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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

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Abstract— Fruit-based agroforestry systems (AFS) can assure food security towards Sustainable Development Goals (SDGs), and improvement in carbon sequestration, soil qualities of low-fertile degraded land. Those were revealed through observations on farmers' practices, literature reviews and results from different agroforestry arrangements of mango with *gamhar* and eucalyptus; and sweet orange with *gamhar* for two years (2017-18 to 2018-19) of alley cropping with pigeon pea, green gram, cowpea and toria in ongoing AF experiments at Regional Research Station (Red & Lateritic Zone), Bidhan Chandra Krishi Viswavidyalaya, Jhargram, West Bengal, India. Total carbon stock as well as potential food energy production were higher in AFS than either in sole silvi tree, fruit tree or plots under alley crops, because of better performances of all tree and crop components in AFS. Mango with eucalyptus-based AFS gave higher carbon stock (62.33 t ha^{-1} yr^{-1}) including improvement in degraded acidic soil pH (6.20%), SOC (11.86%), available N (9.09%), available P (13.97%), available K (11.64%) contents in soil. In that way, fruit-based agroforestry systems can be used as a viable alternative land use to improve soil health, diet and livelihood security even of resource-poor farm families throughout the year, especially during their impoverished needy times in a year.

Index Terms— agroforestry system, alley crop, carbon sequestration, food energy, livelihood, red and lateritic zone, SDGs, soil health

1. INTRODUCTION:

Fruit-based agroforestry is a suitable alternative land use to be successfully followed in agricultural system to make farming more profitable and a support for protection of agricultural lands from degradation and, thereby sustaining food production as well as securing suitable change in diet in farming community and the local population as a whole through food production from initially almost barren rainfed upland with low fertile soil in red and lateritic tract of West Bengal in India. Selecting the present study on suitability of fruit-based AFS was ascertained on the basis of i) observations on practices of AFS on farmers' land and ii) the literature survey, concerning (a) fruit-based agroforestry as the potential means for considerable carbon sequestration, (b) improvement in soil physicochemical and soil fertility status through fruit-based AF, (c) fruit-based AF as a potential support to change the diet of the local people through production of pulses, oilseeds, fruits in contrast with a change from traditionally monocropped rainfed low and rice growing area and mostly barren upland lateritic tract, (d) potentiality of fruit-based AF for enhancing livelihoods of the farming community through production of timbers as enumerated in Background information.

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1.1 Background information: This is based on (i) field surveys on farmers' practice and (ii) literature reviews

1.1. (i) From the field surveys on farmers' practices: Trees are still associated with modern farming community and civilisation as we see planting of trees by the road sides and along the boundary of farming plots. As the farming is extended around a tree, sometimes that tree is left out to grow bigger. Though except fruit trees farmers hardly prefer to plant trees within their agriculture plots. The Red and Laterite Agroclimatic Zone, selected for the present works, is predominantly under rice – fallow cropping pattern under rainfed condition on low land; and rice – vegetable cropping pattern with adequate irrigation facilities in medium to low land situations. Uplands are mostly non-fertile and cultivated with pigeon pea, black gram and other pulses as rainfed crops. The multipurpose trees are found scattered in farmers' fields with greater concentration on the field bunds and boundaries. From the present investigation it has been observed that there was predominance of marginal category of farmers having fragmented landholdings with average farm size of less than 1 ha. In that agroclimatic zone, various agroforestry models with different silvi (i.e., wood producing) trees/ fruit tree - crop combinations were studied under rainfed conditions at the Regional Research Station of Bidhan Chandra Krishi Viswavidyalaya at Jhargram, West Bengal, India. In that on-station research, various multipurpose silvi tree species such as lamboo (*Dysoxylum binectariferum*), kadam (*Neolamarckia cadamba*), eucalyptus (*Eucalyptus tereticornis*), akashmoni (*Acacia auriculiformis*), *gamhar* (*Gmelina arborea*), teak (*Tectona grandis*), *sal* (*Shorea robusta*), *nim* (*Azadirachta indica*), etc. have tremendous potential in those different agroforestry systems. Similarly, among fruit trees mango (*Mangifera indica*), guava (*Psidium guajava*), cashew (*Anacardium occidentale*), ber (*Ziziphus mauritiana*) and sweet orange (*Citrus sinensis*) were more successful in that zone. Moreover, agricultural inputs along with good planting materials of silvi and fruit trees are required to be made easily available to the farmers for successful adoption of agroforestry [1,2]

1.1. (ii) Literature Review: This is noted under sub-sections of (a), (b), (c) and (d).

1.1.(ii). (a) Fruit-based agroforestry - potential means for considerable carbon sequestration: Agroforestry (AF) is a desirable and promising option for carbon sequestration in agricultural soils, because it may retain substantial amounts of carbon as well as giving agricultural outputs [3]. Agroforestry is essential for reducing the atmospheric build-up of GHGs [4]. For complicated agroforestry, border planting, hedgerow intercropping, and home gardens (i.e., homestead agroforestry), carbon sequestration rates are highly encouraging [5,6]. Agroforestry systems including fuelwood, and fibre plantations, bioreserves, intercropping systems, and shelterbelts/ windbreaks are additional promising land-use systems and techniques that have been discovered to preserve and/ or temporarily store C [7]. Tree-based land-use systems have been recognized as an effective strategy across all ecological regions and farming situations and the most effective farmer-friendly technology to control greenhouse gas emissions [8]. The eucalyptus stands are also real carbon sinks, with the amount of carbon stored varied with the age of the parcels, 20 (+) year old stand of eucalyptus might store eight times the CO_2 emissions than from a degraded savannah [9]. Although agroforestry systems (AFS) are not primarily designed for carbon sequestration, there are many recent studies to substantiate the evidence that agroforestry systems can play a major role in storing carbon in aboveground biomass [10] as well as in belowground biomass [11,12].

