Agroforestry: A Holistic Approach for Agricultural Sustainability

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Abstract

Agroforestry is gaining a higher position and becoming a specialized science with integration of both crops and forestry science. The sustainable land use farming practices are involved in various life forms of plants/trees with livestock on a single piece of land creating more diversification with multiple outputs, enhance biomass productivity, reduce atmospheric carbon dioxide (CO_2) through absorption and fixation and protect the environment through ecosystem services. In modern day, the adoption of agroforestry is continuously rising due to their biophysical, socio-economical, cultural and environmental services in the tropical condition. In the era of climate change, it gives diversifying food and fruits under different type of agroforestry models (AFM) and can solve the food and nutritional problem of the people in society. From the Indian perspective, agroforestry is being practiced about 14 Mha, but if explored properly it has further higher potential to increase the land area under agroforestry. It was found that up to 65.0% of timber and 50.0% of fuelwood come from the agroforestry sector. Therefore, agroforestry has also the potentiality to reduce poverty, increase income generation and provide alternate economic sources. Along with other benefits, the practices of agroforestry are economically viable for the farmers which generate employment. Various choices for farmers are available for adopting different types of AFM integrating numbers of the tree crop with livestock in various agroclimatic zones. Farmers have an option to select AFM as per socio-physical conditions (i.e. land holding, economic condition, climatic condition, resource availability, market economy). Apiculture- and sericulture-based agroforestry is another option for farmers for alleviating poverty and enhancing socio-economic conditions. From the ecological point of view, agroforestry may potentially maintain the soil quality and health which is linked with the fertility of soil and decomposition of soil organic matter. Thus, there is a nexus between soil fertility and crop productivity in various agroforestry systems (AFS). From a research point of view, there is a need for conservation of superior germplasm of agroforestry components along with their proper domestication and utilization. This chapter deals with interrelationship between soil health, productivity under AFS addressing natural resource conservation, food security and livelihood security towards sustainability. Research should be undertaken for maximizing the productivity of trees and crops under agroforestry for continuous benefits to farmers along with environmental protection and ecological security and sustainability.

Keywords
Agroforestry · Ecological security · Productivity · Soil fertility · Sustainability

Abbreviations

AFS	Agroforestry system
AFM	Agroforestry models
C	Carbon
CO_2	Carbon dioxide
GHGs	Greenhouse gases

1 Introduction

Agroforestry has its origin since ancient times as an age-old practice over earth surface. In such a system, cultivation practice was done under economically important plant species. Such an integrated approach serves the dual purpose of crop cultivation and off-farm output. The inclusion of a tree in the agroecosystem serves the function of protection to soil health and improves the soil nutrient status. Under changing climate throughout the world, agricultural productivity is declining. As a consequence, farming community is suffering from huge economic crisis. Therefore, agroforestry is a suitable solution for them to mitigate climate change consequences as well as keep pace with the growing population. It is totally an eco-friendly approach having multifaceted benefits (Verchot et al. 2007; Jhariya et al. 2015; Raj et al. 2018a; Meena et al. 2015b).

Today changing climate is imposing high vulnerability under the extreme conditions of the climatic elements such as severe rainfall, frequent occurrence of flood, fire, drought, cyclones, etc. resulting in loss of life and money. As we know, both natural and human (anthropogenic) factors are the cause of climate change and producing greenhouse gases (GHGs) which result in warmer climate affecting the earth's system and biodiversity (Raj et al. 2018b). The effect of extreme weather is not limited and confined to traditional agricultural system, and it can also affect the complex type of farming practice like agroforestry in terms of detrimental effects on productivity, profitability and sustainability through loss of biodiversity and ecosystem services. Agroforestry is regarded as a boon in the form of coping up with climate change by its nature of complexity, diversifying yield capacity, enhancement of overall biomass productivity, improved food and nutritional security and soil amelioration capacity through various ecosystem services along with environmental resilience capacity (Verchot et al. 2007; Jhariya et al. 2015; Raj and Jhariya 2017; Verma et al. 2015). As we know, agroforestry is site-based farming systems, which prevailed in the tropics of the world, and consists of three elements (tree, crop and livestock/pasture). It appears in the form of various models, namely, agrisilvicultural, silvipastoral and agrisilvopastoral, as per the combination of these three components. Systems of agroforestry can be implemented anywhere such as in field boundary, bunds and wasteland areas. It maintains overall biodiversity and plays a significant role in soil conservation, carbon dioxide (CO_2) absorption through carbon (C) sequestration, enhancement of overall biomass productivity and employment generation along with poverty eradication of farmers. Also, the complexity of agroforestry system (AFS) gives a more diverse form of produce along with environmental protection through intangible/indirect benefits like soil water conservation, watershed management, efficient nutrient cycling and better ecosystem sustainability. It is very well known that agroforestry produces more than one output as tangible/direct benefits in the form of timber, fruits, food, fuelwoods, etc. which may promote upliftment in socio-economic status of poor farmers.

Agroforestry practice varies depending upon various climatic zones, biogeography as well as environmental factors. Besides these factors, land holding, adoption by the farmers, funding supports from governmental and non-governmental organization and nation policies also influence the extent of agroforestry across the world. As per the FAO report, the total area of agroforestry system in the world is 1023 million hectare (FAO 2000). Globally, 307 mha area is under agroforestry practice out of 823 mha area (both agroforestry and silvopastoral system) (Nair and Garrity 2012). Similarly, South America covers maximum areas of agroforestry (3.2 million km^2) followed by sub-Saharan Africa (1.9 million km^2) (Kumar et al. 2014). The area of agroforestry in India has been increasing from 7.4 mha in 2007 (Zomer et al. 2007) to 25.32 mha in 2013 (Dhyani et al. 2013). From Indian perspective, agroforestry is being practiced in a large area, but if explored properly it has further higher potential to increase the land area under agroforestry. It was found that up to 65.0% of timber and 50.0% fuelwood comes from the agroforestry sector.

The agroforestry model (AFM) is a unique one and based upon the structural and functional complexity and gives more diversification and multifarious benefits in terms of production of multiple outputs along with protection of the environment through better ecosystem services. Ecological services may vary as per different traditional and developed models of agroforestry in the given site because agroforestry is the site-specific farming system. Along with the provision of ecosystem services, agroforestry maintain diversification in productivity which enhance production and improved quality of food under changing climate (Verchot et al. 2007). In due course of time, diversification in agroforestry produce can increase through successional changes in each and every stage of agroforestry development (Leakey and Simons 1996).

This chapter is focused on the study of prevalent AFM in the tropics and the provision of ecosystem services along with a potential role in climate mitigation. This chapter also throws a light on nexus among soil health and productivity under AFS along with the linking concept between them. Natural resource conservation, food security and livelihood security are another paradigm of AFS and sustainability.

2 Agroforestry in the Tropics

It is well known that tropical region has a wide array of AFS with greater promises of adoption as compared to other climatic region. Agroforestry is not a recent practice; it is an age-old sustainable farming system comprising both trees and agricultural crops and their cultivation practices from the beginning of domestication of plant and animals. Ever since today several models of agroforestry have been initialized in both developed (Europe and America) and developing countries (Asia and Africa) (King 1987).

The model of agroforestry varies from arid to humid tropics comprising different combinations of tree, crops and livestock as per availability of resources, soil characteristics and prevailing climate (Fig. 1). Also, there are many models of agroforestry which can vary as per their functions (protection and productions), roles and outputs (multiple). Similarly, the ecological adoption of different models of agroforestry in the tropics depends on the prevailing climate of that region. For example, alley cropping is suitable for humid tropics due to ample of sunlight and moisture rather than other tropics (arid and semiarid). The presence of moisture and light is helpful for decomposition of mulches which is the basic feature of alley cropping.

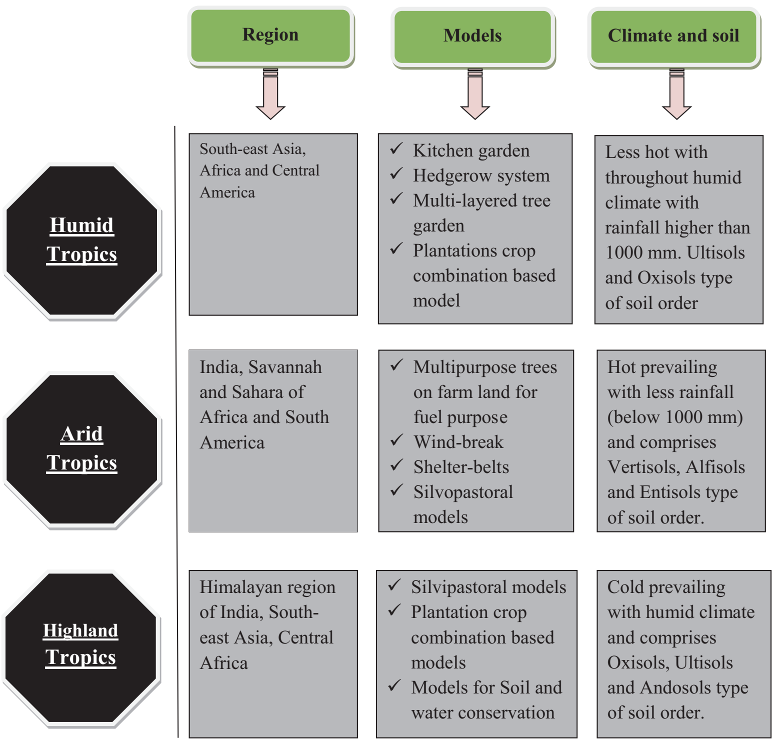

Fig. 1 AFS in the tropics. (Atangana et al. 2014a; Mercer 2004)

The various forms of agroforestry practices under tropics and various regions across the world are depicted in Tables 1 and 2.

