AN INVESTIGATION ENTITLED “PRODUCTIVITY AND CARBON SEQUESTRATION UNDER PREVALENT AGROFORESTRY SYSTEMS IN THE NAVSARI DISTRICT” was carried out in the year 2011-2012, in Navsari District of Gujarat.

The agroforestry systems were identified through filed survey following Stratified Random Sampling in five talukas of Navsari district. Four major agroforestry systems i.e. agri-silvi-horticulture (ASH) agri-silviculture (AS), agri-horticulture (AH), and horti-pasture (HP). AH system had maximum (3) system types- Mango + sapota + lemon + coriander, mango + cabbage, mango + rice and followed by AS system representing two system types i.e. Teak + sugarcane and eucalyptus + spider lily. ASH and HP systems had only one system type i.e. mango + teak + brinjal and sapota + grass, respectively. Besides these AS system 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 AS (Teak+Sugarcane) system gave maximum biomass. Total biological yield (all components) was higher from AS (system type Eucalyptus+Spider lily) and minimum) was from AH (Mango + sapota + lemon + Coriander) system. Among seven agroforestry system types, highest carbon tonnes per hectare (tree + intercrop) was sequestered by AS (Eucalyptus+Spider lily) 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 (Teak + mango + brinjal) system followed by AH (Mango + rice) system.
I. INTRODUCTION

The increasing population need food security along with better environment for healthy living. Human as well as cattle needs like food, housing timber, fuel wood, clothes, medicines, fodder etc., are mostly derived from the plants grown in agricultural field and from natural habitats. Land use systems to secure food availability vis a vis create better living environment needs to be devised and improved keeping in view the needs and changing climatic conditions without compromising the productivity and sustainability of land use system put in place and resources used. One such land use system being advocated fit to address above said questions world over is agroforestry (Jackson et al., 2007; Jose, 2009; Padmavathy and Poyyamoli, 2013). The monoculture of fruit/fodder/timber trees being risk prone whereas suitable crop combination in the interspaces in the plantations of fruit, timber and fodder and fuel wood tress generate additional income and helps improve productivity per unit area and efficient utilization of natural resources results in improved ecological conditions by locking the atmospheric carbon in woody components for longer period. This technology has dual role in supporting the socio-economic status of the farmers on one hand and mitigating adverse climatic effect of deforestation to greater extent by increasing the green cover index on the other. Agroforestry also leads to a more diversified and sustainable rural production system than many treeless farming alternatives (Pandey, 2007). Escalating concentration of greenhouse gases in the atmosphere and the adverse effects associated with climate change have also necessitated the need for identification of systems with high carbon sink
as a mitigation strategy. Tree-based systems either as farm forestry or agroforestry systems have the potential to sequester carbon in a short period. Agroforestry is an ideal land-use option as it optimizes tradeoffs between increased food production, poverty alleviation and environmental conservation. Izac et al. (2000) by sequestering carbon in vegetation and soil, produces wood, serving as substitute for similar products that are unsustainably harvested from natural forests, and also contributes to farmers’s income (Sudha et al. 2007). World over, it has been estimated that the potential area suitable for agroforestry from land-use change could be up to 630 million ha which would result in storing 586 mt C/yr by 2040, mostly in developing countries (Watson et al., 2000). The transformation of low productive crop lands into agroforestry can triple carbon stocks from 23 to 70 t/ha in a 25-year period. Average carbon sequestration potential in agroforestry has been estimated to be 25 t/ha over 96 million ha land in India (Sathaye and Ravindranath, 1998). Adoption and sustainability of agroforestry systems depend on the positive interface effects between the physical and biological components both above and below ground. Diagnoses of existing and improved agroforestry land use systems can divulge their production and carbon sequestration potential. 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. The objectives of the study were:

i. To identify the prevalent agroforestry systems in Navsari District

ii. To evaluate the biological and economic yield of agroforestry systems

iii. To estimate carbon stocks in different agroforestry systems
II. REVIEW OF LITERATURE

Agroforestry is relatively a new area of research. Investigations on agroforestry interface both above and below ground are still needed to evolve with variety of economically and ecologically feasible agroforestry systems.

To augment better comprehension on the present study the available literature have been reviewed on various aspects under different land use systems under following major heads.

2.1. Growth and yield

2.2. Carbon sequestration

2.3. Nutrient dynamics

2.4. Economics

2.1. Growth and yield

In India, due to competition for land due to intense population pressure, rapidly depleting fuel wood resources, time- scale orchard operations, and dispersed distribution of benefits from forestry and seasonal shortage of labour; the growing of trees did not find a suitable place in rural economy and rangeland development programmes in the past. However, due to enormous pressure on non-renewable land resource, emphasis is now shifting towards agroforestry based land use system. Intercropping of agricultural crops with woody species is an age-old practice in traditional farming systems in the tropics. Growing of arable crops in association with
trees is one of the viable sources to sustain the agricultural production and stabilize the rural economy (Rekha et al., 2007).

Depommier (2003) revealed that agroforestry is extensively practiced in India in the form of the shifting agriculture, a variety of cereal cropping system, home garden system, traditional plantation system etc, but in recent times many of these system have started breaking down because in many situation, high diversity based agroforestry system have been replaced by low diversity simplified cash crop systems. He also observed that gaps in the knowledge of multipurpose trees and systems functioning needs to be better understood for sustainable agroforestry.

Varadaranganatha and Madiwalar (2010) found that there were six prominent agroforestry systems practiced in the three distinct agroecological situations in Uttara kannada district of Karnataka. In all the three situations, bund planting (21.66 to 36.67 %) was the most prominent agroforestry practiced by farmers, followed by horti-silviculture system (3.33 to 23.33 %) and less prominent practice was block plantation (5.0 to 11.66 %).

Bijalwan et al., (2009) in mid hill situation of Garhwal Himalaya studied structure and composition of tree species and productivity of agricultural crop under existing agroforestry system viz. agrihortisilviculture and agrihoriculture system during Rabi and Kharif seasons in the year 2004-2006. In the agricultural crop the grain yield was recorded highest (1197 kg/ha/yr and biological yield
4110 kg/ha/yr) under AHS in northern aspect as compared to 2027 and 6070 kg/ha/yr sole cropping. On an average reduction of 46.38 percent in gain yield and 39.93 percent in biological yield compared to sole cropping but this reduction is supplemented by multipurpose benefit of wood production which has greater importance for rural community of this region.

Dwivedi et al. (2007) in their study on outcome of socio-economic diagnosis of traditional as well as commercial agroforestry practices followed by farmers in western Uttar Pradesh, observed that tree species like Azadirachta indica, Acacia nilotica, Dalbergia sissoo and Eucalyptus spp. were dominant species in traditional system whereas, Populus deltoides and Eucalyptus spp. were the main species of commercial agroforestry. The net return from tree produce ha\(^{-1}\) per annum in traditional system was Rs. 989, 541 and 440 for marginal, small and medium farmers, respectively. In commercial region, B:C ratio has higher (3.00) for poplar based agrisilviculture than poplar (2.84) and eucalyptus (2.68) based bund system. Although traditional agroforestry seems less promising as compared to commercial agroforestry, but it is also relevant to the farmers’ livelihood.

Oraon et al., (2005) found that in Kumharia village of Ranchi district people adopts different land use practices such as agriculture, agroforestry home garden and fallow land on their agricultural land. The yield performance of agricultural crops, vegetable and grasses
indicated additional benefits from same land, thereby raising per unit area production. Their study further revealed that, amongst agroforestry systems viz. agrisilvicultural, silvipastoral and home garden systems, wood volume production by subabul (*Leucaena leucocephala*) under agrisilviculture was maximum, whereas in silvipastoral system gamhar (*Gmelina arborea*) produced highest wood volume.

Kala (2010) in the hilly villages of Uttarakhand state of India, observed a gradually decline in the rainfed hill agro-forestry system. Water scarcity, migration of youth in search of employment and changing socio-economic and climatic conditions were some of the major reasons for declining agro-forestry system and abandoning the agricultural land. The major cereals produced by farmers were *Oryza sativa* L., *Echinochloa frumentoacea* Link., *Eleusine coracana* (L.) Gaertner and *Triticum aestivum* L.

Studies carried out by Tynsong and Tiwari (2011) in south Meghalya revealed that arecanut agroforests are less diverse and less dense than the natural forests. In arecanut agroforests, the density of economically important species was significantly higher indicating deliberate promotion of such species.

Bellow *et. al.*, (2008) find out that fruit based agroforestry systems are common in northwest Guatemala as low intensity home garden and are known to increase total farm productivity in communities where farm size is a limiting factor. They also observed
that fruit based agroforestry was potentially more attractive to relatively prosperous families or those with larger land holdings.