1.1.(ii). (b) Improvement in soil physicochemical and soil fertility status through fruit-based AF: Fruit-based agroforestry systems that were integrated with the growth of arable crops like pulses along with fruit trees, and silvi components, could preserve nutrients in soil and reduce the risks of soil erosion from crop fields with marginal soil fertility [13]. The cultivation of intercrops of sorghum, groundnut, and papaya along with teak (*Tectona grandis*) based agri-silviculture system in red gravely soils in Karnataka, India improved soil fertility over the years as well as increased soil bulk density, pH, soil organic carbon, (SOC), potassium, and phosphorus due to incorporation of leaf litterfall and subsequent decomposition of litter in soil [14]. *Gamhar* (*Gmelina arborea*) + sweet orange (*Citrus sinensis*) + groundnut (*Arachis hypogaea*) - based agroforestry model showed highest increases in nearly all the soil parameters like organic carbon percent, pH, available N and P after three cycles of cropping. *Gamhar* (*Gmelina arborea*) + guava (*Psidium guajava*) + groundnut (*Arachis hypogea*)-based agroforestry model came in the second place for enhancing soil fertility caused by interactions between different tree species and intercrops [15]. From research at three locations in the southeastern U.S. it was reported that short-rotation woody and herbaceous crops have a significant potential to store carbon in their underground components when conventional agricultural areas were converted to their cultivation. For those perennial crops, crop cycles lasting for 5 to 20 years showed the ability to store soil carbon underground for a very long time. Large-scale perennial root systems and litter layers appeared to be the key contributors for increasing carbon sequestration [16]. In coconut (*Cocos nucifera*)-based gliricidia (*Gliricidia sepium*) systems, plots under gliricidia differed in their soil chemical attributes and showed added higher levels of soil nutrients when compared to plots under coconut monocrop at younger ages and that system was highly potential to improve poor soil characteristics particularly in drier agroecosystems [17]. Tree-based systems were highly potential to increase SOC stocks especially at deeper depths as well as in soils beneath the trees. SOC stocks within the 1.25 m depth of soil were observed to be 16 percent higher compared to the adjacent field [18]. Alley cropping deals with growing of crops on the same piece of land within the interspaces under the trees. One of the most important properties of alley cropping is that the addition of organic mulch, especially nutrient-rich mulch, has a favourable effect on the physical and chemical properties of soil and on crop productivity [19].

Thus, fruit-based AFS can perform a vital role in enhancing and maintaining soil fertility, assuring food security reducing poverty, preserving the environment, and sustainability in food production.

1.1.(ii). (c) Fruit-based AF as a potential support to change the diet of the local people through production of pulses, oilseeds, fruits in contrast with a change from traditionally monocropped rainfed low and land rice growing area and mostly barren upland lateritic tract: Fruit-based agroforestry has an important role in production of vegetables, pulses with fruit, and providing nutritionally balanced diets rather than calories alone [20]. In the red and lateritic zone, marginal lands are not able to sustain arable crops particularly during the drought years with some kinds of land degradation. In such agricultural landscape under red and lateritic rainfed upland, integration of economic trees in agriculture on a massive scale would create an effective income generation and sustainable crop production year after year and could improve and maintain good health of human beings [21]. Under the fruit-based AF system, fruit trees could be grown successfully with legumes like pigeon pea, black gram and cowpea as bonus crops for marginal and sub marginal lands for providing an economic alternative system along with improvement of soil health [22]. Fruit trees serve the human beings with the supply of nutrients through production of fruits and also provide valuable by-products like fuel wood and fodder from their annual pruning. Yield of all intercrops were more in agroforestry systems as compared to sole crop cultivation. In red and lateritic tract of West Bengal in India, among all the intercrops cowpea showed better performance with production potentiality of 1.94 t ha^{-1} under *gamhar* + sweet orange-based agroforestry systems as compared to *gamhar* (*Gmelina arborea*) + guava-based agroforestry system with 1.84 t ha^{-1} production [23]. Yield of pigeon pea was slightly higher in sole cropping (1.65 t ha^{-1}) than under AF systems. Most of the growth parameters, yield attributes and yields of pigeon pea were higher under *karanj* (*Pongamia pinnata*) plantation as compared to under *neem* (*Azadirachta indica*) plantation [24]. Under agri-horti system at Barkachha, Mirzapur of U.P. in India, higher grain yield (0.92 t ha^{-1}), stover yield (1.86 t ha^{-1}) of green gram could be achieved by following conventional method of two hand weedings at 20 and 40 days after sowing (DAS) as compared to other intercultural techniques where labours are easily available [25]. Among the different models of agro-production system, yield of winter season crop like mustard showed better result (0.65 t ha^{-1}) under *gamhar* + mango – okra – mustard AFS, and yield of mango was higher (3.28 t ha^{-1}) when pigeon pea was cultivated with fruit and silvi species in rainfed uplands under red and laterite zone of West Bengal in India which were supposed to improve and maintain good health of the local community through reducing the deficiency of nutrients by producing fruits, pulses and oilseeds [26]. It was also reported that growing of *gamhar* and mango trees with pigeon pea as intercrops resulted in higher fruit yield of mango and better growth characteristics of *gamhar* tree in red and lateritic zone of West Bengal [27]. Yield of sweet orange (994 dozen ha^{-1}) was maximum in *gamhar* + sweet orange + cowpea-toria combination under the humid and sub-humid zone (i.e., red and lateritic tract) of West Bengal in India [28]. Pulses are among the most widely used foods around the globe, and are considered as the power house of nutrients with rich source of dietary fibre, complex carbohydrates, starch, minerals such as potassium, iron, zinc. Consumption of half a cup of beans or peas per day can enhance diet quality and improve global nutrition [29]. Besides, the inclusion of mustard oil could improve digestive system and maintain the heart health [30]. Fruits and vegetables can also play a key role in diet by providing essential minerals, micronutrients and vitamins and dietary fibre required for the normal daily functionality of the body [31]. It is reported that calorific (or energy) values of 100g pulses like pigeon pea, cowpea, green gram and oilseed like mustard could provide 358, 320, 326 and 510 Kcal respectively for human body [32]. Besides the gross and digestible energies of 100g mango flesh (var. *Amrapali*) was 112.12 Kcal [33]; and 100g edible portion of sweet orange could provide 43 Kcal, making diet healthy for human beings [34].

