Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Mangifera indica (Mango) and Dysoxylum binectariferum (Lamboo) based agroforestry system: An Ideal Model for Alternative Land Use System for Food Security and Socioeconomic benefits with Assessment of Carbon Sequestration

Suren Murmu (murmu.suren@bckv.edu.in)
Bidhan Chandra Krishi Viswavidyalaya
Gayatri Kumari Padhi
Piprakothi- Krishi Vigyan Kendra, Dr. Rajendra Prasad Central Agricultural University
Sachin Verma
Tropical Forest Research Institute
Paritosh Murmu
Nabarangpur- Krishi Vigyan Kendra, Odisha University of Agriculture & Technology
Lalit Upadhyay
Reasi- Krishi Vigyan Kendra, Sher-E-Kashmir University of Agricultural Sciences and Technology, Union Territory of Jammu and Kashmir)
Pratap Kumar Dhara
Regional Research Station, Bidhan Chandra Krishi Viswavidyalaya

Research Article

Keywords: Agroforestry system, food security, socioeconomic benefits, land use system, carbon sequestration

Posted Date: June 14th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-3053857/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Abstract

Agroforestry is a sustainable land use system that combines tree and crops for productive and protective purposes. Integration of trees in agroforestry system results in positive or negative tree-crop interactions, hence, selection of suitable tree – crop combinations is important. To find out the suitable tree-crop combination, a field experiment was conducted at Regional Research Station (Bidhan Chandra Krishi Viswavidyalaya), Jhargram, West Bengal, India. The different crops were cultivated and evaluated during 2017- 18 in alley space of mango (Mangifera indica) and Lamboo (Dysoxylum binectariferum) plantation raised during 2010. Mango plants were planted at 10x10m spacing and Lamboo plants were introduced between two mango plants with in the row i.e., each at 5m distance from mango plant. The crops viz pigeon pea (Cajanus cajan), black gram (Vigna mungo), bottle gourd (Lagenaria siceraria), okra (Abelmoschus esculentus) and maize (Zea mays) were cultivated during monsoon-autumn and mustard (Yellow Sarson i.e., Brassica campestris) in winter season. The data revealed that Lamboo and Mango trees in agroforestry system recorded significantly higher growth and yield in comparison to pure plantations. The growth attributes of Lamboo and Mango were recorded to be highest in treatment (T1). The productivity of Lamboo and Mango was also recorded to be highest in the treatment accompanied with Mango and Pigeon Pea. After completion of two cycles of cropping, the results revealed that increase in percentage of organic carbon, N, P and K was found to higher in T1 (Lamboo + Mango + Pigeon pea) i.e., Organic Carbon -29.73%, N-39.21%, P-38.20% and K-19.66%). The maximum gross income was recorded in T3 (Lamboo + Mango + Bottle gourd – Mustard) i.e., ₹7,64,995 per hectare. Hence, this tree-crop combination can be adopted for highest return in Paschim Medinipur, West Bengal.

Introduction

Indian agriculture is facing diverse challenges and constraints due to growing demographic pressure, increasing food, feed and fodder needs, natural resource degradation and climate change. There is a quintessential requirement for alternate land use systems for upliftment of livelihood of the farming community in a sustainable manner. The prognosis of the present scenario of agricultural farming community and meeting the demands of the future generation infers us to adoption of diversification of land use systems with agroforestry as a necessary strategy for providing variety of products for meeting requirements of the people and insuring against risks caused by weather aberrations, controlling erosion hazards and ensuring sustainable production on a long-term basis, particularly in view of the effects of climate change (CAFRI 2021); Swodesh R (2019); Toppo and Raj (2018). Well planned agroforestry system can play an important role in solving acute problem of food, fuel wood, fodder, soil fertility and ecology as well as plays significant role in improving the economic status of the farmers Hombegowda et al. (2022); Dhyani and Handa (2014). Agroforestry is a collective name for land use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence Amatya et al. (2014); (FAO 2010). In agroforestry system, there are different components and interaction between ecological and economic factors. In other words, agroforestry is combination of agricultural technology and foresting in order to complete, variety, productivity, health and sustainability of land Amatya et al. (2018); Murmu et al. (2016). It is also a dynamic and ecologically based natural resource management system Mondal and Palit (2022).

Negash and Starr (2015) cited that agroforestry can mitigate climate change through creating and enhancing carbon sinks by capturing carbon from the atmosphere through photosynthesis and storing it in biomass and soil. The beneficial outcomes of agroforestry include carbon sequestration, increased soil quality, erosion control, reduced fossil fuel use, and increasing resilience in the face of an uncertain agricultural future.

Monocropping neither provides gainful employment opportunities nor generates sufficient income to meet the family expenses Singh et al. (2016); Dhara and Sharma (2015). Fruit based agroforestry is a proven land use system for vertically enhancing productivity and risk coverage against unstable weather conditions. Das et al. (2022); Dhara and Panda (2019); Hemrom and Nema (2015); Alam et al. (2014) focussed on selection of intercrops, fruit trees and silvi species which depends on agro-climatic conditions and farmers choice for effective utilization of available space, both horizontally and vertically by making use of available technology thus enhancing physical and socioeconomic resources of the farmers.

Murmu and Dhara (2022); Dhyani (2018); Das et al. (2017) explained the advantages of mango based agroforestry systems with integration of tree component and fruit component where the tree components provides food, timber, construction materials, raw materials for forest-based small scale enterprises and other cottage industries and in some cases, enrich soil with essential nutrients. Leakey (2012) explained that average carbon stock in agroforestry systems ranges between 9 and 63 Mg C ha $^{-1}$ year $^{-1}$ depending on the climate (semi-arid to temperate).Carbon stocks in agroforestry systems of the tropics vary even for similar types of agroforestry systems due to the diversity of agroforestry practices (e.g., home gardens, windbreaks, intercropping, woodlots, etc.) and the impact of environmental (e.g., access to soil moisture, light and nutrients) and management (e.g., pruning and felling) factors (Nair and Nair 2014 and Dawson et al. 2014).

Lamboo (*Dysoxylum binectariferum*) is an important forest tree of eastern region of India which provides substantial earning to the livelihood of the farmers. It grows up to 45m height trunk erect, 1-1.8m in diameter; crown is large. It is a source of pollen and caramel-flavoured honey. It is widely used for firewood, charcoal good quality pulp and paper. It is also planted in shelter-belts as a wind break and for shade and a suitable species in reforestation programme. (Murmu et al. 2017). The literature survey reveals that a number of *Dysoxylum* species are good amount of medicinal value in India and other countries of the world. The *Dysoxylum* species are considered to possess various pharmacological activities like in treatment of anti-inflammatory, analgesic, anti-microbial, antitumor, CNS activities, molluscicidal and cardiac activities etc. It is a promising drug to be utilised in anti-cancerous properties (Arya et al. 2017 and Parcha et al. 2004).

Hardy and deep rooted fruit plants like Mango (*Mangifera indica*), Guava (*Psidium guajava*) and Ber (*Ziziphus mauritiana*) can be planted as high value horticultural crops on degraded waste lands in red and laterite tract of West Bengal (Tiwari and Baghel 2014). Mango trees on crop lands were widely perceived as having a positive effect on soil fertility and soil moisture as well as mango litter is used for soil amelioration (Rathore et al. 2013). Despite its limitation for short term correction of soil fertility, Mango leaves can be used for long–term buildup of soil organic matter (Das et al. 2022), and well adapted

to cultivation and have been grown commercially for centuries as a source of fruit, medicine, fodder, firewood, timber, poles and shade Chavan et al. (2015); National Agroforestry Policy (2014); Dhyani (2014); Chauhan et al. (2012).

Crop production on red and laterite soil under rainfed condition is low and unstable. It is estimated that nearly 50% of western part of West Bengal is under rainfed cultivation and encounters land degradation. The soil erosion prone zones are to be managed with adaptation of agroforestry models to enhance the livelihood of the farmers in a different way. Intercropping of rainfed arable crops with fruit/forest trees is of immense importance for bringing in quick returns during initial years of plantation. Keeping in view the above facts, a field experiment was undertaken to develop a fruit-based agro-production system for rainfed humid sub-tropical region of West Bengal.

The scrutiny of role of silvi-fruit based agroforestry system which is an ideal model for alternative land use system for food security, socio-economic benefits and assessment of carbon sequestration helps to improve the application, scaling and sustainability of agroforestry systems. The focal point of the present studies the features to be examined are:

- The agroforestry systems acts as carbon sink which increases the soil fertility and water holding capacity of the soil hence improving the livelihood of the farmers unlike monocropping.
- Intercropping of rainfed arable crops with fruit/forest trees impacts on social-ecological drivers, processes, and impacts and analysis of silvi-fruit based agroforestry system is very important for deriving returns for enhancement of economic returns in rainfed humid sub-tropical region of West Bengal.
- Analysis of Soil Organic Carbon derived from agroforestry systems is an important performance indicator of silvi-fruit based agroforestry systems which enhances soil health cumulatively.

