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Potential of Agri-horti and agro-forestry systems for sustainability

Dr. Krishna D Kurubetta, Dr. Kumar CJ and Dr. Sourabh Munnoli

Abstract
In the post green revolution era, agro-horti and agro-forestry systems are becoming prominent areas within the agriculture sector to ensure food, wood, shelter, nutrition, and environmental security and it begins and ensures for the evergreen revolution. Compared to shifting agriculture, which results in higher annual runoff and soil loss (7.0% and 40.9 t ha^{-1}, respectively), agri-horti system will experience lower runoff and soil loss (3.5% and 3.0 t ha^{-1}, respectively). By producing maximal biomass (127.0 t ha^{-1}) and carbon stock (60.32 t C ha^{-1}), the mango+wheat intercropping system may contribute to greater CO_2 mitigation (221.37 t ha^{-1}) in the atmosphere. It will improve biodiversity; in an intercropping system of citrus and maize, the number of coccinellid beetle predators, resulting in a considerable decrease in infestation of citrus leaves. Ber, fenugreek and okra produced better economic returns than other combinations, with the highest gross returns (₹ 9,82,275 ha^{-1}) and net returns (₹ 8,09,215) and BCR (4.68) compared to other intercropping systems.

Keywords: Agri-horti, Agro-foresrty, Sustainability, Tree based farming

Introduction

India has a severely unbalanced natural resource base, supporting around 18% of the world's human population and 15% of its animal population on 2.4 percent of its land area, 1.5 percent of its pasture and forest areas, and 4.2 percent of its water resources. Because the expansion of the farm sector in the post-reform period has not outpaced that of the 1980s, there are grave worries over the country's agricultural sector's performance. Over the past ten years, this industry has grown at a rate of less than 2 per cent annually due to the production of main food crops reaching a plateau. The weather and climate of India have a significant impact on agriculture. Farmers are already leaving agriculture owing to the inadequate earnings and great risk associated with weather fluctuations. Even though Indian agriculture has evolved throughout time, climate change is currently having a detrimental impact on the sector as a whole. Therefore, it is anticipated that there would be a significant danger to growing food grain production and satisfying the growing population's needs for food, fibre, fuel, and fodder (Inder Dev *et al.*, 2018) [13]. The primary environmental crises are caused by climate change, global warming, floods, droughts, forest fires and other events. Recent increases in forest fires have resulted in a sharp decline in the amount of land covered by forests. Deforestation is the primary cause of many global problems, including food security, biodiversity loss, resource depletion and global warming (Fig. 1).

What is the solution?

Every common man says that planting a tree or greening the earth is the ultimate solution. The major problem arises here is, how to increase the area under forest? As the area available is very limited. Hence, the tree based farming like Agri-horticulture and Agro-forestry is the best alternate option to increase the area under trees.

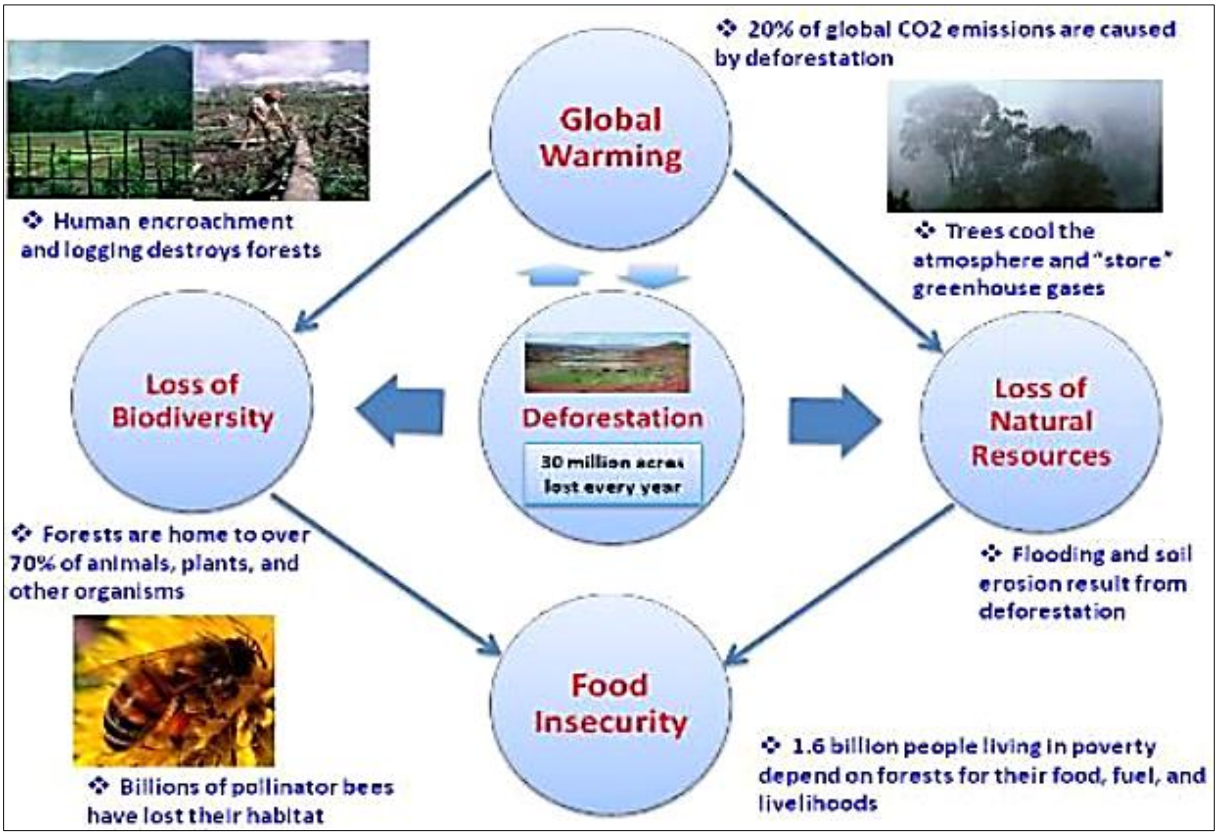

Fig 1: Impact of Deforestration

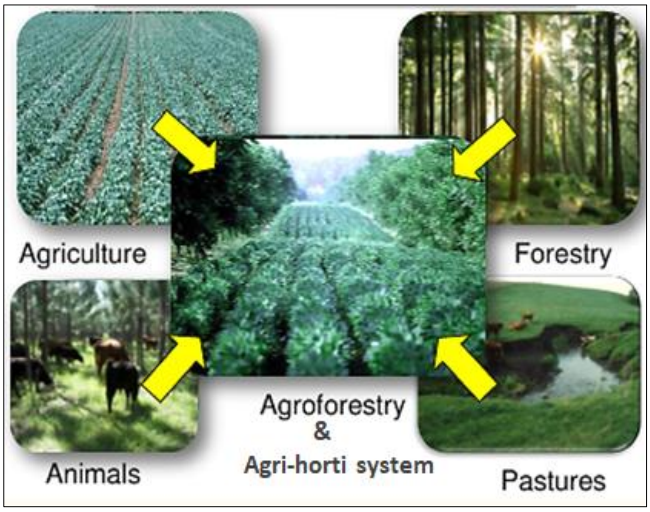

Fig 2: Components of Tree based farming

Indians have long used agroforestry as a means of subsistence and a way of life. According to Dhyani *et al.* (2016) [10] and CAFRI Vision (2015 & 2020) [6], expanding the nation's agroforestry sector can aid in addressing a few of the most significant issues brought on by climate change. The relevance of agroforestry is being further bolstered by projections of decreasing land under agriculture and rising need for food grain and fuel (twice), fodder (twice), and wood output (thrice). Agroforestry not only provides environmental advantages but also fulfils about half of the need for fuel wood, 65 per cent for small timber, 70–80 per cent for wood for plywood, 60 per cent for raw material for paper pulp, and 9–11 per cent for green cattle fodder (NRCAF 2013) [19]. In addition to providing a means of subsistence for its practitioners, agroforestry offers a range of ecosystem services, including the provision of food, fuelwood, fodder, timber, poles, and other materials; hydrological benefits and microclimatic modifications; nutrient cycling and agro-biodiversity conservation; and cultural services like recreation and aesthetics (Fig. 2). Since organised agroforestry research became a global endeavour, the nation has likewise been in the forefront. According to CAFRI Vision (2015) [6], it produced strong agroforestry research, inventions, and practises that are gaining attention across the world. Particularly in the wake of the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), agroforestry in poor countries has gained a lot of attention for its ability to solve a variety of issues and provide a range of socioeconomic, environmental, and economic advantages. Agroforestry can be a useful tool for increasing agricultural resilience, reducing vulnerability, and protecting families from extreme weather events (Dhyani 2014) [9].

Definition

- **Agroforestry**: it is a land use system which integrate trees and shrubs on farmlands and rural landscapes to enhance productivity, profitability, diversity and ecosystem sustainability.
- **Agri-horti system**: This system is defined as growing of agriculture crops and fruit trees or ornamental trees or vegetables/flower together in same lands at the same time.

In order to conserve forest resources and encourage sustainable agricultural production, the idea of Trees Outside Forests (TOF) or agroforestry, first surfaced in the early 1990s. It is a comprehensive strategy that includes an integrated tree-based farming system on farmlands and pasturelands. A total of 7,12,249 square kilometres, or 21.67% of the country's land area, are thought to be covered with trees (ISFR 2019) [14].

Agro-Forestry Area In India

In India, agroforestry is practiced 25.32 million ha (Dhyani *et al.*, 2013) [8].

- Uttar Pradesh (1.86 m ha),
- Maharashtra (1.61 m ha)
- Rajasthan (1.55 m ha)
- Karnataka – (0.93 m ha)

It is anticipated that the area covered by trees, or "Tree Outside Forests," would rise significantly over the next 40 years, with agroforestry accounting for a significant share of this growth. According to the Task Force on Greening India (Planning Commission, 2001), an additional 28 million hectares of agroforestry have been set aside for this purpose, along with another 18 million hectares of rainfed land and 10 million hectares of irrigated but problematic fields.

