Productivity and Carbon Sequestration under Prevalent Agroforestry Systems in Navsari District, Gujarat, India

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A B S T R A C T

The present study was conducted on stratified random sampling in five talukas of Navsari district, Gujarat, India to evaluate the productivity and carbon sequestration under prevalent agroforestry systems during 2011-12. Agroforestry practices such as Agri-silvicultural systems (ASHS) Agrisilvicultural systems (ASS), Agri-horticultural systems (AHS), and Silvopastural systems (SPS). Data records showed that AHS had maximum three practices Mango + Sapota + Lemon + Coriander, Mango + Cabbage, Mango + Rice followed by ASS representing two system types i.e. Teak + Sugarcane and Eucalyptus + Spider lily. ASHS and SPS had only one system type i.e. Mango + Teak + Brinjal and Sapota + grass, respectively. Besides these ASS was represented by two more system types (Teak + Rice and Arjun + Nagali) however these system types were found existing with only one farmer. The data of biological and economical yield, carbon sequestration was collected in one cropping season and was analysed to find out the economic viability. Among woody perennials, eucalyptus, under Eucalyptus + Spider lily, gave significantly higher woody biomass. Among intercrops under different agroforestry systems, sugarcane under ASS (Teak + Sugarcane) system gave maximum biomass. Total biological yield was higher from ASS and minimum was in AHS. Among seven agroforestry system types, highest carbon tonnes per hectare (tree + intercrop) was sequestered by ASS system. Most viable agroforestry system on the basis of NPV (Net Present Value), Benefit Cost Ratio (BCR), Equivalent Annual Income (EAI) and compounded revenue was ASH system followed by AHS.

Keywords
Agroforestry system, Carbon sequestration, Agrisilvicultural systems, Agri-silvicultural systems, BC ratio, NPV, biomass and economic yield

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Introduction

An increasingly industrialized global economy, rapid population growth, land degradation, land use pattern and role of various human activities have led to dramatically increased the pressure on the natural resources such as the available land for sustaining the livelihoods, and with over exploitation and extraction of the natural resources the ecosystems are becoming unsustainable and fragile since last century (Kumar and Tiwari, 2017; Kumar, 2018). On one hand, several researchers noticed that agroforestry has potential for ecological benefits such as carbon sequestration, mitigation of climate change, enhancing soil fertility and water use efficiency, biodiversity conservation, biological pest control, sustainable land use, shelterbelt and windbreaks, microclimate amelioration, breaking the poverty and food insecurity.
circle, Caveats and clarifications (Pandey, 2007; Jose, 2009; Nair, 2011; Dhyani et al., 2013; Kumar, 2015; Kumar, 2016; Kumar and Tripathi, 2017). While resulted in soil contamination has become a major environmental problem worldwide because of its detrimental effects on human and ecosystem health, soil productivity, and socioeconomic well-being (Conesa et al., 2012; Waseem et al., 2014). The aim of Agroforestry System (AFS) as sustainable land use system aims at incorporating agricultural crops and/or livestock along with woody perennial components on the same unit of land so that not only productivity increases but also to avoid the deterioration of soil (soil fertility and structure) and environment without compromising on the economic returns under a particular set of climatic, edaphic conditions and socioeconomic status of local people. Nair et al., (2008) and Garrett (2009) reported that aboveground and belowground diversity provides more stability connectivity with forests and other landscape features at the landscape and watershed levels. Agroforestry has an important role in reducing vulnerability, increasing resilience of farming systems and buffering households against climate related risk in addition to providing livelihood security (NRCAR 2013).These ecological foundations of agroforestry systems manifest themselves in providing environmental services such as soil conservation, carbon storage, biodiversity conservation, and enhancement of water quality. Deforestation and continuous cultivation deplete SOM and soil nutrient reserves by hastening decomposition, reducing replenishment through litter input, and increasing soil erosion, which together result in vegetation and soil degradation (Demessie et al., 2015). Lal (2002) reported that improved land management practices such as reduced tillage, mulching, croprotations, composting, manure application, fallowing, agroforestry, and soil salinity control as well as changes in land use patterns are not only expected to increase the rate of carbon dioxide (CO\textsubscript{2}) uptake from the atmosphere but also to contribute to erosion and desertification control and enriched biodiversity. Biomass productivity of the agroforestry systems, however, differs enormously with species, site characteristics and stand management practices (Kumar et al., 1998). Nonetheless, Deans et al., (1996) revealed that it is useful to know the stock of carbon s biomass per unit area, not only to facilitate choice of species but also to assess the impact of deforestation and re-growth rates on the global carbon cycle. Various interacting factors through which a tree influences carbon stock in the soil under agroforestry are addition of litter, maintenance of higher soil moisture content, reduced surface soil temperature, proliferated root system, enhanced biological activities and decreased risk of soil erosion (Singh and Rathod 2002, Schultz et al., 2004, Singh and Sharma 2007).

