# Chapter 20
# An Insight into Prevalent Agroforestry Land Use Systems of North Western Himalayan Region, India: Challenges and Future Prospects

**Harish Sharma, K. S. Pant, Rohit Bishist, Prem Prakash, and Krishan Lal Gautam**

**Abstract** The north-western Himalayan region of India is comprised of Jammu & Kashmir, Ladakh Himachal Pradesh and Uttarakhand, covering about 10% geographical area of the country. The region is ecologically as well as biologically rich in diversity and source of livelihood to large no. of people constituting 89.90%, 69.40%, 72.62% and 61.33% of rural people in Himachal Pradesh, Uttarakhand, J&K and Ladakh, respectively. India has just 2% of the world land resources yet it supports about 18% of the human population and 12% of the livestock population throughout world. Exploitive resource use due to fast growing human and livestock population coupled with natural and anthropogenic disturbances cause degradation of the land and bio-resources thereby affecting the fragile ecosystem. Changing climatic conditions and the increasing land-use conflicts call for the development of such sustainable land use systems that reconcile the production from the agriculture along with the provision of multiple ecosystem services, including climate change mitigation. Estimates suggest that about 30% of the emission reductions and carbon sequestration can be contributed by the sustainable land use interventions to meet the target set by Paris agreement. Agroforestry is practiced traditionally in north-western Himalayan region as is evident from the various multipurpose tree species deliberately retained by farmers on their farmland. The various traditional land uses are the outcome of the topographical features, socio-economic conditions, cultural and aesthetic values in the region. Besides providing multiple benefits, such as food, fodder, fuelwood, fibre etc., agroforestry systems act as a cushion against the several

H. Sharma (✉)
Faculty of Agricultural Sciences, DAV University, Jalandhar, Punjab, India

K. S. Pant
Department of Silviculture and Agroforestry, College of Horticulture and Forestry, Dr. YS Parmar University of Horticulture and Forestry, Neri, Hamirpur, India

R. Bishist · P. Prakash · K. L. Gautam
Department of Silviculture and Agroforestry, College of Forestry, Dr. YS Parmar University of Horticulture and Forestry Nauni, Solan, HP, India



H. S. Jatav et al. (eds.), *Agroforestry to Combat Global Challenges*, Sustainable Development and Biodiversity 36, https://doi.org/10.1007/978-981-99-7282-1_20

ecological hazards associated with the developmental activities and helps in conservation of resources in a sustainable manner. Various traditional agroforestry practices reported in the north-western Himalayan region are agrisilviculture, agrihorticulture, agrisilvihorticulture, agrihortisilviculture, hortisilviculture, silvopastoral, pastoralsilviculture, agrisilvopastoral, pastoralsilvihorticulture etc. varying in structural and functional composition as per the needs and preferences of the farmers well adapted to the ecological conditions. This article is an overview of the various agroforestry practices prevalent, their compositional variation, bio-economic productivity and carbon stock potential in north-western Indian Himalayan region.

**Keywords** Agroforestry · Himalayas · Composition · Productivity · Carbon

## 20.1 Introduction

Himalaya forms the northern boundary of the India and is geographically vast ranging from Nanga Parbat in the west to Namcha Barwa in the east, having complex and diverse ecosystems (Rawat and Vishvakarma, 2011; Kumar et al., 2018a, b). Indian Himalayan region, covering about 12% of the geographical area of the country (ISFR, 2013), is inhabited by about 51 million people practicing hill agriculture in fragile and diverse ecosystems. Owing to richness in biological as well as socio-cultural diversity, the region has been identified as one of the 34 biological hotspots (Tiwari et al., 2017). Western Himalayan region, constituting 10% of Indian geographical area (ISFR, 2013), comprised of J&K and Ladakh, Himachal Pradesh and Uttarakhand is agro-biodiversity rich region with large number of species under cultivation (Singh, 2009). With variation in site factors such as altitude, slope, temperature, humidity, rainfall, edaphic factors and distance from snowline or plains, have led to the diversified farming landscapes. In Himalayan states of the country, indigenous agroforestry systems form an integral part of the communities and planting trees on farms helps farmers to satisfy their multifarious needs, which leads to an increase in tree cover and thereby reducing the burden on existing forests (Phondani et al., 2020). Further, agroforestry being an integrated farming system plays a key role in sustaining the fragile ecosystems of the region (Kaler et al., 2017) and investment risk of farmers' because they diversify their crop and income source, which reduces economic and social risks (Lefroy, 2009). The knowledge of agroforestry has been continuously used as a way to tackle problems of rural livelihood in India traditionally. The area under agroforestry during next four decades is expected to increase to 53 million ha from 25.32 million ha presently; therefore, agroforestry land use will be having substantial contribution in meeting the societal requirements through increase in production and provision of environmental benefits as well (Dhyani et al., 2013). In India, agroforestry practices are mostly traditional and practiced in a variety of ways (Solanki, 1998; Sharma, 1996) subjected to multiple factors like demographic, socio-economic, cultural factors, as well as farmers' experiences. Agroforestry systems in India have a lot of component diversification both structurally and functionally, which mainly depends upon the temperature, topography, elevation, aspect, edaphic properties and rainfall pattern (Combe, 1982; Nair and Dagar, 1991; Tiwari, 1995). Several agroforestry systems, their floristic diversity, biological productivity, carbon sequestration potential, amelioration of soil physico-chemical properties etc. in north-western Himalayan region have been delineated by Toky et al., 1989; Khosla and Toky (1996); Thakur et al. (2004). Various traditional agroforestry practices reported in the north-western Himalayan region are agrisilviculture, agrihorticulture, agrisilvihorticulture, agrihortisilviculture, hortisilviculture, silvopastoral, pastoralsilviculture, agrisilvopastoral, pastoralsilvihorticulture etc. with structural and functional composition varying in accordance with day-to-day needs and preferences of the farmers well suited with ecological conditions. This article gives an overview of the various agroforestry practices prevalent, their compositional variation, bio-economic productivity and carbon stock potential in north-western Indian Himalayan region.

## 20.2 Agroforestry Systems in the North-Western Himalayas

Agroforestry in tropical, sub-tropical and temperate region is being practiced traditionally (Kumar et al., 2018a, b). Agroforestry, incorporating tree, crop and livestock component, is a multidisciplinary land use system satisfying productive as well as protective objectives (Singh et al., 2015). In Indian Himalayan region also, agroforestry has been recognized as the productive land use; however, regional causes of adoption, factors causing changes in traditional practices and socio-economic development associated with agroforestry need to be studied thoroughly. Agroforestry helps in satisfying the diverse and multifarious needs of the humans along with providing economic benefits as well as environmental services in the form of carbon sequestration, watershed protection and climate change mitigation and adaptation. Tree-based systems affect local economy by economic stabilization, product diversification, food and fuel security, improvement of natural environment (Dar et al., 2018). With dramatic changes in the altitudinal ranges in the western Himalayan region, vegetation pattern also changes (Tewari et al., 2017) and so is the composition of the agroforestry systems. Over the years, farmers have accustomed several multipurpose tree species on their farmlands which have evolved into extant agroforestry practices. The traditional tree-based systems prevalent in the western Himalayan region are generally location specific regarding relevance, performance and adoption (Dar et al., 2018) and depends mainly on the topography, altitude, climate, edaphic factors etc. Traditionally prevalent as well as adopted agroforestry systems in any area provides much needed information for the extension and further improvement in the systems as it is time tested regarding its potential and possible constraints under specific conditions prevailing in the area. The major agroforestry systems in the Indian north western Himalayan region have been summarized in the Table 20.1. Major agroforestry systems practiced in the region comprised of

