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Quantification and valuation of ecosystem services in tree based land use system

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Abstract: Inevitability and importance of trees or perennial species could be appreciated only when the ecosystem services offered by tree species are quantified and evaluated effectively. No doubt, economic evaluation is a difficult task as monetization of many services is difficult, yet it appears to provide a sound base for comparison of benefits and for decision making. It is, therefore, attempted here to enhance our understanding of the true value of market and non-market benefits of tree-based land use systems. Further, frameworks are discussed to quantify and monetize ecosystem services for agroforestry systems. Though, more than one valuation approaches are possible for every ecosystem service, limitation is that each providing a different value it would be difficult to select the most appropriate approach and model in the given context and the availability of required data.

Key words: Ecosystem services, Energetics, Tree based intercropping, Total economic value

Agricultural systems including tree based land use systems, historically, have been managed, above all, for the production of food and fiber; however, agricultural landscapes can provide a wide range of goods and services to society termed as 'Ecosystem Services'(ES). Ecosystem services are those functions of ecosystems - including agroecosystems - that are useful to humans or support human well-being (Daily, 1997 and Kremen, 2005). People have been aware of these critical services rendered by ecosystem long before the dawn of industrial agriculture (Rapidel *et al.,* 2011). However, with growing importance to food products and economical benefits thereof the focus was shifted away from the ecological services rendered by tree based land use systems. Of late, the changing climate, the pollution of atmosphere and ground water, loss or endangering of many biospecies and habitat turning unsparing for productive living renewed our interest to understand agroecology, agroecosystems and ecosystem services.

In the past two decades, work at the interface of ecology and economics to characterize, value, and manage ecosystem services has supported a paradigm shift in how society thinks about ecosystems and human relationships to them. As both major providers and major beneficiaries of ecosystem services, agricultural landscapes and the people within them are at the centre of this shift (Garbach *et al.,* 2014). Agroecosystems both provide and rely on ecosystem services to sustain production of food, fiber, and other harvestable goods. Ecosystem interactions are considered to be the complex interactions that occur between the different components of the ecosystem through the energy flow and material cycle, most importantly these functions produce various goods and services valued for ecological, sociological and economical benefits (Daily, 2009). Generally, ecosystem services are the benefits people obtain from ecosystems which in turn directly contribute to human well-being and economic wealth. These benefits can be direct/on-farm (*e.g.,* for farmers) or indirect, tangible or intangible and can be provided locally and/or at broader scales (Garbach *et al.,* 2014). Unless these are emphasized, the agroforestry systems would be relegated to backstage.

Why ecosystem services need to be studied?

Over the past 50 years, humans have changed ecosystems more rapidly and extensively in any comparable period of time in the human history mainly to meet out the rapidly growing demands for food, water, timber, fuel and other basic needs. To feed the need more and more land was converted into croplands which led into unprecedented changes in structure and function of ecosystem (Anon., 2005). However, the changes that have been brought into ecosystems have contributed to substantial net gains in human well-being and economic development, but these gains have been achieved at growing costs in the form of the degradation of many ecosystem services, increased risks of non linear changes, and the exacerbation of poverty for some groups of people.

The Millennium Ecosystem Assessment measured 24 different ecosystem services out of which 15 services are being degraded or unsustainably used which accounts approximately 60 per cent of the ecosystem as consequences of agriculture management and other human activities. The change in structure and function also caused non linear change in biogeochemical cycle. The human activity has increased the flow of biological available nitrogen and phosphorus in terrestrial ecosystem and over 60 per cent of increase in atmospheric CO_2 which have led to eutrophication, collapse of fisheries, loss of biodiversity and climate change (Anon., 2005).

The ecosystem services are the main stay of economy for many of the industries such as food, timber, fisheries and marine resources. Agriculture is a major contributor in many of the low income developing countries where it accounts for 24 per cent of GDP and 22 per cent of total labour force of the globe (Anon., 2005). More critically dryland agriculture which is closely linked with ecosystem services accounts for 41 per cent of the total earth surface and around more than 2 billion population inhabit them, 90 per cent of whom are from developing countries. People living in dryland have low income and higher mortality. Similar is the status of tribes depending on forests for livelihood.

Poverty and low human development index are linked with poor ecosystem services mainly because 70 per cent of the total rural population is highly dependent on the ecosystem services for their livelihood and basic needs such as quality water. Half the urban population in Africa, Asia, Latin America, and the Caribbean suffers from one or more diseases associated with inadequate water and sanitation. The declining state of capture fisheries is reducing an inexpensive source of protein in developing countries. Per capita fish consumption in developing countries, excluding China, declined between 1985 and 1997. Desertification affects the livelihoods of millions of people, including a large portion of the poor in dry lands. Water scarcity affects roughly 1-2 billion people worldwide. It is imperative that the ecosystem services are either expensive or impossible to replace with any technological solutions.