Land use changes have also contributed substantially to the rising concentration of CO\textsubscript{2} in the earth’s atmosphere. Tropical deforestation and decreasing carbon sinks are one of the major drivers increasing the concentration of atmospheric carbon dioxide (CO\textsubscript{2}), thereby enforcing global climate change (Achard et al., 2002; De Fries et al., 2007; Miettinen et al., 2011).The global warming potentials (GWP) of atmospheric methane (CH\textsubscript{4}) and nitrous oxide (N\textsubscript{2}O) gases over a time span of 100 years are approximately 25 and 298 times greater, respectively, than that of carbon dioxide (CO\textsubscript{2}) (IPCC, 2007).Under the Kyoto Protocol’s Article 3.3, A&R (afforestation and reforestation) with agroforestry as a part of it has been recognized as an option for mitigating greenhouse gases. As a result, there is now increasing awareness on
agroforestry’s potential for carbon (C) sequestration (Nai et al., 2009; 2010). Enhancing terrestrial C sinks and decreasing greenhouse gas (GHGs) emissions have been recognized as priorities for increasing global sustainability (http://unfccc.int/press; UNFCC, 2007; IPCC, 2007). Worldwide soils store organic carbon, as much as 1550 Pg plus an inorganic carbon stock of over 1000 Pg (Lal 2004), up to one meter depth, playing a key role in global carbon cycling and climate change. As such, carbon sequestration in soils could provide the vital link between three international conventions: the UN Framework Convention on Climate Change (UNFCC), the UN Convention to Combat Desertification (UNCCD), and the UN Convention on Biodiversity (UNCBD). There are at least two important advantages of sequestering carbon in soil organic matter (SOM) of degraded agro-ecosystems rather than above-ground biomass. First, direct environmental, economic, and social benefits are expected to accrue for local populations inhabiting and cultivating degraded agro-ecosystems that are now perceived as potential carbon sinks. Secondly, carbon sinks in degraded agro-ecosystems are more likely to secure carbon storage in the long run, primarily because of the longer residence time of carbon in soils.

Also, small holders who depend on soil fertility as the basis for their livelihoods are likely to have a greater incentive to protect this resource (Olsson and Ardo 2002). Therefore present study is intended to investigate the comparative performance of prevalent agroforestry systems types with varied structure and magnitude to ascertain their production potential, economic viability as well as ecological sustainability. In this study we evaluated the prevalent agroforestry systems in Navsari district, Gujarat. Also determined the biological and economic yield of agroforestry systems and carbon stocks in different agroforestry systems.

**Materials and Methods**

**Description of the study site**

This study focused on land uses that include different five taluka of Navsari district, Gujarat (78° 17” N and 78° 19” N and 38° 48” E and 38° 49” E) during 2011-2012. Navsari district is located in the south eastern part of Gujarat state in the coastal lowland along Purnariver (Figure 1). The climate is typically tropical characterized by fairly hot summer, moderately cold winter and warm humid monsoon. Generally monsoon in this region commences in the second week of June and ends in September. Most of the precipitation is received from South West monsoon, concentrating in the months of July and August. Average annual rainfall of this region is about 1431 mm. From stratified random sampling we found that different agroforestry systems in five talukas of Navsari district (Navsari, Gandevi, Jalalpore, Chikhli and Vansada) (Table 1) and the structure and composition (Table 1) and growth attributed of woody components under different agroforestry systems (Table 2) has mentioned.

**Biological yield**

To estimate the biological yield of agricultural crops plants were uprooted to the depth possible in 1x1m area. Thereafter, the triplicate samples were immediately transferred to the laboratory in double-sealed polythene bags. After recording the fresh weights, they were dried to constant weight at 70 °C, with the help of electronic balance. Biological yield was calculated using formula

\[
\text{Biological yield} = \frac{\text{dry weight of sample}}{\text{fresh weight of sample}} \times \text{total fresh weight of branches/leaves}
\]

**Economical Yield**

To estimate the economic yield of each intercrop and woody perennials under
different agroforestry systems saleable part was taken in to consideration and total yield per hectare was calculated.

**Growth and biomass attributes**

The trees were measured for their top height, diameter at breast height (DBH) and crown spread. The total height was measured with Altimeter (m) from ground to top of the trees. The diameter at breast height (1.37 m above the ground level) was taken with the help of digital caliper. Crown spread was measured using meter tape and two poles holding straight touching to the outmost tip of the opposite sides of the tree. The distance between these two poles were recorded with the help of measuring tape. Similarly, it was repeated at perpendicular to measure the other direction. Standing volume of trees was calculated with the help of following formula

\[
Total\ volume\ (m^3) = \pi (D/2)^2 \times h
\]

Where, \( \pi = 3.14; \ D = DBH\) (m) and \( h = \) Height of tree (m)

Since the wood samples collected were dry and blocks collected were of different shape and size, the specific gravity was measured by volume displacement method. The volume of each sample was determined from the volume of water it displaced when submerged, according to American society for testing and Materials (ASTM) standard norms. The basic specific gravity was calculated as oven-dry weight (105 °C, 48 h) divided by volume. Above ground stem biomass of selected trees in the system was determined by following formula

\[
Above\ ground\ biomass = Volume/Specific\ gravity\ of\ wood
\]

Branch biomass of standing trees (horticultural trees) was determined by taking average branch length and branch diameter and number of branches. The value then converted in to volume and the biomass determined by above given formula.

For eucalyptus and teak, all the leaves and fruits of three selected trees were harvested oven dried and leaf biomass was determined. However for horticultural crops like Mango, Sapota and Lemon, this practice was not feasible. So, for these crops, average fruit yield and number of leaves were counted in standing tree. Representative samples of branch, leaves and fruit then brought to the laboratory.

All tissue-types were oven-dried at 70 °C to constant weight. The tree below ground biomass was estimated by multiplying the tree above ground biomass with factor 0.26. (IPCC default value). The total system above ground biomass was calculated adding biomass of all the components (Below ground and above ground). The carbon sequestration was calculated by multiplication of biomass with default value 0.48 given by Chaturvedi (1984) for Indian conditions.

Soil samples were collected from the inter space between two rows of the trees at three points in each plot (0-15 cm soil layer). Triplicate samples were analysed as follows: organic carbon was determined by Walkley and Black, wet oxidation method by oxidizing the organic matter in soil (passed through 2 mm sieve) which chromic acid as described by Black, 1965. Available nitrogen was determined by alkaline permanganet (0.32% KMnO₄) method (Subbaih and Asija, 1956). Available phosphorus was determined by Brays No. 1 method of extracting the soil P with 0.03 NH₄F in 0.025 N HCl. Phosphorus in the extractant was determined colorimetrically by using spectrophotometer at 660 nm wavelength as outlined by Bray and Kurtz, 1945. Available potassium was determined by using neutral normal
ammonium acetate as an extractant on Systronics Flame Photometer as described by Jackson, 1973.