Advantages of Tree Based Farming

1. Soil fertility and closed nutrient cycles

Trees have a mechanism for recycling nutrients. Although the main recycling occurs when leaves decompose and roots rot, deep-rooted plants draw nutrients from the lower soil depths, increasing the nutrient content of the top soils. By fixing nitrogen from the atmosphere, legume-producing plants, shrubs, and trees help improve the soil (Fig.3)

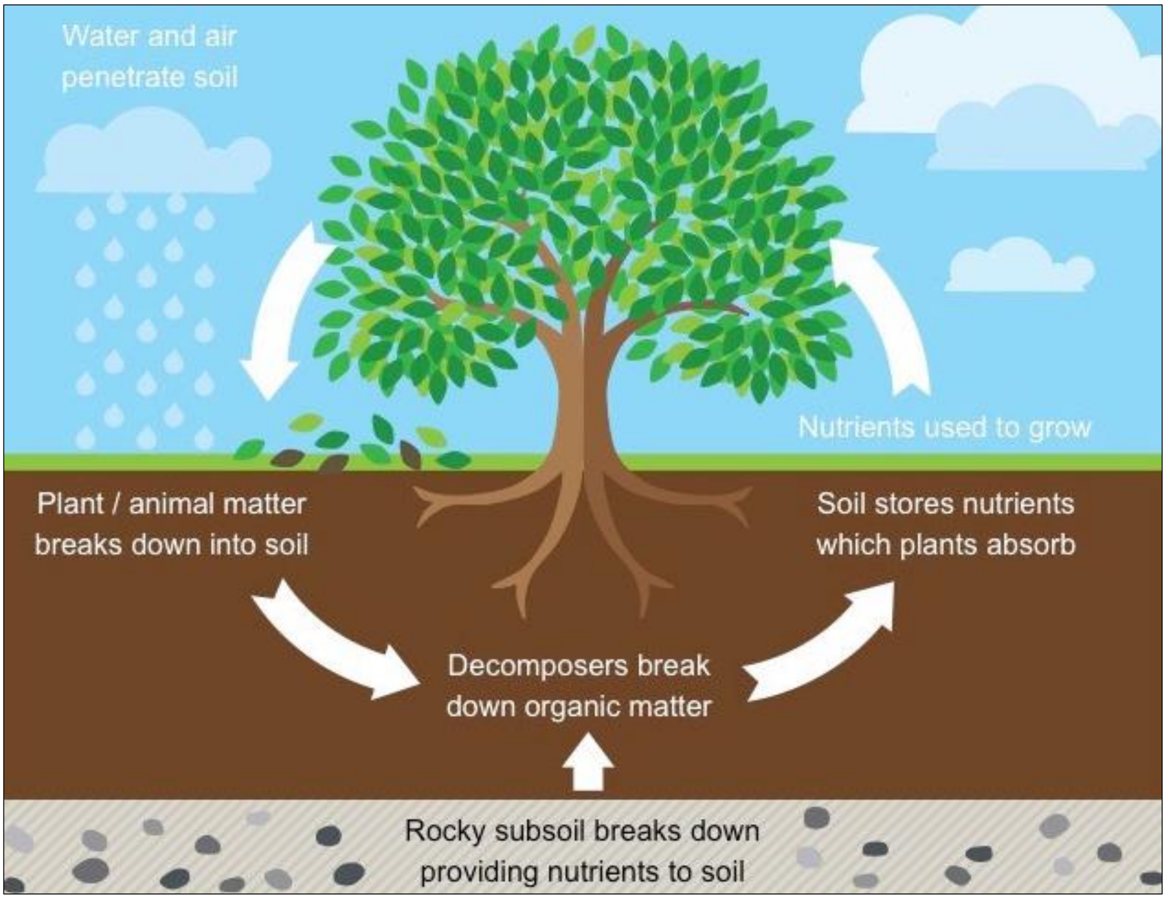

Fig 3: Nutrient recycling by the trees

2. Soil salinity management
3. Prevention of runoff and better water management

This farming method helps prevent landslides and erosion of the soil. The most environmentally friendly option, agroforestry, safeguards the environment and natural resources—a vital necessity in this day and age.

4. Stabilization of soils and microclimate
5. Low input of agrochemicals
6. Improvement of wildlife and pollinator habitat
7. Remediation of polluted soils
8. Provision of diverse products and poverty reduction

Provide firewood, timber and other associated non-wood forest products that farmers want, especially in dry and semi-arid areas. avoidance of forest harm. Youth in rural areas can find work producing animals, collecting, processing, and manufacturing value-added goods from grasses and trees if agroforestry systems are used. In a drought, it addresses the hazards faced by farmers. When rainy seasons cause one crop to fail, others prosper.

9. Climate change mitigation

Difficulties of Tree Based Farming

1. Labour intensive system
2. Long waiting time
3. Allelopathy

System for soil, water conservation and soil fertility

According to Dhyani *et al.* (2007) [11], the ICAR Research Complex for North-Eastern Hill Region, Umiam (Meghalaya) created alternatives to shifting cultivation agroforestry systems in the area's red loamy soil by using local resources and conservation-based techniques. With the help of the natural resources in the area, alternative land-use systems including horticulture, forestry, agroforestry, and agriculture have been planned for almost the same hydrological behaviour as the natural system. When appropriate conservation measures were implemented, agriculture produced very little runoff (3.5–5.8%) and soil loss (2.3–3.0 t ha^{-1}), which was significantly less than the 40.9 t ha^{-1}of soil loss that was seen in the conventional shifting cultivation regions in Table 1. Using slopes below 50% for agricultural crops and pisciculture in lower foothills and valley lands, medium slopes between 50% and 100% for horticulture and top slopes above 100% for forestry/silvipastoral enterprises are the recommended land-use strategies according to the model.

Table 1: Erosion losses from different farming systems in the North-Eastern Hill region

Erosion losses	Shifting cultivation	Agri- horticulture	Agriculture with bench terracing
Runoff (mm)	114	57	95
Runoff (%)	7.0	3.5	5.8
Soil loss, t ha^{-1}	40.9	3.0	2.3
Organic carbon (kg ha^{-1})	698.0	40	34
Available P_2O_5 (kg ha^{-1})	0.15	0.02	0.01
Available K_2O (kg ha^{-1})	7.10	0.50	0.05

(Dhyani *et al*,. 2007) [11]

At the Machakos Research Station in Kenya, Paul Kiepe (1995) [20] carried out an experiment on runoff (mm) and soil loss (t ha-1) over the course of six seasons on sandy clay loam soil. On a 14% slope in a maize field, four 10 x 40 m runoff plots were established, and cassia (*Cassia siamea* L.) was planted as a hedge row (Fig. 4). Measurements of runoff and soil loss were made following each erosion episode, starting in March 1990. Four treatments make up the experiment: T_1 is the control, T_2 is mulch only, T_3 is hedge, and T_4 is mulch plus hedge. T_4 hedge + mulch recorded the lowest annual mean runoff (3.9 mm) among the four treatments (Table 2), mostly because the hedge lowers the runoff's velocity.

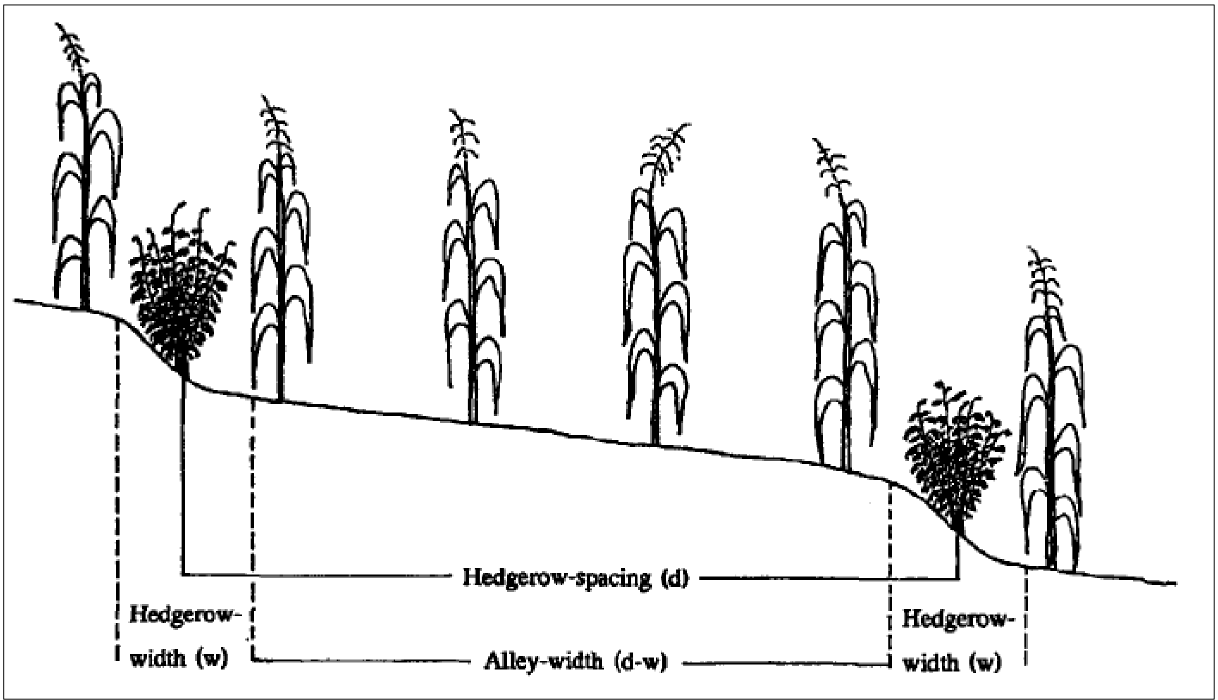

Fig 4: Hedge row planting of *Cassia* in maize crop

Table 2: Runoff (mm) over six seasons at Machakos Research Station

Season	Rain (mm)	Control	Mulch-only	Hedge only	Hedge + Mulch
LR 1990	631	3.2	2.5	1.3	0.8
SR 1990	333	1.0	0.6	0.4	0.5
LR 1991	214	1.7	0.4	0.2	0.2
SR 1991	352	13.0	4.0	0.9	0.4
LR 1992	222	11.2	0.7	0.7	0.4
SR 1992	808	64.1	30.5	17.8	9.5
Ann. Mean	853	31.4	12.9	7.1	3.9

(Paul Kiepe, 1995) [20]

Table 3: Soil loss (t ha^{-1}) over six seasons at Machakos Research Station

Season	Rain (mm)	Control	Mulch- only	Hedge-only	Hedge + Mulch
LR 1990	631	36.1	4.6	2.2	0.2
SR 1990	333	0.0	0.0	0.0	0.0
LR 1991	214	0.0	0.0	0.0	0.0
SR 1991	352	5.4	1.1	0.0	0.0
LR 1992	222	3.8	0.0	0.0	0.0
SR 1992	808	12.6	4.1	1.6	1.2
Ann. Mean	853	19.3	3.3	1.3	0.5

(Paul Kiepe, 1995) [20]

According to Australian researchers Nick Schofield and Phil Scott (1991) [18], trees have a role in regulating the salt of the soil. Plants with deep roots assist to keep the water table below the rhizophere (Fig. 5). Rising ground water also dissolve salt that typically accumulates in the soil profile and deposits on the soil's surface. Salt is mostly composed of sodium chloride. More rainfall seeped through the plant root zone and replenished groundwater systems as a result of the annual, shallow-rooted agricultural plants replacing the permanent, deeply rooted native vegetation (Plate 1). Salt has been building up in the soil for thousands of years. Seeps in the hillside and valley floor allow the rising, saline groundwaters to finally reach the soil's surface. Higher rainfall locations could see this happen in a few years, whereas lower rainfall areas would need 50 years or longer. The substitution of annual, shallow-rooted agricultural plants for the natural vegetation's by perennial and deeply rooted counterparts.

