Int.J.Curr.Microbiol.App.Sci (2017) *6*(9): 3405-3422

International Journal of Current Microbiology and Applied Sciences
***ISSN: 2319-7706* Volume 6 Number 9 (2017) pp. 3405-3422**
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2017.609.419

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

Panchal Jeegarkumar Sureshbhai[1], N. S. Thakur[1], S. K. Jha[1] and Vikas Kumar[2*]

[1]College of Forestry, Navsari Agricultural University, Navsari, Gujarat, India
[2]College of Forestry, Vellanikkara, Kerala Agricultural University, Thrissur, Kerala, India
**Corresponding author*

Keywords

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

Article Info

Accepted:
25 July 2017
Available Online:
10 September 2017

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-silvi-horticultural 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.

Introduction

An increasingly industrialized global economy, rapid population growth, land degradation, land use pattern androle 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_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_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_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_4) and nitrous oxide (N_2O) gases over a time span of 100 years are approximately 25 and 298 times greater, respectively, than that of carbon dioxide (CO_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; IPCCC, 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 agreater 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 (78^0 17" N and 78^0 19" N and 38^0 48" E and 38^0 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 1×1m 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 ^{0}C, with the help of electronic balance. Biological yield was calculated using formula

$$\text{Biomass of branch or leaves} = \frac{\text{Dry weight of sample}}{\text{Fresh weight of sample}} \times \text{total fresh weight of branches/leaves}$$

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

$$Total\ volume\ (m^3) = \pi\ (D/2)^2\ X\ h$$

Where, π = 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, Sapotaand 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% $KMnO_4$) method (Subbaih and Asija, 1956). Available phosphorus was determined by Brays No. 1 method of extracting the soil P with 0.03 NH_4F 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) andMango + 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 (14.70kg/tree) was recorded in lemon followed by Sapota (14.53kg/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 (31.77kg/tree), whereas minimum (20.05kg/tree) was recorded in Mango. Below ground biomass was maximum (11.62 kg/tree) in Eucalyptus followed by Teak (8.26kg/tree) and it was recorded minimum (5.21kg/tree) in mango (Table 3).Total tree biomass amounting to 56.32 kg/tree was recorded in Eucalyptus followed by Teak (40.03kg/tree). Minimum total tree biomass (25.26kg/tree) was recorded in Mango.

Intercrop crop biomass (Kg/m^2)

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/m^2 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/m^2) 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 (16.79t/ha), below ground (5.78t/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 (1.06t/ha), below ground (0.09t/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 + Brijal) 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 Mango followed by Sapota (1.95). Minimum leaf carbon (0.26) was recorded in Teak. 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/m^2 was recorded in Sugarcane followed by Spider lily (0.48) whereas, least (0.08) was recorded from Coriander (Table 8).

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		Age of woody perennial
		Woody perennials	Intercrops	
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
	Teak (boundary plantation) + Sugarcane	2.5 m plant to plant (80 trees)	30x90 cm	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 (33trees 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 (m^3)	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 perennialsof 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/m^2) 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	1	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/m^2) 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)	P_2O_5 (kg/ha)	K_2O (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