**Table 20.1** Composition of prevalent agroforestry systems in north-western Himalayan region

| State/Union Territory | Agroforestry systems | Forest Trees | Fruit Trees | Agricultural crops | Grasses | References |
|---|---|---|---|---|---|---|
| J&K | Agrisilviculture, Agrihorticulture, Hortiagriculture, Hortisilviculture, Hortisilvopastoral, Hortiagrisilviculture, Silvopastoral, Hortipastoral, Agrisilvipastoral, Agrihortisilviculture | *Populus deltoids, Populus nigra, Ulmus wallichiana, Aesculus indica, Salix alba, Robinia pseudoacacia, Morus alba, Pinus wallichiana, Ailanthus altissima, Cedrus deodara, Albizzia lebbeck, Acacia catechu, Dalbergia sissoo, Abies pindrow, Picea smithiana* | *Malus* spp., *Prunus amygdalus, Juglans regia, Prunus persica, Prunus avium, Cydonia oblonga, Punica granatum, Vitis vinifera* | *Zea mays, Brassica juncea, Daucas carota, Raphanus sativus, Brassica rapa, Oryza sativa, Solanum lycopersicum, Abelmoschus esculentus, Glycine max, Triticum aestivum, Pisum sativum, Brassica oleracea var. capitata, Brassica oleracea var. botrytis, Solanum tuberosum, Allium sativum, Allium cepa, Cucumis sativus, Lagenaria siceraria, Momordica charantia, Phaseolus vulgaris, Vigna radiata* | *Avena sativa, Trifolium repens., Dactylis glomerata, Festuca pretense, Aegilops tauschii, Echinochola crusgalli, Lolium perenne, Lolium multiflorum, Bromus japonicas, Poa* spp., *Bromus inermis, Cynodon dactylon, Chrysopogon fulvus, Dicanthium* spp. | Choudhary et al. (2012); Kashyap et al. (2014); Gupta and Arora, (2015); Banyal et al. (2016); Khaki et al. (2016); Ahmad et al. (2017); Islam et al. (2017); Dar et al. (2018); Zahnoor et al. (2022) |
| Ladakh | Agrisilviculture, Agrihortisilviculture, Agrihorticulture, Silvopastoral, | *Populus* spp., *Salix* spp., *Ulmus wallichiana, Juniperus* spp. | *Malus domestica., Prunus armeniaca., Juglans regia, Morus alba* | *Triticum aestivum, Hordeum vulgare, Avena sativa, Fagopyrum* | *Avena sativa, Trifolium* spp., *Medicago sativa, Iris lactea* | Pateria et al. (2003); Butola et al. (2012); Banyal et al. (2016); Handa, (2019); |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Hortisilvopastoral, Hortipasture | | | *esculentum, Fagopyrum tataricum, Panicum miliaceum, Solanum tuberosum, Brassica* spp., *Pisum sativum, Allium cepa, Coriandrum sativum, Carum carvii, Chenopodium album, Setaria italic, Brassica oleracea var. capitata, Brassica oleracea var. botrytis, Phaseolus vulgaris* | | Namgial et al. (2020) |
| Himachal Pradesh | Agrisilviculture, Agrihorticulture, Agrisilvihorticulture, Agrihortisilviculture, Hortiagriculture, Silvopastoral, Hortipastoral, Pastoralsilviculture, Agrisilvopastoral | *Grewia optiva, Celtis australis, Dalbergia sissoo, Toona ciliata, Morus alba, Bauhinia variegata, Melia composita, Albizia chinensis, Acacia catechu, Quercus spp, Cedrus deodara, Pinus roxburghii, Robinia pseudoacacia, Ulmus villosa, Salix alba, Pinus wallichiana, Abies pindrow, Picea* | *Mangifera indica, Citrus* spp., *Prunus domestica, Litchi chinensis, Psidium guajava, Carica papaya, Phyllanthus emblica, Malus domestica, Prunus persica, Pyrus communis, Prunus armeniaca, Diospyros kaki, Punica granatum, Juglans regia, Prunus amygdalus, Pistacia vera* | *Zea mays, Oryza sativa, Vigna mungo, Solanum lycopersicum, Abelmoschus esculentus, Glycine max, Triticum aestivum, Hordeum vulgare, Brassica juncea, Cicer arietinum, Pisum sativum, Brassica oleracea var. capitata, Brassica oleracea var. botrytis, Solanum* | *Apluda mutica, Imperata cylindrica, Chrysopogon montanus, Seteria glauca, Cymbopogon martinii, Heteropogon contortus, Dicanthium annulatum, Themeda anathera, Paspalum notatum, Apluda mutica, Andropogon nardus, Pennisetum* | Kumari et al. (2008); Chisanga et al. (2013); Goswami et al. (2014); Kashyap et al. (2014); Gupta et al. (2017); Rajput et al. (2017); Tiwari et al. (2018); Kumar et al. (2018a, b); Salve and Bhardwaj, (2020) |

(continued)

**Table 20.1** (continued)

| State/Union Territory | Agroforestry systems | Forest Trees | Fruit Trees | Agricultural crops | Grasses | References |
|---|---|---|---|---|---|---|
| | | *smithiana, Populus ciliata* | | *tuberosum, Allium sativum, Allium cepa, Avena sativa, Amaranthus hypochondriacus* | *clandestinum, Dactylis gloemerata, Arundinella nepalensis Agrostis* spp., *Poa annua, Trifolium repens, Cynodon dactylon* | |
| Uttarakhand | Agrisilviculture, Agrisilvihorticulture, Agrisilvopastural, Silvipastural, Agrihorticulture, Agrihortisilviculture, Silvihorticulture, Hortipastoral | *Quercus leucotrichophora, Grewia oppositifolia, Celtis australis, Pinus roxburghii, Prunus cerasoides, Rhododendron arboretum, Pyrus pashia, Pinus wallichiana, Cedrus deodara, Ficus auriculata, Ficus palmata, Morus serrata, Melia azedarach, Myrica esculenta, Toona ciliata* | *Juglans regia, Prunus armeniaca, Prunus domestica, Malus domestica, Pyrus pyrifolia, Musa paradisiacal, Punica granatum, Carica papaya, Psidium guajava, Prunus* spp., *Emblica officinalis, Citrus* spp., *Mangifera indica* | *Zea mays, Triticum aestivum, Oryza sativa, Phaseolus vulgaris, Eleusine coracana, Amaranthus caudatus, Amaranthus spinulosa, Vigna umbellate, Vigna mungo, Cajanus cajan, Glycine max, Hordeum vulgare, Lens culinaris, Brassica campestris, Pisum sativum, Lycopersicon esculentum, Abelmoschus esculentus, Spinacea oleracea, Brassica juncea, Brassica* | *Cynodon dactylon, Andropogon munroi, Apluda mutica, Euphorbia hirta, Avena fetua, Setaria* spp., *Paspalum* spp. | Kashyap et al. (2014); Mahato et al. (2016); Vikrant et al. (2018); Yadav et al. (2018); Yadav et al. (2019); Bhatt and Parihaar. (2020); Gariya et al. (2020); Himshikha et al. (2020); Kumar et al. (2021a, b) |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | *oleracea var. capitata, Brassica oleracea var. botrytis, Coriandrum sativum, Curcuma longa, Zingiber officinale, Capsicum annuum, Allium cepa, Allium sativum* | | |

