Print : ISSN 0970 – 7662
Online : ISSN 2455 – 7129

Journal of Tree Sciences

online available at www.ists.in

Volume 40 No. 1 June, 2021

Ecosystem Services Of Traditional Large Cardamom Based Agroforestry Systems Of Darjeeling and Sikkim Himalayas

Vineeta, Bisleshna Tamang, Sajitha Saril, Manendra Singh, Subrata Das, Gopal Shukla, Sumit Chakravarty*

Department of Forestry, Uttar Banga Krishi Viswavidyalaya, Pundibari Cooch Behar, West Bengal India

*c_drsumit@yahoo.com

DOI: 10.5958/2455-7129.2021.00006.6

ABSTRACT

Indigenous large cardamom (*Amomum subulatum* Roxb.) based agroforestry systems are prevalent in the Darjeeling and Sikkim Himalayas and are life line for people of these mountainous regions. The paper reviews the earlier studies on large cardamom based traditional agroforestry system from Sikkim and Darjeeling Himalayas and outlined the ecosystem services provided by the systems along with the major problems of this system identified by the earlier studies. The system provides numerous ecosystem services from provisional to cultural with potential role in increasing carbon sink, avoiding deforestation and conserving natural resources thereby providing multiple goods and services including productivity, nutrient cycling, nitrogen fixation, energy fixation and nutrient use efficiency. However, in the past few decades, productivity of this farming system has declined significantly which has been attributed to climate change, increased incidences of insect pest and diseases along with anthropogenic pressure. Creating alternate opportunities for livelihood diversity and security are also suggested in the studies.

Key Words:

Agroforestry system, climate change, cultural services, provisional services, traditional

INTRODUCTION

The global issue of climate change is one of the major concerns for sustaining present and future generation (Rijal 2019). Climate change is itself a natural process but in the last few decades, it has lead to major changes in human life-supporting climatic patterns. To muddle up through various intense conditions, we require the practice or technology that can develop coping capacity. Agroforestry practices are one of the emerging strategies which have the potential to reduce the vulnerability of climate change. Agroforestry, sustainability-enhancing practice that combines the best attributes of forestry and agriculture, has been recognized by the Intergovernmental Panel on Climate Change (IPCC) as a viable climate change mitigation strategy involving small landholder producers (Watson et al. 2000). Thus, agroforestry practices are now recognized for its potential in assuring food security, reducing poverty and enhancing ecosystem resilience at micro-landscape level (Gari 2001).

The concept of modern agroforestry comes from the traditional agroforestry system which is still practised globally by indigenous people. India the country of diversified cultures supports numerous traditional farming practices including agroforestry. These indigenous agroforestry systems support livelihood ensuring production of food, fodder and fuelwood while, mitigating the impacts of climate change through carbon sequestration (Singh et al. 2008; Bargali et al. 2009). Productivity and sustainability are mutually exclusive properties of these agroecosystems (Altieri 2009). One of the greatest challenges today is therefore to achieve optimum productivity from the agroecosystems without losing its diversity of components and functions. The Darjeeling and Sikkim Himalayan region included in the Indo Malayan Biodiversity Hotspot is one of the biodiversity-rich regions of India (Myers et al. 2000) with numerous farm- and forest-based traditional agroforestry systems of varying composition and structures along the altitudinal gradient (Sharma et al. 2016$_{a,\ b}$); prominent of which is *Alnus nepalensis*-large cardamom agroforestry system (Sharma et al. 2008).

TRADITIONAL LARGE CARDAMOM BASED AGROFORESTRY SYSTEM

Large Cardamom (*Amomum subulatum* Roxb.; Photo1 and 2) is one of the oldest traditionally used spices by mankind belonging to the family Zingiberaceae.

Photo 1. Large cardamom plantation

Photo 2. Mature large cardamom-*Alnus* plantation

It is commonly known as *Alaichi* in Nepali and *Badi Alaichi* in Hindi and popular as black cardamom, black gold and queen of spices. It is a shade loving and evergreen perennial herbaceous plant grown on the north-facing slopes of the hill (Shreshtha et al. 2018) and native to Sikkim, India. Numbers of wild relatives (Table 1) are easily found in the forest areas, among them, *A. subulatum* is only cultivated. There are reported 12 local varieties and seven wild varieties of cardamom crop readapted to different agro-climatic conditions of the eastern Himalayan region (Sharma et al. 2007).

It is believed that the Large Cardamom crop was naturally grown in the forest of eastern Himalayan region of Darjeeling, Sikkim, north-eastern states of India, Nepal and Bhutan. It is a perennial cash crop of the region grown beneath tree cover on marginal lands between altitudes of between 600 m and 2000 m (Table 1) *i.e.* from subtropical to cool temperate zones. The crop requires high moisture and it grows suitably in a region of annual mean rainfall of 1500-3500 mm with soil pH of 4.5-7.0. The commercial part of the crop is the greyish brown to dark red-brown dried capsule enclosing 40-50 small seeds in it. The 20-25 mm long oval to globule shaped capsules is held together inside the spike with viscous sugary pulp (Thomas et al. 2009). It is harvested before it ripens to avoid the capsules from splitting during the drying process. The capsules used as a spice or condiment contain about three per cent essential oils and are rich in cineole (Gupta et al. 1984).

Large cardamom plantation is associated with many important trees due to its sciophytic nature but the altitudinal range of *Alnus nepalensis* is sympatric with the agro-climatic range of large cardamom and has proved to be ecologically and economically viable.