2.1 AFS in Arid Tropics

Arid tropics are characterized by higher temperature with less rainfall (below 1000 mm) and comprised of vertisols, alfisols and entisols soil orders. India, Savannah and Sahara of Africa and South America are the major geographical distributions of arid tropics. Multipurpose trees on farmland for fuel purpose,

Table 1 AFM in major tropics (Nair 1993; Sinclair 1999; Mercer 2004; Atangana et al. 2014a)

Tropics	Models	Components
Arid/ semiarid	Agrihorticulture system	Agricultural crops + fruit trees
	Agrihortisilviculture system	Agricultural crops + fruit trees+ trees other than fruits
	Hortipasture	Fruit trees + pasture for livestock feeding
	Horti-silvipastoral system/ silvihortipastoral/ Agri-hortipastoral systems	Combination of horticultural trees, trees other than fruits, agricultural crops and pastures
	Agrosilvopastoral	Introduction of livestock in tree-crop systems
	Windbreak	Row of tree such as *Eucalyptus* species, neem (*Azadirachta indica*), *Dalbergia sissoo* (shisham), *Casuarina equisetifolia* (beach oak), etc. around the crop field works as a windbreak
	Alley cropping	Wide spacing tree planting along friendly crops grown in alley among rows. Subabool (*Leucaena leucocephala*) is a suitable tree because of its N_2-fixing property and its multipurpose nature
	Protein bank (cut and carry systems)	It is a type of silvopastoral systems having various protein-rich multipurpose trees like babool (*Acacia nilotica*), neem, black siris (*Albizia lebbeck*), etc. which are in and around farmlands and rangelands
	Parkland system	Trees such as khejri (*Prosopis cineraria*) in Rajasthan and apple-ring acacia (*Faidherbia albida*) in East Africa are dominant in crop fields. Prevalent in sub-Saharan Africa
Humid	Home gardens/kitchen garden	Most prevalent in high rainfall areas having combination of various multistory annual and perennial crops along with livestocks around the home
	Plantation tree-crop combination	Combination of some plantation crops like coffee (*Coffea arabica*), cocoa (*Theobroma cacao*), rubber (*Hevea brasiliensis*), oil palm (*Elaeis guineensis*), coconut (*Cocos nucifera*), spice and fruits crops, etc. with shade-loving crops
	Multilayered tree garden	Characterized by multispecies of multipurpose in nature with no organized planting arrangements

Table 2 Agroforestry areas in different regions of the world

Agroforestry systems	Area cover in million ha	References
Agrisilviculture (dominant) system in China	45	Huang et al. (1997)
National cover in India	25.32	Dhyani et al. (2013)
Silvopastoral system in Central America	9.2	Beer et al. (2000)
Dehasa agroforestry in Spain/Portugal	6.0	Gaspar et al. (2007)
All multi-strata and jungle rubber agroforestry	6.3	Van Noordwijk and Ong (1999) and Wibava et al. (2006)
Coffee agroforestry in Central America	0.77	Beer et al. (2000)

windbreak, shelter belts, silvopastoral models, etc. are the major AFS that are practiced in this region.

2.1.1 Agrihorticulture System

Integration of herbaceous field crops with fruit-bearing trees is a common practice in the arid region and can enhance the productivity of land and may be profitable to farmers in various ways. Tree-crop interactions and their competitiveness, complexity and compatibility are the major factors that decide whether the selected models are suitable for the given soil and regions or not (Krishnamurthy 1959; Naik 1963; Toppo et al. 2016). According to them, several agricultural produce such as wheat (*Triticum aestivum*), sugarcane (*Saccharum officinarum*), cotton (*Gossypium* spp.), maize (*Zea mays*), etc. are not compatible with horticultural tree species except the combination of jujube (*Ziziphus jujuba*) with other agricultural crops like green gram (*Vigna radiata*), sesame (*Sesamum indicum*) and guar (*Cyamopsis tetragonoloba*) where fruit yield increased from 5.2 to 14.8 kg per tree along with a higher yield (782 kg seeds) of guar (Singh 1997). Similarly, major horticultural crops like Indian mesquite (*Prosopis spicigera*), harbour guar and cucurbits are most suitable with moth bean (*Vigna aconitifolia*), guar, sesame and pearl millet (*Pennisetum glaucum*) under rainfed condition but suitable with chickpea (*Cicer arietinum*), groundnut (*Arachis hypogaea*), green gram and spices crops under irrigated conditions (Bhandari et al. 2014; Kumar et al. 2018).

2.1.2 Agrihortisilviculture System

High wind blow and intense sunlight are the major characteristics in arid regions. In this case integration of some woody perennial trees with any prevailing model is helpful for checking high wind speed along with soil erosion. These practices will be helpful for maintaining soil productivity and health status of both crops and trees along with amelioration of very harsh environment. Thus, integrating trees in that region works as shelter belts and windbreaks in and around the agricultural farm. Therefore, this practice will be more diverse, socially acceptable and economically sound to farmers by providing several timbers, fuel, fibre, fruits and medicinally important plants.

2.1.3 Hortipasture

Integration of some edible/nonedible grasses such as pasture for livestock with recommended horticultural crops is another type of AFS that prevails in the arid region. This system can enhance livestock's economy and profitability for farmers. Integration of some horticultural trees such citrus (*Citrus* spp.), guava (*Psidium guajava*), pomegranate (*Punica granatum*), aonla (*Phyllanthus emblica*), mango (*Mangifera indica*), etc. with some edible grasses/pasture is the major characteristic for the establishment of this model in which ground pasture can be fed by livestock and cattle. Therefore, we can say the health of livestock depends on the type and palatability of fodder and pasture species. This system can maintain food and nutritional security for both people and cattle/livestock (Atangana et al. 2014a). Furthermore, fruit tree like ber (*Ziziphus mauritiana*) in drought region can perform a better substitute in the case of any crop failure condition with the provision of nutritious fruits, fuelwood, fodder, etc.

2.1.4 Horti-Silvopastoral System

The integration of horticultural crops with trees and pasture is advantageous for arid region. This integration can check soil erosion and improve productivity and fertility of soil through continuous addition of organic matter. Therefore, the suitable combination of different elements (horticultural crops, trees and pasture) could potentially ameliorate microclimate of the arid region along with enhancement of nutritive quality and palatable characteristics of pastures and grass species on which livestock depends. Thus, several species like Kardhai (*Anogeissus pendula*), gum arabic tree (*Acacia senegal*), axlewood (*Anogeissus rotundifolia*), umbrella thorn acacia (*Acacia tortilis*), black siris, neem, phog (*Calligonum polygonoides*), phalsa cherry (*Grewia tenax*), mountain spike thorn (*Gymnosporia spinosa*), khejri, kikar (*Prosopis juliflora*), pilavapilu (*Salvadora oleoides*), rohida (*Tecomella undulata*) and jujube are suggested for cattle and livestock's feeding purpose due to higher palatability ratings of leaves which remain green in hot arid conditions (Ganguli et al. 1964). For management perspectives, the arrangement of these three elements such as horticultural crops, trees and pasture is a prerequisite for minimizing the competitions for natural resources among them.

2.2 AFS in Semiarid Tropics

Semidry tropics are extensively distributed in the area of around 2.1 billion hectares in the world. Ten percent area of semiarid is contributed by Indian sub-continent which is associated with 72 million hectares of vertisols (Burford and Virmani 1983; Murthy et al. 1982). Mango, guava, aonla, ber, custard apple (*Annona squamosa*), tamarind (*Tamarindus indica*), sapota (*Manilkara zapota*), jamun (*Syzygium cumini*), etc. are very promising fruit trees in terms of utilization from both nutritive and medicinal purposes under harsh climate. Furthermore, development of superior varieties for drought resistant and high yielding is the major concern in the area which can open the door for enhancement of productivity and health of soil along with microclimate amelioration with sustainable productions of some nutritive fruits for peoples. With the deciduous nature of trees which can make soil productive through addition and decomposition of leaf litter and another residue into soil organic matter (Hiwale 2004; Raj et al. 2016; Jhariya et al. 2018a; Meena et al. 2018), these systems can convert unproductive wasteland and degraded land to productive and cultivable lands.