Materials and methods

Location of the study area

The present study was carried out at Regional Research Station (Red and Laterite Zone) of Bidhan Chandra Krishi Viswavidyalaya at Jhargram, Paschim Medinipur, West Bengal, India. The experimental site is located at $22^0$30”N latitude and $87^0$0”E longitude and at an elevation of 78.77 above mean sea level.

Climate and weather

The experimental site is characterized with short winter and long hot summer. The annual precipitation varies between 1100 to 1300 mm, about 80% of which is usually received during monsoon period (June – September). Maximum and minimum temperatures during the month of cropping period were found between 25.5°C – 38.8°C and 16.4°C– 28.2°C, respectively (Dhara and Sharma 2015).

Soil

Soil is characterized as coarse texture and acidic with pH 5.5 and poor in organic matter, available nitrogen, phosphorus, potassium and lime content, and highly susceptible to erosion hazards.

Tree and plant material

Previously established mango (*Mangifera indica*) trees were used as fruit tree component and Lamboo (*Dysoxylum binectariferum*) was used as tree component with six arable crops as intercrops viz. pigeon pea (var. UPAS 120), black gram (var. WBU 109), okra (var. Parvani Kranti), bottle gourd (var. Pusa Summer prolific round) and maize (var. Kanchan-K-25).

Experimental design and treatment combination:

One year old saplings of mango grafts *cv.* Amrapally (100 Nos.) were planted during August, 2010 at 10m× 10m spacing. Alongside, 2 months old seedlings of Lamboo (*Dysoxylum binectariferum*) were planted in between two mango plants and 5m spacing in between two mango rows and as boundary plantation of the experimental field for shelter belt. The plot size of experiment was 20m× 20m for each treatment. Six arable crops viz. pigeon pea (var. UPAS 120), black gram (var. WBU 109), okra (var. Parvani Kranti), bottle gourd (var. Pusa Summer prolific round) and maize (var. Kanchan-K-25) were grown during *kharif* season (mid June to last October) followed by mustard crop in *rabi* season (October to March) as intercropping under Lamboo-Mango based agroforestry system during 2016-17 and 2017-18, Mustard (var. B-9/Binoy) was cultivated by using residual soil moisture mustard (var. B-9/Binoy) was cultivated during *rabi* season of 2016-17 and 2017-18.

The experiment has been laid out in a randomized block design having 8 treatments (T_1 = Lamboo + Mango + Pigeon pea; T_2 = Lamboo + Mango + Blackgram followed by Mustard; T_3 = Lamboo + Mango + Bottle gourd followed by Mustard; T_4 = Lamboo + Mango + Okra followed by Mustard; T_5 = Lamboo + Mango + Maize followed by Mustard; T_6 = Lamboo + Mango; T_7 = Lamboo; T_8 = Mango) with 3 replications. Inter crops were grown with standard agronomic package of practices. Different growth parameters of silvi species and fruit tree (height, DBH, crown diameter and fruit yield) were recorded. Standard management practices were adopted for intercrops.

Land preparation

The experimental land was ploughed in the month of April, 2016. Weeds and stubble were removed from the field and then left exposed to natural weather for several days before the land was finally prepared for sowing seeds of arable crops.

Management practices

Different management practices such as fertilizer and manures application, weeding, irrigation, thinning or filling, pest and disease management etc. were done for better growth of the plants.

Data analysis

Different growth parameters of tree species/ fruit tree (height, diameter at breast height / basal diameter and fruit yield) were recorded.

Height of the tree species was recorded by means of a measuring tape and a bamboo pole from the ground level to the tip of the plant. For this, the tape is made to run along the middle of the stem to the tip of the plant.

Bole height of the tree species was recorded by using measuring tape and a bamboo pole from the ground level to the crown point of tree. For this, the tape is made to run along the middle of the stem to the crown point of tree.

Diameter at breast height (DBH) of the tree species was measured at 137 cm above the ground with the help of a Vernier calliper because Diameter at BH 137 cm was the most commonly reported value (Condit 1998). Some scientists suggested that 'DBH' is ambiguous, they propose abandoning that term and instead using 'D' and a subscript to indicate diameter measured at a specific height. Thus 'D_{137}' would indicate tree diameter at 137 cm. 'DBH' may still be needed as a generic term (Brokaw and Thompson 2000; Dahdouh-Guebas and Koedam 2006).

Basal area refers to the ground actually penetrated by the stem. It is one of the chief characters determining the dominance or otherwise of a particular species in a community or vegetation stand. Total basal area per unit land area was calculated by multiplying the basal area per tree with corresponding density and converting as total basal area by the multiplication of total number of tree per hectare. Basal area (BA) of individual tree was calculated using the equation.

$$BA = \pi \times \frac{(DBH)^2}{4}$$

The ultimate object of all mensurational activity in forest is to calculate or estimate quantity of wood contained in trees and consequently in crops not only for sale but also for research, predicting future yields, estimating increment to assess return on capital, etc. Volume has been the traditional measure of wood quantity and continues to be the most important measure in spite of increasing use of weight or biomass as a measure of forest productivity. For calculating volume yield of standing trees, parabolic volume (PV) using Smalian's formula (Newbould 1967; Chaturvedi and Khanna 2000) was calculated by using Eq. 3.3. To convert as total volume yield of tree per hectare was done by the multiplication of total number of tree standing in one-hectare land.

The volume yield calculation (for tree species) was done by quarter girth formula postulated by (Jackson 1973). The volume yield of per tree was estimated by given equation then convert to on per hectare basis.

$$Y_{vol} = BA \times h_t \times 0.5$$

Where, V = Timber volume yield; ht = Bole height of tree

The commercial biomass was estimated by the help of commercial volume yield and wood density (Brown et al. 1989).

$$Biomass = VolumeYield\left(kg/m^3/ha/yr\right) \times WoodDensity(kg/m^3)$$

To calculate the carbon stock as biomass, the equation postulated by Winrock (1977), as generalized for conversions from biomass to carbon stock was calculated by using following formula:

$$C = 0.50 \times Biomass$$

To calculate the carbon stock as crop biomass (Woomer 1993) was used, as generalized for conversions from crop biomass to carbon stock.

$$C = CropBiomass \times 0.45$$

To estimate total C under fruit-based AFS, the carbon stock as total agroforestry biomass and soil organic carbon (here, SOC) present in soil were considered. Estimation of SOC (Calfapietr et al. 2010) from percentage values to tonnes per hectare was computed by multiplying SOC (%) values with soil bulk density and the thickness of soil layer (here, 15 cm, considering crop root zone in soil) following formula:

$$SOC(t/ha) = OC\,(\%) \times BD(g/cm^3) \times Depth\,(cm) \times 100$$

The total carbon stock (Dixon et al. 1994) for the present land use was calculated by using following formula:

$$CarbonStock\,(total) = Castotalagroforestrybiomass + SOC$$

Data on soil nutrient status had also been taken both prior to commencement of the experiment and after completion of two cycles of inter cropping for calculation of increase or decrease percentage of soil nutrients. Soil nutrient build up in terms of available nitrogen, phosphorus, potassium (Walkley et al. 1934) and organic carbon (Chaturvedi and Jha 1998) was measured from each treatment after the completion of two cycles of intercropping following standard procedures. The increase or decrease percent of soil nutrient was calculated pertaining to the initial status of the soil nutrient.

Economics of the system were calculated on prevailing prices of inputs and outputs. The data collected during both the years of experimentation were analysed following the method of analysis as described by (Gomez and Gomez 1984).

For economic evaluation of the system, prevailing market prices were used. The data gathered in each observation were statistically analyzed using SPSS version 20 software. The critical differences were calculated to assess the significance of the treatments.

Results

Growth parameters of Lamboo (Dysoxylum binectariferum)

Different growth characters of Lamboo viz. height, diameter at breast height (DBH) and volume yield was interpreted in (See Table 1 in Appendix). The maximum height (5.88 m) of the Lamboo tree was recorded in T_1 when it was grown with Mango and Pigeon pea. This was followed by T_2 (5.66 m). The lowest height was recorded in sole Lamboo i.e., 4.42 m.