Rai et al., (2009) observed that among multipurpose tree species (MPTs), viz. *Acacia nilotica* var cupressiformis, *Dalbergia sissoo* and *Hardwickia binata* in a silvipastoral system, *D. sissoo* attained highest growth parameters at research farm of National Research Centre for Agroforestry, Jhansi. Pruning of MPTs resulted into decrease in height, collar diameter, diameter at breast height and canopy spread. *D. sissoo* gave 0.36 t ha$^{-1}$ yr$^{-1}$ of leaf fodder and 1.8 ha$^{-1}$ yr$^{-1}$ fuel wood followed by *H. binata*. They also found that fourth year onwards, pasture production decrease significantly under different MPTs based silvipastoral system with maximum decrease in *D. sissoo* as compared to pasture alone. Irrespective of MPTs pruning result an increase in understorey pasture production.

Ravi et al., (2009) carried out an investigation with four shade tolerant fodder crops to find out the combatable *Ailanthus excelsa* based agroforestry system at forest college and Research Institute, Mettupalayam. Study revealed that the growth and yield of the test crop were reduced under intercropping when compare to pure cropping. Among the test crop, Desmanthus was most affected and fodder cowpea was least affected.

Patil et al., (2010) conducted a long-term agroforestry experiment consisting of arable crops (Paddy, maize, sunhemp). Silvicultural trees viz., *Eucalyptus tereticomis*, *Casuarina-
equisetifolia. *Albizia molucana, Tectona grandis, Dalbergia sissoo*, horticultural tree (sapota) and pasture crop (guinea grass) on black clayey soils at Prabhunagar (Dharwad) during 1976. Sapota (*Achras sapota*) was planted at 10 m apart and three tree species were planted in between 2 Sapota plants. Guinea grass (*Panicum maximum*) slips were planted on either side of sapota and tree species in a small strip of 1 m width. At the end of 17 years (felling all short rotation trees and only adjoining long rotation trees), economic analysis indicated that, benefit cost ratio and internal rate of returns were highest in agroforestry system with *T. grandis* (1.67:1 and 23.2%, respectively) and were lowest in sapota+*C. equisetifolia* (0.99:1 and 12%, respectively). The economic analysis at the end of 28 years (felling trees) indicated that benefit cost ratio was higher in sapota+*T. grandis*+field crops (3.23:1) followed by sapota+*Lagerstroemia lanceolata*+field crops (2.71:1) and sole sapota (2.36:1). This teak based agroforestry model is economically viable agroforestry system.

Jaimini *et. al.*, (2006) worked on khejri based silvipastoral system and indicated higher fodder yield below the Khejri tree canopy (49.50 q/ha) followed by between Khejri rows (40.25 q/ha.) and lowest forage yield was observed in sole dhaman grass without khejri tree (38.75 q/ha.)

Sharma and Chauhan (2003) studied the performance of Soyabean corp under tree species (*Prunus domestica, Morus alba* and *Punica granatum*) at Dr. Y. S. Parmar University of Horticulture and
Forestry, Solan (HP). The growth and yield attributes of soyabean recorded lower values under shade in comparison to open conditions. The crop yield was less in the close proximity with the tree, however it increased with the increase in distance from the tree.

Nandal and Hooda (2005) investigated the production potential of different agricultural crops under different spacings of poplar plantation and observed that the yield of all agricultural crops including cowpea and moongbean showed increased yield with wider spacing of poplar plantation whereas decreased yield with the increasing age of poplar plantation. Among all crops during rainy seasons cowpea for fodder was found most compatible with poplar.

Jaimini et. al., (2003) carried out on ardu (Ailanthus excelsa) based agri-silvicultural system during 1999-00 to 2001-02 at GAU, Sardar Krushinagar and indicated beneficial effects of ardu on environment and soil health. The raising of arable leguminous crops viz., cowpea, cluster bean and green gram as sole and as intercrops in between tree (528 trees/ha) rows indicated reduction in production under agri-silvicultural system as compared to sole, though, there was an improvement in soil fertility status under ardu based agroforestry system.

Baghel et. al., (2004) studied the intercropping system in bearing orchard of mango under rainfed agro-ecosystem. The crops grown under mango were cowpea, pigeon pea, bengal gram and tomato. Maximum production per hectare was recorded from mango
intercropping cow pea system in *kharif* and mango- bengal gram in *Rabi* seasons, respectively.

Chauhan *et. al.*, (2008) studied the performance of maize (*Zea mays* L.) varieties under different spacing of poplar (*Populus deltoids* M.) in lower western Himalayas and found that increase in distance between tree rows resulted higher growth in height, diameter at breast height, crown diameter and crown length of tree and grain yield in maize crops.

Meena *et. al.*, (2001) observed that intercropping of fodder crops with ardu (*Ailanthus excelsa*) tree resulted positive impact on growth and development of ardu. These parameters were also observed higher with plantation of cenchrus and cowpea in 1:2 ratios.

Shinde (2001) studied the effect of tree species on the growth and production of forage crops. Maximum number of leaves, number of branches, fresh weight, dry weight and water status of leaves was observed, when crops were grown under Kalam (*Mitragyna parviflora*) and Arjun(*Terminalia arjuna*). Similarly, maximum root length of forage crops was also recorded in open condition followed by Kalam based agroforestry system. However, the higher yield of forage per hectare was recorded in open condition as compared to yield obtain Kalam and Arjun.

Subash (2002) conducted a trial on productivity of four kharif crops like paddy, greengram, blackgram and groundnut in the alleys of four tree species *viz.*, *Eucalyptus tereticornis*, *Dalbergia sissoo*,
Acacia auriculiformis and Gmelina arborea in a slopy barren land. The mean annual increase in tree growth (height + girth) was maximum in Eucalyptus teriticornis followed by Dalbergia sissoo. The productivity of kharif crops was invariably maximum under the canopy of Dalbergia sissoo followed by Acacia auriculiformis. The lowest yield of above crops were obtained from the inter spaces of Eucalyptus teriticornis.

Parekh and Patil (2003) in an investigation on intercropping of in Mitragyna parvifolia and Adina cordifolia with three pulse crops viz., Vigna radiata, Vigna sinensis and Vigna mungo observed the maximum fresh weight and water status of leaves were recorded when crops grown under open field, as compared to under Adina cordifolia and Mitragyna parviflora based agroforestry system. Similarly maximum root length, number of branches, number of pods and leaf area were recorded when crop grown in open field as compared to Mitragyna parviflora and Adina cordifolia.

Handa et. al., (2004) conducted an experiment on growth of fruit trees and their effect on intercrops at National Research Centre for Agroforestry, Jhansi with four fruit trees viz., guava, ber, anar and kinnnow along with four crop rotation viz., sorghum-wheat, sorghum-chickpea, groundnut-wheat and groundnut-chickpea. Study revealed higher yield with increase in distance from tree in all tree crop combination.
Mohapatra (2003) conducted an experiment on Silvo-pastoral system in years 1996-1998 on sloppy waste land. Six popular tree species (viz. *Eucalyptus tereticornis*, *Acacia auriculiformis*, *Acacia nilotica*, *Dalbergia sissoo*, *Samanea saman* and *Albizia lebbek*) were different significantly in growth of plant height (PH) and girth at shoulder height (GSH). *Eucalyptus* showed maximum growth of PH and GSH followed by *Acacia auriculiformis*. Fodder yield of Dinanath grass in two cuts was highest under the tree canopy of *Dalbergia sissoo* followed by *Samanea saman* and lowest in the interspaces of *Eucalyptus*.

Rajput *et. al.*, (1988) carried out experiments on intercropping of vegetables (potato, brinjal, onion, okra, chillies, tomato, colocasia, bittergourd, Indian squash, cauliflower and long melon); pulses (cowpea, blackgram, pigeonpea, pea and gram) and cereal (wheat) in young mango orchards at Lucknow. All the intercrops grown under the canopy of Mango trees produced normal yield. In case of vegetables, the highest monetary returns (Rs. 4120/ha) were obtained from cowpea + potato + mango, whereas the returns were lowest in control (Rs. 192/ha). In second experiment, black gram + wheat + mango gave the highest monetary return (Rs. 7992.75/ha). Whereas, the lowest income was obtained in the control (Rs. 729/ha).

Patil and channabasappa (2008) studied that the seed yield of black gram was significantly higher due to tree management practices imposed to *Acacia auriculiformis*. Significantly higher seed yield was
recorded in treatment receiving trenching (730 kg/ha) which was statistically on par with treatment receiving 50 per cent branch pruning (715 kg/ha). Significantly higher seed yield was recorded at 12 to 14 m distance from the tree row (742 kg/ha), which was on par with 10 to 12 m distance from tree row (714 kg/ha). The seed yield of black gram significantly lower with the combination of control and 0 to 2 m distances from tree row.