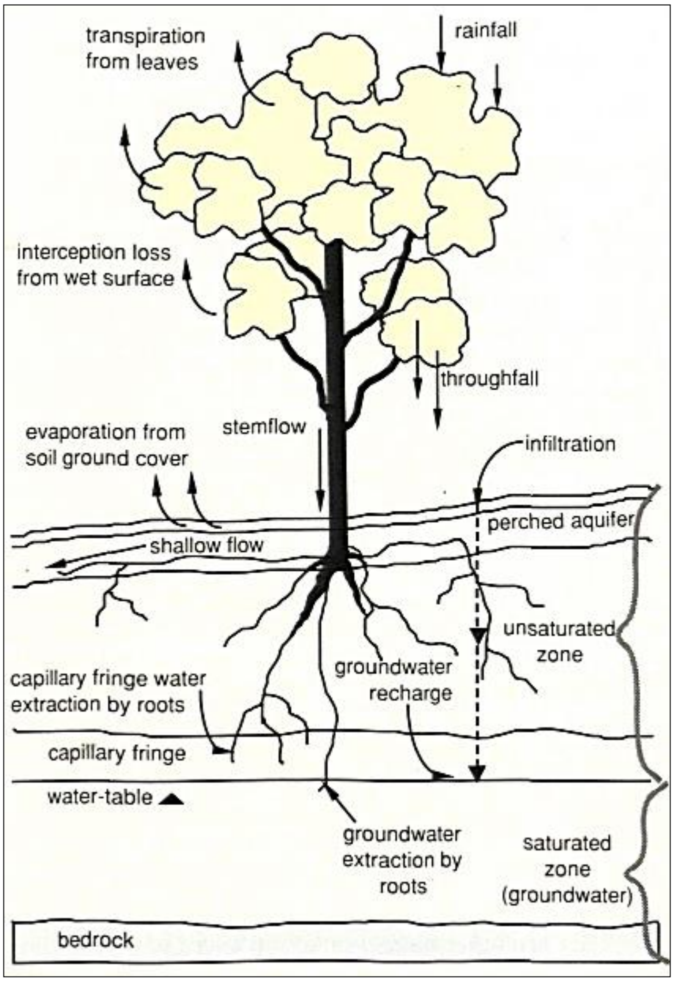

Fig 5: Schematic diagram showing the interaction of trees with groundwater.

Plate 1. Perennial removed places accumulated with salt at Australia

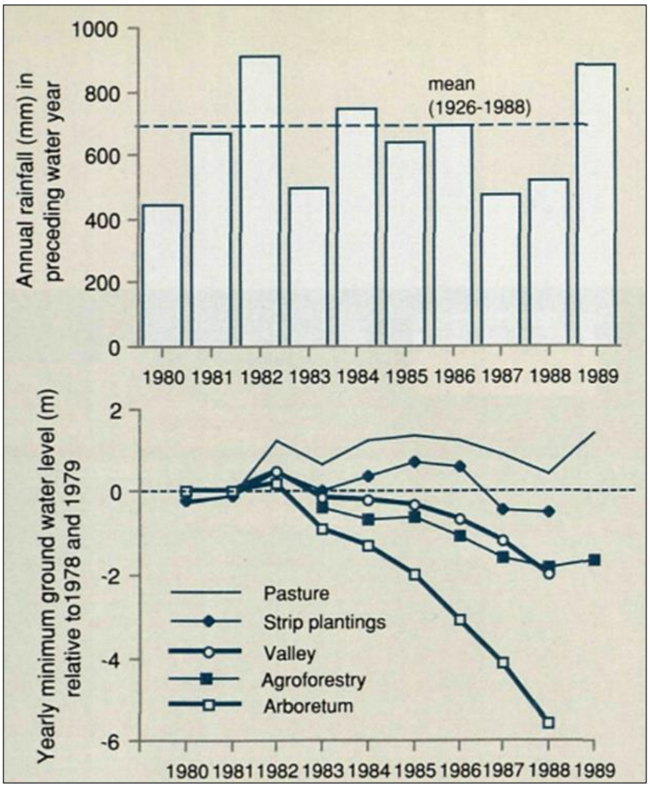

Fig 6: Groundwater level changes relative to the ground surface and pasture for various reforestation strategies at Stene's farm. (Nick Schofield and Phil Scott, 1991) [18S]

The study (Fig. 6) showed that, among the various land use patterns, the agroforestry system maintained the ground water level well below (1.5 to 2.0 m) the rhizopshere of annual crops, which in turn reduced the amount of salt deposition on the soil's surface. These areas at Stene's farm in Australia receive an average of 700mm of rainfall per year.

According to a research done in Vijayapura, Das and Itnal (1994) [30] found that, as compared to sole cropping, the soil organic carbon content was greater in the soil under agroforestry, agro-horticulture, and agro-silviculture systems (Table 4). Comparing the agro-horticulture system to a solo cropping system, the organic carbon content at the 0–15 cm (0.73%) and 15–30 cm (0.74%) depths is greater.

Table 4: Organic carbon content in soil after six-years of plantation with different land use options

Systems	Organic C (%)	
	0-15 Cm	15.30 Cm
Sole cropping	0.42	0.37
Agroforestry	0.71	0.73
Agro-horticulture	0.73	0.74
Agro-silviculture	0.68	0.67

(Das and Itnal, 1994) [30]

Anusha (2012) [3] studied the effectiveness of fingermillet and carbon sequestration in an agroforestry system at GKVK, Bangaluru (Table 5). The enduring elements comprised the following: MA: *Melia azedarachta*, PP: *Pongamia pinnata*, ML: *Madhuca latifolia*, CI: *Calophyllum inophyllum* and filed crop, FM: Fingermillet.

According to her study, planting a tree had a positive impact on the chemical composition of the soil, but growing a single crop had no such effect. The slower rate of decomposition of litter and the consequent release of organic acids is the reason why *Pongemia pinnata*, *Melia dubia*, and *Simarouba* had the lowest soil pH values among species of trees. The soil under every type of tree had a higher organic carbon concentration than a single crop. The highest organic carbon was recorded in *Pongemia pinnata* (0.65%) due to higher litter fall.

Table 5: Soil pH and nutrient status under different finger millet based agroforestry system

Treatment	Soil p^H	Soil organic carbon (%)	Available nitrogen (kg ha^{-1})	Available phosphorus (kg ha^{-1})	Available potassium (kg ha^{-1})
Initial values	6.18	0.60	320.0	38.49	240.90
T_1: SG+FM	5.85	0.62	321.92	24.59	310.69
T_2: MD+FM	5.85	0.64	322.58	24.96	324.88
T_3: AI+FM	5.99	0.57	304.68	22.93	295.00
T_4: MA+FM	5.89	0.58	311.67	23.04	307.83
T_5: PP+FM	5.84	0.65	329.75	26.50	347.49
T_6: ML+FM	6.05	0.51	269.58	21.08	246.58
T_7: CI+FM	6.04	0.54	297.98	21.37	294.68
T_8: Sole crop	6.20	0.49	248.33	19.67	223.87

(Anusha, 2012) [3]

At the Hawalbagh Experimental Farm, ICAR-VPKAS, Almora, Uttarakhand, Mondal *et al.* (2018) [31] conducted an experiment on the soil enzymes, indicator for soil health under fruit-based agri-horti system (Table 6). The objective of the study was to determine the impact of different fruit trees, namely plum, pears, lemons, and apricot, on various soil enzymatic activities, such as urease, beta-glucosidase, phosphomonoesterase (acid and alkaline phosphatase), dehydrogenase, and beta-glucosidase, in comparison to the control (without fruit tree).

The study involved the random collection of soil samples from four temperate fruit crops located in the field at two different distances from trees (0-1 and 1-2 m) and at two different depths (0-15 cm and 15-30 cm). The study's findings on the varying responses of enzyme activity in soils from fruit crops and open plantation control plots. Enzymatic activity decreased as soil depth and plant distance increased, despite the fact that these fruit crops have deep roots. In the experimental field, there were four different fruit trees. The plum, pear, and apricot plantations had the highest soil enzymatic activity.

Table 6; Different soil enzyme activities in the fruit based agri-horti system of different fruit crops, at surface soil (0-15 cm)

Land use	Radius (m)	Acid Phosphatase (mg PNP/g soil/hr)	Alkaline phosphatase (mg PNP/g soil/hr)	Dehydrogenase (lig soil/hr) TPF/g	Urease (mg urea/kg soil/hr)	Beta-glucosidase (mg PNG/g soil/hr)
Plum	0-1	444.72 ± 7.07[a]	244.80 ± 5.40[a]	68.84 ± 1.09[a]	398.14 ± 0.04[b]	451.71 ± 12.13[a]
	1-2	369.24 ± 4.08[c]	200.60 ± 8.02[c]	56.89 ± 0.54[b]	398.02 ± 0.04[c]	395.37 ± 7.95[b]
Pear	0-1	382.16 ± 11.56[bc]	193.80 ± 5.40[c]	55.70 ± 0.69[b]	397.85 ± 0.04[d]	411.89 ± 5.14[b]
	1-2	274.72 ± 6.04[f]	163.20 ± 7.72[d]	45.53 ± 1.33[e]	397.72 ± 0.04[e]	368.17 ± 6.80[c]
Lemon	0-1	363.80 ± 13.24[cd]	157.76 ± 6.70[d]	48.98 ± 1.00[d]	398.44± 0.07[a]	349.71 ± 5.83[cd]
	1-2	224.40 ± 3.12[g]	128.52 ± 2.04	38.76 ± 0.36[f]	397.79 ± 0.02[de]	330.29 ± 5.14[d]
Apricot	0-1	396.44 ± 4.46[b]	219.64 ± 3.60[b]	52.13 ± 0.57[c]	397.89 ± 0.03[d]	391.49 ± 7.59[b]
	1-2	298.52 ± 8.84[e]	114.92 ± 1.80	37.63 ± 0.57[f]	397.34 ± 0.02[f]	333.20 ± 9.71[d]
Open	0-1	344.08± 5.93[d]	186.32 ± 2.96[c]	45.95 ± 1.02[e]	398.35 ± 0.05[a]	331.26 ±7.01d

(Mondal *et al.*, 2018) [31]

Effective tool for mitigating climate change

One of the most risks to agriculture is thought to be climate change and variability, especially for developing nations where a sizable portion of the population depends on the agricultural sector (IPCC fifth assessment report). According to Ray *et al.* (2019) [22], there is a prediction that the consumption of food calories in prominent crops in numerous developing nations may decrease by up to 1% due to rising temperatures, variability, and severe occurrences. In addition to minimising greenhouse gas emissions and improving carbon sequestration, climate smart agriculture strives to increase agricultural production in a sustainable manner. Agroforestry techniques may be a viable choice in these circumstances to help the farmers maintain their standard of living. Agroforestry is a land-use system that can significantly improve all three of these factors, strengthening the system's resilience to the negative effects of climate change (Dhyani *et al.* 2016) [10].