Ecosystem services from tree based land use system

Agricultural intensification to feed the ever-growing population of the world has raised environmental concerns such as soil erosion, water pollution, and degradation of biological diversity in agricultural landscapes. In view of these ecological problems related to conventional agriculture, a pressing question is how to simultaneously increase agricultural production while conserving a healthy and well-functioning life support system. Agroforestry has long been seen as an option to work at the interface of these global challenges (Nair and Garrity, 2012). Studies have shown that this land use has the potential to maintain agricultural productivity, conserve biodiversity in agricultural landscapes as well as help mitigate climate change impacts (Udawatta and Jose, 2012; Aertsens *et al.,* 2013). Despite the demonstrated contribution of agroforestry in producing these ecological services, economic analyses on non-market services, as well as on the potential trade-offs between bundles of services, are either little or non-existent. Some studies provide a general account of the role of agroforestry systems in providing ecosystem services (Jose, 2009), while others provide frameworks for cost benefit analysis of tropical agroforestry systems (Alavalapati and Mercer, 2004). However, a comprehensive analytical framework for quantifying and valuing ES is missing in the context of tree based land use systems.

Integrating trees in the agricultural land could be good option for sustainable land use management and maximizing the provision of ecosystem goods and services. As these land use systems provide economical benefits which include the production of marketable goods such as timber, fuel wood, fodder, food etc., and ecological benefits commonly associated with tree based land use systems are potential to enhance soil fertility, improve water quality, enhance biodiversity, increase aesthetic and carbon sequestration. Ecological benefits may have higher value than traditionally produced marketable goods but are not taken into account by the farmers because they are currently not traded in the market (Nair, 2011). It has been well recognized that these services and benefits provided by agroforestry practices occur over a range of spatial and temporal scales (Izac, 2003; Table 1). Many of these environmental externalities derived at the farm scale or landscape scale are enjoyed by society at larger regional or global scales.

Table 1. Spatial scales of various ecosystem services provided by tree based land use system

Ecosystem service	Spatial Scale Farm/ Local	Landscape / Regional	Global
Net primary production	√		
Pest control	√		
Pollination/seed dispersal	√		
Soil enrichment	√		
Soil stabilization/erosion control	√		
Clean water	√		
Flood mitigation	√	√	
Clean air	√	√	
Carbon sequestration	√	√	√
Biodiversity	√	√	√
Aesthetic/cultural	√	√	√

Why valuation of ecosystem services are necessary?

Assessment of the monetary value of ecosystem services play a multiple role in managing the links between human and natural system and also help to make better decisions regarding the sustainable use and management of ecosystem services for future generations. At the micro level, valuation studies reveal information on both the structure and functioning of ecosystems and the varied and complex roles of ecosystems in supporting human welfare (Barbier *et al.,* 1997).

Estimates of marginal benefits can be used as signals to guide the human use of ecosystems, providing information on the relative scarcity and qualitative condition of the natural environment. Valuation is particularly useful in settings where institutional arrangements (such as markets and common property regimes) are not functioning well to reflect the social costs of environmental degradation. Decisions about conservation or restoration actions can lead to the misuse of resources when not guided by some concept of value.

Methods used in valuation of ecosystem services

The advantage of economic valuation is that it puts ecosystem values 'on an equal footing' with other economic benefits and costs. Some ecosystem services are traded and valued on market *e.g.*, many (but not all) provisioning services, but many others are not because they bear characteristics of public goods; nobody can be excluded from their use, and markets cannot form. Some values cannot be measured (intrinsic, religious values) but need to be recognized nevertheless. Others can be measured but are difficult to monetize their values need to be demonstrated (by other tools). Still others can be measured and monetized their value can be demonstrated by applying economic valuation tools.

Table 2. Methods used for quantification of economic value of ecosystem services

Approach	Method	Application
Market Price (Marketable goods)	Market value	Money paid to ecosystem goods and services that are treated in commercial market. example Timber, grain etc.
	Change in productivity	Value is inferred by considering change in quality and/or quantity of marketed goods that result from change in ecosystem service (example Fisheries income due change in quality of water)
Revealed preference method (Uses market based information to infer a non marketable value)	Travel cost	It assumes that the value of a site is reflected in how much people are willing to pay to travel to visit the site. Costs considered are travel expenditure, entrance fee and value of time
	Hedonic price	Value of environmental amenities (air quality, scenic beauty, cultural benefits *etc.*) that affect price of marketable goods
Cost based	Avoided damage cost	Value is based on the cost of action taken to avoid damages if specific ecosystem service did not exist
	Replacement cost	Value is based on the cost of replacing the ecosystem service (function)
State preference method (questionnaires, survey: these methods are used to estimate non use values)	Contingent valuation	Involves directly asking the people how much they are willing to pay to prevent loss of or to enhance the ecosystem service
	Choice modeling	People choose from a menu of options with differing level of ecosystem services and differing costs
Transfer of values	Benefit transfer	Transferring values from studies is already completed in another location and/or context

Quantifying ecosystem services is achieved by using a variety of techniques, such as travel costs, hedonic prices, avoidance / replacement costs, contingent evaluation, modeling choice, *etc.* (Table 2). This is complemented by a range of methods and techniques using secondary data such as transfer of value / benefits and meta-analysis techniques. In general, each method is advantageous in a certain context, and hence their typologies take precedence. The most common criteria are, at one hand, based on the existence or inexistence of market prices (Fig. 1) and, on the other hand, on the way the preferences are expressed. Methods based on market mechanisms reveal preferences taken into account, while methods that quantify ecosystem services without market prices are used mainly by stated preferences with respect to a series of scenarios describing a hypothetical market.