2.2 Carbon sequestration

Montagini and Nair (2004) studied that average carbon storage by agroforestry practices has been estimated as 9, 21, 50, and 63 Mg C ha$^{-1}$ in semiarid, subhumid, humid, and temperate regions. For smallholder agroforestry systems in the tropics, potential C sequestration rates range from 1.5 to 3.5 Mg C ha$^{-1}$ yr$^{-1}$.

Shingh and Lodhiyal (2009) studied that agroforestry systems can play an important role in carbon mitigation programmes through carbon sequestration and can reduce the pressure on existing natural forests by providing fuel, fodder, timber and wood products to the farmers. Biomass and carbon allocation in Poplar agroforestry plantation in the Tarai region of central Himalaya, India have been studied and it is found that the Poplar agroforestry plantation in the Tarai region of central Himalaya had a significant amount of biomass and carbon, which acts as an additional carbon sink in the region.

Albrecht et. al., (2003) carried out an analysis of C storage in some tropical agroforestry systems. The C sequestration potential of
agroforestry systems is estimated between 12 and 228 Mg ha\(^{-1}\) with a median value of 95 Mg ha\(^{-1}\). Therefore, based on the earth’s area that is suitable for the practice (585–1215 × 106 ha), 1.1–2.2 Pg C could be stored in the terrestrial ecosystems over the next 50 years. Long rotation systems such as agroforests, home gardens and boundary plantings can sequester sizeable quantities of C in plant biomass and in long-lasting wood products. Soil C sequestration constitutes another realistic option achievable in many agroforestry systems.

Thakur et al. (2011) estimated above ground biomass, carbon stocks and carbon dioxide (CO\(_2\)) removal from the atmosphere under three agroforestry systems namely agri-silviculture (AS), pastoral-silviculture (PS) and pastoral-silvi-horticulture (PSH) in two villages, Kuthar (Site-I) and Arla-Kalyana (Site-II), in Solan district of Himachal Pradesh, India. *Murraya koenigii* gave maximum above ground biomass to the tune of 18.09, 68.52 and 14.85 q ha\(^{-1}\); under AS, PS and PSH system, respectively at site-I. Therefore, carbon sequestered i.e. 9.23, 34.95 and 7.57 q ha\(^{-1}\), under AS, PS and PSH system, was higher by *M. koenigii*. Also the CO\(_2\) removal, 33.86, 128.25 and 27.79 q ha\(^{-1}\), under AS, PS and PSH system was also higher for *M. koenigii* than other shrubs. Similarly, at site-II, *M. koenigii* gave maximum above ground biomass (31.81, 89.76 and 22.52 q ha\(^{-1}\) under AS, PS and PSH system, respectively), carbon stocks (16.22, 45.78 and 42.15, under AS, PS and PSH system, respectively) and higher CO2 removal (59.54, 167.99 and 42.15, under AS, PS and PSH system, respectively). *Justicia adhatoda* also
contributed substantially in all agroforestry systems in both sites. Out of three agroforestry systems, PS system had maximum above ground biomass (117.72 and 176.51 q ha\(^{-1}\), in site-I and II, respectively), carbon stocks (60.04 and 90.02 q ha\(^{-1}\), site- I and II, respectively) and CO\(_2\) removal (220.33 and 330.37 q ha\(^{-1}\), in site-I and II, respectively). The total above ground biomass, carbon sequestered and CO\(_2\) absorbed from the atmosphere was in the order PS>AS>PSH both sites.

Rizvi et al., (2011) observed that contribution of poplar plantation to carbon storage was found to be 27-32 t ha\(^{-1}\) in boundary system, whereas it was 66-83 t ha\(^{-1}\) in agrisilviculture system at a rotation period of 7 year in the two districts. Thus poplar plantation makes important contribution towards atmospheric co\(_2\) assimilation and hence plays a significant role in the mitigation of atmospheric accumulation of greenhouse gases.

Schoeneberger (2009) studied that agroforestry is an appealing option for sequestering carbon on agricultural lands because it can sequester significant amount of carbon while leaving the bulk of the land in agricultural production. Simultaneously it can help land owners and society in economic diversification, biodiversity and water quality.

Yadava (2010) carried out studies on biomass production and carbon sequestration in *populous deltoides* + wheat (S\(_1\)), *Eucalyptus hybrid*+wheat – boundary plantation (S\(_2\)), *P.deltoides* + wheat
boundary plantation ($S_3$) and $P. deltoides +$ lemon grass ($S_4$) in Udhamsingh Nagar, Uttarakhand. He observed that number of woody perennial involved in the system and the management practices plays a major role in influencing the biomass level, carbon storage, CO$_2$ mitigation potential and total carbon sequestration (in trees) of 70.59 t ha$^{-1}$, 21.38 t ha$^{-1}$, 116.29 t ha$^{-1}$ and 18.53 t C ha$^{-1}$ in system $S_1$ followed by 68.53 t ha$^{-1}$, 20.63 t ha$^{-1}$, 113.03 t ha$^{-1}$ and 17.60 t C ha$^{-1}$ in system $S_4$, respectively. It was also observed that all the agroforestry systems can sequester more carbon as compared to sole agricultural land use systems. It was also observed that $Populus deltoides +$ wheat and $Populus deltoides +$ lemon grass under block plantation have the maximum potential to sequester carbon than the boundary plantations of $Populus deltoides$ and $Eucalyptus hybrid$.

Chauhan et. al., (2011) studied that the carbon storage potential in agroforestry system was recorded very high in comparison to sole crop and carbon storage in agroforestry system increased with the age of the plantation and the major contribution came from the timber, roots and litter (37.30 mg/ha after six years). However, wheat crop yield decreased under poplar but this may be compensated by the poplar trees in terms of biomass, economic returns and the carbon sequestration potential. The enrichment of soil through litter and roots enhanced the organic carbon in the surface layer of soil (0-15 cm) under poplar blocks as compared to open fields with wheat crop only.
Sharma et al., (2007) studied that the cardamom agroforestry stored 3.5 times more carbon than the rainfed agriculture showing potential mitigation possibilities of the agroforestry by sequestration of the atmospheric carbon. The agroforestry is an efficient management system where ratio of output to input is more than 13 compared to rainfed agriculture. Cost benefit analysis showed that the cardamom agroforestry is profiting the farmers by 5.7 times more compared to the rainfed agriculture.

2.3 Nutrient dynamics

Bhardwaj et al., (2005) Studied that the plant nutrient pool represented 5.2 to 8.7% (P, Ca and Mg) and 20.2 to 23.0% (N and K) of the soil nutrient pool. In the trees, the major nutrient pool was in stems, branches and roots. Crops accounted for 22 to 59% of the total uptake of nutrients by the plants. Annual return of nutrients (kg ha\(^{-1}\)) in litterfall and fine roots was: 95.96 N, 8.85 P, 48.08 K, 64.73 Ca and 27.42 Mg. The pattern of release of nutrients from the decomposing litter was K>Mg>Ca>P>N. Rapid turnover of litter and fine roots favored rapid intra system cycling. The retention of nutrients in stems, branches and roots of trees varied from 6.66 to 69.80 kg ha\(^{-1}\) yr\(^{-1}\). About 48 to 58% of N and K and 19 to 24% of P, Ca and Mg of the total nutrient uptake were lost from the system in crop harvest and fuel wood extraction. The nutrient return in litterfall and fine roots almost balanced the removal of nutrients in crop
harvest excepting N and K. Thus the efficient use of nutrients from
the soil pool and rapid intra-system cycling maintained high
biological productivity of the agroforestry system.

Kibria and saha (2011) reported that the soil pH, moisture
content, organic matter, organic carbon, phosphorus and total
nitrogen showed statistically significant variation while bulk density,
particle density, sulphur and potassium did not show any statistically
significant variation among the land uses in Madhupur sal forest. Soil
fertility status showed that pineapple agroforestry is more fertile than
rest of other land uses.

2.4 Economics

Kibria and saha (2011) conducted a study in Madhupur sal
forest of Tangail, Bangladesh to identify the suitable agroforestry
practices of the area. The Net Present Value (NPV) indicated that
banana agroforestry is financially more profitable than other two
systems, while the Benefit-Cost ratio (BCR) is higher in pineapple
agroforestry (4.21 in participatory agroforestry and 3.35 in privately
managed land). Even though banana agroforestry gives higher NPV,
capital required for this practice is much higher. The findings suggest
that pineapple agroforestry has a tendency towards becoming
ecologically and economically more sound than other two practices
as it has better ecological attributes and required comparatively low
investment.
Momen et. al., (2006) performed a study in five villages of Sandwip Upazila, Chittagong district with a view to identify the tree resources, utilization pattern and economic return of major fruit and timber tree species. Information collected from a total of 60 households ranging from marginal, small, medium and large categories. The investment analysis showed that average benefit-cost ratios were greater than one, net present values were positive and internal rate of returns were more than 10%. Long term investment on horticulture and timber tree species is highly profitable if species like *Artocarpus heterophyllus*, *Cocos nucifera*, *Tectona grandis* and *Swietenia macrophylla* are planted.

