

Cultivating Sustainability : Exploring Diverse Agroforestry Practices in West Bengal

Kanchan¹, Arshad A¹, Abha Manohar K², Gopal Shukla³,

Manendra Singh¹, Sumit Chakravarty¹ and Shankharaj Roy⁴

(Received : December 31, 2023; Revised : January 05, 2023; Accepted : January 15, 2024)

ABSTRACT

West Bengal contributes significantly to national value in agricultural crop production, highlighting its critical role in shaping the country's agrarian landscape. This article will investigate the many facets of agroforestry in the state, with a focus on three key aspects. To begin, it examines the significance and role of agroforestry in fostering sustainable land-use systems from both an economic and ecological standpoint. Second, it provides a detailed analysis of agricultural and soil conditions in West Bengal's various agroclimatic zones. Finally, the article investigates the various agroforestry systems that are actively practiced in the state. Agroforestry has historical roots in West Bengal that predate the Green Revolution, but the arc of increased agricultural production has significantly influenced its trajectory. In recent decades, scientists have questioned the economic and ecological sustainability of agroforestry. This article examines the role of agroforestry in restoring a balance between productivity and sustainability. West Bengal, a heavily endowed agricultural state, is grappling with the negative effects of its topography as well as the escalating effects of climate change, posing challenges to the ecological and economic sustainability of its land-use system. In light of this, the article provides a concise overview of major agroforestry systems and practices in West Bengal, shedding light on their potential to address contemporary ecological concerns while also improving economic resilience.

Keywords : Agroclimatic zones, Biodiversity conservation, Climate change, Economic resilience, Sustainable land-use systems.

Introduction

Against this backdrop, the article provides a concise overview of major agroforestry systems (AFS) and practices in West Bengal, shedding light on their potential to address contemporary

ecological concerns while also enhancing economic resilience. Agroforestry has many definitions, all pointing to the intensive and intentional/deliberate integration of trees on farms for the mutual interactions of all the components in an efficient way to grasp

¹Department of Forestry, Uttar Banga Krishi Viswavidyalaya, Pundibari-736165, Cooch Behar, West Bengal, India; ²Department of Agronomy and Agroforestry, Centurion University of Technology and Management, Odisha, India -761211; ³Department of Forestry, North Eastern Hill University, Tura Campus, Tura-794002, Meghalaya; ⁴Pulses and Oilseeds Research Station, Berhampore, West Bengal, 742101. Email: gopalshukla12@gmail.com/kanchannjaswall@gmail.com

the production and sustainability attributes in ecological as well as economic terms (Nair *et al.*, 2008, 2009). Agroforestry, according to the National Agroforestry Policy (2014), is a land use system that intentionally incorporates trees in farms and rural landscapes to increase productivity, diversity, income, and ecosystem sustainability. Diverse agroforestry systems are firmly rooted in the tropics due to favourable climatic conditions and socioeconomic factors such as demographic pressures, reduced land holding area, unfavourable land tenures, greater labour accessibility, and proximity to markets (Nair, 2007; Nair *et al.*, 2008). As a tropical country, India has faced numerous challenges in the agricultural and associated agricultural systems due to demographic pressure, rising demand for food/fodder/fuel, natural resource depletion, and the effects of climate change. For centuries, the AFS has been laying the scientific foundations for decoding these problems of rural livelihood in India by providing farmers with economic and ecological stability. Ecological security can only lay the groundwork for long-term food and nutrition stability or security, which means the stability and security of land, flora, water, fauna, and the atmosphere, as these are the fundamental life-supporting systems (Swaminathan, 1981).

West Bengal has a stronghold on AFS, which is agriculturally classified into six agroclimatic zones (ACZ): northern hill, new alluvial, terai-tista alluvial, coastal saline, undulating red and laterite regions, and Vindhyan alluvial (Dhara *et al.*, 2017). Some of these zones are under severe threat in terms of fertility and productivity (Dhara *et al.*, 2017; Murmu *et al.*, 2018).

AFS made significant changes in these fields in economic terms as well as in ecological terms. However, introducing location-specific (agro-ecology region) AFS is imperative to justify its scientific and economic importance over other systems. The role of land use systems in maintaining economic and ecological sustainability in rural livelihoods became important research during the past decade. Agroforestry attained immense attention in achieving this sustainability scientifically. Congruous inter-cropping with amalgamations of trees and arable crops in AFS has immense importance in bringing back early sustainable economic and ecological returns to the farmer. Agroforestry renowned in its potential to enhance the overall productivity of the system, soil conservation, soil fertility improvement, micro-climate improvement, nutrient cycling, bio drainage, carbon sequestration, biofuel and bio-energy (Fanish and Priya, 2013). The highest biomass of AFS in the eastern and north eastern region including west Bengal was from home gardens having a range of 30.76–140 Mg ha⁻¹ (Chavan *et al.*, 2022). Although agroforestry has since past decades, a converged data of AFS in West Bengal is minimal and is essential for the comprehensive understanding of agroforestry in different ecological zones of West Bengal. Also, it is important in itself for feeding the massive datasets to research projects and for other development/planning purposes. With all this in mind, this chapter focuses on bringing together the agriculture and soil conditions of various ACZ of the state and major AFS practices in the state, with a special emphasis on the All India Coordinated

Research Project (AICRP) role in bringing out the agroforestry as a successful land use system which can easily adopt by the farmers.