Table 1. Important cultivars of large cardamom

Cultivar	Altitudes	Description	Susceptible to
Varlangey	above 1200 m	Plant is robust with height of 1.5-2.5 m. Bold capsule with 50-70 seeds. Flowering starts during June-July with harvesting in end of November.	-
Sawney	above 1350 m	It is a widely adaptable robust cultivar of 1.5-2.0 height. Leaves are ovate and broad with maroon tillers. Bold capsules with 35-50 seeds. Flowering time is March-May with harvesting time of September-November.	Chirke and Foorkey diseases
Dzongu Golsey	below 1500 m	Plant height is 1.0-1.5 m with green tillers and leaves are narrow and erect. Capsules are big and bold with 50-70 seeds. Flowering starts in March with harvesting in September-October.	Foorkey and leaf streak diseases
Ramsey	above 1200 m	Plants are 1.5-2.0 m tall and robust with maroon tillers. Flowering starts in May and harvested during October-November. Capsules are small with 25-40 seeds	Chirkey and Foorkey

Source: Bhutia et al. 2018

The trees associated in particular to this system are *Alnus nepalensis, Albizia species, Scima wallichii, Maesa chassis, Ficus nemoralis, Ficus hookeri, Nyssa sessiliflora, Osbeckia paniculata, Viburnum cordifolium, Litsaea polyantha, Macaranga pustulata, Saurauvia nepalensis, Machilus edulis, Melia composite, Engelhardtia acerifolia, Eurya acuminata, Leucosceptrum canum, Maesa chisia* and *Symplocos theifolia* (Sharma et al. 2007; Anitha and Hore 2018). *Alnus* is by nature an actinorhizal (nitrogen fixer) tree and easily grows naturally on landslide affected areas (Sharma and Ambasht 1986). Farmers used to grow the crop on steeper marginal and fragile land to minimize soil erosion and landslides (Sharma and Sharma 1997). The practice of growing nitrogen-fixing *Alnus* as shade trees have been adopted by the indigenous communities to maintain soil fertility and increasing productivity (Sharma et al. 1994). Its cultivation is an example of how a local mountain niche can be exploited in a sustainable way (Sharma 2013). This system shows how an ecological and economic traditional farming practice has evolved indigenously as the main agroforestry practice in the region (Singh et al. 1989).

Area and Status of Large Cardamom based Agroforestry system

The cultivation of large cardamom has spread over other Indian North-Eastern regions of Nagaland (550 ha), Mizoram (35 ha), Meghalaya (35 ha), Manipur (10 ha) and the central Indian Himalayan state of

Uttarakhand (41 ha) in the past two decades covering a total of 34,252 ha (Srinivasa 2006). Sikkim was the leading producer globally but currently is second-largest after Nepal. Total Indian production during 2018 was about 16,860.20 metric tons. Nepal leads with 52 % of the total global production followed by India with 37 % and least by Bhutan with 11 % (Metha et al. 2015; Bhutia et al. 2018). Areas of large cardamom continued to increase in Sikkim (Table 2) which was due to ease of cultivation and high cash income including other ecological benefits realised from the system like erosion control and soil fertility improvement (Sharma et al. 2000, 2007).The area of cultivation in Sikkim and Darjeeling Himalayas in 2011-12 was 23154 ha 3305 ha, respectively with production of 3237 tonnes and 626 tonnes, respectively (Gudade et al. 2013).

Table 2. Decadal change in large cardamom based agroforestry cultivation in Sikkim

Indicators	1975	1985	1995	2005
Area (in thousand hectare)	10.00	20.90	23.50	27.59
Proportion of total cropped area (in %)	15	17	17	22
Annual cash income (in million US $)	1.90	5.70	6.40	13.75

Source: Sharma et al. 2007

In Darjeeling Himalayas during 2015-16 area of cultivation, production and productivity of large cardamom was 2829 ha, 848.84 tonnes and 300.5 kg ha^{-1}; of which cultivation is prominently done the district of Kalimpong (80 % of the total cardamom area) and less in Darjeeling (Tarafder et al. 2018).

ECOSYSTEM SERVICES

Large Cardamom based agroforestry is an age-old traditional agroforestry practice of Darjeeling and Sikkim Himalayas offering many ecosystem services from provisional to cultural (Fig. 1; Millennium Ecosystem Assessment, 2005) with positive impact on productivity, nutrient cycling, nitrogen fixation, energy fixation and nutrient use efficiency (Sharma et al. 2000, 2007). The system also provides firewood, fodder and other products. It also contributes to soil and water conservation, soil fertility, carbon storage and flaws and a favourable microclimate. The people living in the hills and mountains of Sikkim later observed the utility and market value of the crop and showed more interest in its production. This traditional agroforestry system further enhances the ecological benefits by enhancing forest cover with intact tree biodiversity in the existing farming system.

