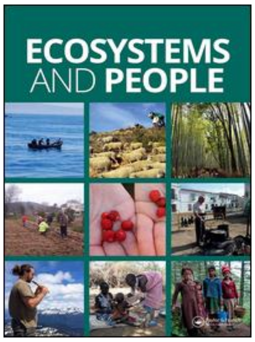

Taylor & Francis
Taylor & Francis Group

International Journal of Biodiversity Science, Ecosystem Services & Management

ISSN: 2151-3732 (Print) 2151-3740 (Online) Journal homepage: www.tandfonline.com/journals/tbsm21

Ecosystem services of native trees: experiences from two traditional agroforestry systems in Karnataka, Southern India

B. Dhanya, B.N. Sathish, Syam Viswanath & Seema Purushothaman

To cite this article: B. Dhanya, B.N. Sathish, Syam Viswanath & Seema Purushothaman (2014) Ecosystem services of native trees: experiences from two traditional agroforestry systems in Karnataka, Southern India, International Journal of Biodiversity Science, Ecosystem Services & Management, 10:2, 101-111, DOI: 10.1080/21513732.2014.918057

To link to this article: https://doi.org/10.1080/21513732.2014.918057

Published online: 04 Jun 2014.

International Journal of Biodiversity Science, Ecosystem Services & Management, 2014
Vol. 10, No. 2, 101–111, http://dx.doi.org/10.1080/21513732.2014.918057

Ecosystem services of native trees: experiences from two traditional agroforestry systems in Karnataka, Southern India

B. Dhanya[a,*], B.N. Sathish[b], Syam Viswanath[a] and Seema Purushothaman[c]

[a]*Tree Improvement and Propagation Division, Institute of Wood Science and Technology, Malleswaram, Bangalore, Karnataka 560003, India;* [b]*Department of Forest Products and Utilisation, College of Forestry, Ponnampet, Kodagu District, Karnataka 571216, India;* [c]*Centre for Environment and Development, Ashoka Trust for Research in Ecology and the Environment, Royal Enclave, Srirampura, Jakkur, Bangalore, Karnataka 560064, India*

Agroforestry systems with native trees provide an interesting instance wherein provisional, regulatory, habitat, and ancillary ecosystem services are simultaneously exploited, but are least recognized. In the present study, the potential of native trees to optimize different ecosystem services is compared, versus introduced species in two traditional agroforestry systems in Karnataka state, Southern India: (a) coffee-based shaded perennial systems in Kodagu district of the tropical humid zone; and (b) dryland agro-ecosystems with *Ficus* trees in Mandya district of the semi-arid zone. Ecosystem services were assessed based on collected field data and farmers' perceptions. Compared with exotic species, native trees provide more direct and indirect benefits, irrespective of differences in type, location, scope, and management of these systems. The role of native trees in supporting the overall sustainability of agroforestry systems is highlighted in the study. Moreover, it is emphasized that the long-term sustenance of traditional agroforestry systems depends on appreciation of the indirect and intangible benefits that are provided.

Keywords: coffee agroforestry; *Ficus*; indigenous trees; exotic species; trade-offs

1. Introduction

Agroforestry is increasingly viewed as providing ecosystem services, environmental benefits, and economic commodities as part of multifunctional working landscapes (Jose 2009). Agroforestry systems (AFS) render (1) provisioning of food, energy, and fodder; (2) regulatory services including microclimate modification, erosion control, mitigation of desertification, carbon sequestration, and pest control; and (3) supporting services, namely soil fertility improvement, biodiversity conservation, and pollination (Sileshi et al. 2007). Native tree-based AFS have especially played a pivotal role in sustaining rural livelihoods through multiple products and services. Some well-documented examples of such systems across the world include *Faidherbia albida* (Delile) A Chev. with millets in the Sahel region of Africa (World Agroforestry Centre 2009), the *dehesa* system of scattered oak trees in rangelands of the Mediterranean region (Joffre et al. 1988), and parkland systems of *Vitellaria paradoxa* CF Gaertn. (karité) and *Parkia biglobosa* (Jacq.) R.Br. ex G. Don (néré) trees in semi-arid sub-Saharan Africa (Kessler 1992). Excellent examples of native tree systems in India are *Prosopis cineraria* L. Druce with millets in Rajasthan (Shankarnarayan et al. 1987) and *Acacia nilotica* (L.) Willd. ex Delile trees in rice paddy fields in central India (Viswanath et al. 2000). In central America, plantations of native species like *Calophyllum brasiliense* Cambess, *Vochysia guatemalensis* D. Sm., *Jacaranda copaia* (Aubl.), *Terminalia amazonia* (Gmell.), and *Dipteryx panamensis* (Pittier) were found to have valuable social and economic functions, including the provision of forest products, carbon sequestration, and recuperation of biodiversity (Montagnini et al. 2005). Although the specific utility of trees in these systems varies across zones, ease of propagation, potential for diversification of farm revenues, and reduction of poverty through multiple woody and non-woody products, besides valuable environmental services, are common features of all such systems.

The traditional ecological knowledge and appreciation of the multiple uses and services of indigenous trees is gradually eroding, with demographic and socio-economic changes in rural societies all over the world. In central Sudan, for instance, the traditional bush fallow systems for gum arabic production have been declining since the mid-1960s, primarily due to decrease in the area of fallow and fluctuating prices of gum arabic (Elmqvist et al. 2005). Such transitions are largely in response to the perceived changes in direct monetary benefits from trees, while their diverse ecosystem services, though essential for rural communities, are seldom accounted for. In India pre-1988 forest policies promoted wide-scale plantations of exotic tree species such as *Populus deltoids* W. Bartram ex Marshall, *Acacia* sp., *Eucalyptus* spp., *Leucaena leucocephala* (Lam.) de Wit, and *Prosopis juliflora* (Sw.) DC. to meet the increasing industrial and fuel wood demands of the public (Bajaj 1997). Total value estimations based

*Corresponding author. Email: krupaias@gmail.com
Present address for B. Dhanya: Department of Environmental Studies, College of Agriculture, University of Agricultural Sciences, PB No. 29, Raichur, Karnataka-584102, India.

solely on monetary returns from wood in short-rotation exotic plantations led to undervaluing of native trees with a longer life span. For example, in a comparison between exotic *Eucalyptus tereticornis* Sm. and native *Dalbergia sissoo* Roxb. plantations in northwestern India, it was found that, 8 years' total monetary value of provisioning services (timber, fuel, fodder, eucalypt oil, and ash) and other ecosystem services (phytodiversity, soil nutrient content, and nutrient return through litter) was 1.6-fold greater in *Eucalyptus* than in *Dalbergia* plantations, chiefly because of timber, while at 19–21 years of age, *Dalbergia* supported 2.7-fold more total benefits than *Eucalyptus* (Sangha & Jalota 2005). The potential of indigenous species to provide a sustained flow of diverse products in the long term and render services that maintain the productivity of farming systems and reduce dependence on external inputs is often ignored. The dominant view is that native trees cater to regulatory services and other environmental benefits at the cost of provisioning services or economic yield. Although widely recognized to foster biodiversity conservation, it is less clear that native tree systems can increase the production of agricultural goods and services as much as AFS, which is dominated by domesticated species (Mc Ginty 2012)

