Ecosystem Services of Trees Outside Forest

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Abstract

Trees or other woody vegetation growing outside designated forest areas are known as trees outside forest (TOFs). These trees have many ecosystem services and economic benefits like their potential role in agriculture, food supply and income by providing goods and services, conservation of biodiversity and carbon (C) sequestration. They can improve soil fertility through fixing atmospheric nitrogen, retaining soil moisture, regulating water shed, reducing topsoil loss and litter fall and regulating microclimate, thus increasing crop yield. In addition to providing aesthetic beauty especially to urban surroundings, they are pollutant sink, reduce ozone levels, check dust flow, reduce noise pollution and cools air temperature. Most importantly, these trees are useful timber resources and will

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alleviate pressure on native forests. Forest and TOF are thus considered as two faces of a coin in relation to their capacity for C stock and biodiversity. Substantial amount of trees are going on lands other than forest land used in every country with a potential of sequestering about 38 giga tonnes of C annually. In India, for example, there are about 24–25 thousand million TOFs, out of which trees in agricultural landscape in Indian state of Uttar Pradesh only sequester 20 million tonnes of C. The C sequestration potential of the TOFs is thus enormous to be included in global climate mitigation strategy through reducing emission from deforestation and forest degradation (REDD+) activities. Moreover, as these are additional plantations, so are they complementary with other land uses in mitigating climate change. Unfortunately, due to absence of efficient inventory methods, TOFs are still not accounted fully in the national forest inventories, due to which very less or no information are available for TOFs. Accounting TOF and its services will not only help to understand its importance for national C budget but also its ecological and economic role benefiting human society.

Keywords
Biomass · Climate change · Diversity · Ecosystem services · Tree outside forest

Abbreviations

CDM	Clean development mechanism
C	Carbon
CO_2	Carbon dioxide
FAO	Food and Agricultural Organization
FSI	Forest Survey of India
NFI	National Forest Inventory
NFMA	National Forest Monitoring and Assessment
TOFs	Trees outside forest
REDD	Reducing emission from deforestation and forest degradation

1 Introduction

Global climatic change and biodiversity loss are major concerns in terms of sustaining future generations and a debatable issue among the global scientific community and policymakers (Zhang et al. 2011; IPCC 2013; ter Steege et al. 2013; Jhariya 2017; Raj et al. 2018a, b). Agro-forests, community forests, village woodlots, road side plantation, urban plantation and other trees outside forest (TOFs) are also pivotal in combating global climatic change and reduce biodiversity loss and can be effective segments of sustainability (Roshetko et al. 2007; Kumar and Nair 2011; Meena et al. 2018; Jhariya et al. 2018). Forest is not all trees and all trees are not forest. Huge amount of tree resources exist in almost all the countries but generally were ignored, and attention is given to forests only. However, from a past decade or two, the ecological and societal benefits of TOF are gaining recognition (Schnell 2015). Schnell (2015) reported that TOF was much mentioned as early as seventeenth century in the book *Silvicultura Oeconomica* by Carlowitz (1713). However, tree has been associated with human civilization outside forest from time immemorial in the form of agroforestry and urban plantations, and abundant TOF inventories have been reported after this book though ignored till Food and Agricultural Organization (FAO) recognition in the 1990s (Boffa 2000; Herzog 2000; Bellefontaine et al. 2002; Pain-Orcet and Bellefontaine 2004). FAO coined TOF during preparation of the Global Forest Resources Assessment 2000 report (Pain-Orcet and Bellefontaine 2004) to increase political attention on TOF (de Foresta et al. 2013).

The basic definition is TOFs are 'trees growing outside forest or other wooded land' (Bellefontaine et al. 2002; Schnell 2015; Yadav et al. 2017a). TOF in India according to Forest Survey of India (FSI) is defined as 'all those trees, which have attained 10 cm or more diameters at breast height, available on lands, which is not notified as forests' (FSI 2013). Definitions of forest vary from country to country and so TOF also (Lund 2002). So, the internationally accepted and applied definition is that of FAO which defines 'TOF as trees available on lands which is not defined as forests or other wooded land' (FAO 2005, 2010; Kumar 2006). The word 'trees' in the FAO definition also includes shrubs, palms and bamboo (de Foresta et al. 2013). TOFs are trees growing both in rural and urban areas on farms, common lands and waste lands and along roads and railway tracks and institutions (FAO 2001a; Bellefontaine et al. 2002, Tamang 2018). Trees outside and inside forests are similar in many ways (McCullough 1999).

In areas where there is no or less forest, the ecological and economical role of TOFs can be pivotal (FAO 2001a; Bellefontaine et al. 2002). TOFs can aid in sustainable development through conserving biodiversity in an agricultural-dominant landscape providing resource base upon which our future generations depend (Pushpangadan et al. 1997). In complementary to the ecological and economical role of forest, these trees store enormous amount of carbon (C) in their biomass, thus can sustain the carbon dioxide (CO_2) balance of the atmosphere. In addition to this role, TOFs can substantially meet the growing wood and wood product demands, thus reducing deforestation promoting sustainable development. Maintenance and periodic assessment of diverse ecosystems and a whole range of biological diversity therein are, therefore, crucial for long-term survival of humans (Berkes et al. 1998; Ayensu et al. 1999). Evaluation of TOF structure and function is needed to understand its status and dynamics (de Foresta et al. 2013; Singh et al. 2017). Tree species richness in any area develops the locality factors for other organisms to develop and breed and its role in increasing biodiversity (Gene et al. 1978). TOF can also be critical in sustaining agriculture, food security, household economy and supply of many products and services apart from being reservoirs of ecological functions like conservation of biodiversity, C sequestration climatic stabilization and livelihood support in rural and urban areas (Rawat et al. 2004; FAO 2005; Acharya 2006;

