**Course Title: ADVANCES IN AGRO-FORESTRY**

**Course Code: FRW-703**

**Course Credit Hours: 3(2-1)**

**Course Incharge: Prof. Dr Tanveer Hussain**

## THEORY

Ecotone concept. Detailed discussions on the interaction between various trees and crops with respect to different methods of mixtures, land capability classes locations and climatic conditions. Discussions on the scope and extent of Agro-Forestry as the only feasible solution of Forestry crises in Pakistan. Discussions of formulating a suitable strategy for its development. Role of small sized forest based industries involving low capital investment. Role of large industries associated with raw material collection points and processing units widely scattered in the rural areas.

## PRACTICALS

Critical evaluation of agricultural farms in various eco-zones with respect to Agro-Forestry, identification of problems and suggesting their solutions. Report writing.

## SUGGESTED READINGS

1. Chuhan, S. K., S. S. Gill, H. N. Khjuria and R. Chuhan. 2006. Production Technology and Management of Agroforestry Models. S. S. S. Printers New Delhi, India.

2. Gary, L. R., J. M. Edington, I. I. Holland and G. C. Fortenberry. 2005. Forest and Forestry. Book Co. Lucknow, India.

3. Kundu, S. S., O. P. Chaturvedi, J. C. Dogar and S. K. Sirohi. 2008. Environment, Agroforestry, and Livestock Management. Salasar Imaging system, New Delhi. India.

4. Nyland, R. D. 2007. Silviculture: Concept and Applications. McGraw-Hill Companies, Inc. Singapore.

**Ecotones** were first defined as a "stress line connecting points of accumulated or abrupt change" on a landscape (Livingston 1903). With the rise of conservation and global climate change biology ecotone research has increased significantly in popularity beginning in the 1980s (Kark & Rensburg 2006). Since then, definitions of ecotones and methods used to delineate them have evolved.

Ecotones, transition zones found at abrupt discontinuities in vegetation, are a part of every landscape and have long been considered hotspots for biodiversity and conservation of both plants and animals. However, many assumptions about ecotone characteristics have not been rigorously tested. The most prevalent claim in the literature is that ecotones support higher species richness than adjacent habitats. Patterns of higher species richness in ecotones has been hypothesized to arise from ecological processes ranging from spatial mass effect, increased environmental heterogeneity, seed predation or introduction by animals or insects, to increased dispersal ability by exotic generalists. The purpose of this project is to document patterns of plant functional group richness and abundance across grassland-aspen ecotones in the Lac du Bois grasslands north of Kamloops, British Columbia. Specifically, this research addresses the following questions: 1) Are ecotones more species-rich than surrounding areas in both north-and south-facing aspects? 2) What is the relationship between functional diversity and species richness across the grassland-aspen ecotones? and 3) How does the method of ecotone definition (statistical versus visual) and data analysis (blocking versus gradient approach) impact the results?

**ECOTONE CHARACTERISTICS**

Recently, ecotones have garnered considerable ecological attention for both conservation and theoretical reasons. The potential of ecotones to contain high species diversity coupled with their role in the flow of energy, nutrients, and genes have led to the argument that ecotones are important landscape elements for conservation of species and habitat (Risser 1995, Fagan et al. 2003, Kark 2013). Like all ecological systems, ecotones can be observed from many spatial scales; from continental i.e., latitudinal vegetation gradients (Gosz 1993), to the local landscape level i.e., riparian zones of small water bodies (Risser 1995). Local scale ecotones can be natural or anthropogenic in origin and range from very young and dynamic to ancient and essentially static. An ecotone's location, extent and sharpness can be influenced by underlying environmental gradients such as soil type, bedrock, site productivity, topography, local hydrology and snow cover (di Castri et al. 1988; Van der Maarel 1990; Bestelmeyer et al. 2006; Gottfried et al. 2011). For example, in reverse treelines, where lower elevations are grassy and trees occur at higher elevations, Coop and Givnish (2007) found that treelines are strongly correlated to shifts in the thermal regime, only weakly associated with soil nutrient and type and not associated with soil moisture.

At the local scale, the study of ecotones has involved two major approaches; the analysis of underlying environmental gradients or the response of populations, species and communities to these gradients (Kark & Rensburg 2006). The plant communities within these ecotonal zones are traditionally thought to be made up of a blending of the two adjacent systems, with some unique ecotonal species (di Castri et al. 1988). Some studies have found that edge-effects (often equated with ecotones) associated with disturbed or managed forests can extend to fifty metres or more into adjacent ecosystems (Matlack 1994). As a result, an ecotone associated with a treeline, for example, can be very wide, reaching beyond the physical treeline on both sides. Ecotones and plant communities are also strongly influenced by aspect (McLean 1970; Vyse & Clarke 2000; Hylander 2005) since differences in solar exposure, prevailing winds and precipitation patterns impact plant abundance and richness. As a result, it is important to measure plant richness and abundance patterns on both north- and south-facing aspects (Holland & Steyn 1975; Orczewska & Glista 2005).

**ECOTONES AND CLIMATE CHANGE**

As changing climates impact the location and extent of ecosystems, ecotones will likely migrate or change size (Loehle 2000). This is often noted when treeline ecotones are discussed. Treelines often shift north or upwards in elevation as climate changes locally (Taylor & Taylor 1997; Díaz-varela et al. 2010). Due to this movement and sensitivity to climate, treeline ecotones are often seen as early indicators of future changes and have been identified as potentially useful for evaluating the stability of forest stands under the increasing stresses of climate change (Walker et al. 2003; Senft 2009; Díaz-varela et al. 2010).

The ecological response of ecotone species to disturbances such as climate change may be related, in part, to the distribution of individual species across environmental gradients (Shipley et al. 2011). Ecotones dominated by a large number of species with narrow distributions are likely to experience more compositional shifts than ecotones dominated by species with wide distributions across the ecotone (Hylander 2005). In dynamic ecotones, the age of the ecotone may also impact patterns of species richness (Halpern et al. 2010).