agrisilviculture, agrisilvihorticulture, agrihorticulture, agrihortisilviculture, hortiagriculture, hortisilviculture, hortisilvopastoral, hortiagrisilviculture, silvopastoral, pastoralsilviculture, hortipastoral, agrisilvipastoral and silvihorticulture, as reported in literature. In J&K, important tree species are *Populus* spp., *Salix* spp., *Ulmus wallichiana*, *Ailanthus altissima*, *Morus alba*, *Aesculus indica* etc. while, in Ladakh region *Populus* spp., *Ulmus wallichiana*, *Salix* spp., *Juniperus* spp. are major tree species. In Himachal Pradesh and Uttarakhand, most of the tree species prevalent are similar such as *Grewia* spp., *Celtis australis*, *Quercus leucotrichophora*, *Toona ciliata*, *Cedrus deodara*, *Morus* spp., *Melia* spp. etc. Being in hilly terrain, local people depend on the forests for several day-to-day needs. Mountain farming systems are generally characterized by presence of livestock component which provide milk, meat, manure and draught power (Nautiyal et al., 2018) in the areas where farm mechanization is having limited scopes. The basic requirement for livestock rearing is fodder availability which is generally fulfilled from fodder grown in community land, forest land and crop residues. India is having about 11% of the world livestock population that is supported on the land area constituting about 2% globally (Roy et al., 2019) creating challenges for fulfilment of the fodder requirement. The issues of fodder availability need to be addressed as feed constitutes about 70% cost of milk production alone, which, in turn is responsible for the 20–60% lower productivity of livestock in Indian conditions. According to report (ICAR-IGFRI, 2021) there is 49.17% shortage of fodder in Jammu and Kashmir, 40–45% in Ladakh (Tewari et al., 2016) and about 33% in Himachal Pradesh (NITI Aayog, 2018). Through adoption of alternate land use systems such as silvopastoral, hortipasture etc. it is possible to increase the productivity of the land along with fulfilment of the fodder requirement, reduction of grazing pressure as well as positive environmental implications (Roy et al., 2019). Further, with wide altitudinal variations in the Himalaya region, the climatic conditions also vary significantly with some regions being covered under snow during winters. Under such conditions, fuelwood serves as an important source of energy for which people mostly depend on the forest resources (Kumar et al., 2020). Studies reported that 93% of the population in Himachal Pradesh uses fuelwood as the source of energy (Parikh, 2011; TERI, 2015) out of which 94% of the fuelwood users depends on the forests for this. Fuelwood consumption per capita per day (in kg) in Jammu and Kashmir varies from 0.05–5.50, in Himachal Pradesh varies from 0.91–5.13 kg, while, in Uttarakhand varies from 1.13–8.75 (Kumar et al., 2020) showing the dependence of the inhabitants on the fuelwood. Govt. initiatives such as Pradhan Mantri Ujjwala Yojana are helpful in meeting the objectives of the clean energy and simultaneously integrated farming practices are also having key role in meeting the demand of fuelwood to certain extent and also to reduce the pressure as well as exploitive utilization of the natural resources. The annual availability of the fuelwood (in million tones) from the tree outside forests (TOF) in J & K including Ladakh, Himachal Pradesh and Uttarakhand is 0.365, 0.290 and 0.297 respectively, in comparison to 0.02 million tones, 50 tones and 0.05 million tones fuelwood available from forests in the respective UTs/ states (Dar and Ahmad 2016). Further, availability of the fuelwood on the farmland will also facilitate the utilization of the cow dung as organic manure in the farm instead of burning it as energy source. In addition to the fodder and fuelwood requirement farmers are also dependent on the natural resources for their timber and small wood needs which generally results into exploitation of the resources when the need turns into greed. Agroforestry not only provides ecological services but also economic benefits as 65% of the timber requirement in the country is met from TOF (GoI, 2016). In the current scenario when there are lack of data for demand as well as supply of tree-based products and natural forests are closed for the protection and conservation purpose, there is greater scope for the promotion of the agroforestry practices (Parthiban et al., 2021). Further, a dedicated agroforestry policy facilitating the selection of suitable species for the specific region, provision of providing quality planting material, permissive felling and transit regulations as well as marketing facilities may encourage the mass towards adoption of scientific agroforestry interventions.

## 20.3 Biomass Production of Agroforestry Systems

Photosynthesis is the process involved in the manufacturing of the food by the primary producers through transformation of the light energy in chemical energy and the product formed is either used or is stored. The energy is stored in the plants in the form of biomass and is having great importance to other individuals present on other tropic levels as well as humans as the stored energy can be harvested to be used as food, fuel, fibre and several other uses (Roberts et al., 1985). Plant biomass is the weight of the biological material contained in aboveground and belowground portion of plant and is generally expressed as plant dry matter dried to constant weight. Biomass served as the primary source of the fuel anciently since humanity became familiar with fire (Fekete, 2013). In the current scenario, fossil fuels have become common source of energy but still biomass energy is an important and preferable source of energy for the poor people that may due to its cheapness and easy availability from the forest area. Global concern towards the woody biomass is increasing due to increased fossil fuel prices, emissions resulting from burning of fossil fuels as well as threat resulting from catastrophic wildfires (Proto et al., 2014). Agroforestry practices having deliberate incorporation of the woody perennials into the land use therefore has immense potential for the production as well as storage of biomass. Biomass production of trees in agroforestry is generally estimated on the basis of region specific allometric equations developed for specific tree species. Biomass production of agroforestry systems depends on several factors such as physiography, structural and functional composition, age and density of trees, specific management practices, environmental, socio-economic, interaction of components affecting efficiency of resource use etc. (Goswami et al., 2014; Rajput et al., 2017; Chisanga et al., 2018; Singh et al., 2020; Panwar et al., 2022). The biological production potential of the prevalent agroforestry practices in the north western Himalayas based on literature review has been summarized in Table 20.2. A lot of work regarding the biomass production potential of the agroforestry systems has