Table 1
Growth attributes of Lamboo tree grown in different AFS model and sole plantation

AFS model	Height (m)		DBH (cm)		Volume yield ($m^3ha^{-1}yr^{-1}$)	
	2017	2018	2017	2018	2017	2018
T_1: Lamboo + Mango + Pigeon pea	5.88	6.09	4.07	4.86	0.028	0.040
T_2: Lamboo + Mango + Black gram – Mustard	5.66	6.02	3.87	4.45	0.024	0.033
T_3: Lamboo + Mango + Bottle gourd – Mustard	5.44	5.93	3.70	4.33	0.021	0.032
T_4: Lamboo + Mango + Okra – Mustard	5.43	5.83	3.63	4.15	0.020	0.029
T_5: Lamboo + Mango + Maize –Mustard	5.29	5.55	3.47	3.92	0.018	0.024
T_6: Lamboo + Mango	4.75	5.39	3.34	3.47	0.015	0.018
T_7: Sole Lamboo	4.42	4.98	3.27	3.36	0.013	0.016
T_8: Sole Mango	-	-	-	-	-	-
SEm(±)	0.05	0.14	0.04	0.21	0.0005	0.0033
CD(P = 0.05)	0.16	0.42	0.11	0.64	0.001	0.010

The results revealed that DBH was also found highest in T_1. The lowest DBH (3.27 cm) being recorded in sole Lamboo. Experimental results shows that all the growth attributing characters of Lamboo were increased gradually with the increasing age of the plant. The results revealed that the growth attributing characters were higher in Mango based Agro-production models as compared to sole crop, thus exhibiting a positive effect of mango- based intercropping on tree growth. The results were corroborated with the findings of Murmu et al. (2017). All the Mango-based agro forestry systems were found to be significantly different from each other and were found to be significantly different from the sole crop.

Volume Yield

The volume yield of Lamboo was significantly higher under different intercropping based agroforestry system. The maximum volume yield (0.028 $m^3ha^{-1}yr^{-1}$ and 0.040 $m^3ha^{-1}yr^{-1}$ in 2017 and 2018, respectively) was founded under T_1 based agro forestry system, followed by T_2. The lowest volume yield was recorded in sole crop as 0.013 $m^3ha^{-1}yr^{-1}$and 0.016m^3ha-^1yr-^{1} in 2017 and 2018. The volume yield was found to be higher in mango based agro forestry systems than the sole crop and were significantly different.Under rainfed situation, fruit tree based framing system resulted in reduced risk. (Basanda et al. 2017) observed that intercropping of rainfed legume crops in ber orchard at rainfed plateau conditions of eastern India gave 3 times higher yield as compared to sole crops (See Table 1 in Appendix).

Growth attributes of Mango

Table 2 represents the growth attributes of Mango under different agroforestry systems. The height of mango was recorded to be highest in (6.31 m), T_1 (Lamboo + Mango + Pigeon pea). The lowest height was recorded in sole Mango i.e., 4.27 m and 5.73 m. The same trend was inferred in case of stem girth and crown diameter of Mango. These results were well supported by findings of (Kaur et al. 2017) and (Das et al. 2014), which gave the inference of significant increase in production and productivity of mango in intercropping as compared to sole plantation. Attempts have been made to intercrop mango orchards with tree species.

Table 2
Growth attributes of Mango tree grown in different AFS model and sole plantation

AFS model	Height (m)		Stem girth (cm)		crown diameter (cm)	
	2017	2018	2017	2018	2017	2018
T_1:Lamboo + Mango + Pigeon pea	6.31	7.04	67.15	78.74	5.55	6.56
T_2:Lamboo + Mango + Black gram – Mustard	6.16	6.87	65.03	75.42	5.42	6.36
T_3:Lamboo + Mango + Bottle gourd – Mustard	5.96	6.46	63.69	72.44	5.09	6.19
T_4:Lamboo + Mango + Okra – Mustard	5.22	5.95	57.15	65.49	4.51	5.35
T_5:Lamboo + Mango + Maize –Mustard	5.56	6.20	59.61	68.10	4.85	5.90
T_6:Lamboo + Mango	4.96	5.73	54.40	62.97	4.40	5.21
T_7:Sole Lamboo	-	-	-	-	-	-
T_8:Sole Mango	4.27	5.06	53.38	61.66	4.24	4.93
SEm(±)	0.0400	0.0525	0.4408	0.6359	0.0649	0.0387
CD(P = 0.05)	0.123	0.162	1.358	1.959	0.200	0.119

Soil nutrients status after two cycles of cropping

The soil nutrient analysis was carried out by measuring the initial nutrient status and after completion of the experiment i.e., after two years (See Table 3 in Appendix). After completion of two cycles of cropping, the results revealed that increase in percentage of N, P and K was found to higher in T_1 (Lamboo + Mango + Pigeon pea) i.e., N-39.21%, P-38.20% and K-19.66%), followed by T_2 (Lamboo + Mango + Black gram – Mustard) i.e., N-37.01%, P-37.89% and K-17.78%). The higher increase in soil nutrients is attributed by intercropping with leguminous crops like Pigeon pea and Black gram.

Table 3
Effect of different AFS model on soil properties

Treatment	Initial status of nutrient	Final status of nutrient	Increase (%)	Initial status of nutrient			Final status of nutrient			Increase (%)		
	pH	pH	pH	N	P	K	N	P	K	N	P	K
T_1	5.5	5.7	3.64	164.1	17.8	174.1	228.45	24.6	A	39.21	38.20	19.66
T_2	5.5	5.7	3.64	169.09	17.5	170.09	231.67	24.13	200.34	37.01	37.89	17.78
T_3	5.4	5.6	3.70	167.37	17.8	177.37	227.32	24.02	207.34	35.82	34.94	16.90
T_4	5.3	5.5	3.77	162.5	19.8	172.5	218.23	26.32	199.32	34.30	32.93	15.55
T_5	5.3	5.5	3.77	173.05	15.1	183.05	224.35	19.21	207.55	29.64	27.22	13.38
T_6	5.1	5.3	3.92	148.2	11.8	158.2	181.34	14.67	182.13	22.36	24.32	15.13
T_7	5.1	5.3	3.92	144.2	11.7	154.2	166.23	14.06	176.34	15.28	20.17	14.36
T_8	5.1	5.1	0.00	140.2	11.7	150.2	158.34	13.9	165.34	12.94	18.80	10.08

(T_1 = Lamboo + Mango + Pigeon pea; T_2 = Lamboo + Mango + Blackgram followed by Mustard; T_3 = Lamboo + Mango + Bottle gourd followed by Mustard; T_4 = Lamboo + Mango + Okra followed by Mustard; T_5 = Lamboo + Mango + Maize followed by Mustard; T_6 = Lamboo + Mango; T_7 = Sole Lamboo; T_8 = Sole Mango)

The lower increase in the nutrient status was recorded in the sole cropping i.e., T_7 and T_8. The maximum increase of soil pH was observed under T_1 to T_4, followed by under both T_5 and T_6 as compared with T_8. The findings are in conformity with the results of Banerjee and Dhara (2010).

Carbon sequestration potential in India

The total carbon storage capacity of an agroforestry system depends on the growth and nature of the tree species, and varies from region to region Nag et al. (2023); IPCC (2021); Koul and Panwar (2012). Estimates of the rate of carbon sequestration with biomass production under different AFS model are presented in Table 4. Estimates of highest Carbon stock total under different AFS model from was observed under T_1 to T_2 followed by T_3, T_4, T_5, T_6, T_7 and T_8.

Table 4
Carbon sequestration of different AFS model

Treatment	Carbon stock as trees and fruit trees biomass (t/ha/yr)		Crop carbon stock (t/ha/yr)		SOC (t/ha)		Carbon stock total (t/ha/yr)	
	2017	2018	2017	2018	2017	2018	2017	2018
T_1	3.12	3.21	14.74	15.21	8.96	9.98	24.88	24.98
T_2	3.07	3.15	14.04	14.71	8.88	8.94	24.73	24.77
T_3	2.88	2.98	13.56	13.59	8.79	8.88	23.54	24.35
T_4	2.79	2.85	13.41	13.55	8.64	8.76	23.12	23.30
T_5	2.71	2.76	12.84	12.98	8.52	8.62	22.60	22.73
T_6	2.67	2.70	-	-	7.14	7.42	18.19	21.66
T_7	0.98	1.01	-	-	6.72	7.00	7.70	8.01
T_8	1.39	1.51	-	-	6.54	7.63	8.11	8.37
SEm(±)	0.01	0.03	0.23	0.22	0.03	0.13	0.96	0.21
CD(P = 0.05)	0.03	0.05	0.66	0.39	0.06	0.37	2.71	0.34

(T_1 = Lamboo + Mango + Pigeon pea; T_2 = Lamboo + Mango + Blackgram followed by Mustard; T_3 = Lamboo + Mango + Bottle gourd followed by Mustard; T_4 = Lamboo + Mango + Okra followed by Mustard; T_5 = Lamboo + Mango + Maize followed by Mustard; T_6 = Lamboo + Mango; T_7 = Sole Lamboo; T_8 = Sole Mango)

Different AFS model have a particularly highest Carbon stock as trees and fruit trees biomass potential was observed under T_1(Lamboo + Mango + Pigeon pea) to T_2 (3.21 and 3.17 t/ha/yr). The maximum increase of Soil Organic Carbon (SOC) was observed under T_1 to T_2 (9.98 and 8.94 t/ha/) in different AFS model. The lowest amount of SOC stock was present in fallow land (10.05 t /ha) in Table 4. The findings of Dhyani et al. (2016) and Basu (2014) found that the yield attribute of tree species were higher under Agri + Silvi + Fruit + Vegetable based cultural system.