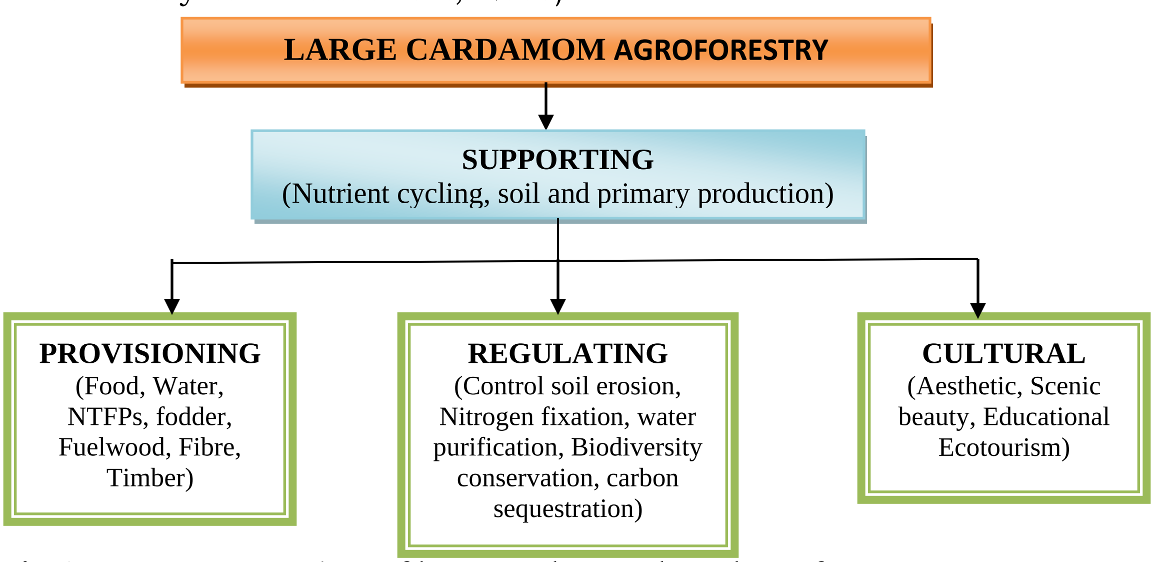

Fig 1. Ecosystem services of large cardamom based agroforestry system

Provisioning services

The large-cardamom based traditional agroforestry systems provide sustainable economic benefits to the farmer community in the sub-Himalayan region mainly as capsule, fuelwood and fodder. The essential oil-rich seeds of large cardamom have a pleasant aromatic odour and can flavour vegetables and many food preparations (Bhutia et al. 2017). Value-added products of large cardamoms, such as essential oil and oleoresin, have high market values and export potentials. After removing the oleoresin from the dry cardamom spices, the residues also have good marketing scope as an ingredient of animal feed. The essential oil of large cardamom is reported to have antimicrobial properties also (Agnihotri and Wakode 2010). Large cardamom based traditional agroforestry system harbour rich diversity of Himalayan flora which were reported to provide numerous provisioning services of food, fodder, timber, fuel wood, medicine, and for earning cash income (Sharma and Ambasht 1991; Sharma and Sharma 1997; Sharma et al. 2000; Avasthe et al. 2007, 2011; Sharma 2013; Gudade et al. 2013; Partap et al. 2014; Singh et al. 2018; Tarafder et al. 2018)

Supporting and regulating services

Large cardamom-based agroforestry system is capable of maintaining the ecological balance of the hilly region (Sharma et al. 1994, 1997, 2000, 2007, 2008, 2009$_{a,\ b}$, 2016$_{a,\ b}$; Avasthe *et al*., 2007, 2011; Sharma and Rai 2012; Singh et al. 2018). The crop is associated with many multipurpose trees that can maintain soil fertility, improve water table, control soil erosion and reduce the chances of landslides in the sloppy area. Soil loss was less in the *Alnus*-cardamom system in comparison to other systems and also the water availability in this system was found to be 81 % higher than rainfed agriculture system (Sharma et al. 2007). The shade trees were reported to ameliorate the microclimate of the area while, agroforestry patches along the mountain slopes regulate it at a landscape level. This system helps in the maintenance of biological diversity by reducing deforestation and pressure on woodlands by providing fuelwood and also helps in climate regulation by sequestering carbon dioxide. So, the overall productivity of the crop is increased without doing much effort.

The multistrata structure of large cardamom based agroforestry systems regulate climate by permanently sequestering atmospheric carbon because the associated tree species of the system will never ever be completely removed like other traditional agroforestry systems (Kumar et al. 1994; Kumar 2006; Henry et al. 2009; Nair et al. 2010; Saha et al. 2009, 2010; Chakravarty et al. 2017$_{a,\ b}$; Coelho, 2017; Shukla et al. 2017; Subba et al. 2017, 2018; Kumar et al. 2018; Dar et al. 2019; Das et al. 2019; Mengistu and Asfaw 2019; Pala et al. 2020). Consequent of permanency in heterogeneous vegetation and undisturbed litter layer along with continuous canopy and dense rhizosphere of large cardamom based agroforestry systems, the soils in the sloping landscape withstand erosive impacts of raindrops and restrict run off while, improving the soil fertility though nitrogen fixation and litter decomposition (Wagachchii and Wiersum, 1997; Gajaseni and Gajaseni, 1999; Sharma et al. 2007, 2008, 2016$_{a,\ b}$; Pushpakumara et al. 2010). The system has higher litter production due to its vegetative heterogeneity and thus has higher organic matter. The decomposing litter and the organic matter regulates the nutrient cycling thus sustaining soil fertility, organic matter, carbon content and soil structure of the system (Gajaseni and Gajaseni 1999; Dawson and Smith 2007; Poeplau et al. 2011; Uthappa et al. 2015; Chauhan et al., 2019 and Chauhan et al. 2016; Pal and Panwar 2013).

The net primary productivity, mobilization of the stored organic and inorganic soil reserves, quality and quantity of nutrient uptake and return, solubilisation of phosphorus and fixation of nitrogen are high in the alder-cardamom system compared to the forest-cardamom systems (Table 3). Alder influenced the system by its fast growth which contributes to higher total biomass and also by enhancing cardamom performance as illustrated by greater tiller number, basal area and biomass (Sharma et al. 1994).