So, the red and lateritic agroclimatic zone of West Bengal in India is characterised by most of the barren uplands, and lowland with rice cultivation in rainy season. Previous works in that agroclimatic zone has revealed that adoption of fruit-based agroforestry system can be successfully practised on uplands of that agroclimatic zone to meet the requirements of essential nutrients and calories due to changes in diet of local community of adjacent area through production of fruits, pulses and oilseeds from the same piece of primarily barren land.

1.1.(ii). (d) Potentiality of fruit-based AF for enhancing livelihoods of the farming community through production of timbers: Out of various types of agroforestry systems, a fruit-based agroforestry system is regarded as a successful tactic for enhancing agricultural production, employment possibilities, economic and nutritional security [1, 2]. In that farming system, fruit production can supplement a farmer's income during a drought; and silvi tree plantation would prevent sand drift, supply animal feed, fuel, and timber (i.e., wood sale as a financial support in the emergent needy times for a family), as well as that AF farming would serve for creation of favourable microclimates that are conducive to agricultural growth. It is reported from the mid-west of the United States of America that the combinations of maize (*Zea* mays) with other crops *viz*., maize + soybean (*Glycine max*), and maize + soybean + wheat (*Triticum aestivum*) gave walnut (*Juglans nigra*) stands of highest net values. But pure walnut stands outperformed agroforestry systems based on walnut trees, with spacing of 8.5 m vs. 12.2 m between rows, essentially restricting yearly crop productivity [35]. From a field study during the years of 2014 – 15 and 2015 – 16 in the semi-arid region of Haryana in India, it was reported that among all the agricultural crops planted in eucalyptus plantations, oat crop had the highest net returns (Rs. 26,535 and 14,580 ha^{-1} respectively in those two years), closely followed by berseem (Rs. 8693 and 7086 ha^{-1} respectively in those two corresponding years). Thus, oat crop grown under eucalyptus plantation gave highest benefit followed by berseem [36]. A mango-based agri-horticulture system produced fruits with a B:C ratio of 2.85 or higher after 5 years of planting in Bhubaneswar, Odisha, India [37]. Adoption of agroforestry in any specific location are decided based on two factors *viz*. relative profitability compared to other existing cropping systems and securing livelihoods from price volatility of farm products by wood production, and for that reason farmers in many areas of India are growing trees in farm as a more profitable option in contrast with monocropping system [38]. Agroforestry increased farmers' incomes through production of cash crops and enhancement of the biomass of trees, which, in turn, helped to increase the standard of living, economic growth and development of farm families [39]. After reviewing the results from various long term field trials throughout the world, it has been found that in a same piece of land fruit-based agroforestry system could give good production of arable crops, wood and the production of fruits to make extra income for farmers even in severe climatic events, that helped the rural people to meet their family expenses [40].

From all those surveys from farmers' practices on AFS and review of research it can be conjectured that fruit-based AF can support sustainable food production and circular bioeconomy, thereby such farming is able to face threats and challenges in achieving SDGs in a transversal way towards attaining food security on a degraded low fertile lateritic area through rainfed farming. Those surveys have also revealed that such alternative farming like fruit-based AFS can be of help in sustainably improving livelihood support even in improving impoverished needy times of farming community in a year. Based on such background the aims of the current study are enumerated.

1.2 Aims of the current study:

i) To establish that fruit-based AFS is the potential means for considerable carbon sequestration,

ii) To show that soil physicochemical health and soil fertility status can be improved through fruit-based AFS,

iii) To show that fruit-based AFS is a potential support to change diet through production of pulses, oilseeds, fruits in contrast with a change from traditionally monocropped rainfed low and land rice growing area and mostly barren upland lateritic tract.

iv) To show the potentiality of fruit-based AFS for enhancing livelihoods of the farming community by AF produces including timbers from such farming.

2. Materials and methods:

A Field experiment was conducted during 2017-18 and 2018-19 under rainfed condition on upland of red and lateritic soil covered with established agroforestry plantations at the Regional Research Station of Bidhan Chandra Krishi Viswavidyalaya, Jhargram, West Bengal, India. That research station is geographically situated at 22°27'23.22'' N Lat. and 87°00'43.24'' E Long. at an elevation of about 78.77 m above mean sea level.