Need for agroforestry

The extramural human and animal population, led to the ever-expanding needs of food, fodder, and fuel, exerted a negative impact on main attributes of agro-ecosystems. Subsistence farming before the green revolution was dominated by the mixed species all over the world (Mbow *et al.*, 2014), demographic pressures had driven forcefully the agriculture system to take over by the monocultures for enhanced production of food, even though subsistence agroforestry continued in the homesteads. Monoculture systems remove a high amount of nutrients from the soil per harvest without replenishing them, causing a high nutrient depletion in these systems. As researchers recognized the urge for ecological stability in the agricultural system for the empowerment of farmers' livelihood and environmental stability, AFS recaptured its limelight from past decades. AFS recognizes the intimate influences and explores the interaction between environmental and human aspects to fulfil livelihood security at local as well as regional levels. The potential of agroforestry over mono-cropping agriculture is the impact that made on the economy through the building up of socio-livelihood basement by the production of fruit, fodder, fuel wood and other produce with agricultural products. Other potential includes additional carbon sequestration, soil conservation, nutrient cycling, improvement of soil health, biodiversity. The subsections that follow provide a

summary of AFS's potential for increasing economic and ecological stability.

Carbon sequestration

The last decade was flooded with literature on carbon sequestration in AFSs from all over the World. Anyway, agroforestry became an attraction in carbon sequestration at the end of the 20th century with the arrival of the Kyoto protocol in 1995 under the afforestation and reforestation category (Nair, 2011). According to the United Nations Framework Convention on Climate Change (UNFCCC), carbon sequestration is the removal of atmospheric CO₂ and its long-term storage in persistent pools (UNFCCC 2007). AFS accomplishes this huge task with its two prime components- above ground and below ground. Above ground biomass (AGB) is from stem, leaf, or any parts of trees, shrubs and herbs while below ground biomass (BGB) is from other plant parts below the soil, such as roots, soil organisms and carbon stored in the soils of different horizons in chemical form. The carbon sequestration in each AFS would differ due to ecoregion, nature of species, previous land use and site quality (Nair, 2011). Anyway, AFS have higher potential than field crops and pastures to sequester carbon growing under identical ecological conditions (Palm *et al.*, 2004; Haile *et al.*, 2008 Roshetko *et al.*, 2002; Kirby and Potvin, 2007).

Agroforestry and soil health

Soil fertility is one of the essential resources for maintaining the sustainable health of the soil. Agroforestry has proven its capacity to enhance soil quality as a promising system and practice in degraded

land. AFS embraces multiple interactions between trees and crops to bring out the soil quality at the sustainable level, which is indeed for a sustainable agriculture. Soil health is defined as the soil's continuous ability to function as a comprehensive biological system to promote floral and faunal healthy growth, as well as to sustain the ecological environments and productivity of the land use systems within that ecosystem (Doran *et al.*, 1996). One of the vital properties of soil fertility is the organic carbon (OC) content in the soil which feeds the soil biota and influences the soil microorganism diversity, also higher OC content has more synergies with the productivity of soil as it enhances the physical, chemical and biological properties. AFS is a complex system which substantially influences the organic matter content of soil through its higher competence of litter decomposition, diverse soil biota, and enhanced nutrient cycling. Anyway, litter decomposition and mineralisation are fairly dependent upon the edaphic, environmental and management factors. Koul *et al.* (2011) reported the SOC stock of AFS (12.14 t/ha) and agriculture fields (6.99 t/ha) in west Bengal, highlighting the potential of AFS to store more carbon in the soil than agricultural land use system.

Agroforestry for microclimate amelioration

The threshold level of microclimate is essential for each species to grow to its greatest potential, variation in this threshold led to vulnerability in the growth and production of crops (Slingo *et al.*, 2005). Accredited the suitable microclimatic condition to the crops by AFS where the

optimal range exceeds normal is well documented (Lin, 2007). Shade trees in an AFS have an ecological effect, it can regulate the variation in radiation fluxes, evapo-transpiration rates, humidity and wind speed of the under storey, which modify a conducive photosynthetic efficiency, transpiration, plant growth and water use efficiency of the crop (Monteith *et al.*, 1991). While unscientific integration of trees causes over shade and it can affect crop production negatively. Removal of shade trees caused the increase of soil temperature (40°C) and relative air humidity (12%) in cacao-based agroforestry systems, previous land use and site quality (Nair, 2011). Anyway, AFS have higher potential than field crops and pastures to sequester carbon growing under identical ecological conditions (Steffan-Dewenter *et al.*, 2007).