1. Total economic value

To analyze the economic value of ecosystems, the concept of 'Total Economic Value (TEV)' has become a frame work widely used for quantifying the utilitarian value of ecosystems. This framework normally disaggregates TEV into two categories: *use values* and *non-use values* (Fig. 2). Despite the existence of valuation methods adapted to different types of values, only provisioning services are routinely valued, while the value of other services, such as supporting, cultural and regulating, is more difficult to assess because the benefits that people derive from these services frequently cannot be directly observed or measured and usually these are not traded (Fisher *et al.,* 2011).

Use values comprise three elements: *direct use, indirect use* and *option values*. It is also known as the extractive, consumptive or structural use value and derives mainly from goods that can be extracted, consumed or enjoyed directly. *Indirect use* value is also known as the non-extractive use value or functional value and derives mainly from the services provided by the environment. *Option value* is the value attached to maintaining the option to take advantage of the use value of something at a later time which derives from the possibility that even though something appears unimportant now, information received later might lead us to re-evaluate it (Dixon and Pagiola, 1998). *Non-use values* as the name states, derives from benefits the environment may provide when it is not used in any way. In many cases, the most important benefit of this kind is *existence value;* the value people derive from the knowledge that something exists even if they never plan to use it (Barbier, 2007).

A general frame work for tree based land use system

Despite the demonstrated contribution of agroforestry in producing the ecological services, economic analyses on non-market services, as well as on the potential trade-offs between bundles of services, are little or non-existent. Studies provide a general account of the role of agroforestry systems in providing ecosystem services (Jose, 2009), while others provide frameworks for cost benefit analysis of tropical agroforestry systems (Alavalapati and Mercer, 2004). A comprehensive analytical framework for quantifying and valuing ES is though missing, a general frame work for the quantification and valuation of ecosystem services developed by Alam *et al.* (2014) for tree based intercropping system could be considered. In the first step, the full suite of ES which are meaningful in the context of the study need be identified; in this regard 10 services are considered here for analysis. In the second step, the service providing units and their relationships with the provision of services have to be quantified. In the third step, economic valuation of each of the ES is done. The final step involved extrapolation of results and examining trade-offs.

A mix of mathematical models has been used for quantification of various ES and their economic valuation. In