**COMMON ASSUMPTIONS REGARDING ECOTONES**

Definitions of ecotones often include several untested assumptions that are important to evaluate empirically. First and foremost, there has been a longstanding assumption that ecotones are areas of high species diversity due to an increased rate of species change across environmental gradients (Camarero et al. 2006). However, several researchers (Lloyd et al. 2000; Walker et al. 2003; Senft 2009) have found evidence that not all ecotones are more species-rich than their surrounding communities. Similarly, a meta-analysis of 21 studies found that riparian ecotones contributed to increased regional species richness through the occurrence of different, rather than more, plant species (Sabo et al. 2005). Other common assumptions regarding ecotone concepts are that ecotones are defined by sharp rather than gradual vegetation transitions, that they encompass changes in physiognomy when compared to adjacent plant communities, that they contain unique ecotonal species (di Castri et al. 1988), or contain more exotic species than in adjacent plant communities (Allen & Knight 1984; Vavra et al. 2007).

Senft (2009) reviewed hypotheses presented to explain the potential richness of ecotones. In general, Senft found that increased ecotonal richness was predicted to result from: 1) increased environmental heterogeneity allowing increased species packing (Auerbach & Shmida 1987) and a higher species richness overall; 2) an increase in animal-dispersed seeds into ecotones (Russo et al. 2006; Vazquez et al. 2009) or animal grazing (Willson & Traveset 2000); 3) an increase of propagules from adjacent areas (spatial mass effect (Shmida & Wilson 1985)); or 4) an increase in exotic species found in the ecotone.

# Introduction and History of Agroforestry

Trees have an important role to play on earth by fulfilling the basic necessities of all living organisms from micro organisms to animals. The world's population is assumed to reach at 10 billion by the middle of 21st century (UN 1995) if it continues to grow at the present rate. This upcoming challenge reveals a great demand of food, fiber and shelter to cover social, medical and economical demands of human beings. Trees are also essential for the survival of about 200 million people worldwide by providing wood and income (Ansari and Iftikhar 1985).

There is no doubt that agroforestry has been practiced since millennia as an arrangement of traditional land-use systems and practices but in late 1970s, it was evolved as a modern and improved land-use system. It has been a customary practice to grow trees and crops in a combination for getting maximum benefits and intermediate income. Not only in Asia, but it has been practiced in European countries like Finland and Germany as well. Beside this, farmers of tropics and Central America have been regularly involved in growing different tropical trees on their farmlands aiming at obtaining timber benefits, shelter tree crop and windbreaks (Nair 1993). Such examples can also be found in Asia i.e., the farmers practiced agroforestry in Philippine by clearing the forest area for agricultural crop production but leaving a few selected trees to provide a partial canopy or shelter to new crop (Nair 1993). These examples indicate that trees are integral part of cropping system to support agriculture. The change of cropping pattern or the inclusion of tree species into traditional farming system started in 1806 from Burma which was under British Empire at that time. U Pan Hle, a Karen in the Tonze forests of Thararrawaddy Division in Burma, established a plantation of teak through the use of "taungya" (hill cultivation) method and presented it to Sir Dietrich Brandis (Blanford 1958). This system was further spread to other parts of Burma and later it reached South Africa in early times of 1887, India in 1890 and Bengal in 1896 (Raghavan 1960). This is important to mention that teak is not the only species that can be used in agroforestry system, other tree species of multiple benefits can also be used for this purpose.

Like the traditional land-use disciplines of agriculture and forestry, agroforestry covers biological, physical and social science disciplines. (Mercer and Miller 1998). Understandably, the biophysical sciences have dominated the first two decades of agroforestry research and development because the interest in agroforestry as a land use emerged from observations of the impacts of non sustainable farming systems on tropical soils and forests (Nair 1996). Concerns over the inadequacy of socioeconomic research in agroforestry began to grow, however, as improved agroforestry systems were transferred from research institutions to rural development projects. As mentioned above, during the 1980s agroforestry became an established focus of international rural development efforts. For example, in 1988 and 1989 ICRAF identified 166 agroforestry projects supported by developmental organizations and government agencies (Miiller and Scherr 1990), and by the early 1990s the US Agency for International Development alone supported 28 agroforestry and technological advances, agroforestry rural development efforts were frequently unsuccessful (Nair 1996).

More than a decade of discussions on how to protect the world's forests has resulted in substantial changes in the way forests are managed. Policies and programs help to promote sustainable forest management. Forest plantations comprise about 5% of the world's forests. Asia has the largest area of plantations, accounting for 62% of the world's total. China accounts for 24% of that total and India, 18% (FAO 2000). The area of forest plantations was increased by an average of 3 million hectares per year during the 1990s. Half of this increase was the result of afforestation on land previously under non-forest land use, whereas the other half resulted from conversion of natural forest. In Pakistan, at present about 90% fuel wood and 60% timber comes from farmlands. Thus, agroforestry is playing a vital role in fulfilling our wood requirements. It is estimated that 10% area of our farmlands can be easily brought under tree cover without harming agricultural crops. At present the tree cover on farmlands is only 2%. There are about 300 million trees on farmlands throughout the country with a standing volume of 70 million $m^3$ (Quraishi 1998).

The significance of wood produced on farmlands has increased sharply during the last two decades. According to FSMP (Forestry Sector Master Plan) the annual growth of forests and trees was 14.4 million $m^3$ of which 7.7 million $m^3$ (53%) was put on by the farmland trees. The farmlands of the Punjab have about 200 million trees of which 95% are in irrigated areas. These trees are mainly comprised of *Dalbergia sissoo* (42%), *Acacia modesta* (20%), *Acacia nilotica* (11%), *Melia azedarach* (7%), and Mango (6%). Ber (31%), *Acacia modesta* (20%), *Acacia nilotica* (19%) and *Dalbergia sissoo* (7%) are the predominant species in rainfed areas (Quraishi, 1998). The farmers have long recognized the value of planting trees on fields for sheltering crops, generating wood for self-consumption and commercial sale. Scattered trees have less competition with agricultural crops and they yield tangible benefits at very little cost and efforts.

Figure 9.1 manifested that agroforestry is adopted for various purposes. This figure provides a detailed overview of agriculture-forestry interface based on the socio-economic need of the community. An agroforestry system possesses three main qualities to obtain maximum benefits i.e., productivity (farm income can be increased by enhanced tree products' output, improvement in crop yield, and optimizing labour efficiency), sustainability (improvement in soil fertility, reclamation of problem soils) and adoptability (introduction of new and improved technologies in agroforestry systems).