Productivity of Lamboo under different agro-forestry systems

The basal area calculated of Lamboo basing on growth attributes was recorded to be highest in treatment T_1 (Lamboo + Mango + Pigeon pea) followed by T_2. The lowest basal area was recorded to be of sole Lamboo, while increase in basal area was recorded to be 30.44%, which was next to (T_4) Lamboo + Mango + Okra – Mustard (Table-5).

The commercial wood mass production of Lamboo also followed the same trend with increase (%) in wood mass as 49.15%, 38.96% and 54.81% in (T_1), (T_2) and (T_3) respectively. The lowest increase in wood biomass was found to be in (T_6 = Lamboo + Mango) i.e., 20.61% (See Table 5 in Appendix). The findings of Das et al. 2014, found that the yield attribute of silvi tree were higher under Agri + Silvi + Fruit + Vegetable based cultural system.

Table 5
Commercial biomass production & Basal Area of Lamboo

Treatment	Wood Biomass of Lamboo ($kg/m^3/ha/yr$)			Basal Area of Lamboo m^2		
	2017	2018	Increase (%)	2017	2018	Increase (%)
T_1	15.46	23.07	49.15	0.009	0.015	64.95
T_2	13.47	18.71	38.96	0.008	0.011	32.63
T_3	11.84	18.33	54.81	0.008	0.011	36.11
T_4	11.42	17.08	49.56	0.007	0.010	30.46
T_5	10.11	13.65	35.02	0.007	0.009	29.57
T_6	8.41	10.15	20.61	0.006	0.007	8.40
T_7	7.52	11.83	57.17	0.006	0.008	30.44
T_8	-	-	-	-	-	-
SEm(±)	0.27	0.87	-	0.0001	0.0011	-
CD(P = 0.05)	0.82	2.67	-	0.0004	0.0035	-

(T_1 = Lamboo + Mango + Pigeon pea; T_2 = Lamboo + Mango + Blackgram followed by Mustard; T_3 = Lamboo + Mango + Bottle gourd followed by Mustard; T_4 = Lamboo + Mango + Okra followed by Mustard; T_5 = Lamboo + Mango + Maize followed by Mustard; T_6 = Lamboo + Mango; T_7 = Sole Lamboo; T_8 = Sole Mango)

Production of Mango

The yields of mango were grown under different mango-based agroforestry system were represented in Table 6. The mango yield obtained from T_1 was highest among all treatments in the consecutive years i.e., 6.42 t ha^{-1} and 9.56 t ha^{-1} in 2017 and 2018 respectively, followed by T_2 i.e., 6.19 t ha^{-1} and 8.75 t ha^{-1} in 2017 and 2018. Respectively, the production of mango was more when legume crops were intercropped with mango. The lowest mango yield was obtained in Sole mango crop in consecutive years i.e., 4.24 t ha^{-1} and 6.09 t ha^{-1} in 2017 and 2018 respectively. The mango yield and production of intercrops increased in the year 2018 as compared to year 2017 (See Table 6 in Appendix). The increase in yield was found to be highest in (T_1) 49.04%, followed by (T_2) 41.28% and (T_3) 40.08%.

Table 6
Yield (t/ha) of Mango grown under different AFS model

AFS model	Yield		
	2017	2018	Increase (%)
T_1: Lamboo + Mango + Pigeon pea	6.42	9.56	49.04
T_2: Lamboo + Mango + Black gram – Mustard	6.19	8.75	41.28
T_3: Lamboo + Mango + Bottle gourd – Mustard	5.95	8.33	40.08
T_4: Lamboo + Mango + Okra – Mustard	5.22	7.35	40.83
T_5: Lamboo + Mango + Maize –Mustard	5.38	7.85	45.88
T_6: Lamboo + Mango	4.88	6.88	41.15
T_7: Sole Mango	4.24	6.09	43.63
SEm(±)	0.03	0.04	-
CD(P = 0.05)	0.11	0.14	-

Yield of intercrops grown under different mango based agroforestry systems were slightly increased in second year (2018) as compared to first year (2017). Yield was increased by 16.48% in pigeon pea, 10.31% in maize, 14.48% in Black gram, 14.29% in Bottle gourd and 27.52% in Okra. The increase in yield in

second year was might be due to the addition of nutrients from crop residues from first year and micro flora activity in the rhizosphere. The results are supported by the findings of Mondal and Dhara (2016) and Panda et al. (2018).

Productivity of mustard in different agroforestry systems

Table 7 represents the height and yield of mustard in different agroforestry models with intercrops. The height of mustard was recorded to be highest in T_3 (Lamboo + Mango + Bottle gourd – Mustard) in both the years i.e., 102.07 m and 103.79 m, respectively followed by T_2 and T_4. The increase (%) of height of mustard was higher in all the treatments in 2018 in comparison to 2017. The highest increase was recorded in Treatment T_2 i.e., 0.88%, followed by T_3.

Table 7
Height and yield of mustard grown under different AFS model

AFS model	Height(m)			Yield(t/ha)		
	2017	2018	Increase (%)	2017	2018	Increase (%)
T_1: Lamboo + Mango + Pigeon pea	-	-	-	-	-	-
T_2:Lamboo + Mango + Black gram – Mustard	96.58	98.40	1.88	0.88	0.94	6.82
T_3:Lamboo + Mango + Bottle gourd – Mustard	102.07	103.79	1.69	0.76	0.79	3.93
T_4:Lamboo + Mango + Okra – Mustard	94.51	95.62	1.17	0.70	0.75	7.66
T_5:Lamboo + Mango + Maize –Mustard	86.44	88.07	1.89	0.58	0.67	16.09
T_6: Lamboo + Mango	-	-	-	-	-	-
T_7: Sole Lamboo	-	-	-	-	-	-
T_8: Sole Mango	-	-	-	-	-	-

The yield of mustard was recorded to be highest in (T_2 = Lamboo + Mango + Black gram – Mustard) in both the years i.e., 0.88 t $ha^{-1}$and 0.94 ha^{-1} respectively, followed by (T_3 = Lamboo + Mango + Bottle gourd – Mustard) i.e., 0.76 t ha^{-1} and 0.79 t ha^{-1} respectively. The former was followed by (T_4 = Lamboo + Mango + Okra –Mustard) in which yields were recorded to be 0.70 t ha^{-1} and 0.75 t ha^{-1} in both the years with the lowest yield to be recorded in (T_5 = Lamboo + Mango + Maize –Mustard) i.e., 0.58 t ha^{-1} and 0.67 t ha^{-1}. The lower mustard yield was attributed to the residual moisture in which mustard was grown. The yield of mustard was low because it was cultivated using by residual soil moisture without irrigation (Murmu et al. 2017).

Yield of different intercrops

The yield of intercrops in both the years was recorded and the increase in the yield of the intercrops was calculated. The increase percent in Pigeon pea was recorded to be 1.85%, blackgram showed an increase of 10.72%, bottle gourd accounted to 6.42%, okra recorded 2.20% increase and Maize showed an increase of 3.01% (Fig. 2). Figure 1 represents the height of intercrops in both the years of experiment. The increase in the height of the intercrops was recorded to be highest in blackgram i.e., 10.72%, followed by bottle gourd – 6.41% and okra – 2.20%. There was a marked increase in the height of the intercrops in the second year of the experiment.

Economic return from different Mango + Lamboo based agroforestry system models

All the mango based agro forestry systems incorporated with intercrops pigeon pea, black gram, bottle gourd, okra and maize had incurred higher economic returns in terms of income of farmers for both the years. Lamboo + Mango + Bottle gourd – Mustard system gave the highest returns in terms of income and yield of tree and intercrops in i.e., ₹6,26,159 per hectare in 2017 and ₹8,05,628 per hectare in 2018. The model consisting of Sole Lamboo gave the minimum gross income of ₹1,22,538 per hectare in 2017 and ₹1,45,573 per hectare in 2018 among all models (See Table 8 in Appendix). All the treatments were significantly different from each other when subjected to statistical analysis.