Table 3. Comparative productivity, yield and nutrient dynamics of large cardamom agroforestry under alder and mixed tree species

Parameters	Alder-cardamom	Forest cardamom
Biomass (kg ha^{-1})	28,422	22,237
Net Primary Production (kg ha^{-1} yr^{-1})	10,843	7,501
Agronomic yield (kg ha^{-1} yr^{-1})	454	205
Nitrogen		
Standing state in biomass (kg ha^{-1})	395.15	205.26
N_2- fixation (kg ha^{-1} yr^{-1})	65.34	-
Uptake from soil (kg ha^{-1} yr^{-1})	78.49	80.56
Retention (kg ha^{-1} yr^{-1})	56.12	49.55
Return to soil (kg ha^{-1} yr^{-1})	83.67	29.23
Exit through agronomic yield (kg ha^{-1} yr^{-1})	4.04	1.78
Use efficiency	73.0	93.0
Back-translocation from senescent tree leaf (%)	3.85	17.49
Phosphorus		
Standing state in biomass (kg ha^{-1} yr^{-1})	32.357	17.900
Uptake from soil (kg ha^{-1} yr^{-1})	13.178	6.517
Retention (kg ha^{-1} yr^{-1})	6.328	3.840
Return to soil (kg ha^{-1} yr^{-1})	6.146	2.347
Exit through agronomic yield (kg ha^{-1} yr^{-1})	0.704	0.330
Use efficiency	823	1151
Back-translocation from senescent tree leaf (%)	22.62	31.37

Source: Sharma et al. 1994

The Alnus-cardamom agroforestry system satisfies the diversity of farmer's needs simultaneously without the need for external inputs or heavy labour, while also stabilizing riparian zones and providing watershed protection (Zomer and Menke 1993). Scientific understanding following adequate analysis of Alnus-cardamom agroforestry systems have proven this traditional practice as economically remunerative, ecologically adapted with comparatively high carbon sequestration potential (Sharma and Sharma 1997; Sharma et al. 2000, 2007, 2008, $2009_{a,\ b}$, $2016_{a,\ b}$; Sharma and Rai 2012). Large cardamom based agroforestry systems are heterogeneous with numerous non-cropping plant species which mimics natural forest and thus provide support and habitat to diverse wildlife like small mammals, birds and insects including diverse pollinators which aids in promoting pollination and seed dispersal (Pushpakumara et al. 2010; Kapkoti et al. $2016_{a,\ b}$).

Spiritual and cultural services

The agroforestry systems provide recreational and spiritual services for the culturally diverse, indigenous and traditional communities in the sub-Himalayan region (Sharma and Sharma 1997; Sharma et al. 2000, 2007, 2008, $2009_{a,\ b}$, $2016_{a,\ b}$; Sharma and Rai 2012). The aesthetic values, which attract tourists, are contributed mainly by its beautiful landscapes and biodiversity-rich fauna and flora. There are cases of home stays by tourists for bird watching and trekking to the higher mountains in parts of cardamom cultivated areas in North Sikkim. The knowledge of traditional agroforestry systems has increased scope in education, research and ecosystem conservation studies (Sharma et al. 2009$_{a, b}$).

Limitations and Suggestions

Climate change

Himalayas are experiencing drastic climatic changes with comparatively more impacts than the plains (Surendra et al. 2010; Arrawatia and Tambe, 2012; Chettri et al. 2012; Pepin et al. 2015; Shukla et al. 2016; Dey et al. 2017$_{a, b}$; Palomo, 2017) causing sharp decline in productivity of the farming systems (Dhaka et al. 2010; Choudhary et al. 2012; Chakravarty et al. 2015; Dey et al. 2017$_{a}$; Meena et al. 2019) as due to inherent livelihood dependency of its indigenous communities on their traditional farming systems and natural resources (Sharma et al. 2009$_{a, b}$; Manandhar et al. 2011, 2013, 2015; Shukla et al. 2016; Dey et al. 2017$_{a, b}$; Meena et al. 2019). In the past few decades the productivity of traditional large cardamom farming of Darjeeling and Sikkim Himalayas has declined due to increased incidences of diseases and pests including decreased pollinator population which was attributed to longer dry spells, changing seasons, erratic, scanty and unseasonal rainfall (Sharma and Partap 2011; Rana *et al.*, 2013; Sharma 2013; Partap et al. 2014; Sharma et al. 2016$_{a, b}$; Shukla et al. 2016; Negi et al. 2018; Meena et al. 2019). The mountain farmers in Sikkim have been applying traditional technologies to adapt to the impacts of climatic changes at temporal and spatial scales. These mitigation measures need scientific and technical support through appropriate policies and investments (Sharma and Rai 2012; Kumar et al. 2015; Shukla et al. 2016; Negi et al. 2018; Tarafder et al. 2018).

Viral diseases

Chirkey (Mosaic disease) and *Phurkey* (stunted) are the most hazardous viral diseases reported in large cardamom crop as it destroys the whole plant (Sharma et al. 2009$_{b}$; Stoep 2010). Aphids were found to transmit these viral diseases. Periodic elimination of diseased plants with their beating up with virus-free cloned plantlets is useful prevention of these viral diseases (Paudel et al. 2018).

Improper agricultural practices

Repetitive use of planting materials from same source of mother stock year after year while, avoiding salvage of virus-infected planting stocks and absence of good agricultural practices lead to the rapid spread of diseases which requires adequate awareness through capacity building through timely and regular research and institutional support for adopting of good agricultural practices by the growers (Aryal et al. 2018; Paudel et al. 2018).

Informal marketing

Market channelization for quality capsules is also a major challenge (Sharma et al. 2009$_{b}$). Many governmental organizations and NGOs are engaged to encourage large cardamom farming, postharvest technology, and marketing in India like the Indian Spice Board, the Indian Cardamom Research Institute, the Department of Horticulture and Cash Crop Development, the Government of Sikkim, and the North Eastern Regional Agricultural Marketing Corporation (Bhutia et al. 2018).