Socio-economic development

Globally around 1.6 billion people depend upon forest resources for their social needs (Wiersum, 1999) and nearly 1.2 billion people use trees from their farms as a source of cash and food in developing countries (FAO, 2011). Livelihood security can be achieved through agroforestry as it provides basic needs such as food, fodder, timber, and fuel with low input cost and an additional income to the farmers and communities which enhances their socio-economic security and economic resilience. AFSs like home gardens have a predominant role in women's empowerment by providing employment opportunities to women to encourage gender equality and becoming a part of income generators to their livelihood. Apart from economic resilience, AFS guarantees food security in the

community, Ickowitz *et al.* (2016) justified a direct relationship between agroforestry and legume intake of communities living in forest fringe areas, strengthening the micronutrient levels of the body. Mono cropping land use system focuses on a single crop that would bring a very quick return to the farmer, but numerous negative factors hinder this system, such as risk in market behaviour, total crop failure due to disasters, and other environmental and ecological threats like climate change.

Agricultural soil conditions of West Bengal

West Bengal is renowned for the supreme production of rice and jute in the country. The state consists of 8% of India's population in 2.7 per cent of India's geographical area. Nearly 96% are small and marginal farmers from 71.23 lakh families, with a mean land holding size of 0.77 ha (Govt. of west Bengal, 2022). The net sown area is around 52 lakh ha from 92% of cultivable land which comprises 68% of the geographical area of the state with a cropping intensity of 184%. The state has a diverse climatic condition with mainly fertile soil, and water resources, which contributed to the national value of 8.21% in agriculture and related sectors, even with 3.7% of the country's net cropped area (DES, 2019). However, the state is in a humid tropic region and close to the Bay of Bengal, often it undergoes natural challenges like cyclones and floods. The productivity of pulses, oilseeds and maize is still below the threshold even though it conquered the productivity of rice, vegetables, and potatoes. Soil health is the miscreant in the low production of other

crops, poor soil health may be due to the excess use of chemical fertilizers, pesticides, monocropping, poor farm mechanization and unscientific management of fields. Beyond this, weather and climatic parameters also hold a precise role in the productivity and soil health of the state. Weather and soil characteristics differ in each ACZ of the state, as addressed below.

Northern hill zone

This zone is mainly comprised of Darjeeling and Kalimpong districts, has porous soil with coarse texture, shallow in-depth, mostly acidic and poor water holding capacity. As the name designates, land area has a peculiar physiographic feature with steep slopes which hampers 70% area unsuitable for agriculture, and is highly susceptible to soil erosion. Even though soil contains high OC, low temperature influences the slow rate of mineralization. Soil is highly acidic with low content of calcium (Ca), magnesium (Mg) and other micronutrients. Landslides are a major threat to agriculture every year which wipe the fertile topsoil (Mandal *et al.*, 2022).

Terai-Teesta alluvial zone

This zone mainly consists of Jalpaiguri, Alipurduar, and Coochbehar. An immense deposition of the Mahananda, Teesta, Torsa and Jaldhaka rivers making the soil is sandy to sandy loam and greyish black in colour. Frequent flooding due to heavy rainfall is a pejorative feature of the zone with a high intensity covering 20% of the land, causing a high deposition of sand which forces the land into a barren condition. Soils are moderately acidic due to heavy leaching all cations are leached beneath the soil (Dutta, 2018); partially

oxidised organic matter is medium to high with low level of Ca, Mg and micronutrients. Most of the strongly acidic area is affected by Aluminium (Al) toxicity (Mandal *et al.*, 2022). Major crops are banana, pineapple, jackfruit, tomato turmeric and guava. However, tea plantations also managed in the low lands of this zone as like in uplands.

Gangetic alluvial (new alluvial zone)

This zone is non-saline alluvial region, dominated by Malda, Murshidabad, Nadia, East Burdwan North and South 24 parganas, Hooghly and Howrah district. Level topography allows cultivation of almost all types of field and fruit crops with a cropping intensity of 170% (Dhara *et al.*, 2017), mango, litchi and mulberry are the major fruit crops and region is favourable for the growth of tropical and sub-tropical fruits (Mandal *et al.*, 2022). The zone is rich in potassium (K) with medium concentration of nitrogen (N) and phosphorous (P), but poor in OC (Dutta, 2018). Generally, this zone is categorized under medium fertility status. Systematic AFS is predominant in the zone (Dhara *et al.*, 2017). Major crops are wheat, paddy, potato, jute, onion and tomato.

Vindhyan alluvial (old alluvial zone)

A major part of the zone is embraced with the South Dinajpur, East Midnapore, the western region of Hooghly and Murshidabad, and the eastern region of Bankura and Birbhum. Mayurakshi, Ajoy, Damodar, Darkeswar and Kangshabati which originate from the eastern part of the Vindhyan range from the soil by deposit, having flat as well as rolling topography with bunded in highlands and

medium lands. The soil has a pH range of 5-7 with all classes of texture, low in OC and available P. Other major nutrients are low to high. The major crop grown is rice and the best potato growing belt in whole India. Jute, pulses, sugarcane, vegetables and pulses also have a great contribution to the agriculture production (Mandal *et al.*, 2022).