In 2018, Moreira *et al.* [16] investigated how lowering the maximum air temperature and photosynthetic active radiation in an agroforestry system using the local macauba (*Acrocomia aculeata*) species may lessen effects on coffee output. This study set out to examine the effects of an agroforestry system utilising macauba on soil physical quality, production and microclimatic features on a cooperative plantation located in the Atlantic Rainforest biome in Southern Brazil. The microclimate circumstances (air temperature, photosynthetic active radiation) and the cofactor production parameters (productivity and yield) were assessed (Table 7). Various planting densities and separations from the next rows were used to plant Macauba palm trees. The treatments viz., T_1 - Coffee grown at 1.4 m from macauba and T_2 - Coffee grown at 4.2 m from macauba with high row density 318 shade trees per ha. T_3 - Coffee grown at 1.4 m from macauba and T_4 - Coffee grown at 4.2 m from macauba with low row density 203 trees per ha. T_5 - Coffee grown open condition (control). The planting density of macauba and their distance from the coffee rows affected soil thermal-water regime. Compared with the traditional unshaded sole coffee planting, the intercropped cultivation provided more coffee yield on both macauba density planting and distance evaluated. However, only a 4.2 m gap between palm trees and coffee rows (Fig. 7) was sufficient for agroforestry systems to boost coffee yield. Cooperative yield and productivity were unaffected by macaubas' planting density. Maximum air temperatures below 30 °C and greater photosynthetic active radiation were associated with the best co-worker harvest in macauba-based agroforestry systems. Future climate unpredictability and change linked to high temperatures and little rainfall may need the use of agroforestry with coffee and macauba trees as an adaptation technique.

Table 7: Air temperature average from April to August in intercropped with macaubas (shade tree)

Temperature (°C)	T_1	T_2	T_3	T_4	T_5
Maximum	28.4± 2.8	28.8 ± 3.1	28.7 ± 3.0	30.0 ± 3.0	31.3 ± 3.9
Minimum	11.9 ± 3.5	11.9 ± 3.6	12.1 ± 3.6	12.2 ± 3.5	11.0 ± 3.8
Mean	20.2± 2.0	20.3 ± 2.3	20.4 ± 2.1	21.1 ± 2.2	21.2 ± 2.4

(Moreira *et al.*, 2018) [16]

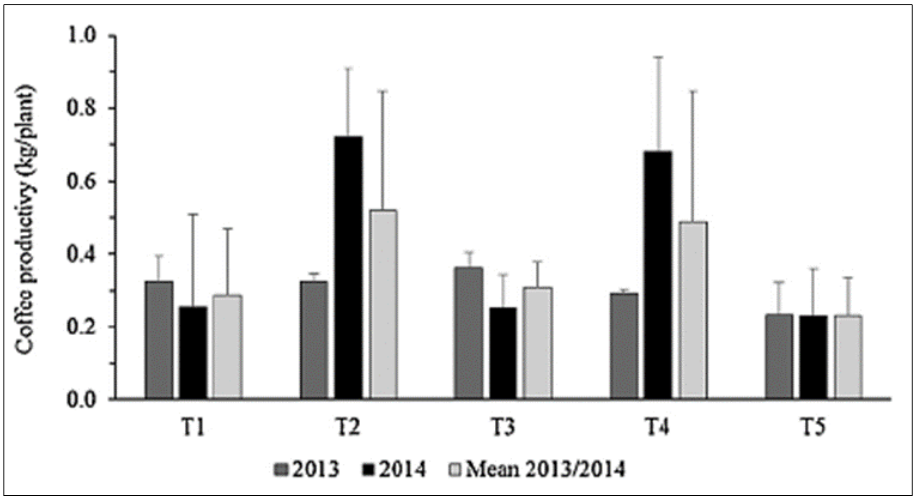

Fig 7: Response of air temperature on coffee processed beans yield per plant

The experiment on the impact of shade tree cover on cocoa plantations was carried out by Blaser *et al.* (2018) [5]. The system's percentage of shadow cover varies from 10 to 80 percent (Fig. 8). The study's findings showed that, even at 30% cover, shade trees are unlikely to have a negative impact on the average yearly output of cocoa. This finding offers a technique to intensify agriculture in a sustainable way. Cocoa productivity decreases as shade-tree cover rises beyond 30%. The extent of these losses can also be noteworthy. Competition for light, water, and nutrients is probably what causes the yield to decline as shadow cover grows. A rise in the amount of shadow cover within the system has changed the microclimate, leading to a corresponding drop in temperature, rise in relative humidity, and an increase in the accumulation of carbon above ground in the plants (Fig. 9).

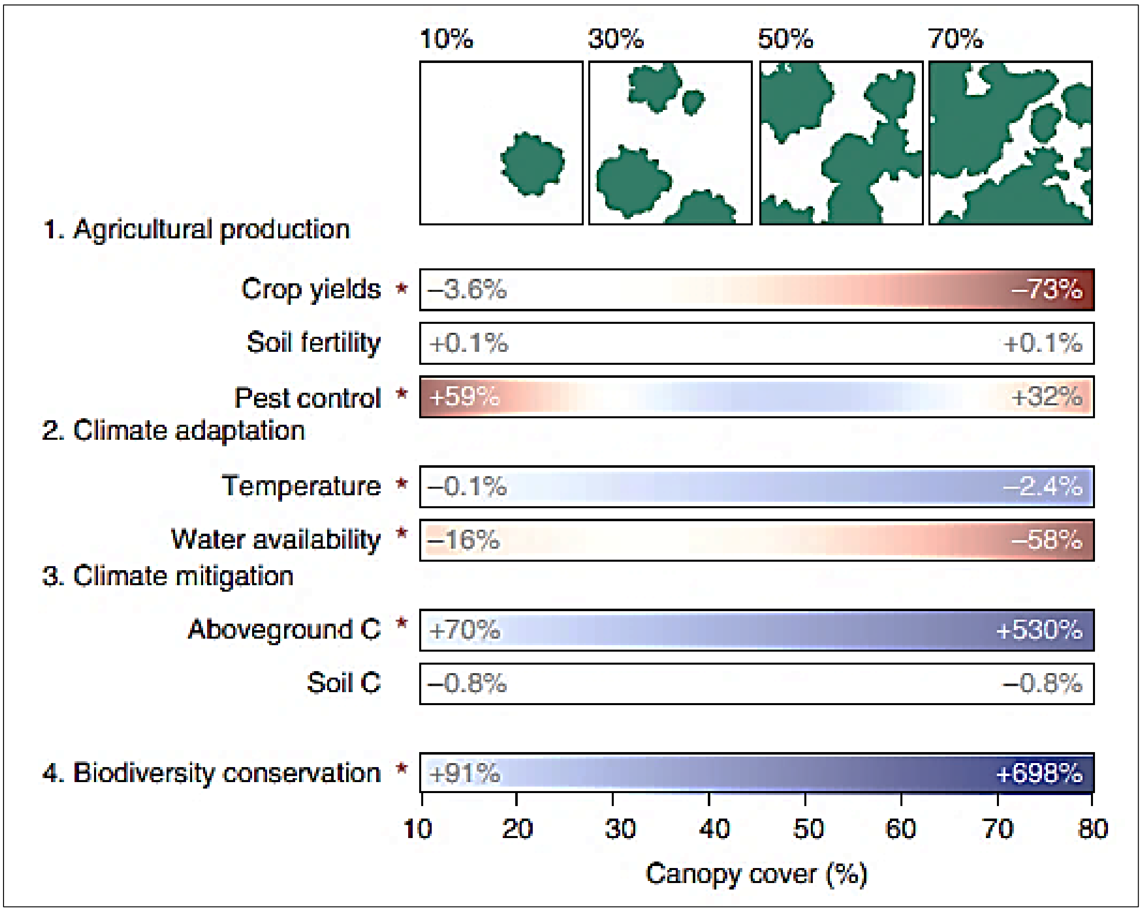

Fig 8: Effects of shade trees in mature cocoa farms (Blaser *et al.*, 2018) [5]

