



Ecosystem services rendered by tree based land use systems

B M CHITTAPUR¹ and D K PATIL²

University of Agricultural Sciences, Raichur, Karnataka 584 102

Received: 14 February 2017; Accepted: 18 July 2017

ABSTRACT

Trees being important components of biosphere need to be planted and protected on arable land for the ecosystem services they offer for the wellbeing of the earth and its living forms. Area under natural forests is coming down and it is not possible to increase area under forests any more due to other anthropological reasons. Properly designed and strategically located agroforestry practices as alternative can contribute to ecological services by mitigation land degradation, climate change and desertification, while conserving natural resources and biodiversity. Besides providing, tree based goods and services, agroforestry can be considered as an adoptive strategy in areas climatically and biologically vulnerable. Being a potential C sink, agroforestry can also mitigate negative impacts of CO₂ emission. As green belt these have a role in maintaining air, water and soil quality in mining and industrial areas also. An attempt, therefore, is made in this article to highlight the ecosystem services rendered by tree based land use systems.

Key words: Agroforestry, Carbon sequestration, Ecosystem services, Resource conservation

Trees are important component of nature and provide stability to biosphere. We cannot visualize life without trees and the history of trees/forests is linked with the progress of human evolution. However, with increasing population and corresponding rise in demands for food, forest products and land, pressure has increased on forests leading to reduction/destruction of forest areas and quality of forests. This impingement with nature in turn affected the ecological services rendered by trees/forests and the unabated damage has catastrophic impact on climate and sustainability and survival of biosphere. Alarmed by the developing situation revival/regeneration of forests and trees in any form is given paramount importance by the policy makers, environmentalists, foresters, farm scientists and philanthropists. The present article mainly aims to enlighten the readers on the benefits of trees/systems in terms of ecosystem services (ES). Since, all lands especially agricultural lands cannot be put back to forests there is need to introduce tree component in the existing agricultural systems, as agroforestry system, such that the resulting ES support and sustain wellbeing of the biosphere.

‘Agroforestry is a sustainable management system for land that increases total production, combines agricultural crops, tree crops and forest plants and animals simultaneously or sequentially and applies management practices that are compatible with the cultural patterns of the local populations.’ Numerous agroforestry systems

have been evolved (Nair 1985) for different areas/situations. Every system differs from other in respect of structure, composition, age, intensity, technology etc. The complementary and competitive effects, and the resulting ES depend upon (i) age and size of the trees, (ii) nature of the tree species, (iii) nature of agri/horti/pasture (either single or combined) crops, (iv) availability of water, nutrients, light and other growth resources, and (v) influence of other biotic and abiotic factors etc. In the interplanting system, complementarity in resource use may be spatial or temporal. Besides, efficient resource use, agroforestry systems also render varied ecosystem services spatially and temporally.

Ecosystem services

‘Ecosystem services (ES)’ is defined as the set of diverse ecological functions that are essential to human welfare (Daily 1997). These services can provide significant, measurable benefits to humanity, potentially providing an economic argument for ecosystem conservation (Kremen *et al.* 2002). The Millennium Ecosystem Assessment (MES 2005) provides a globally recognized classification that emphasizes relationships between ES and human wellbeing and describes four types of ES, viz. (i) provisioning services, (ii) regulating services, (iii) supporting services, and (iv) cultural services (Tallis and Kareiva 2005, Haines-Young and Potschin 2012). Provisioning services include the production of food, fuel, fiber, and other harvestable goods. Regulating services include climate regulation, flood control, disease control, waste decomposition, and water quality regulation. Supporting services include the foundational processes necessary for production of other services, including soil formation, nutrient cycling, and photosynthesis (primary

¹Chief Scientific Officer (basavarajc7@gmail.com), University of Agricultural Sciences, Raichur, Karnataka. ²Assistant Professor of Farm Forestry (dkpatil2020@gmail.com), College of Agriculture, Bhimaranagudi, Yadgir District, Karnataka.

production). And, cultural services provide recreational, aesthetic, spiritual, and other nonmaterial benefits.

Agroecosystems both provide and rely on ES to sustain production of food, fiber, and other harvestable goods. Many services have on-farm benefits (e.g. for farmers), whereas others have broader public benefits to off-farm users; some benefit both groups (Garbach *et al.* 2014). The understanding of ES in agricultural landscapes has become important for several reasons. First, agricultural ecosystems – including croplands and pastures – are among the largest terrestrial biomes and account for approximately 40% of the Earth's surface (Foley *et al.* 2005). Second, increases in food and fiber production have often been achieved at the cost of other critical services. The Millennium Ecosystem Assessment (MES 2005) reported that approximately 60% (15 out of 24) of services measured in the assessment were being degraded or unsustainably used as a consequence of agricultural management and other human activities (Table 1). Further, modern, industrial agriculture activities have most significantly undermined the Earth's life-support systems (Rockström *et al.* 2009). Major negative impacts have occurred through converting natural habitat to agriculture and infrastructure, environmental pollution, and environmental change induced by shifts in nitrogen and phosphorus use.

Provisional services

Enhanced productivity: In agroforestry, the potentially higher productivity could be due to capture of more growth resources. Alternate tree based land use systems offer possibilities to increase income from drylands, besides

serving some important environmental functions. At dry farming Centre, Bijapur significantly higher gross returns were obtained with plantation of sapota + guava and simarouba + guava, and inter planting of guava always ensured higher returns (Alagundagi 2016). In North Eastern hill regions of India, Borthakur *et al.* (1981) developed an ideal agroforestry model as an alternative to shifting cultivation with net income about four times higher than with 'Jhum' or shifting cultivation. In this, the lower one-third area of the hill slope was terraced and utilized for arable crops (fodder grasses and legumes). The middle one-third slope was utilized for horti-pastoral systems and top most steep slopes for growing fuel and fodder plantations.

Under Jhansi conditions, Rai (1999) reported that *A. lebbeck*, *A. amara*, *L. leucocephala* and *A. tortilis* were suitable for natural pasture for getting higher biomass. Agroforestry, thus helps improve productivity of impoverished agriculture lands, as tree species with multiple uses are the main stay of agroforestry (Table 2 and 3). Further, the Land Equivalent Ratio (LER) for alley cropping systems under European climate ranged between 1.0 to 1.4, and hence tree based intercropping is more productive than monocropping, however at some places LER is expected to decrease with time as trees age (Tsonkova *et al.* 2012) (Table 3).

Food and medicinal products: Non-timber products such as fruits, medicinal products, mushrooms, honey, flying termites and bush meat are central to the livelihoods of both tribal/rural and urban dwellers. These are the important sources for Ayurvedic medicine too. Indigenous miombo fruits form a staple food during the hunger periods in the agricultural cycle and periods of famine in southern Africa (Akinnifesi *et al.* 2006, Mangu 1999). There it is argued that without this valuable contribution many children who are most vulnerable and the chief consumers of fruits would be affected by dietary deficiencies (Makombe 1993). The bark extract of *Scleocarya birrea* are used for treatment of diseases such as malaria, dysentery and rheumatism (Hall *et al.* 2002).