Fruit-based AFS of ten years old stands of *Amrapali* var. of mango trees (*Mangifera indica*) with ten-year-old stands of eucalyptus trees (*Eucalyptus tereticornis*) and with ten-year-old *gamhar* trees (*Gmelina arborea*); and three years' stand of sweet orange (*Citrus sinensis*) with ten years old stand of *gamhar* were selected for the present study. Mango and sweet orange were planted at a spacing of 10 m × 10 m. However, *gamhar* or eucalyptus were planted in between two fruit trees in rows at 5 m spacing. The crops *viz*., pigeon pea (*Cajanas cajan*) *var*. *UPAS 120*, green gram (*Vigna radiata*) *var*. *Samrat,* and cowpea (*Vigna unguiculata*) *var*. *Birsha Shweta* were cultivated during *kharif* season (i.e., monsoon season: mid-July to end of September), followed by toria (*Brassica campestris*, *var*. toria) *var*. *B85* in *rabi* season (non-monsoon season: October to March) in the experimental plots after harvesting of green gram and cowpea. The experiment was laid out in a randomized block design (RBD) with twenty treatments with three replications as follows:

T_1: *Gamhar* + sweet orange + pigeon pea, T_2: *Gamhar* + sweet orange + green gram-toria, T_3: *Gamhar* + sweet orange +cowpea-toria, T_4: *Gamhar* + mango + pigeon pea, T_5: *Gamhar* + mango + green gram-toria, T_6: *Gamhar* + mango + cowpea-toria, T_7: Eucalyptus + mango + pigeon pea, T_8: Eucalyptus + mango + green gram-toria, T_9: Eucalyptus + mango +cowpea-toria, T_{10}: *Gamhar* + sweet orange, T_{11}: *Gamhar* + mango, T_{12}: Eucalyptus + mango, T_{13}: Gamhar, T_{14}: Eucalyptus, T_{15}: Mango, T_{16}: Sweet orange, T_{17}: pigeon pea, T_{18}: Green gram-toria, T_{19}: Cowpea-toria, T_{20}: Barren field (control).

2.1 Calculation of wood volume:

2.1.1 Calculation of wood volume of both silvi and mango fruit trees by allometric methods:

To estimate wood volume of the silvi trees and mango trees some tree growth parameters like height, bole height, diameter at breast height (DBH) were considered. Among those parameters DBH of the trees was measured at 137 cm above the tree-base at ground level with the help of a measuring tape [41,42,43].

2.1.2 Calculation of wood volume of sweet orange fruit trees:

Calculation of volume of standing sweet orange fruit trees was done by following the quarter girth formula as shown in Eq.1 [44].

$$\textbf{Volume of tree log, } V = (g/4)^2 \times L \quad (1)$$

where V is volume of the tree trunk, g is basal girth and L is the length of tree trunk.

2.2 Calculation of above ground biomass:

Total trunk or log biomass in kilograms was calculated by multiplying the volume of the log (V) by the wood density (WD) corresponding to each tree species as estimated through Eq. 2.

$$\text{Biomass} = V \times WD \times 1000 \quad (2)$$

For obtaining total above ground biomass of trees, the value of biomass from Eq. 2 was added with biomass of litter and biomass from necessary pruning of canopies. For estimating total above ground biomass of fruit trees, total biomass estimated from Eq. 2 was added with litter and biomass from necessary pruning of canopies of trees and fruit biomass.

2.3 Estimation of belowground biomass:

2.3.1 Estimation of root biomass:

Roots play an important role in the carbon cycle as they transfer considerable amounts of C to the ground and C remains there in soil for a relatively long period of time [45, 46, 47]. Generally, non-destructive (or, conservation) method was followed to calculate the belowground biomass by using the Eq. 3 [48].

$$\text{Belowground biomass} = \text{Aboveground biomass} \times 0.2. \quad (3)$$

2.4 Carbon stock as biomass:

To calculate the carbon stock as biomass, the Eq. 4 [49] was used, as generalized for conversions from biomass to carbon stock.

$$C = 0.50 \times \text{biomass} \quad (4)$$

2.4.1 Carbon stock as crop biomass:

To calculate the carbon stock as crop biomass, Eq. 5 [50] was used, as generalized for conversions from crop biomass to carbon stock.

$$C = \text{Crop biomass} \times 0.45 \quad (5)$$

2.4.2 Total carbon sequestration under AFS:

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 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 Eq. 6.

$$\text{SOC (t/ha)} = \text{OC (\%)} \times \text{BD (g/cm}^3) \times \text{Depth (cm)} \times 100 \quad (6)$$

The total carbon stock for the present land use was calculated by using Eq. 7

$$\text{Carbon stock (total)} = \text{C as total agroforestry biomass} + \text{SOC} \quad (7)$$

2.5 Soil analysis:

2.5.1 Collection and analysis of soil samples:

Soil samples were collected before experimentation and after every cropping season from soil depth of 0-15 cm (i.e., considering root zone of alley crops) with the help of soil auger. The collected soil samples were completely air-dried in the shade at room temperature and were ground by a wooden mortar to break the soil aggregates and were passed through 0.5 mm sieve for analysis of SOC and 2 mm sieve for other soil physicochemical parameters and then analysed [51].

Soil pH was measured by using a pH Meter [52]. Soil organic carbon (OC) was estimated by wet digestion method [53]. Estimation of available nitrogen in soil samples as mineralizable nitrogen [54] was performed by using nitrogen analyser. As soil pH was acidic, Bray No.1 method was used for analysis of available phosphorus in soil [55]. Soil available potassium was analysed by ammonium acetate method [56].

Increment in values of soil analysis (d %) from the control was computed through the Eq. 8 [57].

$$d = (y \sim c)/c \times 100 \quad (8)$$

The difference between soil data was recorded as initial (c) and end of experiment data (y).