**Table 20.2** Biomass production potential of agroforestry systems in north-western Himalayan region

| State/Union Territory | Agroforestry systems | Aboveground biomass (Mg/ha) | Belowground biomass (Mg/ha) | Total biomass (Mg/ha) | References |
|---|---|---|---|---|---|
| J&K | Agrisilviculture | 6.70–159.41 | 1.58–71.55 | 15.94–202.59 | Ajit et al. (2017); Panwar et al. (2022) |
| | Agrihorticulture | 15.79–137.56 | 2.40–34.39 | 18.19–171.95 | Zahnoor et al. (2021); Panwar et al. (2022) |
| | Silvopastoral | 34.49–53.20 | 9.01–34.42 | 43.51–136.42 | Panwar et al. (2022) |
| Ladakh | Agrisilviculture | 17.11 | 6.03 | 23.14 | Namgial (2018) |
| | Agrihortisilviculture | 19.11 | 8.05 | 27.16 | Namgial, (2018) |
| | Agrihorticulture | 16.15 | 6.97 | 23.12 | Namgial, (2018) |
| | Silvopastoral | 16.91 | 9.51 | 26.43 | Namgial, (2018) |
| | Hortisilvopastoral | 19.95 | 10.93 | 30.88 | Namgial, (2018) |
| Himachal Pradesh | Agrisilviculture | 6.70–159.41 | 1.58–71.55 | 13.47–202.59 | Goswami et al. (2014); Singh et al. (2015); Gupta et al. (2017); Panwar et al. (2022) |
| | Agrihorticulture | 9.58–137.56 | 2.40–34.39 | 12.29–171.95 | Goswami et al. (2014); Singh et al. (2015); Gupta et al. (2017); Rajput et al. (2017); Chisanga et al. (2018); Singh et al. (2020); Panwar et al. (2022) |
| | Agrisilvihorticulture | 15.15–67.97 | 4.30–20.20 | 16.31–88.17 | Goswami et al. (2014); Gupta et al. (2017); Thakur, (2020) |
| | Agrihortisilviculture | 13.26–85.49 | 3.38–23.08 | 18.40–108.60 | Goswami et al. (2014); Bammanahalli, (2016); Gupta et al. (2017); Chisanga et al. (2018); Thakur, (2020); Janju, (2021); Sharma et al. (2021) |
| | Hortiagriculture | 14.17–26.42 | 3.99–7.10 | 19.26–33.26 | Janju, (2021); Singh et al. (2020) |
| | Silvopastoral | 4.58–162.80 | 1.33–35.70 | 5.92–198.20 | Goswami et al. (2014); Singh et al. (2015); Gupta et al. (2017); Rajput et al. (2017); Chisanga et al. (2018); Singh et al. (2019); Sharma et al. (2021); Panwar et al. (2022) |
| | Hortipastoral | 11.24–24.97 | 3.23–6.33 | 14.47–31.30 | Thakur, (2020); Singh et al. (2020); Janju, (2021) |

| | | | | | |
|---|---|---|---|---|---|
| | Pastoralsilviculture | 3.77–10.58 | 0.59–3.27 | 5.13–13.85 | Bammanahalli, (2016); Singh et al. (2019); Thakur, (2020); Janju, (2021) |
| Uttarakhand | Agrisilviculture | 6.7–159.41 | 1.58–71.55 | 0.52–202.59 | Newaj et al. (2016); Vikrant et al. (2018); Kumar et al. (2021a, b); Panwar et al. (2022) |
| | Silvopasture | 34.49–53.20 | 9.01–34.42 | 43.51–136.42 | Panwar et al. (2022) |
| | Agrihorticulture | 15.79–137.56 | 2.40–34.39 | 0.33–171.95 | Yadav et al. (2016); Yadav et al. (2017); Vikrant et al. (2018); Adhikari et al. (2019); Panwar et al. (2022) |
| | Agrihortisilviculture | – | – | 0.13–1.37 | Vikrant et al. (2018) |

been carried out in the states of Himachal Pradesh and Uttarakhand, while in union territories of Jammu & Kashmir and Ladakh, work has been carried out regarding the identification of the agroforestry, which needs to be further elaborated to assess the productivity of the prevalent systems. From Table 20.2, it can be seen that the total biomass production potential of agrisilviculture is highest (202.59 Mg/ha) among prevalent systems in Jammu and Kashmir. Also, lowest total biomass production (15.94 Mg/ha) is also reported in agrisilviculture system in the region. The preponderance of fast growing tree species such as *Populus* spp., *Salix* spp., *Robinia pseudoacacia* etc. may be the reason for more accumulation of the biomass as contributed by perennial component, while varying tree densities retained as per farming practices may affect the overall productivity of the system. Aboveground and belowground biomass is also more in agrisilviculture system with overall range varying between 6.70–159.41 Mg/ha and 1.58–71.55 Mg/ha, respectively. In Ladakh, hortisilvopastoral resulted in maximum aboveground, belowground and total biomass viz., 19.95 Mg/ha, 10.93 Mg/ha and 30.88 Mg/ha, respectively attributed to the diverse components, more tree density and specific practices adopted for the management of the system. In Himachal Pradesh, aboveground biomass is reported maximum under silvopastoral system (162.80 Mg/ha), while belowground biomass (71.55 Mg/ha) under agrisilviculture. Dominance of forest trees in silvopastoral system may be the factor for the higher aboveground biomass as contributed through tree component, however, management practices in agrisilviculture system as well as withdrawal of nutrition by components from different zones in the soil may have resulted in better belowground biomass in agrisilviculture system. In total biomass production is highest (202.59 Mg/ha) in agrisilviculture that may be due to higher tree density as well as differences in management practices. In Uttarakhand also, agrisilviculture system is reported most productive among all the systems with aboveground biomass production potential to a tune of 159.41 Mg/ha, belowground production potential of 71.55 Mg/ha with total biomass production to the tune of 202.59 Mg/ha. Tree density along with the type of species incorporated plays significant role in influencing the productivity of the system.

## 20.4 Carbon Stock Potential of Agroforestry Land Uses

Currently, climate change is among one of the most important topic of discussion world over that bring up unique challenges directly or indirectly. Concentration of the GHGs (greenhouse gases) in the atmosphere shows the equilibrium between the source (natural and anthropogenic activities) and sink (biosphere and ocean). The concentration of $CO_2$ in earth's atmosphere is 413.20 ± 0.2 ppm, methane 1889 ± 2 ppb and nitrous oxide 333.20 ± 0.1 ppb that is 149%, 262% and 123% above the pre-industrial level, respectively, and considered main cause behind this global warming (WMO, 2021). It is believed that through alternate cultivation practices of the agricultural and forest crops this increase in the concentration of the $CO_2$ can be checked and can be partially mitigated through biomass production (Jose and Bardhan, 2012). International concern about the changing climatic conditions resulted in the Kyoto protocol in 1997 and ever since this protocol, agroforestry has been highlighted as a sustainable strategy for the mitigation of the increasing concentration of $CO_2$ throughout the world. Agroforestry being the deliberate incorporation of woody perennial on the farmland helps in storage of higher amount of biomass carbon through carbon sequestration as compared to monocropping and thus plays an important role in mitigation as well as adaptation of climate change. In addition to the carbon stored in the form of biomass aboveground, agroforestry also helps in the storage of considerable amount of carbon belowground. However, for the adoption of agroforestry in the carbon sequestration, projects under the schemes such as clean development mechanism exact information of the carbon stored aboveground, belowground and in soil are needed. Carbon stock potential of the agroforestry practices in the north western Himalayan region has been collected from literature of the area and highlighted through Table 20.3. In J&K, highest (71.78 Mg C/ha) vegetation carbon stock is reported under agrisilviculture having the carbon range 32.61–71.78 Mg C/ha, while soil carbon stock range is reported equal to 25.99–58.07 Mg C/ha. Range of carbon stored is more for vegetation in agrisilviculture and agrihorticulture land use systems, while silvopastoral system has more carbon stored in soil as that of vegetation which may be due to more litter addition along with root decay material in the soil as contributed by fine roots of the grasses (Goswami et al., 2014). In Ladakh region, maximum vegetation carbon (44.59 Mg C/ha) is reported to have stored under silvopastoral system that may be due to more tree density, while, soil carbon is reported to have stored more (64.34 Mg C/ha) under agrihorticulture system that may be due to management practices adopted for agriculture as well as horticulture components as both the components hold economic values. In Himachal Pradesh, maximum total carbon (109.93 Mg C/ha) is reported to have stored under silvopastoral land use ascribed to continuous carbon accumulation by the perennial component which is present in more number under silvopastoral system and is the major cause for the higher vegetation carbon (71.61 Mg C/ha) stored in silvopastoral land use system. Agrisilvihorticulture system is reported to have stored maximum soil carbon (56.70 Mg C/ha) which is quite identical to the soil carbon stored under agrihorticulture, agrihortisilviculture, silvopastoral and agrisilviculture system. Diverse composition of the land use system may be responsible for the more soil carbon as facilitated by the more addition of litter as well as better decomposition. In Uttarakhand also, silvopastoral system was reported to have stored more vegetation carbon to a tune of 51.14 Mg C/ha, while soil carbon was more (64.34 Mg C/ha) in agrihorticulture system. Overall, maximum carbon storage (79.92 Mg C/ha) is found under agrihorticulture system attributed to more biomass stored by the fruit tree component as compare to sole cropping. The biomass production is subjected to the composition of the system as affected by the factors of the locality (Yadav et al., 2017; Adhikari et al. 2019).