## Agroforestry Systems and Practices

Based upon the concept and definition of agroforestry, different agroforestry types can be observed around us. Based upon ecological, geographical and farming system combinations, different agroforestry systems can be classified. These classifications were made on the basis of findings and reports described by ICRAF and Nair (1987). These reports explain the collection and evaluation of present land-use systems. These reports not only assist in classifying the agroforestry systems but it also provided a detailed and comprehensive database to evaluate the strengths and weaknesses of current agroforestry systems and the proposed ones. Reviewing the classification of agroforestry, a common objective can be found in all, which is the essence of agroforestry i.e., “the purposeful growing or deliberate retention of trees with crops and/or animals in interacting combinations for multiple products or benefits from the same management unit” (Nair 1993).

Generally, agroforestry systems are classified into three systems on structural basis i.e., agrisilviculture (combination of trees and crops), silvopastoral (combination of pasture, livestock and trees) and agrosilvipastoral (combination of crops, pastures, livestock and trees) (Figure 9.2). A few other classifications are also proposed based on the function, agro-ecological and environmental adoptability, and socio-economic and management level. These classification criteria are confined only to specific geographical regions. So, here we will discuss only above mentioned three agroforestry systems.

It’s a common misunderstanding that growing agriculture crops and trees on the same piece of land is considered as agroforestry. It has been wrongly interpreted somewhere in literature. For a detailed understanding about agroforestry concept, the components should be understood. In an agroforestry system, three components have prime importance i.e., trees, pastures/ livestock and agriculture crops.

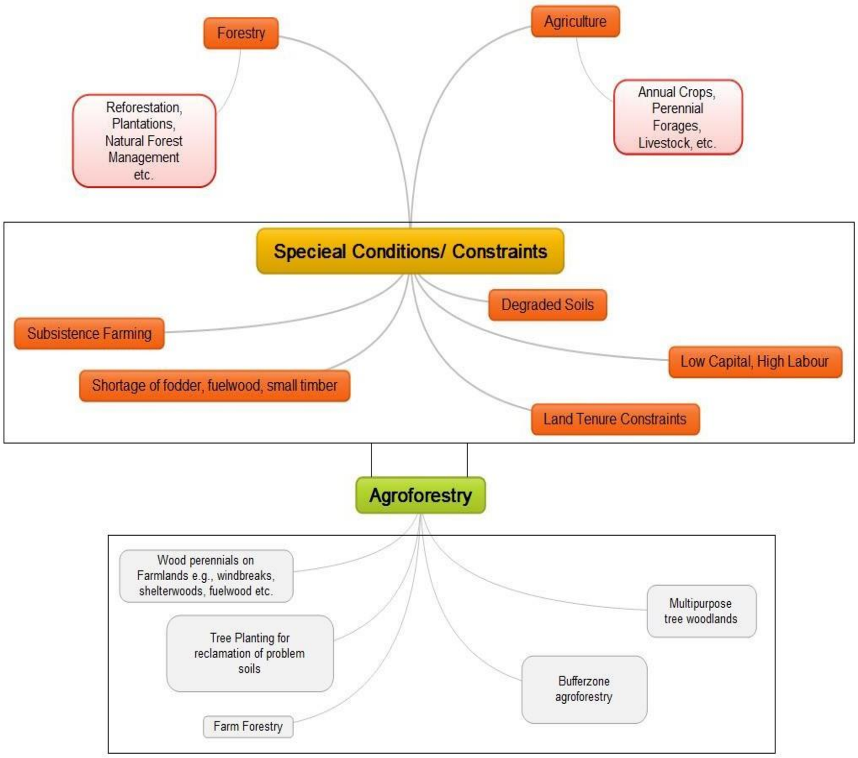


**Fig 9.1** Special conditions and constraints of Agroforestry

Source: Modified from Nair (1993).

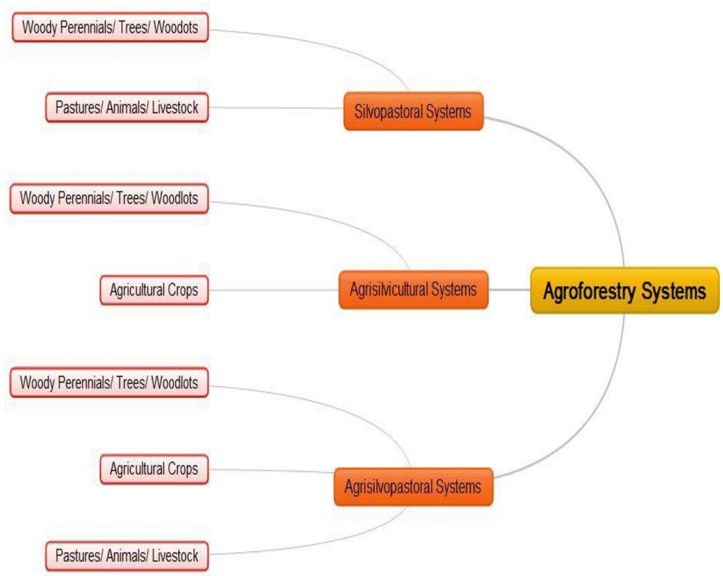


**Fig. 9.2** Classification of Agroforestry Systems

It is clear from the definition and concept of agroforestry that trees are the main components of each agroforestry system that cannot be deleted. Beside these three agroforestry systems, a few other are also in practice, for example multipurpose woodlots, apiculture (with trees), sericulture (with trees especially mulberry plants) and aquaculture/ fish farming (with trees) (Nair 1985). These systems also improve the socio-economic conditions of community livelihoods but these types do not fall in above mentioned three main agroforestry systems, hence, these are brought under *others* term. It is important to mention here that a few other sub-divisions are also in practice worldwide that include agrihorticulture (combination of agriculture crops and fruit trees) and agrisilvihorticulture (combination of agriculture crops, timber trees and fruit trees). The application of all these agroforestry systems may vary according to the main and specific objective. For example, fodder and food production, livestock production, timber production, shelterbelts, windbreaks, fuelwood production, soil rehabilitation etc.