2.6 Economic analysis of fruit-based AFS:

The economics of different treatments was worked out separately by taking into account of the existing local market price of various inputs and outputs for identifying

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the most remunerative treatment. The investment on fertilizer, labour and power for various farming operations such as ploughing, weeding, irrigation, picking/ harvesting (in ₹ ha^{-1}) were considered. The cost of cultivation was calculated for finding out the economics of treatments and to work out the economic return per hectare (in ₹ ha^{-1}) and for estimation of benefit: cost ratio for each individual treatment.

Gross returns were obtained by converting the economic harvest into monetary values as per prevailing market price during the course of studies for every treatment. Net return was obtained by subtracting cost of cultivation from gross return and the benefit: cost ratio was calculated on the basis of net return per unit cost of cultivation by using Eq. 9.

$$\text{B:C ratio} = \frac{Gross\ return/ha}{Cost\ of\ cultivation/ha} \quad (9)$$

2.7 Statistical analysis:

Critical differences were calculated from data assembled from each observation and were analysed for assessing the significance of treatment means considering F-values being significant at 5% level of probability [58]. Data processing was carried out with OPSTAT software [59].

3. Results and discussion:

3. (i) Fruit-based AFS – the potential means for carbon sequestration in red and lateritic zone: Fruit-based AFS plots of sweet orange-*gamhar*, mango-*gamhar* and mango-eucalyptus intercropped with green gram – toria showed higher carbon sequestrations than in plots under sole fruit trees, sole silvi and sole crops. After the analysis of total carbon stock in different fruit-based AFS, it was found that mango-eucalyptus based AFS sequestrated higher carbon as compared to both the mango-*gamhar* and sweet orange-*gamhar* based AFS **(Table 1)**.

3. (ii) Fruit-based AFS – the potential means for improvement of soil physicochemical status, soil health and fertility in red and lateritic zone: The agroforestry system showed increase in soil pH as compared to sole experimental crop plots, whereas barren land of red and laterite soil on upland was unaffected or continued with decreasing trend in soil degradation **(Figure 1)**. Mango with *gamhar*-based agroforestry systems showed higher soil pH, as compared to sweet orange with *gamhar* and mango with eucalyptus-based AF systems. Among the three legumes, pigeon pea played a vital role in increasing soil pH in fruit-based agroforestry systems. The mango and sweet orange-based agroforestry systems enhanced the status of SOC **(Table 1, Figure 2)** and major available soil nutrients i.e., N, P and K, as compared to the sole tree and sole crop experimental plots. Soil under mango with *gamhar* AFS showed improved SOC and available N, P, K contents than plots under sweet orange with *gamhar* and mango with eucalyptus-based agroforestry systems. Soils under cowpea showed improved SOC content, whereas available N and K was improved in soils under green gram and soils under pigeon pea showed higher values of available K contents (**Table 1, Figures 3, 4, 5**).

Table 1 Carbon sequestration of different fruit-based AF systems during the years of 2017-18 and 2018- 19

(After attaining the ages of 10th, 11th year of gamhar, eucalyptus, mango and 3rd, 4th year of sweet orange in the corresponding cropping years of 2017-18 and 2018-19)

Treatments	Carbon stock as trees and fruit trees biomass ($t\ ha^{-1}\ yr^{-1}$)		Crop carbon stock ($t\ ha^{-1}\ yr^{-1}$)		SOC ($t\ ha^{-1}$)		Carbon stock (total) ($t\ ha^{-1}\ yr^{-1}$)	
	Cropping years		Cropping years		Cropping years		Cropping years	
	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19
T_1	2.11	2.19	13.77	14.23	7.98	8.54	23.86	24.96
T_2	2.16	2.28	38.73	41.37	7.84	8.12	48.73	51.77
T_3	2.18	2.30	11.24	12.37	8.12	8.68	21.54	23.35
T_4	3.07	3.32	14.51	15.05	8.54	8.96	26.12	27.33
T_5	3.12	3.45	41.19	44.23	8.26	8.68	52.57	56.36
T_6	3.14	3.50	11.64	12.99	8.82	9.24	23.60	25.73
T_7	15.84	16.94	12.59	12.90	7.7	8.12	36.13	37.96
T_8	15.60	16.69	36.63	37.80	7.56	7.84	59.79	62.33
T_9	15.51	16.34	10.69	11.61	7.84	8.12	34.04	36.07
T_{10}	2.00	2.08	-	-	7.14	7.42	9.14	9.50
T_{11}	2.77	2.96	-	-	7.42	7.7	10.19	10.66
T_{12}	14.34	14.74	-	-	7.01	7.28	21.35	22.02
T_{13}	0.98	1.01	-	-	6.72	7.00	7.70	8.01
T_{14}	10.20	10.25	-	-	6.58	6.86	16.78	17.11
T_{15}	1.39	1.51	-	-	6.72	6.86	8.11	8.37
T_{16}	0.52	0.54	-	-	6.44	6.72	6.96	7.26
T_{17}	-	-	10.62	10.86	6.02	6.16	16.64	17.02
T_{18}	-	-	29.90	30.51	6.16	6.3	36.06	36.81
T_{19}	-	-	8.47	8.90	6.30	6.44	14.77	15.34
SEm (±)	0.03	0.05	0.23	0.28	0.06	0.13	0.96	1.31
CD (0.05)	0.09	0.14	0.66	0.79	0.18	0.37	2.71	3.70