**Table 20.3** Carbon storage (vegetation + soil) in agroforestry systems of north-western Himalayas

| State/Union Territory | Agroforestry systems | Vegetation carbon (Mg C/ha) | Soil carbon (Mg C/ha) | Total carbon (Mg C/ha) | References |
|---|---|---|---|---|---|
| J&K | Agrisilviculture | 32.61–71.78 | 25.99–58.07 | 97.77 | Ajit et al. (2017); Panwar et al. (2022) |
| | Agrihorticulture | 29.61 | 64.34 | – | Zahnoor et al. (2021); Panwar et al. (2022) |
| | Silvopastoral | 44.59 | 47.63 | – | Panwar et al. (2022) |
| Ladakh | Agrisilviculture | 11.57–32.61 | 11.78–58.07 | – | Namgial, (2018); Panwar et al. (2022) |
| | Agrihortisilviculture | 13.58 | 11.71 | – | Namgial, (2018) |
| | Agrihorticulture | 11.56–29.61 | 10.65–64.34 | – | Namgial, (2018); Panwar et al. (2022) |
| | Silvopastoral | 13.21–44.59 | 11.34–47.63 | – | Namgial, (2018); Panwar et al. (2022) |
| | Hortisilvopastoral | 15.44 | 11.63 | – | Namgial, (2018) |
| Himachal Pradesh | Agrisilviculture | 8.44–52.95 | 9.37–51.19 | 35.11–87.99 | Singh et al. (2015); Bammanahalli, (2016); Gupta et al. (2017); Singh et al. (2019); Panwar et al. (2022) |
| | Agrihorticulture | 8.64–51.65 | 17.05–55.64 | 36.58–96.67 | Singh et al. (2015); Bammanahalli, (2016); Gupta et al. (2017); Rajput et al. (2017); Singh et al. (2019); Panwar et al. (2022) |
| | Agrisilvihorticulture | 11.17–44.08 | 19.80–56.70 | 49.97–100.78 | Bammanahalli, (2016); Gupta et al. (2017) |
| | Agrihortisilviculture | 12.10–46.65 | 12.40–54.06 | 32.12–100.71 | Bammanahalli, (2016); Gupta et al. (2017); Singh et al. (2019) |
| | Silvopastoral | 15.34–71.61 | 17.96–53.12 | 46.13–109.93 | Gupta et al. (2017); Rajput et al. (2017); Singh et al. (2019) |
| | Pastoralsilviculture | 1.19–4.94 | 20.18–32.62 | 29.72–38.32 | Bammanahalli, (2016) |
| Uttarakhand | Agrisilviculture | 7.00–38.84 | 10.35–15.50 | 18.39–25.17 | Newaj et al. (2016); Bhattacharjya et al. (2017); Kumar et al. (2021a, b); Panwar et al. (2022) |
| | Silvopasture | 42.34–51.14 | 40.69–49.75 | – | Kumar et al. (2021a, b); Panwar et al. (2022) |
| | Agrihorticulture | 21.93–44.14 | 35.78–64.34 | 79.92 | Yadav et al. (2017); Vikrant et al. (2018); Adhikari et al. (2019); Rathore et al. (2020); Panwar et al. (2022) |

## 20.5 Socio-Economic Impact of Agroforestry Systems

The combined measure of the social and economic position with respect to others in the society represents the socio-economic condition of the society. It is having general influence on the resource accessibility, societal livelihood pattern, food security etc. (Roy et al., 2013) and greatly influences the farm-based enterprises by affecting the organization, management, production and marketing of the enterprise. The understanding of socio-economic factors holds great importance in farming systems and helps in formulating the policies for the well-being of the society as ignorance of socio-economic aspects results in the suffering of the various developmental programs (Sood et al., 2008). Agroforestry and socio-economic considerations act as two phases of the same coin as improved socio-economy affects the integration of trees on the farm land on one hand, while, adoption of the agroforestry helps in improvement of the socio-economy of the farming families. Agroforestry is having vast potential for the improvement of the society as can be realized through its benefits to the vulnerable sections mainly marginal and small farmers, women and children (Murthy et al., 2016). Throughout the country various studies confirm the positive impact of the agroforestry land use on farmer socio-economic in terms of women welfare, upliftment of the marginal sections, food security, improved financial resilience, reduced crop failure, regular employment and income, increased land productivity, annual and periodic economic benefits from multiple outputs. Generation of more than 5.76 million mandays per year from agroforestry if implemented on an area of 75,500 ha in Indian Himalayan region shows the employment potential of this sustainable land use in the region and as an option for rural development in the challenging terrains of the Himalayas (Arunachalam et al., 2020). Agroforestry in the Himalayan region plays an important role owing to the topographical factors which on interacting with different socio-economic parameters get modified in various location-specific systems. Although much of the research has been carried out on the identification, productivity, carbon sequestration potential, yet there is dearth of research work highlighting the impact of adoption these systems on the socio-economic condition of the farmers. This poses constraint in framing the suitable policies for the betterment of the farming community but on the other hand offers a scope that can be addressed in the future research projects.