Kumar et al. 2017). However, to realize full potential, TOF needs holistic management approach of resource management locally, regionally and globally (Bellefontaine et al. 2002). This requires efficient inventorying methods integrated fully with the national forest inventories. The chapter thus briefs the need of TOF accounting and underlines its services to understand its importance for national C budget along with its ecological and economic role benefiting human society.

2 TOF Classification

TOF by definition consist of tree formations with varied functions and arrangements, making classification difficult (Kleinn 2000). Such classifications are based on origin, land use, geometry and function of the trees (Bellefontaine et al. 2002). FAO also recognized three distinct TOF types as TOF on agricultural, urban and non-urban non-agriculture land (FAO 2012; Yadav et al. 2017a). TOF on urban land are trees and/or shrubs growing in gardens, parks, parking lots, along streets and others. TOF on agriculture land include trees and/or shrubs growing on lands under agricultural land use. Agroforestry systems, non-forestry tree crop plantations and orchards are included in agricultural land use. Trees growing on natural lands like grasslands, tree line in mountainous areas and peat lands are categorized as TOFs other than urban and agricultural lands. TOFs on non-agricultural/non-urban land have trees and/or shrubs growing on lands other than agricultural or urban land use, i.e. outside forests. TOFs growing isolated or scattered, in groups and linearly, are categorized based on spatial arrangement (Alexandre et al. 1999). TOFs are also classified functionally like production (food, fodder, firewood), protection (windbreaks, erosion checks), ornamental and aesthetic purposes. Classification of TOFs based on origin is based on whether trees are planted or are leftover of former forests. The trees leftover of a former forest is reported from Latin America where virgin forests are harvested (Kleinn 1999).

3 Ambiguities in TOF Classification

Sometime TOF cannot be distinctly classified from forest as for grasslands or pastures and commercial plantations with shade trees and orchards (Kleinn 1999). de Foresta et al. (2013) also reported problems classifying trees under shifting cultivation, rubber plantations and linear formation and in some agroforestry practices as TOF. Shifting cultivation fallow period follows after a crop period when vegetation regrows making it debatable whether the land is forest or abandoned land after agricultural use. Trees are thus falsely classified either as forest or TOF on such land. Agroforestry in forest land use where temporary grazing is permitted or interculture of annual crop is permitted during early age of forest plantations are not TOF (Schnell 2015). Rubber plantations are also debated, earlier considered as agricultural land use but now recognized as forest (de Foresta et al. 2013).

Classifying linear tree formations in non-agricultural or non-urban also creates problem after FAO included trees either growing in lines having more than 20 m width or in land with area of more than 0.5 ha as forest (Schnell 2015). Moreover, the definitions and meaning of agricultural and urban lands vary from country to country (de Foresta et al. 2013). Sometimes, urban forest is not all included in urban land use but those within and close to the urban areas, i.e. partly in forest land use also (Konijnendijk 2003). In such a case, Rydberg and Falck (2000) recommended considering ground vegetation as a basis for classifying, i.e. uncultivated land as urban forest and cultivated as TOF.

4 TOF and Sustainability

The ecosystem services and economic benefits associated with these trees have begun to attract more attention towards them (Singh and Chand 2012; de Foresta et al. 2013). The trees fix atmospheric nitrogen in the soil and aid in nutrient cycling through litter fall, increasing fertility and thus crop yield. Trees help to retain moisture in soil and topsoil by reducing soil evaporation, checking erosion and reducing water flow. Trees regulate and maintain watershed-building materials. Trees act as a live fence in form of windbreaks and shelterbelt performing protection function. Interest is growing among researchers and policymakers to promote green spaces in urban areas to curb negative impact of urbanization on biodiversity and humans (Shwartz et al. 2014). Moreover, these plantations ensure continuous tree cover to attain benefits for current and future generations (Ajewole 2010).

Every country has extensive tree wealth outside continuous forested areas, and they make important contribution to sustainable agriculture and supply many products similar to forests (Yadav et al. 2017b). TOF include urban and other plantations like road side, homestead gardens, residential areas or in various institutional or academic landscapes. They form important green region in urban and industrial sectors (Schnell 2015, Yadav et al. 2017a; Tamang 2018). An important feature of urban landscape is its trees growing along the roadside or streets (Houde 1997; McPherson and Luttinger 1998). These trees give aesthetic beauty to an urban surrounding providing psychological harmony to the urban residents (Kuchelmeister and Braatz 1993). Several studies also have highlighted these trees as an important feature of rural landscapes (Bellefontaine et al. 2001; Gutzwiller 2002; de Foresta et al. 2013; Datta et al. 2017). These trees are planted widely in all physiographic regions of the globe with socioeconomic and ecological implications (de Foresta et al. 2013). The green spaces are useful for different habitats, provide cultural services and promote human well-being making positive contribution to living conditions of different towns and cities (Mitchell and Popham 2008; Bowler et al. 2010; Arnberger 2012; Buchel and Frantzeskaki 2015).