In any assessment framework for ecosystem services, trade-offs between provisioning and regulatory services are very common (Elmqvist et al. 2011). In general, land-use decisions intended to maximize a single output such as agricultural or timber production are likely to generate an accompanying decline in the provision of other ecosystem services (Polasky et al. 2011). In the present study, however, we argue that native tree-based AFS can create a win-win situation where a sustained flow of provisioning services can be maintained without compromising other ecosystem services, taking the examples of two traditional AFS in Karnataka State, South India: (a) coffee-based shaded perennial systems in Kodagu district of the tropical humid zone, and (b) dryland agro-ecosystems with *Ficus* trees in Mandya district of the semi-arid zone. We examine whether indigenous tree species fare better than exotic ones in reconciling provisioning and non-provisioning services in agricultural landscapes. The two AFS selected offer excellent study systems for comparing the performance of native species *vis-à-vis* exotic ones in different categories of ecosystem services, as these have been undergoing rapid transformations, with indigenous species being increasingly replaced by introduced species. In view of the prominent role played by AFS in maintaining biodiversity, this article follows the Economics of Ecosystems and Biodiversity (TEEB) typology of ecosystem services in which the category of supporting services for Millennium Ecosystem Assessment is replaced by habitat services (TEEB 2010).

2. Materials and methods

This section provides a detailed description of the location, components, and characteristics of the two AFS studied and the methodology used for assessing the different ecosystem services they deliver.

2.1. *Coffee agroforestry systems (CAFS) in Kodagu, Karnataka*

Kodagu (11° 56′ – 12° 52′ N and 75° 22′ – 76° 11′ E), located in the hill zone of Karnataka State of southern India, is one of the most densely forested districts not only in the state, but also in the entire country (see location map in Figure 1). Eighty-one percent of the 4102 square kilometers of Kodagu is forested (Forest Survey of India 2009). Kodagu is a micro-hotspot of biodiversity within the larger Western Ghats, one of the 25 hotspots and eight hottest hotspots of biodiversity in world (Mittermeier et al. 2005). Coffee plantations cover 33% of the land area of Kodagu (Boreux et al. 2013), making it the largest coffee-producing district in India.

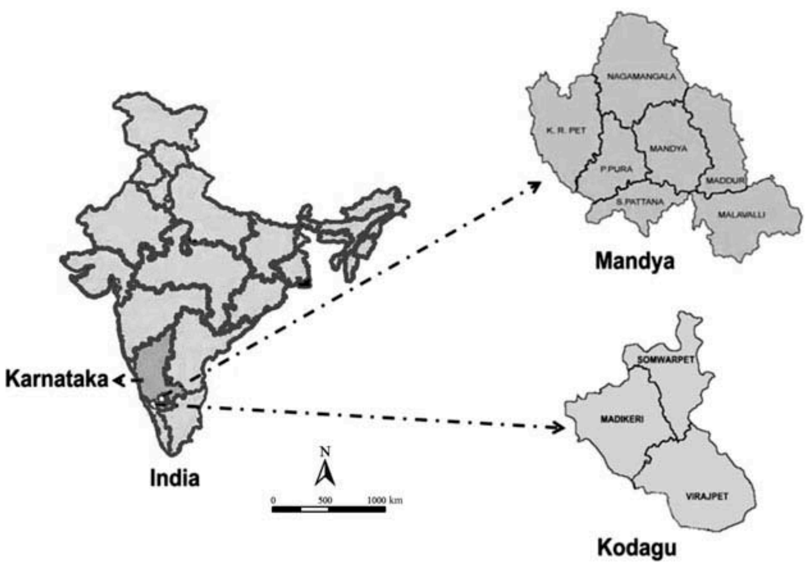

Figure 1. Location map of Kodagu and Mandya districts in Karnataka, South India.

In the last decade, due to increases in the price of coffee, the area under coffee cultivation has increased at the cost of natural forested ecosystems. While some consider coffee plantations as a looming threat to forested ecosystems, it is also true that they harbor shade trees, and thus help in the conservation of biodiversity. The CAFS of Kodagu, under the prevailing unique land tenure systems, have high potential in conserving biodiversity. Common shade trees found in CAFS include indigenous trees like *Aporusa lindleyana* (Wt.) Baill, *Artocarpus heterophyllus* Lam., *Dalbergia latifolia* Roxb., *Artocarpus hirsutus* Lam., *Lagestroemia lanceolata* Wt., *Terminalia bellirica* (Gaetn.) Roxb, *Acrocarpus fraxinifolius* Wt. & Arn., *Olea dioica* Roxb., and *Grevia tilifolia* Vahl. Popular exotic shade species include *Grevillea robusta* A. Cunn. ex R. Br. and *Acacia mangium* Wild. (Sathish 2005; Boreux et al. 2013). Coffee AFS were initially developed with *Coffea arabica* L. species, which notably requires shade, but this has now been replaced by *Coffea canophora* Pierre ex Froehner (robusta coffee), which is higher yielding and less shade demanding. Recent coffee plantations of robusta coffee are shaded by only one or two exotic species, or have no shade trees at all, thus altering the floristic composition of the system (Depommier 2003). *Grevillea robusta* (silver oak), a fast-growing exotic species, has become the most popular shade tree choice due to its high suitability as trellis for pepper vines, the common secondary crop in CAFS. Besides, this species' fast growth rate facilitates early timber harvesting and does not require prior government permission for harvesting (Garcia et al. 2010). At present a variety of shade regimes can be recognized based on the canopy cover of CAFS, viz. canopy with native trees, canopy with exotic trees, a mixture of both native and exotic trees, and plantations with very few shade trees. Traditional native tree-shaded coffee agro-ecosystems generally harbor higher plant, arthropod, bird, amphibian, and reptile diversity and high structural complexity (Perfecto et al. 1997; Moguel & Toledo 1999). Previous studies in Kodagu have shown that native tree-based CAFS are highly biodiverse, with a Shannon's diversity index value of 2.44 in moist deciduous zones, while purely exotic tree-based CAFS had a value of only 0.50 and CAFS with a mixture of exotic and native had the highest value of 2.94. Tree species richness was 60, 17, and 78 ha^{-1}, respectively, for native tree-based, exotic tree-based, and mixed systems (Sathish 2005).