Price (1995) carried out financial appraisal of agroforestry and concluded that the agroforestry may offer a quantifiable value in short-term sustainability, and might meet recent economic definitions of long-term sustainable development, without encountering the full dangers to future generations embodied in conversion of natural to human capital.

While conducting economic analysis of industrial agroforestry, Jain and Singh (2000) concluded that with agroforestry experience, farmers can expect high dividends in subsequent rotations. Life-time matrices developed through group interviews are useful for thorough economic analyses of agroforestry projects, particularly in cases where data over a period of time are not available.
Wannawong et. al., (1991) estimated potential productivity and financial returns from selected agroforestry systems and traditional monocrops located in the Phu Wiang watershed from limited trials of cropping alternatives using cost-benefit analysis. The agroforestry systems studied consisted of combinations of Eucalyptus (*Eucalyptus camaldulensis*), Leucaena (*Leucaena leucocephala*), or Acacia (*Acacia auriculiformis*) inter-cropped with cassava (*Manihot esculenta*) or mungbean (*Vigna radiata*). Evidence from trials at short, 3-year rotations, demonstrate that early supplementary and complementary relationships between some system components can imply synergistic financial gains. Although these biological interactions turn competitive over time, in this case, the gains should be sufficient to make early adopters consider the agroforestry systems financially preferable to traditional monocropping.

Singh et. al., (1997) while evaluating agriculture, forestry and agroforestry practices in a moderately alkali soil in northwestern India found that the benefit-cost ratio was highest (2.88) in poplar based system and minimum (1.86) in Acacia based system. The study indicated that growing trees and agricultural crops together is a better land use option in terms of productivity, maintenance of soil conditions and economics.

Economic analysis carried out by Patil et. al., (2010) at the end of 28 year indicated that benefit cost ratio was higher in
sapota + *T. grandis* + field crop (3:23:1) followed by sapota + *Largestroemia laceolata* + field crop (2:71:1) and sole sapota.

Shanmughavel and Francis (1999) studied the growth performances and economic returns of pigeonpea (*Cajanus cajan*) growing as intercrop in Bamboo plantation. Pigeonpea intercropped in 1:1 rows at 3 x 3 m spacing (250 plants/ha) and in 1:2 rows at 2 m x 2 m spacing (500 plants/ha) in Bamboo plantations. That on annual basis a net amounts of Rs. 7900/- at 2 x 2 m spacing and Rs. 13,300/- at 3 x 3 m spacing can be obtained. This agrisilviculture model provides fodder, fuel, fodder and timber to rural population.

Singh et al., (1996) observed that intercrops did not affect the growth of mango plant in initial year of planting, whereas significantly differences were recorded in next year. Maximum net return were obtained with okra-gram-okra followed by chilli as annual crop in both the year. The growth of mango was not adversely affected by different treatments.

Viswanath et al. (2000) found that combination of Acacia and rice traditional agroforestry system has a benefit/cost (B/C) ratio of 1.47 and an internal rate of return (IRR) of 33 at 12% annual discount rate during a ten-year period. In the northeast Indian State of Meghalaya, guava and Assam lemon-based agroforestry systems (that is, farming systems that combine domesticated fruit trees and forest trees) the yields were 2.96 and 1.98-fold higher net return
respectively, in comparison to farmlands without trees (Bhatt and Misra, 2003; Pandey, 2007).
III. MATERIALS AND METHODS

The details of the experimental materials used, methods followed and the techniques adopted during the course of the investigation are described here under.

3.1 Description of study area

The present investigation entitled “Productivity and carbon sequestration of prevalent agroforestry systems in Navsari district”, during 2011-2012. Navsari district is located in the south eastern part of Gujarat state in the coastal lowland along Purna river. The district has 5 talukas of which Navsari, Gandevi, and Chikhli are major talukas. The district abounds in sugarcane fields, chikoo plantations, and mango trees. 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.

3.2 Selection of AF (Agroforestry) systems

The agroforestry systems were identified through filed survey following Stratified Random Sampling in five talukas of Navsari district (Navsari, Gandevi, Jalalpore, Chikhli and Vansada). There are several agroforestry systems in vogue in different villages of Navsari district.
Table 3.1. Structure and composition of prevalent agroforestry system in Navsari district.

<table>
<thead>
<tr>
<th>Major Systems</th>
<th>System type</th>
<th>Spacing/number per ha</th>
<th>Age of woody perennial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Woody perennials</td>
<td>Intercrops</td>
</tr>
<tr>
<td>Agri-silvi-horticulture (ASH)</td>
<td>1 Mango + Teak (on boundary) +</td>
<td>Mango - 8x8 m (156 trees); teak-5 m plant to plant (80 trees on boundary)</td>
<td>40x40 cm</td>
</tr>
<tr>
<td></td>
<td>Brinjal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agri-silviculture (AS)</td>
<td>3 Eucalyptus + Spider lily</td>
<td>2.5x2.5 m (1600 trees)</td>
<td>1x1 m</td>
</tr>
<tr>
<td></td>
<td>4 Teak (boundary plantation) +</td>
<td>2.5 m plant to plant (80 trees)</td>
<td>30x90 cm</td>
</tr>
<tr>
<td></td>
<td>Sugarcane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agri-horticulture (AH)</td>
<td>5 Mango + Rice</td>
<td>10x10 m (100 trees)</td>
<td>20x20 cm</td>
</tr>
<tr>
<td></td>
<td>6 Mango + Cabbage</td>
<td>8x8 m (156 trees)</td>
<td>45x45 cm</td>
</tr>
<tr>
<td></td>
<td>7 Mango + sapota + lemon +</td>
<td>Sapota-Lemon-Mango 10x10 m (33 trees of each species)</td>
<td>Broadcasted</td>
</tr>
<tr>
<td></td>
<td>Coriander</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horti-pasture (HP)</td>
<td>2 Sapota + Grass</td>
<td>Sapota-8x8 m (156 trees)</td>
<td>Broadcasted</td>
</tr>
</tbody>
</table>
Among them seven prevalent agroforestry system were selected (described in results). The structure and composition and growth attributed of woody components under different agroforestry systems is given in table 3.1 and 3.2, respectively.

Table 3.2 Growth attribute (average of 10 trees) of different woody perennial in agroforestry system

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Species</th>
<th>Height (m)</th>
<th>Diameter (cm)</th>
<th>Volume ($m^3$)</th>
<th>Specific gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mango</td>
<td>1.2</td>
<td>6.1</td>
<td>0.0035</td>
<td>0.39</td>
</tr>
<tr>
<td>2</td>
<td>Sapota</td>
<td>1.8</td>
<td>6.2</td>
<td>0.0054</td>
<td>0.44</td>
</tr>
<tr>
<td>3</td>
<td>Lemon</td>
<td>1.7</td>
<td>6.2</td>
<td>0.0033</td>
<td>0.51</td>
</tr>
<tr>
<td>4</td>
<td>Teak</td>
<td>5.8</td>
<td>7</td>
<td>0.012</td>
<td>0.57</td>
</tr>
<tr>
<td>5</td>
<td>Eucalyptus</td>
<td>10</td>
<td>11</td>
<td>0.09</td>
<td>0.42</td>
</tr>
</tbody>
</table>

3.3 Biological and economic yield of intercrops

3.3.1 Biological yield

To estimate the biological yield of agricultural crops plants were uprooted to the depth possible in 1×1m area. Fresh weight (above and below ground) parts were taken with the help electronic balance. Thereafter, the representative samples, from all treatment and replications were taken and brought to laboratory and dried in oven at 60 °C till the constant weight to record dry weight. Biological yield was calculated using formula:
Biomass of branch/leaves = \frac{\text{Dry weight of sample}}{\text{Fresh weight of sample}} \times \text{Total fresh weight of branch/leaves}

3.3.2 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.

3.4 Growth and biomass estimation of woody perennials

3.4.1 Tree Height (m)

The tree height was measured from the ground level to the tip of the apical bud of the stem with the help of ‘Ravi Altimeter’. The observation of height was taken on ten plants in each agroforestry systems.

3.4.2 Tree DBH (cm)

The Diameter at Breast Height (DBH) of trunk of the trees was measured in centimetres at breast height (1.37 cm from ground level) with the help of callipers. The observations of diameter were taken on ten plants in each agroforestry systems.

3.4.3 Standing volume of trees (m³)

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)

### 3.4.4 Wood specific gravity

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 (ASTM, 1986). The basic specific gravity was calculated as oven-dry weight ($105 \degree C$, 48 h) divided by volume.