Trees in urban landscape not only have aesthetic value but make these localities serene and green for agreeable places to work and live. Studies reported a concept ‘proximate principle’ (Table 1) wherein people are willing to own a property in a greener and open locality even with higher price (Wolf 2005, 2007; Chaudhury 2006).

Table 1 Proximate principle

Property value hike	Location of property
10%	Within ¼ mile (0.4 km) of a park
20%	Near to or facing a park
32%	Within or close to green belts

These trees are useful timber resources that will alleviate the pressure on native forests; nutrient cycling and CO_2 sink (Chavan and Rasal 2010; Curlevski et al. 2010; Mandal and Joshi 2014; Nowak et al. 2018). The consequences are reducing the pressure on natural forest in one way and C enhancement and species diversity in other way (Singh and Lodhiyal 2009; Thompson et al. 2009; Singh and Chand 2012). This satisfies the objective of reducing emission from deforestation and forest degradation (REDD+) mechanism. Therefore, forest and TOF are considered as two faces of a coin in relation to their capacity for C stock and biodiversity (Kleinn 2000). The C sequestration potential of these plantations is also high enough to be included in global climate mitigation strategy. These are additional plantations and so are complementary with other land uses (Schoeneberger 2009; Plieninger 2011; Thangata and Hildebrand 2012).

Urban trees and plantation along the road and canal side can act as sink for pollutants; reduce urban O_3 levels; check dust flow, fly ash and noise pollution; cool air temperature; and provide aesthetic beauty to the urban landscape (Chavan and Rasal 2010; Nowak et al. 2018).TOFs are ecologically important for urban localities as they fix atmospheric C in their biomass, modify microclimate, fix airborne pollutants and control storm water runoff (Rowntree and Nowak 1991; McPherson 1994; Srinidhi et al. 2007). Road side trees are more efficient to fix particulate matter than other trees and thus are critical in controlling point source pollution (Beckett et al. 2000). Short-rotation trees, i.e. eucalyptus (*Eucalyptus* spp.), poplar (*Populus* spp.), willows (*Salix* spp.) etc., are the most commonly employed trees for combating toxic chemicals and keep intrusion of pollutants away from the food chain. Other important trees are neem (*Azadirachta indica*), siris (*Albizia* spp.), kassod (*Cassia siamea*), silver oak (*Grevillea robusta*), etc.

TOFs are valuable vegetation C pools and plant biodiversity or microhabitat centres and are critical biodiversity hotspots (Kharal and Oli 2008; Oleyar et al. 2008; Jim and Chen 2009; Goddard et al. 2010). Isolated trees and urban woods have cultural and socioeconomic with aesthetic and recreational values as well (Herzog 2000; Tyrvainen et al. 2005; McDonnell et al. 2009; Grala et al. 2010; Buragohain et al. 2017). Their importance is recognized now due to biodiversity loss, desertification and poverty alleviation. These plantations have the potential to provide ecosystems services in the form of preventing soil erosion, removing air pollutants, modifying microclimate and soil properties, nutrient and water cycling, regulating water flows, biodiversity conservation, pest control, food or fodder and wood products (Baudry et al. 2000; Verma 2000; Chiesura 2004; Plieninger et al. 2004; Lumsden and Bennett 2005; Ahmed 2008; Bhagwat et al. 2008; Pandey 2008; Jim and Chen 2009; Manning et al. 2009; Bowler et al. 2010; Paletto and Chincarini 2012; Ament and Begley 2014).

5 Diversity, Biomass and C Stock of TOF

Deforestation and climate change has threatened extinction of about 8000 tree species, or 9% of the total global tree species (Singh et al. 2005; FAO 2010). Assessing plant diversity, its management and sustainable utilization requires proper documentation and quantification of qualitative and quantitative parameters of plant community (Jayanthi and Rajendran 2013; Padalia et al. 2014; Rajendra et al. 2014). The cultural, socioeconomic and ecological potential of TOFs was increasingly recognized after the mid-1970s with popularization of tree planting programmes mainly outside forests. These programmes were initiated mainly to meet the growing demands of wood and its products along with reclamation of problematic lands and maintaining ecological health (Nair 2012). Plantation of trees outside forest has been playing positive roles in C enhancement and biodiversity conservation (Leah et al. 2010). There are many reports on plant diversity and C stocks from areas outside forest especially from institutional landscapes (Dubal et al. 2013; Suryawanshi et al. 2014; Tiwari et al. 2014; Thankappan et al. 2015; Ranjan et al. 2016; Sharma and Ekka 2016).

These institutional areas generally have large vegetative areas supporting excellent tree cover which can counter balance C emissions through C storage and sequestration (Gavali and Shaikh 2016; Singh et al. 2017). C capture rates of these landscapes vary with locality factors and management practices (Rahman et al. 2015). Studies on vegetation cover from various universities and roadside plantations have documented species richness, dominant species, plant population and uses along with tree biomass and C storage (Baral et al. 2013; Rajendra et al. 2014; Suryawanshi et al. 2014; Tiwari et al. 2014; Rahman et al. 2015; Singh and Singh 2015; Gavali and Shaikh 2016; Sharma and Ekka 2016; Singh et al. 2017; Varma et al. 2017). Deforestation can be checked by extensive plantations of trees in such landscapes which will reduce the pressure on natural forest as these trees have the potential to meet the demand of wood and its products.