## 20.6 Challenges Associated with Farming Communities in North-Western Himalayas

India has become the most populous country surpassing China, and agriculture is the important sector providing employment to about half of the population; however, the share of agriculture towards GDP has declined since independence to about 17.8% (Sharma and Raina, 2021). Western Himalayan region is generally characterized by the variations in topography, edaphic factors, climate and land use practices. Being hilly and mountainous terrain, the ecosystems in the north western Himalayan region are fragile with respect to topography, geological hazards, land degradation, land use and land cover, biodiversity etc. (Saha and Kumar, 2019). Several anthropogenic activities including deforestation, indiscriminate and over utilization of resources, faulty agricultural practices etc. along with challenging and unstable terrain has resulted in soil erosion, depletion of land resources, lower productivity etc. Keeping in mind the vulnerability of the bio-physical characteristics of Himalayan region necessary actions are required in order to maintain the sustainability of the ecosystem. Sustainable land use practices as well as their management can help in acting as sink to the carbon along with providing livelihood opportunities to the rural population and help in reducing the vulnerability of the natural resources towards changing climatic conditions. Agroforestry can help in the stabilization of the fragile landscapes through the addition of litter, binding of soil by extensive root network thereby preventing the soil erosion, provision of multiple products improving the socio-economic conditions, preventing the pressure on natural resources such as forests, pastures etc. Although agroforestry seems the most suitable land use facilitating the fulfilment of the needs in a conservative way but the limited land resource seems hindering its true potential. The average land holding size in the western Himalayan region has declined for all the categories and has come down to about 1 ha on an average. The condition is even worse by the continuous fragmentation of this limited asset making farming non-viable from food as well as income point of view. Land fragmentation is one of the major causes for the reduced agricultural productivity in the Himalayan region (Shukla et al., 2018). As hill farming is mainly done manually and is dependent on draught animal, the land fragmentation leads to increase of input costs involved in agriculture thus turning the asset into liability. Farmers having limited land area have less scope of incorporating trees on the farmland as over agricultural component. But, diversified farming can help getting better benefits along with natural security towards total crop failure. In addition to the fragility of the ecosystems in the north western Himalayas, presence of cold desert region also make the region susceptible to vagaries of climate and livelihood more difficult. Cold desert in the western Himalayas exists in Leh and Kargil districts of Ladakh, Lahul & Spiti as well as some pockets of Chamba district and some areas in Janvi valley of Uttarkashi district (Tewari and Kapoor, 2013). Herbaceous plants of annual and perennial nature along with few bushes dominate the vegetation of the cold desert region which is generally xerophytic or mesophytic in nature. The area under cultivation in the cold desert region is very less which is generally flatter portion of valleys, but, with increase in population people are cultivating sloppy area also which has resulted in ecosystem degradation. Integrated land use as well as management techniques are necessary for the ecological restoration of the area which includes management of pastures, plantations, livestock component in harmonic association. Agroforestry seems the answer to all the problems concerned which along with the fulfilment of the basic need of the agricultural crop helps in the provision of the fodder, fuelwood, fruit, fibre, timber etc.

## 20.7 Future Perspective

- Strengthening of the research and extension activities towards the land use systems having better potential from ecological as well as economical point of view such as horticulture-based and pasture-based systems.
- Development of the fodder tree-based systems for checking the fodder scarcity, enhancing carbon stock potential of the land use and facilitating the rearing of the livestock.
- Holistic approach towards the estimation of biological productivity and carbon sequestration potential of location specific agroforestry systems so that degraded and wastelands can be reclaimed with the system having high production potentials.
- Tree breeding techniques for the exploitation of the quality planting material for mass propagation, distribution of planting material to the farmers and the socio-economic development of the society.
- Tree-based farming systems should be popularized among farmers residing in fragile areas based on suitable models developed and tested regarding their feasibility in terms of checking natural hazards as well as act as a source of livelihood.
- As choice of tree components for incorporation in farming systems is limited in cold desert region and generally includes *Salix* spp. and *Populus* spp. So, research needs to be focused on the genetic improvement of the species and development of superior clones having better productivity and adoptability by the people.

## References

Adhikari B, Lodhiyal N, Lodhiyal LS (2019) Carbon sequestration efficiency of mango-based agri-horticulture system in Shiwalik plain of Central Himalaya, India. Indian J Agrofor 21(1):75–80

Ahmad S, Khan PA, Verma DK, Mir N, Singh JP, Dev I, Roshetko JM (2017) Scope and potential of hortipastoral systems for enhancing livestock productivity in Jammu and Kashmir. Indian J Agrofor 19(1):48–56

Ajit HAK, Dhyani SK, Bhat GM, Malik AR, Dutt V, Masoodi TH, Uma JA (2017) Quantification of carbon stocks and sequestration potential through existing agroforestry systems in the hilly Kupwara district of Kashmir valley in India. Curr Sci 113(4):782–785

Arunachalam A, Handa AK, Dev I, Kaushal R, Panwar P, Dhyani SK (2020) Alternate land use and agroforestry systems for resource conservation and enhanced productivity in the hills. Indian J Hill Farming 33(1):176–193

Bammanahalli S (2016) Productivity and carbon storage in prevalent agroforestry systems in subtropical region of Himachal Pradesh. Ph.D. Thesis. Dr YS Parmar University of Horticulture and Forestry, Nauni Solan (HP), P 209

Banyal R, Qaiser KN, Abidi RA (2016) Temperate agroforestry systems in Jammu and Kashmir. In: Agroforestry for increased production and livelihood security, pp 41–59

Bhatt GD, Parihaar RS (2020) Use of remote sensing and geographic information system on agroforestry ecosystem in Himalayan Region of Uttarakhand. In: Seema S, Singh RB, Kumar M (eds) Geoecology of landscape dynamics. Springer, Singapore, pp 167–185

Bhattacharjya S, Bhaduri D, Chauhan S, Chandra R, Raverkar KP, Pareek N (2017) Comparative evaluation of three contrasting land use systems for soilcarbon, microbial and biochemical indicators in North-Western Himalaya. Ecol Eng 103:21–30

Butola JS, Malik AR, Baba JA (2012) Livelihood diversification in cold arid desert of Indian Himalaya: urgent need of transforming traditional agroforestry system with emphasis on adoption of herbal farming. Int J Med Aromatic Plants 2(3):544–548

Chisanga K, Bhardwaj DR, Sharma S (2013) Bio-economic appraisal of agroforestry systems in Dry Temperate Western Himalayas. J Tree Sci 32(1&2):1–7

Chisanga K, Bhardwaj DR, Pala NA, Thakur CL (2018) Biomass production and carbon stock inventory of high-altitude dry temperate land use systems in North Western Himalayas. Ecol Process 7(22):1–13

Choudhary P, Tandon V, Sharma R (2012) Traditional agroforestry practices for sustainable livelihood in Rajouri district of Jammu and Kashmir. J Tree Sci 31(1&2):102–107

Combe J (1982) Agroforestry techniques in tropical countries: potential and limitations. Agrofor Syst 1:13–28

Dar MD, Ahmad S (2016) Current status and prospects of fuel wood species in North-western Himalayan Region–a review. Ann Agri-Bio Res 21(2):164–167

Dar M, Qaisar KN, Ahmad S, Wani AA (2018) Inventory and composition of prevalent agroforestry systems of Kashmir Himalayas. Adv Res 14(1):1–9

Dhyani SK, Handa AK, Uma (2013) Area under agroforestry in India: an assessment for present status and future perspective. Indian J Agrofor 15:1–11

Fekete BM (2013) Biomass. Elsevier, Alpharetta, GA, pp 83–84

Gariya K, Dwivedi GK, Kumar V, Tewari SK (2020) Agrobiodiversity, composition and functional characteristics of Homegardens in Bhimtal Block of Nainital District, Uttarakhand, India. Int J Agric Environ Biotechnol 13(2):1–11

GoI (2016) Sub mission on agroforestry operational guidelines. Department of Agriculture, Cooperation and Farmer Welfare, Government of India, p 30

Goswami S, Verma KS, Kaushal R (2014) Biomass and carbon sequestration in different agroforestry systems of a Western Himalayan watershed. Biol Agric Hortic 30(2):88–96