Table 8
Economics returns obtained from different AFS model

AFS model	*Production of wood (m3/ha/year)		Yield of Mango (t/ha)		Yield of Mustard (t/ha)		Production of Intercrops (t/ha)		Return from tree (₹./ha/year)		Return from fruit Crops (Mango) (₹./ha/year)		Return from Mustard crop(₹./ha/year)	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
T_1	8.40	12.09	6.42	9.56	-	-	1.55	1.72	2,518,53.47	362585.15	192500	286900	-	-
T_2	7.31	9.98	6.19	8.75	0.88	0.94	1.28	1.39	219289.78	299342.15	185800	262500	35200	37600
T_3	6.43	9.85	5.95	8.33	0.76	0.79	14.96	15.24	192825.72	295444.83	178400	249900	30533.33	31733.33
T_4	6.20	8.94	5.22	7.35	0.70	0.75	2.67	2.87	185999.76	268087.34	156500	220400	27866.66	30000
T_5	5.49	7.35	5.38	7.85	0.58	0.67	4.17	4.53	164620.06	220602.55	161500	235600	23200	26933.33
T_6	4.57	5.61	4.88	6.88	-	-	-	-	137011.66	168294.51	146300	206500	-	-
T_7	4.08	4.85	-	-	-	-	-	-	122538.54	145573.03	-	-	-	-
T_8	-	-	4.24	6.09	-	-	-	-	251853.47	362585.15	127200	182700	-	-
SEm(±)	0.45	0.92	0.03	0.04	-	-	-	-	-	-	-	-	-	-
CD(P = 0.05)	0.14	0.30	0.11	0.14	-	-	-	-	-	-	-	-	-	-

(T_1 = Lamboo + Mango + Pigeon pea; T_2 = Lamboo + Mango + Blackgram followed by Mustard; T_3 = Lamboo + Mango + Bottle gourd followed by Mustard; T_4 = Lamboo + Mango + Maize followed by Mustard; T_6 = Lamboo + Mango; T_7 = Sole Lamboo; T_8 = Sole Mango)

(*Production of Wood = Volume Yield × No. of plants grown in One ha. Farm gate Price = Lamboo - (₹30000/m^3), Mango = ₹30/kg, Mustard = ₹40/kg, Pigeon ₹15/kg, Okra = ₹20/kg, Maize = ₹60/kg)

Discussions

The complementary effect of Mango-based agro-production accompanied with inter-cropping of Pigeon pea on growth and timber volume yield of Silvi species was further elaborated by (Dupraz et al. 2019) and (Sharma et al. 2017), where the growth attributes of tree species was higher in the mango-based agro forestry model than in sole cropping. The results were similar with (Dhara and Sharma 2015) which stated that growth and productivity of tree species and fruit trees showed positive co-relation along with field crops as intercrop.

Swaminathan et al. 1999 gave the inference that mature mangoes can be successfully mixed with other similarly vigorous species such as jackfruit (*Artocarpus heterophyllus*), avocado (*Persea americana*), breadfruit (*Artocarpus altilis*), coconut (*Cocos nucifera*), guava (*Psidium guajava*), or rambutan(*Nephelium lappaceum*). About 11% increase in height growth of mango was registered when mango was interplanted with *Leucaena leucocephala*.

Dagar et al. (2014) and Dhyani (2018) reported the effect of integration of different components along with cropping for better utilization of natural resources. Murmu et al. (2023) described that short-rotation intensive silviculture offers definite potential for the reclamation of abandoned land and is therefore one of the technological options that should be considered for agricultural land in harmony with other types of agroforestry production. The findings of the soil nutrient analysis were corroborated by (Swain 2014) where it was described that the increase in available nitrogen might also be due to fixation of atmospheric nitrogen through increased enzymatic and microbial activity in the rhizosphere by the aforesaid legume crops and release of bound nutrient after their decomposition in the soil (Swain 2014). The increase in the availability of phosphorus content in the soil by intercropping might be due to increase in the total micro-flora population, particularly phosphorus solublizers in the rhizosphere of plant. More or less, similar findings on beneficial effect of intercropping in increasing phosphorus availability in the soil have been reported by (Das et al. 2022) and (Das 2021).

Trees can reduce the impacts of weather extremes such as droughts or torrential rain Kumar (2020). Research has also demonstrated that the tree component of agroforestry systems stabilize the soil against landslides and raise infiltration rates.

(Dhara 2016) advocated that Mango (cv. Amrapali / Himsagar) can be grown in New Alluvial Zone under humid climate which was established with suitable pit filling mixtures (4.0kg FYM + recommended NPK) / pit on lands for sustainable productivity supported with soil moisture conservation measure / irrigation for initial 2 years.

Kunhami and Santhosh Kumar (2012) explained the growth habit, spatial and temporal advantages that permits integration of mango with many other crops, qualifying its suitability as an agroforestry species. Traditionally mango was cultivated in conjunction with other trees/crops especially at marginal and small farming levels. At larger orchard level, mango offers wide scope for intercropping with compatible trees and arable crops. However, on the contrary heavy shade in mature mango orchards may limit the range of crops suitable for integration with mango. Extensive field trials are yet to be taken up to evaluate the performance of mango under diverse polyculture systems and to evolve suitable crop combinations for different agroclimatic conditions.

Ravitchandirane and Haripriya (2011) reported that mango intercropped with aloe and periwinkle recorded the highest yield of 15.71 and 10.91 kg tree^{-1} respectively with the supply of vermicompost @ 5 Mg ha^{-1} + groundnut oil cake @ 500Kg ha^{-1}. All the organic manurial treatments for intercrops exerted a positive influence on the yield of main crop.

Mango offers good scope for growing many shade tolerant medicinal crops. Like other plants, light demanding medicinal plants could be incorporated in mango orchards early in its development stage. Mango forms excellent avenue tree due to the evergreen nature and spreading crown that casts heavy shade. Mango based alley cropping is popular and widely followed in many parts of the world (Sharma 2016). Since mango takes several years to grow to its full size, intercropping to utilize the interspaces is desirable. (Sarkar 2019a; Sarkar et al. 2017; Sarkar 2019b) advocated that the intercrop yields increased with increase in tree row spacing (or alley width). The increasing yields of intercropping can be further supported by opinion of Das et al. (2014), who opined that the dry land horticultural fruit trees like, mango, guava etc. integrated with short duration arable crops like, pulses, vegetables, groundnut etc. proved to be the most profit oriented among different agro-production system.

A large number of intercrop under mango were tried by Tiwari and Baghel (2014) and Swain et al. (2012) where they observed good response in terms of yield and economics without any adverse effect to main crop.

The increase in income is the complementary effect of growing the intercrops in both the seasons and alongside the returns from forest species and fruit tree which adds on to the higher income of the farmers. The results were similar with Murmu et al. (2017). The integration of crops with components of tree and fruit gave higher gross income than tree and fruit tree alone Basanda et al. (2017). The findings are in conformity with Singh et al. (2016a), Singh et al., (2016a) and Singh et al. (2018) reported the effect of integration different components along with cropping for better utilization of resources.

(Dhara 2016) conducted an experiment on different agro-forestry models and established that the modern cropping system *i.e.* fruit based agro-forestry system generate higher biomass, yield more produce, provide high and steady income and create gainful on farm employment, in addition to meeting the requirements of food, vegetables and fuel for the family. The major bottlenecks in agroforestry adoption, is a resultant of best efforts made in last few years by educating, facilitating and creating water resources by the former.

The present results obtained do correlate with (Dhara 2016) who concluded that amongst the agroforestry systems demonstrated in the new alluvial region mango, guava, ber and lambo (*Dysoxylum binectariferum*) and kadam (*Anthocephalus cadamba*) based, guava, ber and mango based agri-horticultural system started fruit production after two /three years of plantation thereby giving source of addition income. He had advocated that increased area under vegetables during winters and summers is proving a big boost for fruit based agroforestry adoption according to his experiments.

Findings of Murmu et al. (2023) have reported six prominent agroforestry systems practiced in the three distinct agroecological situations. In all the three situations, bund planting was the most prominent agroforestry practiced by farmers, followed by horti-silviculture system and less prominent practice was block plantation. Mango was found as dominant fruit tree species.

Other findings were also similar with the result of the present experiment enumerated as the gross return was significantly high under mango based agroforestry system as compared with sole plantation Dhara and Sharma (2015). CAFRI (2015) and Gera and Bhojvaid (2013) also stated that intercropping with rainfed arable crops is of immense importance for bringing in quick returns during first few years of establishment of agroforestry plantation.

Agriculture and forestry with the traditional approach trying to satisfy the demand of food, fiber, timber and other products, but there is the question of production sustainability and ecological sustainability. Agroforestry is any land use system, practice or technology where woody perennials are integrated with agricultural crops and or animals in the same land management unit, in some form of spatial arrangement or temporal sequence.

From the study it is distinctly clear that the efficiency of marginal and small farms was improved in agro economic productivity with the increase of number of farming enterprises intervened in respective of farm sizes. The marginal and small farmers appeared to be the most efficient performers in the integration and arrangement of farming enterprises. Integrated farming also improved farm environment by application of compost through its production and preservation of kitchen waste by polythene pit method (Bhuiya et al. 2014).