In northeastern Karnataka, neem (*Azadirachta indica*) which, apart from timber valued for medicinal properties in rural areas and in organic pest management, predominates (19.7/ha) both on bunds and in farm lands in the traditional agroforestry (Doddabasava *et al.* 2017). *Acacia nilotica*, whose bark decoction is used for strengthening teeth

Table 1 State of different ecosystem services

| Service | Status | Service | Status |
|-------------------------|-------------------|--------------------------------|--|
| Food | Crops | ↑ | <i>Regulating services</i> |
| | Livestock | ↑ | Air quality regulation |
| | Capture fisheries | ↓ | Climate regulation -global |
| | Aquaculture | ↑ | Climate regulation regional and local |
| | Wild foods | ↓ | Water regulation |
| Fibre | Timber | +/- | Erosion regulation |
| | Cotton, silk | +/- | Water purification and waste treatment |
| | Wood fuel | ↓ | Disease regulation |
| Genetic resources | ↓ | Pest regulation | ↓ |
| Biochemical's medicines | ↓ | Pollination | ↓ |
| Fresh water | ↓ | Natural hazard regulation | ↓ |
| | | <i>Cultural services</i> | |
| | | Spiritual and religious values | ↓ |
| | | Aesthetic values | ↓ |
| | | Recreation and ecotourism | +/- |

Table 2 Changes in soil properties (0-30 cm) under different tree crop system

| Land use systems | PH ₂ | Organic C (%) | Available N (kg/ha) |
|-------------------------|-----------------|---------------|---------------------|
| Crop based system | - 0.45 | + 0.07 | + 10 |
| <i>Eucalyptus</i> based | - 0.67 | + 0.12 | + 21 |
| <i>Acacia</i> based | -0.63 | + 0.20 | + 31 |
| <i>Populus</i> based | -0.80 | + 0.17 | + 25 |

Source: Singh *et al.* (1997)

Table 3 Changes in soil nitrogen content measured in alley cropping systems with tree species of different ages

| Species | Soil depth (cm) | N content (g/kg) | | Age (year) | Annual increase | Location | Reference |
|--------------|-----------------|------------------|-------|------------|-----------------|--------------------------------|---------------------------------|
| | | Initial* | Later | | | | |
| Black alder | 0-20 | 0.32 | 0.52 | 7 | 0.030 | Northeast Estonia ^a | Kuznestova <i>et al.</i> (2011) |
| Black locust | 0-30 | 0.20 | 0.53 | 9 | 0.014 | Northeast Germany ^a | Nii-Annang <i>et al.</i> (2009) |
| Poplar | 0-30 | 0.20 | 0.28 | 9 | 0.009 | Northeast Germany ^a | Nii-Annang <i>et al.</i> (2009) |
| Black locust | 0-30 | 0.10 | 0.52 | 14 | 0.030 | Northeast Germany ^a | Matos (2009) |
| Grey alder | 0-10 | 0.10 | 1.40 | 14 | 0.030 | Southeast Estonia ^b | Uri <i>et al.</i> (2011) |

* Measured before trees were planted, or in the first year of growth, ^a Post mining site, ^b Arable land. Source: Tsonkova *et al.* (2012)

gum while the gum forms special recipe during post-partum recovery, occupies next position. Hedge species gaiga (*Caesalpinia bonduc*), shikai (*Acacia sinuata*), vasuka (*Adhatoda vasica*), henna (*Lawsonia inermis*) are medicinally important and hence, can be part of dry land agroforestry systems (Narashima Reddy 2006). Similarly, tall and perennial medicinal trees such as *Prunus africana*, *Santalum album*, *Saraca indica*, *Aegle marmelos*, *Anona squamosa*, *Embllica indica*, *Terminalia chebula*, *Terminalia arjuna*, *Jatropha curcas* etc. can be planted at wide spacing as shade providers or boundary markers in a agroforestry system (Kalaichelvi and Swaminathan 2009). Poplar (*Populus deltoides*) based agroforestry systems have been economically adopted in dryfarms of India because of several advantages. Because the tree causes negligible effect on the intercrops during the first three years of growth, perennial plants, viz. *Glycyrrhiza glabra* (Mulathi), *Asperagus racemosus* (Shatawari), *Aloe vera* (gwarpatha) and *Tinospora cordifolia* (Giloe) were effectively demonstrated in a three tier system in Haryana (Bimalendra Kumari and Madan 2016).

Energy: In many areas, people depend on trees for energy needs. Some communities in western Maharashtra north Karnataka earn their livelihood through production of charcoal from *Prosopis juliflora* from agricultural waste lands. The charcoal is in much demand in cities like Hyderabad. The demand for fuel wood and charcoal would continue to rise. Agroforestry practices can provide significant amounts of fuel wood. Studies have shown that trees grown in contour strips, rotational woodlots and fallows can produce large quantities of fuel wood. For example, *Grevillea robusta* trees planted on contours on an average farm size of 1.64 ha in parts of Tanzania could meet the entire annual household demand for fuel wood (Mwihomeke and Chamshma 2004).

Fuel wood production in rotational woodlots has been studied widely especially in Tanzania (Kimaro *et al.* 2007, Nyadzi *et al.* 2003, Otsyina 1999). After five years rotation, *Acacia crassiparva* produced about 51 t/ha at low nutrient costs (Kimaro *et al.* 2007). According to Kimaro, on a semi-arid site (Morogoro) in Tanzania, wood productivity in tree fallows averaged three times higher than that produced by typical miombo woodlands. Therefore, agroforestry plantations are probably the only option to meet major share of the wood demand, and adoption of agroforestry

practices can significantly reduce deforestation by providing fuel wood.

Regulating services

Soil structure and soil processes: Warmer conditions favour net N mineralization rather than its immobilization in soil system. For instance Joshi *et al.* (2017) observed rise in soil NO₃⁻-N, PNM, MBC by 27, 21 and 18%, respectively with 3°C rise in ambient temperature in wheat ecosystem in north India. Thus, mineralization process would enhance while immobilization decrease under climate change which is not a welcome situation in tropics and subtropics. Soil structure and fertility enhancement services include the processes of soil formation, structural development (including physical, chemical, and biological properties of soil), and nutrient cycling mediated by biotic and abiotic factors to support plant growth. These soil characteristics are important determinants of the quantity and quality of farming outputs (Zhang *et al.* 2007). As soil organisms process dead organic matter, and their waste replenishes nutrients required for primary production, the fertility needed to support primary production is maintained (Daily *et al.* 1997).

Soil structure is enhanced through the activities of macro-fauna – such as earthworms, centipedes, millipedes, and isopods – that aerate soil by creating pores as they burrow through the soil profile, mixing organic and mineral particles, redistributing organic matter and microorganisms, and enriching soil with castings (Hendrix *et al.* 1990, Edwards 2004). A host of microfauna also act as biological mediators of soil fertility and structure. Their activities support soil fertility as they break down plant detritus and other organic matter, and incorporate nutrients into their biomass, which may otherwise move through the system or be lost downstream (Paul and Clark 1996). Micro- and macrofauna (e.g. acarina and collembola) influence nutrient cycling by regulating bacterial and fungal populations, release energy by breaking down large molecules into smaller units (catabolizing organic matter), and mineralizing and immobilizing nutrients. Their activities influence soil structure by producing organic compounds that bind soil aggregates. Bacteria and fungi are also part of an important cadre of microflora that mediates nitrogen fixation from the atmosphere, transforming it into plant available forms (Hendrix *et al.* 1990).

Erosion control: Plant diversity enhances belowground plant and microbial biomass, which is associated with the ES of erosion control through the effects of large root and mycorrhizal networks holding soil in place (Balvanera *et al.* 2006). Conversion of woodlands to crop land is the major reason for soil erosion at many instances. In such situations, reintroduction of trees contributes to effectively reduce water erosion by (i) acting as a barrier, and (ii) providing surface cover in the form of living and dead plant material which dissipates the energy of falling raindrop and the velocity of surface runoff (Nair 1991b). Studies in Europe revealed usefulness of both alley cropping and contouring practices (up to 70% reduction in erosion) (Palma *et al.* 2007). Agroforestry through control of erosion, maintenance of organic matter and enhancing nutrients helps in conservation of soil and thereby sustainable land use. Grevil (1993) developed and standardized *Eucalyptus-Eulaliopsis* silvipastoral model for eroded lands of Shivalik foot hills for wood and grass production and also for checking water erosion and soil loss. They reported that under *Eucalyptus* –bhabar grass (*Eulaliopsis binata*) system, the soil loss was negligible (0.07 t/ha) followed by *Acacia catechu* –Napier grass (0.28 t/ha) and Teak-Bhabar (0.43 t/ha). Studies in Europe revealed that erosion rates were comparable with agriculture crops during first year while erosion was minimized afterwards due to provision of soil litter cover, increased organic matter and improved infiltration. Typical erosion rates on moderate slopes ($\leq 5\%$) under woody short rotation coppices were between 2 and 4 Mg/ha/yr compared to reported erosion rates for conventional agriculture with maize between 18 to 22 Mg/ha/yr (Hohenstein and Wright 1994, Mann and Tolbert 2000, Pimentel and Krummel 1887). To enhance the beneficial effects of short rotation coppices on soil erosion reduction, longer rotation periods are recommended.

