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Ecology of Bamboos in Mizoram, Northeast India : Implications for Their Management and Climate Change Mitigation

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ABSTRACT

Increasing human population and decreasing ecosystem services due to global change phenomena, particularly altering land use patterns and increasing carbon dioxide concentration in the atmosphere has led to identify cost effective options to mitigate climate change issues faced by humanity. Bamboo ecosystems have recorded fast growth and rapidly regenerates following the ecosystem degradation. Therefore, the species of bamboo has immense importance in the current climate change mitigation efforts of the Government by rapidly occupying the degraded areas and produces considerably high biomass within a short interval of time. In addition to sequester considerably high amount of carbon each year, the species of bamboo has multiple uses and high acceptance in the society. In recent years, considering many ecological services provided to the society by bamboo, the species-specific management plans are required towards climate change mitigation efforts. Productivity data of bamboo ecosystem would therefore be resourceful in assessing the potential of the bamboo forest in rendering ecological services to the humanity that can be profitably en-cashed as carbon credit by the nation and part can be transferred to the bamboo growers (small stackholders). Improvement in the bamboo biomass production through proper management plans by considering the ecosystem level strategies for dry matter production and nutrient allocations would be important criterions in selecting species suitable for afforestation and reforestation programs in particular locations. This paper provides a general synthesis of information collected regarding the dry matter productivity and edaphic conditions of bamboo ecosystems. The notable functional traits and ecological strategies involved in bamboo forests, including the management protocols for the climate change mitigation measures are discussed.

Keywords Bamboo ecosystem, Carbon sequestration, Carbon off setting, Mizoram.

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INTRODUCTION

Globally, due to exponential increase in human population from 2.5 billion in 1950 to 7.8 billion in March 2020, the demand for natural resource is continuously increasing which has drastically decreased the capacity of the ecosystems to provide goods and services to the society (Tripathi 2010). It is mainly because of landscape conversions from natural ecosystems to the multitude of ecosystems types which has drastically affected the structure and functioning of modified ecosystems (Tripathietal. 2008, Tripathiet al. 2012). The bamboo ecosystems are one such modified ecosystem which has continuously expanded in the degraded land following the conversion of natural ecosystems. In these oligotrophic degraded ecosystems, bamboo ecosystems developed certain ecosystem level strategies, for example, increased below ground/above ground biomass ratio means investing more biomass for developing profuse root systems, conserving nutrients in the structural components through re-translocation during leaf senescence and immobilization of significant amount of nutrients in the process of litter decomposition (Tripathi and Singh 1992a and b, 1994, 1995, 1996,Tripathiet al. 1999,Tripathiet al. 2005). Bamboos are widely distributed over the world except Europe and more than three-fourth of the bamboo growing areas are confined to South and South-East Asia (Perez et al. 1999, Zhengyiet al. 2006, Newman et al. 2007). Species of bamboos are distributed in the tropical, sub-tropical, mild temperate andalpine regions of the world (Sharma 1980, Dransfield and Widjada 1995). Tropical forests constitute about half of the world's forest area and plays an important role in the global cycles of carbon (C) and nitrogen (N) by storing significant fractions of C in the world's vegetation and soil pools (Brown and Lugo 1982, Brown et al. 2000, Pandey et al. 2010). In Indian tropical regions, the occurrence of extensive landscape transformations from natural forests to a multitude of vegetation types (including bamboos) are occurring which are accompanied by massive changes in ecosystem structure and functioning (Tripathi and Singh 1992a and b, 1994,1995, 1996,2008).

Sub-family Bambusoideae of the family Poaceae comprises 1575 species of woody and herbaceous bamboos (Ohrnberger1999) which cover 14 million ha area worldwide (Dransfield and Widjada 1995) with an annual estimated cost of $10 billion of bamboo resources in the world market (Anon 2003). India is one of the world largest bamboo reserves, harbouring over 20 genera and 113 species (Naithani 2008). Species of bamboos are known for their multiple use and special characteristics of flowering after a long interval of time (that varied from 10-150 years in different species) followed by death of all culms and rapid re-growth of culms to attain maturity within short interval (3-5 years) of time (Tripathi and Singh 1994, 1996).