Agroforestry practices and agroforestry systems are often used synonymously while Nair (1992) differentiate both terms as following. "An agroforestry system is a specific local example of a practice, characterized by environment, plant species and their arrangement, management, and socioeconomic functioning. An agroforestry practice denotes a distinctive arrangement of components in space and time. Although hundreds of agroforestry systems have been recorded, they all consist of about 20 distinct agroforestry practices". In other words, in a system, more than one practice can be found simultaneously or at different times.

## Trees and Arable Crops (Agrisilviculture)

Agroforestry practices mainly consisting of trees and crops growing together are known as agrosilvicultural practices. It includes 'taungya'. In Taungya, the farmers grow their agricultural crops with young trees either on borders or in between. It's a common practice in West Africa and savannas as discussed earlier. In these areas, the farmers retain the native trees present on their farmlands and cultivate their crops amongst those trees with the addition of modern technology as hedgerow intercropping cropping or alley cropping. In such system, fast growing and nitrogen fixing tree species are preferred to retain or grow between crop lines which are periodically pruned, thinned and harvested to provide nutrient-rich mulch as fertilizer to the crop. In sloping areas, tree species are planted on contour especially to control soil erosion, improve water infiltration and reduce run-off effects. In this system, following practices have been used in various parts of the world. Some important practices in this system are elaborated here.

- Improved Fallow: In this practice, fast growing, leguminous trees are grown during a fallow period.
- Taungya: During early stages of plantation, agricultural crops are cultivated among young trees. In this practice, fast growing leguminous trees are used.
- Alley cropping: Fast growing, leguminous or fodder trees are grown between crops or as hedges.
- Multipurpose trees (MPTs) on agriculture land: MPTs Trees which can benefit in terms of timber, fuelwood, fruit and fodder are planted on bunds or terraces.
- Shelterbelts, windbreaks and live fences: tall growing trees are grown along / around agriculture land.

## Trees, Livestock and Rangelands/ Pastures (Silvopastoral)

Growing trees in combinations with pastures are termed as silvopastoral system. It includes growing and retaining forest trees in pastures to provide food and fodder to livestock and shade or shelter for both human beings and livestock. Tree browsing in silvopastoral system may occur mainly for productive or conservation purposes. For example, in United Kingdom, forest grazing in pastures is allowed periodically to conserve the habitat and retain understory ferns. Such examples have also been reported for Northern Europe, Southern Mediterranean region and Spain. Scattered trees grown or retained in dry tropical pastures contribute to feed cattle in dry seasons while in wetter tropical areas, trees may contribute in improving soil fertility by nitrogen fixation and atmospheric input.

Sometimes, agroforestry practices are encouraged without the involvement of pastures i.e., having a direct interaction between trees and livestock. In such practices, trees serve as fodder banks. Fast growing trees with better nutritional qualities are grown which can be harvested at intervals providing fodder to livestock. Moreover, trees are also used in sericulture and apiculture. These both systems are also considered under this system but this is the opinion of a few scientists. Some common practices of this system are discussed here.

- Protein banks: Plantation of protein rich and nutritious trees on agriculture land/ pastures/ rangelands for cut-and-carry fodder production.
- Fodder Tree plantation on rangeland/ pastures: Trees are grown and retained to provide a regular supply of fodder to livestock

### Trees, Crops and Livestock (Agrosilvopastoral System)

The practical approach of agrosilvopastoral system is to combine tree plantation, agriculture crop production and animal husbandry. This system is especially used to focus on conserving the resources and their efficient utilization with minimum energy losses. Here, a few main practices are mentioned which exist in this system.

- Apiculture: Trees are grown for honey production
- Sericulture: Preferably, *Morus alba* is grown for silk worm rearing.
- Multipurpose woody hedgerows: Fast growing trees with better fodder qualities are grown for livestock grazing/ browsing, mulching, fertilizer, soil conservation, etc.
- Home-gardening along livestock: Closed, multistory combination of multipurpose trees preferably fruit trees, vegetable crops around homesteads.

## Importance of Agroforestry in Pakistan

Pakistan's economy has undergone considerable diversification over the years yet; agriculture is the most important sector of its economy. The cultivated cropped area covers 22.15 million hectares with its present contribution to GDP at 22%. Agriculture accounts for 44.8% of the total employed force of Pakistan (Government of Pakistan 2014). Most importantly 65.9% (Government of Pakistan 2014) of country's population currently living in rural areas is directly or indirectly dependent on agriculture for their livelihood. Agriculture is the largest source of country's foreign exchange by serving as base sector for its major industries viz. textile, sugar etc. Consequently, this sector has a substantial effect on the overall growth of GDP of the country. The area under cropping system in Pakistan is 22.15 million hectares (Government of Pakistan 2014) out of which 76% is cultivated area under irrigation (Government of Pakistan 2014). Being an agricultural country, mostly the inhabitants of Pakistan depend on natural resources and fulfill their requirements from agriculture, livestock, poultry, forestry and fisheries. But these resources are not too much to meet the needs of all the people, especially, those living below poverty line. It has been reported that 28.1% of rural population is living below poverty line, who are earning Rs. 878.64 per adult equivalent per month. Therefore, there is a need to justify the necessities of life by generating natural along with income resources.

Forests can also play an important role in Pakistan's economy. These are the important sources for protection of land and water resources, particularly in prolonging the lives of dams, reservoirs and the irrigation network of canals. The trees are also essential for maintaining a sustained supply of wood and wood products. Pakistan is a land of great diversity, which has yielded a variety of vegetation. According to FAO report 2000, 3.9 billion hectares or 40 million km2 of the globe is covered with forests which are almost 30 percent of total land area. This corresponds to an average of 0.62 ha (6200 m2) per capita, though this is unevenly distributed. For example, 64 countries with a combined population of 2.0 billion have less than 0.1 ha of forest per capita. This estimate was based on data on forest area reported by 228 countries and territories. Among world regions, Europe (which, for the purpose of this assessment includes the Russian Federation) accounts for one-quarter of total forest area, followed by South America and then North and Central America. South America is the region with the highest percentage of forest cover (almost half of the land area) and Asia is the region with the lowest percentage of forest cover (less than 20% of land area). If a comparison is carried out among Asian countries, India stands first representing 21.6% of its area under forest and China ranked 2nd having 17.5% while Pakistan has only 3.1% or about 1,902,000 hectares of total land area while in 2005 it remained only 2.13%, which is very low as compared other Asian countries (World Bank 2011). The figure of Government of Pakistan is different from above. She reported that the area under forest cover in Pakistan is about 5%, out of which 85% is public forest, including 40 % coniferous and scrub forests on the Northern hills and mountains (Government of Pakistan 2005). The balance is made up of irrigated plantations and Riverain forests along major rivers on the Indus plains, mangrove forests on the Indus delta and trees planted on farmlands. If we consider the official figure of Pakistan, then it is also less than the world forest area, which is 30% of total land. Forest cover is divided into four percentage groups (>70%, 40-69%, 10-39%, 0-9%), thus the Pakistan lies in the last category i.e., 0-9%. Moreover, it can further be categorized into primary, protected, conserved and production forests (FAO 2000).