Control of soil degradation: At CAZRI, Jodhpur agroforestry system was developed on the principle reducing the threshold velocity of wind at the dune surface by establishing pre-planting mechanical system to stabilize sand dune. Bushwoods like *Leptadenia pyrotechnia*, *Zizyphus nummularia*, *Acacia jacquimontii*, *Crotalaria bushia* and *Saccharum munja* are useful which can be used as checkerboard or parallel head systems for initial stabilization of sand dunes. These should be used together on the tops and windward sides of the dunes and widely spaced on low dunes or depression (Gupta 1990). At Rajasthan in arid regions *A. tortilis* or *P. cineraria* with *C. ciliaris* in a silvipastoral system gave maximum returns compared to other combinations. Similarly, *Eucalyptus*, *Acacia* and *Populus* based crop system improved soil chemical properties (Singh *et al.* 1997) (Table 3).

Hazara (1994) concluded that association of trees with pastures provide faster recovery of the degraded lands. He reported that after 10 years maximum pore space, organic carbon and nutrients were available under *Leucaena leucocephala*. Samar and Singh (2000) observed an increase in soil organic carbon of surface soil from 0.39 to 0.52%

under *Acacia nilotica* + *Saccharum munja* and from 0.44 to 0.55% under *Acacia nilotica* + *Eulaliopsis binata* after five years and suggested that *Acacia nilotica* + *Eulaliopsis binata* as effective and ecofriendly conservation and rehabilitation of degraded lands of Sivalik foot hills of sub-tropical northern India. Ram Newaj *et al.* (2008) observed that in an agri-silviculture system *Albizia procera* with different pruning regimes increased soil organic carbon by 13 -16% which was 5 – 6 times higher over growing of either sole tree or crop.

Mine soils result in shifting mass of sand and rubble, denudation of forests, reduction in water holding capacity of reservoirs, rivers, streams etc. Agroforestry is a viable option for rehabilitation of such sites (Singh *et al.* 2000). Establishment of permanent vegetative cover of suitable trees and grass mixtures will improve the deteriorated conditions and stop further degradation. For revegetation of minesoils, plant species which are native, hardy, have N₂ fixing ability, have aesthetics, provide quick coverage during establishment and are ecologically and economically acceptable have been identified for different kinds of mine soils (Dadhwal and Kumar 1996).

Microclimate modification: Trees and shrubs in agroforestry/windbreak/shelterbelt systems can contribute to better microclimate. The trees bring about a whole complex of environmental changes, affecting not just available light but also air temperature, humidity, soil temperature, soil moisture content, wind movement and pest and disease complexes (Sileshi *et al.* 2007). These factors impact plants, and the effect can be beneficial to a wide array of crops and help conserve biodiversity as well (Bos *et al.* 2007, Rice and Greenberg 2000). Further, the tree litter and canopy have been documented to influence the microclimate in terms of improved rainfall infiltration, soil structure and microfauna, reduced evapotranspiration and temperature extremes, and increased relative humidity (Saka *et al.* 1994). In agroforests and home gardens, crops such as coffee, cardamom, pepper, other spices, cocoa etc., under a canopy of shade trees is a common sight in Western Ghats and north eastern states of India which flourish because prevailing congenial microclimate. These systems have also become the main stay of the inhabitants.

Pollination: Pollination is necessary for sexual reproduction in many crops, including fruits, vegetables, nuts, and seeds as well as many wild plants known to contribute calories and micronutrients to human diets. For instance, in litchi (*Litchi chinensis*) at Muzaffarpur, Bihar Srivastav *et al.* (2017) observed as many as 20 pollinating species under 20 genera of 8 families belonging to order Diptera, Hymenoptera and Coleoptera involved in pollination, while bees predominate (> 65%). Animal pollinators are essential for approximately 35% of global crop production, and 60–90% of all plant species are pollinator-dependent (Klein *et al.* 2007). Bees are recognized as the taxon providing most pollination services, yet other taxa – including birds, bats, thrips, butterflies and moths, flies, wasps, and beetles – also pollinate some of the

world's most important food crops (Nabhan and Buchmann 1997, Srivastava *et al.* 2017). Boreux *et al.* (2013) opines that pollination service from bees matters a lot in coffee production in Kodagu, Karnataka, India, while in litchi in Muzaffarpur, Bihar (Srivastava *et al.* 2017). Interestingly, Srivastava *et al.* (2017) revealed that all honeybee species differed in their responses to temperature, light intensity and solar radiation, the three most important factors influencing foraging behaviour.

Although honeybees (*Apis* spp.) are the most important commercially managed pollinator, native and wild bee species also make significant contributions. Approximately 15% of the value associated with pollination services comes from native bees and other animals living in farmlands and adjacent natural habitat (Mader *et al.* 2011). Both agricultural management and landscape configuration are important in determining availability and distribution of pollination services. Some wild (native) pollinators nest within fields, including ground-nesting bees, or disperse from nearby unmanaged habitats to pollinate crops (Ricketts *et al.* 2004). Conserving wild pollinators in unmanaged or restored natural habitats adjacent to agricultural fields can improve pollination levels and stability, which can support increases in agricultural yields (Klein *et al.* 2003). Recommendations for managing pollinator-friendly landscapes include maintaining areas of natural and semi-natural perennial habitat (e.g. grass and woodlands, forests, old fields, and hedgerows) to provide ample floral and nesting resources available throughout the year (Kremen *et al.* 2007, Mader *et al.* 2011).

Pest control: Strategies for enhancing pest control services to agriculture may require understanding predator ecology to ensure that pest predators have suitable food and habitat resources throughout their life cycles (Landis *et al.* 2000, Shivprasad 2009, Potdar 2010). Plants that provide floral or nectar resources can be used to sustain predators and parasitoids. Sweet alyssum (*Lobularia maritima*) has proven especially effective for bolstering syrphid fly abundances in California (Tillman *et al.* 2012). Predator populations can also be enhanced indirectly through agricultural practices that increase non-pest prey, for example, by applying mulch or intercropping (Riechert and Bishop 1990, Bugg *et al.* 1991, Shivprasad 2009, Potdar 2010). Small patches of native vegetation on and around farms can provide these species with food resources and overwintering habitat (Landis *et al.* 2000; Tillman *et al.* 2012). Emerging evidence suggests that conservation activities at a landscape scale can also benefit farmers. For example, conserving natural habitat surrounding farms increases predators and often enhances pest control services (Thies and Tschamtk 1999, Bianchi *et al.* 2006, Chaplin-Kramer *et al.* 2011b, Karp *et al.* 2013).

Hydrologic services – water flow regulation and water purification

Ecosystems through modification of the amount of water moving through the landscape influence the hydrologic cycle, including local climate, water use by plants, and

Table 4 Land equivalent ratio (LER) in alley cropping systems (ACS)

| Alley cropping systems | Location | LER | Reference |
|------------------------|-----------------------------|-----------|--------------------------------|
| Leucaena-sorghum | Dharwad, India ^a | 1.38-1.43 | Palled (1985) |
| Poplar-w/a/s/f | France ^a | 1.37 | Graves <i>et al.</i> (2010) |
| Poplar-w/fb/w/f/b/fb | United Kingdom ^a | 1.28 | Graves <i>et al.</i> (2010) |
| Black locust-Alfalfa | Germany ^b | 0.98 | Grunewald <i>et al.</i> (2007) |
| Poplar-Soybean | Canada | 2.40 | Rivest <i>et al.</i> (2010) |

Crop rotation: a asparagus, b barley, fb field beans, f fallow, s sorghum, w wheat ^aarable land, ^bpost mining site

modification of ground surfaces that alter infiltration and flow patterns (Brauman *et al.* 2007). The understanding of how water availability changes with land use and land cover change is elementary (Brauman *et al.* 2007). Planting of forests and trees – native or introduced – can either increase or decrease evapotranspiration and downstream water availability, depending on the context. In one study, analysis of paired catchment experiments found that stream flows were reduced 45% on an average when grasslands were converted to forests (Farley *et al.* 2005). Other studies from the Amazon basin illustrate that evapotranspiration from a pasture can be up to 24% less than a nearby forest (Von Randow *et al.* 2004). Vegetation can also be selected to support management goals based on water requirements.