North-East region, comprising seven states of India, is characterized by shifting cultivation practice in which forest vegetation is slashed and burnt for agriculture followed by fallow period of 5-40 years, which allow the vegetation to develop naturally. As a result vast area of the region is dominated by secondary successional forests of varying ages where bamboo forms major components apart from the wide distribution and profuse growth of bamboos in the natural forest areas. Bamboo species flower suddenly and simultaneously followed by death of all clumps and as result drastic changes occurred in forest composition and environmental conditions, for example, light intensity, seedling survival, organic matter decomposition and nutrient cycling (Takahashi et al. 2007). Several studies have suggested efficient nutrient cycling in bamboo communities by vigorous bamboo growth followed by litter return and successive nutrient release to maintain soil fertility and regenerate nutrients to support high growth (Toky and Ramakrishnan 1983,Tripathi and Singh 1992 a and b,1994, 1995, 1996, 2008, 2009, Christanty et al. 1997). Because of these characteristics bamboo species has immense capacity to sequester C from the atmosphere and effectively recycle C and nutrients within the system. Therefore, if managed properly this species have great potential to mitigate increasing carbon dioxide concentration in the environment in current scenario of climate change.

Mizoram, a hilly state in the Northeast India, is quite rich in bamboo with an area of 3,476 km2 under bamboo forest which is about 16.5% of the total Geographical land of the state (SFR 2019) distributed thoroughly between 400m and 1520 m amsl. Out of total 150 species of bamboo in India, more than 50% species are confined in Northeast India with 35 species (including 25 indigenous and 10 exotic) occurring in Mizoram (Lalramnghinglova and Jha 1997,Anon 2010) with estimated total bamboo growing stock of about 24.0 million metric tonnes (Anon

2008). Melocannabacciferra is predominant species and occupied about 90% of the total bamboo dominated land in the state with other co-dominant species like Dendrocalamushamiltonii, D. longispathus and Bambusatulda. The bamboo is a multiple use species considered as poor mens timber in the state of Mizoram where huge amount of C (>10 million metric tonnes) is sequestered every year.Considering the huge production, if this resource is managed scientifically through people's participation by providing a considerable amount of incentives to the small stakeholders of Mizoram, C can be sequestered in the above and below ground component of bamboo that can offset the anthropogenic emission of C to the atmosphere (Tripathi 2013). Culm recruitment, harvesting, management and their impact on climate change

Culm recruitment and shoot extraction

Growth of new shoots in a bamboo forest occurs as a result of transfer of the energy accumulated in the rhizomes through photosynthesis in the previous year leaves via culms (Magelet al. 2005). The emergence of new shoots begins during the rainy season of the year after planting, however, seasonal variation is observed in the development of new shoots that varies from species to species. The number of shoots produced per clump also varies from species to species. It is best not to harvest new shoots developed from clumps below 3 years (Salam and Deka 2007). A small amount of edible young shoots may be harvested in the third year of the plantation, i.e. two rainy seasons after planting. In the same way, in monopodial bamboos the extraction of shoots needs to be worked out and can be taken out carefully and uniformly as to ensure proper spacing for each culm.

Apart from the physical factor, development of new shoots is greatly influenced by the age of the clumps, harvesting procedure and intensity, density of culms and other management systems. Even though there is no clear-cut system for age determination of bamboo, especially in natural forest, it was observed that shoots development is lower in aged clumps, as well as in highly congested clumps. It seems that clumps which were never subjected to harvesting of shoots tend to lose their productivity. Like all other grasses, thinning of culms is required to enhance the productivity. Removing of aged culms is required to give more space for the newly developed shoots and to sanitize the clumps from pest and diseases. Harvesting of culms

Bamboo harvesting is recommended in the dry season where all culms over 3 years or older can be removed from a clump by cutting them just above a node approximately 20cm above the ground level. However, the younger shoots should remain be there for further nourishment of the root systems. In the growing season, selective removal of shoots that are going to create over crowding are beneficial. Healthy shoots with higher diameter which have potential to produce straight strong poles for timber use should be promoted.