2.3 AFS in Humid Tropics

Humid tropics are characterized by warm climate with high level of humidity accompanied by higher rainfall (> 1000 mm) and have ultisols and oxisols types of soil orders. Southeast Asia, Africa and Central America are the major geographical distributions of humid tropics. Kitchen garden, hedgerow system, multi-strata tree garden, plantation crop combination, etc. are the major AFM practiced in this region. Homegarden or kitchen garden is the most prevalent type of AFS prevalent in high rainfall areas having a combination of various multistory annual and perennial crops along with livestocks around the homestead. Similarly, a combination of some plantation crops like coffee, cocoa, coconut, rubber, oil palm, spice and fruits crops, etc. with shade-loving crops is another type of AFS in the form of plantation tree-crop combination. Moreover, another type of prevalent AFM such as multistratum tree garden is characterized by various species of multipurpose nature with no organized planting arrangements. The production under different agroforestry models under tropical condition has been mentioned in Table 3.

3 Climate Change: A Global Concern or Perspective

Climate change is not a recent phenomenon, and it has changed throughout history. However, because of human interventions, the change has become alarming and devastating. A human-caused anthropogenic impact on climate has been seen through emissions of GHGs (CO_2, nitrogen oxides, methane, water vapour, etc.) through various sectors such as power stations (21.3%) which is followed by industrial process (16.8%), transportation (14.0%), agriculture sectors (12.5%), fossils fuel (11.5%), domestic, economic and allied sources (10.30%), land utilization and burning of biomass (10%) and disposal of waste material (3.4%), respectively (IPCC 2015) (Fig. 2).

As we know, some practices like fuel burning (gas, coal and oil), changing land utilization and deforestation cause continuous emission of GHGs. Among all gases, CO_2, methane and nitrous oxide are considered most potent GHGs (Fig. 3) contributing 72%, 18% and 9%, respectively, in the emissions of GHGs (IPCC 2015). The concentration of atmospheric CO_2 has been increasing since pre-industrial era

Table 3 Production of multipurpose trees under different agroforestry models in major tropics

Tree combinations of AF model in different climates	NPP	References
NPP of above ground		
Plantation crop combination comprising coffee and shade trees in the humid climate of Colombia	8800 kg ha^{-1} $year^{-1}$	Bornemisza (1982)
Plantation system of mangium (*Acacia mangium*) in the humid climate of Malaysia	18,000 kg ha^{-1} $year^{-1}$	Lim (1985)
Plantation system of mangium in São Paulo University of Brazil	37 mg C ha^{-1} $year^{-1}$	Laclau et al. (2008)
Plantation system of loblolly pine (*Pinus taeda*), Gympie messmate (*Eucalyptus cloeziana*) and miombo woodland stands	14.1, 19.7 and 5.9 mg C ha^{-1} $year^{-1}$	Guedes et al. (2018)
Monoculture stands of loblolly pine in the coastal plains of North Carolina	20–25 mg C ha^{-1} $year^{-1}$	Sampson et al. (2008)
Plantation system of subabool in the humid climate of Hawaii	25,000 kg ha^{-1} $year^{-1}$	Pound and Cairo (1983)
Hedgerow intercropping comprising Mexican lilac (*Gliricidia sepium*) in the moist subhumid climate of Nigeria	3750 kg ha^{-1} $year^{-1}$	Bahiru et al. (1988)
Plantation system of subabool in the subhumid climate of India	38,200 kg ha^{-1} $year^{-1}$	Mishra et al. (1986)
Plantation system of kikar in the dry subhumid climate of India	30,000 kg ha^{-1} $year^{-1}$	Gurumurti et al. (1984)
Woodland system of honey mesquite (*Prosopis glandulosa*) in the arid region of the USA	3700 kg ha^{-1} $year^{-1}$	Rundel et al. (1982)
Leaf production		
Plantation system of mangium in the humid climate of Malaysia	3060 kg ha^{-1} $year^{-1}$	Lim (1985)
Hedgerow intercropping comprising Mexican lilac in the moist subhumid climate of Nigeria	2300 kg ha^{-1} $year^{-1}$	Agboola (1982)
Plantation system of subabool in the subhumid climate of India	2300 kg ha^{-1} $year^{-1}$	Mishra et al. (1986)

(280 ppm in the year of 1750) to the industrial revolution (379 ppm in the year of 2005), and today (2017) the figure is 407.62 ppm. Therefore, it clearly indicates how the concentration is increasing which results in the rising of temperature and leads to global warming. GHG emission leading to global warming has significant influence over ecosystem services as well as biodiversity of the concerned region (Fig. 4). Higher level of global warming alters the hydrological cycle of the concerned site leading to production of heat stress for living organism. Under such conditions, most of the species becomes vulnerable towards extinction. Therefore, the major indicators for climate change are the rise in global mean temperature, melting of ice, ocean acidification and continuous rise in sea level which results in

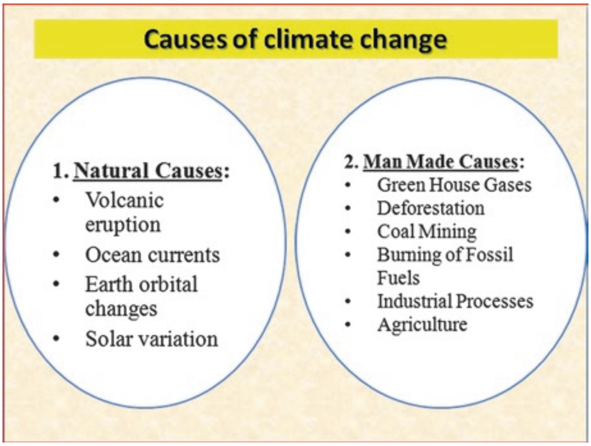

Fig. 2 Cause of climate change. (Riphah 2015)

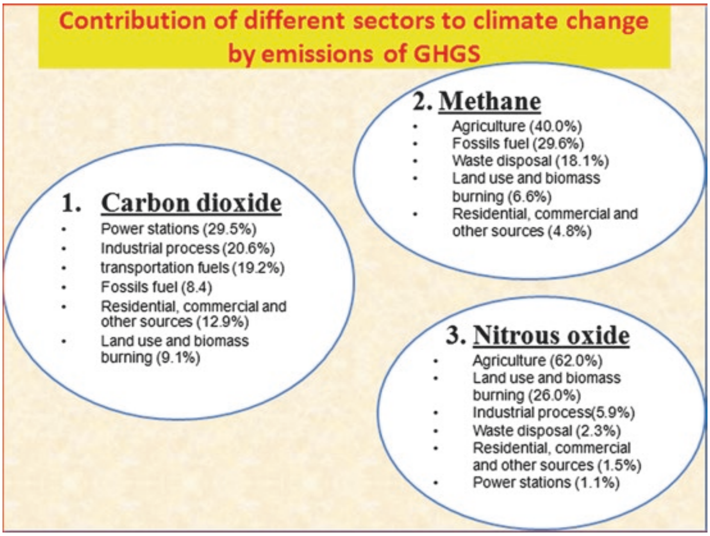

Fig. 3 Percentage share of different sectors in GHG emission in the world. (IPCC 2015)

a more frequent occurrence of flood, drought, fire, hurricanes, etc. that claimed hundreds of lives and property.

4 Agroforestry Under Changing Climate

Today, climate change is not only affecting agriculture and forestry, but it is disturbing several models of AFS in terms of reduction in productivity, profitability and sustainability. Agroforestry consists a variety of annual and perennial plants with some livestocks resulting in more complex and diverse interaction in comparison to monoculture systems. Extreme weathers like severe temperature, humidity and high CO_2 concentration affect all these organisms including microbial and insects which are associated with AFS. Therefore, each and every component of agroforestry (woody perennial trees, herbaceous crops and livestocks) systems response depends upon climate. It has been reported that selection of suitable species under AFS schemes helps to reduce a considerable amount of CO_2 in the atmosphere. Therefore, combating climate change is the secondary role played by AFS apart from giving economic benefits (Fig. 5). However, the existence of traditional models and improved models along with their management practices according to prevailing weather can upsurge the deleterious impact of climate change on different life form components (tree, crops and pasture/livestocks) (Fig. 6).