CONCLUSION AND RECOMMENDATIONS

Socio-ecological and socio-cultural benefits of large cardamom based traditional agroforestry system has ecological and socio-cultural importance towards sustainable livelihoods for indigenous communities of Darjeeling and Sikkim Himalayas. The economic benefits of this agroforestry system compared to alternative cropping systems have been strong incentives for its adoption by the farmers of the region. Ecological stability and poverty eradication can link with this system and be considered as a true vision of sustainable development of the rural community of this Himalayan region. The values and services of the cardamom agroforestry system are enormous, especially when grown under nitrogen-fixing alder as shade trees. The efficiencies of alder in terms of energy fixation, production and nutrient use and alders accelerating effect on nitrogen and phosphorus nutrient cycling have a beneficial impact on cardamom and thereby on the ecosystem as a whole. However, inadequate marketing facilities, shrinking cropping area, unsustainable management, absence of extension and supporting services and unavailable quality planting are making the system less remunerative and unpopular. Research, extension and institutional support for assured quality planting material, proper crop management, value addition, and market is recommended. Creating alternate opportunities for livelihood diversity and security with policy support is also recommended.

REFERENCES

Agnihotri S. and Wakode S. 2010. Antimicrobial activity of essential oil and various extracts of fruits of greater cardamom. Indian Journal of Pharmaceutical Science, 72(5): 657-659.

Altieri M. A. 2009. Agroecology, Small Farms, and Food Sovereignty. Monthly Review, 61:102-113.

Anitha M. and Hore J. K. 2018. Production technology of some major and minor crops. In: Indian Spices: The legacy production and Processing of India's Treasured Export, ed. Sharangi A. B. Springer International Publishing. Pp. 95-175.

Arrawatia M. L. and Tambe S. 2012. Preface. Climate change in Sikkim: Patterns, impacts and initiatives. Information and Public Relations Department, Government of Sikkim, Gangtok, Sikkim.

Aryal M., Paudel N. and Ranjit M. 2018. Elimination of Chirkey and Foorkey viruses from meristem culture of large cardamom (*Amomum subulatum* Roxb.). European Online Journal of Natural and Social Sciences, Česká Republika, 7(2): 424-443

Avasthe R. K., Singh K. K. and Tomar J. M. S. 2011. Large cardamom *Amomum subulatum* (Roxb.) based agroforestry systems for production, resource conservation and livelihood security in the Sikkim Himalayas. Indian Journal of Soil Conservation, 39: 155-160.

Avasthe R. K., Singh M. and Srivastava L. S. 2007. Traditional agroforestry systems of Sikkim with special reference to large cardamom-alder relationship. The Indian Forester, 133: 888-898.

Bargali S. S., Bargali K., Singh L., Ghosh L. and Lakhera M. L. 2009. *Acacia nilotica* based traditional agroforestry system: effect on paddy crop and management. Current Science, 96(4): 581-587.

Bhutia E. H., Sharangi A. B., Lepcha R. and Yonzone R. 2018. Post-harvest and value chain management of large cardamom in hills and uplands. International Journal of Chemical Studies, 6(1): 505-511.

Bhutia K. C., Bhutia S. O., Chatterjee R. and Pariari A. 2017. Post harvest processing and marketing of large cardamom in India. Journal of Crop and Weed, 13(3): 212-218

Chakravarty S., Puri A. and Shukla G. 2015. Climate change vis-à-vis agriculture: Indian and global view-Implications, abatement, adaptation and tradeoff. In: Climate Change effect on Crop Productivity, eds. Sengar R. S. and Sengar K. CRC Press, Boca Raton. Pp. 1-88.

Chakravarty S., Puri A., Subba M., Pala N. A. and Shukla G. 2017$_a$. Homegardens: drops to sustainability. In: Agroforestry: Anecdotal to Modern Science, eds. Dagar, J. C. and Tewari, V. P. Springer Nature Singapore. Pp. 517-528.

Chakravarty S., Subba M., Pala N. A., Dey T. and Shukla G. 2017$_b$. Climate Change and Homegardens: Involving Small Landholders for Mitigation. In: Agroforestry: Practices and Potential Services, eds. Kumar, M. and Rajwar, G. S. OMICS Group eBooks, 731 Gull

Ave, Foster City, CA 94404, USA. (Available at www.esciencecentral.org/ebooks)

Chauhan S.K, Sharma R., Panwar Pankaj, Chander J. 2016. Short rotation forestry: a path for economic and environmental prosperity. Forestry Technologies- A Complete Value Chain Approach, 1: 260-288.

Chauhan S. K., Singh S., Sharma S., Sharma R. and Saralch H. S. 2019. Tree biomass and carbon sequestration in four short rotation tree plantations. Range management and Agroforestry, 40: 77-82.

Chettri N., Shakya B., Lepcha R., Chettri R., Rai K. R. and Sharma E. 2012. Understanding the linkages: climate change and biodiversity in the Kanchenjunga landscape. In: Climate change in Sikkim, eds. Arrawatia M L and Tambe S. Government of Sikkim, Gangtok. Pp. 161-178.

Choudhary J. S., Shukla G., Prabhakar C. S., Maurya S., Das B. and Kumar S. 2012. Assessment of local perceptions on climate change and coping strategies in Chotanagpur plateau of Eastern India. Journal of Progressive Agriculture, 3: 8-15.

