergy, 33,1188-1196.

Scurlock, J.M.O.; Dayton, D.C.; Hames, B. 2000. Bamboo: an overlooked biomass resource? Biomass and Bioenergy, 19 (4), 229-244.

Shanmughavel, P.; Francis, K. 1996. Biomass and nutrient cycling in bamboo (*Bambusa bambos*) plantations. Journal of Bamboo and Rattan, 1 (2), 157-170.

Shanmughavel, P.; Francis, K. 2001. The dynamics of biomass and nutriens in bamboo (*Bambusa bambos*) plantations of tropical areas. Biol Fertil Soils, 23, 431-434.

Shanmughavel, P.; Peddappaiah, R.S.; Muthukumar, T. 2001. Biomass production in an age series of *Bambusa bambos* plantations. Biomass Bioenergy, 20,113-117.

Sharma, Y.M.L. 1990. Bamboos in the Asia pacific region In : Lessard, G. and Choumard, A. (eds) Bamboo Research in Asia, IDRC, 99-120.

Singh, S.R.; Dalal, S.; Singh, R.; Dhawan, A.K.; Kalia, P.K. 2012. Micropropagation of *Dendrocalamus asper* {Schult. & Schult. F.} Backer ex k. Heyne): An exotic edible bamboo. J. Plant Biochem. & Biotech. 21 (2), 220-228.

Singh, V.; Tewari, A.; Ram, J.; Singh, C. 2009. Aspect related changes in biomass stocks and carbon sequestration rates of *Shorea robusta* (Sal) forest of Central Himalaya. Report and Opinion, 1 (2), 56-60.

Yen, T. M. 2016. Culm height development, biomass accumulation and carbon storage in an initial growth stage for a fast- growing moso bamboo (*Phyllostachy pubescens*). Botanical studies, *http://as-botanicalstudies.springeropen.com/articles/10.1186/s40529-016-0126-x*

Zhou, B.Z.; Fu, M.Y.; Xie, J.Z.;Yang, X.S.; Lia, Z.C. 2005. Ecological functions of bamboo forest: research and application. Journal of Forestry Research, 16, 143-147.