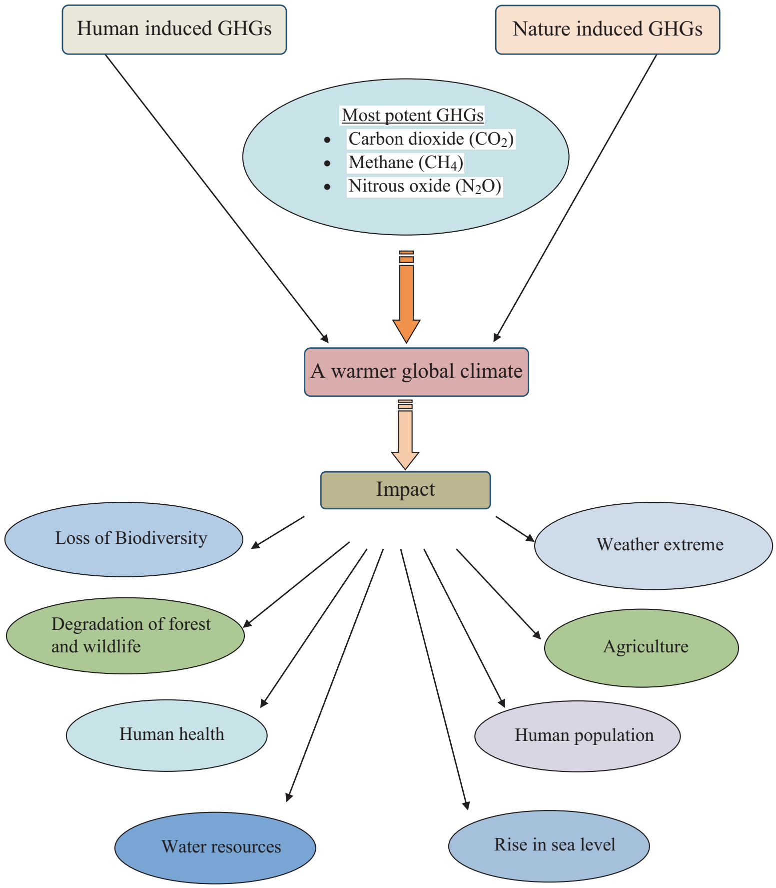

Fig. 4 GHG impact on ecosystem and biodiversity. (del Rio 2012)

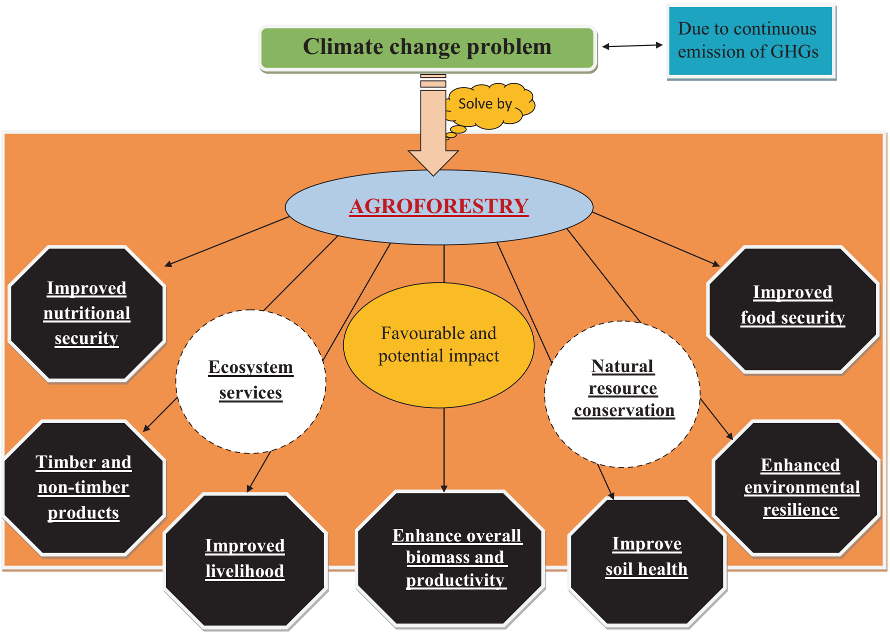

Fig. 5 Agroforestry impacts and climate mitigation. (Pachauri 2012; Swamy and Tewari 2017)

5 Agroforestry Solutions for Climate Change

Indeed, the practices of different AFM undoubtedly can reduce atmospheric CO_2 concentration in the course of fossil fuel substitution. Due to the complex nature of AFS, it can absorb atmospheric C and store in different components such as bole, branch, foliage and root. Thus, agroforestry is the type of C farming system in which ambient C can be sequestered in soil and vegetation with the management of the natural resources like light, land, water and nutrient along with the provision of food security under changing climate with landscape restoration (Jhariya et al. 2018b; Yadav et al. 2017).

The mechanism of C fixation during photosynthesis, storage through C sequestration and removal of C by respiration of both above-ground and below-ground biomass is depicted in Fig. 7. Similarly, internal transfer of C from above to below ground, i.e. soil, is another important area where more C can be added. The option of the fast-growing tree with high yield under short rotation forestry programme gives greater biomass through higher CO_2 absorption. As per one estimate, the storage capacity of C under AFS is 0.3–15.2 mega C/ha/year in the world, and according to Nair et al. (2011), the storage capacity was found to be maximum in humid tropics as compared to other areas of high rainfall.

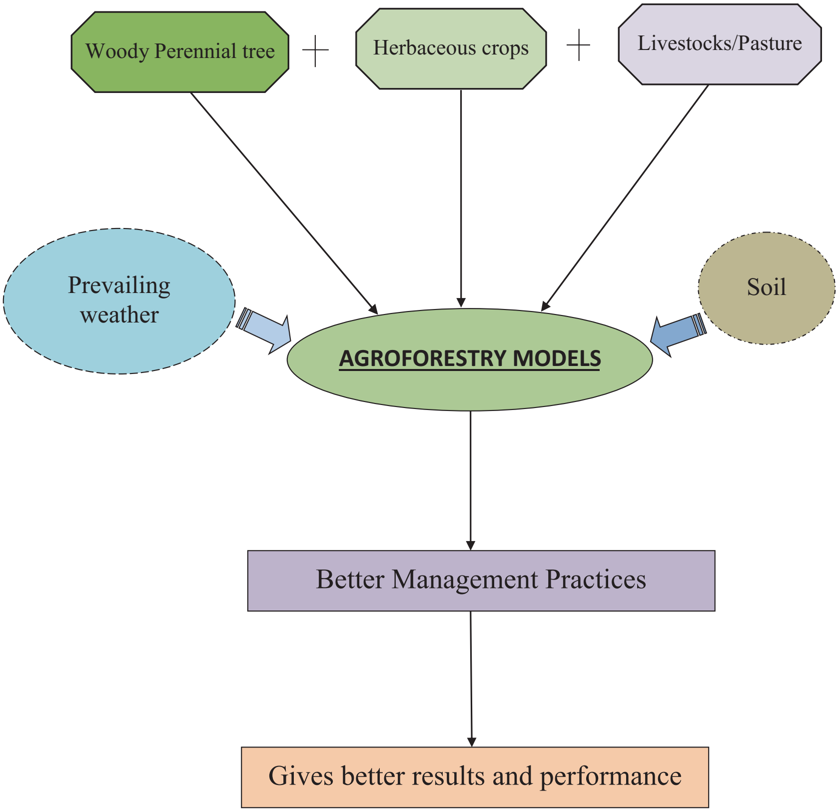

Fig. 6 General models for agroforestry performance. (Nair 1993)

6 Addressing Food Insecurity Through Agroforestry

Agroforestry is a better practice of a farming system for maintaining biodiversity along with the diversified production of food, fruits, fibres, etc. and maintaining food and nutritional security. However it has some limitations. Apart from its inherent limitation, the scope of agroforestry has widened up in the era of climate change as secondarily it helps in mitigation and adaptation of climate change (Fig. 8). Incorporation of horticulture trees under horti-based AFS could potentially enhance both productivity and profitability in terms of producing fruits and vegetables which are the good sources of essential nutrition (protein, vitamins, minerals, etc.) for peoples and fulfil the requirement of minimum balance diet per day per capita (85 g for fruits and 220 g for vegetables) (Roy 2011). Similarly, several fruit trees comprising mango, aonla, citrus, papaya (*Carica papaya*), etc. are very nutritious and have essential biochemical substances for healthy life. Thus, the addition of some horticultural crops (fruits, vegetables, etc.) guarantees food and nutritional security through provision of multifarious benefits as edible fruits, vegetables, etc. to