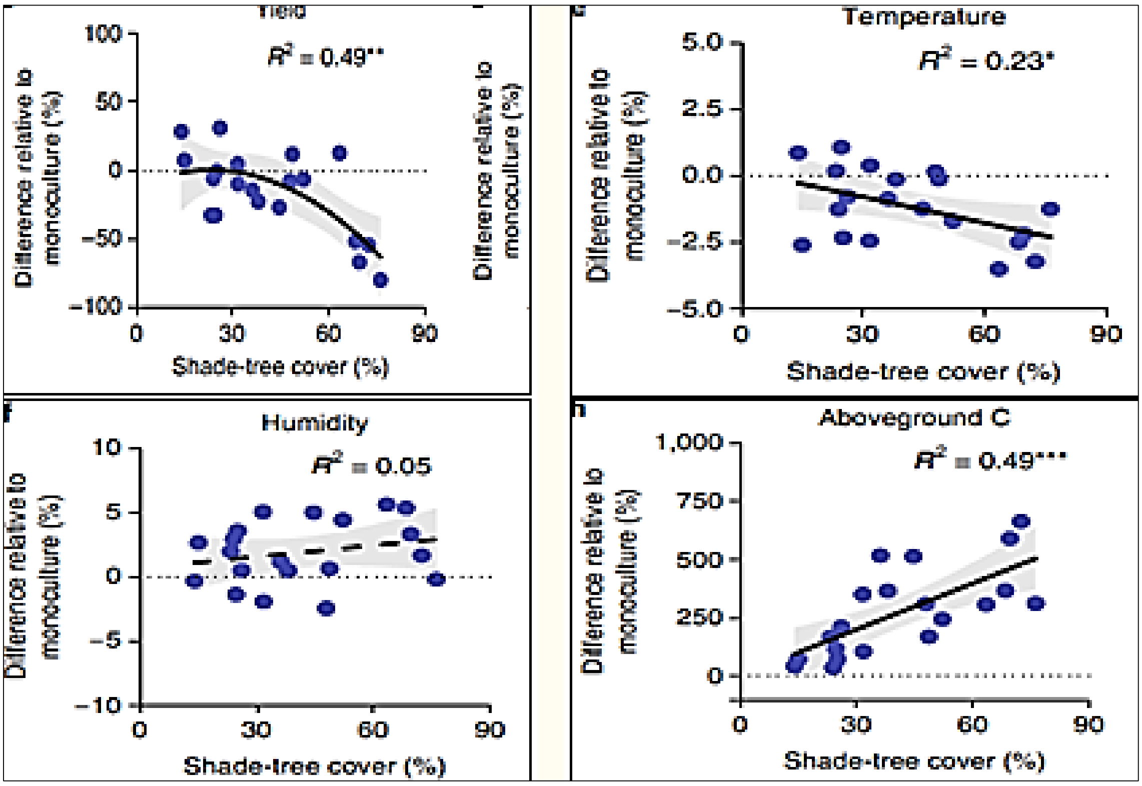

Fig 9: Effects of shade trees on yield and microclimate in mature cocoa farms (Blaser *et al.*, 2018) [5]

Singh and Singh (2015) [25] conducted a study that to compare carbon accumulation in both tree biomass and soil (0-30 cm in depth) in a six year old agri-silvi-horti system grown on a farmer field in arid region of Rajasthan (Table 8). Silvicultural species were *Prosopis cineraria* (PC), *Ailanthus excelsa* (AE) and *Colophospermum mopane* (CM) along with *Zizyphus mauritiana* (ZM), *Cordia myxa* (COM) and *Emblica officinalis* (EO) horticultural species planted alternate plant to each other. Wheat (*Triticum aestivum*) was planted as intercrop. Furthermore, controls were included for both crop and tree species separately. Compared to the other two species of silviculture, *P. cineraria*-based agroforestry had the largest average carbon stock. It was more common in agroforestry than in isolated horticultural and silvicultural species or agricultural areas. The findings indicate that while the soil carbon pool remained steady, the primary carbon sink in horti-silviculture is the wooden portions of trees, which increased with stand age.

Table 8: Carbon stock (Mg ha) in different agri-horti-silvi agroforestry systems

Sl No.	Species combination	Biomass ($Mg\ ha^{-1}$)	Biomass C ($Mg\ ha^{-1}$)	Soil C ($Mg\ ha^{-1}$)	Total C ($Mg\ ha^{-1}$)
1	*Z. mauritiana* + *P. cineraria*	2.85	1.25	2.25	3.50
2	*Z. mauritiana* + *A. excelsa*	1.03	0.46	2.70	3.16
3	*Z. mauritiana* + *C. mopane*	2.54	1.16	1.35	2.51
4	*Cordia myxa* + *P. cineraria*	3.36	1.47	3.60	5.07
5	*Cordia myxa* + *C. mopane*	1.51	0.66	0.91	1.57
6	*Cordia myxa* + *C. mopane*	3.16	1.43	3.15	4.58
7	*E. officinalis* + *P. cineraria*	2.55	1.12	1.80	2.92
8	*E. officinalis* + *A. excelsa*	0.81	0.36	2.26	2.61
9	*E. officinalis* + *C. mopane*	2.31	1.06	0.90	1.96
10	Sole *A. excelsa*	0.10	0.05	0.10	0.15
11	Sole *C. mopane*	0.30	0.13	0.31	0.44
12	Sole *P. cineraria*	0.36	0.15	0.36	0.51
13	Sole *Cordia myxa*	0.20	0.08	0.20	0.28
14	Sole *Z. mauritiana*	0.24	0.10	0.24	0.34
15	Sole crop (Wheat)	-	-	0.55	0.55

(Singh and Singh, 2015) [25].

The biomass, productivity, and carbon efficiency of the agri-horticulture system in the Central Himalayan Shiwalik plain were investigated by Adhikari *et al.* (2019) [1]. The above-ground section of the mango tree contributes 80% of the biomass output (Table 9) and carbon stock, whilst the below-ground portion contributes 20%. When compared to other components of the mango tree, the bole's contribution (35.96%) is the largest. The two cropping patterns used in the study were mango (*Mangifera indica*) + wheat (*Triticum aestivum*) and mango + black bhatt (*Glycine max*). The study was carried out in an agroforestry system based on mangos (Table 10). During the winter and rainy seasons, respectively, the pulse crop (black bhatt) and cereal crop (wheat) were grown beneath mango trees. The carbon and biomass stock above ground (127 t ha^{-1}) was at its greatest. The shared biomass and carbon stock of the agroforestry system (i.e., 6.24 and 1.58 t ha^{-1} biomass and 2.96 and 0.75 t C ha^{-1} carbon stock) between the wheat and black bhatt in the mango-based agri-horticulture system was 4.3% and 1.2%, respectively, smaller than that of the solo system. Overall, cropping system or crop mix was found to have an impact on biomass output and carbon potential. Agroforestry systems are also more carbon efficient and have a higher potential for biomass yield than solitary systems. Adopting such land uses therefore benefits producers financially and contributes significantly to carbon reduction on an ecological level.

Table 9: Component-wise efficiency of biomass, carbon stock and CO_2 mitigation of mango trees in agri-horticulture system.

Component	Biomass (t ha^{-1})	Carbon stock (t C ha^{-1})	CO_2 mitigation (t ha^{-1})	Percent contribution
Bole	54.65	25.96	95.01	35.96
Branch	46.57	22.12	80.96	30.65
Twig	8.63	4.10	10.91	5.68
Foliage	4.33	2.06	5.48	2.85
Reproductive part	7.39	3.51	12.48	4.86
Above-ground	121.57	57.75	211.36	80.00
Below-ground	30.39	14.44	52.85	20.00
Total	151.96	72.18	264.21	100.00

(Adhikari *et al.*, 2019) [1]

Table 10: Biomass, carbon stock and CO2 mitigation efficiency in above-ground part of agri-horticulture system

Parameters	Agri-horticulture (mango+ wheat)	Sole cropping (wheat)	Agri-horticulture (mango+black bhatt)	Sole cropping (black bhatt)
Biomass (t ha^{-1})				
Tree	121.57 (95.7)*	-	121.57 (98.8)	-
Crops	5.43 (4.3)	6.24	1.41 (1.2)	1.58
Total	127.00 (100)	6.24	122.98 (100)	1.58
Carbon stock (t C ha^{-1})				
Tree	57.74	-	57.74	-
Crops	2.58	2.96	0.67	0.75
Total	60.32	2.96	58.41	0.75
CO2-mitigation (t ha^{-1})				
Tree	211.90	-	211.90	-
Crops	9.47	10.86	2.46	2.75
Total	221.37	10.86	214.36	2.75

*Values in parentheses indicate the percent contribution.
(Adhikari *et al.*, 2019) [1]

In May and July of 2015, Bhagya *et al.* (2017) carried out a field experiment at ICAR-CPCRI, Kasaragod, Kerala, in a coconut garden with red sandy loam soil to investigate the impact of cropping system on above and below ground carbon sequestration in a 50-year-old plantation intercropped with fruit crops that were seven years old. In the rhizosphere of the various crops in the system, the data shown in Table 11 shows soil organic carbon (%), bulk density (g/cm3), and soil carbon stock (t/ha) at 0-30 and 31-60 cm depth. With respect to bulk density, there was no statistical significant difference among the different cropping system, and it was in the range of 1.58 to 1.64 g/cm^3. Among the different fruit crops and coconut, the highest soil organic carbon (0.56 and 0.41%) was recorded in coconut basin at 0-30 and 31-60cm depth, and it was followed by mango (0.43 and 0.31%), jamun (0.40 and 0.25%) and it was on par with garcinia (0.38 and 0.28%) and the lowest was recorded in interspaces (0.36 and 0.28%) where no crop is being grown. Among the different crops, coconut rhizosphere had sequestered more carbon (26.87 and 20.19 t ha^{-1}), followed by mango (20.52 and 14.89 t ha^{-1}), jamun (19.45 and 13.76 t ha^{-1}) and garcinia (18.31 and 12.18 t ha^{-1}) at 0-30 and 31-60 cm depth. The carbon sequestered in the interspace was the lowest (17.09 and 13.87 t ha^{-1}) at 0-30 and 31-60 cm depth, respectively might be due to absence of crops and management practices. Coconut basin rhizosphere had recorded high carbon stock at both depths (0-30 and 31-60 cm), which might be due to increase in organic carbon in the soil due to decomposition of root system over a period of time and organic manure incorporation to the coconut crop as compared to other crops and interaction effect of organic manure and green manure incorporation by sustainable practice.

The total carbon stock involving above and below ground is depicted in the Fig. 10. Total carbon stock recorded in the coconut + jamun system was the highest (140.06 t ha^{-1}) followed by coconut + mango (138.91 t ha^{-1}) and coconut + garcinia (131.72 t ha^{-1}) system, whereas, coconut monocrop recorded lower total C stock (98.2 t ha^{-1}). Higher C storage in the intercropping system was due to additional storage of carbon by these fruit intercrops. As depicted in Fig. 11, CO_2 sequestration recorded followed the same trend and it was the highest in coconut + jamun (514.00 t ha^{-1}) system followed by coconut + mango (509.80 t ha^{-1}), coconut + garcinia (483.39 t ha^{-1}) and the lowest (360.38 t ha^{-1}) was recorded in coconut mono-cropping system. This result is due to higher carbon storage by growing intercrops especially perennial crops as compared to mono-cropping system. Thus, by cultivating intercrops in the interspace of coconut, storage of carbon in the soil and above ground can be expected.

Table 11: Estimated soil carbon stock of coconut and different fruit crops.