Biodrains

The biodrainage technique is ecofriendly as the biodrainage plantations purify our environment by releasing oxygen into the environment and releasing oxygen into the environment. Trees also drain out the filtered fresh water into the atmosphere. Of late, the rise in ground water table followed by water logging and secondary salinization of soils has become serious problems in canal irrigated areas located in arid and semiarid regions. To combat problem, agroforestry shows the way. Evaluation of tree/grass species for the control of seepage, rising water table and soil salinity in levels in TBP irrigation command revealed that *A. nilotica* was the most promising at all salinity ranging from < 5 to > 15 dS/m, whereas *C. equisetifolia* promising initially registered high mortality and cease growth after 6-8 years (Vishwanath 2015). In contrast, *H. binata* less promising initially became promising after 6-8 years. In terms of seepage control, *A. nilotica* and *C. equisetifolia* were effective in arresting emerging seepage flows from the canals. *A. nilotica* and *C. equisetifolia* intercepted seepage over 80% and remained most promising over other species. The grasses in between complimented the effects. The water table receded significantly underneath the plantation while increased at the rate of 10 cm rise outside the plantation area. *A. nilotica* followed by *C. equisetifolia*

also improved soil organic carbon and porosity, while bulk density decreased. Trees improved hydraulic conductivity and infiltration rate and brought about a significant change in soil stability by improving aggregates, decreased soil and water erosion (Vishwanath 2015).

Under extreme conditions of high water table (WT) and salinity (WT: 0.75 to 1.0 m and saline 10-12 dS/m), *Acacia ferruginea*, *Albizia lebbek*, *Glyricidia maculata* and *Casuarina equisetifolia* were most tolerant, while *Dalbergia sissoo*, *Inga dulse*, *Eucalyptus hybrid* and *Pongamea pinnata* were moderately tolerant to salinity level up to 10-12 dS/m and WT up to 0.75 m (Vishwanath 2015). That apart, all the tree species also enriched the soil nutrient pool (NPK) and organic carbon. Jamun and sapota survived and grew better under relatively lower salinity and shallower water table conditions, whereas wood apple was promising under relatively high salinity but deeper water table conditions. Pomegranate and ber maintained a moderate survival and steady growth rate in low salinity and shallow water table conditions. For example, Australian studies describe use of plants such as lucerne (*Medicago sativa*), eucalyptus trees (*Eucalyptus* spp.), and saltbush (*Atriplex* spp.), which are thought to mitigate potential crop damages in areas where rising water tables bring saline water into root zones by lowering water tables through high transpiration rates (Heuperman *et al.* 2002).

Water quality

Maintaining water quality for agriculture and other uses is increasingly thought to require maintaining buffers of vegetation with intact groundcover and root systems throughout the watershed. Vegetation, microbes, and stabilized soils can remove pollutants from overland flow and from groundwater by physically trapping water and sediments, by adhering to contaminants, by reducing water speed to enhance infiltration, by biochemical transformation of nutrients and contaminants, and by absorbing water and nutrients from the root zone (Naiman and Décamps 1997). Vegetated riparian buffer zones in particular perform critical functions to support water quality.

Along with a decrease in erosion, pollutants carried with surface runoff causing non-point source pollution

are reduced in agroforestry systems (Udawatta *et al.* 2002) (Table 5). Agroforestry riparian buffers are widely recommended to trap movement of pollutants, i.e. excess nutrients from agricultural lands into water, and their effect relatively well documented in the temperate region (Daniels and Gilliam 1996, Lee *et al.* 2003, Schoonover *et al.* 2005, 2006). The reduction in sediment and nutrient losses is strongly dependent on the site conditions, precipitation factor, and vegetation. Measured reductions were between 0 and 100% for sediment loss, 20-90% for total N, 20-100% for NH₄-N, 24 -100% for NO₃-N, 8-91% for total P, and 58 – 100% for PO₄-P. Both grass and grass/wood strips were effective in reducing loss of sediments and nutrients. The ability of these systems to reduce erosion and nutrients exported with surface runoff is often related with measured higher microporosity and infiltration rates (Anderson *et al.* 2009, Kumar *et al.* 2010, Schoonover *et al.* 2005).

Trees planted at agricultural fields may contribute to reduce leaching related adverse effects on seepage quality (Dimitriou *et al.* 2009, Updegraff *et al.* 2008). Such regions could use lower quantity of fertilizers compared to intensively managed annual crop lands (Boehmel *et al.* 2008, Di Nasso *et al.* 2010). Furthermore, the use of pesticides is only marginal and especially limited to the first 2 years after planting (Dimitrou *et al.* 2009, Hofmann Schielle *et al.* 1999). Other reasons are the increase of soil organic matter caused by an increase of litter. Mulch and roots under trees that result in increased cation exchange capacity as well as nutrient retention or higher uptake rates of nutrients in the percolating soil solution (Lehmann and Schroth 2003). Deep rooted trees are able to capture and retrieve nutrients leached below the rooting zone of crops referred to as safety net effect (Jose *et al.* 2004).

Carbon sequestration

Atmospheric carbon as CO, CO₂, CH₄ etc. is the major culprit for the green house effect and ozone holes endangering biosphere. For all demerits, this carbon has to be sequestered in to solid phase bound carbon. Land use change has a significant impact on below ground carbon (C) stocks. Conversion of woodland to agricultural land depletes terrestrial C stocks by drastically reducing

Table 5 Reduction in sediment and nutrient loss with surface runoff in agroforestry buffer strips

| System | Slope (%) | Sediments | Nutrients | | | | | Reference |
|--------|-----------|-----------|-----------|--------------------|--------------------|----|--------------------|---------------------------------------|
| | | | TN | NH ₄ -N | NO ₃ -N | TP | PO ₄ -P | |
| G | 1-2 | 19 | 21 | ND | 24 | 8 | ND | Udawatta <i>et al.</i> (2002) |
| G | 1 | 94-100 | ND | 100 | 100 | ND | 100 | Schoonover <i>et al.</i> (2005, 2006) |
| G | 5 | 95 | 80 | ND | 62 | 78 | 58 | Lee <i>et al.</i> (2003) |
| G/W | 1-2 | 0 | 20 | ND | 37 | 17 | ND | Udawatta <i>et al.</i> (2002) |
| G/W | 5 | 97 | 94 | ND | 85 | 91 | 80 | Lee <i>et al.</i> (2003) |
| G/W | 4-15 | 80 | 50 | 20-50 | 59-90 | 60 | 50 | Daniels and Gilliam (1996) |
| F | 1 | 76-86 | ND | 68 | 97 | ND | 78 | Schoonover <i>et al.</i> (2005, 2006) |

TN total N, NH₄-N ammonical N, NO₃-N nitrate N, TP total P, PO₄- phosphate P, G grass strip, G/W grass/woody strip, F forest buffer, ND not determined. Source: Tsonkova *et al.* (2012)

the vegetation C and soil organic carbon (SOC) pools. Introduction of trees in agroforestry arrangements has the potential to increase soil organic matter (SOM) and store significant amount of C in woody biomass (Unruh *et al.* 1993). For smallholder agroforestry systems in the tropics, potential C sequestration rates range from 1.5 to 3.5 t C/y (Montagnini and Nair 2004). For instance, in Zambia, 2 to 12 year old *Leucaena* spp woodlots stored up to 74 t/ha in above ground biomass and 140 t/ha in the soil (Kaonga 2005). Coppicing fallows of *Gliricidia sepium*, *Senna siamea*, *Acacia* and *Leucaena* spp stored more C than the short duration fallows of Tephrosia, Sesbania and pigeonpea (Sileshi *et al.* 2007). Even simple systems such as the glyricidia - maize intercropping recycle substantial amounts of above ground C stocks to the soil via the organic materials. In India also agroforestry is promising alternate land use system to increase aboveground and soil C to mitigate climate changes. The average potential of agroforestry has been estimated to be 25 t C/ha over 96 m ha (Sathaye and Rvindrath 1998) and in this way there is a potential to store about 2400 m t.