2.2. Ficus *agroforestry systems (FAS) in Mandya, Karnataka*

In Mandya district (see location map in Figure 1) of the southern dry agroclimatic zone of Karnataka, trees of the genus *Ficus* are abundant in rainfed farmlands in association with field crops of millet, maize, pulses, and oilseeds. *Ficus benghalensis* L. is the major species of *Ficus* grown in these agroforestry systems, followed by *Ficus religiosa* L., *Ficus amplissima* Sm., *Ficus virens* Aiton, *Ficus racemosa* L., and *Ficus mysorensis* var. *pubescens* (Roth) (Dhanya, Viswanath, Purushothaman 2012). These trees have traditionally provided farmers with direct benefits including fodder, timber, fuel wood, and shade, in addition to crucial environmental services including soil and water conservation. Recently, however, a declining trend in planting of *Ficus* has been noted in Mandya due to increased availability of assured irrigation water supplies, promotion of fast-growing exotic trees, and spread of intensive monocultures (Dhanya 2011).

2.3. *Methodology*

In the case study on CAFS of Kodagu, we attempted to determine whether native shade trees provide more tangible benefits to farmers through provisioning services including timber, non-timber products, coffee yield, and coffee quality, along with their proven habitat services. The study was carried out in CAFS growing robusta coffee in Virajpet Taluk, Kodagu during the period 2007–2008. CAFS were categorized into different groups based on the shade tree composition, viz. canopy with only native trees, canopy with only exotic tree species, mainly silver oak, canopy with mixture of both native and exotic trees, and canopy with very few shade trees. Ten CAFs were randomly sampled from each shade regime and the following data were collected.

2.3.1. *Multiple uses of shade trees*

The probable additional uses of each shade tree species were documented by interviewing estate owners using a pre-categorized questionnaire which provided four major categories of use (timber, fuel wood, edible fruits, and medicinal value as additional uses) identified from preliminary field visits and interactions with planters. Any other use value in the opinion of the land owner was considered under 'other uses'.

2.3.2. *Stumpage value of shade trees*

Economic value of timber was estimated in terms of stumpage value, but only for trees of diameter above 20 cm at breast height:

$$\text{Stumpage value} = \text{Price of timber} \times \text{Volume of the tree}$$

(Muthappa et al. 2001)

The average market price over the previous three years at Karnataka Forest Department timber depot was considered, while volume was calculated from observations on girth and total tree height for tree species in each CAFS using the formula: Volume = $\pi r^2 h$, where r is the radius at breast height and h is the height of the tree.

2.3.3. *Coffee yield*

Data on total yield from each CAFS for the previous 10 years was collected from the estate owner. Mean yield and coefficient of variation in yield over the 10 years were computed for each shade regime for comparison.

2.3.4. Reproductive traits of coffee plants

Observations were recorded on the reproductive characters of coffee plants, such as total number of flowering nodes per branch, number of coffee fruits per node, and weight of the coffee beans.

2.3.5. Coffee quality

Fruits collected from coffee plants growing under a few common native and exotic shade tree species were assessed for both external and internal quality traits. External characters evaluated included defects in the beans (presence of unwashed, unripe, bleached, insect-damaged, or faded beans), the smell of the beans, and visual appraisal graded as fair average quality (FAQ), FAQ+, FAQ−, etc. Internal quality (beverage quality) was evaluated based on parameters such as body, neutrality, softness, cleanliness of cup, additional cup attributes, and overall impression, leading to a cup rating of FAQ, FAQ+, FAQ−, etc. Coffee quality was analyzed at the Coffee Board of India laboratory in Bangalore, Karnataka.

In the case study on *Ficus* agroforestry in Mandya, we conducted a detailed primary survey to garner information on the ecological and socio-economic aspects of this system. We also attempted to compare these native species with the common, fast-growing exotic tree species in Mandya under different categories of ecosystem services. Primary surveys were conducted using a two-stage sampling procedure in which villages with high abundance of *Ficus* trees were selected at 1% sampling intensity from seven taluks of Mandya district, with six to nine *Ficus* growers sampled from each village (total sample size of 147). Pre-tested semi-structured questionnaires were administered for collecting information on farmers' perception of provisioning services from this AFS. Regulatory services (provision of clean air, soil quality improvement, soil moisture conservation, soil erosion mitigation), habitat services (supporting biodiversity), and cultural services (aesthetic value, recreational value by providing space for games and entertainment, role in facilitating social interaction, religious importance/tree worship, and cultural heritage value indicating the use of tree parts for various functions and festivals) were pictorially represented and farmers were asked to rank the trees which they found useful in providing each of these services. Effect of trees on soil fertility, compost usage and crop yield, biodiversity services from trees (pest control by birds, soil enrichment through bird excreta, etc.), and general trends in the planting of *Ficus* trees were explored in detail.

Statistical parameters such as averages and percentages were computed to summarize data collected on tree species. Wherever possible, benefits from trees were quantified and monetized based on farmers' responses. Farmers' perception of environmental and cultural services was assessed using a composite index developed with the score for the tree species based on the ranking given by farmers for that species in regard to each service (score of 1 for rank 1, 0.5 for rank 2, 0.25 for rank 3, etc.), followed by summing of the scores among the farmers for each environmental and cultural service listed in the questionnaire schedule. These indices were then compared between *Ficus* and other tree species grown on farmlands.

3. Results and discussion

In the CAFS of Kodagu, native trees were found to deliver substantial provisioning services (fruits, timber, fodder, fuel wood, and medicinal uses) contrary to the popular perception of such species being beneficial for regulatory or habitat services only. The study showed that indigenous trees in CAFS provided multiple benefits in comparison with exotic trees, with up to four different uses documented for the same species, while for exotic species two or three uses could be documented at most (Figure 2). Timber was the most preferred additional use of shade trees, followed by fuel wood and fruits; medicinal values were relatively less acknowledged and, whenever reported, this benefit was derived mostly from native species. Stumpage value was also markedly high for native trees (mean value Rs. 5.88 lakhs ha^{-1}) compared with exotic species (Rs. 1.26 lakhs ha^{-1}) in CAFS. Coffee yield data over the last 10 years under different shade management regimes showed that, while larger native tree cover did not result in the highest coffee yield, there was consistency in yield from CAFS with a higher proportion of native tree species (Figure 3). The mean coffee yield of CAFS with a majority of native trees was 1488 kg ha^{-1}, which was better than the mean yield of plantations with very few shade trees, while yield variation was the lowest for native tree-based CAFS (coefficient of variation −0.045) (Figure 4). Canopy with silver oak shade trees and a mixture of exotic and native species had a comparable mean yield, but this fluctuated widely in silver oak-shaded plantations. CAFS with very few shade trees had the lowest mean yield, again with wider fluctuations across the years. In the long term, the productivity of such systems may be further reduced by soil erosion and degradation in the absence of tree cover (Davidson 2005). The yield consistency of native

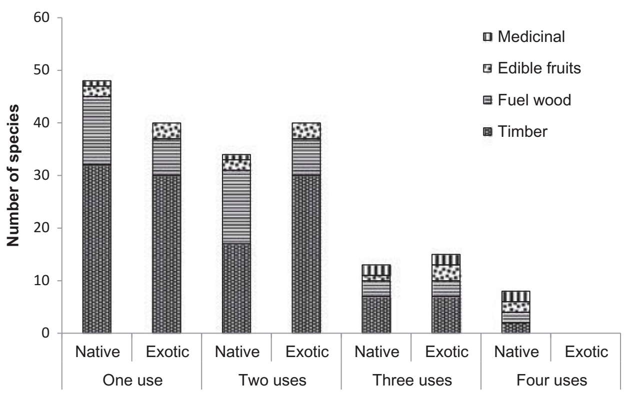

Figure 2. Multiple additional uses of different shade tree species.