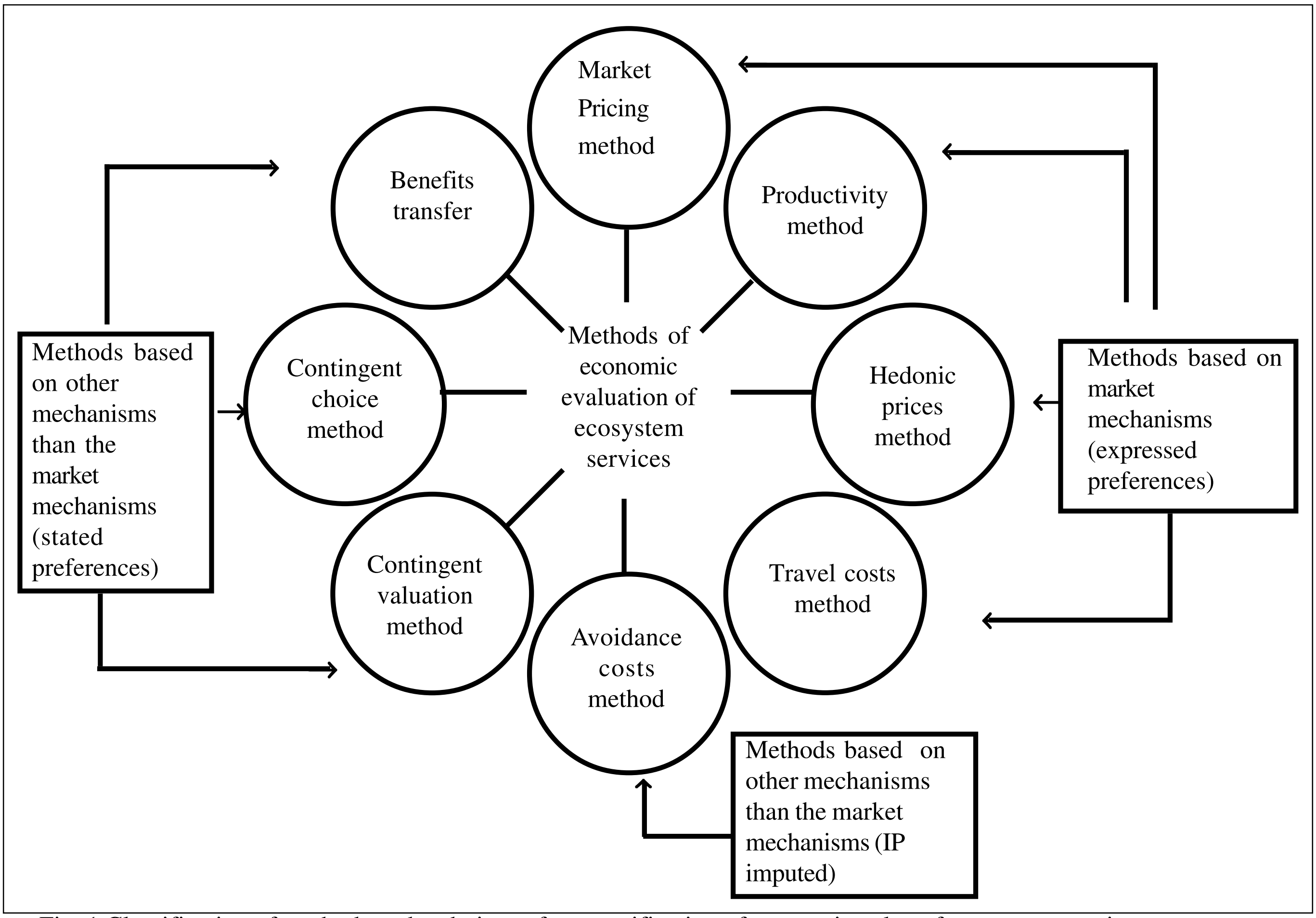


Fig. 1 Classification of methods and techniques for quantification of economic value of ecosystem services (adopted from Giani Gradinaru, 2013)

TOTAL ECONOMIC VALUE (TEV)

	USE VALUE			NON-USE VALUE
TEV CATEGORIES	Direct use value consumptive non-consumptive	Indirect use value	Option value	Existence value Bequest value (for future generations)
EXAMPLES	Hunting Fishing Timber harvesting Harvesting of non-timber forest products Harvesting of biomass Recreation/tourism	Watershed protection (erosion control, local flood reduction, regulation of streamflows, strom protection) Ecological processes (fixing and cycling of nutrients, soil formation, circulation and cleaning of air and water, climate regulation, carbon fixing, global life support)	Genetic resources Old-growth forest (Irreversibilities)	Chairsmatic mega-fauna (Whales, great apes, etc.) and their habitats
COMMNLY USED VALUATION METHODS	Change in productivity, cost-based approaches, hedonic prices, travel cost, stated preference methods	Change in productivity, cost-based approaches, stated preference methods	Change in productivity, cost-based approaches, stated preference methods	Stated preference methods

Fig.2. Total economic valuation of ecosystem services

some instances, existing models and equations are considered, but in most instances existing models are modified or new ones are developed to meet the needs. Many a times the published data from related experiments on various tree based intercropping (TBI) particularly from in Que´bec and Ontario (Canada) are considered.

The ES included for quantification are - nutrient mineralization (ES_1), water quality (ES_2), soil quality (ES_3), pollination (ES_4), biological control (ES_5), air quality (ES_6), windbreak (ES_7), timber provisioning (ES_8), agriculture provisioning (ES_9) and climate regulation (ES_{10}). Further, the following sets of general equations for economic analysis were used.

$$TEV = \Sigma ES_n = \Sigma ES \text{ non-market} + \Sigma ES \text{ market}$$

Where, n = 1, 2, 3,… 10, the individual ecosystem service (ES), TEV = Total economic value, ΣES non-market = ΣES 1–7, 10 and ΣES market =ΣES8, 9.

Below are the methods used for quantification of individual ES along with economic data and assumptions associated with the evaluation for a poplar based intercropping system with a density of 111 trees per hectare.

Assessment of annual margins

Nutrient mineralization

In the system poplar trees add nitrogen, phosphorus and potassium by 7 kg ha^{-1} y^{-1}, 11.2 kg ha^{-1} y^{-1} and 21.22 kg ha^{-1} y^{-1}, respectively through litter fall and stem flow (Thevathasan and Gordon, 2004; Zhang, 1999). Further, the replacement cost method is used for valuation which means annual fertilizer cost could be saved for that amount. Hence, quantity of fertilizer added by the system was multiplied with the cost of fertilizer.

It is observed that the above-ground biomass of hybrid poplar trees associated with various intercrops was 40 per cent higher on an average than what was observed in controls without intercrop after 3-4 years of establishment. As mineralization of soil nutrients contributes to plant available nutrient, it is thus reasonable to assume that a certain percentage of tree yields are attributable to nutrient inputs and soil management of the system. Conservatively it is assumed that 10 per cent of mean annual increment in biomass is attributable to nutrient mineralization through the system. The annual increment of poplar trees was found to 1.62 m^3 ha^{-1} y^{-1}. The 10 per cent of this equals to 0.162 $m^3 ha^{-1}$ y^{-1} and this value was multiplied with the market price of the wood to monetize it (Rivest *et al.,* 2009) .

Water quality

Water quality services was evaluated in terms of cost of decontamination of nutrient loads as well as of the sediment dredging cost using the following equation.

$$Vwater = LN * CdN + LP * CdP + S * Cdred$$

Where, Vwater, is the value of water quality regulation, LN is the rate of N leaching reduced, CdN is cost of N decontamination, LP is the rate of P leaching, CdP is the cost of P decontamination, S is the sedimentation rate and Cdred is the dredging cost.

The tree based intercropping system reduced nutrient leaching by 11 kg N $ha^{-1}y^{-1}$ and 7.5 kg P $ha^{-1}y^{-1}$ compared to mono cropping and to get monetary value of water quality it was multiplied with cost involved for removing nutrient load in waste water by using above equation. Costs of removing excess nutrients in waste treatment plants were reported to be \$ 8.50 kg^{-1} for N and \$ 61.20 kg^{-1} for P (Olewiler, 2004), and erosion control and sediment retention by pasture lands, hedgerows and cultural woodlands (*i.e.,* agricultural land) are worth an estimated \$ 5.60 $ha^{-1}y^{-1}$ (Wilson, 2008).