Studies also reported potential of orchards for C cycling, storage and net CO_2 flux (Sekikawa et al. 2002; Sofo et al. 2005). Orchards are similar to forests in terms of C sequestration during its initial years of establishment (Kerckhoffs and Reid 1997). Fruit tree-based plantations in southern Philippines were reported with a C storage of 112.18–203.62 tonne/ha (Janiola and Marin 2016). Fruit trees with diameter more than 30 cm in certain land use make large contribution to total C stock, and the above-ground components especially the fruit trees show the greatest amount of biomass and C (Janiola and Marin 2016). Orchards store C in their woody biomass, and it can also be viable strategy for climate change mitigation in an agricultural-dominant landscape. Forests and also TOFs in the developing countries coexist with smallholder farming systems including agroforestry, thus sustaining smallholders and diversity as well in an agricultural-dominant landscape (Gilmour 1997; Regmi 1998; Garforth et al. 1999; Baral et al. 2013). In addition, agroforestry systems are also efficient C sink in human-dominated landscapes especially in the urban areas (Bhagwat et al. 2008; Kharal and Oli 2008; Pandit et al. 2014). The major social and agroforestry tree species in India are eucalyptus, babool (*Acacia* *nilotica*), poplar, maharukh (*Ailanthus excelsa*), bakain (*Melia azedarach*), willows, shisham (*Dalbergia sissoo*), subabul (*Leucaena leucocephala*), gamhar (*Gmelina arborea*), beach oak (*Casuarina equisetifolia*) and white locust tree (*Robinia pseudoacacia*) grown on about eight million hectares area (Chauhan et al. 2008; Dogra and Chauhan 2016).

Commercial plantations of cacao (*Theobroma cacao*), tea (*Camellia sinensis*), rubber (*Hevea brasiliensis*) and others are reported to restore C stocks after replacement of the native forests (Sonwa et al. 2009; Oke and Olatiilu 2011; Norgrove and Hauser 2013; Dawoe et al. 2016). Forest and tree plantation have the capacity to store more C than other types of vegetation (Lasco et al. 2002). The long life span of these plantations makes them potential C sink under different ecosystems (Cotta et al. 2006; Ranasinghe and Silva 2007; Ranasinghe and Thimothias 2012). Controlling the present level of atmospheric CO_2 through REDD+ activities is the most viable and feasible strategy recommended by scientists and policymakers (Kanowski et al. 2011; Pandey et al. 2014; Rahman et al. 2015; Yadava et al. 2017), and trees outside forest efficiently can fulfil the objectives of this strategy (FAO 2006; Canadell et al. 2007; Lewis et al. 2009). This is because of positive relationship between species diversity and total biomass reported for these plantations (Singh and Singh 2015; Jhariya and Yadav 2018).

Globally there is very less or no information available on TOF resources that too are rarely integrated with national forest inventories. This is because till date there are no efficient methods of inventorying TOF resources, except for a recent analysis of existing data from available country-level TOF inventories by Schnell (2015). This analysis reported that in the analysed countries, TOFs contribute substantial amount of biomass and C to national stock. The result of this work will be a way forward from forest centred to all trees including TOFs that are valuable resource economically and ecologically. The analysis concluded that forest- and tree-based land uses of the studied countries varied extensively (Table 2).

Kyrgyzstan, Bangladesh and Lebanon were reported with lowest forest cover but has highest OL indicating land use category where TOF grows. In continuation of

Table 2 Area of TOFs and forest (Schnell 2015)

Country	Forest	Other wooded land	Other land
Bangladesh	8.1[a]	0.7	76.8
Cameroon	44.2	31.1	23.5
Costa Rica	46.7	1.8	43.1
The Gambia	26.6	10.9	52.1
Guatemala	37.3	16.3	42.6
Honduras	42.7	11.7	34.7
Kyrgyzstan	3.4	3.1	88.8
Lebanon	12.6	10.4	71.7
Nicaragua	25.0	17.0	48.8
Philippines	23.8	12.2	61.3
Zambia	63.9	7.4	19.7

[a]Figures are per cent of total land area

Table 2, Table 3 presents the live above-ground tree biomass of TOF of the countries in comparison to its forest (Schnell 2015).

Six countries were estimated with above 10% of their total tree biomass contributed by TOFs, and exceptionally high contribution (73.2%) was reported from Bangladesh (Schnell 2015). Significant amount of TOF (more than 80%) was found by Schnell (2015) growing on agricultural land (Table 4).