The analysis of C stocks from various parts of world revealed that 1100 – 2200 Tg C could be removed from the atmosphere over the next 50 years if agroforestry systems are implemented on a global scale (Albercht and Kandji 2003). Based on assessment on national and global terrestrial C sinks, Kursten and Burschel (1993) identified two migratory effects of agroforestry on CO₂ emissions. The first direct near-term effect is C storage in trees and soils through accumulation in live tree biomass (3 – 60 t/ha), wood products (1 – 100 t/ha), and SOM (10 – 50 t/ha), and through protection of existing forests (up to 1000 t/ha). Secondly, agroforestry has potential to offset greenhouse gas emission through energy and material substitution, and reduction of fertilizer carbon foot print. About 5 – 360 t/ha of green house gas emissions are offset through energy substitution, up to 100 t/ha through material substitution and 1- 5 t/ha through reduction in fertilizer inputs. In addition, agroforestry can enhance C sequestration by decreasing pressure on natural forests, which are a terrestrial C sink. Therefore, there is growing consensus among scientists that agroforestry is a viable option of enhancing the terrestrial C sink (Lal 2004).

Biodiversity

Biodiversity – the variation of life in all forms from genes, to species, to communities, to whole ecosystems – is a significant determinant of ecosystem function and provision of ES. Although relationships between biodiversity and ES are complex and vary widely across different types of ecosystems, at the broadest level, increased native biodiversity is generally associated with higher levels of ES within a given system (Balvanera *et al.* 2006, Cardinale *et al.* 2012). It is also important to note that some ES are provided in part by the abiotic (nonliving) components of ecosystems, such as aquifers and inorganic portions of soils. Biodiversity can be considered a form of ‘biological

insurance’ that helps to assure ecosystem performance, including providing ecosystem services, as diversity increases the chances that one or more species will be able to perform critical functions, even in the event of disturbance or species loss (e.g. natural disaster and human-induced land use change) (Naeem and Li 1997).

Genetic resources provide a pool of raw material necessary to support the process of natural selection and produce evolutionary adaptations in unmanaged ecosystems. In agroecosystems, crop and animal breeders draw on genetic diversity using traditional breeding and biotechnology to artificially select and perpetuate desirable traits (Zhang *et al.* 2007). A broad portfolio of genetic resources increases the likelihood of maintaining production, particularly as environmental pressures such as climate, pests, and disease fluctuate. Production stability comes through an array of genotypes, each with different characteristics of disease resistance, tolerance for environmental extremes, and nutrient use (Esquinas-Alcázar 2005). Different genotypes, or cultivars, are required for planting in orchard systems and hybrid seed production to set fruit or seed (Free 1993, Delaplane and Mayer 2000). The benefits of genetic variation at the species level include enhanced biomass production, reduced loss to pests and diseases, and more efficient use of available nutrients (Tilman 1999).

Crop production is supported by genetic resources from two important sources. First are ‘landraces,’ the varieties of crops and livestock that have been cultivated and selected by farmers over many generations practicing traditional agriculture (Shand 1997). Second are closely related species that survive in the wild, known as crop ‘wild relatives.’ Areas with high concentrations of landraces and wild relatives are considered centers of crop genetic diversity (Shand 1997). These centers are critical, as many important crops could not maintain commercial production without periodic infusions of genetic resources from wild relatives (de Groot *et al.* 2002).

Ecosystem resilience

Agroforestry, due to above mentioned ES, can play a crucial role in improving resilience to uncertain climates through microclimate buffering and regulation of water flow. It helps to conserve and protect natural resources, mitigate non-point source pollution (e.g. dust), and create wildlife habitat. It facilitates flexible responses to rapid shifts in ecological conditions. Microclimatic improvement through agroforestry has a major impact on crop performance as trees can buffer climatic extremes that affect crop growth (Madiwalar 2016). In particular, the shading effects of agroforestry trees can buffer temperature and atmospheric saturation deficit reducing exposure to supra-optimal temperatures, under which physiological and developmental processes and yield become increasingly vulnerable. Scattered trees in agroforestry farms can enhance the understory growth by reducing incident solar radiation, air and soil temperature, while improving water status, gas exchange and water use efficiency. Lott *et al.* (2003)

reported that about 25% of the water transpired by trees is used during the dry season, indicating that they are able to utilize off-season rainfall (comprising 15–20% of the total annual rainfall) and residual soil water after the cropping period, with the rest being lost by evaporation (40%) or deep percolation (Mbow *et al.* 2014). Despite its small size, agroforestry can add a high level of diversity within agricultural lands and, with it, an increased capacity for supporting numerous ecological and production services that impart resilience to climate change (CC) impacts (Verchot *et al.* 2007). From a landowner's perspective, the most valued services would be those that dampen the negative effects of CC and weather extremes while augmenting the positive benefits provided by tree systems. CC risk management is difficult in annual-only systems due to the increasing uncertainty and volatility of inter-annual variability in rainfall and temperatures. The mixing of woody plants into crop, forage, and livestock operations provides greater resiliency to this inter-annual variability through crop diversification produced seasonally, as well as through increased resource-use efficiency (Olson *et al.* 2000).

Conclusion

World becoming more and more industrial, ES needs more attention and emphasis than ever before. Properly designed and strategically located agroforestry practices can contribute to ES by mitigation of land degradation, climate change and desertification, while conserving natural resources and biodiversity. Besides getting tree based goods and services, agroforestry can be considered as an adoptive strategy in areas climatically and biologically vulnerable. Being a potential C sink agroforestry can also mitigate negative impacts of CO₂ emission. As green belt, trees have a role in maintaining air, water and soil quality in mining and industrial areas. However, what presently understood is very little and there is need to understand the organisms, guilds, and ecological communities that provide ecosystem services and how these aggregate at different scales from cultivated fields to broader regions. Continued work on this front is needed to answer the growing call for agricultural landscapes that can simultaneously meet production and conservation goals.

ACKNOWLEDGEMENT

Authors would like to acknowledge sincerely all those whose work forms the base of this article particularly the Millennium Ecosystem Assessment (MES 2005) and Dr K Garbach *et al.* (2014) from Elsevier which have been extensively used. Besides, authors take pride in expressing their thanks to the University of Agricultural Sciences which has facilitated to carry out this work.