Soil quality

Soil quality regulation was assessed in terms of soil formation based on earthworms and other soil invertebrate data, the amount of soil formed was calculated, which was then multiplied by market price of soils. The equation can be expressed as

$$VSoilF = (Qearth + Qinvert) \times Psoil$$

$$= (Nearth \times 0{:}0002 + Qinvert) \times Psoil$$

Where, VSoilF is the price of soil produced $ha^{-1}y^{-1}$, Qearth is the amount of soil formed by earthworms, Qinvert is the amount of soil formed by invertebrates, Psoil is the market price of soil (\$ ton^{-1}), Nearth is the number of earthworms in the soil and 0.0002 is the weight of one earthworm (kg).

In this equation the weight of one earthworm equals 0.2 g and 1 ton of earthworm produces 1,000 kg soil $ha^{-1}y^{-1}$. The study revealed that the number of earthworms equals 119-394 m^{-2} and biomass equals 245-557 g m^{-2} in poplar intercropping. The biomass of earthworms is assumed 250 g m^{-2}, and then there is 2.5 ton of earthworm biomass per hectare. If one ton earthworms produces 1,000 kg soils $ha^{-1}y^{-1}$, then total soil produced in poplar agroforestry is 2.5 ton $ha^{-1}y^{-1}$. Further, contribution of soil invertebrates in soil formation is assumed 1 ton $ha^{-1}y^{-1}$ and to get monetary value it was multiplied with the price of soil.

Pollination

There are several methods of getting the value of pollination services. 'Replacement cost method' looks at how much the farmer spends to replace natural pollination with pollination by rental bees. Thus, pollination service value could be obtained by multiplying area under crop production by industry wide recommended honeybee stocking and rental price of honey bee (Winfree *et al.,* 2011). The second approach used is the 'production function approach'. Morse and Calderone (2000) used the following equation to estimate the value of honey bee in crop pollination:

$$Vhb = \Sigma(V * D * Phb)$$

Where, Vhb is the sum of the total annual value of insect pollinated crops that are pollinated by honey bees, V is the annual value of each crop, D is the dependency of each crop on insect pollinators, and Phb is the estimate of the proportion of the effective insect crop pollinators that are honey bees.

The function was modified assuming that single crop evaluation and thereby avoiding summation. Further, proportion of honeybee Ph was excluded from the equation since accounting the contribution of all pollinating agents has to be done as opposed to a single insect group. Additionally, variable costs were deducted from the revenue to attribute pollinators' contribution in the net profit. To avoid complexities in calculations timber management costs were excluded from the variable cost. In calculating yield per hectare exact land area under crop was considered by deducting the area under tree management in the agroforestry plot. The final equation takes the following form

$$ESVpol = (Y*P - VC) * D$$

Where, ESVpol is the Ecosystem Services Value of pollination, Y is the soybean yield = 1.47 ton ha^{-1} yr^{-1}, P is the soybean price = $ 533.97 ton^{-1}, VC is the variable cost = $ 554 ha^{-1} (Toor 2010; Toor *et al.,* 2012), and D is the pollinator dependence for soybean = 0.1 (Morse and Calderone, 2000).

Biological control

An economic model based on the difference in the proportion of berries infested by berry-borer between exclosure and control plants estimated an average benefit of $ 75 ha^{-1} with a range of $ 44 to $ 105 $ha^{-1}yr^{-1}$ (Kellermann, 2007). Calculations of the benefits provided here were obtained by documenting pest infestation levels in the presence and absence of bird foraging (via exclosures) and translating higher saleable crop yields in the presence of birds into a dollar figure using crop market prices. The average value (*i.e.,* $ 75 ha^{-1}) was used in the final analysis.

Air quality

In 'contingent valuation approach' local residents are questioned on their willingness to pay (WTP) for a certain level of improved air quality enhanced by agroforestry. A scarce population will also result in scarcity in air quality appreciation; therefore willingness to pay will not make sense. Hedonic pricing could be another option, but is faced with the same limitation as with contingent valuation. The remaining option was 'alternative cost of pollutant removal'. The role of trees in removing air pollutants such as NO_2, SO_2, dust and other particulate matter has been assessed by many researchers (Dwyer *et al.,* 1992; Nowak *et al.*, 2006; McPherson *et al*., 1999). Findings reveal that a single tree removes 1.67 kg of pollutants per year.

Agroforestry landscapes, however, are not found in urban areas, and thus the same rate of pollutant removal is unlikely. Arbitrarily assuming the air quality maintenance service provided by each tree in an agroforestry plot to be a removal of 0.67 kg pollutants per tree and assuming per kilogram removal cost of $ 6.29 (Wilson, 2008), a single tree provides a service worth $ 4.20 per year. In a 111 trees ha^{-1} plot we obtain the annual air quality maintenance service provided by agroforestry by multiplying the dollar amount (*i.e.,* $ 4.20) with the total number of trees.

Windbreak

Tree belts established around agricultural infrastructure, around livestock barns or close to residential infrastructures provide services through several mechanisms, including enhancing microclimate and conserving the natural environment. These also increase agricultural productivity in providing crops with shelters against wind storms and better snow management in the crop field (Jairell and Schmidt, 1999). The economic value of windbreaks can be evaluated using the following equation.

$$EVwb\,(c) = EVp$$

Where, EVwb(c) is the value of ecosystem services provided by windbreak in the crop fields, EVp is the value of overall increased productivity in agriculture due to reduction of wind erosion and snow management.