About 49 million trees on private land were reported from Gujarat state of India (GoG 1984). Farmlands in India were estimate with a total of 16,578 million trees (Kotwal and Bhattacharya 2000). National assessment of trees outside forest estimated between 24,000 and 25,000 million trees in India (Prasad et al. 2000). A total of 671,852 trees of teak (*Tectona grandis*), 483,876 trees of mango (*Mangifera indica*), 288,995 trees of shisham, 99,053 trees of neem, 36,748 trees of jackfruit (*Artocarpus heterophyllus*) and 68,909 tree of babool were inventoried into

Table 3 Estimated above-ground biomass (Schnell 2015)

	Forest		Other wooded land		Other land	
Country	AGB	PTTB	AGB	PTTB	AGB	PTTB
Bangladesh	33.4	26.7	7.7	0.5	9.6	72.8
Cameroon	159.9	89.4	14.6	5.8	16.4	4.9
Costa Rica	104.0	93.0	0.0	0.0	8.5	7.0
The Gambia	21.8	57.6	8.0	8.7	6.5	33.7
Guatemala	80.6	86.0	9.3	4.3	7.9	9.6
Honduras	79.2	91.0	9.3	2.9	6.5	6.0
Kyrgyzstan	30.2	84.2	1.0	2.6	0.2	13.2
Lebanon	24.6	51.6	4.6	7.9	3.4	40.5
Nicaragua	74.1	74.4	12.6	8.6	8.6	17.0
Philippines	82.6	69.0	10.5	4.5	12.3	26.5
Zambia	32.0	95.1	4.9	1.7	3.6	3.3

AGB above-ground biomass expressed as Mg ha^{-1}, *PTTB* proportion of total tree biomass of the studied country expressed as per cent

Table 4 Distribution of trees outside forests (values in %) (Schnell 2015)

Country	Natural	Agriculture	Settlement
Bangladesh	0.0	16.0	84.0
Cameroon	17.6	80.7	1.8
Costa Rica	0.0	96.4	3.6
The Gambia	17.3	82.1	0.5
Guatemala	10.9	83.2	5.9
Honduras	6.4	85.6	8.1
Kyrgyzstan	35.6	26.4	37.4
Lebanon	3.3	89.8	6.9
Nicaragua	2.7	93.5	3.8
Philippines	6.4	88.4	5.2
Zambia	30.0	62.7	7.3

different diameter classes for 66 villages of Gorakhpur district, Uttar Pradesh, in India (Srivastav et al. 2012). The total number of enumerated trees in this inventory for all six species with respect to diameter class is given in Table 5.

The study described above adopted a field survey method following stratified random sampling to select villages to enumerate number of trees. This study though classified tree based on diameter classes but did not monitor the biomass accumulated. Such studies are very laborious and time consuming. Biomass quantification is required to estimate C sequestration, so TOF inventory must include estimates of biomass and C storage in it. Stand-wise TOF inventory of Haryana, India, was made using finer spatial resolution of IRS-P6 LISS-IV satellite data (Singh and Chand 2012). Above-ground TOF biomass estimated for scattered trees was 1.26 tonnes/ha and for trees growing canal side was 91.5 tonnes/ha. The total above-ground TOF biomass and C stock estimated were 367.04 and 174.34 tonnes/ha, respectively (Table 6). The study shows that assessment of TOF biomass and its C accumulation can be successfully achieved by integrating GIS techniques, field data and high-spatial-resolution data of IRS-P6 LISS-IV for the larger areas.

Trees growing in agricultural landscapes improve productivity and create C sink as well. C accumulated by semiarid, subhumid, humid and temperate region of agroforestry land use system was 9, 21, 50 and 63 Mg C ha^{-1}, respectively (Schroeder 1994). In the next half a century or so, about 38 giga tonnes of C would be sequestered globally by afforestation/reforestation and agroforestry practices. About 20

Table 5 Diameter class-wise classification of tree species (Srivastav et al. 2012)

DC	M i	A i	D s	A h	A n	T g
0–50 cm	297,512	88,970	285,333	35,435	68,806	671,852
50–100 cm	186,364	10,083	3662	1313	103	0
Total no. of villages	9599	1965	5733	729	1367	13,328
Av. no. of trees/village	145	30	87	11	21	202
Total no. of trees	**483,876**	**99,053**	**288,995**	**36,748**	**68,909**	**671,852**

DC diameter class, M i *Mangifera indica*, A i *Azadirachta indica*, D s *Dalbergia sissoo,* A h *Artocarpus heterophyllus*, A n *Acacia nilotica*, T g *Tectona grandis*

Table 6 Tree density, biomass and C stock of TOF (Singh and Chand 2012)

TOFs	Number of trees[a]	Biomass[b]	C stock[b]
Linear		40.71	19.34
Road	171–1556	41.59	19.75
Rail	478–557	11.15	21.47
Canal	852–1440	45.21	5.30
Block	447–1200	18.24	8.66
Scattered		7.15	3.40
Urban	170–416	9.53	4.53
Rural	132–336	6.79	3.22
Agroforestry	64–164	6.33	3.10