Lateritic, red and gravelly undulating zone

As the name indicates, it has laterite, red, gravelly and alluvial soil with undulating topography major part of this ACZ is in West Burdwan, Purulia, Bankura, West Midnapur, Jhargram Birbhum, Burdwan, Bankura and Purulia districts. Red soils are mainly handled by the Malda and west Dinajpur districts, while gravelly soils are in the Purulia district (Mandal *et al.*, 2022). Generally, upland soils are susceptible to erosion and highly coarse textured with a strongly acidic nature has poor OC and other major nutrients and is categorized under low fertility, while low land area soils are fertile compared to upland. Major crops are onion tomato, pulse and oil seeds and rice under rainfed condition (Dutta, 2018).

Coastal saline zone

The southern part of the state is bounded by this zone, crossing a large number of rivers and their tributaries across the zone that brings alluvial soil, generally saline with irregular patches of acid saline, saline-alkali and non-saline alkali having a pH of 6.5 to 8.5. Acid sulphate soils are also found in this zone with a pH 4 and a deep black colour. Fine textured soils have a silty clay nature and rich organic matter, K and Mg. High Mg

content causes hard and dry soil and becomes impeded in drainage conditions. Monsoon season is monopolised by rice and post-monsoon is occupied by other crops also like watermelon, chillies, safflower, sunflower, sugar beet, groundnut and vegetables (Mandal *et al.*, 2022).

Agroforestry systems prevalent in West Bengal

Different Agroforestry Systems like Agri-horticulture, Agri-silviculture, Agri-silvi-horticulture, aqua-forestry and Boundary plantations are practised in West Bengal (Dhara *et al.*, 2016). Karanj, Mahogany, Neem, Mulberry, Shisham, Gulmohar, Gamhar and Kapok are some of the most important species in the Agroforestry systems of the State (Das *et al.*, 2016). Home gardens are a significant Agroforestry system in North Bengal (Chakravarty *et al.*, 2017).

Bamboo based agroforestry systems

Bamboo is regarded as an atmosphere and soil healer because it produces a lot of oxygen, has low light intensity, shields against UV radiation, and defends against them. Furthermore, it considerably decreases soil erosion and preserves water (Amneth, 1996). Bamboo-based agroforestry system is practised in the moist humid zones of Bengal (North Bengal). The bamboo species cultivated are *Bambusa nutans*, *Bambusa balcooa*, *Bambusa vulgaris*, *Bambusa tulda* and *Bambusa bambos* etc along with *Musa paradisiaca* (Banana), *Areca catechu* (Betelnut), *Cocos nucifera* (Coconut), *Emblica officinalis* (Aonla), *Albizia procera* (Siris) and *Bombax ceiba* (Semul) etc. Banerjee *et al.* (2009) studied Bamboo agroforestry system using two Bamboo

species viz. *Bambusa tulda* and *Bambusa balcooa* and the results showed that a wide spacing of 12 m × 10 m and 10 m × 10 m allowed for the successful intercropping of crops such *Oryza sativa* (Paddy), *Abelmoschus esculentus* (Okra), *Arachis hypogaea* (Groundnut), *Cajanus cajan* (Pigeon pea), *Lagenaria sicerari* (Bottle gourd), *Colocasia esculenta* (Colocasia), *Amorphophallus paeoniifolius* (Elephant foot yam), *Vigna unguiculata* (Cowpea) and *Curcuma longa* (Turmeric).

Gmelina arborea based agroforestry system

The most frequently grown *Gmelina arborea* is also regarded as a significant spiritual and therapeutic tree (Pathala *et al.*, 2015). Moreover, it returns a significant amount of nutrients to the soil, greatly reducing nutrient losses and boosting soil productivity (Dutta and Dhiman, 2001). Under the agroforestry system, Gamhar (*Gmelina arborea*) may hold promise, especially in West Bengal's red and laterite zones (Banerjee and Dhara, 2009). In West Bengal, *Gmelina arborea* agroforestry system is practiced with agriculture crops like *Vigna unguiculata* (Cow pea), *Vigna mungo* (black gram), *Oryza sativa* (Rice) and *Arachis hypogaea* (Groundnut). Blackgram/groundnut produced the highest return (Rs. 13,800.00 ha⁻¹ year⁻¹) from the crop, while cowpea produced the lowest (Rs 6,180.00 ha⁻¹ year⁻¹). (Vanlalngurzauba *et al.*, 2010). Integration of *Gmelina arborea* with fruit tree such as *Mangifera indica* (Mango) and crops like *Abelmoschus esculentus* (Okra) and *Brassica juncea* (Mustard) also resulted in higher gross income (Momin *et al.*, 2017). It is frequently grown in home gardens for

timber production and for the root extract's use in stomach disorders (Niyas *et al.*, 2016). Thus, it makes substantial contribution in meeting farmer's need and preservation of biodiversity (Subba *et al.*, 2016; Chakravarty *et al.*, 2017).