**Economics**

Gross returns: The gross realization in terms of rupees per hectare was worked out on the basis of total economical yield. The prevailing market prices of different intercrop species were accounted to calculate the gross returns.

Net returns: The total cost incurred on cultivation and management of agroforestry systems was deducted from total gross returns and net returns were calculated under each AF system.

**Results and Discussion**

Agroforestry technologies vary from region to region. Adoption and practice of these technologies depends on the edapho-climatic, socioeconomic status and needs of peasants. These attributes lead to variation in the structure and composition of recommended technologies and existing agrarianism. In total four major agroforestry systems were found to be practiced by the farmers *i.e.* agri-silvi-horticulture system (ASHS), agri-silviculture system (ASS), agri-horticulture system (AHS), and horti-pasture system (HPS). AHS had maximum (3) types of system such as Mango + Sapota + Lemon + Coriander (multi-storey) (Fig. 2.E), Mango + Cabbage (Fig. 2.A) and Mango + Rice (Fig. 2.D) followed by ASS representing two types of system *i.e.* Teak + Sugarcane (Fig. 2.B) and Eucalyptus + Spider lily (Fig. 2.C). ASHS and HPS had only one type of system *i.e.* Mango + Teak + Brinjal and Sapota + Grass, respectively. Besides these ASS was represented by two more types of system (Teak + Rice and Arjun + Nagali). However these system types were found existing with only one farmer. Generally in South Gujarat mango is major fruit tree species therefore mango based agroforestry systems are practiced more. Amongst the forestry tree species teak and eucalyptus are being integrated in agroforestry systems. Eucalyptus based traditional and commercial agroforestry systems have been reported in vogue in Western Uttar Pardesh (Dwivedi et. al., 2007). Findings of Varadaranganatha and Madiwalar (2010) 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.

**Biological yield and economical yield of prevalent agroforestry systems**

**Biological yield**

**Tree biomass (Kg/tree)**

Biomass (kg/tree) (tree parts i.e. above and below ground and total tree biomass) of woody perennials of different prevalent agroforestry systems under study has described in Table 3. The maximum stem biomass (40 kg/tree) was recorded in Eucalyptus followed by Teak (27.0 kg/tree) and minimum (1.37 kg/tree) was recorded in Mango. The branch biomass was maximum (6.66 kg/tree) in Sapota followed by mango (4.80 kg/tree). Minimum branch biomass (2.7 kg/tree) was recorded in Teak. Higher leaf biomass to tune of 4.53 kg per tree was recorded in Mango followed by Sapota (4.06), whereas, minimum of 0.55 and 0.92 kg/tree was recorded in Teak and Eucalyptus, respectively (Table 3). This is because of the fact that horticultural trees are trained and pruned in such a way that crown surface area increase, which leads to more fruiting and
hence more branch biomass and restricted stem growth. Similar finding was observed by Koul and Panwar, (2008). Furthermore, manual pruning in teak and self-pruning ability of eucalyptus (Jacobs, 1955) may be ascribed to less branch and leaf biomass.

The maximum fruit biomass (14.70 kg/tree) was recorded in lemon followed by Sapota (14.53 kg/tree) and minimum of 0.37 kg per tree was recorded in Eucalyptus (table 3). Maximum above ground biomass i.e. stem, branch, leaf, and fruit to the tune of 44.70 kg/tree was recorded in Eucalyptus followed by Teak (31.77 kg/tree), whereas minimum (20.05 kg/tree) was recorded in Mango. Below ground biomass was maximum (11.62 kg/tree) in Eucalyptus followed by Teak (8.26 kg/tree) and it was recorded minimum (5.21 kg/tree) in mango (Table 3). Total tree biomass amounting to 56.32 kg/tree was recorded in Eucalyptus followed by Teak (40.03 kg/tree). Minimum total tree biomass (25.26 kg/tree) was recorded in Mango.

**Intercrop crop biomass (Kg/m²)**

The data on crop biomass (above and below ground) of individual intercrops recorded under different agroforestry systems has mentioned (Table 4). Maximum above ground intercrop biomass to the tune of 1.77 kg/m² was recorded in Sugarcane followed by Spider lily (1), whereas least (0.16) was recorded from Coriander (Table 4). Below ground crop biomass was recorded maximum (0.61) in Sugarcane followed by Spider lily (0.326), and minimum (0.014) was recorded in Coriander. The maximum total crop biomass (2.38 kg/m²) was recorded in Sugarcane followed by Spider lily (1.32), and was minimum (0.18) from Coriander (Table 4). The biomass of tree in different parts, viz., stem, branch wood, leaves and fruits depend upon number of factors viz., growth habit of the species, site quality, soil on which it is growing, age of the tree, management practices, frequent intercultural operations and moisture conservation and its interaction with intercrop (Yadava, 2010). Similarly crop biomass production depends on the edapho-climatic factors and nature of the crop in different agroforestry systems.

**Biological yield of prevalent AF system (t/ha)**

**Biological yield of trees**

Perusal of data on biomass of woody and non-woody components of different agroforestry systems (Table 5). Indeed, data showed that Eucalyptus, under Eucalyptus + spider lily system gave significantly higher above and below ground and total woody biomass to the tune of 70.93, 18.44 and 89.38 t/ha, respectively followed by Teak and Mango under ASHS (Teak + Mango + Brinjal) 7.58, 2.86 and 10.44 t/ha, respectively. AHS (Mango + rice) system gave minimum above (2.01) and below ground (0.52) and total biomass (2.53). The above ground tree biomass (70.93 t/ha) of eucalyptus under (Eucalyptus + Spider lily) at the age of 6 years in the present study is higher than what has been reported by Yadava (2010) in AS (Eucalyptus + Wheat in boundary plantation) system in Tarai areas of Himalayas.