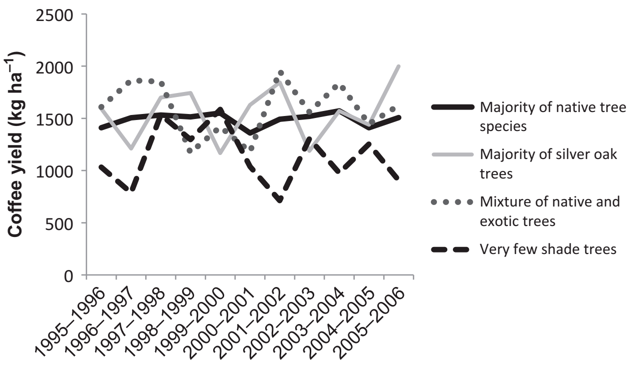

Figure 3. Coffee yield under different shade managements over 10 productive years (1996–2006).

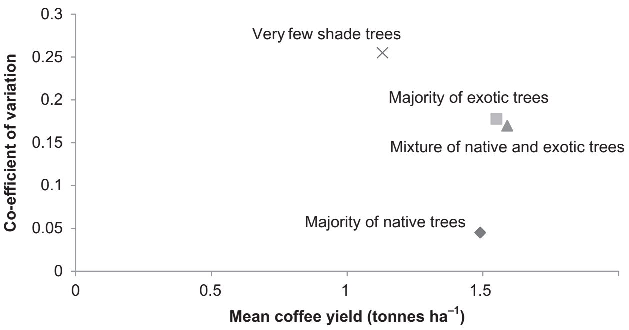

Figure 4. Yield variation in coffee under different shade managements.

tree-shaded CAFS could be due to the high moisture retention capacity and adequate supply of organic matter from the leaf litter of native tree species, which maintains productivity (Sathish & Kushalappa 2008). Yield consistency may also be attributed to the abundance and long-term survival of the pollinator bee *Apis dorsata* Fabricius in native tree-shaded CAFS, owing to the availability of floral resources throughout the year (Jha & Vandermeer 2009; Krishnan 2011; Boreux et al. 2013). Though native tree-shaded systems might not produce the largest quantity of coffee, they had the highest total production including food, fuel wood, and timber.

Coffee grown under native shade trees also exhibited better reproductive traits including the number of nodes per plant, number of coffee fruits per node, and bean density, and these parameters were lowest in CAFS with very few shade trees (Table 1). However this cannot be generalized as a regular trend as sometimes coffee with exotic shade trees can also show better reproductive features – as indicated by higher yield in some years in Figure 3. Coffee quality assessed in terms of external characters revealed that crops grown under *Dalbergia latifolia* and *Grevellia robusta* were of FAQ while plants grown under *Achras zapota, Artocarpus heterophyllus*, and *Lagerstromia microcarpa* produced beans below FAQ by external visual appraisal (Table 2). Internal quality traits in terms of softness, cleanliness of the cup, and additional attributes were superior for coffee grown under *A. heterophyllus* and *D. latifolia*, with a hint of fruity flavor in the case of *A. heterophyllus* (Table 2). The poorest cupping quality was found in coffee plants grown under *L. microcarpa*.

Summarizing the results (Table 3), it may be concluded that coffee grown under the native *Dalbergia* species is of superior quality in both external characters and beverage quality. In the case of *Artocarpus*, although external characters are below FAQ, cupping quality is fairly good while this was the reverse in the case of *Grevillea robusta*, which produces beans superior in external appearance but of poor beverage quality. *Achras zapota* and *L. microcarpa* produce coffee that scores poorly in both external characters and cupping quality. Thus native trees like *D. latifolia* and *A. heterophyllus* contribute to the quality and consistency of coffee production, probably due to, among others, consistent pollination services, organic matter inputs through litter fall, and higher nutrient turnover due to faster decomposition. For Indian coffee production which is ranked only sixth worldwide, this is of profound relevance as the competitive advantage rests on quality rather than quantity. Native species-based systems also alleviate the pressure on natural forests by providing substantial amounts of high-value timber and non-timber products. The subsistence products integrated within coffee production reduce the risk associated with boom–bust cycles in international coffee markets (Davidson 2005). The value of harvest from such CAFS can further be boosted by 'shade, fair trade or biodiversity friendly' certification and selling at a higher price (Gobbi 2000). Indigenous shade trees thus could maximize both provisioning (timber, non-timber products, and coffee yield and quality) and habitat services (biodiversity) of CAFS.

The study on FAS of Mandya also revealed the potential of these native tree species to render multiple products and ecosystem services that support rural livelihoods, as detailed below.

Table 1. Reproductive traits of coffee plants under different shade regimes.

Trait	Canopy with majority of native tree species	Canopy with mixture of native and exotic trees	Canopy with majority of silver oak trees	Canopy with very few shade trees
Mean number of nodes	10.330	9.600	9.000	9.000
Mean number of beans/node	24.670	20.200	21.000	18.000
Bean weight (g)	0.080	0.076	0.075	0.072

Table 2. External and beverage quality traits of coffee grown under different shade tree species.

Traits	Shade tree species				
	Grevillea robusta	*Achras zapota*	*Artocarpus heterophyllus*	*Lagerstroemia microcarpa*	*Dalbergia latifolia*
I. External traits					
1. Defects (% by weight)					
a. Unwashed beans	3	4	13	18	6
b. Unripe beans	1	1	0	0	0
c. Presence of bleached beans	12	0	0	0	0
d. Insect-damaged beans	0	0	1	0.5	1
e. Faded beans	0	3	2	15	4
2. Smell	Normal	Normal	Normal	Normal	Normal
3. Visual award	FAQ	Slightly below FAQ	FAQ–	FAQ–	FAQ
II. Beverage quality traits					
1. Body	Fair	Fair+ to good	Fair	Fair+	Fair+
2. Neutrality	–	Fairly neutral	Neutral	–	Neutral
3. Softness	–	–	Fairly soft	–	Soft
4. Cleanliness of cup	Unclean woody/ stale	Traces of spice notes	Clean	Unclean	Clean
5. Additional cup attributes	Light bitterness	Light bitterness	Hint of fruity flavor	Light bitterness	Light acidity
6. Overall impression	An unclean cup	An unclean cup	A pleasant and flavorful cup	An unclean cup	A pleasant cup
7. Cup rating	FAQ–	FAQ–	FAQ+	Falling off	FAQ+

Table 3. Grouping of shade trees based on external and internal characters of coffee beans.