Large cardamom based traditional agroforestry systems

The oldest spice, Large Cardamom (*Amomum subulatum*), a significant perennial cash crop, is indigenous to Sikkim and Darjeeling Himalaya, as well as the eastern highlands of Nepal (Shrestha *et al.*, 2018). Cardamom agroforestry has a greater tree diversity index than other agroforestry approaches in the area, and it supports a wide variety of tree species. Farmers take precautions to produce the crop on higher, more vulnerable terrain to reduce soil erosion and landslides (Sharma and Sharma, 1997).

Amomum subulatum is a shade-loving crop (Vineeta *et al.*, 2021, 2022), thus it is intermingled traditionally as an understory with natural forest trees such as *Alnus nepalensis* (Himalayan Alder) (Negi *et al.*, 2018). Because of its poor nutrient conservation and low nutrient usage efficiency, *Alnus nepalensis* is a great partner for fostering increased nutrient availability and quicker nutrient cycling (Singh *et al.*, 1989). The addition of Frankia as an endophyte to the roots of *Alnus* species improves biological nitrogen fixing (Garg *et al.*, 2003). Other tree species such as *Cryptomeria japonica* (Japanese cedar), *Schima wallichiana* (Needlewood Tree) and *Cupressus cashmeriana* (Kashmir cypress) are also cultivated in Large cardamom agroforestry system in the region (Vineeta *et al.*, 2022). This

agroforestry system provides numerous advantages from environmental to livelihood sustenance, including limiting carbon emissions and guaranteeing financial security, and is typically viewed as the shadow of natural forest (Das *et al.*, 2016, Vineeta *et al.*, 2023).

Arecanut based agroforestry system

Areca catechu is one of the significant plantation crops of Northern region of West Bengal. Because of the significant amount of recyclable biomass present in the system, Areca-based cropping systems offer nutrient regulation functions (Bhat and Sujatha, 2007). Moreover, it offer opportunities for agro-ecotourism, which in turn allows for the provision of cultural services (Kumar *et al.*, 2021). Arecanut farming is typically low-input, with local farmers using some organic manures from the dairy animals they keep on their farms (Harikumar, 2015). The Arecanut Agroforestry systems practised along with *Musa Paradisiaca* (Banana) and *Curcuma longa* (Turmeric) resulted in higher net economic returns (Chandrashekhar and Bhattacharjee, 2018). Singh and Baranwal (1993) studied Arecanut based Agroforestry and concluded that it's production would rise by 4.1% when combined with *Musa Paradisiaca* (Banana), *Piper nigrum* (Black pepper), *Theobroma cacao* (Cocoa), and/or *Amorphophallus paeoniifolius* (Elephant foot yam).

Coconut based agroforestry system

The coconut farming technique is gaining significance because of its maximum spacing, increased incidence of light under the canopy, and also allowing other crops to grow within the spacing due

to the effective root zone (Panda *et al.*, 2020). It is widely acknowledged that inter-cropping systems under coconut are more profitable than monoculture farming since it offers farmers a lot of opportunities for growth in addition to creating more jobs (Nath, 2002).

A study conducted by Bandyopadhyay *et al.* (2017) revealed that under a cropping strategy based on *Gladiolus palustris* (Gladiolus), *Tagetes* spp. (Marigold), *Gerbera jamesonii* (Gerbera), and *Polianthes tuberosa* (Tuberose) produced higher yields and were more economical than pure coconut plantation. Black pepper also proved effective in Coconut based Agroforestry system. This approach resolves the problem of establishing different trees specifically for growing peppers (Ghosh, 2009). Under the conditions of West Bengal, a fruit-based cropping system containing *Cocos nucifera* (Coconut), *Piper nigrum* (Black pepper), and (*Ananas comosus*) Pineapple was proven to be the most effective (Ghosh and Bandopadhyay, 2011).

Home gardens

Home gardens act as sustainable land cultivation, conserving natural resources (Ricketts and Imhoff, 2003; Chakravarty *et al.*, 2017). In areas with high population densities, home gardens have attained significant levels of growth in terms of plant richness, labour input, and income generation (Soemarwoto, 1987; Chakravarty *et al.*, 2017). Home gardens are still an important resource sustaining the livelihood of Indigenous communities of the Northern part of West Bengal (Subba *et al.*, 2015; Sarkar *et al.*, 2020; Pala *et al.*, 2020; Roy *et al.*, 2022). Study conducted