### 3.4.5 Above ground biomass of perennials

Above ground stem biomass of selected trees in the system was determined by following formula

\[
\text{Biomass} = \text{volume} \times \text{specific gravity of wood}
\]

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 into 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 value of average fruit weight and leaf weight further extrapolated to individual tree level and dry weight was calculated using formula given in sub head 3.3.1.

3.4.6 **Below ground biomass**

The tree below ground biomass was estimated by multiplying the tree above ground biomass with factor 0.26. (IPCC default value)

3.5 **Total system biomass**

The total system above ground biomass was calculated adding biomass of all the components (Below ground and above ground).

3.6 **Carbon sequestration**

The carbon sequestration was calculated by multiplication of biomass with default value 0.48 given by Chaturvedi (1984) for Indian conditions.

3.7 **Soil characteristics**

Soil samples were taken from surface level (0-15 depth) covering the whole experimental site. The composite soil samples were prepared for analysis of chemical properties as per the method mentioned in Table3.3.
Table 3.3 Methods used for the determination soil samples.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Particulars</th>
<th>Method adopted</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.</td>
<td>Available N (kg ha⁻¹)</td>
<td>Alkaline Permanganate Oxidation</td>
<td>Subbiah and Asija (1956)</td>
</tr>
<tr>
<td>4.</td>
<td>Available P₂O₅ (kg ha⁻¹)</td>
<td>Spectrophotometric (Extraction with 0.5 M NaHCO₃, pH of 8.5)</td>
<td>Olsen et al., (1954)</td>
</tr>
<tr>
<td>5.</td>
<td>Available K₂O (kg ha⁻¹)</td>
<td>Flamephotometric (Extraction with NH₄OAc of pH 7)</td>
<td>Jackson (1973)</td>
</tr>
<tr>
<td>6.</td>
<td>Organic carbon (%)</td>
<td>Walkley and Black rapid titration method</td>
<td>Jackson (1967)</td>
</tr>
</tbody>
</table>

3.8 Economics

3.8.1 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.

3.8.2 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.
IV. RESULTS

The results of the present study are described under the following heads:

4.1 Identification of agroforestry systems (AF)

4.2 Biological and economic yield of AF systems

4.3 Carbon sequestration by AF systems

4.4 Soil chemical properties AF systems

4.5 Economics of AF systems

4.1 Identification of AF systems

The structure and composition of prevalent agroforestry systems and system types, in Navsari District, are presented in table 3.1 (given in Chapter-3).

In total four major agroforestry systems were found to be practiced by the farmers i.e. agri-silvi-horticulture (ASH), agri-silviculture (AS), agri-horticulture (AH), and horti-pasture (HP) system. AH system had maximum (3) system types- Mango + sapota + lemon + coriander [(multi-storey) Plate-III], mango + cabbage (Plate-I a) mango + rice (Plate-II b) and followed by AS system representing two system types i.e. Teak + sugarcane (Plate-I b) and eucalyptus + spider lily (Plate-II a). ASH and HP systems had only one system type i.e. mango + teak + brinjal and sapota + grass, respectively. Besides these AS system was represented by two more system types (teak + rice and arjun + nagali) however these system types were found existing with only one farmer.
Plate I

(a) Agri-horticulture system (Mango + Cabbage)

(b) Agri-silviculture (Teak + Sugarcane)
(a) Agri-silviculture system (Eucalyptus + spider lily)

(b) Agri-horticulture system (Mango + rice)
Plate II

(Mango + sapota + lemon + coriander)

Plate III
4.2 Biological yield and economical yield of prevalent AF systems

4.2.1 Biological yield

4.2.1.1 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 is presented in table 4.1 and is described as under:

4.2.1.1.1 Tree stem biomass

The maximum stem biomass (40 kg/tree) was recorded in eucalyptus followed by teak (27.0) and minimum (1.37) was recorded in mango.

4.2.1.1.2 Tree branch biomass

The branch biomass was maximum (6.66 Kg per tree) in Sapota followed by mango (4.80). Minimum branch biomass (2.7) was recorded in teak.

4.2.1.1.3 Tree leaf biomass

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 4.1: Biomass accumulation (kg/tree) of different parts of woody perennials.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Species</th>
<th>Stem</th>
<th>Branch</th>
<th>Leaf</th>
<th>Fruit</th>
<th>Above ground</th>
<th>Below ground</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mango</td>
<td>1.37</td>
<td>4.80</td>
<td>4.53</td>
<td>9.33</td>
<td>20.05</td>
<td>5.21</td>
<td>25.26</td>
</tr>
<tr>
<td>2</td>
<td>Sapota</td>
<td>2.42</td>
<td>6.66</td>
<td>4.06</td>
<td>14.53</td>
<td>27.65</td>
<td>7.19</td>
<td>34.84</td>
</tr>
<tr>
<td>3</td>
<td>Lemon</td>
<td>1.70</td>
<td>3.16</td>
<td>2.07</td>
<td>14.70</td>
<td>21.64</td>
<td>5.63</td>
<td>27.27</td>
</tr>
</tbody>
</table>
4.2.1.1.4 Fruit biomass

The maximum fruit biomass (14.70) was recorded in lemon followed by sapota (14.53) and minimum of 0.37 kg per tree was recorded in eucalyptus (table 4.1).

4.2.1.1.5 Above ground tree biomass

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), whereas minimum (20.05) was recorded in mango.

4.2.1.1.6 Below ground tree biomass

Below ground biomass was maximum (11.62 kg/tree) in eucalyptus followed by teak (8.26) and it was recorded minimum (5.21) in mango (Table 4.1).

4.2.1.1.7 Total tree biomass

Total tree biomass amounting to 56.32 kg/tree was recorded in eucalyptus followed by teak (40.03). Minimum total tree biomass (25.26) was recorded in mango.

4.2.1.2 Intercrop crop biomass (Kg/m²)
The data on crop biomass (above and below ground) of individual intercrops recorded under different agroforestry systems are presented in table 4.2 and is depicted as under:

4.2.1.2.1 Above ground intercrop biomass

Maximum above ground intercrop biomass to the tune of 1.77 kg/m$^2$ was recorded in sugarcane followed by spider lily (1), whereas least (0.16) was recorded from coriander (table 4.2).

4.2.1.2.2 Below ground intercrop biomass

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.

4.2.1.2.3 Total intercrop biomass

The maximum total crop biomass (2.38 kg/m$^2$) was recorded in sugarcane followed by spider lily (1.32), and was minimum (0.18) from coriander.

Table 4.2: Biomass accumulation (kg/m$^2$) of different intercrops.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Crops</th>
<th>Above ground</th>
<th>Below ground</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Caabbage</td>
<td>0.523</td>
<td>0.045</td>
<td>0.568</td>
</tr>
<tr>
<td>2</td>
<td>Brinjal</td>
<td>0.672</td>
<td>0.078</td>
<td>0.750</td>
</tr>
<tr>
<td>3</td>
<td>Coriander</td>
<td>0.166</td>
<td>0.014</td>
<td>0.180</td>
</tr>
<tr>
<td>4</td>
<td>Rice</td>
<td>0.244</td>
<td>0.047</td>
<td>0.291</td>
</tr>
<tr>
<td>5</td>
<td>Sugarcane</td>
<td>1.773</td>
<td>0.61</td>
<td>2.383</td>
</tr>
<tr>
<td>6</td>
<td>Spider lily</td>
<td>1</td>
<td>0.32</td>
<td>1.326</td>
</tr>
<tr>
<td>7</td>
<td>Grass</td>
<td>0.281</td>
<td>0.053</td>
<td>0.334</td>
</tr>
<tr>
<td>CD</td>
<td>0.146</td>
<td>0.016</td>
<td></td>
<td>0.152</td>
</tr>
</tbody>
</table>
4.2.1.3 Biological yield of prevalent AF system (t/ha)