Brandle *et al.* (2004, 2009) reported that the overall increased productivity in agriculture due to reduction of wind erosion and snow management is 15-20 per cent. However, trees in the intercropping systems are widely spaced on the lines planted, but many more of them are installed across a given field. Therefore, it could not exactly be known how they contribute to wind control with respect to windbreak. Conservatively, it was assumed a 5 per cent increase in yield of 1.47 ton ha^{-1} (*i.e.,* 73.5 kg ha^{-1}) attributable to windbreak.

Provisioning services

Valuation of provisioning services is relatively straightforward and can be accomplished in terms of provision of agricultural, timber and non-wood tree outputs. In the above study, however, non-wood tree products such as medicines and fruits, firewood and intermediate thinning and pruning products were excluded. Following Toor *et al.* (2012), the crop yield (soybean) of 1.47 ton $ha^{-1}y^{-1}$, timber yield (hybrid poplar) of 3.5 m^3 $ha^{-1}y^{-1}$ assessed to have market prices of $ 533.97 ton^{-1} for crop and $ 40 m^{-3} for timber.

Climate regulation

Net carbon sequestration from an agroforestry plot can be estimated as the sum of above ground C sequestration plus below ground C sequestration less carbon liberation into atmosphere through various processes. For operational purpose the equation for C sequestration accounting can be written as:

$$NCS = (Bt + Br + Bl + CR + SOC) - (Cr + Cl) + CN_2O$$

Where, NCS is the net carbon sequestered, Bt, and Br is the carbon stored in tree trunk biomass (including branches and leaves) and roots respectively, Bl is the carbon stored in litter fall, CR is the carbon stored in crop residues, SOC is the carbon

Table 3. Indicators and economic value of ecosystem services of tree based intercropping system

TBI ecosystem	Indicator	Indicator quantity	Economic value ($ $ha^{-1}y^{-1}$)	Reference
Nutrient mineralization	N input	7 kg $ha^{-1}y^{-1}$	3.8	Thevathasan and Gordon (2004)
	P input	11.42 kg $ha^{-1}y^{-1}$	7.5	Zhang (1999), Rivest *et al.* (2009)
	K input	21.22 kg $ha^{-1}y^{-1}$	13.5	Toor *et al*. (2012); USDA
	Change in yield (timber)	0.162 m^3 $ha^{-1}y^{-1}$	6.4	
Water quality	N decontamination	11 kg $ha^{-1}y^{-1}$	93.5	Olewiler (2004)
	P decontamination	7.5 kg $ha^{-1}y^{-1}$	459	Olewiler (2004)
	Sediment dredging	-	5.6	Wilson (2008)
Soil quality	Earthworms	2.5 t $ha^{-1}y^{-1}$	125	Sandhu *et al*. (2008); Price and Gordon (1999)
	Invertebrates	1 t $ha^{-1}y^{-1}$	50	Pimentel *et al.* (1995 and 1997)
Pollination	Yield changes (crop)	1.47 t $ha^{-1}y^{-1}$	24.1	Morse and Calderone (2000) Toor *et al*. (2012)
Biological control	Pest infestation levels	-	75	Kellermann (2007)
Air quality	Pollutant removal	1.67 kg $tree^1$	462	Wilson (2008)
Windbreak	Productivity change	1.47 t ha^{-1}	39.2	Brandle *et al.* (2004, 2009)
Timber provisioning	Annual yield	3.5 $m^3ha^{-1}y^{-1}$	140	Toor *et al*. (2012)
Agriculture provisioning	Annual yield	1.47 t $ha^{-1}y^{-1}$	784.9	Toor *et al*. (2012)
Climate regulation	Carbon sequestration	8.3 Mg CO_2 $ha^{-1}y^{-1}$	356.9	Unpublished data

pool in soil, Cr, is the carbon returned back through soil respiration, Cl is the carbon lost through leaching into soil profiles, CN_2O is the CO_2 equivalent avoided emission of N_2O.

The above equation reveals total carbon sequestration potential of tree based intercropping system to be of 6.86 Mg C $ha^{-1}y^{-1}$. Data indicate an above ground carbon sequestration of 4.16 Mg C $ha^{-1}y^{-1}$, while below ground estimate is 2.7 Mg C $ha^{-1}y^{-1}$, just over a quarter of above ground sequestration rates. Total carbon lost through leaching and soil respiration is higher than total below ground sequestration. Out of the total carbon sequestered 4.6 Mg C $ha^{-1}y^{-1}$ will go back to the atmosphere through these processes. Hence, net carbon sequestration potential is 2.26 Mg C $ha^{-1}y^{-1}$. This amount of C represents immobilization of 8.3 Mg CO_2 (1 ton of carbon equals 44/12 = 3.67 tons of carbon dioxide) from one hectare tree based intercropping system (TBI) plot in a year. The social cost of carbon (SCC) value of $ 43 (Yohe *et al.*, 2007) was used in the present analysis. The SCC, also referred to as Damage Cost Avoided, represents the marginal cost of emitting an additional unit of CO_2 into the atmosphere, *i.e.,* the estimate of monetary value of damage resulting from CO_2 emissions.