by Subba *et al.* (2016) from the Sub-humid region of West Bengal revealed that wide diversity exists in the Homegardens of this region. Major tree species present in the homegardens are *Areca catechu* (Arecanut), *Cocos nucifera* (Coconut), *Sweitenia mahogany* (Mahogany), *Gmelina arborea* (Gamhar), *Anthocephalus cadamba* (Kadamba), *Artocarpus heterophyllus* (Jackfruit), *Mellia azedarach* (Chinaberry tree), *Chukria tabularis* (Chukrasia), *Tectona grandis* (Teak) etc. along with herbs like *Ocimum sanctum* (Tulsi), *Dolichos lablab* (Lablab bean), *Musa* spp., *Tagetes erecta* (African marigold), *Tabernaemontana coronaria* (East India rosebay) etc. and fruit plants like *Caricapapaya* (Papaya), *Psidium guajava* (Guava), *Syzygium cumini* (Jaman), *Litchi chinensis* (Litchi), *Aegle marmelos* (Bael), *Mangifera indica* (Mango), *Citrus lemon* (Lemon), *Ziziphus mauritiana* (Ber) etc. Majority of the documented species of homegardens are used by the growers for food, fibre, firewood, fodder, medicinal purposes, etc. Homegardens based agroforestry systems of the regions act as gene bank for traditional plant resources (Chakravarty *et al.*, 2017).

Conclusion

Agroforestry systems are restoring rural people's livelihoods while also helping to mitigate climate change. Agroforestry systems aid in the efficient use of land resources. As a result, the significance of these systems should be recognised and carefully documented. Farmers should understand the value and application of agroforestry systems through various training programmes and schemes. West Bengal's traditional agroforestry systems must be recognised and restored in order

to preserve the region's biological diversity. Local residents must be encouraged to use local flora in agroforestry systems. Thus, agroforestry systems can alter farming perspectives, resulting in a more sustainable farming system.

References

- Amneth, R. R. 1996. The role of bamboo on the social, cultural and economic life of the Philippines. *Bamboo People Environment* **4**: 70-78.
- Bandyopadhyay, A., Ghosh, D. K., Biswas, B., & Sahu, P.K. 201). Coconut based cropping system with floricultural crops helps in enhancing the income of coconut plantation under West Bengal condition. (in) *International Symposium on Eco – Efficiency in Agriculture & Allied Research (EEAAR'17), West Bengal*.
- Banerjee, H. and Dhara, P. K. 2009. Evaluation of gamhar (*Gmelina arborea*)-based agroforestry model under red and lateritic tract. *Environment and Ecology* **27**: 1507-1510.
- Bhat, R. and Sujatha, S. 2007. Soil fertility status as influenced by arecanut based cropping system and nutrient management. *Journal of Plantation Crops* **35**: 158.
- Chakravarty, S., Puri, A., Subba, M, Pala, N. A. and Shukla G. 2017. Homegardens: drops to sustainability. (in) *Agroforestry: anecdotal to modern science* (Dagar, J.C. and Tewari, V.P. eds). Springer Nature, Singapore, pp 517–528. https://doi.org/10.1007/978-981-10-7650-3_20.
- Chandrashekhar, G. and Bhattacharjee, H. 2018. Economics of different horticultural crops under Arecanut basedmultistoreyed cropping system in West Bengal condition. *International Journal of Current Microbiology and Applied Sciences* **7**: 2756-2761.
- Chavan, S.; Uthappa, A.R. and Keerthika. 2022. Can Agroforestry Help Achieve Sustainable Developmental Goals?. Available online: <https://www.downtoearth.org.in/blog/forests/can-agroforestry-help-achieve-sustainable-developmental-goals—82769>
- Das, B., Naik, S. K., Sarkar, P. K., Singhal, V., Arunachalam, A., Acharyya, G., Borah, D., Kumar, J., Shukla G. and Bhatt, B. P. 2016. Agroforestry for livelihood security in Eastern India. ICAR-RC for Eastern Region, Patna.
- DES, Agricultural Statistics at a Glance-2019, Directorate of Economics and Statistics, Department of Agriculture, Cooperation and Farmers, Ministry of Agriculture and Farmers Welfare (MoAFW), Government of India (GoI), 2020; www.agricoop.nic.in
- Dhara, P., Panda, S., Sarkar, S., Sarkar, S. and Das, N. 2017. Agroforestry Systems Practised in New Alluvial Zone of West Bengal. (in) *International Conference on Agriculture, Food Science, Natural Resource Management and Environmental Dynamics: The technology, the People and Sustainable Development, New Delhi* (pp. 162-164).
- Dhara, P.K., Panda, S., Sarkar, S., & Das, N. C. 2016. Agroforestry Systems Practised in New Alluvial Zone of West Bengal.