Gupta RD, Arora S (2015) Agroforestry as alternate landuse system for sustaining rural livelihoods in Himalayan ecosystem. In: Bhan S, Arora S (eds) Advances in soil and water resource management for food and livelihood security in changing climate. Soil Conservation Society of India, New Delhi, pp 656–669

Gupta B, Sarvade S, Singh M (2017) Species composition, biomass production, and carbon storage potential of agroforestry systems in Himachal Pradesh. In: Gupta SK, Panwar P, Kaushal R (eds) Agroforestry for increased production and livelihood security. New India Publishing Agency, New Delhi, pp 242–270

Handa AK, Dhyani SK, Rizvi J (2019) Guidelines to produce quality planting material of agroforestry species. ICAR (CAFRI) & WAC, p 42

Himshikha NAK, Poonia PK, Kumar M, Daneva V (2020) Evaluation of existing agroforestry systems in plain region of Uttarakhand, India. Indian J Agrofor 22(2):44–50

ICAR-IGFRI (2021) Fodder resources development plan for Jammu & Kashmir. ICAR-Indian Grassland and Fodder Research Institute, Jhansi, p 56

ISFR (2013) Indian State of Forest Report 2013. FSI, Dehradun, p 252

Islam MA, Qaisar KN, Bhat GM (2017) Indigenous knowledge in traditional agroforestry systems of Kashmir valley: current challenges and future opportunities. Int J For Crop Improv 8(1): 68–77

Janju S (2021) Appraisal of existing agroforestry systems in Seraj valley of District Mandi, HP. M. Sc. Thesis. Dr YS Parmar University of Horticulture and Forestry Nauni-Solan (HP), p 79

Jose S, Bardhan S (2012) Agroforestry for biomass production and carbon sequestration: an overview. Agrofor Syst 86:105–111

Kaler NS, Gupta B, Negi V (2017) Traditional agroforestry systems in cold desert region of Himachal Pradesh, India. Popular Kheti 5(2):35–36

Kashyap SD, Dagar JC, Pant KS, Yewale AG (2014) Soil conservation and ecosystem stability: natural resource management through agroforestry in Northwestern Himalayan Region. In: Dagar JC et al (eds) Agroforestry systems in India: livelihood security & ecosystem services, advances in agroforestry. Springer, India, pp 21–55

Khaki BA, Wani AA, Bhardwaj DR, Singh VRR (2016) Soil carbon sequestration under different agroforestry land use systems. Indian Forester 142(8):734–738

Khosla PK, Toky OP (1996) Status of agroforestry in the western Himalaya. Current researches in plant sciences. pp 367–377

Kumar BM, Handa AK, Dhyani SK, Arunachalam A (2018a) Agroforestry in the India Himalayan region. In: Gordon AM, Newman SM, Coleman BRW (eds) Temperate agroforestry systems, 2nd edn. CAB International, Wallingford, pp 153–171

Kumar P, Thakur CL, Rai P, Attri K (2018b) Identification of existing agroforestry systems and socio-economic assessment in Kandaghat block of Solan district, HP, India. Int J Curr Microbiol App Sci 7(4):3815–3826

Kumar B, Singh K, Sharma J, Gairola S (2020) A comprehensive review of fuelwood resources and their use pattern in rural villages of western Himalaya, India. Plant Arch 20(2):1949–1958

Kumar A, Tewari S, Singh H, Kumar P, Kumar N, Bisht S, Devi S, Nidhi KR (2021a) Biomass accumulation and carbon stock in different agroforestry systems prevalent in the Himalayan foothills, India. Curr Sci 120(6):1083–1088

Kumar S, Bijalwan A, Singh B, Rawat D, Yewale AG, Riyal MK, Thakur TK (2021b) Comparison of carbon sequestration potential of *Quercus leucotrichophora*–based agroforestry systems and natural forest in Central Himalaya, India. Water Air Soil Pollut 232:350

Kumari A, Sehgal RN, Kumar S (2008) Traditional agroforestry systems practiced in Lahul (Lahul & Spiti) and Kinnaur Districts of Himachal Pradesh. Indian Forester 8:1003–1010

Lefroy E (2009) Agroforestry and the functional mimicry of natural ecosystems. In: Nuberg I, George B, Reid R (eds) Agroforestry for natural resource management. CSIRO Publishing, Collingwood, pp 23–36

Mahato S, Dasgupta S, Todaria NP, Singh VP (2016) Agroforestry mapping and characterization in four districts of Garhwal Himalaya. Energy Ecol Environ 1(2):86–97

Murthy IK, Dutta S, Varghese V, Joshi PP, Kumar P (2016) Impact of agroforestry systems on ecological and socio-economic systems: a review. Global J Sci Front Res Environ Earth Sci 16(5):15–27

Nair PKR, Dagar JC (1991) An approach to developing methodologies for evaluating agroforestry systems in India. Agrofor Syst 16:55–81

Namgial J (2018) Floral spectrum and productivity of different land uses in Leh region of Himalayan cold desert. M.Sc. Thesis. Department of Silviculture and Agroforestry, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, HP, p 66

Namgial J, Prabhakar M, Bishist R, Gautam KL, Sharma H, Sharma A (2020) Identification of different land use systems in Leh region of Himalayan Cold Desert. Int J Curr Microbiol App Sci 9(11):1–11

Nautiyal M, Tiwari P, Tiwari JK, Rawat DS (2018) Fodder diversity, availability and utilization pattern in Garhwal Himalaya, Uttarakhand. Plant Arch 18(1):279–287

Newaj R, Dhyani SK, Ajit PR, Rizvi RH, Alam B, Chavan SB, Handa AK, Jha A (2016) Carbon sequestration potential of agroforestry systems in Indo-gangetic plains of India. India Farming 66(3):41–43

NITI Aayog (2018) Demand and supply projections towards 2033. The Working Group Report, p 220

Panwar P et al (2022) Biomass production and carbon sequestration potential of different agroforestry systems in India: a critical review. Forests 13(1274):1–15

Parikh J (2011) Hardships and health impacts on women due to traditional cooking fuels: a case study of Himachal Pradesh, India. Energy Policy 39:7587–7594

Parthiban KT, Fernandaz CC, Sudhagar RJ, Sekar I, Kanna SU, Rajendran P, Devanaand PS, Vennila S, Kumar NK (2021) Industrial agroforestry- a sustainable value chain innovation through a consortium approach. Sustainability 13:1–14

Pateria HM, Sharma OP, Bhatt BP (2003) Sustainability through agroforestry in Himalayas: an overview. Proceeding. In: Bhatt BP, Bujarbaruah KM, Sharma YP, Patiram (eds) Approaches for increasing agricultural productivity in hill and mountain ecosystem. ICAR Research Complex for NEH Region, Umiam, Meghalaya, pp 129–138

Phondani PC, Maikhuri RK, Rawat LS, Negi VS (2020) Assessing farmers' perception on criteria and indicators for sustainable management of indigenous agroforestry systems in Uttarakhand, India. Environ Sustain Indicators 5:1–8

Proto AR, Zimbalatti G, Abenavoli L, Bernardi B, Benalia S (2014) Biomass production in agroforestry systems: V.E.Ri.For project. Adv Eng Forum 11:58–63

Rajput BS, Bhardwaj DR, Pala NA (2017) Factors influencing biomass and carbon storage potential of different landuse systems along an altitudinal gradient in temperate northwestern Himalayas. Agrofor Syst 91:479–486