REFERENCES

- Alagundagi S C. 2016. Alternate land use systems for semiarid tropics. (In) *Climate Smart Agriculture: Status and Strategies*, pp 61-169. Chittapur B M, Halepyati A S, Umesh M R and Desai B K (Eds). University of Agricultural Science, Raichur, Karnataka.
- Albercht A and Kandji S T. 2003. Carbon sequestration in tropical agroforestry systems. *Agriculture, Ecosystem and Environment* **99**:15–27.
- Akinnifesi F K, Kwesiga F, Mhango J, Chilanga T, Mkonda A, Kadu C A C, Kadzere I, Mithofer D, Saka J D K, Sileshi G and Dilwayo P. 2006. Towards the development of miombo fruit trees as commercial tree crops in Southern Africa. *Forest Trees and Livelihood* **16**: 103–21.
- Anderson S H, Udawatta R P, Seobi T and Garret H E. 2009. Soil water content and infiltration in agroforestry buffer strips. *Agroforestry Systems* **75**: 5–16.
- Anitta Fanish S and Sathya Priya R. 2013. Review on benefits of Agroforestry system. *International Journal of Education and Research* **1**: 1–11
- Balvanera P, Pfisterer A B and Buchmann N. 2006. Quantifying the evidence for biodiversity effects on ecosystem functioning and services. *Ecology Letters* **9**: 1146–56.
- Bianchi F J J A, Booij C J H and Tschamtk T. 2006. Sustainable pest regulation in agricultural landscapes: A review on landscape composition, biodiversity and natural pest control. *Proceedings of the Royal Society B: Biological Sciences* **273**: 1715–27.
- Bimaendra Kumari and Madan V K. 2016. Performance of perennial medicinal crops in a three tier agroforestry system. *The Indian Forester* **142**(11) (www.indiaforester.co.in).
- Boehmel C, Lewandowski I and Claupein W. 2008. Comparing annual and perennial energy cropping systems with different management intensities. *Agricultural Systems* **96**: 224–36.
- Bohm C, Quinkenstein A, Frees D and Hutt R F. 2010. Energieholzproduktion in *Agroforestry systemen als ein Beitrag zur Verbesserung des Bodenschurzes*. *Bodenschutz in Europa: Ziele and Umsetzung – Marktredwitzer Bodenschutztag*, 06-08. Oktober 2010 in Marktredwitz, Bayern, Stadt Marktredwitz, pp 78–84.
- Boreux V, Kushalappa C G, Vaast P and Ghazoul J. 2013. Interactive effects among ecosystem services and management practices on crop production: Pollination in coffee agroforestry systems. *PANS* **110**: 8387–92.
- Borthakur B N, Prasad R N and Gosh S P. 1981. Agroforestry based farming systems as an alternative to jhumming. *Proceedings of Agroforestry Seminar*, ICAR, New Delhi, pp.109–31.
- Bos M M, Steffan-Dewenter I and Tschamtk T. 2007. Shade tree management affects fruit abortion, insect pests and pathogens of cacao. *Agriculture, Ecosystems and Environment* **120**: 201–5.
- Brauman K A, Daily G C, Duarte T K and Mooney H A. 2007. The nature and value of ecosystem services: An overview highlighting hydrologic services. *Annual Review of Environment and Resources* **32**: 67–98.
- Bugg R L, Wackers F L, Brunson K E, Dutcher J D and Phatak A C. 1991. Coolseason cover crops relay intercropped with cantaloupe: Influence on a generalist predator, *Geocoris punctipes* (Hemiptera: Lygaeidae). *Journal of Economic Entomology* **84**: 408–16.
- Cardinale B J, Duffy J E and Gonzalez A. 2012. Biodiversity loss and its impact on humanity. *Nature* **486**: 59–67.
- Chaplin-Kramer R, O'Rourke M E, Blitzer E J and Kremen C. 2011b. A metaanalysis of crop pest and natural enemy response to landscape complexity. *Ecology Letters* **4**: 922–32.
- Doddabasawa, Mahadeva Murthy M and Chittapur B M. 2017. Assessment of tree diversity, productivity and carbon sequestration potential in agroforestry systems. Ph D Thesis, University of Agricultural Sciences, Bangalore, Karnataka.
- Daily G C, Matson P A and Vitousek P M. 1997. Ecosystem services

- supplied by soil. (*In Nature Services: Societal Dependence on Natural Ecosystems*, pp 113–32. Daily G (Ed). Island Press, Washington.
- Daniels R B and Gilliam J W. 1996. Sediment and chemical load reduction by grass and riparian filters. *Soil Science Society of America Journal* **60**: 246–51.
- de Groot R S, Wilson M A and Boumans R M. 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics* **41**: 393–408.
- Delaplane K S and Mayer D F. 2000. Crop Pollination by Bees. CABI Publishing, New York, NY:
- Di Nasso N N O, Guidi W, Ragolini G, Tozzini C and Bonari E. 2010. Biomass production and energy balance of a 12 year-old short-rotation coppice poplar stand under different cutting cycles. *Global Change Biology and Bioenergy* **2**: 89–97.
- Dimitriou I, Busch G, Schmidt-Walter P and Lamerdorf N. 2009. A review of the impacts of short rotation coppice cultivation on water issues. *Landbauforschung Agriculture and Forestry Research* **59**: 197–206.
- Edwards C. 2004. *Earthworm Ecology*. CRC Press, Boca Raton, FL:
- Esquinas-Alcázar J. 2005. Protecting crop genetic diversity for food security: Political, ethical and technical challenges. *Nature Reviews Genetics* **6**: 946–53.
- Farley K A, Jobbágy E G and Jackson R B. 2005. Effects of afforestation on water yield: A global synthesis with implications for policy. *Global Change Biology and Bioenergy* **11**: 1565–76.
- Free J B. 1993. *Insect Pollination of Crops*. Academic Press, London, UK:
- Garbach K, Lubell M and DeClerck F A. 2012. Payment for ecosystem services: The roles of positive incentives and information sharing in stimulating adoption of silvopastoral conservation practices. *Agriculture, Ecosystems and Environment* **156**: 27–36.
- Graves A R, Burgess K J, Palma J H N, Keesman K J, van der Werf W, Dupraz C, van Keullen H, Herzog F H and Mayas M. 2010. Implementation and calibration of the parameter-sparse Yield-SAFE model to predict production and land equivalent ratio in mixed tree and crop system under two contrasting production situations in Europe. *Ecological Models* **221**: 1744–56.
- Grunewald H, Brandt B K V, Schneider B U, Oliver B, Kendzia G and Huttel R F. 2007. Agroforestry systems for the production of woody biomass for energy transformation purposes. *Ecological Engineering* **29**(4): 319–28.
- Gupta J P. 1990. Sand dunes and their stabilization. (*In Technologies for Wasteland Development*, pp 9–68. Abrol I P and Dhruv narayan V V (Eds). ICAR, New Delhi.
- Haines-Young R and Potschin M (Eds). 2012. CICES (Common International Classification System of Ecosystem Services). Consultation on Version 4, August–December 2012, Centre for Environmental Management, University of Nottingham, Nottingham:
- Hall J B, O'Brien E M and Sinclair F L. 2002. *Sclerocarya birrea*: a monograph. Publication No. 19, School of Agriculture and Forest Science, University of Wales, Bangor, UK, p 157.
- Hawtin G C. 2000. Genetic diversity and food security. UNESCO Courier, May 2000, pp 27–29. Available at http://www.unesco.org/courier/2000_05/uk/doss23.htm (accessed 15.01.14).
- Hazra C R. 1994. Soil and water conservation for natural resource regeneration in agroforestry. *Range Management and Agroforestry* **15**: 229–39.
- Hendrix P F, Crossley Jr. D A, Blair J M and Coleman D C. 1990. Soil biota as components of sustainable agroecosystems. (*In Sustainable Agricultural Systems*, pp 637–54. Edwards C A, Lal R, Madden P, Miller R H and House G (Ed). CRC Press, Boca Raton, FL:
- Heuperman A F, Kapoor A S and Denecke H W. 2002. *Biodrainage – Principles, Experiences and Applications*. Food and Agriculture Organization of the United Nations, Rome, Italy:
- Hofmann Schielle C Jug A, Makeschin F and Rchfuess K E. 1999. Short-rotation plantations of balsam poplars, aspen and willows on former arable land in Federal Republic of Germany: I Site-growth relationships. *Forestry and Ecology Mangement* **121**: 41–55.
- Hohenstein W G and Wright LL. 1994. Biomass energy production in the United States: an overview. *Biomass and Bioenergy* **6**: 161–73.
- IPCC. 2000. Land use, land-use change and forestry. IPCC special report. http://www.grida.no/climate/ipcc/land_use/500.htm
- UNCCD. 2007. www.unccd.entico.com/english/glossary.htm
- Jose S, Gillespie A R and Pallardy S G. 2004. Interspecific interactions in temperate agroforestry. *Agroforestry Systems* **61**: 237–55.
- Joshi B, Shiva Dhar Singh, Megla Devi B, Pathatk H, Sharma D K and Choudhary A. 2017. Effect of elevated temperature on soil microbial activity and nitrogen transformation in wheat crop (*Triticum aestivum*). *Indian Journal of Agricultural Sciences* **87**: 167–72.
- Kakaichelvi K and Swaminathan A A. 2009. Alternate land use through cultivation of medicinal and aromatic plants – A review. *Agriculture Reviews* **30**(3): 176–83.
- Kaonga M L. 2005. Understanding carbon dynamics in agroforestry systems in Eastern Zambia. Ph D thesis, Fitzwilliam College, University of Cambridge, UK.
- Karp D S, Mendenhall C D and Sandi R F. 2013. Forest bolsters bird abundance, pest control, and coffee yield. *Ecology Letters* **16**: 1339–47.
- Kimaro A A, Timmer V C, Mugasha A G, Chamshama S A O and Kimaro D A. 2007. Nutrient use efficiency and biomass production of tree species for rotational woodlot systems in semi arid Morogoro,, Tanzania. *Agroforest Systems* DOI 10, 1007/s 104457-007-906-x.
- Klein A M, Steffan-Dewenter I and Tschardt T. 2003. Fruit set of highland coffee increases with the diversity of pollinating bees. *Proceedings of the Royal Society of London. Series B: Biological Sciences* **270**: 955–61.
- Klein A M, Vaissiere B E and Cane J H. 2007. Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B: Biological Sciences* **274**: 303–13.
- Kremen C, Williams N and Aizen M. 2007. Pollination and other ecosystem services produced by mobile organisms: A conceptual framework for the effects of land-use change. *Ecology Letters* **10**: 299–314.
- Kremen C, Williams N M, Bugg R L, Fay J P and Thorp R W. 2004. The area requirements of an ecosystem service: Crop pollination by native bee communities in California. *Ecology Letters* **7**: 1109–19.
- Kruess A and Tschardt T. 1994. Habitat fragmentation, species loss, and biological control. *Science* **264**: 1581–4.
- Kumar S, Anderson S H, Udawatta R P and Gantzer C J. 2010. CT-measured macropores as affected by agroforestry and grass buffers for grazed pasture systems. *Agroforestry Systems* **79**: 59–65.