[a]The figures are number of trees/ha
[b]The figures are in tonnes/ha

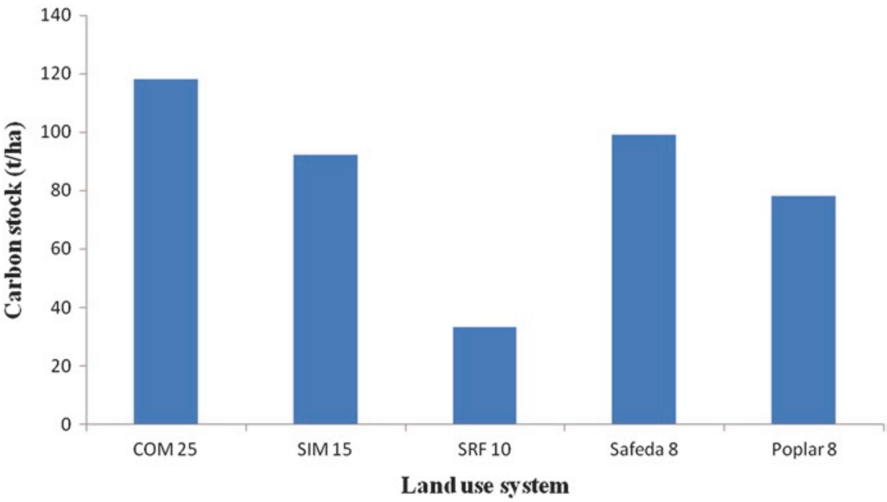

Fig. 1 Comparison of C stock in different land use systems. (Adopted: Dogra and Chauhan 2016) *Com25* complex agroforestry of 20–40-year rotation, *Sim15* simple agroforestry of 15-year rotation, *Safeda8* eucalyptus agroforestry of 8-year duration, *Poplar8* poplar agroforestry of 8-year rotation

Table 7 TOF biomass C stock in China (Guo et al. 2014)

Period	Woodlands	Shrubberies	Trees on non-forest land	Total
1977–1981	70 (8.5)[a]	335 (40.7)	418 (50.7)	823
1984–1988	74 (7.7)	350 (36.5)	535 (55.8)	960
1989–1993	69 (6.2)	374 (33.6)	672 (60.3)	1114
1994–1998	108 (9.0)	427 (35.7)	660 (55.2)	1195
1999–2003	97 (7.8)	512 (41.5)	625 (50.7)	1233
2004–2008	83 (6.2)	605 (45.2)	651 (48.6)	1339
1977–2008	12 (2.4)	270 (52.4)	234 (45.3)	516

Figures are expressed in terra grammes (1 Tg = 10^{12} g)
Figures in parentheses are per cent of total C stock

million tonnes of C were sequestered by farm forestry plantations in Uttar Pradesh (Dogra and Chauhan 2016). The potential of long-rotation species is higher, yet the potential of poplar and eucalyptus plantations at short rotation is substantial (Fig. 1).

In China, Guo et al. (2014) reported that total TOF biomass C stock increased by 62.7% from 1977 to 2008 (Table 7).

6 TOF Inventory

TOF needs to be assessed because of its production role and ecological functions and moreover for sustainable natural resource management (Singh and Chand 2012; Pujar et al. 2014). Information about TOF is felt necessary now for monitoring landscapes to formulate mitigation and adaptation strategies (Plieninger 2011; Schnell 2015) like in international agreements (UNCCD 1994; SCBD 2005; UNFCCC 2008). TOF inventories nationally will be helpful to design and formulate policies and legislation for its conservation and use. Locally such inventories will aid in management for its sustainable utilization and conservation of local forest (Schnell 2015). TOF inventories will be helpful for managing social, economic and ecological benefits in tropical countries (Guo et al. 2014) through planning and executing large-scale plantations outside forests. As of now, land-cover and land-use assessments and national forest inventories in some countries include biophysical and socioeconomic data of TOFs which can be used for monitoring and evaluating TOF.

Consequent of FAO's drive, many countries like India, Sweden, France, Switzerland, the USA, Great Britain and many more have included TOF in their National Forest Inventory (NFI) and National Forest Monitoring and Assessment (NFMA) (Barr and Gillespie 2000; Bélouard and Coulon 2002; Riemann 2003; Cumming et al. 2008; Brändli 2010; FAO 2012; Lister et al. 2012; de Foresta et al. 2013; Fridman et al. 2014; Tewari et al. 2014; Meena et al. 2017). Including TOF in the NFIs have clearly accounted huge amount of wood resources that otherwise remained unaccounted when TOFs were not included in the monitoring systems (Nowak 2002; Riemann 2003; Cumming et al. 2007; Nowak et al. 2008; Lister et al. 2012; Schnell et al. 2015). It was reported that in India, more than a quarter of growing stock of trees are from outside forests (Ahmed 2008; Pandey 2008; FSI 2011). Unfortunately, till date all kinds of TOFs are not included in NFIs and even not floated in public domain (de Foresta et al. 2013). Forest inventories do not often include TOF, and involvement of multi-stakeholders across sectors like agricultural, forest and urban is a major problem for monitoring TOF (Perry et al. 2009; de Foresta et al. 2013). Only two inventory systems, i.e. NFMA of the FAO (FAO 2012) and the Indian NFI (Tewari et al. 2014), monitor all types of TOFs. NFMA inventory is worked out in a single-phased sampling of few large units distributed uniformly in the study area (Schnell 2015). In contrast, Indian inventory is worked out in two-phased sampling with districts as first sampling units and TOFs in second phase sampling (Tewari et al. 2014).