		External characters	
		FAQ/FAQ+	FAQ–
Beverage quality	FAQ/ FAQ+	*Dalbergia latifolia*	*Artocarpus heterophyllus*
	FAQ–	*Grevillea robusta*	*Achras zapota* *Lagerstroemia microcarpa*

3.1. *Provisioning services*

Ficus trees were primarily grown as a source of fodder for livestock, especially sheep and goats, by 37% of respondents. Other important benefits from these trees were shade (26%), fuel wood for household uses and brick making (14%), and lumber (11%). Shade is a highly valued service in the hot climate of Mandya and during the summer months, when even a 0.5°C reduction in temperature may provide considerable relief, tree canopies reduce soil temperature by 5.85°C and air temperature by around 1.33°C and facilitate resting of livestock and farmers under tree shade during agricultural operations (Dhanya, Viswanath, Purushothaman, Suneeta 2012). Nearly 5% of farmers retain *Ficus* trees to sell them in case of unforeseen financial contingencies or crop failures. *Ficus* trees thus insure farmer livelihoods against the uncertainties of a rainfall-dependent agricultural regime.

3.2. *Regulatory and habitat services*

Ficus trees are frequently preferred by farmers for the regulatory and habitat services these provide (Figure 5). Other native species such as *Pongamia pinnata* (L.) Pierre. and *Tamarindus indica* L. are also preferred by farmers for certain service benefits, while exotic species such as *Casuarina* and *Eucalyptus* score nil or very low for most environmental services evaluated. Among the various services rendered by *Ficus*, soil quality enhancement through litter fall had the maximum aggregate score across respondents (137.25), followed by habitat services (129.00) and prevention of soil erosion (107.00). Litter fall from *Ficus* reduced compost usage by an average of three cartloads per acre in farmers' perception, which translated to a monetary value of Rs.[1] 1093 ha^{-1} at market rates of compost in Mandya in 2008. Litter fall estimation and chemical analysis of litter showed that *F. benghalensis* at a density of 16 trees ha^{-1} produced 3.5 Mg ha^{-1} of litter annually which, on decomposition, returns 37 kg ha^{-1} N, 8.58 kg ha^{-1} P, and 20.42 kg ha^{-1} K to soil leading to an avoided expenditure on compost of Rs. 1823.63 ha^{-1} $year^{-1}$ in dryland farming systems (Dhanya et al. 2013a). Exotic species such as *Eucalyptus hybrid* produce 41 kg ha^{-1} N, 0.5 kg ha^{-1} P, and 20 kg ha^{-1} K (Kushalapa 1985), and *Casuarina equisetifolia* produces N, P, and K at 12.63, 0.56, and 4.21 kg ha^{-1}, respectively (Saravanan et al. 2006), at much higher plant densities. The slow rate of *Ficus* litter decomposition results in a mulch effect that aids soil moisture conservation (Dhanya et al. 2013a).

An average of 30% reduction in crop yield has been reported by farmers in FAS. This, when monetized in

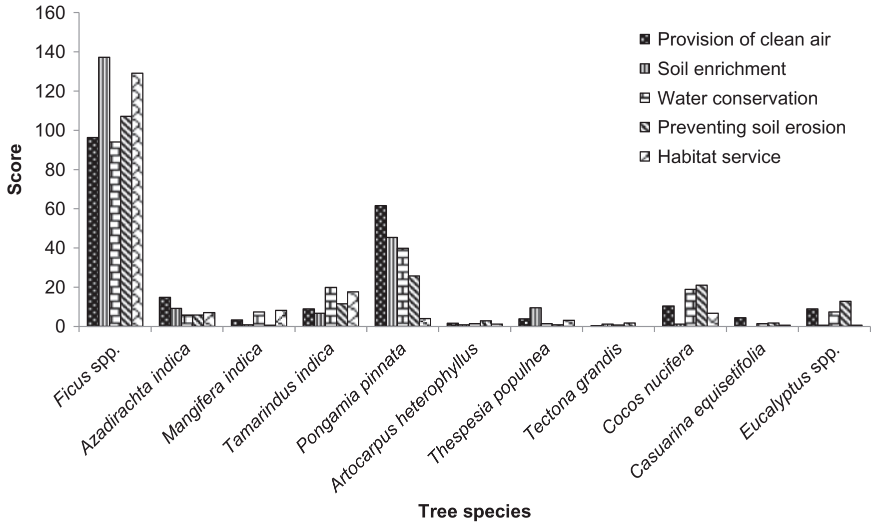

Figure 5. Environmental services from different tree species according to farmers' perception in Mandya, Karnataka.

terms of crop yield of finger millet, amounted to Rs. 4463 ha^{-1} annually. Respondents felt that this loss could be compensated by various direct benefits from trees and also could be minimized through proper pruning. Yield estimation studies of finger millet grown under *F. benghalensis*, however, showed the loss to be much less, at 20.48% ha^{-1} for grain and 13.73% ha^{-1} for straw, equivalent to Rs. 3603 ha^{-1} (Dhanya et al. 2013b).

Habitat services of *Ficus* trees in providing food and shelter to birds, insects, and small mammals were also highly appreciated by farmers. Birds such as the coppersmith barbet (*Megalaima haemacephala* Muller), common myna (*Acridothers tristis* L.), and red-whiskered bulbul (*Pycnonotus jocosus* L.) and small mammals such as bats help to propagate *Ficus* species through frugivory and seed dispersal; *F. religiosa* is exclusively propagated in this way. For farmers, this mutualism between birds and trees provide collateral benefits including control of insect pests on crops and improving soil fertility through excreta. Birds such as the black ibis (*Pseudibis papillosa* Temminck) commonly spotted in FAS are effective pest control agents in millets (Soni 2008), though harmful effects by bird herbivory were reported by 17% of respondents.