**Biological yield of intercrops (t/ha)**

Among intercrops under different agroforestry systems, Sugarcane under ASS (Eucalyptus + Sugarcane) gave maximum above ground (16.79 t/ha), below ground (5.78 t/ha) and total biomass (22.56 t/ha) followed by spider lily under ASS (Eucalyptus + Spider lily) with values of 7.80, 2.55 and 10.35 t/ha for above ground, below ground and total biomass (Table 5). Minimum above ground (1.06 t/ha), below ground (0.09 t/ha) and total crop biomass (2.43 t/ha)
was obtained from coriander under AHS (Mango + Sapota + Lemon + Coriander). Maximum total biological yield (99.72 t/ha) was obtained from ASS (Eucalyptus + Spider lily) followed by Teak + Sugarcane (25.76) and minimum (4.06) was from AHS. The economic yield (saleable part of system components) of different agroforestry systems has presented in Table 5.

Among the seven agroforestry system types i.e. Mango + Teak + Brinjal, Eucalyptus + Spider lily, Teak + Sugarcane, Mango + Rice, Mango + Cabbage, Mango + Sapota + Lemon + Coriander and Sapota + Grass, highest biomass was recorded in AS system (Eucalyptus + Spider lily) which may be attributed to high density plantation of tree species and relatively fast growing nature of eucalyptus clones. Structural composition of agroforestry system, and number of woody components involved, their nature and management practices applied influence the biomass production. The lower biomass production under fruit tree based agroforestry system types may be attributed to dwarf nature of grafted plants which are subjected to training and heavy pruning regimes and also due less biomass accumulation in stem as compared to branches. Lowest biomass was recorded in complex agri-horticulture system with system components Mango + Sapota + Lemon + Coriander preceded by AH system type Mango + Rice. The cause of, later being complex, less biomass production is due to less stem biomass and number of individuals per hectare.

**Fruit yield (kg/ha)**

A yield of 9360 kg/ha was obtained from both ASH system (Teak + Mango + Brinjal) and (Mango + Cabbage) respectively. On the otherhand a system integrating (Mango + Rice) and Mango + Sapota + Lemon + Coriander produced 6000 and 1980 kg/ha respectively. Spota yield to the tune of 9360 and 2000 kg was obtained from Sapota + Grass and Mango + Sapota + Lemon + Coriander, respectively. Lemon integrated in Mango + Sapota + Lemon + Coriander system gave 2310 kg of fruit yield. In ASH system involving Eucalyptus as forest tree species, 16000 poles per hectare were estimated (Table 6). Teak trees were 6 years old and is not considered in economical yield.

Economic yield of brinjal under AS system Teak + Mango + Brinjal was 9141 kg/ha, sugarcane under Teak + Sugarcane 58780 kg/ha, Rice under AH system Mango + Rice 3500 kg, Cabbage under Mango + Cabbage 9750, coriander under Mango + Sapota + Lemon + Coriander 3840 and grasses under HP system Sapota + Grasses was 4875 kg/ha. Yield of spider lily under AS system Eucalyptus + Spider lily was 585 bunches/ha (Table 6).

**Carbon storage (kg/tree) in woody component**

The results on carbon stocks per tree, in different parts of woody perennials, under agroforestry systems in the study area present has presented Table 7. Highest stem carbon per tree amounting to19.20 kg/tree was recorded in eucalyptus followed by teak (12.96) and minimum (0.66) was recorded in Mango. Branch carbon was maximum (3.20 kg/tree) in Sapota followed by mango (2.30) and minimum was recorded in Teak (1.29). The maximum leaf carbon of 2.17 kg/tree was recorded in lemon followed by Sapota (2.30) and minimum was in Teak (1.29). The maximum fruit carbon amounting to 7.06 kg/tree was recorded in lemon followed by Sapota (6.97), and minimum was recorded in Eucalyptus (0.18) (Table 7). Above ground carbon (21.46) was maximum recorded in Eucalyptus followed by Teak (15.24), and minimum (9.62) was recorded in
Mango. Below ground carbon was recorded (5.58) in Eucalyptus followed by teak (3.9) whereas it was minimum (2.50) in Mango. Highest total carbon of 27.03 kg/tree was recorded in Eucalyptus followed by teak (19.21), and minimum (12.12) was recorded in Mango (Table 7).

The total carbon sequestered by agroforestry systems was highest (47.87 t/ha) in the Eucalyptus + Spider lily system. Average sequestration potential in agroforestry systems has been estimated to be 25 tonnes C per hectare (Sathaye and Ravindernath, 1998).

The present study revealed that C sequestration of Eucalyptus + Spider lily system is higher than the above findings whereas it is very less from rest of the agroforestry systems. Carbon sequestered under AS system involving Eucalyptus + Wheat in Himalayan Tarai region has been estimated to be 14.42 t/ha and about 32 t/ha under various agroforestry systems involving poplar as woody component (Yadava, 2010) is higher as compared to the present findings. Prasad et al., (2012) have estimated carbon sequestration potential of eucalyptus based to the tune of 34 MgC/ha.

Carbon sequestration estimates of all the systems were in line with their biomass production potential. CO2 mitigation by plant is directly related to biomass production of the different plant components. Higher carbon stock value of system can be attributed to more biomass in any system.

In present study, there was significant variation in carbon sequestration potential of different agroforestry practices. The amount of C sequestered largely depends on the agroforestry system put in place, the structure and function of which are, to a great extent, determined by environmental and socio-economic factors. Other factors influencing carbon storage in agroforestry systems include tree species and system management (Albrecht and Kandji, 2003, Yadava 2010).