Trees are being cut at in an unmanaged system i.e., there is no balance between harvesting of trees and regeneration or afforestation activities. Such brutal practice is fashioned due to increasing demands for fuel to meet domestic and industrial needs. Unbalanced harvesting and afforestation activities hamper forest decline rate which is consequently leading towards environmental and land degradation, air pollution, and biodiversity loss. For this, efforts should be undertaken to multipurpose tree plants new and improved varieties of trees and plants that have a good growth rate. It has been reported that Pakistan lost about 214,000 ha forest @ 2.1% deforestation rate only between 2000-2005 which correspond to 43,000 ha/year loss. Pakistan's total deforestation rate from 1990-2000 was 41,000 ha or 1.8% per year. Hence this report shows that the deforestation rate in Pakistan is increasing day by day. This is very alarming figure of a great concern (FAO 2000).

Pakistan is forest deficient country with only 0.03 ha as compared to world average of 1 ha per capita (Government of Pakistan 1992), is facing timber and fire wood shortage of about 29 million cubic meters (Government of Pakistan 2005) and our forests produce only 32% of fuel wood supply to meet national energy requirements (Government of Pakistan 1992). In a study, it has also been estimated that this shortage of 29 million cubic meters will become 52.6 million cubic meters up to 2018 thus increasing future needs by 23 million cubic meters (Wani 2003). This forest area per capita is declining due to growing population rate at 1.90% annually. According to safe estimates, the annual import bill for pulp, paper and paper products runs into RS 8 billion which is expected to increase many times due to increase in population. The area under public forest cannot be further expanded to keep pace with population growth rate and increasing demands for forest products. The only available option is to increase wood production on private or farmlands so as to meet pulp and paper demand locally to reduce import bill and save foreign exchange. It is estimated that state forests contribute only 14% of timber and 10% of fuel wood whereas 46% of timber and 90% of fuel wood requirements are being met from farmlands (Government of Pakistan 2014). To counter the deficit issues in timber and fuelwood supply, agroforestry is an important practice. It will be discussed in next sections of this chapter that how agroforestry can be helpful in soil conservation, improving soil fertility, erosion control, for improving food, fodder and fuelwood production of the country. Below are some facts demonstrating the role of agroforestry in developed and developing countries.

- Intercropping of Paulownia elongate with cereals is practiced on 3 million hectares in China (Sen 1991).
- In Henan province of China, agroforestry was introduced in late 1970s. 30 years after initiation of agroforestry practices, two-thirds of the 46,000 ha of farmland were intercropped with Paulowina elongate (Wu and Zhu 1997).
- In Tabora District of Tanzania, about 1,000 farmers intercropped Acacia crassicarpa with tobacco and maize (Ramadhani et al. 2002).
- In Uttar Pradesh, India, 30,000 farmers cultivate Populus deltoids on their farms. The average farm size under populous deltoids plantation is 1.3 ha. These plantations support their national match industry and minimize the import cost. (Jain and Singh 2000; Scherr 2004).
- According to McAdam et al. (1999) ash trees were intercropped with ryegrass pastures at 40 years rotation in United Kingdom. No reduction in ryegrass yield was recorded for first 10 years of rotation.
- In the Canada, more than 43,000 km of windbreaks has been planted since 1937 which protect 700,000 ha of Canadian prairies.
- In 1987, approximately 858,000 windbreaks were planted in the United States, especially in the north central and Great Plain areas, covering 281,000 km which protected 546,000 ha (Williams et al. 1997).
- An increase of 8, 12, 23 and 25% in yield of spring wheat, maize, winter wheat and barley, respectively was recorded by Kort (1988).

# Agroforestry on Marginal Lands

Poor physical and chemical quality of soils severely affects the crop growth and productivity (Flowers 2004). A vast area of the world is wasteland due to excessive salts, waterlogging, acidity, alkalinity, or even the presence of sand or gravel in soil (Zhu et al. 1997). Agroforestry practices can be implemented to bring such wasteland under cultivation by imparting different techniques (Munns 2002; Munns and Tester 2008). In general, selection of suitable tree species especially multipurpose trees is the key factor in reclaiming such kind of areas (Cavalcante and Perez 1995). These trees not only provide timber and fuelwood to the farmers but rehabilitate the soil conditions improving its fertility. Detailed discussion can be seen in Chapter No. 14.

# Agroforestry for Soil Conservation

Agroforestry is a unique, ecologically balanced and sustainable ecosystem. This is greatly to the fact that trees being a woody component offer the most: food, fuel wood, fodder, shade etc. They also minimize nutrient losses as a result of leaching and erosion. The large tap root with wide spreading lateral roots not just provide anchorage but also play an important role in nutrient uptake, absorbing nutrients from the lower strata of the soil. Nutrient cycling is another major aspect whereby the nutrients absorbed by the tree are returned back in form of litter fall, stem flow and decomposition. This again provides nutrients for fresh use to the same trees. Soil microbial associations such as rhizobia with the tree roots improve nutrient uptake especially in the case of nitrogen. Such fast growing species combined with herbaceous crops enhance the soil fertility status and improve the microclimate, improving survival conditions for both plants and animals. The roots of the trees are long to give the tree anchorage and wide to avoid soil erosion. Some trees fix nitrogen and produce nitrates which are essential for plants. The mycorrhizal roots play a vital role in the poor and the dehydrated soil. Productivity and protection of system and soil conservation are certainly most important functions of trees. Though originally equated with control of erosion, soil conservation now associates with maintenance of soil fertility (Young 1987). Moreover, the plantation of trees improves physical and chemical characteristics of soil by adding soil nutrients through leaf litter decomposition. Tree roots uptake soil nutrients below crops' roots level and make them available by fixation (Hartemink et al. 1996; Allen et al. 2004). In this way, trees can maintain soil organic matter and nutrients but it depends on tree species, planting space, tree age and agroforestry system (Szott et al. 1991; Mohsin et al. 1996; Young 1997). For example, *Populus deltoides* is considered as a potential multipurpose tree or agroforestry system as it has single and tall stem, fast growth, deep roots and narrow crown which enable less competition with associated crops (Jain and Singh 2000).