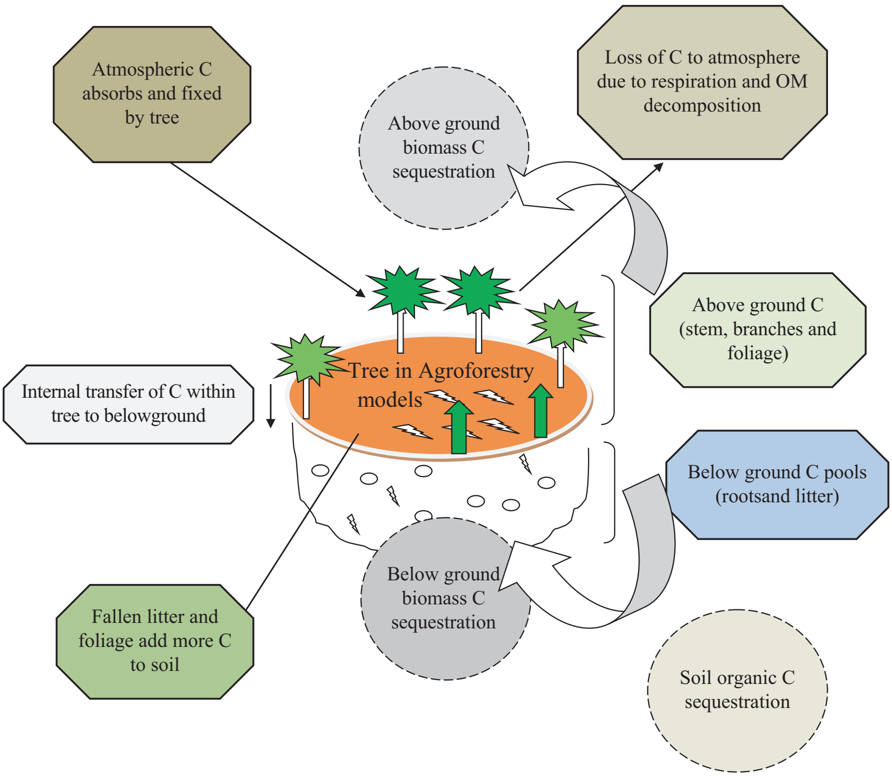

Fig. 7 Role of agroforestry in C sequestration. (Atangana et al. 2014b; Nair 2012)

farmers and enhances employment along with socio-economic development (Samara 2010).

7 Agroforestry for Wasteland Reclamation

The land is the non-renewable and important natural resource for the existence of civilization and cultivation of agriculture. A faulty land use practice (non-sustainable land management) leads to degradation causing loss of soil fertility, soil and water erosion and other uncountable ecosystem problems. This can affect the overall productivity and profitability of any farming practices. Therefore, integration of perennial trees in AFS can pave this problem of land degradations through addition and decomposition of organic matter to the soils, enhancement of fertility that results in close and efficient nutrient cycling and maintaining the health of the ecosystems. Thus, reclamation, restoration and development of wasteland are another area of scope and potential of AFS (Jhariya et al. 2015; Datta et al. 2017).

Salinity and sodicity are few of the major types of wasteland that not only affect the life cycle of trees and crops but also reduce the productivity of that land.

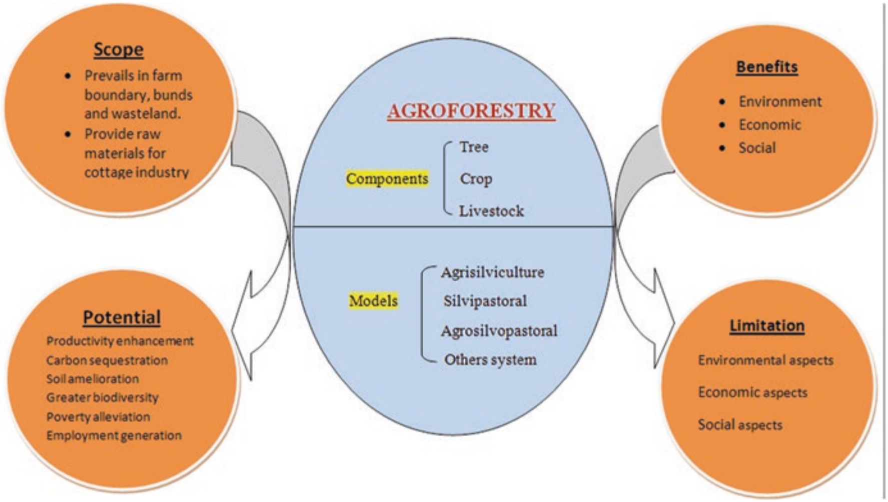

Fig. 8 Schematic representations of AFS. (Sinclair 1999)

Waterlogging (marshy) land, degraded pasture/grazing land, land under the practice of shifting cultivation, ravine land, mining and industrial lands, etc. are another category of wasteland that spread throughout the world. Soil runoff, erosion, desertification, acidification, the occurrence of frequent floods, drought, loss of soil nutrients and productivity, loss of biodiversity and poverty are the major impacts of land degradation. Therefore, this wasteland is to be utilized through the adoption of different AFM that can make a scope for multiple uses of this land. The incorporation of suitable fodder trees, bushes, pasture, grasses and fruit crops is the viable option for both reclamation and economic gain. Thus, agroforestry for a different form of wasteland areas is summarized in Table 4.

8 Prospects of Agroforestry in Soil Management

Soil is that which we call the soul of infinite life. Definitely, soil gives unique ecosystem services to sustain life on the earth. In AFS, close-type nutrient cycling exists rather than the open-type nutrient cycling in which chances of loss of nutrients are prominent under the sole type of cropping practices. Soil provides ecosystem services like regulation of soil structure, function, efficient nutrient cycling and C sequestration and acts as a habitat for different soil organisms which plays a vital role in good soil health. The schematic representation of ecosystem services provided by soil under AFS is depicted in Fig. 9.

From the array of beneficial effects of agroforestry on soil, it is a matter of fact to discuss the problems and prospects of agroforestry components such as trees on productivity and health of the soil in the tropics. Tree adds organic inputs through its litter components and roots as decaying of both can enhance the presence of C

Table 4 Wasteland and its reclamation by different species under AFM

Type of wasteland	Reclamation through AF	References
Salt-affected soils	Kikar + swamp grass (*Leptochloa fusca*)-based silvipastoral model and forest red gum tree (*Eucalyptus tereticornis*)-, poplar (*Populus deltoides*)-, teak (*Tectona grandis*)- and beach oak-based AFM. Fruit trees like jujube, aonla, pomegranate, tamarind, etc. and grasses like smut grass (*Sporobolus indicus*), doob grass (*Cynodon dactylon*) and buffel grass (*Cenchrus ciliaris*) based silvopastoral, agrisilviculture, agrisilvopastoral and hortipastoral systems, etc.	Singh et al. (1994)
Alkali soils	MPTs like kikar- and babool-based AFS. Farash (*Tamarix articulate*), pilavapilu, arjun (*Terminalia arjuna*), karanj (*Pongamia pinnata*), forest red gum tree and common sesban (*Sesbania sesban*) are another tree species suitable for alkaline soils. Fruit trees like guava, date palm (*Phoenix dactylifera*), tamarind, jamun, etc. and grasses like rhodes grass (*Chloris gayana*), doob grass, species of millets, etc. based silvopastoral, agrisilvopastoral, hortipastoral systems, etc.	Ahmed (1991)
Acid-affected soils	Suitable tree species like silk tree (*Albizia chinensis*), *Ficus* species, Himalayan mulberry (*Morus serrata*), elm tree (*Ulmus nepalensis*), etc. legume species includes centro (*Centrosema pubescens*), stylo (*Stylosanthes guianensis*), calopo (*Calopogonium mucunoides*), tropical kudzu (*Pueraria phaseoloides*), *Desmodium* species, etc. and suitable grasses species like crown grass (*Paspalum notatum*), kyasuwa grass (*Pennisetum pedicellatum*), mission grass (*Pennisetum polystachion*), etc. based silvopastoral system	–
Ravine land	Suitable trees species like khejri, *Acacia* spp., shisham, male/solid bamboo (*Dendrocalamus strictus*), kachnar (*Bauhinia purpurea*), etc.; fruit trees comprising mango, aonla, guava, beal (*Aegle marmelos*), pomegranate, etc.; and suitable grasses species like marvel grass (*Dichanthium annulatum*), blue panicgrass (*Panicum antidotale*), kyasuwa grass, buffel grass, etc. based silvopastoral, hortipastoral, silvihortipastoral systems	Meena et al. (2015a)
Arid desert and sand dunes	Suitable tree species like kikar, neem, umbrella thorn acacia, etc. and fruit trees comprising ber, beal, pomegranate, tamarind, date palm, etc. based silvihorticulture systems. Suitable grass species like buffel grass, birdwood grass (*Cenchrus setigerus*), etc.	Tewari (2016)
Waterlogged, marshlands and swamps. Swampy and wet lands	Suitable tree species comprises of shisham, *Eucalyptus* species, Indian willow (*Salix tetrasperma*), Euphrates poplar or desert poplar (*Populus euphratica*), etc.; suitable grass species comprise Nadi blue grass (*Dichanthium caricosum*), crowngrass, Para grass (*Brachiaria mutica*), etc.; and legumes comprise common sesban, wild tantan (*Desmanthus virgatus*), perennial soybean (*Glycine wightii*), etc.	–
Mine-affected land	Species such as babool, black siris, neem, khair (*Acacia catechu*) and fruit trees like ber, etc. are suitable for this area	–