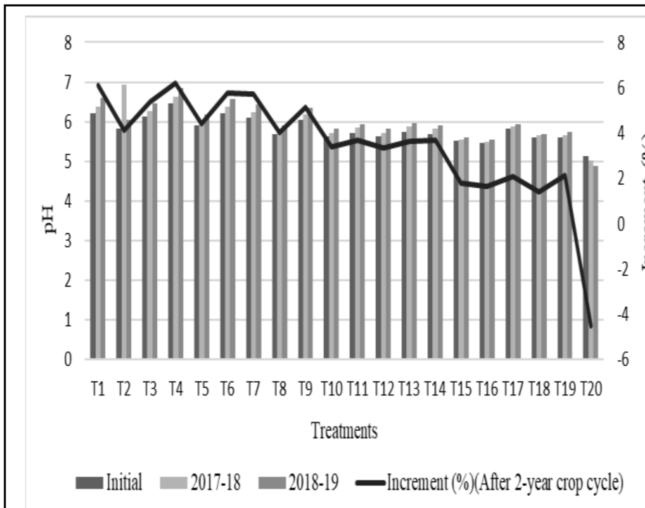

Figure 1 Fluctuation of soil pH under agroforestry and sole cropping systems during study period (2017-18 and 2018-19)

3. (iii) Fruit-based AFS - the potential means for change in diet in red and lateritic zone: Fruit-based agroforestry systems considerably increased the yield of fruits as compared to sole plots under fruit trees **(Table 2)**. Maximum fruit yield from fruit-based AFS was obtained from plots grown with cowpea followed by toria, while the lowest values were observed from sole fruit plots. Mango-*gamhar* based AFS produced more fruits than the sole mango plots and the AFS based on mango-eucalyptus. Higher yields of arable crops were obtained from plots under the fruit-based agroforestry systems as compared to the sole cropping, with better results from mango-*gamhar* based agroforestry system **(Table 3)**. Food energy production was higher in fruit-based agroforestry systems as compared to sole fruit and crop cultures. Higher food energy from fruit, pulses and oilseed was recorded from mango-*gamhar* based AFS with cowpea – toria as compared to other food growing systems in the experiment. Among the three fruit-based agroforestry systems, total food energy production was higher in mango-*gamhar* based AFS **(Table 4)**.

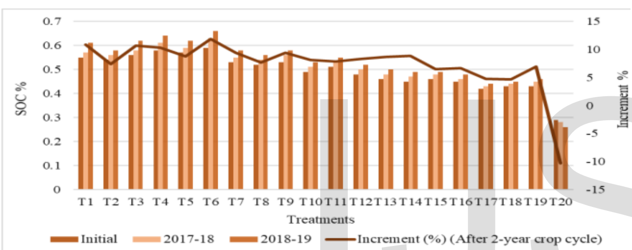

Figure 2 Soil organic carbon status under different mango and sweet orange - based agroforestry, sole cropping systems and barren field during experiment

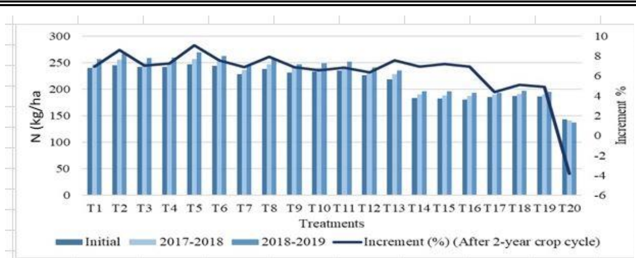

Figure 3 Assessment of soil available N (kg ha^{-1}) in between different mango and sweet orange - based AF systems, mono-cropping system and barren field

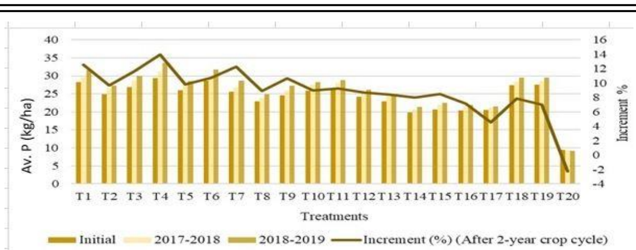

Figure 4 Assessment of soil available P (kg ha^{-1}) in between different mango and sweet orange - based AF systems, mono-cropping systems and barren field

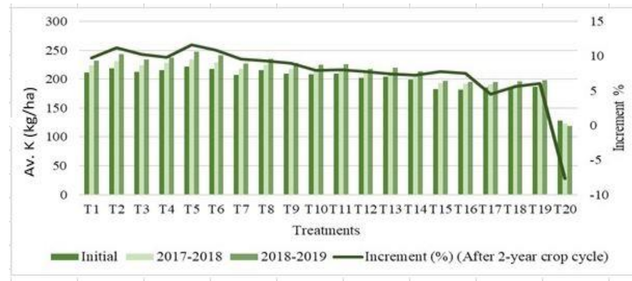

Figure 5 Assessment of soil available K (kg ha^{-1}) in between different mango and sweet orange - based AF systems, mono-cropping systems and barren field

Table 2 Yield of sweet orange and mango fruits under different fruit-based agroforestry systems

(After attaining the ages of 10th, 11th year of gamhar, eucalyptus, mango and 3rd, 4th year of sweet orange in the corresponding cropping years of 2017-18 and 2018-19)