4.2.1.3.1 Biological yield of trees

Perusal of data on biomass of woody and non woody components of different agroforestry systems (table 4.3) show 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 ASH (Teak+Mango+Brinjal) system 7.58, 2.86 and 10.44 t/ha, respectively. AH (Mango + rice) system gave minimum above (2.01) and below ground (0.52) and total biomass (2.53).
Table 4.3: Biomass accumulation (t/ha) by different agroforestry systems in Navsari District.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>System</th>
<th>Woody component</th>
<th></th>
<th>Intercrops</th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Above ground</td>
<td>Below ground</td>
<td>Total</td>
<td>Above ground</td>
<td>Below ground</td>
</tr>
<tr>
<td>1</td>
<td>ASH (Mango+Teak+Brinjal)</td>
<td>7.58</td>
<td>2.86</td>
<td>10.44</td>
<td>3.69</td>
<td>0.43</td>
</tr>
<tr>
<td>2</td>
<td>AS (Eucalyptus+Spider lily)</td>
<td>70.93</td>
<td>18.44</td>
<td>89.38</td>
<td>7.80</td>
<td>2.55</td>
</tr>
<tr>
<td>3</td>
<td>AS (Teak+sugarcane)</td>
<td>2.54</td>
<td>0.65</td>
<td>3.20</td>
<td>16.79</td>
<td>5.78</td>
</tr>
<tr>
<td>4</td>
<td>AH (Mango+rice)</td>
<td>2.01</td>
<td>0.52</td>
<td>2.53</td>
<td>1.22</td>
<td>0.30</td>
</tr>
<tr>
<td>5</td>
<td>AH (Mango+cabbage)</td>
<td>2.14</td>
<td>0.43</td>
<td>2.57</td>
<td>2.29</td>
<td>0.20</td>
</tr>
<tr>
<td>6</td>
<td>AH (Mango + sapota + lemon + Coriander)</td>
<td>2.29</td>
<td>0.6</td>
<td>2.86</td>
<td>1.06</td>
<td>0.09</td>
</tr>
<tr>
<td>7</td>
<td>HP (Sapota+grass)</td>
<td>4.31</td>
<td>1.12</td>
<td>5.44</td>
<td>1.71</td>
<td>0.32</td>
</tr>
<tr>
<td>CD</td>
<td></td>
<td>1.35</td>
<td>0.353</td>
<td>1.709</td>
<td>0.909</td>
<td>0.143</td>
</tr>
</tbody>
</table>
4.2.1.3.2 Biological yield of intercrops (t/ha)

Among intercrops under different agroforestry systems, sugarcane under AS (Eucalyptus+Sugarcane) system gave maximum above ground (16.79), below ground (5.78) and total biomass (22.56 t/ha) followed by spider lily under AS (Eucalyptus+Spider lily) with values of 7.80, 2.55 and 10.35 t/ha for above ground, below ground and total biomass (Table 4.3). Minimum above ground (1.06), below ground (0.09) and total crop biomass (2.43 t/ha) was obtained from coriander under AH (Mango + sapota + lemon + Coriander) system.

4.2.1.3.3 Total Biological yield of AF system (t/ha)

Maximum total biological yield (99.72 t/ha) was obtained from AS (Eucalyptus+Spider lily) followed by Teak+Sugarcane (25.76) and minimum (4.06) was from AH (Mango + sapota + lemon + Coriander) system.

4.2.2 Economic yield of different AF systems (kg/ha)

The economic yield (salable part of system components) of different agroforestry systems is presented in table 4.4 and the results are described as below:

4.2.2.1 Fruit yield (kg/ha)

Yield of mango was 9360 kg/ha from Teak+Mango+brijal and Mango+Cabbage, 6000 and 1980 kg/ha from Mango+Rice and Mango + sapota + lemon + Coriander, respectively.
Table 4.4: Economic yield (kg/ha) of different agroforestry system in Navsari District.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Systems</th>
<th>Fruit yield</th>
<th>Timber yield</th>
<th>Inter crop yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mango</td>
<td>Sapota</td>
<td>Lemon</td>
</tr>
<tr>
<td>1</td>
<td>ASH (Teak+mango+brinjal)</td>
<td>9360</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>AS (Eucalyptus+spiderlily)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>AS (Teak+sugarcane)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>AH (Mango+rice)</td>
<td>6000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>AH (Mango+cabbage)</td>
<td>9360</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>AH (Mango + sapota + lemon + Coriander)</td>
<td>1980</td>
<td>2000</td>
<td>2310</td>
</tr>
<tr>
<td>7</td>
<td>HP (Sapota+grass)</td>
<td>-</td>
<td>9360</td>
<td>-</td>
</tr>
</tbody>
</table>
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.

4.2.2.2 Economic yield of forest Trees

In ASH system involving Eucalyptus as forest tree species, 16000 poles per hectare were estimated (Table 4.4). Teak trees were 6 years old and is not considered in economical yield.

4.2.2.3 Economic yield of intercrops

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 4.4).

4.3 Carbon storage (kg/tree) in woody component

The results on carbon stocks per tree, in different organs of woody perennials, under agroforestry systems in the present investigation are presented table 4.5 and are described as under:

4.3.1 Stem carbon

Highest stem carbon per tree amounting to 19.20 kg/tree was recorded in eucalyptus followed by teak (12.96) and minimum (0.66) was recorded in mango (table 4.5).
4.3.2 Branch carbon

Branch carbon was maximum (3.20 kg/tree) in sapota followed by mango (2.30) and minimum was recorded in teak (1.29).

Table 4.5: Carbon storage (kg/tree) of different parts of woody perennials.

<table>
<thead>
<tr>
<th>No</th>
<th>Species</th>
<th>Stem carbon</th>
<th>Branch carbon</th>
<th>Leaf carbon</th>
<th>Fruit carbon</th>
<th>Above ground carbon</th>
<th>Below ground carbon</th>
<th>Total carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mango</td>
<td>0.66</td>
<td>2.30</td>
<td>2.17</td>
<td>4.48</td>
<td>9.62</td>
<td>2.50</td>
<td>12.12</td>
</tr>
<tr>
<td>2</td>
<td>Sapota</td>
<td>1.16</td>
<td>3.20</td>
<td>1.95</td>
<td>6.97</td>
<td>13.27</td>
<td>3.45</td>
<td>16.72</td>
</tr>
<tr>
<td>3</td>
<td>Lemon</td>
<td>0.82</td>
<td>1.52</td>
<td>0.99</td>
<td>7.06</td>
<td>10.39</td>
<td>2.70</td>
<td>13.09</td>
</tr>
<tr>
<td>4</td>
<td>Teak</td>
<td>12.96</td>
<td>1.29</td>
<td>0.26</td>
<td>0.72</td>
<td>15.24</td>
<td>3.9</td>
<td>19.21</td>
</tr>
<tr>
<td>5</td>
<td>Eucalyptus</td>
<td>19.20</td>
<td>1.64</td>
<td>0.44</td>
<td>0.18</td>
<td>21.46</td>
<td>5.58</td>
<td>27.03</td>
</tr>
<tr>
<td>CD</td>
<td></td>
<td>0.67</td>
<td>0.75</td>
<td>0.23</td>
<td>0.42</td>
<td>1.32</td>
<td>0.87</td>
<td>1.68</td>
</tr>
</tbody>
</table>

4.3.3 Leaf carbon

The maximum leaf carbon of 2.17 kg/tree was recorded in mango followed by Sapota (1.95). Minimum leaf carbon (0.27) was recorded in teak. (Table 4.5).

4.3.4 Fruit carbon

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).

4.3.5 Above ground carbon
Above ground carbon (21.46) was maximum recorded in eucalyptus followed by teak (15.24), and minimum (9.62) was recorded in mango.

**4.3.6 Below ground carbon**

Below ground carbon was maximum (5.58) in eucalyptus followed by teak (3.9) whereas it was minimum (2.50) in mango.

**4.3.7 Total carbon (kg/tree)**

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 4.5).

**4.3.8 Carbon storage by intercrops (kg/m²)**

The data on crop carbon (above and below ground) of individual intercrops recorded under different agroforestry systems are presented in table 4.6 and is depicted as under:

**4.3.8.1 Above ground crop carbon**

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 4.6).

**Table 4.6: Carbon storage (kg/m²) of different crops.**

<table>
<thead>
<tr>
<th>No.</th>
<th>Crops</th>
<th>Above ground</th>
<th>Below ground</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cabbage</td>
<td>0.251</td>
<td>0.022</td>
<td>0.273</td>
</tr>
<tr>
<td>2</td>
<td>Brinjal</td>
<td>0.323</td>
<td>0.037</td>
<td>0.360</td>
</tr>
<tr>
<td>3</td>
<td>Coriander</td>
<td>0.080</td>
<td>0.007</td>
<td>0.086</td>
</tr>
<tr>
<td>4</td>
<td>Rice</td>
<td>0.117</td>
<td>0.023</td>
<td>0.140</td>
</tr>
</tbody>
</table>
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.

4.3.8.3 Total crop carbon

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.