Treatment	Organic carbon (%)		Bulk density (g cm^{-3})		Soil carbon stock (t ha^{-1})	
	0-30 cm	31-60 cm	0-30 cm	31-60 cm	0-30 cm	31-60 cm
Coconut- (*Cocos nucifera*)	0.56^a	0.41^a	1.59	1.63	26.87^a	20.19^a
Mango- (*Mangifera indica*)	0.43^b	0.31^b	1.58	1.61	20.52^b	14.89^b
Garcinia- (*Garcinia indica*)	0.38^{cd}	0.28^{bc}	1.61	1.63	18.31^{cd}	12.18^c
Jamun – (*Syzygium cumini*)	0.40^c	0.25^c	1.63	1.64	19.45^{bc}	13.76^{bc}
Interspace	0.36^d	0.28^{bc}	1.60	1.62	17.09^d	13.87^{bc}
C.D. @ 5 %	0.03	0.04	NS	NS	1.37	4.11

(Bhagya *et al.*, 2017)

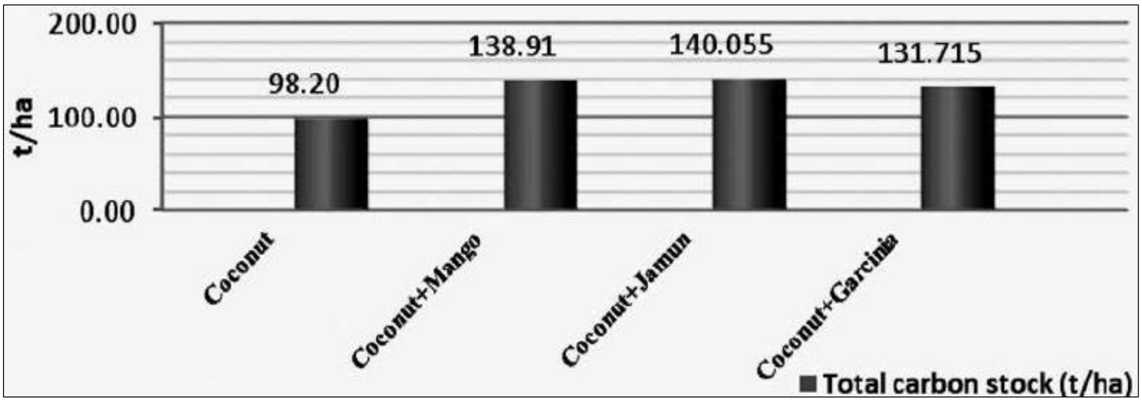

Fig 10: Total carbon stock in coconut-based fruit cropping systems (Bhagya *et al.*, 2017)

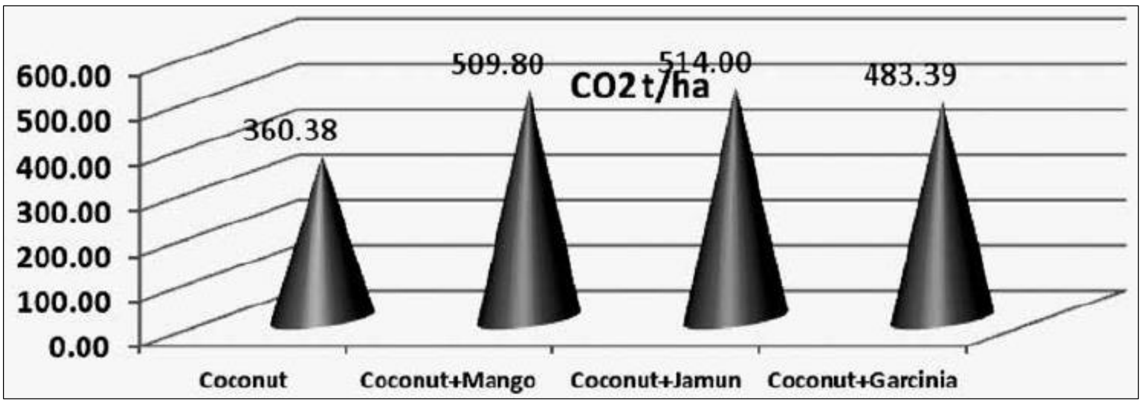

Fig 11: Amount of CO_2 sequestered by coconut-based fruit cropping systems (Bhagya *et al.*, 2017)

Resolving rural lively hood crises

One of the key factors influencing a country's overall prosperity and well-being is the security of its livelihoods. According to Chakraborty *et al*. (2009) [7], India is on the verge of a situation where the extent of overexploitation has compromised the renewability of the majority of its natural resources. A sizeable portion of the Indian populace, especially the impoverished residing in rural areas, rely on natural resources for their daily needs. The lack of resilience in natural resources has resulted in an ongoing fall in agricultural and forest output, which has fueled the livelihood crisis among India's rural poor. A livelihood is a way for a family, society, or person to earn a fair and respectable existence. It consists of the resources (human, financial, material, natural, and social capital) that households have access to, as well as the activities and access to these resources (through the use of institutions and social relationships) that together define the standard of living enjoyed by the community, households, and individuals. Depending on the environment in which a family makes their living, a livelihood might be either urban or rural. In agro-ecosystems, producing goods and providing services is necessary, but so is stepping up conservation efforts. The integration of various vegetation management regimes in cultural landscapes, such as individual farms, watersheds, and regional landscapes, along with tree-growing in conjunction with agriculture (agroforestry systems) and ethno-forestry systems, can leverage the benefits offered by nearby natural, semi-natural, or restored ecosystems. Adapting society is necessary to increase livelihood security and decrease vulnerability. Combining such adjustments with conventional resource management techniques makes them feasible. Therefore, agroforestry is a potential field of study as a local adaptation (Sahoo and Wani, 2019) [23].

In addition to meeting households' subsistence needs for food, fodder, fruit, fibre, fuel, medicine, and other necessities, agroforestry provides nearly 72% of the demand for fuel wood, 2/3 of small timber, 70–80% of the wood needed for plywood, 60–80% of the raw material needed for paper pulp, and 9–11% of the requirement for green fodder (Dhyani *et al.*, 2013) [8].

Agroforestry also includes tree-based apiculture, aquaforestry, and multifunctional woodlots (Plate 2). On borders, a variety of honey-producing tree species that are often visited by honeybees are planted and combined with agricultural products. This will aid in the honey-producing process. Fish-preferred trees and bushes are planted around fishponds and along the edge of aquaforestry systems. Fish graze on the leaves of trees. This system's major functions are fish production and bund stabilisation around fish ponds. Multipurpose wood lots are planted either independently or in mixtures for a variety of uses, including feed, timber, soil reclamation, and protection. Seventy to eighty percent of people live in rural areas in most developing nations, depending on forest resources for livelihood. For example, over 450 million people in Asia rely primarily on forests and tree resources for their livelihoods, while over 60% of people in Africa get their food and health from forests. Smallholder farmers who use few inputs and reside in isolated mountain regions, semi-arid savannahs, or dry plains make up the majority of the rural impoverished (Shukla *et al*., 2018) [24]. These areas are distinguished by delicate ecosystems, Farmers are now compelled by agroforestry's improved lifestyles to use few inputs to produce as much food as possible from delicate ecosystems, which frequently leads to the collapse of conventional agricultural practises and the depletion of natural resources. Large-scale deforestation in this area has resulted in a drop in soil fertility and production, particularly during the dry seasons.

Plate 2: Apiculture and fishery component in agroforestry system

In agroforestry systems, trees can serve as a host for goods of international value, therefore sustaining local livelihoods. Briquetting, often referred to as densification, is the process of compacting wastes to create a product that has a higher density than the initial raw materials from biomass. The handling properties of the material for storage, transit, and packing are also enhanced by densification. Briquettes made from locally accessible biomass are inexpensive and simple for consumers to get for use in home cooking and agro-industrial processes (Wilaipon, 2009) [28]. It serves as compliments to fire wood and charcoal thereby reducing the high demand for both. Besides, briquettes have advantages over fire wood in terms of greater heat intensity, cleanliness, convenience in use and relatively smaller space requirement for storage. The briquettes are normally cylindrical or rectangular in shape.

- 1 ton of Briquette = 1.6 ton of raw biomass
- 1 kg of briquette can give about 1 kWh of electrical energy

According to Inder Dev *et al.* (2018) [13], agroforestry systems are improving farmers' livelihoods, particularly in rain-fed environments. Agroforestry systems offer a strong chance of improving farmers' socioeconomic standing and advancing the general development of the area. This is seen in the rise in income and the creation of job possibilities. It is anticipated that 25.4 million hectares may produce an additional 943 million person-days of work yearly (Table 12).

Table 12: Employment generation potential of agroforestry in India

Agroforestry system	Area (million ha)	Additional employment (Person-day $ha^{-1}yr^{-1}$)	Total annual employment (million person-days)
Silviculture	1.8	30	53.3
Agrisilviculture (irrigated)	2.3	40	91.3
Agrisilviculture (rainfed)	1.3	30	38.0
Agrihorticulture (irrigated)	1.5	50	76.1
Agrihorticulture (rainfed)	0.5	40	20.3
Silvipasture	5.6	30	167.4
Tree-borne oil seeds	12.4	40	497.1
Total	25.4	-	943.4

(Inder Dev *et al.*, 2018) [13]

Biodiversity conservation

According to Blaser *et al.* (2018) [5], biodiversity was significantly impacted by the percentage of shade trees on cocoa plantations. Richness of trees, birds, ants, and frogs increased with a shade cover rise from 0% to 90%. It was discovered that a 30% shade cover was superior because it enhanced biodiversity without compromising the typical cocoa production.