At the time of bamboo harvesting general felling rules should be followed which are hardly practiced by the contractors to reduce the cost of harvesting (Anon 2010). Harvesting of the culms from the periphery of the clumps is easier but deteriorates the outward development of rootsystems resulting in to congestion of clumps. Therefore, it is recommended that the Department of State Forest be careful at the time of harvesting and properly monitor the harvesting of bamboo culms and impose penalty on the contractors for their wrong practices.

Clump management and their likely impact of climate change mitigation

The proper maintenance of the clump not only improves productivity but also eases the job of the plantation worker. As a maintenance activity it involves removing unwanted culms to prevent clump congestion. This is particularly necessary with densely tufted species. It is sometimes necessary to sacrifice a few culms in order to allow for better shoot production in the clump. Clump management rule propounded by Salam and Deka (2007) should be considered and modifications may be made with a deeper research in context with the region.

Climate change mitigation and adaptation services cannot be fulfilled by establishing new plantations through afforestation or reforestation programs alone, rather it also requires broader approach to optimize management of existing bamboo resources (Kuehl and Yiping 2012) through their ecological management.As per recent forest report on bamboos in Mizoram, more than 90% of the bamboo clumps are badly congested in the state (Anon 2010).Therefore, clump management is one of the important factors which has been widely ignored that can be scientifically managed to enhance the productivity of a bamboo through maintaining health of the clumps. One of the most serious problems in clumps managementis the bamboo culm congestion within the clumps which requires proper management to enhance the quality and quantity of bamboos in the region. Further, interference of human agencies should be taken care to optimize bamboo production in the region. Congestion in bamboo clumps have reported to occur as a result of soil compaction and insufficient soil depth that prevents the formation of sufficient coarse roots in a season (Kondas 1982,Tripathi and Singh 1993). Further, the cumulative effect of careless felling considerably affects the congestion of clumps in bamboo ecosystems in Mizoram. Possible remedies to overcome with the problems of congestion in bamboos includes; providing adequate protections in the area for grazing to avoid soil compaction, mounding of earth around the clump in order to influence the development of future root systems outwards that can effectively control requirement of soil depth, removing or harvesting excess new shoots in the beginning to effectively control congestion, prohibition of hacking and looping of top ends for fodder by grazers, optimizing the point of harvesting of culms preferably just above the first node and slanting or oblique cutting of the culms and avoiding of flat cutting of culms.

Biomass, productivity and carbon dynamics of bamboo ecosystems

A comparison of bamboo biomass in several bamboo ecosystems are summarized in Table 1.The aboveground biomass of bamboo ecosystem ranged from 0.8 – 84.1 Mg h^{-1} and the annual biomass offsetting through the bamboo shoots ranges from 1.8 – 49.5 Mg ha^{-1} yr^{-1}. The above ground biomass reported from Mizoram, India (Vanlalfakawma 2014) is broadly comparable to the bamboo biomass reports from Assam (21.7 – 76.6 Mg ha^{-1}). Rao and Ramakrishnan (1989) reported a much lower Dendrocalamushamiltoniibiomass (0.8–6.2 Mg ha^{-1}) from Meghalaya.

The annual production of biomass (20.2–49.5 Mg ha^{-1} yr^{-1}) by Bambusatulda, Dendrocalamuslongispathusand Melocannabacciferafrom the bamboo ecosystems in Mizoram, India(Vanlalfakawma 2014) is comparable with that of the bamboo stand of Philippines (20 – 45 Mg ha^{-1} yr^{-1}) as reported by Uchimura (1978); whereas a much lower net production of biomass was reported the Indian dry tropical region by Tripathi and Singh (1996).

In terrestrial ecosystems, C stock refers to the

Table 1. Comparative account of above ground biomass (Mg ha^{-1}), net production (Mg ha^{-1} yr^{-1}) and rate of C sequstration Mg $ha^{-1}yr^{-1}$) of various bamboo ecosystems. * Including above and below ground.