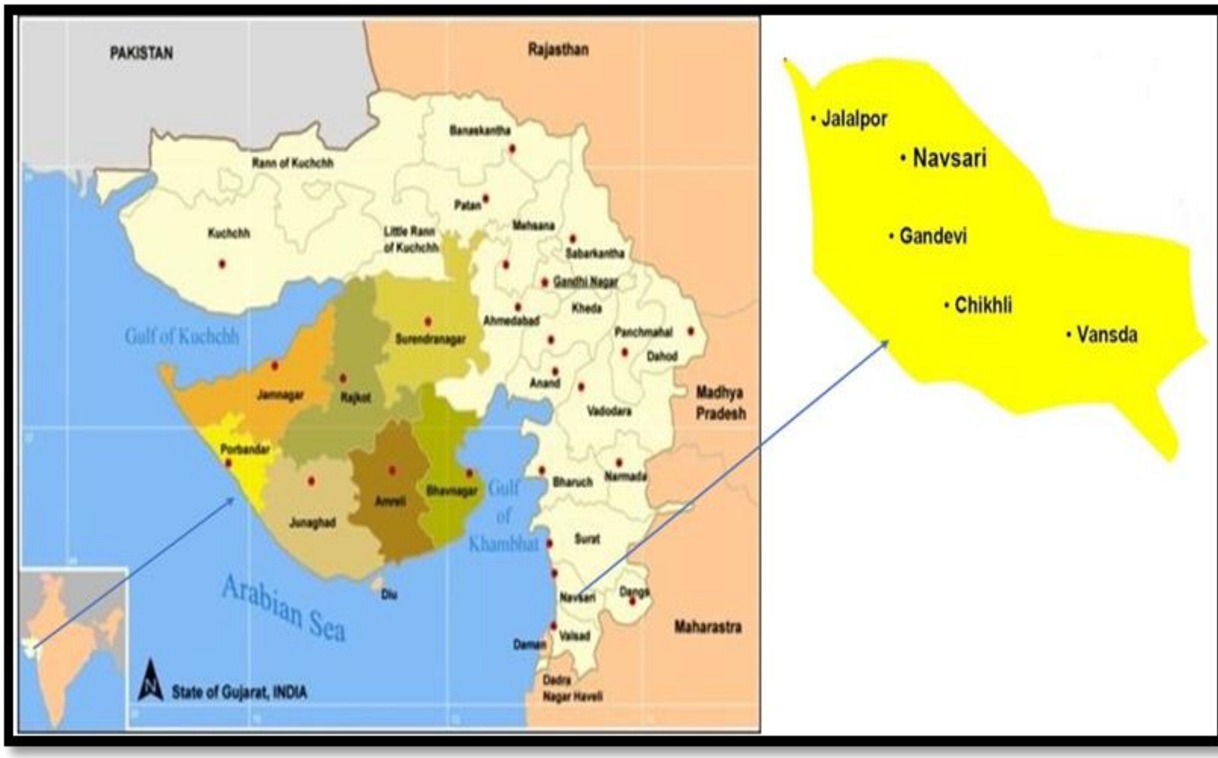
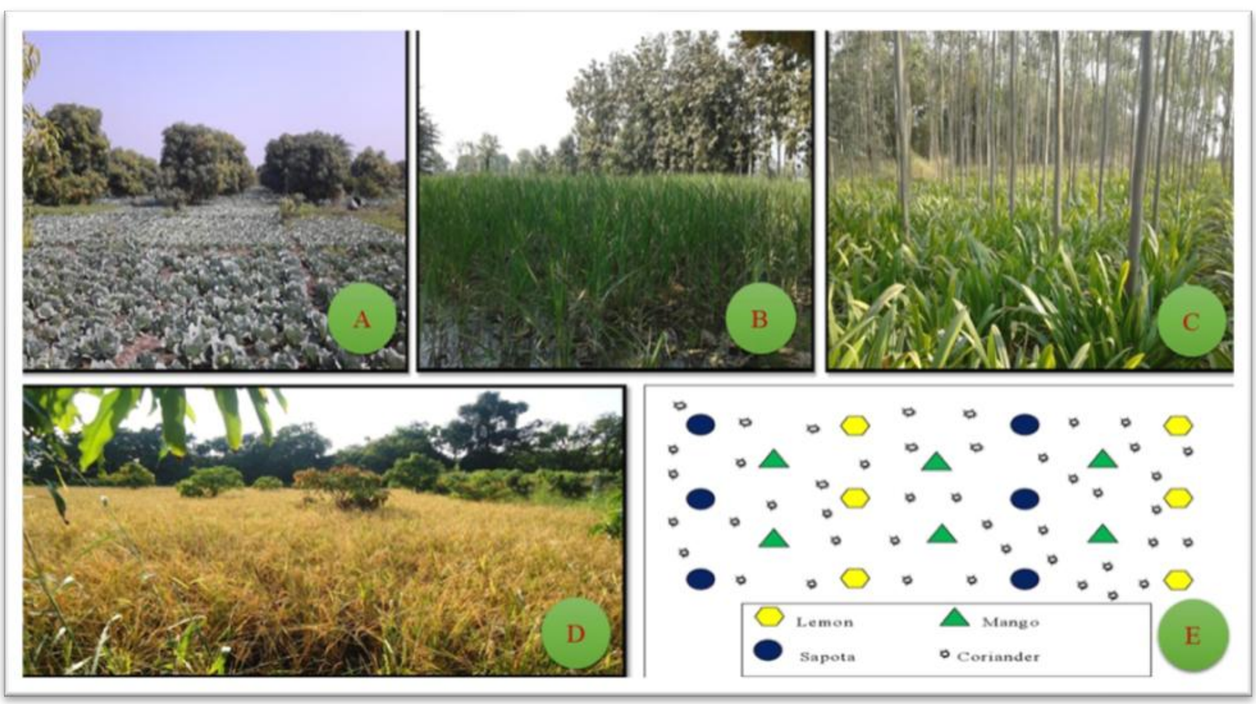