Treatments	Sweet orange (*Citrus sinensis*) fruit yield (Dz ha^{-1})		Mango (*Mangifera indica*) fruit yield (t ha^{-1})	
	Cropping years		Cropping years	
	2017-18	2018-19	2017-18	2018-19
T_1	965	985	-	-
T_2	950	981	-	-
T_3	975	995	-	-
T_4	-	-	6.46	7.98
T_5	-	-	6.71	8.36
T_6	-	-	6.89	8.65
T_7	-	-	5.82	7.14
T_8	-	-	5.94	7.32
T_9	-	-	6.14	7.64
T_{10}	904	935	-	-
T_{11}	-	-	5.35	6.41
T_{12}	-	-	5.07	6.12
T_{15}	-	-	4.94	5.75
T_{16}	803	833	-	-
SEm (±)	0.55	0.59	0.19	0.28
CD (0.05)	1.66	1.79	0.54	0.81

3.(iv) Fruit-based AFS – the potential means for enhancing livelihoods in red and lateritic zone: The production and productivity of mango, sweet orange and silvi trees (*gamhar* and eucalyptus) were significantly improved with intercropping as compared to sole plantations. Financial achievements based on B: C ratio were better under AFS, whereas mango-eucalyptus with cowpea followed by toria system was observed with best performance, whereas poorest results were obtained from all sorts of sole plots either under fruit trees or silvi trees or crops **(Table 5)**. Out of the three fruit-based agroforestry systems, mango-eucalyptus based AFS achieved a higher B: C ratio due to higher wood volume productivity of eucalyptus than *gamhar* trees.

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Table 3 Effect of different agroforestry systems on yield of *kharif* and *rabi* season crops

(After attaining the ages of 10th,11th year of gamhar, eucalyptus, mango and 3rd, 4th year of sweet orange in the corresponding cropping years of 2017-18 and 2018-19)

a) *Kharif (Rainy season)*				
Treatments	**Pigeon pea (q. ha^{-1})**			
	Cropping years		**POOLED**	**MEAN**
	2017-18	**2018-19**		
T_1	7.72	7.90	7.81	**7.44**
T_4	7.85	8.05	7.95	
T_7	7.46	7.61	7.53	
T_{17}	6.42	6.54	6.48	
SEm (±)	0.24	0.30	0.28	
CD (0.05)	0.76	0.95	0.87	
Treatments	**Green gram (q. ha^{-1})**			
	Cropping years		**POOLED**	**MEAN**
	2017-18	**2018-19**		
T_2	6.64	6.82	6.73	**6.29**
T_5	6.72	6.90	6.81	
T_8	6.26	6.41	6.33	
T_{18}	5.24	5.35	5.29	
SEm (±)	0.23	0.30	0.26	
CD (0.05)	0.70	0.93	0.81	
Treatments	**Cowpea (q. ha^{-1})**			
	Cropping years		**POOLED**	**MEAN**
	2017-18	**2018-19**		
T_3	14.48	15.02	14.75	**14.27**
T_6	14.65	15.21	14.93	
T_9	14.20	14.68	14.44	
T_{19}	12.82	13.15	12.98	
SEm (±)	0.27	0.33	0.31	
CD (0.05)	0.84	1.04	0.98	
b) *Rabi (Non-monsoon season)*				
Treatments	**Toria (q. ha^{-1})**			
	Cropping years		**POOLED**	**MEAN**
	2017-18	**2018-19**		
T_2	3.54	3.69	3.61	**3.34**
T_3	3.64	3.82	3.73	
T_5	3.65	3.80	3.72	
T_6	3.72	3.91	3.81	
T_8	3.26	3.38	3.32	
T_9	3.29	3.45	3.37	
T_{18}	2.52	2.58	2.55	
T_{19}	2.55	2.65	2.60	
SEm (±)	0.18	0.24	0.21	
CD (0.05)	0.54	0.72	0.61	

Table 4 Potentiality of food energy production from ten-eleven years old silvi and mango tree plantations and three-four years old sweet orange orchard with alle crops (i.e., arable crops of pigeon pea, green gram, cowpea and toria) grown during 2017-18 and 2018-19 in Agroforestry Systems (AFS) raised on rainfed and initially degraded upland with red and lateritic soil of Jhargram, West Bengal, India

Treatments	**Potentiality of food energy production from AFS (MMKcal ha^{-1})**							
	***Fruits (mango, sweet orange)**		***Pulses (pigeon pea, green gram, cowpea)**		***Oilseed (toria, considered as mustard)**		**Total**	
	Cropping years		**Cropping years**		**Cropping years**		**Cropping years**	
	2017-18	**2018-19**	**2017-18**	**2018-19**	**2017-18**	**2018-19**	**2017-18**	**2018-19**
T_1	1.245	1.271	2.764	2.828	-	-	4.009	5.371
T_2	1.226	1.265	2.165	2.223	1.805	1.882	5.196	8.038
T_3	1.258	1.284	4.634	4.806	1.856	1.948	7.748	11.820
T_4	7.235	8.938	2.810	2.882	-	-	10.046	13.551
T_5	7.515	9.363	2.191	2.249	1.862	1.938	11.567	**16.549**
T_6	**7.717**	**9.688**	**4.688**	**4.867**	**1.897**	**1.994**	**14.302**	10.721
T_7	6.518	7.997	2.671	2.724	-	-	9.189	12.012
T_8	6.653	8.198	2.041	2.090	1.663	1.724	10.356	15.014
T_9	6.877	8.557	4.544	4.698	1.678	1.760	13.099	1.206
T_{10}	1.166	1.206	-	-	-	-	1.166	7.179
T_{11}	5.992	7.179	-	-	-	-	5.992	6.854
T_{12}	5.678	6.854	-	-	-	-	5.678	6.440
T_{13}	-	-	-	-	-	-	-	-
T_{14}	-	-	-	-	-	-	-	-
T_{15}	5.533	6.440	-	-	-	-	5.533	**1.075**
T_{16}	**1.036**	**1.075**	-	-	-	-	**1.036**	2.341
T_{17}	-	-	2.298	2.341	-	-	2.298	3.060
T_{18}	-	-	**1.708**	**1.744**	**1.285**	**1.316**	2.993	5.560
T_{19}	-	-	4.102	4.208	1.301	1.352	5.403	5.371