Species	Locality	Biomass (Mg ha^{-1})	Biomass production (Mg ha^{-1} yr^{-1})	Authors
Bamboo stand	Phyllipines	—	20—25	Uchimura (1978)
Phyllostachys edulis	Central Taiwan	79.3*	16.1*	Kao and Wang (1988)
Dendrocalamushanitonii	Meghaya, India	0.8—6.2	—	Rao and Ramkrishnan (1989)
Arundinariafalcata	Nainital, India	22.4—29.2*	7.3—14.7*	Pandey (1990)
P. bambusoides	Japan	165.1	—	Isagi (1994)
D. strictus	Mirzapur, India	3.2—26.0 11.2—36.0*	1.8—8.0 7.8—15.7*	Tripathi and Singh (1996)
D. strictus	Singrauli, India	46.9—74.7*	17.0—24.7	Singh and Singh (1998)
Bambusabalcooa	Thissur, Kalara, India	54—499	12.1	Kumar et al. (2005)
B. cacharensis B. Vulgaris, B. balcooa	Cochar, Assam, India	21.7—76.6	—	Nath and Das (2012)
B. tulda, M. baccifera, D. longispathus	Mizoram, India	43—84.1	20.2—49.5	Vanlalfakawma (2014)

prolonged storage of C in the vegetation and/or soil compartments over a period of time. However, Csequestration refers to the annual C fixed in thebiomass production in the vegetation through the process of photosynthesis that restricts the release of C to the atmosphere. Bamboo culms of most species attain maturity within sort period of time (approximately 5 – 10 years) because of their rapid growth rates (Tripathi and Singh1996), after which they deteriorate rapidly and releasing C from the above-ground biomass back into the atmosphere (Liese 2009). Therefore, in a natural state, bamboo reaches a stable level of above ground C relatively quickly, where C accumulation through sequestration is offset by C release through deterioration of old culms. In order for the bamboo system to continue to be a net sink of C has to be stored in other forms so that the total accumulation of C in a solid state exceeds the C released to the atmosphere (Yiping et al. 2010). Prolonged sequestration of C is provided through a great variety of bamboo products that range from construction materials to pulp (Liese 2009). An assumptive comparison between bamboo species and wood species suggested that there is an equal rate of conversion from living C to biomass (Yipinget al. 2010). A number of factors may affect this assumption, amongst which the durability of product is of key concern. The longevity and durability of bamboo products may determine the C storage performance to a great degree. It is important to reduce by-products and waste and to produce durable bamboo products during bamboo processing, which in-turn is a way of maintaining the C in the bamboo itself. Processing technologies and innovations have greatly increased the proportion of durable bamboo products. Development and promotion of durable products sustain the longevity of C storage. Processing of bamboo into products with long life cycles, such as construction materials, panel products and furniture will prolonged the C storage in bamboo biomass. Durable bamboo products during bamboo processing, which in-turn is a way of maintaining the C in the bamboo itself. Processing technologies and innovations have greatly increased the proportion of durable bamboo products. Development and promotion of durable products sustain the longevity of C storage. Processing of bamboo into products with long life cycles, such as construction materials, panel products and furniture will prolonged the C storage in bamboo biomass. The C- sequestration rates of several bamboo ecosystemscomprising of 5 genera and 16 different species, are summarized in Table 2. The mean C sequestration rates of these bamboo ecosystemranged from 1.2 – 23.6 Mg ha^{-1} yr^{-1} In comparison to other ecosystems C sequestration in selected bamboo species are considerably high (Table 2).

Role of bamboo in C offsetting

The implementation of Kyoto Protocol for C offset-

Table 2. Comparative account of C sequestation (Mg $ha^{-1}yr^{-1}$) rates of various bamboo ecosystems.