The data on crop carbon (above and below ground) of individual intercrops recorded under different agroforestry systems are presented. Maximum above ground crop carbon to the tune of 0.85 kg/m² was recorded in Sugarcane followed by Spider lily (0.48) whereas, least (0.08) was recorded from Coriander (Table 7).

Below ground crop carbon was recorded maximum (0.29) in sugarcane followed by spider lily (0.15), and minimum (0.007) was recorded in coriander. The maximum total crop carbon (1.14 kg/m2) was recorded in sugarcane followed by spider lily (0.63), and was minimum (0.86) from coriander (Table 8).

According to recent projections, the area of the World under agroforestry will increase substantially in the near future. Undoubtedly, this will have a great impact on the flux and long-term storage of C in the terrestrial biosphere (Dixon, 1995). Agro ecosystems play a central role in the global C cycle and contain approximately 12% of the world terrestrial C (Smith et. al., 1993, Dixon et al., 1994; Dixon, 1995). Soil degradation as a result of land-use change has been one of the major causes of C loss and CO2 accumulation in the atmosphere.

Agroforestry may involve practices that favour the emission of GHGs including shifting cultivation, pasture maintenance by burning, paddy cultivation, N fertilisation and animal production (Dixon, 1995; Le Mer and Roger, 2001). However, several studies have shown that the inclusion of trees in the agricultural landscapes often improves the productivity of systems while providing opportunities to create C sinks (Winjum et al., 1992; Dixon et al., 1994; Krankina and Dixon, 1994; Dixon, 1995).
**Table 1.** Structure and composition of prevalent agroforestry system in Navsari district, Gujarat

| Major Systems                                      | System type                                      | Spacing/number per ha                      | Intercrops          | Age of woody perennial |
|---------------------------------------------------|-------------------------------------------------|--------------------------------------------|---------------------|------------------------|
| Agri-silvi-horticulture system (ASHS)             | Mango + Teak (on boundary) + Brinjal             | Mango - 8x8 m (156 trees); teak-5 m plant to plant (80 trees on boundary) | 40x40 cm            | 6                      |
| Agri-silviculturesystem (ASS)                      | Eucalyptus + Spider lily                        | 2.5x2.5 m (1600 trees)                    | 1x1 m              | 6                      |
| Agri-horticulture system (AHS)                    | Mango + Rice                                    | 10x10 m (100 trees)                       | 20x20 cm           | 6                      |
|                                                   | Mango + Cabbage                                 | 8x8 m (156 trees)                         | 45x45 cm           | 6                      |
|                                                   | Mango + sapota + lemon + Coriander              | Sapota-Lemon-Mango 10x10 m (33 trees of each species) | Broadcasted | 6                      |
| Horti-pasture system (HPS)                        | Sapota + Grass                                  | Sapota-8x8 m (156 trees)                  | Broadcasted        | 6                      |

**Table 2.** Growth attribute (average of 10 trees) of different woody perennial of prevalent agroforestry system in Navsari district, Gujarat

| Species | Height (m) | Diameter (cm) | Volume (m³) | Specific gravity |
|---------|------------|---------------|-------------|------------------|
| Mango   | 1.2        | 6.1           | 0.0035      | 0.39             |
| Sapota  | 1.8        | 6.2           | 0.0054      | 0.44             |
| Lemon   | 1.7        | 6.2           | 0.0033      | 0.51             |
| Teak    | 5.8        | 7             | 0.012       | 0.57             |
| Eucalyptus | 10     | 11            | 0.09        | 0.42             |

**Table 3.** Biomass accumulation (kg/tree) of different parts of woody perennials of prevalent agroforestry system in Navsari, Gujarat

| Sr. No. | Species | Stem | Branch | Leaf | Fruit | Above ground | Below ground | Total |
|---------|---------|------|--------|------|-------|--------------|--------------|-------|
| 1       | Mango   | 1.37 | 4.80   | 4.53 | 9.33  | 20.05        | 5.21         | 25.26 |
| 2       | Sapota  | 2.42 | 6.66   | 4.06 | 14.53 | 27.65        | 7.19         | 34.84 |
| 3       | Lemon   | 1.70 | 3.16   | 2.07 | 14.70 | 21.64        | 5.63         | 27.27 |
| 4       | Teak    | 27.0 | 2.7    | 0.55 | 1.52  | 31.77        | 8.26         | 40.03 |
| 5       | Eucalyptus | 40   | 3.42   | 0.92 | 0.37  | 44.70        | 11.62        | 56.32 |
| CD      |         | 0.89 | 0.41   | 0.16 | 0.94  | 1.33         | 0.35         | 1.68  |

**Table 4.** Biomass accumulation (kg/m²) of different intercrops of prevalent agroforestry system, Navsari, Gujarat

| Sr. no. | Crops | Above ground | Below ground | Total |
|---------|-------|--------------|--------------|-------|
| 1       | Cabbage | 0.523        | 0.045        | 0.568 |
| 2       | Brinjal | 0.672        | 0.078        | 0.750 |
| 3       | Coriander | 0.166      | 0.014        | 0.180 |
| 4       | Rice   | 0.244        | 0.047        | 0.291 |
| 5       | Sugarcane | 1.773      | 0.61         | 2.383 |
| 6       | Spider lily | 0.32        | 1.326        |       |
| 7       | Grass  | 0.281        | 0.053        | 0.334 |
| CD      |       | 0.146        | 0.016        | 0.152 |
### Table 5  Biomass accumulation (t/ha) by different prevalent agroforestry system, Navsari, Gujarat