4.3.9 Carbon sequestration by different AF system (t/ha)

Carbon sequestered, above and below ground (woody as well as non woody components), by different agroforestry systems is given in table 4.7 and results obtained are as under:

4.3.10 Carbon sequestration by woody component

Maximum above ground (34.05), below ground (8.85) and total (42.90 t/ha) sequestered carbon was recorded for Eucalyptus in AS (Eucalyptus+Spider lily) system, followed by mango and teak in ASH (Mango+Teak+Brijal) system with 3.63, 1.37, 5.0 tones of carbon above ground, below ground and total, respectively. Minimum values for above ground (0.64), below ground (0.16) and total carbon (0.82) were obtained from sapota under HP (sapota + grass) system.
4.3.11 Carbon sequestration by intercrops (t/ha)

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 AS (Teak+sugarcane) followed by spider lily under AS (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 4.7).
<table>
<thead>
<tr>
<th>No.</th>
<th>System</th>
<th>Woody component</th>
<th>Intercrops</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Above ground</td>
<td>Below ground</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>ASH (Mango+Teak+Brinjal)</td>
<td>3.63</td>
<td>1.37</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>AS (Eucalyptus+Spider lily)</td>
<td>34.05</td>
<td>8.85</td>
<td>42.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>AS (Teak+sugarcane)</td>
<td>1.21</td>
<td>0.31</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>AH (Mango+rice)</td>
<td>0.96</td>
<td>0.24</td>
<td>1.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>AH (Mango+cabbage)</td>
<td>1.9</td>
<td>0.28</td>
<td>1.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>AH (Mango + sapota + lemon + Coriander)</td>
<td>2.06</td>
<td>0.53</td>
<td>2.61</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>HP (Sapota+grass)</td>
<td>0.64</td>
<td>0.16</td>
<td>0.82</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CD</td>
<td></td>
<td>0.651</td>
<td>0.169</td>
<td>0.821</td>
</tr>
</tbody>
</table>

Table 4.7: Carbon sequestration (t/ha) by different agroforestry system in Navsari District.
Coriander intercropped in AH (Mango + sapota + lemon + Coriander) system, sequestered minimum carbon (0.51, 0.04 and 0.55, above ground, below ground and total carbon, respectively).

4.3.12 Total carbon sequestered in different AF systems (t/ha)

The data in table 4.7, show that maximum carbon to the tune of 47.87 t/ha was sequestered by AS (Eucalyptus + Spider lily) system, followed by system type Teak + Sugarcane (12.36) and it was minimum (1.93 t/ha) from AH (Mango + sapota + lemon + Coriander) system.

4.4 Soil chemical properties under different AF systems

4.4.1 Soil Organic Carbon (SOC)

Perusal of table 4.8 Revealed that SOC that was higher (0.82%) under AS (Eucalyptus + Spider lily) system followed by ASH (Mango + Teak + Brinjal) system with SOC 0.75 per cent and minimum (0.36 %) was recorded in AH (Mango + Rice) system.

4.4.2 Nitrogen (kg/ha)

Data in table 4.8 show that Maximum available N (278 kg/ha) was recorded in AS (Eucalyptus + spider lily) system followed by ASH systems type Mango + Teak + Brinjal (260) AH system types Mango + Cabbage (236). Minimum available N (199) was recorded under AH system (Mango + rice).
Table 4.8: Soil properties in different agroforestry systems in Navsari District.

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>System</th>
<th>SOC (%)</th>
<th>N (kg/ha)</th>
<th>P$<em>{2}$O$</em>{5}$ (kg/ha)</th>
<th>K$_{2}$O (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ASH (Mango+Teak+Brinjal)</td>
<td>0.75</td>
<td>260</td>
<td>33.03</td>
<td>332.22</td>
</tr>
<tr>
<td>2</td>
<td>AS (Eucalyptus + spider lily)</td>
<td>0.82</td>
<td>278</td>
<td>144.70</td>
<td>295.6</td>
</tr>
<tr>
<td>3</td>
<td>AS (Teak + sugarcane)</td>
<td>0.44</td>
<td>212</td>
<td>35.20</td>
<td>434.72</td>
</tr>
<tr>
<td>4</td>
<td>AH (Mango + Rice)</td>
<td>0.36</td>
<td>199</td>
<td>28.20</td>
<td>572.38</td>
</tr>
<tr>
<td>5</td>
<td>AH(Mango+Cabbage)</td>
<td>0.57</td>
<td>236</td>
<td>85.30</td>
<td>411.46</td>
</tr>
<tr>
<td>6</td>
<td>AH [Mango + sapota + lemon + Coriander (Multi-storey)]</td>
<td>0.65</td>
<td>254</td>
<td>49.06</td>
<td>282.94</td>
</tr>
<tr>
<td>7</td>
<td>HP (Sapota+Grass)</td>
<td>0.52</td>
<td>221</td>
<td>116.64</td>
<td>721.34</td>
</tr>
</tbody>
</table>

4.4.3 Available P$_{2}$O$_{5}$ (kg/ha)

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.

4.4.4 Available K$_{2}$O (kg/ha)

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 AH (Mango + Rice) system with 572 kg K$_{2}$O/ha whereas, it was minimum (282) under Multi-storey AH (Mango + sapota + lemon + Coriander).

4.5 Economics of prevalent AF Systems
Table 4.9 shows the comparisons for financial viability of different agroforestry practices prevalent in Navsari district of Gujarat.

4.5.1 Net Present Value

Perusal to the table shows that the maximum value of NPV (Net Present Value) amounting to 16,30,526 INR was recorded in ASH (Teak + mango + brinjal) system followed by AH (Mango + rice) system (4,000,953), and minimum NPV (3,76,388) was recorded in multi-storey (Mango + sapota + lemon + coriander) system.

4.5.2 Benefit Cost Ratio (BCR)

Highest value (6.24) of Benefit Cost Ratio (BCR) was recorded in ASH (Teak + mango + brinjal) system followed by AS (Teak + sugarcane) system (3.52), and minimum (2.71) was recorded in AH (Mango + rice) system (Table 4.9).

4.5.3 Equivalent Annual Income

Equivalent Annual Income (EAI) was maximum (2,24,910 INR) from ASH (system type, Teak + mango + brinjal) followed by AS (system type, Teak + sugarcane) system (1,80,195 INR), and minimum (55,306 INR) was recorded in AH (Mango + rice) system.
Table 4.9: Comparison criteria for financial viability of different agroforestry practices in 18 year duration in Navsari District.

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Agroforestry system</th>
<th>NPV</th>
<th>BCR</th>
<th>EAI</th>
<th>Compounded revenue</th>
<th>Compounded Cost</th>
<th>NPV:IEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ASH (Mano+Teak+Brinjal)</td>
<td>1630526</td>
<td>6.24</td>
<td>224910</td>
<td>1941632</td>
<td>311106</td>
<td>16.97</td>
</tr>
<tr>
<td>2</td>
<td>AS (Eucalyptus+Spider lily)</td>
<td>620467</td>
<td>4.15</td>
<td>85585</td>
<td>817177</td>
<td>196710</td>
<td>6.91</td>
</tr>
<tr>
<td>3</td>
<td>AS (Teak+Sugarcane)</td>
<td>1306354</td>
<td>3.52</td>
<td>180195</td>
<td>1823511</td>
<td>517156</td>
<td>9.04</td>
</tr>
<tr>
<td>4</td>
<td>AH (Mango+Rice)</td>
<td>4000953</td>
<td>2.73</td>
<td>55306</td>
<td>632062.5</td>
<td>231109</td>
<td>5.87</td>
</tr>
<tr>
<td>5</td>
<td>AH (Mango+Cabbage)</td>
<td>767004</td>
<td>4.04</td>
<td>105798</td>
<td>1019035</td>
<td>252030</td>
<td>10.85</td>
</tr>
<tr>
<td>6</td>
<td>Multistorey system (Mango+Sapota+Lemon+Coriander)</td>
<td>376388.</td>
<td>2.71</td>
<td>51918</td>
<td>596516</td>
<td>220127</td>
<td>9.79</td>
</tr>
<tr>
<td>7</td>
<td>HP (Sapota+Grass)</td>
<td>410244</td>
<td>4.05</td>
<td>56588</td>
<td>544628</td>
<td>134384</td>
<td>18.17</td>
</tr>
</tbody>
</table>

*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.

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

Maximum compounded revenue (19,41,632 INR) was accrued from AHS system type mango + Teak + brinjal followed by AS (type Teak + sugarcane) system (18,23,511), and minimum (5,44,628) was from HP (Sapota + grass) system (Table 4.9).

4.5.5 Compounded Cost

Maximum compounded cost amounting to INR 5,17,156 was incurred in AS system type teak + sugarcane followed by ASH system type mango + teak + (3,11,106) and minimum (1,34,384) was for HP (Sapota + grass) system.

4.5.6 Net Present Value: Initial Establishment Cost ratio (NPV:IEC)

NPV: IEC was recorded highest (18.17) in HP system (Sapota + grass) followed by ASH (Teak + mango + brinjal) system (16.97) whereas minimum (5.87) was recorded in AH (Mango + rice) system.
The results of the present investigation entitled “Productivity and carbon Sequestration under Prevalent Agroforestry Systems in the Navsari District”, are discussed establishing cause and factors and corroborated with the available literature.