Conclusion

All Mango-based agroforestry systems evaluated were found to be profitable in respect to tree yield, fruit yield, yield of arable crops and soil health improvement compared to sole tree or sole fruit. Agroforestry system consisting of Lamboo + Mango + Bottle gourd – Mustard can be best system for the farmers as it generated highest gross income and improvement of soil health leading towards sustainability and improvement of livelihood in rainfed and sub-tropical region of West Bengal. The other systems viz. Lamboo + Mango + Maize followed by Mustard and Lamboo + Mango + Pigeon pea also gave higher returns as compared to sole cropping, hence may be preferred over sole plantation.

Agroforestry systems are thus recognized to have the potential to regain some of the carbon lost to the atmosphere in the clearing of primary or secondary forests. The rotation ages for plantations and trees in agroforestry systems play a large role in the amount of carbon they can sequester. In mixed plantations or agroforestry systems, since rotation lengths vary within the system according to the species, a complete clearing of the plot (which would increase the release of soil carbon) is less likely. Consideration of how the biomass from managed plots is used should also play a role in the carbon equation. The recent trends in economic valuation of the ecosystem services of forests and trees, and the development of private capital markets to actually monetize the value of those services to the benefit of forest landowners, point to exciting opportunities and new developments in this area. In the face of carbon markets, C storage becomes an additional output that landowners might consider in their management decisions. This would change the dynamics of their agroforestry systems in terms of the rotation age of trees, crop-tree mixture, and silviculture and other management practices. With the introduction of carbon payments,

agroforestry systems that are otherwise less profitable may become more attractive or vice-a-versa. This suggests that research addressing both biophysical and socioeconomic issues of carbon sequestration is needed.

Declarations

Conflict of interest

The authors declare that they have no known competing financial interests regarding the publication of this article.

Contribution of each author

This work was carried out collectively by all the authors. The first author Suren Murmu designed the study, formulated the protocol, methodology, collected the data resources, formal analysis, investigation, visualization and wrote the first draft of manuscript. The second author Gayatri Kumari Padhi managed the analysis of data curation, investigation, formal analysis, figures and the tables. The third author Sachin Verma wrote the review, editing and fourth author Paritosh Murmu contributed to the evolving outline, visualization, literature resources and reviewed the editing. Fifth author Lalit Upadhyay provided input to the writing of the manuscript and investigation. Sixth author Pratap Kumar Dhara supervised the complete experiment and approved the final manuscript. All authors had read and approved the final manuscript.

Acknowledgement

The first author would like to express heartfelt thanks to Ministry of Tribal Affairs, Govt. of India, which provided National Fellowship for Scheduled Tribe, for pursuing his Ph. D programme.

Special gratitude for the Assistant Director of Research and field staffs of the AICRP on Agroforestry, Regional Research Station (Red and Laterite Zone) of Bidhan Chandra Krishi Viswavidyalaya at Jhargram, West Bengal, India for providing additional support and advice for carrying out the study. The corresponding author also grateful to Dr. Swoyambhu Man Amatya of Coordinator, IUFRO Agroforestry Unit (1.04.00) for his useful comments and devoting his precious time to provide us with information and sharing his knowledge for this study.

The research was funded by AICRP on Agroforestry and we are very much grateful to Director, ICAR- Central Agroforestry Research Institute, All India Coordinated Research Project on Agroforestry, Jhansi, Uttar Pradesh, India for providing necessary facilities to carry out this experiment smoothly.

References

1. Alam M, Olivier A, Paquette A, Dupras J, Reveret JP, Messier C (2014) A general framework for the quantification and valuation of ecosystem services of tree-based intercropping systems. Agrofor Syst 88:679–691.
2. Amatya SM, B Pandit, Subedi YR, Nuberg I, Shrestha K (2014) Survey of Agroforestry Systems in Kavre and Lamjung Districts of Nepal. Research Paper Series on Agroforestry and Community Forestry in Nepal 06:1–21.
3. Amatya SM, Cedamon E, Nuberg I (2018) Agroforestry systems and practices in Nepal. Faculty of Forestry, Agriculture and Forestry University, Rampur, Nepal.
4. Anshiso A, Woldeamanuel T, Asfaw Z (2017) Financial analysis of fruit tree based agroforestry practice in Hadero Tunto Zuria Woreda, Kembata Tembaro Zone, South Ethiopia. Res j finance account 8(3):72–80.
5. Arya D, Goel S, Shinde P, Joshi GC, Sharma OR, Sharma SK (2017) Dysoxylum binacteriferum Hook. F.: A promising herbal drug used in folk medicine by Tharu community of Uttarakhand. World J Pharmaceut Res 6(9):296–301.
6. Banerjee H, Dhara PK (2010) Evaluation of fruit-based agroforestry model for rainfed upland under red and lateritic tract of West Bengal. Crop Res (Hisar) 39(1/2/3):200–206.
7. Basanda GM, Dhara PK, Tarafdar PK (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 J Agric Res 51(1):86–89.
8. Basu JP (2014) Agroforestry, climate change mitigation and livelihood security in India. N Z J For Sci 44:1–10.
9. Bhuiya MSU, Karim MM, Hossain SMA (2014) Study on integrated farming systems model development. J Bangladesh Agril Univ 12(2):325–336.
10. Brokawa N, Thompson J (2000) The H for DBH forest. For Ecol Manag 129(1):89–91.
11. Brown S, Gillespie AJ, Lugo AE (1989) Biomass estimation methods for tropical forests with applications to forest inventory data. For Sci 35(4):881–902.
12. Calfapietr C, Gielen B, Karnosky D, Ceulemans R, Mugnozza GS (2010) Response and potential of agroforestry crops under global change. Environ Pollut 158(4):1095–1104.
13. Chaturvedi AN, Khanna LS (2000). Forest Mensuration and Biometry (3rd edn.), Khanna Bandhu, Dehra Dun, India.
14. Chaturvedi OP, Jha MK (1998) Crop production and economics under Litchi *Chinensis Sonn*. plantation across 1-to 9-year age series in north Bihar, India. Int Tree Crops J 9(3):159–168.
15. Chauhan SK, Sharma R, Dhillon WS (2012) Status of intercropping in poplar based agroforestry in India. For Bull 12(1):49–67.
16. Chavan SB, Keerthika A, Dhyani SK, Handa AK, Ram Newaj, Rajarajan K (2015) National Agroforestry Policy in India: a low hanging fruit. Curr Sci 108(10):1826–1834.
17. Condit R (1998) Tropical Forest Census Plots. Springer-Verlag B and RG Landes Company, Georgetown, Texas.