| System                                      | Woody component | Intercrops | Total |
|---------------------------------------------|-----------------|------------|-------|
|                                             | Above ground    | Below ground | Total | Above ground | Below ground | Total |
| ASHS (Mango + Teak + Brinjal)               | 7.58            | 2.86       | 10.44 | 3.69         | 0.43         | 4.12  | 14.56 |
| ASS (Eucalyptus + Spider lily)              | 70.93           | 18.44      | 89.38 | 7.80         | 2.55         | 10.35 | 99.72 |
| ASS (Teak + Sugarcane)                      | 2.54            | 0.65       | 3.20  | 16.79        | 5.78         | 22.56 | 25.76 |
| AHS (Mango + Rice)                          | 2.01            | 0.52       | 2.53  | 1.22         | 0.30         | 1.53  | 4.06  |
| AHS (Mango + Cabbage)                       | 2.14            | 0.43       | 2.57  | 2.29         | 0.20         | 2.49  | 5.06  |
| AHS (Mango + Sapota + lemon + Coriander)    | 2.29            | 0.6        | 2.86  | 1.06         | 0.09         | 1.15  | 4.04  |
| HPS (Sapota + Grass)                        | 4.31            | 1.12       | 5.44  | 1.71         | 0.32         | 2.04  | 7.48  |
| CD                                          | 1.35            | 0.353      | 1.709 | 0.909        | 0.143        | 0.984 | 1.38  |

### Table 6  Economic yield (kg/ha) of different prevalent agroforestry system, Navsari, Gujarat

| Systems                                      | Fruit yield | Timber yield | Intercrop yield kg/ha |
|----------------------------------------------|-------------|--------------|------------------------|
|                                              | Mango       | Sapota       | Lemon                  | Eucalyptus (pole/ha) | Teak |                     |
| ASHS (Teak + Mango + Brinjal)                | 9360        | -            | -                      | -                     | -    | 9141                 |
| ASS (Eucalyptus + Spider lily)               | -           | -            | -                      | 16000                 | -    | 585 bunches/ha       |
| ASS (Teak + Sugarcane)                       | -           | -            | -                      | -                     | -    | 58780                |
| AHS (Mango + Rice)                           | 6000        | -            | -                      | -                     | -    | 3500                 |
| AHS (Mango + Cabbage)                        | 9360        | -            | -                      | -                     | -    | 9750                 |
| AHS (Mango + Sapota + lemon + Coriander)      | 1980        | 2000         | 2310                   | -                     | -    | 3840                 |
| HPS (Sapota + Grass)                         | -           | 9360         | -                      | -                     | -    | 4875                 |

### Table 7  Carbon storage (kg/tree) of different parts of woody perennials of prevalent agroforestry system, Navsari, Gujarat

| Species           | Stem carbon | Branch carbon | Leaf carbon | Fruit carbon | Above ground carbon | Below ground carbon | Total carbon |
|-------------------|-------------|---------------|-------------|--------------|---------------------|---------------------|---------------|
| Mango             | 0.66        | 2.30          | 2.17        | 4.48         | 9.62                | 2.50                | 12.12        |
| Sapota            | 1.16        | 3.20          | 1.95        | 6.97         | 13.27               | 3.45                | 16.72        |
| Lemon             | 0.82        | 1.52          | 0.99        | 7.06         | 10.39               | 2.70                | 13.09        |
| Teak              | 12.96       | 1.29          | 0.26        | 0.72         | 15.24               | 3.9                 | 19.21        |
| Eucalyptus        | 19.20       | 1.64          | 0.44        | 0.18         | 21.46               | 5.58                | 27.03        |
| CD                | 0.67        | 0.75          | 0.23        | 0.42         | 1.32                | 0.87                | 1.68         |
Table 8: Carbon storage (kg/m²) of different crops of prevalent agroforestry system, Navsari, Gujarat

| No. | Crops           | Above ground | Below ground | Total   |
|-----|-----------------|--------------|--------------|---------|
| 1   | Cabbage         | 0.251        | 0.022        | 0.273   |
| 2   | Brinjal         | 0.323        | 0.037        | 0.360   |
| 3   | Coriander       | 0.080        | 0.007        | 0.086   |
| 4   | Rice            | 0.117        | 0.023        | 0.140   |
| 5   | Sugarcane       | 0.851        | 0.293        | 1.144   |
| 6   | Spider lily     | 0.480        | 0.154        | 0.636   |
| 7   | Grass           | 0.135        | 0.025        | 0.160   |
|     | CD              | 0.16         | 0.018        | 0.17    |

Table 9: Carbon sequestration (t/ha) by different agroforestry systems in Navsari district

| Agroforestry System | Woody component | Intercrops | Total |
|---------------------|-----------------|------------|-------|
|                     | Above ground    | Below ground | Total | Above ground    | Below ground | Total |       |
| ASHS (Mango + Teak + Brinjal) | 3.63 | 1.37 | 5.0 | 1.77 | 0.21 | 1.98 | 6.98 |
| ASS (Eucalyptus + Spider lily) | 34.05 | 8.85 | 42.90 | 3.74 | 1.22 | 4.97 | 47.87 |
| ASS (Teak + Sugarcane) | 1.21 | 0.31 | 1.5 | 8.06 | 2.77 | 10.83 | 12.36 |
| AHS (Mango + Rice) | 0.96 | 0.24 | 1.21 | 0.59 | 0.15 | 0.73 | 1.94 |
| AHS (Mango + Cabbage) | 1.9 | 0.28 | 1.37 | 1.10 | 0.10 | 1.19 | 2.42 |
| AHS (Mango + Sapota + Lemon + Coriander) | 2.06 | 0.53 | 2.61 | 0.51 | 0.04 | 0.55 | 1.93 |
| HPS (Sapota + Grass) | 0.64 | 0.16 | 0.82 | 0.82 | 0.16 | 0.98 | 3.5   |
| CD                  | 0.651 | 0.169 | 0.821 | 1.595 | 0.070 | 0.473 | 0.662 |