***Conversions from yield data to Kcal from Tables 2 and 3:**

i) Fruits: a) Mango: 112 Kcal $100g^{-1}$ [33];
b) Sweet orange: 3kg $dozen^{-1}$ (Experimental data) and 43 Kcal $100g^{-1}$ [34]

ii) Pulses: a) Pigeon pea: 358 Kcal $100g^{-1}$ [32]; b) Green gram: 326 Kcal $100g^{-1}$ [32]; c) Cowpea: 320 Kcal $100g^{-1}$ [32]

iii) Oilseeds: Toria (considered as mustard): 510 Kcal $100g^{-1}$ [32]

1 kcal = 1.0E-6 MMKcal

Treatments: T_1: *Gamhar* + sweet orange + pigeon pea, T_2: *Gamhar* + sweet orange + green gram-toria, T_3: *Gamhar* + sweet orange +cowpea-toria, T_4: *Gamhar* + mango + pigeon pea, T_5: *Gamhar* + mango + green gram-toria, T_6: *Gamhar* + mango + cowpea-toria, T_7: Eucalyptus + mango + pigeon pea, T_8: Eucalyptus + mango + green gram-toria, T_9: Eucalyptus + mango +cowpea-toria, T_{10}: *Gamhar* + sweet orange, T_{11}: *Gamhar* + mango, T_{12}: Eucalyptus + mango, T_{13}: *Gamhar*, T_{14}: Eucalyptus, T_{15}: Mango, T_{16}: Sweet orange, T_{17}: pigeon pea, T_{18}: Green gram-toria, T_{19}: Cowpea-toria, T_{20}: Barren field (control).

Table 5 Benefit: cost analysis of different mango and sweet orange-based AF systems, sole cropping and sole tree culture during 2017 -18 and 2018 – 19

(After attaining the ages of 10th, 11th year of gamhar, eucalyptus, mango and 3rd, 4th year of sweet orange in the corresponding cropping years of 2017-18 and 2018-19)

Treatments	Cost of cultivation (Rs ha^{-1})		Gross return (Rs ha^{-1})		Net Return (Rs ha^{-1})		B:C	
	Cropping years		Cropping years		Cropping years		Cropping years	
	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19
T_1	66651	66651	95517	103849	28866	37198	1.43	1.55
T_2	66537	66537	99462	110458	32925	43921	1.49	1.66
T_3	66889	66889	107263	118601	40374	51712	1.60	1.77
T_4	66651	66651	201342	283382.5	134691	216731.5	3.02	4.25
T_5	66537	66537	211168	299891	144631	233354	3.17	4.50
T_6	66889	66889	221171	313946.5	154282	247057.5	3.30	4.69
T_7	66651	66651	259884	342368.5	193233	275717.5	3.89	5.13
T_8	66537	66537	264066	344362.5	197529	277825.5	3.96	5.17
T_9	66889	66889	272638	355610	205749	288721	4.07	5.31
T_{10}	58620	58620	81308	88536	22688	29916	1.38	1.51
T_{11}	58620	58620	161734	221980	103114	163360	2.75	3.78
T_{12}	58620	58620	221556	284736	162936	226116	3.77	4.85
T_{13}	25970	25970	19716	20034	-6254	-5936	0.75	0.77
T_{14}	25970	25970	78154	81984	52184	56014	3.00	3.15
T_{15}	32650	32650	121000	156300	88350	123650	3.70	4.78
T_{16}	32650	32650	44165	49980	11515	17330	1.35	1.53
T_{17}	8031	8031	7740	8112.5	-291	81.5	0.96	1.01
T_{18}	7912	7912	8768	9487.5	856	1575.5	1.10	1.19
T_{19}	8269	8269	14595	16021	6326	7752	1.76	1.93

4. Conclusions:

1) Fruit-based agroforestry systems were with high potentiality for carbon sequestration as compared to either sole trees or crop cultures. Mango-eucalyptus based agroforestry system could stock higher carbon than other AF and cropping systems

2) Physicochemical properties of the soil were improved under fruit-based agroforestry as compared to sole tree and crop cultures, in contrast with the degraded barren plot. Mango-*gamhar* based AFS could store higher SOC and available soil nutrients than other AF systems.

3) The yield of fruits and arable crops were higher under fruit-based agroforestry systems as compared to sole cropping. Fruit-based agroforestry systems could potentially generate food energy, and, thus potential enough to change diet of the farming community and a potential support for health of community members as a whole through assuring food security towards achieving SDGs.

4) The B: C ratio was higher in fruit-based agroforestry systems, as compared to mono tree and crop cultivations. Because such fruit-based AFS could generate sustainable income sources as well as employment covering all the year-round as compared to mono-cropping systems, and thus, such AFS were very effective to improve living standards even of the marginal and resource-poor farm families, if owning only the traditionally barren rainfed uplands.

5) In such multiple ways fruit-based agroforestry systems could reduce the risk of crop failures and were proved to be potential means in achieving multiple SDGs in Red and Laterite Agroclimatic Zone of West Bengal in India.

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