TOF area covering larger than 1 ha area is captured by the resources survey satellite used for forest-cover assessment in present methodology, and area less than 1 ha is not (Dogra and Chauhan 2016). Thus, trees included in the tree cover constitute only a part of TOF, albeit a large part. Remote sensing can also be employed for TOF monitoring (Baffetta et al. 2011; Gregoire et al. 2011; Lam et al. 2011; Ståhl et al. 2011; Tewari et al. 2014; Schnell 2015), for example, coarse, medium and high spatial resolution (Foschi and Smith 1997; Lee and Lathrop 2005; Small and Lu 2006; Thornton et al. 2006, 2007; Walker and Briggs 2007; Walton 2008; Perry et al. 2009; Tansey et al. 2009; Fehrmann et al. 2014; Pujar et al. 2014; Schumacher and Nord-Larsen 2014; Zomer et al. 2014; Dadhich and Meena 2014). These remote sensing studies found out that traditional forest inventories underestimated in accounting the tree resources and established that globally in 43% farm land is covered with more than 10% tree canopy. TOFs are monitored simply with both unsupervised and supervised classification methods (Kumar et al. 2008) along with image-derived metrics for C stocks (Myeong et al. 2006). Some studies also used manual image interpretation based on only sampling (Hansen 1985; Fensham and Fairfax 2003; Fehrmann et al. 2014). TOF can remotely be studied on object-based classification also with 80–90% accuracies as metropolitan regions (Walker and Briggs 2007; Ouma and Tateishi 2008; Taubenbock et al. 2010), agricultural landscapes (Sheeren et al. 2009; Tansey et al. 2009; Liknes et al. 2010), scattered landscapes, suburban areas (Zhou and Troy 2008) and savannahs (Boggs 2010). In addition, active remote sensing technique like ALS was also employed to monitor TOFs (Rutzinger et al. 2008; Straub et al. 2008; Eysn et al. 2012). LiDAR data was reported effective to develop models for estimating TOF volume and biomass (Lefsky and McHale 2008).

TOF biomass and C models were also developed using allometric equations. These models however were not used very widely (Chave et al. 2005; Zhou et al. 2007, 2014; Nilsson 2008; McHale et al. 2009; Kuyah et al. 2012; Yoon et al. 2013). It was reported that allometry of trees and specific gravity of wood in the same species vary for TOFs and forest trees (Zhou et al. 2011). Specific gravity of TOF is higher in highly tapered trunk woods with more biomass allocated to crown than forest trees of same species. Moreover, TOFs are shorter than forest trees of same species (Harja et al. 2012). This is because these trees are more exposed to solar radiation, wind and agricultural residuals. Bamboo and palms are included in TOFs as they contribute substantially to national biomass stock; some crude estimation methods like Brown (1997) was used (Schnell 2015).

7 Livelihood Importance

Interaction of climate with farming practices and society has developed many tree-based farming practices (Gibbon and Schultz 1989; Gilmour and Nurse 1991; Kharal and Oli 2008; Painkra et al. 2016). Many trees and shrubs with multiuses are grown or allowed to grow in and around homesteads, farmland and other land uses. These trees are socially and culturally associated and hence, considered as integral component of livelihoods especially for rural areas in terms of food, medicines, fodder, timber, constructions, domestic energy and source of income along with maintaining ecological health (Regmi and Garforth 2010; Sayer et al. 2013; Sihag et al. 2015; Painkra et al. 2016). Trees on farmland are an integral part of the farming system and has the potential to meet the need of growing population by sustaining crop agriculture and livestock, production of commodities for exchange and as a form of energy and diverse tree products for sustaining rural livelihoods through income generation (Chakravarty et al. 2017a, b). Traditional Nepalese alder (*Alnus nepalensis*)-based agroforestry system with large cardamom crop is most suitable and offers comparative advantage over other livelihood options in Sikkim Himalayas where farmers are earning about one lakh rupees INR/ha/yr which is double remunerative than popular maize-potato cultivation, also providing much needed fodder and fire wood to the households along with other environmental services like resource conservation (Avasthe et al. 2011; Meena and Yadav 2014).

TOFs satisfy over two-thirds of the domestic energy demand in the Asia-Pacific countries in form of firewood and charcoal (FAO 2001b). TOFs are also known as ‘trees that nourish’ as poor and landless people derive essential products from them (Halavatau 1995) and are planted in African and Asian countries for producing food and other non-wood forest products. In Africa, Asia and Latin America, these trees are source of savings for the future in terms of their timber value, thus a sort of piggybank (FAO 2001b; Negreros-Castillo and Mize 2002). In these countries TOFs satisfy about 80% of the needs of the wood-based industries (Chave et al. 2004) generating income for the people. Trees and tree-based products provide jobs and products as well (Biswas 2006). Trees contribute towards sustainable livelihoods of rural poor but also have a special ethical role for Indians (Pandey 2007). TOFs are also an important source of feed for livestock in tropical countries, thus ensuring livelihood for the many who are primarily relying on animal husbandry for their well-being. In the Sudano-Sahelian Africa, three-fourths of 10,000 TOFs species in agricultural land use satisfies half of the fodder need of the livestock (FAO 2001b).

8 Problems of Growing TOFs

Many constraints are reported to slow down the growth and development of TOFs especially the farm and agroforestry to its full potential (Dogra and Chauhan 2016). These are:

- Long gestation period and market uncertainties.
- Not supported by financial institutions and extension services.
- No regulated markets.
- Unavailable improved planting material.
- Limited choice of profitable planting models.
- No separate laws and regulations for TOFs, guided by Forest Act.
- No regulated price mechanism.
- Unfavourable export and import policy.
- Trees on farm may compete with food crops for space, sunlight, moisture and nutrient reducing yield and can damage crops during its harvesting.
- Trees are host to insects and birds.
- Allelopathic effect by trees (eucalyptus) on crops.
- Rapid regeneration may take over the entire land like raimuniya (*Lantana camara*) and subabul.
- Labour intensive which may sometime cause scarcity in farm activities.
- Longer gestation period to realize income.
- TOFs may compete with crops especially where land is scarce.