- Doran, J. W. 1996. Soil health and sustainability. *Advances in Agronomy* **56**: 1-54.
- Dutta, K. 2018. The comparative study of three agroclimatic zones in West Bengal, India. *International Journal of Creative Research Thoughts* **6**: 1348-1364
- Dutta, M. and Dhiman, K. R. 2001. Effect of some multipurpose tree on soil properties and crop productivity in Tripura area. *Journal of the Indian Society of Soil Science* **49**: 511-515.
- Fanish, S.A. and Priya, R.S. 2013. Review on Benefits of Agro Forestry System. *International Journal of Education and Research* **1**: 1-12.
- FAO 2011. Forests and poverty reduction. Available at: <http://www.fao.org/forestry/livelihoods/en/> Accessed on February 23, 2013
- Garg, V.K., Singh, P.K. and Singh, K.K. 2003. Distribution of nutrients in soils and plants of Sikkim **51**: 208-211.
- Ghosh, D. K. 2009. Performance of black pepper (*Piper nigrum* L) as intercrop with coconut in the alluvial plains of West Bengal. *Indian Coconut Journal* **51**: 4-7.
- Ghosh, D. K. and Bandopadhyay, A. 2011. Productivity and profitability of coconut based cropping systems with fruits and black pepper in West Bengal. *Journal of Crop and Weed* **7**: 134-137.
- Govt. of West Bengal, 2022. State portal; department of agriculture. <https://wb.gov.in/departments-details.aspx?id=D170907140022669&page=Agriculture> Accessed on 03/03/2023
- Harikumar, V.S. 2015. Arbuscular mycorrhizal association in sesame under low-input cropping systems. *Archives of Agronomy and Soil Sciences* **61**: 347-359.
- Ickowitz, A., Rowland, D., Powell, B., Salim, M. A. and Sunderland, T. 2016. Forests, trees, and micronutrient-rich food consumption in Indonesia. *PloS one* **11**: e0154139.
- Koul, D. N., Shukla, G., Panwar, P. and Chakravarty, S. 2011. Status of soil carbon sequestration under different land use systems in Terai Zone of West Bengal. *Environment and We: An International Journal of Science and Technology* **6**: 95-100.
- Kumar, P., Desai, A.R., Arunachalam, V., Gupta, M.J., Paramesha, V., Rajkumar, R.S., Maneesha, S.R., Srikanth, G.B., Mahajan, G.R., Desai, S., Shishira, D. and Janjal, A.V. 2021. A conceptual framework for agro-ecotourism development for livelihood security. *Indian Journal of Agronomy* **66** (5th IAC Special issue): S184-S190.
- Lin, B. B. 2007. Agroforestry management as an adaptive strategy against potential microclimate extremes in coffee agriculture. *Agricultural and Forest Meteorology* **144**: 85-94.
- Mandal, K. G., Thakur, A. K., Mohanty, R. K., Mishra, A., Sinha, S., & Biswas, B. 2022. Policy perspectives on agricultural water management and associated technologies suitable for different agro-climatic zones of West Bengal, India. *Current Science* **122**: 386.

- Mbow, C., Van Noordwijk, M., Luedeling, E., Neufeldt, H., Minang, P. A. and Kowero, G. 2014. Agroforestry solutions to address food security and climate change challenges in Africa. *Current Opinion in Environmental Sustainability* **6**: 61-67.
- Momin, B. G., Dhara, P. K. and Tarafdar, P. K. 2017. Differential responses of arable crops with gamhar (*Gmelina arborea*) and mango (*Mangifera indica*) based agroforestry system in red and lateritic soils of West Bengal, India. *Indian Journal of Agricultural Research* **51**: 86-89.
- Murmu, S., Chowdary, K., Roy, D., Patra, B., & Dhara, P. 2018. Productivity and soil fertility status of mango-based agroforestry system in red and laterite zone of West Bengal *Current Journal of Applied Science and Technology* **25**: 1-8.
- Nair, P. K. R., Gordon, A. M., and Mosquera-Losada, M.-R. (2008). Agroforestry. (in) *Encyclopedia of Ecology* (S. E. Jorgensen and B. D. Faith, eds.) **1**: 101– 110. Elsevier, Oxford, UK
- Nair, P. K. R., Kumar, B. M., and Nair, V. D. 2009. Agroforestry as a strategy for carbon sequestration. *Journal of Plant Nutrition and Soil Science* **172**: 10–23
- Nair, P. R. 2011. Methodological challenges in estimating carbon sequestration potential of agroforestry systems. *Carbon sequestration potential of agroforestry systems: opportunities and challenges*, 3-16.
- Nair, P.K.R., 2007. The coming of age of agroforestry. *Journal of the Science of Food and Agriculture* **87**: 1613–1619
- Nath, J. C. 2002. Prospects of Coconut Based High Density Multistoreyed Cropping in Assam. *Indian Coconut Journal* **33**: 10-11.
- National Agroforestry Policy. 2014. Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, 1–13
- 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 Bioscience and Biotechnology* **7**: 189-199.
- Niyas, P., Kunhamu, T. K., Ali, S. K., Jothisna, C., Aneesh, C. R., Kumar, N., and Sukanya, R. 2016. Functional diversity in the selected urban and peri-urban homegardens of Kerala, India. *Indian Journal of Agroforestry* **18**: 39-46.
- Pala, N.A, Sarkar, B.C., Gokhale, Y., Abha Manohar K, 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.
- Panda, N. K., Sarangi, S. K., Das, H. K. and Kar, M. R. 2020. Role of coconut (*Cocos nucifera*) based agroforestry system in coastal Odisha. *Journal of Pharmacognosy and Phytochemistry* **9**: 1742-1745.
- Pathala, D., Harini, A. and Hegde, P. L. 2015. A review on gambhari (*Gmelina arborea* Roxb.). *Journal of Pharmacognosy and Phytochemistry* **4**: 127-132.