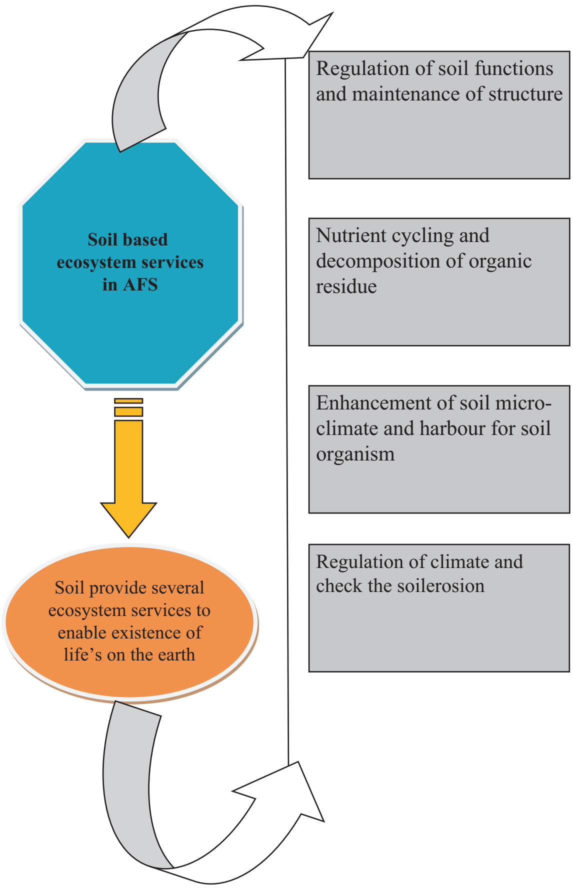

Fig. 9 Ecosystem services by soil under AFS. (Udawatta et al. 2017)

which results in the occurrence of a vast range of soil-inhabiting organisms (earthworms, etc.). Further, their interactions improve the status of nutrients and fertility of soils (Bertin et al. 2003; Dadhich et al. 2015). Also, accumulation of C in soils depends on the type of tree species involving litterfall, texture of leaf litter, decaying of organic matter, decaying agents and, in broad sense, we can say overall management of agroforestry practices that can affect not only soil health but also sequestration capacity of C. Similarly, tropical soil is comparatively more diverse in terms of biomass, C (which is derived by decomposition of organic matter) and microorganism than in temperate region.

9 Agroforestry and Soil Health: A Linking Concept

The soil is intricately related with various components of the environment such as lithosphere (parental rocks and earth crust), hydrosphere (water body), atmosphere (through cycling of gases) and biosphere (through flora and fauna), and their proper

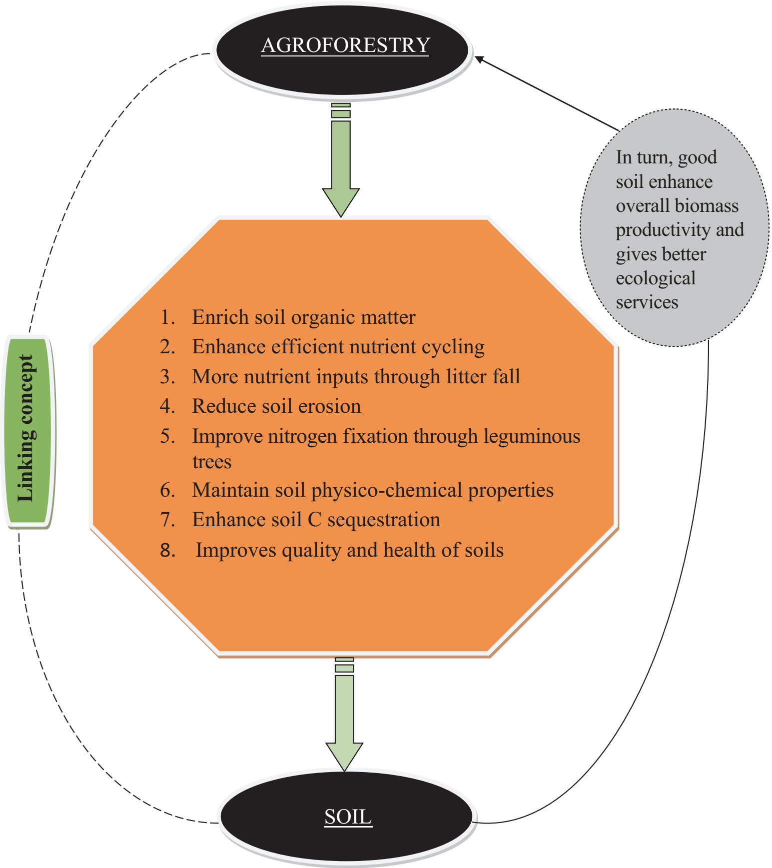

Fig. 10 Agroforestry and soil – a linking concept. (Barrios et al. 2012; Udawatta et al. 2017)

health services are prerequisites for better productivity, quality and sustainability. Soil forms habitat for flora, and its health can be uplifted through the incorporation of various types of multiple and complex farming practices rather than sole type and monoculture farming system. Agroforestry suits for the multiple and complex types of the farming system which can enhance soil fertility and productivity through the addition of organic matter and performs close-type nutrient cycling rather than open-type nutrient cycling in monoculture (sole) farming systems. Thus betterment of AFS and soil health are linked in various ways. For example, good management of AFS can enrich soil organic matter, enhance efficient nutrient cycling, add more nutrient inputs through litter fall, reduce soil erosion, enhance nutrient input from atmosphere, improve nitrogen-fixing ability through incorporation of leguminous trees, maintain soil physicochemical properties, enhance soil C sequestration in climate change scenario and overall improve quality and health of soils (Fig. 10).

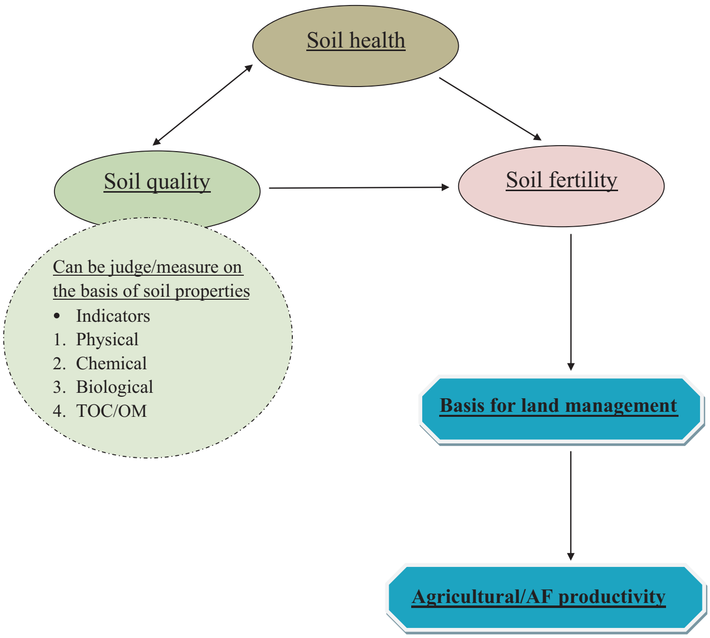

Fig. 11 Synergies between soil health, fertility and productivity under AFS. (Dollinger and Jose 2018; Barrios et al. 2012)

10 Synergies Between Soil Health and Productivity Under AFS

There is the nexus between soil health, quality, fertility and production potential of various AFM. Overall agroforestry productivity depends on quality and health of soil which can be judged and measured by soil indicators or properties such as soil physicochemical attributes and soil biota that reflects the fertility of soil, which is the basis of land management practices and indicates productivity of any model (Fig. 11). Good soil health reflects better ecosystem services that maintain environmental health along with human health (and other organisms and soil-inhabiting organism). Similarly, several management practices such as agroforestry, multiple cropping, cover cropping, non-tillage practices and incorporation of organic manures can potentially enhance the quality and health of soil which is the pillar of higher productivity along with environmental quality (air and water quality) (Fig. 12).