9 Conclusion

TOF can be pivotal for balancing earth's CO_2 by fixing the C in its biomass and mitigate climate change. These plantations improve the microclimate and act as a valuable vegetation C pool and plant biodiversity centres. There are many species in TOF which give its inputs in mitigating environmental pollution, checking dust flow and noise pollution and helping to reduce atmospheric CO_2 and provide benefits to global climate. TOF is a remedial measure and alternative opportunity for controlling the present level of atmospheric CO_2 through increasing afforestation, preventing biodiversity loss and maintaining the bio-resources and ecological balance. TOF can be very helpful to bring back harmony to urban environment by providing ecosystem services. In recognizing the magnitude of the TOF resources, efficient inventorying is vital to formulate suitable national policy for its sustainable management.

10 Recommendations and Future Research

TOFs can efficiently fix atmospheric CO_2 in its woody biomass and fulfil the timber demands but need to be managed and monitored properly for which local, regional or national inventory is required. TOF is becoming a part of existing national forest inventory systems. Only the Indian and FAO inventories are including trees growing in all land uses. However, harmonization in analysing and reporting is still not advanced like in forestry sector creating difficulties locating the results from TOF assessments. Efforts are also needed by other countries to include all types of tree in their national inventories. Specific allometric biomass models need to be formulated and developed for the TOFs as uncertainties exist while applying forest-specific models. If forest models are to be used, they should be assessed for adequacy and validity. Terrestrial laser scanning effectively estimates tree volume without cutting or uprooting the tree, thus reducing manual work. Remote sensing is an effective tool in vegetation analysis though remotely sensed data is also an effective method to monitor and assist field inventories. However, more research is required to study model-assisted estimation and spatially balanced sampling methods for effective TOF inventories (Schnell 2015). Reconstruction techniques that verify the applicability of summary statistics for describing TOFs should be efficiently developed to generate artificial tree populations with varied spatial properties (Schnell 2015). TOF sampling simulation will use wall-to-wall remotely sensed data like two-phase sampling strategies.

The depletion of forest resources and increasing demands for forest products especially by the forest-dependent rural people have widened the gap between demand and supply in developing countries of the tropical world. This has warranted finding alternative options that will increase the supply of forest products to support rural livelihoods which now has become a fundamental concern for policymakers and planners. TOFs can be a forerunner as an alternative option for rural livelihoods and biodiversity conservation. Several national government policies which emphasize the need to initiate TOF in form of community and agroforestry programmes have empowered the NGOs to play a pivotal role in its popularizing for addressing the livelihood needs of poor households (Chakravarty et al. 2017a, b). Most of the households in rural tropics are not self-sufficient in food production as most of them either are landless or small and marginal land holders. The practice of growing TOFs as agroforestry on these small land holdings or village commons can serve as a source of food and some cash. Trees on farmland can also contribute towards the subsistence needs of the households in terms of fuel wood, fodder, fruits/food and local medicine and sometime hard-earned cash by selling the excess left after their use. Strengthening of self-help groups especially the women's savings groups in parallel with the development of TOFs programme may ensure a sustainable source of funds for group members' income-generating activities. Converting women farmer groups into savings and credit cooperative can represent the common interests of a larger proportion and can be a means to market TOF products in an organized way. Such institutions not only increase income but also strengthen the group capacity to mobilize community resources.

Forests in India cannot fulfil the timber and industrial needs on a sustainable basis due to insufficient growing stock, poor growth rates, inadequate financial and technical inputs and serious biotic pressures. The TOFs have to supplement the demand but need support from institutional research. A way forward lies in improving productivity of degraded forests and encouraging farm and agroforestry by encouraging and ensuring more and more TOF plantation through quality planting material. TOF in general and agroforestry in particular is a viable option for C sequestration and subsequent C trading, under the clean development mechanism (CDM). Potential of TOF under CDM can be increased with improved clonal seedlings, and area under it can be extended without affecting agricultural production. Availability of superior planting materials of eucalyptus, gamhar, maharukh and bakain under TOF in general and agroforestry in particular will substitute pulp-producing species, thus making TOF a viable CDM option. In addition, Dogra and Chauhan (2016) enlisted the following issues which need to be addressed on priority:

- Strengthening tree-based and farm forestry research and extension, i.e. increased support to R&D projects
- Strengthening extension and financial support system including digital support
- Nursery registration and certification to facilitate availability of quality planting stock
- Formalizing stakeholders
- Friendly harvest and transit laws and regulations for TOFs
- Agro-based status to wood-/timber-based cottage industries on value addition

Climate change places new and more challenging demands on maintaining sustainability requiring investments for enhancing research to offset the negative effects of climate change. Thus, partnerships with other national systems and international centres along with investment in laboratory scientists and infrastructure are needed.

Strong extension linkages among the stakeholders is essential for transferring technology, facilitating interaction, building capacity among farmers and encouraging farmers to form their own networks. This requires strengthening the global efforts for collecting and disseminating spatial data on tree resources through remote sensing. Statistical programmes should be also increased and encouraged through funding. International development agencies and national governments should encourage and support community participation in plantation programme planning and execution through technical, financial and capacity-building of local communities.

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