3.3. Cultural services

Ficus scored highly for most social and cultural values services, except for cultural heritage value (use for various social and religious functions and festivals), which was higher for *Mangifera indica* L. and *Pongamia pinnata* (Figure 6). As in the case of environmental services, exotics also scored low for cultural values. *Ficus* trees are highly appreciated for providing platforms for social

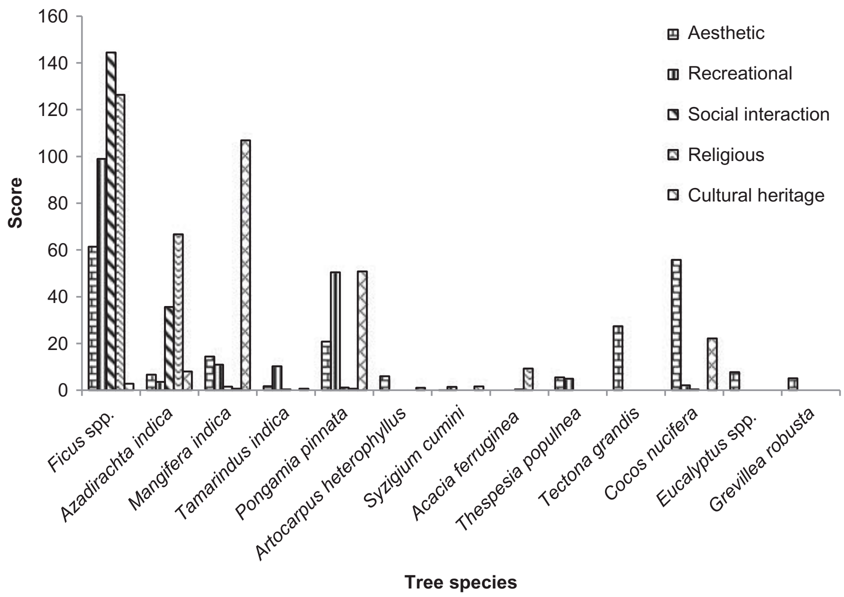

Figure 6. Cultural services of different tree species according to farmers' perception in Mandya, Karnataka.

interaction such as village meetings (aggregate score of 144.50), religious values (score of 126.25), and recreational values (score of 99). Such values are mostly attributed to trees near temples or near common meeting places in villages.

The study thus highlighted the role of *Ficus* in providing multiple products and environmental and cultural services for the rural farming communities of Mandya. Compared with the exotic trees species currently being promoted through government schemes in Mandya, these native species augment nutrient availability to crops, save nutrient input costs to the farmer, and conserve the physical resource base, contributing to the sustainability of rainfed farming systems even in the absence of external inputs.

4. Lessons from the case studies

The two agroforestry systems discussed here are entirely different in features such as type, zone, scope, and management. Whereas the CAFS of the humid zone are shaded perennial systems that are intensively managed for commercial production, the FAS of the semi-arid zone are annual cropping systems with scattered trees and are traditionally subsistence oriented. The transformations occurring in these systems are also different in nature, with CAFS witnessing a decline in native shade trees and their replacement by an exotic species (silver oak), as the main variety of coffee has been replaced with one of greater productivity and no shade requirement, while in *Ficus* agroforestry, the main crop is also being replaced with the intensification of the system and a consequent decrease in tree numbers maintained. However, assessment of various ecosystem services from the field data and farmers' perceptions demonstrates that in comparison with introduced species, indigenous trees in both these systems provide multiple direct products and sustained crop yield to farmers, as well as maintain valuable environmental services including biodiversity conservation, soil enrichment, and microclimate amelioration. Exotic trees in AFS do not maintain the same quantity and quality of biodiversity and environmental services as native species (Peeters et al. 2003).

Trade-offs between profitability and non-provisioning ecosystem services have been extensively studied in CAFS in different parts of the world and the results are highly contradictory. Some studies reported significant increase in yields in the absence of shade (Campanha et al. 2004, daMatta 2004), while others found no effect of shade on yield (Romero-AlvaradoY et al. 2002) or maximum yields at intermediate levels (35–65%) of canopy cover (Perfecto et al. 2005). In Kodagu, Abraham et al. (2013) found higher berry weights and yield in the native shade regime in comparison with silver oak-shaded coffee. However, most of these studies rely on only berry yield or weight as an indicator of the impact of shade, without considering the quality traits, and thus fail to capture the financial profits accrued to the farmer from both niche market products and the additional use benefits of shade trees. Many of them also do not involve long-term monitoring of production to assess the sustainability of shade management practices.

In several well-studied cases of traditional AFS with scattered trees, analysis of the impact of native tree cover on provisioning services shows mixed results. *Faidherbia albida* was reported to increase the yield of maize by more than 100% in Malawi (Saka et al. 1994) and 76% in Ethiopia (Poschen 1986), and that of sorghum (*Sorghum bicolor* (L.) Moench) by 36% in Ethiopia (Poschen 1986) and 125% in Burkina Faso (Depommier et al. 1992). On the other hand, in Haryana, India, *A. nilotica* had a markedly negative effect with a reduction of 40–60% in wheat yield and *D. sissoo* reduced yield by 4% to 30% (Pandey 2007). Even in such cases, the contribution of non-provisioning ecosystem services such as improved soil fertility, soil water retention, and microclimate amelioration to reducing the input costs in these AFS, thereby offsetting the loss of provisioning services, is not universally appreciated. It is generally accepted that the trade-offs between economic profitability and other ecosystem services are context specific and depend on local conditions and management practices (Cerdán et al. 2012). In both the contexts which the present study had analyzed, synergistic relationships between native trees and component crops increasing long-term productivity were revealed, despite the contrasting nature of the study systems.

Native tree systems rank very low in the list of recommendations of developmental agencies, and development approaches to AFS often shy away from including indigenous trees because these species are not well known and their management is not well researched (Viswanath et al. 2000; Mc Ginty 2012). From the farmer's point of view, fear of crop yield reduction is a common reason for avoiding native trees in AFS, especially in small landholdings (Dhanya 2011). However, the present study showed that native species can enhance the quality of the product and maintain yield consistency, and can also reduce external input cost leading to higher net profits for the farmer in spite of lower volume of production. More in-depth scientific investigation and better communications on the effect of different native tree species on provisioning services is hence required to allay the unwarranted apprehensions of farmers.

Forging linkages with carbon markets could be an added incentive for native tree growing in AFS. Though the present study has not looked into the carbon sequestration aspect, tree volume measurements for stumpage value estimation in CAFS indicate higher biomass and carbon storage potential in native species compared with exotics. Similar trends have been illustrated by Kasel and Bennet (2007) and Omoro (2012), who demonstrated higher biomass and soil carbon and floristic diversity in indigenous forests compared with exotic plantations. Enhanced diversity of tree stands increases the resilience of ecosystem carbon stocks and reduces the vulnerability of livelihoods (Epple 2013).

The present study suggests a need to carry out total value assessments of agricultural systems by considering both tangible and intangible benefits for designing appropriate policy measures. Focusing on single provisioning ecosystem services in isolation from regulatory services has frequently resulted in policy failures. A case in point is the European biofuel policy that has resulted in management of ecosystems for a single provisioning service – the production of biofuel, completely ignoring other services of importance (Elmqvist et al. 2011). It is now realized, from a number of studies, that novel agricultural techniques and management practices by adjusting methods and intensities of use can result in a reduction of ecosystem service trade-offs, even as crop yields increase (Pretty et al. 2006). The present analysis of native tree-based AFS clearly supports this view.