The researchers have mentioned certain qualities which are necessary for trees to maintain soil status like a high yield, better aboveground biomass production, more nitrogen fixation, dense adventitious roots capable of mycorrhizal association, existence of deep roots, less toxic substances and adequate amount of nutrients.

There are many mechanisms involved in soil fertility improvement such as compatibility of trees and their suitability to the soil. A leguminous tree fixes nitrogen and improves nutrient status. Leaf litter increases organic content. The organic matter is greatly influenced by the microbial activity in the rhizosphere, which are beneficial for the companion crops. Physical properties such as water holding capacity (WHC), permeability, aggregate stability of soil and soil temperature are some of the more essential aspects. Soil conservation and erosion control through biological measures lend stability to the system and decrease siltation rate in downstream reservoirs.

Previous research reports, observations and farmers' experiences support the hypothesis that the plants improve the soil quality, texture, organic matter and nutrients accumulation. Following points strongly support this concept:

- From ancient times, the farmers have been interested in cultivating their agricultural crops on cleared forest lands.
- Forest soils have been found with better physical and chemical properties pertaining ample amount of organic matter and essential nutrients in comparison with fallow lands.
- Being a closed ecosystem, woodlands are preferred for nutrient transfer, storage, and cycling.
- The best way to reclaim a marginal land or improve the soil fertility on sustainable basis is to incorporate tree cultivation either as compact plantation, linear or alley cropping. It will gradually improve soil organic matter, nutrients accumulation and water holding capacity.

The summarized beneficial effects of agroforestry on soil fertility and productivity are given in Table 9.1.

Nutrient cycling includes the conservation of sources and their partitioning between soil and plant within a system. Agroforestry systems have been cited as potential land-use systems for their efficient nutrient cycling which in turn improve soil fertility. As discussed earlier, trees possess deeper root system than other herbaceous plants having the potential to retrieve nutrients from deep soil horizons. Moreover, forest, an undisturbed ecosystem, takes nutrients from the atmosphere, or by nitrogen fixation etc enabling the atmospheric input to soil. Such input of biologically important elements is caused though precipitation. Nitrogen is essential element as first floor contains 2225 kg/ha which is mostly in humus complexes (Young 1987). The amount of nitrogen and potassium is higher in the leaves and fruit of plant than in branches, poles and litter. Leaf fall is an important process as the litter continuously provides the nutrients back to the soil and they keep the cycle in progress. With respect to the nutrient intake, the major part of nutrients is in the leaves of the nutrients. The mechanisms include uptake from lower soil horizon, reduction of leaching to lower horizons, balanced nutrient supply and improvement ratio between available and fixed nutrients for a tree leave biomass production of 4000kg dry matter per ha year. The potential nutrients returns in form of nutrients are of the order of 80-120 kg N, 8-12 kg phosphorus, 40-120 kg potassium, and 20-60 kg calcium. The nutrient uptake in trees is  currently explained by a hypothesis that trees are most efficient agents than the herbaceous plants in intake of nutrients. Potassium, phosphorus, bases and macronutrients are released by rock weathering particularly in the B/C and C-horizon on to which tree roots often penetrate. The strong gradient in nutrient content, control between top soils and sub soils indicate recycling through litter whereas other processes are also involved. It is important to note here that almost 20-30% of tree total living biomass is present in soil as roots which are constantly adding organic matter to soil through its dead and decaying parts.

**Table 9.1** Beneficial effects of trees on soil fertility

| Addition to soil | Reduction of losses from soil | Effect on physical properties of soil | Effect on chemical properties of the soil |
|---|---|---|---|
| Sustainable supply of organic matter to soil | Protection from soil erosion: proper planning and management of trees on wind/ water eroded soil can minimize the effects of soil erosion in terms of loss in organic matter | Improvement of soil physical properties i.e., soil structure, texture, porosity, water holding capacity | Decrease in soil acidity |
| Nitrogen fixation through leguminous tree roots | Nutrient reclamation: soil nutrients which are deeply deposited in soil horizons are absorbed and uptaken by tree roots | Amelioration of soil temperature | Decrease in salinity and sodicity |
| Nutrient uptake as trees are more active in uptaking soil nutrients from deep root zones especially in B/C and C horizons | | | Effect of shading: by lowering down soil temperature, loss of organic matter through oxidation can be minimzed |
| Atmospheric input: nutrients dissolved in rainfall and then | | | |

deposited in soil

The plantation of trees in the agroforestry systems increases soil fertility by improving the physical properties of the soil. Sreemannarayana et al. (1994) studied influence of *Albizialebbeck* on soil properties with cowpea as intercrop in different seasons and with pruning treatments. The soil organic matter improved over the recorded value. Great improvement in soil fertility was shown by *Albizia lebbeck*. Karite (*Vetellaria paradoxa*) and Ner (*Parkia bilobosa*) were observed in this regard. They showed that the organic matter was rich in the soil under the trees and soil fertility improvement was least in the fallow land and was highest in *Albezia lebbeck* based system. Induced crop yield are from 0-60%. The study in Rampur (Utter perdesh, India) shows benefit of poplar (*Populus deltoides*) plantation. The litter produced had higher content of N P K. Alley cropping has also proved much beneficial. Soil carbon was found to be 8.7 % higher than sole crop plant. However, C/N ratio decreased.

When woody perennials and agricultural crops are together cultivated they improve soil conditions and fertility greatly. The productivity, fertility, and erosion under cassava based agroforestry systems were studied by Gosh et al. (1989). There was increase in the phosphorus and potassium status. Alley cropping also has a significant effect on it. It showed that large biomass could be obtained from this system. In most cases 30% of nitrogen is available; the rest is lost by leaching and gaseous losses Gosh et al. (1989). In leucaena, 50% of N is released in first 25 days.