- Kursten E and Burschel P. 1993. CO₂ mitigation by agroforestry. *Water, Air and Soil Pollution* **70**: 533–44.
- Kuznetsova T, Lukjanova A, Mandre M and Lohmus K. 2011. Above ground biomass and nutrient accumulation dynamics in young black alder, silver birch and Scots pine plantations on reclaimed oil shale mining areas of Estonia. *Forest Ecology Management* **262**: 56–64.
- Lal R. 2004. Terrestrial carbon sequestration in tropical forest ecosystems. *Book of Abstracts*. 1st World Congress of Agroforestry: Working together for sustainable land use systems. 27 June 2 July 2004, Orlando, Florida, USA, p 14.
- Landis DA, Wratten S D and Gurr G M. 2000. Habitat management to conserve natural enemies of arthropod pests in agriculture. *Annual Review of Entomology* **45**: 175–201.
- Lee K H, Isenhardt T M and Schultz R C. 2003. Sediment and nutrient in an established multi-species riparian buffer. *Journal of Soil and Water Conservation* **58**: 1–8.
- Lehmann J and Schroth G. 2003. Nutrient leaching. (In) *Trees, Crops and Soil Fertility*, pp 151–66. Schroth G and Sinclair F L (Eds). CAB International, Wallingford.
- Lott J E, Khan A A H, Black C R and Ong C K. 2003. Water use in a *Grevillea robusta* — maize overstorey agroforestry system in semi-arid Kenya. *Forest Ecology and Management* **180**: 45–59.
- Mader E, Shepherd M, Vaughan M, Black S H and LeBuhn G. 2011. *Attracting Native Pollinators: Protecting North America's Bees and Butterflies*. The Xerces Society Guide. Storey Publishing, Portland, OR:
- Madiwalar S L. 2016. Role of trees in climate smart agriculture. (In) *Climate Smart Agriculture: Status and Strategies*, pp 170–3. Chittapur B M, Halepyati A S, Umesh M R and Desai B K (Eds). University of Agricultural Sciences, Raichur, Karnataka.
- Makombe L (Ed). 1993. *Sharing the Land: Wildlife, People and Development in Africa*. IUCN, Harare and Washington DC, p 36.
- Mangu P. 1999. Community use and management of Licuati reserve and surrounding areas, (In) *Integrated Analysis and Management of Renewable Resources in Mozambique*, p 36. Desanker P V and Santos L (Eds). Maputo, Mozambique.
- Mann L and Tolbert V. 2000. Soil sustainability in renewable biomass plantings. *Ambio* **29**: 492–8.
- Matos E S. 2010. Organic carbon dynamics in soils under different land use systems. Ph D thesis, Faculty of Environmental Sciences and Process Engineering, University of Technology Brandenburg. p 91.
- Matson P, Parton W, Power A and Swift M. 1997. Agricultural intensification and ecosystem properties. *Science* **277**: 504–9.
- Mbow C, Smith P, Skole D L and Bustamante M. 2014. Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa. *Sustainability Challenges* **6**: 8–14.
- Montagnini F and Nair P. 2004. Carbon sequestration: An underexploited environmental benefit of agroforestry systems. *Agroforestry Systems* **61**: 281–95.
- Mwihomeke S T and Chamshma S A O. 2004. Fuelwood production by tree species planted along contour strips on the slopes of west Usambara Mountains, Tanzania. (In) *Proceedings of the Regional Agroforestry Conference on Agroforestry Impacts on livelihoods in Southern Africa: Putting Research into Practice*. Rao M R and Kwesiga F R (Eds). World Agroforestry Centre (ICRAF), Nairobi, Kenya, pp 165–71.
- Nabhan G P and Buchmann S L. 1997. Services provided by pollinators. (In) *Nature's Services: Societal Dependence on Natural Ecosystems*, pp 133–50. Daily G C (Ed). Island Press, Washington DC:
- Naiman R J and Décamps H. 1997. The ecology of interfaces: Riparian zones. *Annual Review of Ecology and Systematics* **28**: 621–58.
- Nair P K R. 1993. Soil conservation. (In) *An Introduction to Agroforestry*, pp 325–46. Nair P K R (Ed). Kluwer Academic Publishers, Dordrecht.
- Nair P K R. 1985. Classification of agroforestry systems. *Agroforestry Systems* **3**: 97–128.
- Narashima Reddy. 2016. *Agriculture and Herbal Vison* **2-3**: 13–7.
- Nii-Annang S, Grunewald H, Freese D, Huttel R F and Dilly O. 2009. Microbial activity, organic C accumulation and 13C abundance in soils under alley cropping systems after 9 years of recultivation of quaternary deposits. *Biology and Fertility of Soils* **45**: 531–8.
- Nysdzi G I, Otsyina R M, Banzi F M, Bakengasa S S, Gama B M and Mbwapo L. 2003. Rotational woodlot technology in northwestern Tanzania: Tree species and crop performance. *Agroforestry Systems* **59**: 253–63.
- Olson R K, Schoeneberger M M and Aschmann S G. 2000. An ecological foundation for temperate agroforestry. (In) *North American Agroforestry: An Integrated Science and Practice*, pp 31–62. Garrett H E, Rietveld W J and Fisher R F (Eds).
- Otsyina R, Rama Dhani T and Asenga D. 1999. Rotational woodlots-An approach to mitigate deforestation in Tanzania. *Faculty of Forestry and Nature Conservation Record* **72**: 122–30.
- Palled Y B. 1985. Agronomic investigation on subabul. Ph D thesis, University of Agricultural Sciences, Bangalore, Karnataka.
- Palm C A, Woomes P L, Alegre J, Arevalo L, Castilla C, Courdeiro D G, Feigi B, Harlan K, Kotto-Same J, Mendes A, Moukam A, Muridiyarso D, Njomgang R, Patron W J, Riese A, Rodrigues V, Sitompul S M and van Noordwijk M. 2000. *Carbon sequestration and trace gas emission in slash and burn alternative land uses in humid tropic: ASB Climate Change Working Group Report. Final Report, Phase II*. ICRAF, Nairobi, Kenya.
- Post W M and Kwon K C. 2000. Soil carbon sequestration and land use change: Processes and potential. *Global Change Biology* **6**: 317–27.
- Palma J H N, Graves A R, Burgess K J, Keesman K J, van Keulen H, Mayus M, Reisner Y and Herzog F. 2007. Methodological approach for the assessment of environmental effects of agroforestry at the land scape scale. *Ecology Engineering* **29**: 450–62.
- Paul E A and Clark F E. 1996. *Soil Microbiology and Biochemistry*. Academic Press, New York, NY.
- Pimentel D and Krummel J. 1887. Biomass energy and soil erosion: assessment of resource costs. *Biomass* **14**: 15–38.
- Potdar M P. 2010. Spectral characterization, acreage and production estimation through remote sensing and management of pod borer (*Helicoverpa armigera*) through polycropping in pigeonpea. Ph D thesis, University of Agricultural Sciences, Dharwad, Karnataka,
- Rai P S, Yadav R S, Solanki K R and Rao G R. 1999. Growth and pruned biomass production of multipurpose tree species in silvi-pastoral system on the graded lands in semi-arid region of Uttar Pradesh, India, *Forest Tree Livelihood* **11**: 347–64.
- Ram Newaj, Dar S A and Bhadur R. 2008. Carbon sequestration in agriculture as affected by canopy pruning of *Albizia procera* under irrigated ecosystem. (In) *Abstracts, National Symposium on Agroforestry Knowledge for sustainability*,