5. Conclusions

In general, management decisions in AFS are made by farmers to maintain crop productivity rather than ecosystem services. Knowledge of both the ecosystem services provided by trees in AFS and the trade-offs or synergies between trees and crop productivity in specific contexts must be imparted to farmers through effective rural extension services. The present study amply demonstrates that traditional AFS with indigenous species can emerge as a promising alternative in mitigating ecosystem service trade-offs. The need of the hour is therefore to recognize such traditional systems through proper policies and incentive schemes, including payments for ecosystem services, reforming environmentally harmful subsidies, or creating new markets for sustainably produced goods and ecosystem services. In the production-oriented CAFS of Kodagu, given the high-income consumers and niche markets for coffee, market-mediated compensation mechanisms such as certification schemes could be effective. In the FAS of Mandya that do not deliver such high-value commercial products, government-mediated incentives including distribution of saplings and fencing materials and awareness creation on ecosystem services could go a long way toward sustaining these keystone native species.

Acknowledgments

The research on *Ficus* agroforestry was undertaken with financial assistance from the University Grants Commission, New Delhi (Senior Research Fellowship to the first author) and the Indian Council of Forestry Research and Education, Dehra Dun. The Director, Institute of Wood Science and Technology, Bangalore is gratefully acknowledged for logistic support to the study. We thank coffee estate owners in Kodagu and farmer respondents in Mandya for their cooperation during the study. Anonymous reviewers who have helped to improve the manuscript are also sincerely thanked.

Note

1. 1 US$ = ~Rs.60.

References

Abraham R, Purushothaman S, Devy S. 2013. Conservation and coffee production: creating synergies in Kodagu, Karnataka. In: Purushothamn S, Abraham S, editors. Livelihood strategies in southern India: conservation and poverty reduction in forest fringes. New Delhi (India): Springer India; p. 89–108.

Bajaj M. 1997. Policy failure and forestry sector: a critique of public policy and governmental intervention in forestry sector. In: Agarwal A, editor. The challenge of the balance: environmental economics in India. Proceedings of the national environment and economic meeting. New Delhi (India): Centre for Science and Environment; p. 207–216.

Boreux V, Krishnan S, Cheppudira KG, Ghazoul J. 2013. Impact of forest fragments on bee visits and fruit set in rain-fed and irrigated coffee agro-forests. Agric Ecosyst Environ. 172:42–48. doi:10.1016/j.agee.2012.05.003

Campanha M, Santos R, de Freitas G, Prieto Martinez H, Garcia S, Finger F. 2004. Growth and yield of coffee plants in agroforestry and monoculture systems in Minas Gerais, Brazil. Agrofor Syst. 63:75–82. doi:10.1023/B:AGFO.0000049435.22512.2d

Cerdán CR, Rebolledo MCG, Soto G, Rapidel B, Sinclair, Sinclair FL. 2012. Local knowledge of impacts of tree cover on ecosystem services in smallholder coffee production systems. Agric Syst. 110:119–130. doi:10.1016/j.agsy.2012.03.014

daMatta F. 2004. Ecophysiological constraints on the production of shaded and unshaded coffee: a review. Field Crop Res. 86:99–114.

Davidson S. 2005. Shade coffee agro-ecosystems in Mexico: a synopsis of the environmental services and socio-economic considerations. J Sustain For. 2:81–95.

Depommier D. 2003. The tree behind the forest: ecological and economic importance of traditional agroforestry systems and multiple uses of trees in India. Trop Ecol. 44:63–71.

Depommier D, Janodet E, Oliver R. 1992. *Faidheribia albida* parks and their influence on soils and crops at Watinoma, Burkina Faso. In: Vandenbeldt RJ, editor. *Faidherbia albida* in the West African semi-arid tropics: proceedings of a workshop; 1991 Apr 22–26, Niamey, Niger. Patancheru (India): International Crops Research Institute for the Semi-Arid Tropics and Nairobi. Kenya: International Centre for Research in Agroforestry; p. 111–115.

Dhanya B. 2011. Integrated study of a *Ficus* based traditional agroforestry system in Mandya district, Karnataka [PhD thesis]. Dehradun (India): Forest Research Institute Deemed University.

Dhanya B, Viswanath S, Purushothaman S. 2012. *Ficus* trees in rainfed agricultural systems of Karnataka, southern India: an analysis of structure, benefits and farmers' perceptions. J Trop Agric. 50:59–62.

Dhanya B, Viswanath S, Purushothaman S. 2013a. Litter decomposition and nutrient dynamics of decomposing litter of *Ficus benghalensis* L. in traditional agroforestry systems of Karnataka, southern India. ISRN For. [Internet]. [cited 2013 Jul 25]. Available from: http://dx.doi.org/10.1155/2013/524679

Dhanya B, Viswanath S, Purushothaman S. 2013b. Crop yield reduction in *Ficus* agroforestry systems of Karnataka, southern India: perceptions and realities. Agroecol Sustainable Food Syst. 37:727–735. doi:10.1080/21683565.2012.757266

Dhanya B, Viswanath S, Purushothaman S, Suneeta B. 2012. Microclimate modification by *Ficus* trees in rainfed agroforestry systems of Mandya District, Karanataka. My For. 48:223–229.

[TEEB] The Economics of Ecosystems and Biodiversity. 2010. The economics of ecosystems and biodiversity: ecological and economic foundations. Kumar P, editor. London (UK): Earthscan.

Elmqvist B, Olsson L, Elamin EM, Warren A. 2005. A traditional agroforestry system under threat: an analysis of the gum arabic market and cultivation in the Sudan. Agrofor Syst. 64:217–218.

Elmqvist T, Tuvendal M, Krishnaswamy J, Hylander K. 2011. Managing trade-offs in ecosystem services. Paper no. 4. Ecosystem services economics (ESE) working paper series. Nairobi (Kenya): Division of Environmental Policy Implementation. The United Nations Environment Programme.

Epple C. 2013. Managing ecosystems for multiple environmental services and biodiversity in the context of climate change. Paper presented in the UNFCCC Workshop on Technical and Scientific Aspects of Ecosystems with High-Carbon Reservoirs not Covered by other Agenda Items under the Convention; Bonn, Switzerland; 2013 Oct 24–25.