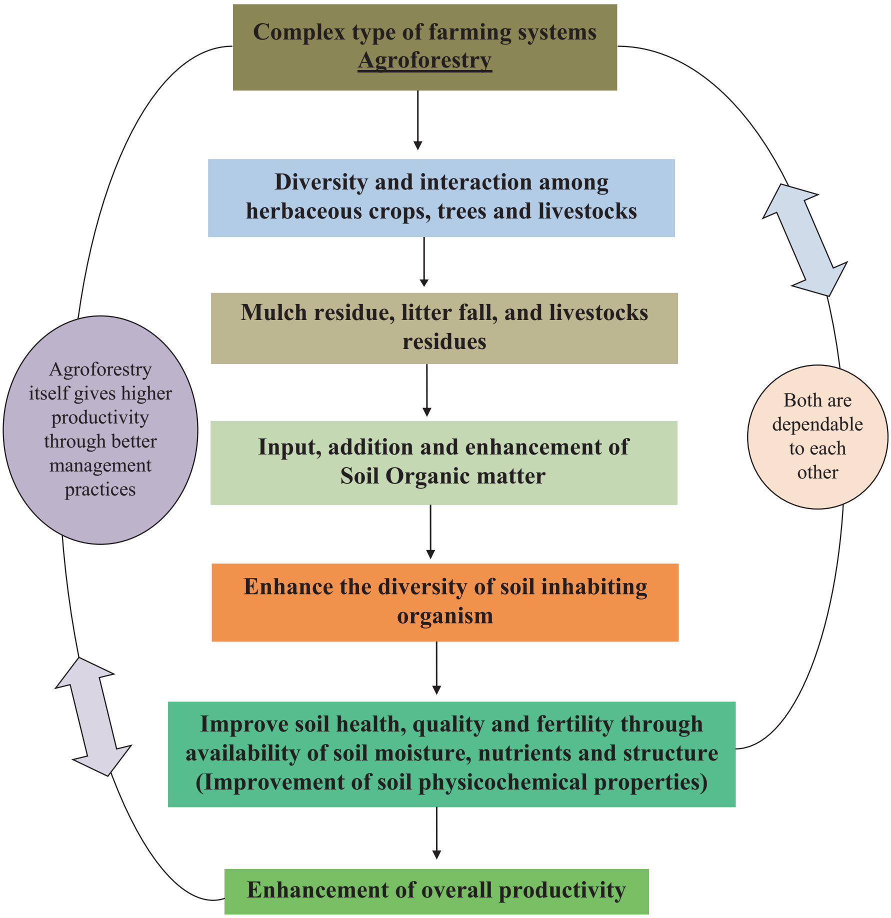

Fig. 12 Nexus between agroforestry, soil health and productivity. (Dollinger and Jose 2018)

11 Ecosystem Services of AFS

Agroforestry provides both ecosystem services and disservices. Ecosystem services comprise of four potential elements, viz. provisioning, regulating, supporting and cultural services produced by the adoption of AFS rather than disservices (Fig. 13). Moreover, agroforestry gives greater biodiversity and higher biomass productivity which shows the absorption capacity of atmospheric CO_2 which results in better environment and provides healthy ecosystem services. Both tangible and intangible benefits of AFS are the major component of ecosystem services. Tangibles, i.e. direct services, include timber, fuelwood, firewood and other non-timber forest produces like gum, fodder, katha, etc. On other side, soil water conservation, watershed management, efficient nutrient cycling, etc. are the major services by AFS that

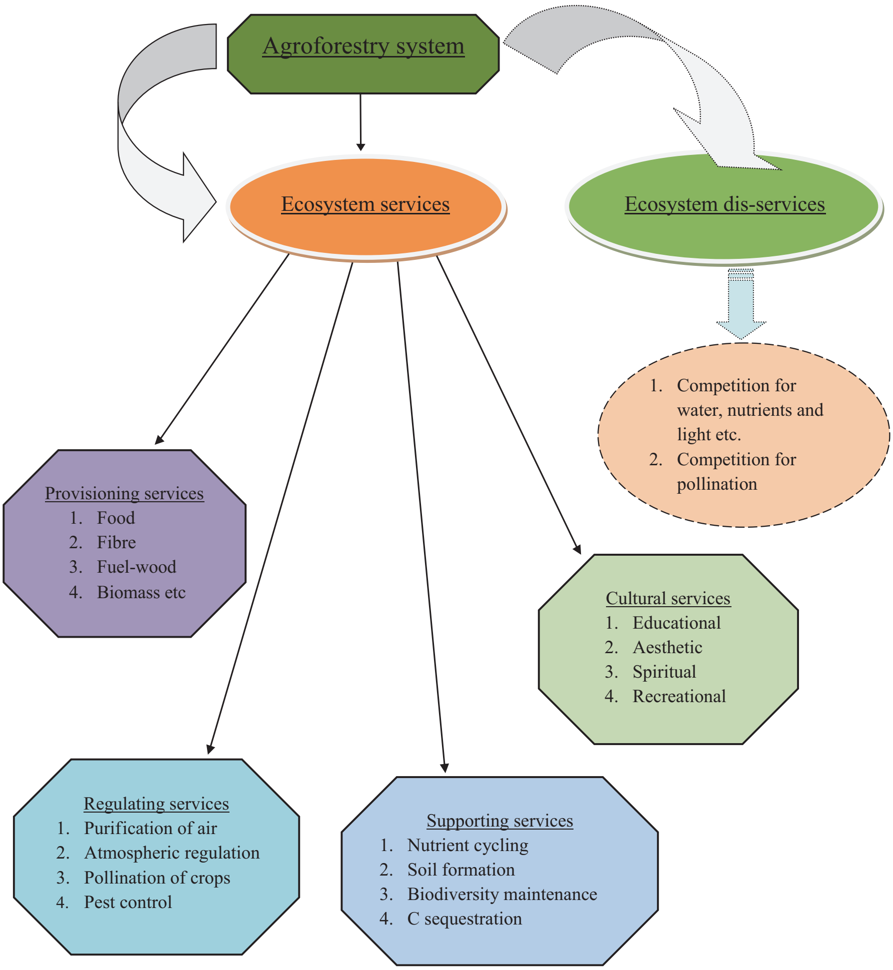

Fig. 13 Ecosystem services and disservices in AFS. (Kuyah et al. 2017)

come under indirect and intangible benefits. Among them, gum production from trees can enhance economic gain of farmers and results in retention of trees either on field bund or as scattered. For example, babul-based bund plantation in Chhattisgarh gives better utilization and economical viability through gum productions other than multipurpose and leguminous characteristics of trees (Das et al. 2014; Raj et al. 2015; Raj 2015a, b; Raj and Singh 2017; Meena and Meena 2017).

Agroforestry is well known for better ecosystem service provider through the provision of excellent economic incentive along with maintenance of biodiversity and environmental sustainability (FAO 2007). Also, agroforestry gives benefits in both spatial and temporal scale (Jose 2009). For example, incorporation of several AFM in the area of deforestation (removal of trees) can check the problem of soil erosion and prevent sedimentation of waterways that lead to protection of downstream ecology and biodiversity through beneficial ecological services (Pearce and Mourato 2004). Moreover, both C sequestration potential and better provision of ecosystem services of AFS give the foremost and good scope of research in the era of climate change (Oelbermann and Voroney 2011; Pagiola et al. 2008; Jhariya et al. 2015). Thus, farmers and peoples enjoy these ecological services at regional and global scales which are derived from multifarious AFS in different agroclimatic zones of the world (Jose 2009).

12 Agroforestry for Natural Resource Conservations

As we know, AFS are the very complex type of farming practices, help in resource conservation and their efficient utilization, give more profitable benefits and maintain ecosystem services by producing both tangible and intangible benefits to people. The management of agricultural land through the integration of some multipurpose and leguminous trees is the great choice for management and utilization of natural resources available in these models in different agroclimatic zones (Jhariya et al. 2018a; Varma et al. 2017).

In this context, the term agroforestry can be the best fit for better NRM. For example, AFM utilizes soil resource efficiency and reduce leaching of essential ions by holding the soil through deepest root systems of available trees which is effective for minimizing soil erosion and form close type of nutrient cycling. Therefore, agroforestry as complex and multifarious farming systems are a better performer for resource conservation than sole cropping of either crops or trees. Moreover, along with conservation, it will be profitable to farmers by producing several types of produce to sustain life and conserve biodiversity (Singh and Jhariya 2016). In this context, tree-crop interaction plays a major role. For example, better management practices of models along with a suitable combination of tree and crops could potentially reduce competition among agroforestry elements (tree, crop and livestock) for light, water, space and soil nutrient.

Among all resources, water deserves foremost and prime position for sustaining the life and proper development of plants. Thus the major question that has been raised is “Can adoption of agroforestry increase the water availability and uptake of crops and trees under varying climatic condition?”. Water use efficiency of the different AFM having trees and crops varies as per availability of water, prevailing climate and topographical condition of the sites. Management for better tree-crop interaction can enhance the water use and proper management of this resource. This is very prime research for the dry region where scarcity of water is prominent. Therefore, identification of suitable species combination and their management practices can optimize the absorption capacity of water (having essential nutrients and ions) and minimize the competitions among different life forms (trees, crops, grass, etc.) (Ong et al. 2006). Also, the main question in this context is how to enhance the resource capture and productivity under different combinations of crops and trees without affecting the yield potential of crops under the tree canopy in AFS. This can be resolved through an appropriate combination of species along with better model with leafing phenology and flushing (Huxley 1996). It may work efficiently on wasteland area.

13 Agroforestry and Livelihood Security

Recalling agroforestry for livelihood security, it will be a better choice to integrate various multipurpose and leguminous trees (and others) on farm field for guaranteed income and farm diversification through the delivery of several tangible products (timber and non-timber products) under continuous changing climate and extreme weather (WAC 2010). Livelihood security under AFS is a linking concept that provides profit and economic gains through combination of economically viable tree species (timber and fruit trees) along with annual herbaceous crops rather than sole cropping. Similarly, complex type of AFM such as homegarden could potentially diversify the outputs and sustain the peoples through provision of nutritious fruits, spice, vegetables, etc. for their household consumption along with economic gain by selling surplus productions in nearby market (Bellow et al. 2008; Meena et al. 2017).