Table 10: Soil properties in different agroforestry systems in Navsari, District

| Sr.No. | System                                      | SOC (%) | N (kg/ha) | P₂O₅ (kg/ha) | K₂O (kg/ha) |
|--------|---------------------------------------------|---------|-----------|--------------|-------------|
| 1      | ASHS (Mango + Teak + Brinjal)               | 0.75    | 260       | 33.03        | 332.22      |
| 2      | ASS (Eucalyptus + Spider lily)              | 0.82    | 278       | 144.70       | 295.6       |
| 3      | ASS (Teak + Sugarcane)                      | 0.44    | 212       | 35.20        | 434.72      |
| 4      | AHS (Mango + Rice)                         | 0.36    | 199       | 28.20        | 572.38      |
| 5      | AHS (Mango + Cabbage)                       | 0.57    | 236       | 85.30        | 411.46      |
| 6      | AHS [Mango + Sapota + Lemon + Coriander (Multi-storey)] | 0.65 | 254 | 49.06 | 282.94 |
| 7      | HPS (Sapota + Grass)                        | 0.52    | 221       | 116.64       | 721.34      |

Table 11: Comparison criteria for financial viability of different agroforestry practices in 18 year duration in Navsari District

| Agroforestry system | NPV     | BCR     | EAI     | Compounded revenue | Compounded Cost | NPV:IEC |
|---------------------|---------|---------|---------|--------------------|-----------------|---------|
| ASHS (Mano + Teak + Brinjal) | 1630526 | 6.24    | 224910  | 1941632 | 311106 | 16.97 |
| ASS (Eucalyptus + Spider lily) | 620467  | 4.15    | 85585   | 817177  | 196710 | 6.91 |
| ASS (Teak + Sugarcane) | 1306354 | 3.52    | 180195  | 1823511 | 517156 | 9.04 |
| AHS (Mango + Rice)    | 4000953 | 2.73    | 55306   | 632062.5 | 231109 | 5.87 |
| AHS (Mango + Cabbage) | 767004  | 4.04    | 105798  | 1019035 | 252030 | 10.85 |
| Multistorey system (Mango + Sapota + Lemon + Coriander) | 376388. | 2.71    | 51918   | 596516  | 220127 | 9.79 |
| HPS (Sapota + Grass)  | 410244  | 4.05    | 56588   | 544628  | 134384 | 18.17 |

*Input and output for the annual crops were considered only up to the year it is cultivated by the farmer under the system. For horticulture crop based system, up to 8 years farmer grows field crop, then after they don’t grow it further.
**Fig.1** Map of Gujarat showing the study area of different taluka of Navsari district

**Fig.2** Prevalent agroforestry systems found in Navsari district, Gujarat, India. 2. A. Mango + Cabbage; 2.B. Teak + Sugarcane; 2.C. Eucalyptus + Spider lily; 2.D. Mango + Rice and 2.E. multi-storey (Mango + Sapota + Lemon + Coriander)
Carbon sequestered, above and below ground (woody as well as non woody components), by different agroforestry systems has given in Table 9 and results obtained are as under: Maximum above ground (34.05), below ground (8.85) and total (42.90 t/ha) sequestered carbon was recorded for Eucalyptus in ASS (Eucalyptus + Spider lily, followed by Mango and Teak in ASHS (Mango + Teak + Brijal) with 3.63, 1.37, 5.0 tons of carbon above ground, below ground and total, respectively (Table 9). Minimum values for above ground (0.64), below ground (0.16) and total carbon (0.82) were obtained from Sapota under HPS (Sapota + Grass).Highest above ground (8.06 t/ha), below ground (2.77 t/ha) and total carbon (10.83 t/ha) was sequestered by sugarcane under ASS (Teak + Sugarcane) followed by Spider lily under ASS (Eucalyptus + Spider lily) with respective values for above ground, below ground and total carbon as 3.74,1.22 and 4.97 t/ha (Table 9).Coriander intercropped in AHS (Mango + Sapota + Lemon + Coriander), sequestered minimum carbon (0.51, 0.04 and 0.55, above ground, below ground and total carbon, respectively) (Table 9).The maximum carbon to the tune of 47.87 t/ha was sequestered by ASS (Eucalyptus + Spider lily), followed by system type Teak + Sugarcane (12.36t/ha) and it was minimum (1.93 t/ha) from AHS (Mango + Sapota + Lemon + Coriander) (Table 9).

**Soil chemical properties under different AF systems**

Perusal of the data presented in table 4.8 revealed that SOC was higher (0.82%) under ASS (Eucalyptus + Spider lily) followed by ASH (Mango + Teak + Brinjal) with SOC 0.75 per cent and minimum (0.36 %) was recorded in AHS (Mango + Rice) (Table 10).Maximum available N (278 kg/ha) was recorded in AS (Eucalyptus + spider lily) system followed by ASHS(Mango + Teak + Brinjal) (260) AHS(Mango + Cabbage) (236) (Table 10). Minimum available N (199) was recorded under AHS (Mango + Rice). Significantly higher available P$_2$O$_5$ (144.70 kg/ha) was recorded under AS (Eucalyptus + spider lily) followed by HP (Sapota + Grass) with 116.64 of P$_2$O$_5$ per hectare. Minimum (28.20) was recorded in AH system type Mango + Rice. Perusal of data in table 4.8 show that maximum available K$_2$O (721 kg/ha) was recorded in HP (Sapota + Grass) system followed by AHS (Mango + Rice) with 572 kg K$_2$O/ha whereas, it was minimum (282) under Multi-storey AHS (Mango + Sapota + Lemon + Coriander) (Table 10).