Forest Survey of India. 2009. State of the forest report [Internet]. Dehradun (India): FSI; [cited 2013 Feb 2]. Available from: http://www.fsi.nic.in/sfr_2009

Garcia CA, Bhagwat SA, Ghazoul J, Nath CD, Nanaya KM, Kushalappa CG, Raghuramulu Y, Nasi R, Vaast P. 2010. Biodiversity conservation in agricultural landscapes: challenges and opportunities of coffee agroforests in the Western Ghats, India. Conserv Biol. 24:479–488. doi:10.1111/j.1523-1739.2009.01386.x

Gobbi JA. 2000. Is biodiversity-friendly coffee financially viable? An analysis of five different coffee production systems in western El Salvador. Ecol Econ. 33:267–281. doi:10.1016/S0921-8009(99)00147-0

Jha S, Vandermeer JH. 2009. Contrasting bee foraging in response to resource scale and local habitat management. Oikos. 118:1174–1180. doi:10.1111/j.1600-0706.2009.17523.x

Joffre R, Vacher J, Llanos CDL, Long G. 1988. The dehesa: an agrosilvopastoral system of the Mediterranean region with special reference to the Sierra Morena area of Spain. Agrofor Syst. 6:71–96. doi:10.1007/BF02344747

Jose S. 2009. Agroforestry for ecosystem services and environmental benefits: an overview. Agrofor Syst. 76:1–10. doi:10.1007/s10457-009-9229-7

Kasel S, Bennet LT. 2007. Land-use history, forest conversions, and soil organic carbon in pine plantations and native forests of south eastern Australia. Geoderma. 137:401–413. doi:10.1016/j.geoderma.2006.09.002

Kessler JJ. 1992. The influence of karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) trees on sorghum production in Burkina Faso. Agrofor Syst. 17:97–118. doi:10.1007/BF00053116

Krishnan S. 2011. An ecosystem services approach to conservation of sacred forests. Perspect. 3:5.

Kushalapa KA. 1985. Productivity of Mysore Gum (Eucalyptus hybrid) plantations in different ecosystems in Karnataka [PhD thesis]. Mysore (India): University of Mysore.

Mc Ginty MM. 2012. Native forest tree conservation in tropical agroforests: case study of cacao farms of Atlantic forest of southern Bahia, Brazil [PhD thesis]. New York (NY). Columbia University.

Mittermeier RA, Gil PR, Hoffmann M, Pilgrim JD, Brooks TM, Mittermeier CG, Lamoreux JL, da Fonseca GAB. 2005. Hotspots revisited: earth's biologically richest and most endangered terrestrial ecoregions. Mexico City (Mexico): CEMEX, Conservation International.

Moguel P, Toledo V. 1999. Biodiversity conservation in traditional coffee systems of Mexico. Conserv Biol. 13:11–21. doi:10.1046/j.1523-1739.1999.97153.x

Montagnini F, Cusack D, Petiti B, Kanninen M. 2005. Environmental services of native tree plantations and agroforestry systems in Central America. In: Montagnini F, editor. Environmental services of agroforestry systems. 1st ed. New York (NY): The Haworth Press; p. 51–68.

Muthappa PP, Chengappa PG, Prakash TN. 2001. A resource economic study on tree diversity in coffee based plantations in the Western Ghats region of Karnataka. Report of the team of excellence in natural resource economics. Bangalore (India): University of Agricultural Sciences.

Omoro LMA. 2012. Impacts of indigenous and exotic tree species on ecosystem services: case study on the mountain cloud forests of Taita Hills, Kenya [PhD thesis]. Helsinki (Finland): University of Helsinki.

Pandey DN. 2007. Multifunctional agroforestry systems in India. Curr Sci. 92:455–463.

Peeters LYK, Soto-Pinto L, Perales H, Montoya G, Ishiki M. 2003. Coffee production, timber and firewood in traditional and *Inga* shaded plantations in southern Mexico. Agric Ecosyst Environ. 95:481–493. doi:10.1016/S0167-8809(02)00204-9

Perfecto I, Vandermeer J, Hanson P, Carti´n V. 1997. Arthropod diversity loss and the transformation of a tropical agro-ecosystem. Biodivers Conserv. 6:935–945. doi:10.1023/A:1018359429106

Perfecto I, Vandermeer J, Mas A, Soto-Pinto L. 2005. Biodiversity, yield, and shade coffee certification. Ecol Econ. 54:435–446. doi:10.1016/j.ecolecon.2004.10.009

Polasky S, Nelson E, Pennington D, Johnson KA. 2011. The impact of land-use change on ecosystem services, biodiversity and returns to landowners: a case study in the state of Minnesota. Environ Resour Econ. 48:219–242. doi:10.1007/s10640-010-9407-0

Poschen P. 1986. An evaluation of the *Acacia albida*-based agroforestry practices in the Hararghe highlands of eastern Ethiopia. Agrofor Syst. 4:129–143. doi:10.1007/BF00141545

Pretty JN, Noble AD, Bossio D, Dixon J, Hine RE, Penning de Vries FWT, Morison JIL. 2006. Resource-conserving agriculture increases yields in developing countries. Environ Sci Technol. 40:1114–1119. doi:10.1021/es051670d

Romero-AlvaradoY Y, Soto-Pinto L, García-Barrios L, Barrera-Gaytán JF. 2002. Coffee yields and soil nutrients under the shades of *Inga* sp. vs. multiple species in Chiapas, Mexico. Agrofor Syst. 54:215–224. doi:10.1023/A:1016013730154

Saka AR, Bunderson WT, Itimu OA, Phombeya HSK, Mbekeani Y. 1994. The effects of *Acacia albida* on soils and maize grain yields under smallholder farm conditions in Malawi. For Ecol Manage. 64:217–230. doi:10.1016/0378-1127(94)90296-8

Sangha KK, Jalota RK. 2005. Value of ecological services of exotic *Eucalyptus tereticornis* and native *Dalbergia sissoo* tree plantations of north-western India. Conserv Soc. 3:92–109.

Saravanan S, Subramanian V, Buvaneswaran C, Rajagopal K, Manivachagam P, George M. 2006. Nutrient cycling in a five year old *Casuarina equisetifolia* based agroforestry system. My For. 42:13–18.

Sathish BN. 2005. Assessment of tree diversity in coffee plantations under different land tenure systems of Kodagu [Master's thesis]. Bangalore (India): University of Agricultural Sciences.

Sathish BN, Kushalappa CG. 2008. Impacts of the canopy cover on the productivity and quality of shade grown coffee in Kodagu district, south India. Paper presented at: International Symposium on Multi-storied Agroforestry Systems with Perennial Crops; Costa Rica.

Shankarnarayan KA, Harsh LN, Kathju S. 1987. Agroforestry in the arid zones of India. Agrofor Syst. 5:69–88. doi:10.1007/BF00046414

Sileshi G, Akinnifesi FK, Ajayi OC, Chakeredza S, Kaonga M, Matakala PW. 2007. Contributions of agroforestry to ecosystem services in the Miombo eco-region of eastern and southern Africa. Afr J Environ Sci Technol. 1:68–80.

Soni KC. 2008. Study on the population, foraging, roosting and breeding activities of the Black ibis/Red napped ibis (*Pseudibis papillosa*) inhabiting the arid zone of Rajasthan [PhD thesis] Ajmer, Rajasthan (India): M. D. S. University.

Viswanath S, Nair PKR, Kaushik PK, Prakasam U. 2000. *Acacia nilotica* trees in rice fields: a traditional agroforestry system in central India. Agrofor Syst. 50:157–177. doi:10.1023/A:1006486912126

World Agroforestry Centre. 2009. Creating an evergreen agriculture in Africa for food security and environmental resilience. Nairobi (Kenya): World Agroforestry Centre.