18. Dagar JC, Singh AK, Arunachalam A (2014) Agroforestry Systems in India: Livelihood Security and Ecosystem services. In: Dagar JC, Singh AK, Arunachalam A (eds.). Advances in Agroforestry, Springer Science & Business Media, New Delhi, India, pp 10:1–19.
19. Dahdouh-Guebas F, Koedam N (2006) Empirical estimate of the reliability of the use of the point-centred quarter method (PCQM): Solutions to ambiguous field situations and description of the PCQM + protocol. For Ecol Manag 228(1–3):1–18.
20. Das B, Dhakar MK, Sarkar PK, Kumar S, Nath V, Dey P, Singh AK, Bhatt BP (2017) Performance of mango (Mangifera indica) based agri-horticultural systems under rainfed plateau conditions of eastern India. Indian J Agric Sci 87(4):97–103.
21. Das GK (2021) Soil characteristics in the forest patches of Jungle Mahal in WB, India. Int J Environ Sci 10(1):81–85.
22. Das P, Dhara PK, Panda S (2022) Fruit based agroforestry systems-potential means for sustaining carbon sequestration, improving soil health and diet of community in red and lateritic zone of West Bengal, India. Int J Sci Eng Res 13(12):832–843.
23. Das R, Dhara PK, Mandal AR, Ray SKD (2014) Agri-Silvi-Fruit-Vegetable based agro-production system-suitable models for sustainable land use and conservation in Red-Laterite and Semi-Arid Tracks. Ecol Environ Conserv 20:S7-S13.
24. Dawson IK, Carsan S, Franzel S, Kindt R, van Breugel P, Graudal L, Lillesø J-PB, Orwa C, Jamnadass R (2014) Agroforestry, livestock, fodder production and climate change adaptation and mitigation in East Africa: issues and options. ICRAF Working Paper No. 178. Nairobi, World Agroforestry Centre. http://dx.doi.org/10.5716/WP14050.PDF
25. Dhara PK (2016) Mango *(Mangifera indica*) and Lamboo (*Dysoxylum binectariferum*) as boundary plantation based agri-hortisilvi system in new Alluvial zone of West Bengal. In: Chaturvedi OP, Sikka AK, Handa AK, Bajpai CK (eds.). Agroforestry technologies for different agroclimatic Zones of the country, ICAR-Central Agroforestry Research Institute (CAFRI) Jhansi, Uttar Pradesh, India, pp 71–73.
26. Dhara PK, Panda S (2019) Agroforestry Model: Gmelina and Eucalyptus based Agri-silvi-horticultural System. Successful Agroforestry Models for different Agro-ecological regions of India. ICAR-Central Agroforestry Research Institute (CAFRI) Jhansi, Uttar Pradesh, India. pp 107–112.
27. Dhara PK, Sharma B (2015) Evaluation of mango-based agroforestry is an ideal model for sustainable agriculture in red and laterite soil. J Pure App Microbio 9(Spl. Edn. 2):265–272.
28. Dhyani SK (2014) National Agroforestry Policy 2014 and the need for area estimation under agroforestry. Curr Sci 107(1):9–10.
29. Dhyani SK (2018) Agroforestry in Indian Perspective. In: Rajeshwar Rao G, Prabhakar M, Venkatesh G, Srinivas I and Sammi Reddy K (eds.). Agroforestry Opportunities for Enhancing Resilience to Climate Change in Rainfed Areas, ICAR - Central Research Institute for Dryland Agriculture, Hyderabad, India, pp 12–28
30. Dhyani SK, Handa AK (2014) Agroforestry in India: Current scenario, Indian Farming 63(11):6–8.
31. Dhyani SK, Ram A, Dev I (2016). Potential of agroforestry systems in carbon sequestration in India. Indian J Agric Sci 86(9):3–12.
32. Dixon RK, Winjum, JK, Andrasko KJ, Lee JJ, Schroeder PE. (1994). Integrated land-use systems: assessment of promising agroforest and alternative land-use practices to enhance carbon conservation and sequestration. Climatic change 27(1):71–92.
33. Do VH, La N, Mulia R, Bergkvist G, Dahlin AS, Nguyen VT, PhamHT, Öborn I (2020) Fruit tree-based agroforestry systems for smallholder farmers in northwest vietnam—A quantitative and qualitative assessment. Land 9(11):451.
34. Dumrongrojwatthana P Wanich K, Trebuil G (2020) Driving factors and impact of land-use change in a fragile rainfed lowland ricesugar palm cultural agroforestry system in Southern Thailand. Sust Sci 15: 1317–1335 https://doi.org/10.1007/s1162 5-020-00819 -<background-color:#D279AA;>5</background-color:#D279AA;>
35. Dupraz C, Wolz JK, Lecomte I, Talbot G, Vincent G, Mulia R, Bussière F, Ozier-Lafontaine H, Andrianarisoa S, Jackson Nick, Lawson G, Dones N, Sinoquet H, Lusiana B, Harja D, Domenicano S, Reyes F, Gosme M, Van Noordwijk M (2019) Hi-sAFe: A 3D Agroforestry Model for Integrating Dynamic Tree–Crop Interactions. Sustainability *11* (2293):1–25.
36. FAO (2010) Global Forest Resources Assessment. Food and Agriculture Organization of the United Nations, Rome, Forestry Paper. pp 163.
37. Gera N, Bhojvaid PP (2013) Promoting livelihood and economic growth through agroforestry: ICFRE endeavours. Indian J Agrofor 15(2):85–99.
38. Gomez KA, Gomez AA (1984) Statistical procedures for agricultural research. An International Rice Research Institute Book (2nd edn). A Wiley-Inter Science Publication (John Wiley and Sons), New York, pp 20–30.
39. Hemrom A, Nema S (2015) A study on traditional agroforestry practices existing at Bastar region of Chhattisgarh. Int J Multidiscip Res Dev 2(3):56–64.
40. Hombegowda HC, Adhikary PP, Jakhar P, Madhu M (2022) Alley Cropping Agroforestry System for Improvement of Soil Health. In: Shit PK, Adhikary PP, Bhunia GS and Sengupta D (eds). Soil Health and Environmental Sustainability, Environmental Science and Engineering, Springer Nature, Switzerland. pp 529–549.
41. ICAR– CAFRI. (2015). Vision 2050. ICAR-Central Agroforestry Research Institute: Jhansi, Uttar Pradesh, India, pp 146.
42. ICAR– CAFRI. Annual report (2021). All India Coordinated Research Project on Agroforestry, ICAR-Central Agroforestry Research Institute: Jhansi, Uttar Pradesh, India, pp 42.
43. IPCC report (2021). Climate Change 2021: The physical science basis. Working Group I contribution to the sixth assessment report of the intergovernmental panel on climate change. Intergovernmental Panel on Climate Change (IPCC), Switzerland.
44. Jackson ML (1973) Soil chemical analysis. Prentice Hall of India Private Limited, New Delhi. pp 498.
45. Kaur N, Singh B, Gill RIS (2017) Productivity and profitability of intercrops under four tree species throughout their rotation in north-western India. Indian J Agron 62(2):160–169.
46. Koul DN, Panwar P (2012) Soil carbon buildup and bioeconomics of different lanuduses in humid subtropics of West Bengal, India. Ann For Res 55(2):253–264.

47. Kumar PN (2020) Effect of intercropping on fruit crops: A review. Int J Curr Microbiol Appl Sci 9(12):745–755.
48. Kunhami TK, Santhosh kumar AV (2012) Mango in agroforestry, mango- production and processing technology (VOL-1:51), stadium press llc, Houston, USA, pp 1–11.
49. Leakey, R. B. (2012) Multifunctional agriculture and opportunities for agroforestry: implications of IAASTD. In: Nair PK, Ramachandran and Garrity, Dennis (eds). Agroforestry: the future of global land use. Advances in Agroforestry, Springer Publishers, New York, USA, pp 203–214.
50. Lindara, LMJK, Johnsen FH, Gunatilake HM (2006) Technical efficiency in the spice based agroforestry sector in Matale district, Sri Lanka. Agrofor Syst 68:221–230.
51. Mondal S, Palit D (2022) Challenges in natural resource management for ecological sustainability. In: Jhariya MK, Meena RS, Banerjee A, Meena, SN (eds.). Natural Resources Conservation and Advances for Sustainability, Elsevier, pp 29–59. https://doi.org/10.1016/B978-0-12-822976-7.00004-1.
52. Mondal U, Dhara PK (2016) System for sustainable agriculture in New Alluvial Zone of West Bengal, India. J Res Innov Manag Sci 2(4):26–37.
53. Monim MA, Islam ABMS, Rahman AKMA, Monim ASMA, Quddus, MA. (2010) Effect of intercropping different vegetables with groundnut. J Agrofor Environ 4(1):27–30.
54. Murmu S, Chowdary KA, Roy D, Patra BC, Dhara PK (2017) Productivity and Soil Fertility Status of Mango-Based Agroforestry System in Red and Laterite Zone of West Bengal. Curr J Appl Sci Technol 25(3):1–8.
55. Murmu S, Dhara PK (2022) Effective Food Safety and Land Use Management by Tribal Farmers through Agroforestry Practices. In: Ghatak A, Vishwakarma Ramanuj, Prakash N and Kumar R (eds). Crop Protection-driven Food Safety and Security, Scientific Books Publisher, Delhi, India, pp 303–308.
56. Murmu S, Dhara PK, Roy D (2016) Agroforestry: A sustainable agro-technique for red and laterite zone of West Bengal. J Agroecol Nat Resour Manag 3(3):280–283.
57. Murmu S, Padhi GK, Murmu P, Roy D, Dhara PK (2022) Potential of Different Fruit-Based Agroforestry Models for Improving Livelihood in Humid and Subtropical Regions of India. Indian J Ecol 49(5) (SI): 1861–1869 https://doi.org/10.55362/IJE/2022/3748
58. Murmu S, Padhi GK, Roy D, Verma S, Murmu P, Upadhyay L, Amatya SM, Dhara PK (2023) Agroforestry Systems as a Substantial Improvement Strategy for Climate Resilience, Food Security and Enhancement of Socio-Economic Strata of Tribal Farmers of Humid and Sub-Tropical Forests of India. In: Kothandaraman S, Prakash A Jaya, Paramanik S, Kumar S and Sen Arnab (eds.). "Commemorating the UN's Decade on Ecosystem Restoration" on Biodiversity and Climate Change-Sustainable Development Perspective, 3rd International Workshop 16-19th February 2023, IIT Kharagpur, West Bengal, India, pp 197.
59. Nag SK, Ghosh DB, Nandy S, Aftabuddin M, Sarkar UK, Das BK (2023) Comparative assessment of carbon sequestration potential of different types of wetlands in lower Gangetic basin of West Bengal, India. Environ. Monit. Assess 195(1):153–168.
60. Nair PKR, Nair VD (2014) 'Solid–fluid–gas': the state of knowledge on carbon-sequestration potential of agroforestry systems in Africa. Curr Opin Environ Sustain 6:22–27.
61. National Agroforestry Policy (2014). Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India.
62. Negash M, Starr M (2015) Biomass and soil carbon stocks of indigenous agroforestry systems on the south-eastern Rift Valley escarpment, Ethiopia. Plant Soil 393:95–107.
63. Newbould PJ (1967) Methods for estimating the primary production of forests. IBP Handbook No. 2. Blackwell Scientific Productions, Oxford and Edinburgh.
64. Panda S, Dhara PK, Sarkar S, Das NC (2018) Agroforestry: A Multipurpose Multi – Storeyed Renewable Plant Treasure with Medicinal Values Giving Multi – Returns for Livelihood and Benefits Over Climate Change. In: Pandey CB, Gaur MK, Goyal RK (eds.). Climate Change and Agroforestry: Adaptation, Mitigation and Livelihood Security, New India Publishing Agency; New Delhi, India, pp 627–637.
65. Parcha V, Gahlot M, Kaur J, Tomar Y (2004) A review on phytochemical and pharmacological studies of Dysoxylum species. J Nat Remedies 4/1:1–11.
66. Rathore AC, Saroj PL, Lal H, Sharma NK, Jayaprakash J, Chaturvedi OP, Raizada A, Tomar JMS, Dogra P (2013) Performance of mango based agri-horticultural models under rainfed situation of Western Himalaya, India. Agrofor Syst 87:1389–1404.
67. Ravitchandirane V, Haripriya K (2011) Intercropping with medicinal plants in mango cv. Alphonso. Plant Arch 11(1):413–416.
68. Rijal S (2019) Agroforestry System: Approaches For Climate Change Mitigation And Adaptation. Big Data in Agriculture 1(2):23–25.
69. Sarkar PK (2019a) CO2FIX model: A tool for estimating carbon sequestration potential of any agroforestry system. Agriculture & Food: e-Newsletter 1(3):61–66.
70. Sarkar PK (2019b) Improving livelihood through agarwood (*Aquilaria malaccensis* Lam.) based agroforestry systems: An option. Agriculture & Food: e-Newsletter 1(6):139–147.
71. Sarkar PK, Das B and Bhatt BP (2017). Bakain (*Melia azedarach* L.): a promising agroforestry species for improving livelihood to farmers of Eastern plateau and hill region of India. BioScan 12(2):1095–1100.
72. Sharma B (2016) Studies on effects of agroforestry on productivity and physico-chemical properties of red and laterite soil of West Bengal Dissertation, Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India.
73. Sharma B, Tripathi SK, Dhara PK, Kumari P, Meena SK, Kumari R Kumar A (2017) Comparative Study of Mango Based Agroforestry and Mono-Cropping System under Rainfed Condition of West Bengal. Int J Plant Soil Sci 15(2):1–7.
74. Singh AK, Gohain I, Datta M (2016) Upscaling of agroforestry homestead gardens for economic and livelihood security in mid–tropical plain zone of India. Agrofor Syst 90:1103–1112.