The potential of C sequestration in agroforestry systems (AFS) is dependent on the tree component (Nair et. al., 2009). Tree presence increase C sequestration per unit of land due to the C sequestered by the tree itself, the inputs of residues (leaves and branches) it makes in to the soil, and incorporation of roots into the soil.

Trees use a greater volume of soil to build up Soil Organic Matter (SOM) than herbaceous crops, as they are able to explore soils farther from the tree trunk and to a greater depth, assuming small tree density is used (Moreno et. al., 2005). The greater soil volume explored by tree roots would enhance belowground organic matter depositions (Howlett et. al., 2011). Similar observations were recorded by Pandey et al., (2000) in Acacia nilotica based agroforestry system. Soil organic C, total N, total P, mineral N (NO$_3^-$N and NH$_4^+$ N) and P were greater under mid canopy and canopy edge positions compared to canopy gap. So tree canopy contribute toward nutrient conservation, soil amelioration and nutrient availability. This may be the reason for less soil nutrient and SOC in Teak + Sugarcane agroforestry system.
Gupta et al., (2009) reported that agroforestry system improves aggregation of soil through huge amounts of organic matter in the form of leaf biomass. The average soil organic carbon was higher in system with more number of perennial trees. Similar findings have been reported by Fassbender (1998). Chander et al., (1998) reported higher organic C and total N, microbial biomass C, basal soil respiration and activities of dehydrogenase and alkaline phosphatase in treatments with tree-crop combination than in the treatment without trees. Soil organic matter, microbial biomass C and soil enzyme activities increased with the decrease in the spacing.

Our results indicate that adoption of the agroforestry practices with fast growing trees led to an improved organic matter status of the soil, which is also reflected in the increased nutrient pool necessary for long-term productivity of the soil. However, tree spacing should be properly maintained to minimize the effects of shading on the intercrops. Potassium concentrations were significantly higher in horti-pasture system (Sapota + Grass). High levels of K in soils under pasture have been mentioned by various authors (Tome, 1997; Tornquist et. al., 1999). According to Tome (1997), high levels of K may occur in acid soils under older pastures due to the capacity of many grass species to extract K from the upper soil and, through recycling, promote the availability of this nutrient in the soil.

Economics of prevalent Agroforestry Systems

Net Present Value

Data showed that the maximum value of NPV (Net Present Value) amounting to 16,30,526 INR was recorded in ASHS (Teak + Mango + Brinjal) followed by AHS (Mango + rice) (4,000,953), and minimum NPV (3,76,388) was recorded in multi-storey (Mango + Sapota + Lemon + coriander) (Table 11).

Benefit Cost Ratio (BCR)

Highest value (6.24) of Benefit Cost Ratio (BCR) was recorded in ASHS (Teak + Mango + Brinjal) followed by ASS (Teak + Sugarcane) (3.52), and minimum (2.71) was recorded in AHS (Mango + Rice) (Table 11).

Equivalent Annual Income

Equivalent Annual Income (EAI) was maximum (2,24,910 INR) from ASHS (Teak + Mango + Brinjal) followed by ASS (Teak + Sugarcane) (1,80,195 INR), and minimum (55,306 INR) was recorded in AHS (Mango + Rice) (Table 11).

NPV=Net Present Value; BCR=Benefit Cost Ratio; EAI= Equivalent Annual Income and IEC=Initial Establishment Cost

In term of EAI, again Mango + teak + brinjal is the most preferable land use type. The other systems showing higher EAI were teak + sugar cane and Mango + cabbage. This suggests that incorporation of forest tree component only costs in initial years but at the end handsome income can be derived. Our finding is in concord with Williams (1998) and Duguma (2012). Most of the expenditure in establishment of perennial crop occurred during first two years.

Most prevalent continuous expenditure in crops like rice, sugarcane and vegetables needs a continuous care like weeding, cultivating, irrigation and fertilizer.

Taking in to account the limited land resource and money constraints, it is logically clear that farmer may opt for option that produce higher value with less IEC. The analysis revealed that NPV: IEC is higher for Sapota +
grass System and produces NPV 18.17 with single unit of IEC. Sapota + grass is most preferred because it requires less capital as compare to other systems. Grasses requires less care as compared to other agricultural crops, this reduces the initial investment cost. Again more number of sapota tree increases the fruit revenue.

The economic analysis at the end of 28 years (felling trees) indicated that benefit cost ratio was higher in Sapota + Teak + field crops (3.23:1) followed by Sapota + Lagerstroemia lanceolate + field crops (2.71:1) and sole Sapota (2.36:1). This teak based agroforestry model is economically viable agroforestry system (Patil et al., 2010). But considering EAI and NPV: IEC value together indicates that Mango + Brinjal + Teak is should be promoted as its NPV: IEC value is also higher and it gives approximately four times more annual income. The cash flow pattern varied with the agroforestry land use types. For the system containing Eucalyptus or teak, the cash flow hits the peak at the rotation age when major harvest occurs at six year in eucalyptus and eighteen years in Teak. Horticulture tree based system, continuous cash flow observed since these tree produces fruit in perpetuity.

In Navsari District, four major prevalent agroforestry systems are in vogue i.e. agri-silvi-horticulture system (ASHS), agri-silviculture system (ASS), agri-horticulture system (AHS), and horti-pasture system (HPS). Among different (fruit and forest tree species) woody perennials incorporated in different agroforestry system, Eucalyptus gave higher biomass and carbon storage values followed by Teak. As regards biomass and carbon sequestration potential of agroforestry systems, ASS (Eucalyptus + Spider lily) gave higher biomass and carbon sequestration potential followed by system type Teak + Sugarcane. Economic yield in terms of production of saleable part, was higher from AHS (Mango + Cabbage) followed by ASHS (Teak + Mango + Brinjal).

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