Species	Locality	C-Sequestation (Mg ha^{-1} yr^{-1})	Authors
Phyllostachysbusoides	Japan	13	Isagi et al.(1993)
Dendrocalamustrictus	Mirzapur, India	6.3—8.7	Tripathi and Singh (1996)
Bambusbambos	India	24	Shamughavel and Francis (1996)
P. Pubescens	Japan	9	Isagi et al. (1997)
D. strictus	India	13	Singh and Singh (1999)
Bambusopallida	India	13	Singh and Kochhar. (2005)
B. bambos	India	6	Kumar et al. (2005)
B. oldhamii	Mexico	16	Cactañeda-Memdoza et al. (2005)
P. makinoi	Taiwa	10	Yen et al. (2010)
B. cacharunsis	Barak, Valley		
B. vulgaris B. balcooa	Assam India	1.2—1.5	Nath and Das (2011)
P. heterocycla	Taiwan	8	Yen et al. (2010)
B. cacharensis, B. vulgaris B. balcooa	Cachar, Assam, India	18.9—23.6	Nath and Das (2012)
P. pubescens	China	7	Zhang et al. (2014)
Schizostachyampurgacile	Manipur India	22.41	Thokchom and Yadava (2015)
B. tulda, M.baccifera D. longispathus	Mizaran, India	8.9—22.7	Vanlalfakawma (2014)

ting or controlling greenhouse gas emissions through Clean Development Mechanism (CDM) allowed the industrialized nations to earn C credit through implementing afforestation/ reforestation programs in the developing nations (Mondal and Sachdev2012, Tripathi 2013). The potential for sequestering C in agriculture and forestry sinks to generate C-credits has received increased attention by several social and academic institutes over the last few years (Williams et al. 2009). Plantations typically combine higher productivity and biomass with greater annual transpiration and rainfall interception thereby making it prominent tools for C sequestration (Jackson et al. 2005).

The focus of forest-based ecosystems for sequestering C has largely been on creating permanent stores of C on defined areas of land with a single payment to the forest owner for the C (Bisby 2009). With their ratification of the Kyoto Protocol, many countries have established forests on previously non-forested land with the view of offsetting greenhouse gas emissions (Whitehead 2011). Hence, C sequestration through Paraserian the sfalcatariabased agroforestry systems in Philippines was found to be more cost effective than pure tree-based systems (Shively et al. 2004).

Bamboo has an important role to play in reducing pressure on forestry resources. For instance, in India and China, since nationwide logging bans of certain forests came into effect in 1997 and 1998 respectively, bamboo has increasingly been seen as a possible substitute of timber.The high amount of C sequestration potential per unit time can make the bamboo based agroforestry system a feasible prototype for Clean Development Mechanism (CDM) type projects. Besides, such agroforestry system can provide other environmental services like improved land and water quality and hence improved microclimate (Nath and Das 2012). Bamboo has been successfully used in different product lines, ranging from furniture to paper and packaging validates the high potential of bamboo as a more sustainable alternative in the fabrication of many services (Yiping et al. 2010).

So far, C accounting methodology for afforestation with bamboo has been developed and adapted in China. In order to meet the objective of implementing bamboo C sequestration projects in all 38 International Network for Bamboo and Rattans (INBAR) member countries, INBAR and partners are in the process of developing a global version and named it "C Accounting Methodology for Afforestation with Bamboo in China" (Kuehl and Yiping 2012). C accounting methodology will ensure that C accounting methodologies comply with national forest definitions and other national laws and regulations in the respective countries.

CONCLUSION

The role of bamboo ecosystem in the socio-economic as well as in the ecological services is a matter of interest. In the context of ecological services through carbon sequestration and carbon offsetting, clump management is the backbone, which directly stimulate the productivity. The same applies with the socio-economic services. Hence, enhancing the productivity of bamboo ecosystemis directly proportional to the managing system of the clumps. Value addition on the other hand requires the intervention of Governments or corporates.

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RETERENCES

Anon (2003) National Mission on Bamboo Technology and Trade Development. Planning Commission, Government of India, New Delhi.

Anon (2008) Statistical Handbook 2008. Environment and Forest Department, Government of Mizoram, Aizawl, pp. 120.

Anon (2010) Bamboos of Mizoram. Environment and Forest Department. Government of Mizoram, Aizawl, pp. 1 – 206.

Bisby H. (2009) Carbon banking : Creating flexibility for forest owners. For. Ecol. Manage. 20 : 378–383.

Brown S. and Lugo A. E. (1982) The storage and production of organic matter in tropical forests and their role in the global carbon cycle.Biotropica. 14: 161-187.