Fig.2 Prevalent agroforestry systems found in Navsari district, Gujarat, India. 2. A. Mango + Cabbage; 2.B. Teak + Sugarcane; 2.C. Eucalyptus + Spider lily; 2.D. Mango + Rice and 2.E. multi-storey (Mango + Sapota + Lemon + Coriander)



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 (Eucalytptus + 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_2O_5 (144.70 kg/ha) was recorded under AS (Eucalyptus + spider lily) followed by HP (Sapota + Grass) with 116.64 of P_2O_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_2O (721 kg/ha) was recorded in HP (Sapota + Grass) system followed by AHS (Mango + Rice) with 572 kg K_2O/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).

Acknowledgments

This research formed part of the MSc (Forestry) thesis submitted to the Navsari Agricultural University, Navsari, Gujarat, India by the first author. Facilities for testing the samples provided by the Dean, College of forestry, NAU, Navsari and the technical guidance rendered by faculty of different department of COF, Navsari are gratefully acknowledged.

References

Achard, F., Eva, H.D., Stibig, H.J., Mayaux, P., Gallego, J., Richards, T., and Malingreau, J.P. 2002. Determination of deforestation rates of the world’s humid tropical forests. Science. 297: 999-1002.

Albrecht, A., and Kandji S.T. 2003. Carbon sequestration in tropical agroforestry system. Agriculture Ecosystems and Environment. 99: 15-27.

Black, C.A., 1965. Methods of soil analysis. Part-I and II Amer. Soc. Agron. Inc. Medison, Visconsin, USA, pp: 63.

Bray, R.H., and Kurtz, L.T. 1945. Determining of total organic and available forms of phosphorus in soil. Soil Science. 59: 39-45.

Chander, K., Goyal, S., Nandal, D.P., and Kapoor, K.K. 1998. Soil organic matter, microbial biomass and enzyme activities in a tropical agroforestry system. Biology and Fertility of Soils. 27(2): 168-172.

Chaturvedi, A.N., 1994. Sequestration of atmospheric carbon in Indian forest. Ambio. 23: 460-461.

Conesa, H.M., Evangelou, M.W, Robinson, B.H., and Schulin, R. 2012. A critical view of current state of phytotechnologies to remediate soils: still a promising tool?

Scientific World Journal. 2012: 1-10.

Deans, J.D., Moran, J., and Grace, J. 1996. Biomass relationships for tree species in regenerating semi-deciduous tropical moist forest in Cameroon. Forest Ecology and Management. 88: 215-225.

DeFries, R., Achard, F., Brown, S., Herold, M., Murdiyarso, D., Schlamadinger, B., and Souza Jr., C.de. 2007. Earth observations for estimating greenhouse gas emissions from deforestation in developing countries. Environmental Science & Policy 10: 385-394.

Demessie, A., Singh, B.R., and Lal, R. 2015. *Land Degradation and Soil Carbon Pool in Different Land Uses and Their Implication for Food Security in Southern Ethiopia*. In R. Lal *et al.*, (eds.), Sustainable Intensification to Advance Food Security and Enhance Climate Resilience in Africa, Springer International Publishing Switzerland.

Dhyani, S.K., Handa, A.K., and Uma. 2013. Area under agroforestry in India: An Assessment for Present Status and Future Perspective. Indian Journal of Agroforestry. 15(1): 1-11.

Dixon, R.K., 1995. Agroforestry systems: sources or sinks of greenhouse gases? Agroforestry System. 31: 99-116.

Dixon, R.K., Brown, S., Houghton, R.A., Solomon, A.M., Trexler, M.C., and Wisniewski, J. 1994. Carbon pools and flux of global forest ecosystems. Science. 263: 185-190.

Duguma, L.A., 2012. Financial analysis of agroforestry land uses and its implications for smallholder farmer's livelihood improvement in Ethiopia. Agroforestry Systems. 87(1): 217-231.

Dwivedi, R.P., Kareemulla, K., Singh. R., Rizvi, R.H., and Chauhan, J. 2007. Socio-Economic Analysis of Agroforestry Systems in Western Uttar Pradesh Indian Research Journal of Extension Education. 7(2&3): 18-22.