The trees may have negative effects on the crops and soil fertility: if the tree plantation is poorly managed it leads to soil erosion. Similarly shading and spectral quality of light in close proximity may have serious effects on agroforestry and adverse chemical and biological effects may result from acidification, allelopathy, etc. According to a phenomenon, the tree roots and leaves have some substances that hinder crop production regardless of their benefits like benzoic and *p*-coumaric acids can create a problem if they are present in large quantity in the trees.

Application of fertilizers to forest trees in agroforesty is generally a costly process but it suits to the trees of economic values as seen in horticulture based trees. An ideal fertilizer must be cheaper to get a unit of plant food, give high growth response, maintain fertility and physical and chemical properties of soil (Maslekar 1990). Generally, hardwoods require more nutrients than conifers and fast growing trees.

Many advanced countries except India have accepted the benefits of fertilizers and it is proved to be better for getting large biomass in short span of time. Significant growth advancements due to the putting of 28 kg N and 15 kg $P_2O_5$ per ha were observed in pines (Singh et al. 1981). Krohn (1981) reported that fertilization of eucalyptus seedlings resulted in better tree growth and survival. The effect of phosphoric fertilizers on growth of teak plantation was also beneficial. Ammonium phosphate also proved beneficial for growth and height of teak plants in initial 2 years. In case of SS, a dose of 120 g per plant showed significant effect on height (Singh et al. 1981)

Generally, soils brought under agroforestry systems are in poor condition with low nutrient availability, and mismanagement may lead to mortality of trees soon after planting. Supplementary nutrients should be ensured at the critical stage of planting. Fast growing leguminous species ensure increased fertility of soil along with herbaceous cover as this constantly contributes in biomass and organic matter in form of leaf litter. This increases nutritive status and prevents erosion. Any biomass that accumulates is decomposed and liberates nutrients for reuse. Further techniques can be introduced for efficient recycling, soil aspects should be assessed in detail. Any negative effects should be remedied in accordance with expert advice and dealt with immediately.

# Interventions for Soil and Water Conservation Through Agroforestry System

Soil and water are the most important resources for life. However, ignorance of soil and water conservation measures, improper use of fertilizers, mismanaged irrigation and water practices, mining, and effluents discharge etc. are responsible for land degradation at a massive scale. This leads to the paradox of getting more production from the increasingly scarce resources to meet the requirements of mounting human population. Demographic pressure is the primary cause of land degradation, along with loss in vegetative cover. Shifting cultivated areas may result in further losses of 18million tonnes of soil. Values for tributary river sediments in the region range from 6.0 to 98.4 cum $ha^{-1}$ per year. Hence agroforestry techniques become crucial for the conservation of soil and water.

Water erosion can cause losses of top soil in 130.5 million ha as well as degradation of terrain in 16.4 million ha. Of the total eroded soil, 29% is lost to sea, 61% relocated or transferred to different places, and 10% is sedimented in reservoirs, reducing their capacity by 1-2 % at an annual basis. The erosion rates have reduced the life of reservoirs increasing rates of sedimentation, especially in the catchment areas.

If we talk about creating barriers for controlling run-off and soil loss on slopes, the most effective and feasible are the vegetative barriers. *Panicum maxicum* used as a barrier in maize succeeded in decreasing run off by 28% and erosion by 48% at Dehradun (Bhardwaj and Khola 1999). The barriers also help in redeposition of soil on contours forming bunds or terraces naturally. However, the effectiveness of the barrier also varies according to situation and conditions. For example, in Doon valley run-off was reduced by 18% and soil loss controlled upto 78% on a 4% slope using barriers of native grasses such as *Vetiveria zizanioides* (Vetiver), *Eulaliopsis binata* (Bhabar) and *Panicum maxicum* (Guinea). But the same grasses cannot be universally accepted to achieve the same result or control erosion and run-off in different countries or zones.

Apart from grasses, tree species too prove to be an effective control measure. Paired contours and hedgerows consisting of *Leucaena leucocaphala* (ipil ipil) and Eucalyptus hybrid (Sufeda) can reduce run-off by 40-48% as well as 12.5t $ha^{-1}$ soil loss in maize on 4% slope. Other suitable grass species include *Panicum maxicum*, *Chrysopogan fulvus*, *Setaria sphacelata*, *Saccharum munja*, *Saccharum spontaneum* and *Arundo donax*. *Panicum maxicum* reduced soil losses from 45t $ha^{-1}$ to 6.12t $ha^{-1}$ in Dehradun (Bhardwaj 1990).

Hedgerows are of multipurpose concept. They don't just reduce soil loss and run-off, but provide fodder too. They also trap soil particles helping to prevent loss of nutrients and finer soil particles. Even small farms can easily raise hedgerows. Grewal (1993) compared agroforestry models for eroded lands stated soil loss to be most negligible when under a Eucalyptus hybrid and *Eulaliopsis binata* system, soil loss being only 0.07t per ha. *Acacia catechu-Pennisetum purpureum* was next with loss of 0.24t per ha, and *Tectona grandis-Leucaena leucocephala-Eulaliopsis* *binata* with loss of 0.43t per ha. Run-off and nutrient losses were reduced too. Eucalyptus trees managed as a sole tree are more effective. Grass cover decreases run off by 73 percent and soil loss by 94 percent. These were further reduced by eucalyptus tree rows. The trees affect the crop yield but this is compensated by tree products (Narain et al. 1998). Local flash floods can be controlled by establishment of vegetative spurs, brushwood check dams, vegetative filters and stream bank lining of native species. This will save a greater portion of land from degradation and erosion (Samra 1994). Leguminous shade trees are of immense importance to tea plants as they provide shade and nitrogen (Tejwani 1994). Shade trees provide 2500-5000 kg leaf litter, 63-126kg N, 18-36kg $P_2O_5$, 22-44kg $K_2O$, 32-64kg CaO and 16-32kg MgO $ha^{-1}$ per year to soil (Gogoi 1976). These trees play a vital role in improving fertility and enhancing production by improving soil nutrient content.