Brown S., Masera O.,Sathaye J.,Andrasko K., Brown P., Frum off P., Lasco R., Leach G., Moura-Costa P., M wakifwamba S., Phillips G., Read P., Sudha P. and Tipper R. (2000) Project-based activities. In : Watson B., Noble I., Bolin B., Ravindranath N. R., Verardo D.J. and Dokken D.J. (eds). Land Use, Change and Forestry. A Special Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press,Camidge, pp. 285-338.

Castañeda-Mendoza A., Vargas-Hernandez J., Gomez-Guerrero A., Valdez-Hernandez J.I. and Vaquera–Huerta H. (2005) Carbon accumulation in the aboveground biomass of a Bambusaoldhamii plantation. Agrociencia39:107 – 116.

Christanty L., Kimmins J.P. and Mailly D. (1997) Without bamboo, the land dies: A conceptual model of the biogeochemical role of bamboo in an Indonesian agroforestry system. For. Ecol. Manage. 91:83–91.

Dransfield S. and Widjaja E.A. (1995) Plant Resources of South-East Asia No. 7. Bamboos. Backhuys Publishers, Leiden, pp. 1 – 89.

Isagi Y. (1994) Carbon stock and cycling in a bamboo Phyllostachysbambusoides stand. Ecol. Res. 9 (1) : 47-55.

Isagi Y., Kawahara T. and Kamo K. (1993) Biomass and net production in a bamboo Phyllostachysbambusoidesstand. Ecol. Res. 8 : 123 – 133.

Isagi Y., Kawahara T., Kamo K. and Ito H. (1997) Net production and carbon cycling in a bamboo Phyllostachyspubescens stand. Pl. Ecol. 130 : 41 – 52.

Jackson R.B., Jobbagy E.G., Avissar R., Roy S.B., Barrett D.J., Cook C.W., Farley K.A., le Maitred.c., McCarl B.A. and Murray B.C. (2005) Trading water for carbon with biological carbon sequestration.Science 310 : 1944 – 1947.

Kao Y.P. and Wang Tze-Ting (1988) Biomass, litterfall and net primary production of 'moso' bamboo stands in Central Taiwan. Bamboo Abstracts.Chinese Academy of Forestry, Beijing, China1(1) : 42 – 48.

Kondas S. (1982) Biology of two India bambos, their culm potential and problems of cultivation. Ind. For. 108 (3) : 179 – 188.

Kuehl Y. andYiping L. (2012) Carbon Offsetting with Bamboo. INBAR Working Paper 71. Published by International Network for Bamboo and Rattan (INBAR) PO Box 100102-86, Beijing 100102, PR China, pp. 25.

Kumar B.M., Rajesh,G. and Sudheesh K.G. (2005) Above ground biomass production and nutrient uptake of thorny bamboo Bambusabambos (L.) Voss in the homegardens of Thrissur, Kerala. J. Trop. Agric. 43 (1-2) : 51 – 56.

Lalramnghinglova, Jha L.K. (1997) Forest Resources an overview. In:Jha L.K. (ed). Natural Resource Management – 1. Mizoram. APH Publishing Corporation, New Delhi, pp. 203 – 253.

Liese W. (2009) Bamboo as Carbon-Sink – Fact or Fiction? J. Bamboo and Rattan 8 : 103-114.

Magel E., Kruse S.,Lütje G. and Liese W. (2005) Soluble Carbo hydrates and Acid Ivertases involved in the rapid growth of the developing culms in Sasapalmata (Bean) Camus. Bamboo Science and Culture, Baton Rouge/USA 19 1, S, pp. 23 – 29

Mondal A. P. and Sachdev S. (2012) Carbon Credit: A Burning Business Issue.The Business and Manage. Rev. 3 (1) : 170 – 178.

Naithani (2008) Diversity of Indian bamboos with special reference to North-East India. Ind. For. 134(6) :756 – 788.

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

Nath A.J. and Das A.K. (2012) Carbon pool and sequestration potential of village bamboos in the agroforestry system of Northeast India.Trop. Ecol.53(3): 287 – 293.

Newman M., Ketphanh S., Svengsuksa B., Thomas P., Sengdala K., Lamxay V. and Armstrong K. (2007) A checklist of the Vascular plants of Lao PDR, Royal Botanic Garden, Edinburgh, Scotland, UK, pp.400.