In addition to improved and managed AFS, bund-based agroforestry can potentially uplift the socio-economic benefits along with environmental protections. For example, babul-based bund plantation is very effective for gum exudation and economically viable if the process of gummosis should be done by ethephon-induced scientific methods (Fig. 14). This system gives valuable and commercial gums in addition to timber and crop yield along with various environmental benefits due to leguminous nature. Thus

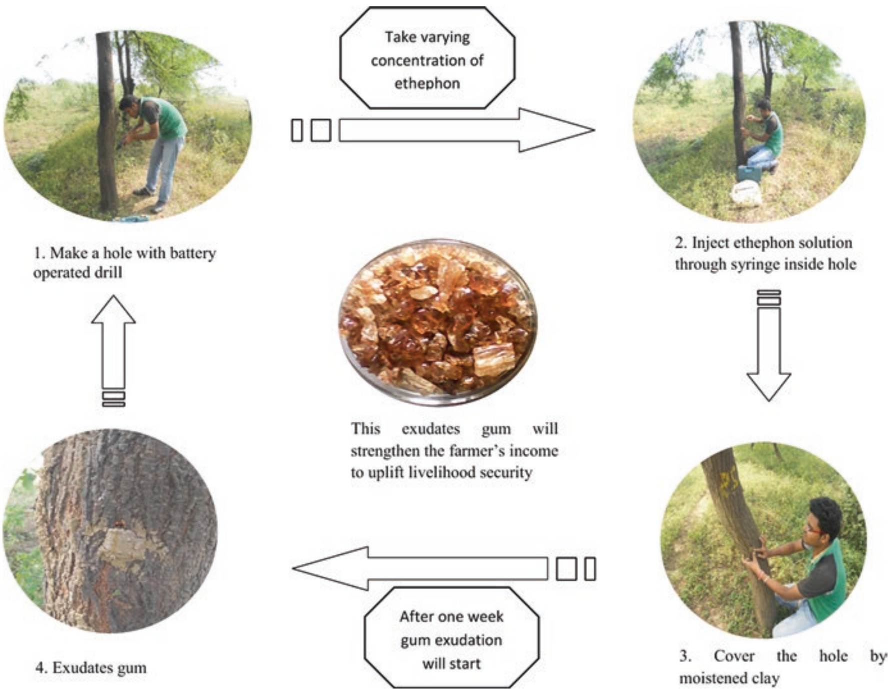

Fig. 14 Strengthening the farmer's income through ethephon-induced gum exudation. (Raj and Singh 2017)

gum tapping by using ethephon is not only economically viable but also conserves biodiversity too. Similarly, the integration of some lac hosting trees under AFS may open the door for economic gain. For example, the addition of only single tree of palash (*Butea monosperma*) under AFS would be viable for farmers for livelihood security through lac cultivation practices and produce 1.5–2.5 kg lac with annual income of 700–800 rupees per tree in central India region (Sridhar et al. 2015).

Likewise, apiculture-based agroforestry can strengthen the income of farmers by producing honey and maintaining diversity and health of honeybees which are natural pollinators (Painkra et al. 2016). Hence, there are various literatures that show agroforestry gives more benefit to the farming community in comparison to traditional farming and enterprises of forestry. Incorporation of agroforestry practices on waste and marginal land is also a good option/choice for better productivity and profitability for farmers. For example, under rainfed condition, the B:C ratio (3.28) of a 13-year-old aonla-based AFS on marginal land indicates more economic gain. Similarly, integration of poplar on both agricultural field and on the bund is more profitable for farmers and gives excellent economic return than sole cropping practice in upper Gangetic region of Punjab, Haryana and Uttar Pradesh (Ram Newaj and Rai 2005; Singh et al. 2014; Yadav et al. 2018). Also, economic profitability in terms of B:C ratio of different AFM in various agroclimatic zones of India is depicted in Fig. 15. As per the figure, the poplar + paddy (*Oryza sativa*) and

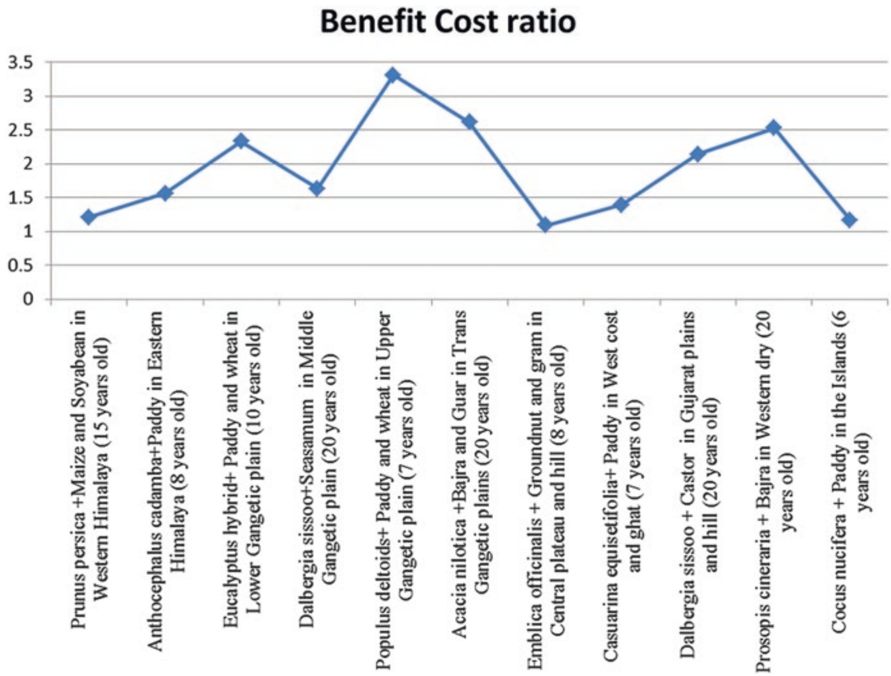

Fig. 15 Economic profitability as B:C ratio of different AFM in various agroclimatic zones of India. (Handa et al. 2016)

wheat-based AFM in upper Gangetic plain (7 years old) are more profitable for farmers through highest B:C ratio (3.31) followed by babool + bajra (*Pennisetum glaucum*) and guar-based AF system in Trans-Gangetic plains (20 years old) having 2.61, khejri + bajra-based AF system in Western dry (20 years old) having 2.53 and eucalyptus hybrid + paddy- and wheat-based AF system in lower Gangetic plain (10 years old) having 2.33 and least in aonla + groundnut- and gram-based AF system in central plateau and hill (8 years old) having 1.09.

14 Scientific Interventions and Policy for Agroforestry

Agroforestry is location specific, and the ecological adaptation of different models of agroforestry is a prime concern for researchers and policymakers. Policy should be in favour of targeting and promoting inclusion of trees in various abandoned and wasteland along with agricultural field and boundaries for the enhancement of land productivity and food and nutritional security along with both employment generation and environment protections. In this connection, a nationwide agroforestry policy has been formulated in 2014 by the Indian government to promote agroforestry across the country for sustainability. This will not only give better landscape but also minimize the health risk of people. Therefore government policy should aim for promotion and development of agroforestry, and this can be achieved easily through the intervention of private sectors and educational institutions. Although agroforestry has been embedded in national agroforestry programme, accordingly agroforestry research should be transformed from descriptive studies to more scientific-oriented research. This can open the door for better understanding about competition, complexity, profitability and sustainability of various AFM. This scientific intervention can maximize the productivity, profitability and sustainability of models under changing climatic condition. Furthermore, research scientist must go for technical research without considering the sociopolitical issue, and this can draw an attention to government and policymakers for drawing and implementing a suitable and favourable policy for existing and improved AFS.

15 Conclusions

The scope and potential of agroforestry are now recognized at the world level. As we know, food insecurity, natural resource conservation and land degradation are the major concerns today under changing climate faced by the world. This can affect global productivity along with the biodiversity of that particular region. In this context, agroforestry is a good option and curb the continuous emission of GHGs by sequestration process of atmospheric C and store in the form of biomass (for productivity), mitigate climate change and gives multifarious products as timber and non-timber products as profits to poor farmers. Thus, agroforestry products give financial benefits to poor farmers along with various ecological services. Also, effective government policy for the promotion of agroforestry, wherever possible, can maintain forest covers on the whole landscape which is better for environmental and ecological security and moving towards sustainable development.

16 Future Prospects of AFS

Agroforestry has three attributes such as adoptability (based on location specific), sustainability (without depleting natural resources) and profitability (term of economic gain to farmers) on which both present and future generations depend. Similarly, agroforestry has been popularized among farmers, peoples and policymakers throughout the world, and it gives an immense potentiality for future benefits to people by provision of direct and indirect benefits through ecological services for better landscape. The multifarious services and benefits of AFS show significant promise towards poor farmers and policymakers.

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