Coelho G. C. 2017. Ecosystem services in Brazilian's southern agroforestry systems. Tropical and Subtropical Agroecosystems, 20: 475-492.

Dar M. U. D., Qaisar K. N., Masoodi A. H., Mughal A. H. and Khan P. A. 2019. Biomass production and carbon stock potential under home gardens of Kashmir Himalaya. Journal of Plant Development Sciences, 11:265-271.

Das M., Nath P. C., Reang D., Nath A. J. and Das A. K. 2019. Tree Diversity and the improved agroforestry systems in North East India. Applied Ecology and Environmental Sciences, 8: 154-159.

Dawson J. J. and Smith P. 2007. Carbon losses from soil and its consequences for land-use management. Science of the total Environment, 382: 165-190.

Dey T., Pala N. A., Shukla G., Pal P. K., and Chakravarty S. 2017_b. Perception on impact of climate change on forest ecosystem in protected area of West Bengal, India. Journal of Forest and Environmental Science,33: 1-7; DOI: 10.7747/JFES.2017.33.1.1

Dey T., Pala N. A., Shukla G., Pal P. K., Das G. and Chakravarty S. 2017_a. Climate change perceptions and response strategies of forest fringe communities in Indian eastern Himalayas. Environment, Development and Sustainability, DOI: 10.1007/s10668-017-9920-1

Dhaka B. L., Chayal K. and Poonia M. K. 2010. Analysis of farmers' perception and adaptation strategies to climate change. Libyan Agriculture Research Center Journal International, 1: 388-390.

Gajaseni J. and Gajaseni N. 1999. Ecological rationalities of the traditional homegarden system in the Chao Phraya Basin, Thailand. Agroforestry Systems, 46: 3-23.

Gari J. 2001. Biodiversity and indigenous agroecology in Amazonia: the indigenous peoples of Pastaza. Etnoecológica, 5(7): 21-37.

Gudade B. A., Chhetri P., Gupta U., Deka T. N. and Vijayan A. K. 2013. Traditional practices of large cardamom cultivation in Sikkim and Darjeeling. Life Sciences Leaflets, 9: 62-68.

Gupta P. N., Naqvi A. N., Misra L. N., Sen T. and Nigam M. C. 1984. Gas chromatographic evaluation of the essential oils of different strains of *Amomum subulatum* Roxb. growing wild in Sikkim. Sonderdruckaus Parumerie und Kodemetik, 65: 528-529.

Henry M., Tittonell P., Manlay R. J., Bernoux M., Albrecht A. and Vanlauwe B. 2009. Biodiversity, carbon stocks and sequestration potential in above ground biomass in smallholder farming systems of western Kenya. Agriculture, Ecosystem and Environment, 129: 238-252.

Kapkoti B., Joshi R. K. and Rawal R. S. 2016_a. Thistle (*Cirsium verutum*): an important forage for pollinators in

Kumaun, West Himalaya. National Academy Science Letters**,** 39: 395-399.

Kapkoti B., Rawal R. S. and Joshi R. K. 2016b. Insect pollinators of *Brassica campestris* in Kumaun, West Himalaya: influence of crop composition, altitude and flowering phenology. National Academy Science Letters,39: 389-394.

Kumar A., Shukla G., Pala N. A. and Chakravarty S. 2015. Knowledge intensity and problem in ginger and large cardamom production technology of Lepcha tribes in Dzongu region of Sikkim. In: Innovative Horticulture: Concepts for Sustainable Development, Recent Trends, eds. Munsi P. S., Ghosh S. K., Bhowmick. N. and Deb P. New Delhi Publishers, New Delhi. Pp. 37-41.

Kumar B. M. 2006. Carbon sequestration potential of tropical homegardens. In: Tropical Homegardens: A time-tested example of sustainable agroforestry, eds. Nair P. K. R. and Kumar B. M. Springer, Netherlands. Pp. 185-204.

Kumar B. M., Handa A. K., Dhyani S. K. and Arunachalam A. 2018. Agroforestry in the Indian Himalayan Region: An Overview. In: Temperate Agroforestry Systems, 2nd Edition, eds. Gorden A. M., Newman S. M. and Coleman B. R. W. CAB International. Pp. 153-172.

Kumar M. B., George S. J. and Chinnamani S. 1994. Diversity, structure and standing stock of wood in the Homegardens of Kerala in peninsular India. Agroforestry Systems,25: 243-262.

Manandhar S., Pandey V. P. and Kazama F. 2013. Climate change and adaptation: an integrated framework linking social and physical aspects in poorly-gauged regions. Climatic Change, 120: 727-739.

Manandhar S., Pratoomchai W., Ono K. and Kazama S. 2015. Daisuke Komori Local people's perceptions of climate change and related hazards in mountainous areas of northern Thailand. International Journal of Disaster Risk Reduction, 11: 47-59.

Manandhar S., Vogt D. S., Perret S. R. and Kazama F. 2011. Adapting cropping systems to climate change in Nepal: Across-regional study of farmer's perception and practices. Regional Environment Change, 11: 335-348.

Millennium Ecosystem Assessment 2005. Millennium Ecosystem Assessment: Ecosystem and Human well being: Synthesis. Island Press, Washington.

Meena R. K., Vikas, Verma T. P., Mahapatra S. K., Surya J. N., Singh D. and Singh S. K. 2019. Local perceptions and adaptation of indigenous communities to climate change: evidences from high mountain Pangi Valley of Indian Himalayas. Indian Journal of Traditional Knowledge, 18: 58-67.

Mengistu B. and Asfaw Z. 2019. Carbon sequestration in agroforestry practices with relation to other land uses around Dallo Mena districts of bale zone, south-eastern Ethiopia. Academic Research Journal of Agricultural Science and Research, 7: 218-226.