Fassbender, H.V.W., 1998. Longterm studies of soil fertility in cacao-shade trees-agroforestry systems: Results of 15 years of organic matter and nutrients research in Costa Rica. Soils of Tropical Forest Ecosystems, pp 150-158.

Garrett, H.E., (ed.) 2009. North American agroforestry: An integrated science and practice. 2nd ed. ASA, Madison, WI.

Gupta, N., Kukal, S.S., Bawa, S.S., and Dhaliwal, G.S. 2009. Soil organic carbon and aggregation under poplar based agroforestry system in relation to tree age and soil type. Agroforestry Systems. 76(1): 27-35.

Howlett, D.S., Mosquera-Losada, M.R., Nair, P.K.R., Nair, V.D., and Rigueiro-Rodríguez, A. 2011. Soil C storage in silvopastoral systems and a tree less pasture in north-western Spain. Journal of Environmental Quality. 40: 1-8.

IPCCC (Intergovernmental Panel on Climate Change. Climate change) 2007. The Physical Science Basis. Working Group I Contribution to the Fourth Report of the Intergovernmental Panel on Climate Change. Cambridge University press, Cambridge, United Kingdom and New York, NY, USA

Jackson, M.L., 1973. Soil chemical analysis, Wisconsin Prentice hall. India Pvt. Ltd. New Delhi, 46: 128-135, 283.

Jacobs, M.R., 1955. Growth Habits of the Eucalypts. Canberra: Forestry and Timber Bureau.

Jose, S., 2009. Agroforestry for ecosystem services and environmental benefits: an overview. Agroforestry Systems. 76: 1-10.

Koul, D.N., and Panwar, P. 2008. Prioritizing land management option for carbon sequestration potential. Current Science. 95(5): 658-663.

Krankina, O.N., and Dixon, R.K. 1994. Forest Management Options to Conserve and Sequester Terrestrial Carbon in the

Russian Federation. World Resource Review. 6: 89-101.

Kumar, B.M., George, S.J., Jamaludheen, V., and Suresh, T.K. 1998. Comparison of biomass production, tree allometry and nutrient use efficiency of multipurpose tree grown in woodlot and silvopastural experiments in Kerala, India. Forest Ecology and Management. 112: 145-163.

Kumar, V., 2015. Estimation of Carbon Sequestration of Agroforestry Systems. Van Sangyan. 2(5): 17-23.

Kumar, V., 2016. Multifunctional Agroforestry Systems in Tropics Region. Nature Environment and Pollution Technology. 15(2): 365-376.

Kumar, V., 2018. Can Homegardens Help to Biodiversity Conservation in Humid Tropical Kerala, India: Agribiodiversity, Structural Composition and Species utilization. Indian Journal of Agroforestry (In press).

Kumar, V., and Tiwari, A. 2017. Importance of tropical home gardens agroforestry system. International Journal of Current Microbiology and Applied Science. 6(9) (In press).

Kumar, V., and Tripathi, A.M. 2017. Vegetation Composition and Functional Changes of Tropical Homegardens: Prospects and Challenges. In: Gupta, S.K., Panwar, P., and Kaushal, R. (Eds), *Agroforestry for increased production and livelihood security*. New India Publishing Agency, New Delhi, pp-475-505.

Lal, R., 2002. Carbon sequestration in dryland ecosystems of West Asia and North Africa. Land Degradation & Development. 13: 45-59.

Lal, R., 2004. Soil C sequestration impacts on global climatic change and food security. Science. 304: 1623-1627

Le Mer, J., and Roger, P. 2001. Production, oxidation, emission and consumption of methane by soils: a review. European Journal of Soil Biology. 37: 25-50.

Miettinen, J., Shi, C., and Liew, S.C. 2011. Deforestation rates in insular Southeast Asia between 2000 and 2,010. Global Change Biology. 17(7): 2261–70.

Moreno, G., Obrador, J.J., Cubera, E., and Dupraz, C. 2005. Fine root distribution in Dehesas of central-western Spain. Plant Soil. 277: 153-162.

Nair, P.K.R., 2011. Agroforestry systems and environmental quality: introduction. Journal of Environmental Quality. 40: 784-790.

Nair, P.K.R., Gordon, A.M., and Mosquera-Losada, M.R. 2008. Agroforestry. p. 101–110. *In* S.E. Jorgensen and B.D. Faith (ed.) Encyclopedia of ecology. Vol. 1. Elsevier, Oxford, UK.

Nair, P.K.R., Kumar, B.M., and Nair, V.D. 2009. Agroforestry as a strategy for carbon sequestration. Journal of Plant Nutrition and Soil Science. 172: 10-23.