Ohrnberger D. (1999) The Bamboos of the World: Annotated Nomenclature and Literature of the Species and the Higher and Lower Taxa. Elsevier, Amsterdam and New York, pp. 585.

Pandey P. (1990) Structure and functions of Ringal (Anurindanar iafalcataNees) community in the oak zone of Kuman Himalaya. Ph.D. thesis.KumaunUniversity, Nainital, India.

PandeyR.R., Sharma G.,Singh T..B. andTripathi S.K.(2010) Factors influencing soil CO2 efflux in a Northeastern Indian oak forest and plantation. Afr. J. Pl. Sci.4 (8): 280-289.

Perez M.R., Zhong M.G., Belcher B., Belcher B., Xie C., Fu M.Y. and Xie J.Z. (1999) The role of bamboo plantations in rural development: The case of Anji county, Zhejiang, China.World Develop. 27:101 – 114.

Rao K.S. and Ramakrishnan P.S. (1989) Role of bamboos in nutrient conservation during secondary succession following slash and burn agriculture (Jhum) in North-East India. J. Appl. Ecol. 26:625 – 633.

Salam K. and Deka N.K.R. (2007) In: Kalita S.N. (ed). Training manual on Nursery raising, commercial plantation, pres ervation and primary processing of bamboo. Cane and Bamboo Technology Center Bamboo Technical Support Group for National Bamboo Mission Zoo-Narangi Road (Mother Teresa Road), Narikal Basti, Guwahati 781024, Assam, India.

SFR (2019) India State of Forest Report 2019. Forest Survey of India (Ministry of Environment Forest and Climate Change. Dehradun248195, Uttarakhand, India, pp.129.

Shanmughavel P. andFrancis K. (1996) Above ground biomass production and nutrient distribution in growing bamboo (Bambusabambos(L.) Voss). Biomass Bioenergy 10: 383–391.

Sharma Y.M.L. (1980) Bamboos in the Asia-Pacific region. In:Lessard G. andChouinard A. (eds). Bamboo research in Asia. Proceedings of a workshop held in Singapore, 28-30 May 1980. International Development Research Center, Ottawa, Canada, pp. 99 – 120.

Shively G.E., Zelek C.A., Midmore D.J. and Nissen T.M. (2004) Carbon sequestration in a tropical landscape : An economic model to measure its incremental cost. Agrofor. Syst. 60:189 – 197

Singh A.N. and Singh J.S. (1999) Biomass, net primary production and impact of bamboo plantation on soil redevelopment in a dry tropical region.For. Ecol. Manage. 119: 195 – 207.

Singh K.A. and Kochhar S.K. (2005) Effect of clump density /spacing on the productivityand nutrient uptake in Bambu sapallidaand the changes in soil properties. J. Bamboo Rattan 4: 323–334.

Takahashi M., Furusawa H., limtong P., Sunanthapongsuk V., Marod D. and Panuthai S. (2007)Soil nutrient status after bamboo flowering and death in a seasonal tropical forest in Western Thailand. Ecol. Res. 22 : 160 – 164.

Thokchom A. and Yadava P. S. (2015) Bamboo and its role in climate change. Curr. Sci. 108 (5) : 762 – 763.

Toky O.P. and Ramakrishnan P. S. (1983) Secondary succession following slash and burn agriculture in northeastern slash and bum agriculture in North-Eastern India. I. Biomass, litterfall and productivity. J. Ecol.71 : 735 – 745.

Tripathi S. K. (2009) Human influences on mobility of nitrogen in the environment : Needs for research and management. Acta. Ecologica. Sinica. 29 : 130–135.

Tripathi S. K.(2010) The need for establishing long-term ecological research stations network in India. Curr. Sci. 98 (1) : 21-22.

Tripathi S. K. (2013) Forest fine roots in changing environment. J. Sci.Technol. 1(2) : 70-77

Tripathi S. K., Kushwaha C. P. and Basu S. K. (2012) Application of fractal theory in assessing soil aggregates in Indian tropical ecosystems. J. For. Res. 23 : 355-364.