- Climate Moderation and Challenges Ahead*, 15-17 Dec. 2008, NRCAF, India, p 82.
- Rice R A and Greenberg R. 2000. Cacao cultivation and the conservation of biological diversity. *Ambio* **29**: 81–7.
- Ricketts T H, Daily G C, Ehrlich P R and Michener C D. 2004. Economic value of tropical forest to coffee production. *Proceedings of the National Academy of Sciences of the USA* **101**: 12579–82.
- Riechert S E and Bishop L. 1990. Prey control by an assemblage of generalist predators: Spiders in garden test systems. *Ecology* **71**: 1441–50.
- Rivest D, Cogliasto A, Bradley R L and Oliver A. 2010. Intercropping hybrid poplar with soybean increased soil microbial biomass, mineral N supply and tree growth. *Agroforestry Systems* **80**: 33–40.
- Rockström J, Steffen W and Noone K. 2009. A safe operating space for humanity. *Nature* **461**: 472–5.
- Saka A R, Bunderson W T, Itimu O A, Phombeya H S K and Mbekeani Y. 1994. The effects of *Acacia albida* on soils and maize grain yields under smallholder farm conditions in Malawi. *Forest and Ecology Management* **64**: 2217–30.
- Samar J S and Singh C S. 2000. Silvopasture systems for soil, water and nutrient conservation on degraded lands of Shivalik foot hills (subtropical northern India). *Indian Journal of Soil Conservation* **28**: 5–42.
- Sathaye J A and Rvindrath N H. 1998. Climate change mitigation in the energy and forestry sectors of developing countries. *Annual Review Energy and Environment* **23**: 387–437.
- Schoonover J, Williard K, Zaczek J, Mangun J and Carver A. 2005. Nutrient attenuation in agricultural surface runoff by riparian buffer zones in Southern Illinois, USA. *Agroforestry Systems* **64**: 169–80.
- Schoonover J, Williard K, Zaczek J, Mangun J and Carver A. 2006. Agricultural sediment reduction by giant cane and forest riparian buffers. *Water, Air and Soil Pollution* **169**: 303–15.
- Shand H. 1997. *Human Nature: Agricultural Biodiversity and Farm-based Food Security*. Report by the Rural Advancement Foundation International (RAFI) for the Food and Agriculture Organization of the United Nations, Rome, Italy.
- Shivaprasad M. 2009. Agronomic investigations for yield maximization in chilli through management of leaf curl (*Murda*) complex. Ph D thesis University Agricultural Sciences, Dharwad.
- Sileshi G, Akinnifesi F K, Ajayi O C, Chakeredza S, Kaonga M and Matakala P W. 2007. Contributions of agroforestry to ecosystem services in the miombo eco-region of eastern and southern Africa. *African Journal of Environment Science and Technology* **1**: 68–80.
- Singh G S, Singh N T, Dagar J C, Singh H and Sharma V P. 1997. An evaluation of agriculture, forestry and agroforestry practices in a moderately sodic soil in north-west India. *Agroforestry systems* **37**: 279–95.
- Singh G, Yadav J S P and Singh G B. 2000. Multipurpose tree species management. (In) *Natural Resource management for Agricultural Production in India*. Yadav J S P and Singh G B (Eds). International Conference on Managing Natural Resources for Sustainable Agricultural Production in the 21st Century, New Delhi, 14-18, Feb. 2000.
- Srivastav K, Sharma D, Pandey S P, Anal A K D and Vishal Nath. 2017. Dynamics of climate and pollinator species influencing litchi (*Litchi chinensis*) in India. *Indian Journal of Agricultural Sciences* **87**(2): 266–9.
- Tallis H and Kareiva P. 2005. Ecosystem services. *Current Biology* **15**: 746–8.
- Thies C and Tschardt T. 1999. Landscape structure and biological control in agroecosystems. *Science* **285**: 893–5.
- Tillman P G, Smith H A and Holland J M. 2012. Cover crops and related methods for enhancing agricultural biodiversity and conservation biocontrol: Successful case studies. (In) *Biodiversity and Insect Pests: Key Issues for Sustainable Management*, pp 309–27. Gurr G M, Wratten S D, Snyder W E and Read D M Y (Eds), John Wiley & Sons, New York, NY.
- Tilman D. 1999. Global environmental impacts of agricultural expansion: The need for sustainable and efficient practices. *Proceedings of the National Academy of Sciences of the USA* **96**: 5995–6000.
- Tsonkova P, Bohm C, Quinkenstein A and Freese D. 2012. Ecological benefits provided by alley cropping systems for production of woody biomass in the temperate region: A review. *Agroforestry Systems* **85**: 133–52.
- Udawatta R P, Krstansky J J, Henderson G S and Garrett H E. 2002. Agroforestry practices, runoff, and nutrient loss: a paired watershed comparison. *Journal Environmental Quality* **31**: 1214–22.
- Unruh J D, Houghton R A and Lefebvre P A. 1993. Carbon storage in agroforestry: an estimate for sub-Saharan Africa. *Climate Research* **3**: 39–52.
- Updegraff K, Gowda P and Mulla D J. 2008. Watershed-scale modeling of the water quality effects of cropland conversion to short rotation woody crops. *Renewable Agriculture and Food Systems* **19**: 118–27.
- Uri V, Lohmus K, Mander U, Ostonen I, Aosas J, Maddison M, Helmsaari H S and Augustin J. 2011. Long-term effect on the nitrogen budget of a short-rotation grey alder (*Alnus incana* (L) Moench) forest on abandoned agricultural land. *Ecological Engineering* **37**(6): 920–30.
- Verchot L V, Van Noordwijk M, Kandji S, Tomich T, Ong C, Albrecht A, Mackensen J, Bantilan C, Anumpama K V and Palm C. 2007. Climate change: linking adaptation and mitigation through agroforestry. *Mitigation and Adaptation Strategies for Global Change* **12**: 901–18.
- Vishwanath. 2015. AICRP on Management of Salt Affected Soils and Use of Saline Water in Agriculture, Agriculture Research Station, Gangavati, Karnataka. pp 1-4 (personal communication).
- Von Randow C, Manzi A and Kruijt B. 2004. Comparative measurements and seasonal variations in energy and carbon exchange over forest and pasture in South West Amazonia. *Theoretical and Applied Climatology* **78**: 5–26.
- Zhang W, Ricketts T, Kremen C, Carney K and Swinton S. 2007. Ecosystem services and disservices to agriculture. *Ecological Economics* **64**: 253–60.