- Ricketts, T. and Imhoff, M. 2003. Biodiversity, urban areas, and agriculture: Locating priority ecoregions for conservation. *Conservation Ecology* **8**: 1.
- Roy, M., Sarkar, B.C., K Abha Manohar, Shukla, G., Vineeta, Nath, A.J. Bhat, J.A. and Chakravarty S. 2022. Fuelwood species diversity and consumption pattern in the homegardens from foothills of Indian Eastern Himalayas. *Agroforestry Systems* **96**: 453-464.
- Sarkar, B. C., Shukla, G., Debnath, M. K., Pala, N. A. and Chakravarty, S. 2020. Diversity and utilization pattern of homegardens: A case study from Eastern Himalayan region of West Bengal. *Indian Journal of Agroforestry* **22**: 31-36.
- Sharma, H. R. and Sharma, E. 1997. Mountain agricultural transformation processes and sustainability in the Sikkim Himalayas, India.
- Shrestha J, Prasai HK, Timsina KP, Shrestha KP, 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 Program, Pakhribas, Dhankuta, Nepal.
- Singh, K.A., Rai, R.N., Patiram and Bhutia, D.T. 1989. Large cardamom (Roxb.) plantation: An age old agroforestry system in eastern Himalayas . *Agroforestry systems* **9**: 241-257.
- Slingo, J. M., Challinor, A. J., Hoskins, B. J. and Wheeler, T. R. 2005. Introduction: food crops in a changing climate. *Philosophical Transactions of the Royal Society B: Biological Sciences* **360**: 1983-1989.
- Soemarwoto, O. (1987). Homegardens: a traditional agroforestry system with a promising future. (in) *Agroforestry: A Decade of Development* (Steppeler, H. A. and Nair P. K. R. eds.), ICRAF, Nairobi Kenya, 157-172.
- Steffan-Dewenter, I., Kessler, M., Barkmann, J., Bos, M. M., Buchori, D., Erasmí, S. and Tscharntke, T. 2007. Tradeoffs between income, biodiversity, and ecosystem functioning during tropical rainforest conversion and agroforestry intensification. *Proceedings of the National Academy of Sciences* **104**: 4973-4978.
- Subba, L. M., Pala, N. A., Shukla, G. and Chakravarty, S. 2016. Inventory of flora in home gardens of sub-humid tropical landscapes, West Bengal, India. *International journal of Usuf. Management* **17**: 47-54.
- Subba, M., Pala, N.A., Shukla, G. and Chakravarty S. 2015. Provisioning type ecosystem services from home gardens in Terai and Hilly region of West Bengal, India. *Journal of Agriculture and Technology* **2**: 32-37.
- Swaminathan, M.S. 1981. Building a national food security system. New Delhi: *Indian Environmental Society*.
- UNFCCC 2007. Report of the conference of parties on its thirteenth session, Bali, Indonesia. United Nations framework convention on climate change, Geneva

- Vanlalngurzauva, T., Dhara, P. K., Banerjee, H. and Maiti, S. 2010. Growth and productivity of different intercrops grown under Gamhar (*Gmelina arborea*) based agroforestry system. *Indian Journal of Agroforestry* **12**: 105-108.
- Vineeta TB, Siril S, Singh M, Das S, Shukla G, Chakravarty S. 2021. Ecosystem services of traditional large cardamom-based agroforestry systems of Darjeeling and Sikkim Himalayas. *Journal of Tree Sciences* **40**:78-91.
- Vineeta, Sarkar, B.C., Tamang, M., Shukla, G., Debnath M.K., Nath A.J. and Chakravarty S. 2022. Floristic diversity, and conservation status of large cardamom based traditional agroforestry system along an altitudinal gradient in the Darjeeling Himalaya, India. *Agroforestry Systems* **96**: 1199-1210.
- Vineeta, Tamang, B., Shukla, G. and Chakravarty S. 2023. The urge of conserving tradition from climate change: A case study of Darjeeling Himalayan large cardamom-based traditional agroforestry farming system. *Nature-Based Solutions* **3**: <https://doi.org/10.1016/j.nbsj.2023.100064>.
- Wiersum, K. F. 1999. *Social forestry: changing perspectives in forestry science or practice?*. Wageningen University and Research.
- Yadav G S, Kandpal B K, Das A, Babu S, Mohapatra K P, Devi A G, Devi H L, Chanda P, Singh R and Barman K A. 2021. Impacts of 28 yeras old agroforestry systems on soil carbon dynamics in Eastern Himalayas. *Journal of Environmental Management* DOI: 10.1016/j.jenvman.2021.111978.