A summary of various indicators, service providing units and marginal economic values described above can be found in Table 3.

Aggregation and extrapolation

Net present value (NPV) of each of the services is discussed hereunder. While marginal benefit shows what the annual economic value of the services per unit area is, a NPV provides an understanding of how the benefit is observed over a longer time-frame, say 40 years in present instance. This could be done by discounting the future values into present values with a discount rate of 4 per cent.

The total annual margin of TBI ecosystem services was estimated to be $ 2,645 $ha^{-1}y^{-1}$. The economic value of combined non-market services was $ 1,634 $ha^{-1}y^{-1}$, which was higher than the value of marketable products (*i.e.,* timber and agricultural products). The economic return from agriculture in monoculture was $ 1,110 $ha^{-1}y^{-1}$, whereas the return from agriculture in TBI was $ 785 $ha^{-1}y^{-1}$. An analysis of the present value of future benefits of ES for the rotation of 40 years revealed that provision of agricultural products ranked highest ($ 16,287 ha^{-1}) among the ES, followed by water quality ($ 11,581 ha^{-1}), air quality ($ 9,510 ha^{-1}), carbon sequestration ($ 7,346 ha^{-1}), and soil quality ($ 3,631 ha^{-1}). Total economic value of all the ES was $ 54 782 ha^{-1}, only a third of which was contributed by agricultural products. Total non-market benefits were twice as high as the provisioning services combined (*i.e.,* timber and agriculture).

2. Quantification based on energetics

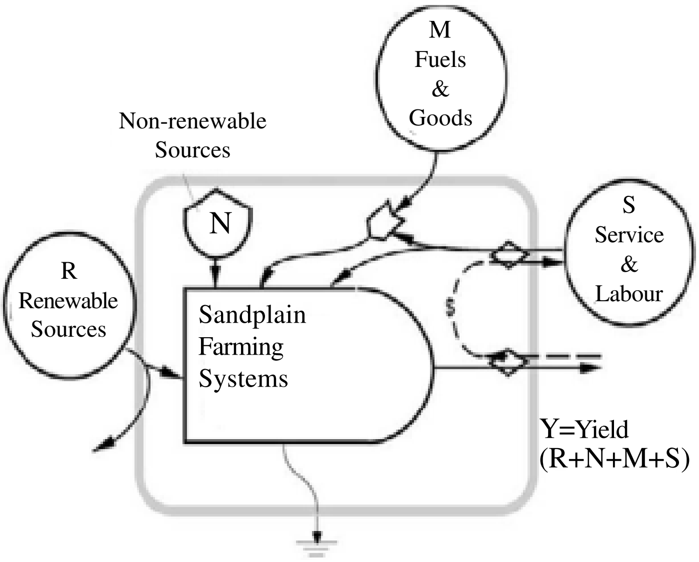
Energy (in terms of solar, fossil fuel or electricity *etc.*) analysis, which evaluates system components on a common unit basis is another promising tool to evaluate resource use and productivity of farming systems (Odum, 1988). For instance, solar energy - defined as the amount of solar energy used up directly and indirectly to make a service or product- is expressed as solar emJoules (sej). Process analysis methodology is commonly used in energy analysis wherein inputs and outputs are traced following physical material flows in a system boundary and which further transformed into energy flows using specific energy equivalents or energy coefficients. The energy of a product or service is calculated by multiplying its available energy by its transformity.

Transformity is defined as the ratio of energy required to make a product or service to the available energy of the product or service expressed as solar emJoules/Joule, or solar emJoules/kg

(Brown and Ulgiati, 1977). E.g. Source - item x raw data in Joule, dollors or other units x solar energy in Joules/Joule or appropriate units (transformity) obtained from previous studies = solar energy of given flow. For instance, the energy for nitrogen fixation varies from 46 x 1012 sej/kg in the lupin/wheat rotation, 10 x 1012 sej/kg in alley cropping and 3 x 1012 sej/kg in the plantation. Fossil energy input, energy output, and energy use-efficiency (EUE) are important indicators of the environmental effects, resource consumption and economic performance of farming systems.

In southern Germany, Lin *et al.* (2017) compared organic and conventional farming systems – mixed farming, arable farming and agroforestry systems (Table 4) and found that conversion from multi-structured organic farming to a specialized organic arable farming reduced fossil energy input in crop production only marginally (from 5.9 Gj ha^{-1}), but considerably decreased dry matter yield (from 5.4 to 2.5 Mg ha^{-1} yr^{-1}), energy output (from 99 to 46 GJ ha^{-1}) and EUE (from 16.8 to 8.3). Improved management in the conventional arable farming system (with high yielding varieties and better N management) reduced energy input from 14.0 to 12.2 GJ ha^{-1}, increased the energy output from 155 to 179 GJ ha^{-1} yr^{-1} and elevated the EUE from 11.1 to 14.6. In general, the establishment of agaroforestry systems with short rotation trees (without fertilization and pesticide use) led to the reduction of energy input. Presently, the energy inputs are highly dependent on non renewable energy such as diesel. The use of renewable energy in agriculture (*e.g.* biodiesel and renewably-produced electricity) is one way to reduce the dependency on fossil fuels and greenhouse gas emission.