5.1 Agroforestry Systems (AF) in Navsari District

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 the present study four major agroforestry systems [agri-silvi-horticulture (ASH) agri-silviculture (AS), agri-horticulture (AH), and horti-pasture (HP)] were found to be practiced by majority of the farmers. In total seven system types (ASH - Mango+Teak+Brinjal; AS-Eucalyptus+Spider lily, Teak+sugarcane; AH-Mango+rice, Mango+cabbage, Mango + sapota + lemon + Coriander; and HP-Sapota+grass) are being practiced. Among fruit based agroforestry systems four mango based (Mango+Teak+Brinjal, Mango+rice, Mango+cabbage and Mango + sapota + lemon + Coriander) system types were found. Generally in South Gujarat mango in 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 Varadarangananatha 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.

5.2 Biological and economic yield of prevalent AF systems

5.2.1 Tree (kg/tree) and crop (kg/m²) biomass

The results on biomass accumulation by different woody perennials evinced that owing to fast growth rate of eucalyptus clones, stem, above and below ground biomass, and total tree biomass was highest in eucalyptus followed by teak. Stem biomass was found significantly less in horticultural trees however branch and fruit biomass was on higher side. 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.

Significantly higher above and below ground and total biomass (kg/m²) was recorded from sugarcane followed by spider lily (above ground and total biomass) among intercrop. 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.

5.2.2 Biological yield of AF systems (t/ha)

Significantly higher above and below ground biomass was obtained from eucalyptus under AS (Eucalyptus+Spider lily) system. 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.

Crop biomass was recorded maximum in agri-silviculture system with system component Teak+Sugarcane (in boundary plantation). This may attributed to the fact that sugarcane had more cropping area under this particular system.

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.

5.2.3 Economic yield of different components in AF systems (kg/ha)

Fruit yield of mango was 9360 kg/ha from Teak+Mango+brijal and Mango+Cabbage, 6000 and 1980 kg/ha from Mango+Rice and Mango + sapota + lemon + Coriander, 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.

In ASH system involving Eucalyptus as forest tree species, 16000 poles per hectare were estimated. Teak trees have not considered to have attained merchantable size therefore yield was not taken in to account.

The economic yield (saleable parts) 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.

5.3 Carbon sequestration potential of prevalent AF systems

Among woody perennials in different agroforestry systems, owing to higher biomass production, eucalyptus had higher per tree above and below ground and total carbon. Per tree, branch, leaf and fruit carbon was more in fruit
tree species whereas it whereas less in forest tree species. Among the fruit trees, leaf carbon was more in mango and branch and fruit carbon was higher from sapota. As regards intercrops C content (kg/m²), above and below ground and total carbon was higher in sugarcane.

The results of C sequestration (t/ha) among seven agroforestry system types revealed that among woody perennials maximum above ground (34.05 t/ha), below ground (8.85 t/ha) and total (42.90 t/ha) sequestered C was recorded for Eucalyptus in AS (Eucalyptus+Spider lily) system. The woody components of agroforestry system type Mango + sapota + lemon + Coriander contributed least in carbon sequestration. The reasons for less carbon sequestration in later complex system may be ascribed to less biomass accumulation in the stem. Among intercrops in different agroforestry system types highest above ground, below ground and total carbon (10.83 t/ha) was sequestered by sugarcane under AS (Teak+sugarcane) system, whereas coriander intercropped in AH (Mango + sapota + lemon + Coriander) system, sequestered minimum carbon.

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 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).

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). Agroecosystems 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 and 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 and 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

5.4 Soil chemical properties under different AF systems

Results have shown that maximum Soil Organic Carbon (SOC), available nitrogen and phosphorus was in AS (system type, Eucalyptus + Spider lily) system. Spider lilies are generally planted once and kept for six to seven year. So frequent culturing practices like tilling is not adopted. Moreover perennial tree density is also more in this system. 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 and 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.

5.5 Economic Evaluation of AF systems
All the agroforestry practices had a positive NPV and greater than unity BCR. Agri-silvi-horticulture system, with Mango+ Teak+ Brinjal as system component, was found to be most financially rewarding practices per unit area of land as indicated by its very high NPV compared to other landuse types. It also recorded highest BCR which also adds to its financial attractiveness to farmers. This indicates that a single unit cost for Mango+ teak+ Brinjal system produces more benefit than investing in the other landuse types. Complex horticulture system with system component Mango+ Sapota+ Lemon + coriander recorded lowest BCR value (2.71). It may be due to lesser number of productive perennials per ha (only 99 horticulture trees) as compared to other fruit based systems and require higher maintenance cost.

In term of EAI, again Mango+ teak+ brinjal is the most preferable landuse 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+T. grandis+field crops (3.23:1) followed by sapota+Lagerstroemia lanceolata+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 landuse 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.
VI. SUMMARY AND CONCLUSION

An investigation entitled “Productivity and carbon Sequestration under Prevalent Agroforestry Systems in the Navsari District” was carried out in the year 2011-2012, in Navsari District of Gujarat. The findings of the investigation are summarized and conclusions drawn are as under:

In total four prevalent AF systems were found to be practiced by the farmers i.e. agri-silvi-horticulture (ASH) agri-silviculture (AS), agri-horticulture (AH), and horti-pasture (HP). AH system had three system types, followed by agri-silviculture representing two system types. ASH and HP systems had only one system type. In total seven system types were prevalent.

The stem biomass (kg/tree) of eucalyptus was maximum. Whereas, branch and leaf biomass was higher in fruit trees. Fruit biomass was maximum from lemon and minimum was from forest tree species. Eucalyptus gave maximum above and below ground and total biomass whereas it was less in fruit tree species. Among the intercrops, above ground and below ground and total crop biomass (kg/m²) was higher from sugarcane.

Among woody perennials, eucalyptus, under Eucalyptus+spider lily, gave significantly higher above and below ground and total woody biomass (t/ha). Among intercrops under different agroforestry systems, sugarcane under AS (Teak+Sugarcane) system gave maximum above and below ground and total biomass (t/ha). Total biological yield (all components) was higher from AS (Eucalyptus+Spider lily) and minimum was from AH (Mango + sapota + lemon + Coriander) system.
Highest above and below ground and total C (kg/tree) was sequestered by Eucalyptus. Stem C was minimum in fruit trees as compared to forest trees species. However the branch and leaf and fruit C was higher in fruit trees with maximum in sapota. Fruit C was higher in lemon. Overall, forest trees sequestered maximum (kg/tree) carbon. Amongst the intercrops sugarcane sequestered higher above and below ground and total C (kg/m²).

Forest tree species sequestered higher C (t/ha) with maximum by Eucalyptus under AS (Eucalyptus+Spider lily). Among intercrops sugarcane under AS (Teak+sugarcane) sequestered higher above, below ground and total carbon. Among seven agroforestry system types, highest C tones per hectare (tree+intercrop) was sequestered by AS (Eucalyptus+Spider lily) system.

Soil organic carbon (SOC) per cent, N and P₂O₅ kg/ha was higher under AS (Eucalyptus+Spider lily) and minimum amount of SOC and P₂O₅ was under AH (Mango + Rice) system. However, K₂O was recorded maximum in HP (Sapota+Grass) system.

Maximum value of NPV (Net Present Value), Benefit Cost Ratio (BCR), Equivalent Annual Income (EAI) and compounded revenue and was recorded in ASH (Teak + mango + brinjal) system followed by AH (Mango + rice) system. However, compounded cost incurred was higher in AS system type teak + sugarcane followed by ASH system type mango + teak. Whereas NPV: IEC ratio was highest in HP system (Sapota + grass) followed by ASH (Teak + mango + brinjal) system.

Conclusions

The following conclusions are drawn from the present investigation:
In Navsari District, four major prevalent agroforestry systems are in vogue i.e. agri-silvi-horticulture (ASH) agri-silviculture (AS), agri-horticulture (AH), and horti-pasture (HP).

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, AS system, system type 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 AH system type Mango+Canbbage followed by ASH system, type Teak + mango + brinjal.

Soil organic carbon per cent (SOC), N and P$_2$O$_5$ kg/ha was higher under AS (Eucalyptus+Spider lily) and minimum amount of SOC and P$_2$O$_5$ was under AH (Mango + Rice) system. However, K$_2$O was recorded in HP (Sapota+Grass) 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 found ASH (Teak + mango + brinjal) system followed by AH (Mango + rice) system.

Therefore, 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.
A default conversion factor of 0.26 of aboveground biomass was used to calculate the belowground biomass (IPCC 2003).


Parekh, D. and Patil, N. S. (2003). Intercropping in *Mitragyna parvifolia* and *Adina cordifolia* and three pulse crops showed the maximum fresh weight and
water status of leaves where recorded when crops grown under open field M.Sc. (Agroforestry) thesis submitted to G. A. U., Navsari.