75. Singh SK, M Sharma, Singh PK (2016a) Combined approach of intercropping and INM to improve availability of soil and leaf nutrients in fruit trees. J Chem Pharm Sci 9(2):823–829.
76. Singh SK, M Sharma, Singh PK (2016b). Intercropping- An approach to reduce fruit drop and improve fruit quality in guava. J Chem Pharm Sci 9(4):3182–3187.
77. Singh SK, Singh SK, Singh S (2018) Vegetable crops as most efficient and economical intercrops: a brief review. Plant Arch 18(1):923–929
78. Swain SC (2014) Performance and profitability study of different mango based intercropping systems in Eastern ghat high land zone of Odisha. J Crop Weed 10(2):170–178.
79. Swain SC, Dora DK, Sahoo SC, Padhi SK, Sanyal D (2012) Influence of Mango-Based Intercropping Systems on Improvement of Soil Health under Rainfed Situation. Commun Soil Sci Plant Anal 43(15):2018–2026.
80. Swaminathan C, Dhanakodi CV, Mariappan S (1999) Early growth performance of mango and cashew co planted with four nitrogen fixers in a tropical alfisol. J Sustain For 8(2):15.
81. Tiwari R, Baghel BS (2014) Effect of intercropping on plant and soil of Dashehari mango orchard under low productive environments. Asian J Hort 9(2):439–442.
82. Toppo P, Raj A (2018) Role of agroforestry in climate change mitigation. J Pharmacogn Phytochem, 7(2):241–243.
83. Walkley A, Black CA (1934) An examination of the different method for determining soil organic matter and proposed modification of the chromic acid titration method. Soil Sci 37(1):29–38.
84. Winrock (1977). A guide to monitoring carbon storage in forestry and agroforestry projects. International Institute for Agricultural Development, Forest Carbon Monitoring and Verification Services Winrock, USA.
85. Wolpert F, Quintas-Soriano C, Plieninger T (2020) Exploring land-use histories of tree-crop landscapes: a cross-site comparison in the Mediterranean Basin. Sust Sci. https://doi.org/10.1007/s1162 5-020-00806 –w
86. Woomer PL (1993) Impact of cultivation of carbon fluxes in woody savannas of Southern Africa. Wat Air and Soil Poll 70(1–4):403–412.

Figures

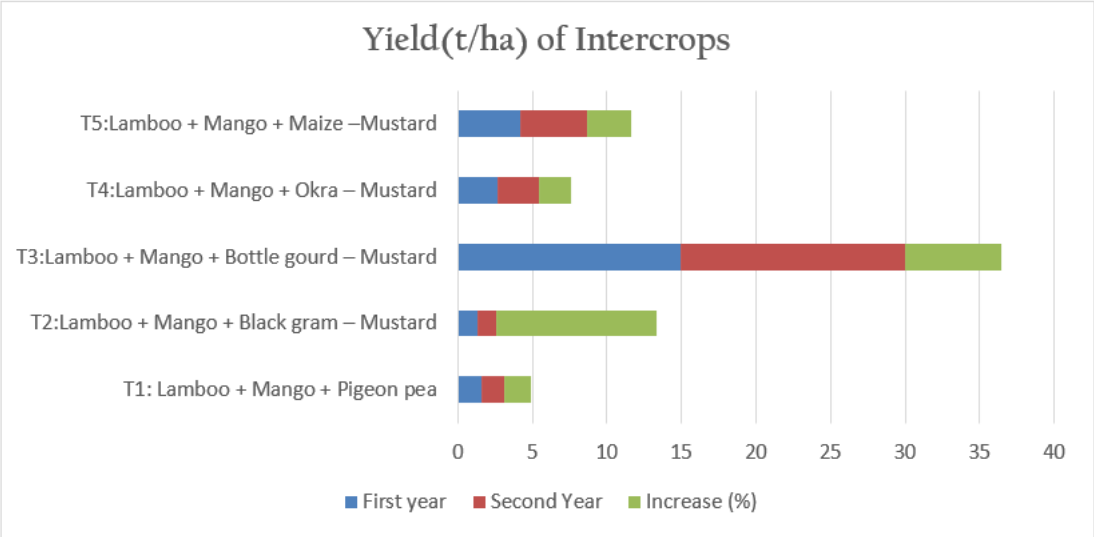


Figure 1

Yield of different intercrops grown under different AFS model

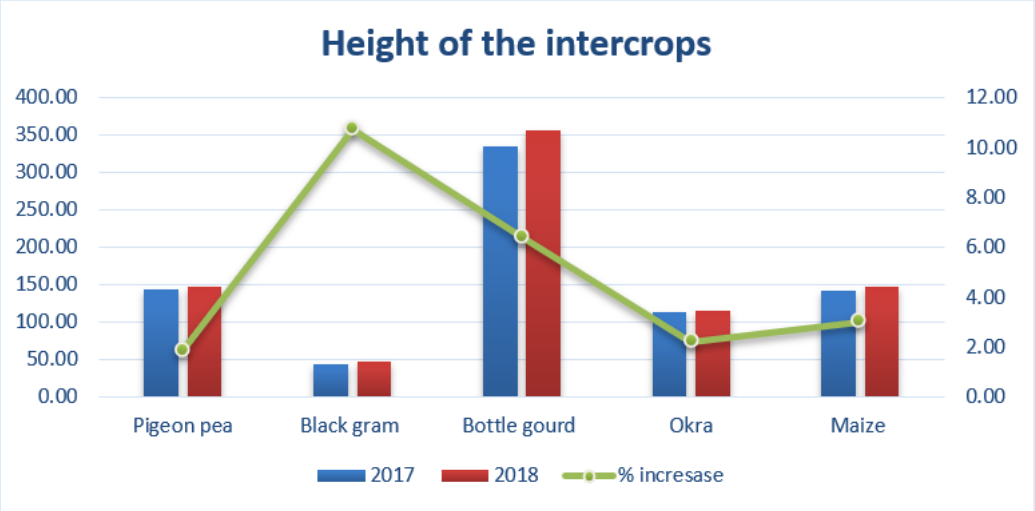


Figure 2

Height of different intercrops grown under different AFS model