Rathore AC, Mehta H, Sharma NK, Gupat AK, Alam NM, Islam S, Dogra P (2020) Performance of litchi (Litchi chinensis Sonn.) based agrihorticultural land uses in rainfed condition on degraded lands in North Western Himalayas, India. Agrofor Syst 94:2225–2236

Rawat YS, Vishwakarma SCR (2011) Pattern of fodder utilization in relation to sustainability under indigenous agroforestry systems, north-western Himalayas, India. Environ Int J Sci Technol 6: 1–13

Roberts MJ, Lomg SP, Tieszen LL, Beadle CL (1985) Measurement of plant biomass and net primary production. In: Techniques in nioproductivity and photosynthesis, pp 1–19

Roy ML, Chandra N, Kharbikar HL, Joshi P, Jethi R (2013) Socio-economic status of hill farmers: an exploration from Almora District in Uttarakhand. Int J Agric Food Sci Technol 4(4):353–358

Roy AK, Agrawal RK, Bhardwaj NR, Mishra AK, Mahanta SK (2019) Revisiting national forage demand and availability scenario. In: Roy AK, Agrawal RK, Bhardwaj NR (eds) Indian fodder scenario: redefining state wise status. ICAR-AICRP on Forage Crops and Utilization, Jhansi, pp 1–21

Saha SK, Kumar AS (2019) Northwest Himalayan ecosystems:issues, challenges and role of geospatial techniques. In: Navalgund RR et al (eds) Remote Sensing of Northwest Himalayan Ecosystems. Springer, Singapore, pp 3–14

Salve A, Bhardwaj DR (2020) Soil carbon stock and nutrient study in different agroforestry systems at Kinnaur district, Himachal Pradesh. Plant Arch 20(2):4251–4260

Sharma KK (1996) Agroforestry in farming system development. Indian Forester 122:547–559

Sharma V, Raina A (2021) Problems and prospects of Himalayan farmers and farming: a case study of District Kishtwar, Jammu and Kashmir. Reg Econ Dev Res 2(1):82–95

Sharma J, Sharma SD, Sharma K, Sharma D (2021) Appraisal of biological yield and economic returns of existing afroforestry systems in Tehsil Bangana of Unda District of Himachal Pradesh, India. Biol Forum Int J 13(2):413–419

Shukla R, Chakraborty A, Sachdeva K, Joshi PK (2018) Agriculture in the western Himalayas – an asset turning into a liability. Dev Pract 28(2):318–324

Singh AK (2009) Probable agricultural biodiversity heritage sites in India: II. The Western Himalayan Region. Asian Agri Hist 13(3):197–214

Singh R (2019) Studies on identification and socio-economic status of existing agroforestry systems in Shimla District of Himachal Pradesh. Ph.D. Thesis. Dr YS Parmar University of Horticulture and Forestry Nauni-Solan (HP), p 144

Singh M, Gupta B, Sarvade S, Awasthe RK (2015) Biomass and carbon sequestration potential in different agroforestry systems in Giri catchment of North Western Indian Himalayas. India J Agrofor 17(2):42–48

Singh R, Bhardwaj DR, Pala NA, Rajput BS (2019) Biomass production and carbon stock potential of natural vegetation, agroforestry and cultivated land use systems along altitudinal gradient in north western Himalayas. Range Manag Agrofor 40(1):94–103

Singh R, Pant KS, Tiwari P, Dhiman R (2020) Biomass productivity of different horticulture based agroforestry systems in North-Western Himalayas. J Pharmacogn Phytochem 9(5):862–866
Solanki KR (1998) Agroforestry research in India. Special issue. Indian J Agric Sci 68:559–566
Sood KK, Najiar C, Singh KA, Handique P, Singh B, Rethy P (2008) Association between socio-economic parameters and agroforestry uptake: evidences from eastern Himalaya. Indian J For 31(4):559–564
TERI (2015) Green growth and forestry in Himachal Pradesh. The Energy and Research Institute, New Delhi, p 16
Tewari VP, Kapoor KS (2013) Western Himalayan cold deserts: biodiversity, eco-restoration, ecological securities and concerns. Ann Arid Zone 52(3&4):223–230
Tewari JC, Pareek K, Raghuvanshi MS, Kumar P, Roy MM (2016) Fodder production system- a major challenge in cold arid region of Ladakh, India. MOJ Ecol Environ Sci 1(1):00005
Tewari VP, Verma RK, Gadow KV (2017) Climate change effects in the western Himalayan ecosystems of India: evidence and strategies. For Ecosyst 4(13):1–9
Thakur A (2020) Appraisal of existing agroforestry systems in Chuhar valley of district Mandi, H.P. M.Sc. Thesis. College of Horticulture and Forestry, Neri, Dr YSPUHF Nauni, Solan (HP), p 113
Thakur NS, Gupta NK, Gupta B (2004) Phytosociology analysis of woody and non woody components under some agroforestry systems in Western Himalaya: case study. Indian J Agrofor 6:65–71
Tiwari DN (1995) Agroforestry Systems. International Book Distributors. Dehradun, pp 31–107
Tiwari P, Pant KS, Singh R (2018) System units under prevalent agroforestry systems in North-Western Himalayas and their constraints. J Pharmacogn Phytochem 7(6):2758–2764
Toky OP, Kumar P, Khosla PK (1989) "Structure and function of traditional agroforestry systems in Garhwal Himalaya" Biomass and productivity. Agrofor Syst 9:47–70
Vikrant KK, Chauhan DS, Rizvi R (2018) Biomass and carbon potential in agroforestry systems along altitudes in Tehri District of Uttarakhand. In: Agroforestry for climate resilience and rural livelihood, pp 171–178
WMO (2021) State of the Global Climate 2021- WMO Provisional Report. World Meteorological Organization, Geneva, Switzerland, 47
Yadav RP, Bisht JK, Gupta B, Mondal T (2016) Toward the carbon sequestration potential of agroforestry practices to combat climate change in Kumaon Himalaya, India. In: Bisht JK et al (eds) Conservation agriculture. Springer, Singapore, pp 293–313
Yadav RP, Bisht JK, Bhatt JC (2017) Biomass, carbon stock under different production systems in the mid hills of Indian Himalaya. Trop Ecol 58(1):15–21
Yadav RP, Bisht JK, Meena VS, Choudhary M (2018) Sustainable agroecosystems for livelihood security in Indian Himalayas. In: Sustainability of agroecosystems, pp 63–77
Yadav RP, Gupta B, Bhutia PL, Bisht JK, Pattanayak A (2019) Sustainable agroforestry systems and their structural components as livelihood options along elevation gradient in central Himalaya. Biol Agric Hortic 35(2):73–95
Zahnoor S, Dutt V, Mughal AH, Pala NA, Rashid M, Khan PA (2022) Influence of intercropping on soil properties and nutrient status of fruit based agroforestry systems in north western region of Indian Himalaya. Indian J Agrofor 24(1):85–92
Zahoor S, Dutt V, Mughal AH, Pala NA, Qaisar KN, Khan PA (2021) Apple-based agroforestry systems for biomass production and carbon sequestration: implication for food security and climate change contemplates in temperate region of Northern Himalaya, India. Agrofor Syst 95: 367–382