In a study on sandy soils in the south west coast of Australia, Lefroy and Rydberg (2003) compared – a lupin/wheat rotation, an alley cropping systems in which this crop rotation was followed in between the rows of the fodder tree tagasaste (*Chamaecytisus proliferous* Link.) 30 m apart (550 trees/ha), and solid plantation of tagasaste (2300/ha) using energetics. The study indicated that the largest energy flows (Fig. 3) in all systems were those associated with wind erosion, evapotranspiration and application of phosphate fertilizer. Farm-forestry had the lowest environmental loading due to reduced wind erosion and the highest annual net returns compared to annual cropping, while alley cropping system with 15 per cent tree cover was intermediate (Table 5). Similarly, energy balance and economic benefits of two agroforestry systems in China



Sustainability indicators

Renewable proportion of total energy used	R/Y
Ratio of renewable to non-renewable energy	(N+M)/R
Environmental loading	(N+M+S)/R
Return on invested energy	
Investment ratio	(M+S)/(R+N)
Energy exchange ratio	Y/(Output price in energy)
Return on investment energy	(Output price in energy)/ (M+S)

Fig. 3. Systems diagram illustrating the flow of energy and materials to and from a farming system expressed as flows of solar energy per unit time where energy is the cumulative measure of the energy used in the past to make a product or service, expressed in units of solar energy (solar emJoules;sej), (Odum, 1996). The aggregated flows shown are local renewable inputs (R), non-renewable storages (N), purchased energy and materials (M) and the service component of purchased inputs (S) and (Y) which is the sum of the energy value of the inputs. The aggregated flows are used to calculate energy-based indices of sustainability.

Table 4. Energetic performance and related parameters at Scheyern Research Farm

Parameter	Unit	Organic arable farming	Organic mixed farming	Conventional arable farming	Conventional mixed farming
Livestock[a]	LU ha^{-1}	0	0.9	0	1.6
N input[b]	kg ha^{-1} yr^{-1}	139	174	246	275
Energy input	GJ ha^{-1}	6.3	7.5	12.1	12.3
Energy output	GJ ha^{-1}	76.3	123.5	153.7	167.3
EUE		12.1	17.2	11.8	13.6

[a] LU – Livestock unit — Lin *et al.* (2017)

[b] N-input = N deposition + symbiotic N_2 fixation + mineral N + farmyard manure + straw/green manure

Table 5. Transformities energy indices and money flows for three alternative farming systems

Index	Expression	Lupin/wheat rotation	Tagasaste plantation	Alley cropping
Transformities				
Grains (sej/J)		117.0E+3		92.7E+3
Crop residues (sej/J)		144.2E+3		115.0E+3
Tree fodder (sej/J)			128.2E+3	914.0E+3
Tree residues (sej/J)			18.8E+3	134.0E+3
N_2 fixation (sej/kg)		46.5E+12	3.0E+3	10.2E+12
Sustainability ratios				
Renewable portion of total energy	R/Y	0.6	0.2	0.3
Environmental loading (ELR)	(N+M+S)/R	5.4	0.7	2.3
Energy investment Ratios				
Investment ratio	(M+S)/(R+N)	0.5	0.6	0.8
Energy exchange ratio	Y/output price in energy	4.5	1.9	2.9
Return on invested Energy	Output price in energy/(M+S)	0.7	1.0	0.7
Gross margins (US$)				
Value of output (US$ $ha^{-1}yr^{-1}$)		170	225	182
Purchased inputs and services (US$ $ha^{-1}yr^{-1}$)		121	69	103
Net income (Purchased inputs and services (US$ $ha^{-1}yr^{-1}$)		49	186	79

Lefroy and Rydberg (2003)

Table 6. Comparison energy input and output of the tea and non-tea intercropping systems

System	Energy (10^6 kcal)		Output/ input	Value (Yuan)		Output/ input
	Input	Output		Input	Output	
Tea+maize-red mungbean-green manure	60.96	73.59	1.12	18435	41722	2.3
Tea	18.00	2.63	0.06	14101	20250	1.4

Jianbo (2006)

clearly revealed the superiority of perennial-annual intercropping system (Jianbo, 2006) and thus proved their effectiveness in system evaluation (Table 6).

Thus, energy analysis using either conventional diesel or natural solar energy or any other base it would also be possible to compare performance of farming systems involving diverse crops and systems/enterprises. When combined with environmental and economic assessment of perspective land use systems energetics appear to be a more potent instrument.

Conclusion

It is attempted to enhance our understanding of the true value of market and non-market benefits of tree-based intercropping systems. Further, a economic framework and energetic based evaluation are discussed to quantify ecosystem services for agroforestry systems. Despite inherent uncertainties in quantification and valuation of ecosystem services which are non-market in nature, a reasonable estimate of the economic contribution is still possible. Though, more than one valuation approaches are possible for every ecosystem service limitation is that each providing a different value it would be difficult to select the most appropriate approach and model in the given context and the availability of required data.

The benefits of ecosystem services are realized at the cost of farmers' private benefits due to reduced provisioning services and the expected cost of adoption and maintenance of this new technology over a longer time frame. Finally, it should also be pointed out that an ecosystem develops over many years of interaction among its various components. Therefore, it may take years to start realizing benefits after establishing an agroforestry system and these may vary with the crops and climatic conditions of the region.

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