Nair, P.K.R., Nair, V.D., Kumar, B.M., and Showalter, J.M. 2010. Carbon sequestration in agroforestry systems. Advances in Agronomy. 108: 237-307.

NRCAF. 2013. NRCAF Vision 2050. National Research Centre for Agroforestry, Jhansi, pp. 03.

Olsson, L., and Ardo, J. 2002. Soil carbon sequestration in degraded semiarid agro-ecosystems: perils and potentials. Ambio. 31(6): 471-477.

Pandey, C.B., Singh, A.K., and Sharma, D.K. 2000. Soil properties under Acacia nilotica trees in a traditional agroforestry system in central India. Agroforestry Systems. 49 (1): 53-61.

Pandey, D.N., 2007. Multifunctional agroforestry systems in India. Curr. Sci. 92(4): 455-463.

Patil, S.J., Mutanal, S.M., Patil, H.Y., Shahapurmath, G., and Maheswarappa, V. 2010. Performance of Sapota-Teak based agroforestry system in hill zone of Karnataka. Indian Journal of

Agroforestry. 12(1): 27-34.

Prasad, J.V.N.S., Srinivas, K., Srinivasa Rao, Ch., Ramesh, Ch., Venkatravamma, K., and Venkateswarlu, B. 2012. Biomass productivity and carbon stocks of farm forestry and agroforestry systems of leucaena and eucalyptus in Andhra Pradesh, India. Current Science. 103(5): 536-540.

Sathaye, J.A., and Ravindernath, N.H. 1998. Climate change mitigation in the enrgy and forestry sectors of developing countries. Annual Review of Energy and the Environment. 23: 387-437.

Schultz, R.C., Isenhart, T.M., Simpkios, W.W., and Colletti, J.P. 2004. Riparian forest buffers in agroecosystem -lessons learned from the Bear Creek watershed, central Iowa, USA. Agroforestry Systems. 61: 35-50.

Singh, B., and Sharma, K.N. 2007. Tree growth and nutrient status of soil in a poplar (*Populusdeltoides* Bartr.) –based agroforestry system in Punjab, India. Agroforestry Systems. 70: 125-134.

Singh, G., and Rathod, T.R. 2002. Plant growth, biomass production and soil water dynamics in a shifting dune of Indian desert. Forest Ecology and Management. 171: 309-320.

Smith, T.M., Cramer, W.P., Dixon, R.K., Lee mans, R., Neilson, R.P., and Solomon, A.M. 1993. The global terrestrial carbon cycle. Water Air Soil Pollution. 70: 19-38.

Subbiah, B.V., and Asija, G.L. 1956. A rapid procedure for the estimation of available nitrogen in soil. Current Science. 25(8): 259-260.

Tomé Jr., J.B., 1997. Manual para interpretação de análise de solos. AgropecuáriaLtda, Gua´ıba, RS.

Tornquiste C.G., Frank, M.H., Sam, E.F., and Jeremmy, H. 1999. Agroforestry system effects on soil characteristics of the Sarapiquo region of Costa Rica, Agriculture, Ecosystems and Environment 73: 19-28.

UNFCC. 2007. Fact Sheet. The need for mitigation. http://unfccc.int/press/items/2794 php.2008

Varadaranganatha, G.H., and Madiwalar, S.L. 2010. Studies on species richness, diversity and density of tree / shrub species in agroforestry systems. Karnataka Journal of Agriculture Science. 23 (3): 452-456.

Waseem, A., Arshad, J., Iqbal, F., Sajjad, A., Mehmood, Z. and Murtaza, G. 2014. Pollution status of Pakistan: A retrospective review on heavy metal contamination of water, soil and vegetables. BioMed Research International. 2014: 1-29.

Williams, M.R.W., 1988. Decision-making in forest management, 2nd edn. Research Studies Press Ltd, London.

Winjum, J.K., Dixon, R.K., and Schroeder, P.E. 1992. Estimating the global potential of forest and agroforest management practices to sequester carbon. Water Air Soil Pollution. 64: 213-228.

How to cite this article:

Panchal Jeegarkumar Sureshbhai, N. S. Thakur, S. K. Jha and Vikas Kumar. 2017. Productivity and Carbon Sequestration under Prevalent Agroforestry Systems in Navsari District, Gujarat, India. *Int.J.Curr.Microbiol.App.Sci.* 6(9): 3405-3422.
doi: https://doi.org/10.20546/ijcmas.2017.609.419