Metha M. P., Rabgyal J. and Acharya S. 2015. Commodity Chain Analysis of Large Cardamom in Bhutan. Food and Agriculture Organization of the United Nations, Rome.

Myers N., Mittermeier R. A., Mittermeier C. G., Gustava A. B. Da Foseca and Kent J. 2000 Biodiversity hotspots for conservation priorities. Nature,403:853-858.

Nair P. K. R., Nair V. D., Kumar B. M. and Showalter J. M. 2010. Carbon sequestration in agroforestry systems. Advances in Agronomy, 108: 237-307.

Negi B. K., Joshi R. K. and Pandey A. 2018. Status of large cardamom (*Amomum subulatum* Roxb.) farming systems in the changing scenario of modern economics of Sikkim, Himalaya. Global Journal of Bio-science and Biotechnology, 7: 189-199.

Pal S and Panwar Pankaj. 2013. Interrelationship of carbon sequestration, soil fertility, and microbial indices as influenced by long-term land uses in Lower Himalayan Region, India. Communications in soil science and plant analysis. 44(5): 869-883.

Pala N. A., Sarkar B. C., Gokhale Y., Manohar K A., Shukla G. and Chakravarty S. 2020. Potential of homestead gardens to gain from global carbon markets to mitigate climate change in Cooch Behar, West Bengal. Indian Forester, 146: 159-164.

Palomo I. 2017. Climate change impacts on ecosystem services in high mountain areas: a literature review. Mountain Research and Development,37: 179-187.

Partap U., Sharma G., Gurung M. B., Chettri N. and Sharma E. 2014. Large cardamom farming in changing climatic and socioeconomic conditions in the Sikkim Himalayas. ICIMOD Working Paper 2014/2, International Centre for Integrated Mountain Development, Kathmandu, Nepal.

Paudel J., Belbase S., Gautam S., Bhusal R. and Kumar S. 2018. The effect of viral diseases of large cardamom (*Amomumsubulatum* Roxb.) on Production and their management. International Journal of Current Microbiology and Applied Science 7(3): 855-860.

Pepin N., Bradley R. S., Diaz H. F., Baraer M., Caceres E. B., Forsythe N., Fowler H., Greenwood G., Hashmi M. Z., Liu X. D., Miller J. R., Ning L., Ohmura A., Palazzi E., Rangwala I., Schöner W., Severskiy I., Shahgedanova M., Wang M. B., Williamson S. N. and Yang D. Q. 2015. Elevation-dependent warming in mountain regions of the world. Nature Climate Change, 5: 424-430.

Poeplau C., Don A., Vesterdal L., Leifeld J., Van Wesemael B. A. S., Schumacher J. and Gensior A. 2011. Temporal dynamics of soil organic carbon after land-use change in the temperate zone - carbon response functions as a model approach. Global Change Biology, 17: 2415-2427.

Pushpakumara D. K. N. G., Wijesekara A. and Hunter D. G. 2010. Kandyan homegardens: a promising land management system in Sri Lanka. Sustainable use of biological diversity in Socio-ecological production landscapes. Background to the Satoyama Initiative for the benefit of biodiversity and human well-being. CBD Technical Series,52: 102-108.

Rana R. S., Bhagat R. M., Kalia V., Lal H. and Sen V. 2013. Indigenous perceptions of climate change vis-à-vis mountain agricultural activities in Himachal Pradesh. Indian Journal of Traditional Knowledge, 12: 596-604.

Rijal S. 2019. Agroforestry system: approaches for climate change mitigation and adaptation. Big Data in Agriculture (BDA), 1(2): 23-25

Saha S. K., Nair P. K. R., Nair V. D. and Kumar B. M. 2009. Soil carbon stock in relation to plant diversity of homegardens in Kerala, India. Agroforestry Systems, 76: 53-65.

Saha S. K., Nair P. K. R., Nair V. D. and Kumar B. M. 2010. Carbon storage in relation to soil size-fractions under some tropical tree-based land-use systems. Plant and Soil, 328: 433-446.

Sharma E. and Ambasht R. S. 1986. Root nodules age class transition, production and decomposition in an age sequence of *Alnus nepalensis* plantation in the eastern Himalaya. Journal of Applied Ecology**, 23:** 689-701.

Sharma E. and Ambasht R. S. 1991. Biomass, productivity and energetic in Himalayan alder plantations. Annals of Botany, 67: 285-293.

Sharma E., Chettri N., Tsering K., Shrestha A. B., Jing F., Mool P. and Eriksson M. 2009$_a$. Climate change impacts and vulnerability in the eastern Himalayas. ICIMOD, Kathmandu.

Sharma E., Sharma R., Sharma G., Rai S. C., Sharma P. and Chettri N. 2008. Values and services of nitrogen-fixing alder based cardamom agroforestry systems in the Eastern Himalayas. In: Advances in agroforestry, small tree growing for rural development and environmental services, eds. Snelder D. J. and Lasco R. D. Springer, vol 5: Pp 393-408.

Sharma E., Sharma R., Singh K. K. and Sharma G. 2000. A boon to mountain population: Large cardamom farming in the Sikkim Himalaya. Mountain Research and Development, 20: 108-111.

Sharma G. 2013. Opportunities and challenges of large cardamom farming, beekeeping, and pollination system in Sikkim. ICIMOD, Kathmandu.

Sharma G. and Rai L. K. 2012. Climate change and sustainability of agrodiversity in traditional farming of the Sikkim Himalaya. In: Climate Change in Sikkim - Patterns, Impacts and Initiatives, eds. Arrawatia M. L. and Tambe, S. Information and Public Relations Department, Government of Sikkim. Pp. 193-217.