Tripathi S.K., Kushwaha C. P. and Singh K. P. (2008) Tropical forest and savanna ecosystems show differential impact of N and P additions on soil organic matter and aggregates structure. Global Change Biol.14 : 2572-2581.

Tripathi S. K. and Singh K. P. (1992a) Abiotic and litter quality control during the decomposition of different plant parts in dry tropical bamboo savanna in India. Pedobiologia 36 : 109–124.

Tripathi S.K., Sumida A., Shibata H., Uemura, S., Ono K. and Hara T. (2005) Growth and sub Tripathi S.K. and Singh K.P. (1992b) Nutrient immobilization and release patterns during plant decomposition in a dry tropical bamboo savanna, India. Biol. Fertil. Soils 14 : 191–199.

Tripathi S.K.and Singh K.P. (1993) An ecological assessment of spatial pattern in site conditions in bamboo plantations in dry tropical regions with a comment on clump spacing. Ind. For.119 : 238-256.

Tripathi S.K. and Singh K.P. (1994) Productivity and nutrient cycling in recently harvested and mature bamboo savannas in the Indian dry tropics. J. Appl. Ecol. 31 : 109-124.

Tripathi S.K. and Singh K.P. (1995) Litter dynamics of recently harvested and mature bamboo savannas in a dry tropical region in India. J. Trop. Ecol. 11 : 403–417.

Tripathi S.K. and Singh K.P. (1996)Culm recruitment, dry matter dynamics and carbon flux in recently harvested and mature bamboo savannas in the Indian dry tropics. Ecol. Res. 11 : 149 - 164.

Tripathi S.K. and Singh K.P. (2008) Role of Active components in carbon and nutrient cycling of bamboo ecosystems in Indian dry tropical region.J. Bamboo and Rattan 7(1-2) : 141 – 150.

Tripathi S.K., Singh K.P. and Singh P.K. (1999) Temporal changes in spatial root masss and nutrient concentrations in Indian bamboo savanna.Appl.Vegetation Sci. 2(2) : 299 – 23strate quality of fine root and soil nitrogen availability in a young Betulaermaniiforest of Northern Japan: Effects of the removal of understory dwarf bamboo (Sasakurilensis). For. Ecol. Manage. 212 : 278–290.

Uchimura E. (1978) Ecological studies of cultivation of tropical bamboo forest in the Philippines. Bull no301. Forestry and Forest Products Research Institute, Ibaraki, Japan, pp. 79 – 118.

Vanlalfakawma D.C. (2014) Carbon and nitrogen sequestration potential of bamboo forests of Mizoram. Ph.D.thesis. Mizoram University.

Whitehead D. (2011)Forests as carbon sinks—benefits and conse quences.Tree Physiol.31 : 893–902.

Williams J.R., Mooney S. and Peterson J.M. (2009) What is the carbon market: Is there a final answer?J. Soil and Water Conserv.64(1) : 27A-35A.

Yen T.M., Ji Y.J. and Lee J.S. (2010) Estimating biomass pro duction and carbon storage for a fast-growing makino bamboo (Phyllostachysmakinoi) plant based on the diameter distribution model. For. Ecol. and Manage.260 : 339 – 344.

Yen T.M. and Lee J.S. (2011) Comparing aboveground carbon sequestration between moso bamboo (Phyllostachysheterocy cla) and China fir (Cunninghamialanceolata) forests based on the allomatric model. For. Ecol. Manage. 261 : 995–1002.

Yiping L., Yanxia L., Buckingham K., Henley G. and Guomo Z. (2010) Bamboo and climate change mitigation: A compar ative analysis of carbon sequestration.International Network for Bamboo and Rattan (INBAR) PO Box 100102-86, Beijing 100102, PR China,pp. 1 – 47.

Zhang H., Zhuang S., Sun Bo, Ji H., Li C. and Zhou S.(2014) Estimation of biomass and carbon storage of moso bamboo (Phyllostachyspubescens Mazel ex Houz.) in Southern China using a diameter–age bivariate distribution model. Forestry 87 : 674–668.

Zhengyi W., Raven P.H. and Deyuan H. (2006) Flora of China, Vol 22: Poaceae, Beijing and St. Louis, MO. Science Press and Mission Botanical Garden.