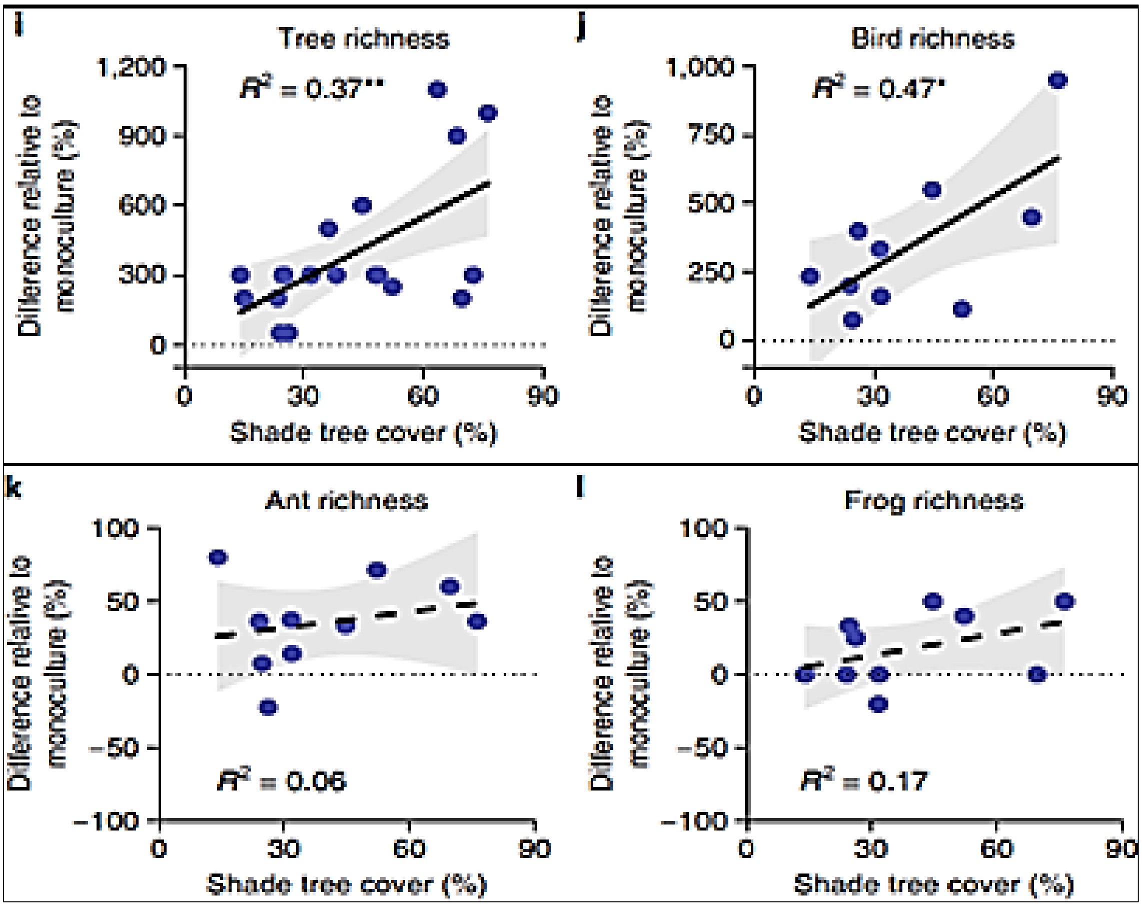

Fig 12: Effects of shade trees on biodiversity in mature cocoa farms (Blaser *et al.*, 2018) [5]

Qinglin Wu *et al.* (2019) [21] reported from the study conducted at China that, agroforestry system also contributes to the increase of soil microfauna species and quantities, compared with other land use types under the same conditions. The walnuts planted (3 m x 4 m) in Jingyang district of Deyang city, Sichuan province, China. The silvapastoral modes (Table 13) were arranged as: walnut + alfalfa (mode I), walnut + chicory (mode II), and walnut + orchardgrass (mode III). The walnut monoculture (mode IV) was practiced as the control group. In order to identify the soil mirofauna species and their number in a lab setting, soil samples were collected from each of the four methods. It said that compared to walnut monoculture, there were more people and species in silvopastoral modes. It is evident from this that the agroforestry system has greater potential for improving the soil micofauna.

Table 13: Species and individuals of soil microfauna in the four modes

Species	Mode I (Walnut+Alfalfa)	Mode II (Walnut+Chicory)	Mode III (Walnut+Orchard grass)	Mode IV (Walnut monoculture)	Total
Nematoda	32	23	25	12	92
Hymenoptera	9	16	25	9	59
Acarina	10	8	7	9	34
Coleoptera (Larvae)	2	12	9	6	29
Oligochaetaopisthopora	3	10	5	6	24
Collembola	8	3	3	0	14
Diplopoda	4	3	0	3	10
Araneae	4	2	3	0	9
Protura	5	0	3	1	9
Orthoptera	2	2	1	0	5
Isopoda	2	2	0	0	4
Geophilomorpha	3	0	0	1	4
Coleoptera	0	2	1	0	3
Lepidoptera (Larvae)	2	0	0	1	3
Thysanoptera	1	0	1	0	2
Lithobiomorpha	1	0	0	0	1
Isoptera	0	1	0	0	1
Total individuals	88	84	83	48	303
Total species	15	12	11	9	17

(Qinglin Wu *et al.*, 2019) [21]

In order to ascertain the impact of intercropping maize fodder during the monsoon season (July to October) in Faisalabad, Pakistan, on citrus leaf miner (CLM) (*Phyllocnistis citrella*) infestation and its predators, Sohail Ahmed *et al.* (2013) [26] conducted an experiment. For the purpose of gathering data on these insects, intercropped lemon, kinnow, grapefruit, and musambi with and without maize were chosen (Tables 14 and 15). The percentage of citrus tree branches randomly chosen for leaf miner infestation and the total number of predators were noted. They discovered that intercropped plots of every cultivar had a high coccinellid population and a low citrus miner infestation. For Kinnow and Musambi, the mean CLM infestation was 8.40±0.144 and 12.72±0.171 in intercropped plots, respectively, and 9.12±0.169 and 14.52±0.200 in plots without intercropping.

Table 14: *Coccinellids* population on different citrus varieties in intercrop and without intercropped orchards

Variety	Intercropping (Maize)		Mean
	With	Without	
Lemon	2.47 ± 0.078	2.15 ± 0.083	2.31 ± 0.058 b
Kinnow	2.56 ± 0.080	2.11 ± 0.101	2.34 ± 0.066 b
Musambi	2.98 ± 0.098	2.49 ± 0.088	2.73 ± 0.067a
Grapefruit	2.13 ± 0.073	1.91 ± 0.073	2.02 ± 0.052 c
Mean	2.54 ± .043 a	2.16 ± 0.044 b	

(Sohail Ahmed *et al.*,2013) [26]

Table 15: CLM infestation on different citrus varieties in intercrop and without intercropped orchards

Variety	Intercropping (Maize)		Mean
	With	Without	
Lemon	7.56 ± 0.153 e	8.06 ± 0.141 de	7.81 ± 0.105 C
Kinnow	8.40 ± 0.144 d	9.12 ± 0.169 c	8.76 ± 0.113 B
Musambi	12.72 ± 0.171b	14.52 ± 0.200 a	13.62 ± 0.142 A
Grapefruit	7.84 ± 0.123 de	8.29 ± 0.124 d	8.07 ± 0.088 C
Mean	9.13 ± 0.114 B	10.00 ± 0.136 A	

(Sohail Ahmed *et al.*, 2013) [26]

Economic sustainability of the system

Meena *et al.* (2017) [15] found that intercropping ber and then aonla increased the economic return on all planting sequences. Due to strong market prices and significant ber fruiting, all cropping sequences with ber had a greater return (Table 16). Fruit output was acceptable in Aonla, although prices were not very high.

The highest gross return (Rs. 982275 ha^{-1}), net return (Rs. 809215 ha^{-1}), and BCR (4.68) were recorded in the fenugreek-okra cropping sequence with ber, which was superior to the other cropping sequences. The nigella-cowpea cropping sequence with ber had the second-highest gross return and net return (Rs. 873750 ha^{-1}and Rs. 705450 ha^{-1}, respectively).

Table 16: Economics of seed spice based intercropping systems

Treatments	Cost of cultivation (Rs ha^{-1})	Gross returns (Rs ha^{-1})	Net returns (Rs ha^{-1})	BCR
Ber + Nigella+ Cowpea	168300	873750	705450	4.19
Ber + Anise+ Cluster bean	159432	797835	638403	4.00
Ber + Rai+ Black gram	151800	724600	572800	3.77
Ber +Ajwain+ Tinda	173300	895375	722075	4.17
Ber +Fenugreek+ Okra	173060	982275	809215	4.68
Ber + coriander+ Green gram	156060	754000	597940	3.83
Aonla +Nigella + Cowpea	173000	721330	548330	3.17
Aonla +Anise + Cluster bean	164132	637740	473608	2.89
Aonla +Rai + Black gram	156500	558950	402450	2.57
Aonla + Ajwain +Tinda	178000	742980	564980	3.17
Aonla +Fenugreek + Okra	177760	804780	627020	3.53
Aonla +Coriander + Green gram	160760	593600	432840	2.69
Ber	110300	614500	504200	4.57

Aonla	115000	484250	369250	3.21
S.Em±	-	23669.00	18729.24	0.06
C.D. @ 5 %	-	67762.59	53620.43	0.18
CV (%)	-	7.06	7.15	7.52

(Meena *et al.*, 2017) [15]

Behera *et al.* (2016) [4] conducted field experiment at Odisha, to study the performance of bamboo based agri-silvicultural systems. The bamboo was grown (Table 17) at three different spacing's (5×5 m^2, 8×5 m^2 and 8×8 m^2) and four intercrops (cowpea, rice bean, turmeric and yam) were taken up within the interspaces. From study they revealed that, all the intercrops yielded maximum at wider spacing and yield decreased progressively with decrease in spacing from 8×8 m^2 to 5×5 m^2. The decrease in bamboo yield obtained from 8×8 m^2 spacing was to the extent of 15.57 and 6.80%, respectively over the narrower spacing of 5×5 m^2 and 8×5 m^2. The net return from intercrops ranged from Rs. 24504 ha^{-1} to Rs.129265 ha^{-1}. Yam under bamboo excelled over others. Yam under bamboo recorded significantly higher return over turmeric, cowpea and rice bean. Yam and turmeric performed better under agri-silvicultural system than cowpea and rice bean. The B:C ratio of intercrops ranged from 1.32 to 2.84. Bamboo (8×8 m^2) with yam exhibited the highest B:C ratio (2.84) and was at par with bamboo (8×8 m^2) with cowpea (2.66) and bamboo (8×5 m^2) with yam (2.41). Bamboo (5×5 m^2) with turmeric exhibited lowest B:C ratio (1.32) and was significantly at par with bamboo with rice bean of same spacing (1.44).