Sharma G., Hunsdorfer B. and Singh K. K. 2016$_a$. Comparative analysis on the socio-ecological and economic potentials of traditional agroforestry systems in the Sikkim Himalaya. Tropical Ecology, 57(4): 751-764.

Sharma G., Partap E., Sharma G. R. and Awasthe R. K. 2016$_b$. Agrobiodiversity in the Sikkim Himalaya: Socio-cultural Significance, Status, Practices, and Challenges. ICIMOD Working paper 2016/2. ICIMOD, Kathmandu.

Sharma G., Sharma R. and Sharma E. 2009$_b$. Traditional knowledge systems in large cardamom farming: Biophysical and management diversity in Indian mountainous regions. Indian Journal of Traditional Knowledge, 8(1): 17-22.

Sharma H. and Partap U. 2011. Climate change adaptation and honeybees in mountain regions. ENVIS Bulletin (Arthropods and their Conservation in India (Insects & Spiders), 14: 50-54.

Sharma H. R. and Sharma E. 1997. Mountain agricultural transformation processes and sustainability in the Sikkim Himalaya, India. International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal. 116p.

Sharma R., Sharma E. and Purohit A. N. 1994. Dry matter production and nutrient cycling in agroforestry systems of cardamom grown under *Alnus* and natural forest. Agroforestry Systems, 27(3): 293-306.

Sharma R., Xu J. and Sharma G. 2007. Traditional agroforestry in the eastern Himalayan region: Land management system supporting ecosystem services. Tropical Ecology, 48: 189-200.

Shreshtha J., Prasai H. K., Timsina K. P., Shreshtha K. P., Pokhrel D., Poudel K. and Yadav M. 2018. Large Cardamom in Nepal: Production practice and economics, Processing and Marketing. Nepal Agriculture Research Council, National Commercial Agriculture Research Program, Pakhribas, Dhankuta, Nepal.

Shukla G., Kumar A., Pala N. A. and Chakravarty S. 2016. Farmer's perception and awareness of climate change: a case study from Khangchendzonga Biosphere Reserve, India. Environment, Development and Sustainability, 18: 1167-1176.

Shukla G., Vineeta, Kumari A. and Chakravarty S. 2017. Plant diversity, structure and uses of plants in homegardens of Jharkhand, India. Indian Journal of Tropical Biodiversity,25: 40-50.

Singh K. A., Rai R. N., Pritam and Butia D. T. 1989. Large Cardamom (*Amomum subulatum* Roxb) plantation: an age old agroforestry system in eastern Himalayas. Agroforestry Systems 9: 241-257.

Singh L., Ghosh L., Bargali S. S. and Saxena R. R. 2008. Response of paddy planted under *Butea monosperma* trees in Chhattisgarh. International Journal of Ecology and Environmental Sciences, 34(1): 63-66.

Singh M., Das S. K. and Avasthe R. K. 2018. Effect of multipurpose trees on production of large cardamom and soil fertility in agroforestry systems in Sikkim, Himalaya. Indian Journal of Agroforestry, 20: 25-29.

Srinivasa H. S. 2006. Large Cardamom Cultivation in India. Report of the Spices Board, Regional Office, Gangtok, Sikkim, India.

Stoep G. A. V. 2010. Enhancing Competitiveness of Nepal's Large Cardamom Value Chain. SNV Netherlands Development Organization, Kathmandu, Nepal.

Subba M., Pala N. A., Shukla G. and Chakravarty S. 2018. Study of the variability of homegardens influencing carbon stock under sub-humid tropical zone of West Bengal, India. Indian Forester, 144: 60-66.

Subba M., Pala N. A., Shukla G., Pradhan K. and Chakravarty S. 2017. Refocusing the correlates of carbon sequestration through maintaining the carbon stock in Homegardens of West Bengal, India. In: Natural Resources Management for Sustainable Development and Rural Livelihoods, Vol. 3, eds. Sati V. P. and Lalmalsawmzauva K. C. Today & Tomorrow's Printers and Publishers, New Delhi. Pp. 1139-1151.

Surendra P. S., Singh V. and Skutsch M. 2010. Rapid warming in the Himalayas: ecosystem responses and development options. Climate and Development, 2: 221-232.

Tarafder H. K., Roy K. and Rai B. 2018. Large cardamom production scenario in mountainous region of West Bengal: Constraints, issues and strategies. Asian Journal of Soil Science, 13: 153-156.

Thomas V. P., Sabu M. and Gupta U. 2009. Taxonomic studies on cultivars of *Amomum subulatum*. Rheedea, 19 (2): 25-36.

Uthappa A. R., Chavan S. B., Dhyani S. K., Handa A. K. and Newaj R. 2015. Trees for soil health and sustainable agriculture. Indian Farming, 65: 2-5.

Wagachchii H. and Wiersum K. 1997. Water management in agroforestry systems: integrated buffalo ponds and forest gardens in the Badulla District Sri Lanka. Agroforestry Systems, 35: 291-302.

Watson R. T., Noble I. R., Bolin B., Ravindranath N. H., Verardo D. J. and Dokken D. J. eds. 2000. Land Use, Land Use Change, and Forestry. A special report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge. 377p.

Zomer R. and Menke J. 1993. Site index and biomass productivity estimates for Himalayan Alder-large Cardamom Plantations: A model agroforestry system of the middle hills of Eastern Nepal. Mountain Research and Development, 13(3): 235-255.

Received: 25th June, 2021 *Accepted: 29th June, 2021*