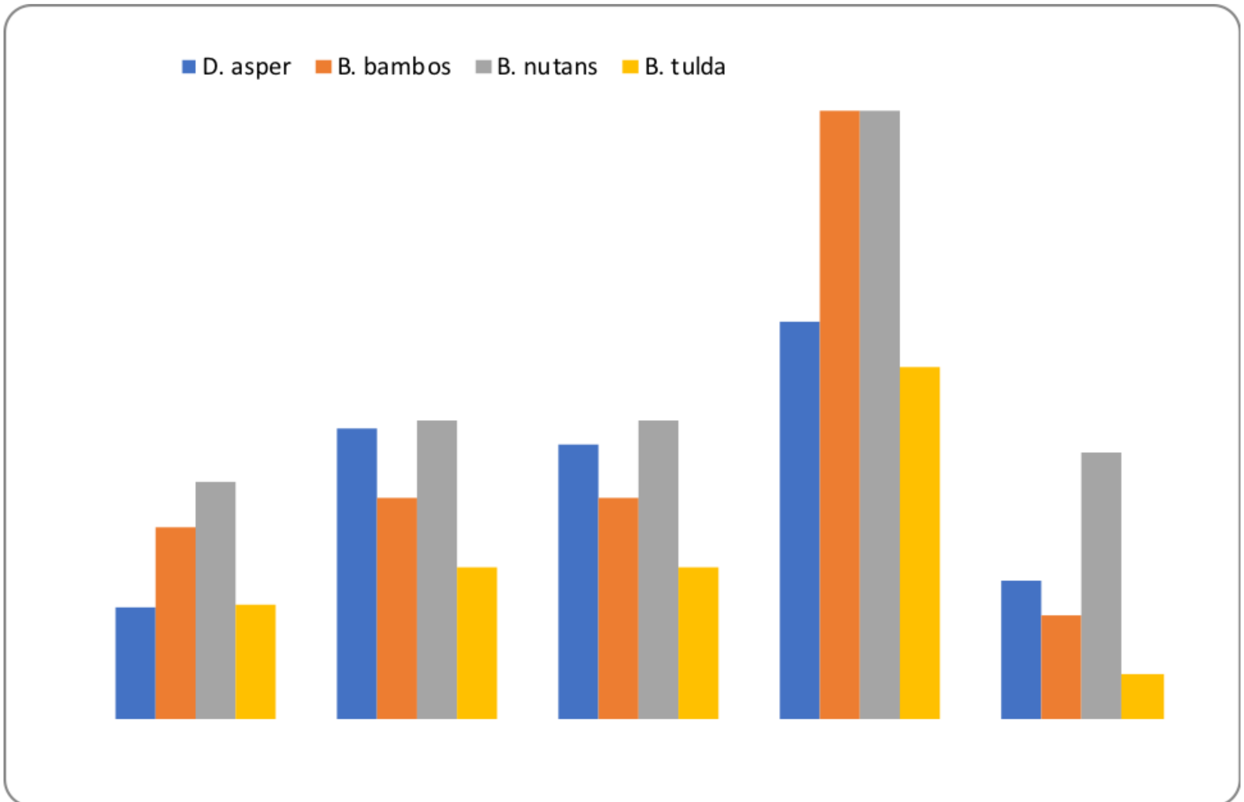

Fig 1: Various growth parameters and fresh weight of *D. asper* and *Bambusa* spp. of newly emerged culms in the 6th year

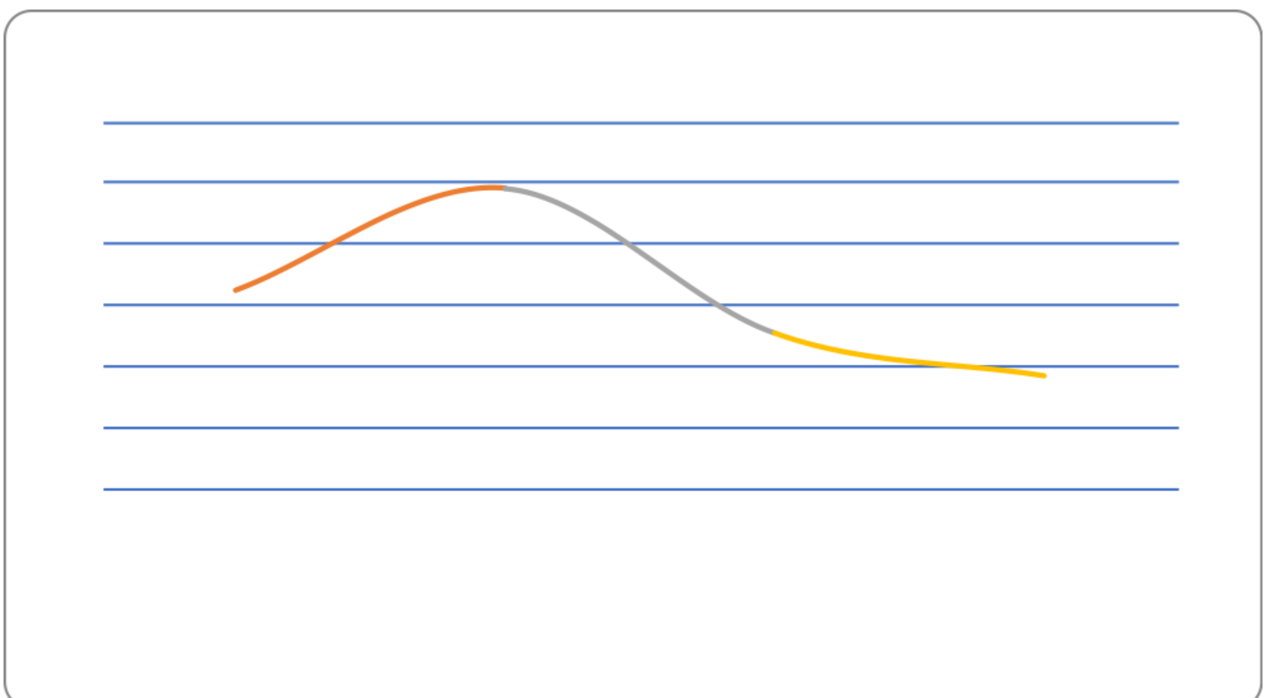

Fig 2: Increment in AGB (kg plant^{-1}) due to new culms of *D. asper* and *Bambusa* spp.