Table 17: Yield and economics of bamboo (5 years old) and intercrops under agri-silvicultural systems

Treatments	Bamboo Biomass yield (t ha^{-1})	Crop Yield (q ha^{-1})	Gross returns (Rs ha^{-1})	Net returns (Rs ha^{-1})	BCR
T_1-Bamboo (5×5 m^2)+Cowpea	38.4	28.56	119640	54640	1.84
T_2- Bamboo (5×5 m^2)+Rice bean	36.8	4.92	79504	24504	1.44
T_3-Bamboo (5×5 m^2)+Turmeric	34.6	42.12	132380	32380	1.32
T_4-Bamboo (5×5 m^2)+Yam	34.4	61.92	161680	81680	2.02
T_5-Bamboo (8×5 m^2)+Cowpea	42.3	32.88	133920	73920	2.23
T_6- Bamboo (8×5 m^2)+Rice bean	41.3	5.75	89500	39500	1.79
T_7-Bamboo (8×5 m^2)+Turmeric	40.3	46.57	150455	55455	1.58
T_8-Bamboo (8×5 m^2)+Yam	40.5	66.55	180825	105825	2.41
T_9-Bamboo (8×8 m^2)+Cowpea	46.5	35.57	146355	91355	2.66
T_{10}- Bamboo (8×8 m^2)+Rice bean	44.5	6.88	97256	52256	2.16
T_{11}-Bamboo (8×8 m^2)+Turmeric	42.5	49.30	158950	68950	1.76
T_{12}-Bamboo (8×8 m^2)+Yam	46.3	71.11	199265	129265	2.84
S.Em±	0.45	1.16			
C.D. @ 5 %	1.32	3.45			

(Behera *et al.*, 2016) [4]

AICRPDA, Vijayapura, Karnataka (2014) revealed that, among the horticulture component, the chickpea equivalent yield was highest with aonla + henna + custard apple (719 kg ha^{-1}) than other horticulture component. Among the arable crops, the chickpea equivalent yield was highest with chickpea + safflower intercropping systems (866 kg ha^{-1}). While in the interaction of horticulture and arable crops, the chickpea equivalent yield was highest with intercropping of safflower + chickpea (2:4) system in the aonla + henna + custard apple (1093 kg ha^{-1}) compared to other practices (Table 18). Higher seed yields were obtained from sunflower intercropped in Hardwickia after stylo (Table 19) when grown for three years as opposed to sunflower intercropped after fallow. The intercropped sunflower was shown to have much greater total financial returns from both the crop and tree. This was mostly caused by taking into account the anticipated yields from the tree at that certain age.

Table 18: Interaction effect on chickpea equivalent yield (kg ha^{-1}) in aonla based agri-horti system for medium deep black soils (8 years mean)

	Aonla only	Aonla + Henna	Aonla + Custard apple	Aonla + Henna + Custard apple	Mean
No inter crop	0	363	108	169	160
Chickpea	506	785	566	896	688
Chickpea + safflower (4:2)	676	962	732	1093	866
Mean	394	703	469	719	

(AICRPDA, 2014)

Table 19: Seed yield and net returns from sunflower intercropped with hardwickia in poor and marginal soils in ley farming (6 years mean)

Cropping system	Seed yield (kg ha^{-1})	Net returns (Rs. ha^{-1})
Sole cropping of sunflower	636	4134
Intercropping of sunflower after stylo in *Hardwickia*	342	6593
Intercropping of sunflower after fallow in *Hardwickia*	248	5287

(AICRPDA, 2014)

The returns from an agri-horticultural system outperformed a solitary cropping approach under various fruit crops by 16.5–136.2%, according to Dwivedi *et al.* (2007) [12] (Table 20). An agrihorti system based on Aonla yielded a maximum return of

Rs. 95007 ha^{-1}, a 136.2% increase over mono cropping. An agrihorticulture system based on ber had a minimum 16.5% higher yield than a solitary crop, yielding Rs. 46879 ha^{-1}. A single crop produced Rs. 40,226 ha^{-1}. The financial benefits of an agrihorti system over a lone crop in the tenth year of plantation management are abundantly evident.

Table 20: Returns from fruit based agroforestry system on a farmer's field-case study

Tree spp.	No. of trees (ha^{-1})	Fruit yield (kg ha^{-1})	Crop yield (kg ha^{-1})		Total net returns (Rs. ha^{-1})	% increase in return compare to sole crop
			Kharif (Groundnut)	*Rabi* (Wheat)		
Aonla	86	6450	902	3005	95007	136.2
Ber	174	3915	975	2980	46879	16.5
Guava	125	5625	925	2875	52431	30.3
Citrus	57	2565	1015	3245	59085	46.9
Sole crop	-	-	1278	3800	40226	-

(Dwivedi *et al.*, 2007) [12]

Swain (2014) [27] investigated from an experiment that included nine treatments (Table 21): upland paddy, ginger, turmeric, tomato, cowpea, french bean, ragi, niger, mango, and control (no intercrop). The purpose of the experiment was to determine how different intercrops affected the yield of mango in Odisha's rainfed uplands. In mango orchards, intercropping was lucrative in every situation. The greatest average net returns, of Rs. 1,19,440 ha^{-1}and Rs. 93,310 ha^{-1}, respectively, were achieved with the mango + guava + turmeric and mango + guava + tomato systems. Mango + guava + cowpea intercropping system yielded the greatest benefit-to-cost ratio (2.02), which was nearly identical to that of the other three combinations (mango + guava + turmeric, mango + guava + frenchbean, and mango + guava + tomato). The higher cost-benefit ratio in the above 3 systems was attributed to higher biological productivity.

Table 21: Net returns and benefit cost ratio of mango based intercropping systems

Treatments	Net return (Rs. ha^{-1})				
	Mango	Guava	Intercrops	Total	B : C ratio
Mango+Guava+Mango ginger	13270	7680	69650	90600	1.83
Mango+Guava+Turmeric	13950	8450	97040	119440	2.00
Mango+Guava+Tomato	13160	7050	73100	93310	2.00
Mango+Guava+Cowpea	19900	9990	26185	56075	2.02
Mango+Guava+Frenchbean	17350	9185	27400	53935	1.99
Mango+Guava+Ragi	10810	6175	4620	21605	1.62
Mango+Guava+Niger	8810	5090	2242	16142	1.57
Mango+Guava+Paddy	11570	6910	5578	24058	1.75
Mango+Guava+No intercrop	8080	3060	-	11140	1.46

(Swain, 2014) [27]

The study by Mutnal *et al.* (2002) [17] used a grass/subabul (pastoral), field crop (agri), and teak (silvi) systems at MARS, UAS, Dharwad, Karnataka. Two metres separated each teak plant when it was planted. The teak row has pastures planted on both sides of it. In comparison to solo crops, the net return from groundnut + teak (Rs. 26585 ha^{-1} yr^{-1}) and sorghum + teak + subabul (Rs. 21475 ha^{-1} yr^{-1}) were greater. When comparing sorghum + teak to solo crops, the benefit cost ratio was greater (2.37) in teak followed by groundnut (2.32). Compared to solo crops or pastures combined with teak, the economically feasible agroforestry system included groundnuts or sorghum (Table 22).

Table 22: Income from components and net returns, benefit cost ratio as influenced by agroforestry systems.

Agro-Forestry System	Income (Rs. ha^{-1} year)				Net returns (Rs. ha^{-1})	B:C ratio
	Field crops	Pasture	Teak	Total		
1. Sorghum (S)	13079	-	-	13079	10225	1.90
2. S + Teak (T)	8807	-	24800	33607	25259	2.98
3. S + T + Grass	8037	2162	20326	30527	21475	2.37
4. S + T + Subabul	7697	771	14809	23277	14239	1.57
5. Groungnut (Gn)	16207	-	-	16207	8188	0.98
6. Gn + Teak	10929	-	27107	38037	26585	2.32
7. Gn + T + Grass	9776	2281	15724	27781	15733	1.31
8. Gn + T + Subabul	9485	885	12644	23011	10958	0.91
S.Em±	266.3	80.7	2385	2317.6	2454.5	-
C.D. @ 5 %	798.4	258.6	7186	6948.4	7358.9	-

Devaranavadgil *et al.* (2010) [29] conducted study on survey of traditional agroforestry systems practiced in northern dry tract of Karnataka. It includes the districts *viz.*, Bijapur, Bagalkot, Gulbarga, Koppal and Raichur. The bund planting was found to be most prominent agroforestry practice both in rainfed and irrigated situations in all the five districts (Table 23). Nearly 88.4 per cent of the respondents followed bund planting in rainfed situation, whereas it was 86.1 per cent in irrigated situation. The other potential agroforestry practices followed were boundary planting and scattered planting in all the five districts. Neem and babul (*Acacia nilotica*) are frequently occurred tree species in all the five districts under both rainfed (82.9% and 46.2%, respectively) and irrigated ecosystems (74.4% and 35.4%, respectively). The highest performance was for fruits, timber and fuel wood tree species in all the five districts in rainfed (70.1%, 64.6% and 37.3%, respectively) and irrigated situations (59.6%, 63.7% and 35.9%, respectively).

Table 23: Agroforestry practices followed by farmers in five districts of northern Karnataka (Survey during 2006)

Agroforestry practices	Percentage of respondents following the practices											
	Bijapur		Bagalkot		Gulbarga		Koppal		Raichur		Average	
	R	I	R	I	R	I	R	I	R	I	R	I
1. Bund planting	92.5	100.0	95.4	74.8	90.2	80.5	81.2	94.6	82.7	80.6	88.4	86.1
2. Boundary planting	52.4	85.4	45.6	62.6	76.8	66.4	18.7	72.8	72.5	65.8	53.2	70.6
3. Agri-silviculture	-	12.4	-	18.6	-	8.2	18.5	26.2	-	8.6	18.5	14.8
4. Horti-silviculture	19.0	8.2	-	4.6	-	12.6	21.4	36.8	-	4.3	20.2	13.3
5. Scattered planting	25.2	78.2	21.2	84.2	12.8	52.6	37.4	24.4	18.4	10.6	23.0	50.0
6. Block plantation	5.8	4.4	6.4	9.2	4.2	7.2	12.6	26.5	4.2	8.2	6.6	11.1
7. Avenue plantation	2.6	14.5	3.5	20.2	3.8	10.6	14.2	20.6	5.4	14.6	5.9	16.1
8. Planting along irrigation canal	-	5.4	-	4.6	-	3.5	-	6.8	-	3.2	-	4.7

(Devaranavadgil *et al.*, 2010) [29]

Conclusion

The appropriate agri-horti and agro-forestry systems control erosion, maintain soil organic matter and physical properties and promote efficient nutrient cycling. The multifunctional agri-horti and agro-forestry systems in tropical region offer innumerable ecological benefits such as carbon sequestration, mitigation of climate change, enhancing soil fertility and water use efficiency, biodiversity conservation, biological pest control, sustainable land use, shelterbelt and windbreaks, microclimate amelioration, breaking the poverty and food insecurity circle, caveats and clarifications. Millions of farmers are dependent on agri-horti and agro-forestry farming systems as a way of increasing and sustaining agricultural productivity, as a source of essential food, fuel wood, fodder and building materials and as a supplementary source of income that buffers instability in agricultural income. Ultimately having better potential for sustainability, secured production with better economic benefit to the farming community.

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