Mine spoils, or mining, results in degradation of land by shifting of soil, denudation, reduction in water holding capacity of soils etc. The disturbed land can be reclaimed by establishing forest cover with trees as well as grasses and shrubs. Agroforestry is the ultimate option for such a solution. Species that are indigenous, hardy, with coverage and nitrogen fixation with good economic and social values are preferred. From the western states of Jammu and Kashmir to Himachal Pradesh, about 10 million ha of land are covered by the cold desert as it lies in the Himalayas and Tibetan plateau. (Rai 1996) lying in the rain shadow of mountains and facing severe extremes of cold and dryness, this is a fragile and unstable area. The constant biotic pressure in terms of grazing, fodder and fuel has led to degradation. Faulty land practices and exploitation of tree cover are other reasons. Eucalyptus and poplar clones have been recently introduced in the Kashmir Valley. Other agroforestry species suited to the region are Quercus spp., *Bauhinia variegate*, *Morus cerata*, *Ulmus wallichiana*, *Celtis australis* etc. A native shrub, Hippophae rhamnoides, is used for both fodder and fuel with promising potential. One ha plantation of the shrub is sufficient to fulfill needs of 20 households. (ICFRE 1993)

Integrated watershed management is an essential to reduce run-off, flooding in down-stream area and improved in-situ moisture conservation, hence improving biomass production (Samra 1994). Vegetation in the catchment area helps ground water recharge and rise in water table. Both run-off and soil loss are decreased when watershed areas are incorporated with trees and grasses, or mechanical measures are taken. (Singh et al. 1990)

To conclude, agroforestry has the distinctive feature that the land use systems have the potential for both production and conservation. (Young 1986) These include products and services such as conservation of resources, prevention of erosion, increased soil fertility, shade, moisture conservation, recreation, biodiversity, etc. The agroforestry interventions are aimed to increase biomass production, soil amelioration and stabilization of degraded lands. Not only are the needs of fodder, food, fuel wood, fiber satisfied but economic and environmental security is ensured too, leading to sustainable development with steady income sources.

# Agroforestry for Food Production

Development and well-being of humanity depends on the degree of sustainability of human activities. A sustainable community must be able to balance the socio-economic development with the production of food and the environment protection. The speedily inflating human population is pushing for greater food requirements, which is in turn, threatening the environment conservation and enlarging the gap between the supply of resources and the demands of basic necessities of life. Since ancient times, people are fulfilling their requirements for food and shelter by depleting natural resources. The scientists and policy makers are encouraging communities to adopt sustainable ways o f harvesting benefits from natural resources without causing any serious environmental concern. Fischer et al. (2009) reported that 12% of total world population (800 million) is undernourished and the policy makers are devising protocols to minimize this figure to its half by 2015. The food security issues can be resolved by imparting various agricultural approaches and technological innovations in current farming system. Currently, a wide array of fruit trees, crops, vegetables, etc. are being practised in agricultural system. however, food shortage threats can be overcome by planting under-utilized forest trees rich in minerals, protein, fiber, etc. (Leakey 1999; FAO 2010; Malézieux 2013). The scientists are working on the domestication of forest trees to provide year around income, food for local communities and feed for livestock.. For this, fruit trees are being utilized as primary option. This said, the significance of wood-based and non-wood based forest products cannot be declined either. A case study in Africa revealed that 90% households cultivate fruit trees. Of these, one fourth of the respondents grew banana, avocado and mango while two third were growing some other fruit species. Likewise, the people of Malawi consume papaya and oranges which are mostly harvested on their own farmlands (Jamnadas et al. 2011).

In addition to the provision of food, feed, fruits and nutrients, forest trees offer meaningful aid in sheltering, nourishing and improving agricultural crop systems through means like providing shade for crops that are sciophytic in nature (grows well under shade conditions); shelter and fodder for livestock production and improving soil fertility through litter-fall and extensive adventitious and tap root system (*how tree root system benefits soil fertility and crop productivity is discussed in "Role of Agroforestry in Soil Fertility"*). Nitrogen fixing trees improve crop yield by improving soil fertility, rain use efficiency of crop plants and better performance under drought conditions (Sileshi et al. 2011). Moreover, these tree species can regulate the climatic factors especially micro ones which can assist agricultural crops to mitigate harsh climatic effects resulting in better growth behaviour and higher yields (Sileshi et al. 2012). In addition to supporting agricultural crops, trees also play their roles in dairy farming by providing, shade, shelter and fodder and supplementary feed.

Home gardening has been considered as a viable option to support food requirements of households. Home gardens are preferably a combination of plants, shade trees, fruit bearing trees, shrubs, vines and medicinal plants. In home gardens, tuber crops, medicinal plants and fruit trees are preferred crops since these can fulfil the basic needs however, a conspicuous character of a home garden is the dominance of fruit trees like mango, guava, date palm etc. and food providing trees like *Moringa oleifera* and *Sesbania grandiflora* which dominate in Asian home gardens. These trees make up the deficiency of local diet providing better nutritious supplements. It has been reported in literature that home gardens support the energy and food requirements of local farming communities substituting vitamins and nutrients' deficiency (Soemarwoto and Conway 1991).

In order to increase the function of agroforestry in food and nutritional security, following recommendations may be considered:

- The present role of agroforestry tree products and services in sustaining food and nutritional security of inhabitants of rural area in different farming systems should be better quantified.
- The expansion of agroforestry policy should not be restricted to the agricultural or forest sectors only. It should be treated as an individual farming system. Required improvements include selecting suitable tree species and land occupancy, in-depth research o practices and behavior of farmers to grow these trees and the credit of agroforestry as an investment option for food production.
- Research studies should be focused on investigating food tree domestication options appropriate for meeting smallholders' needs, and assess complementarity and resilience in agroforestry systems under climate change in the context of other global challenges to food and nutritional security.

## Agroforestry for Fuelwood Production

Traditional energy sources could not have much consideration in current energy debates, but firewood and charcoal from trees are vital for the endurance and well-being of approximately two billion people (FAO 2008). In sub-Saharan Africa, the use of charcoal is increasing speedily, as the value of charcoal industry is supposed to reach about US$ 8 billion in 2007 (World Bank 2011). The charcoal industry is an essential element for food and nutritional safety because it provides both energy and income. As the prices of modern energy sources are increasing, this situation is improbable to change for some time.

In developing communities/ in below-the-poverty-line/In communities with inadequate economic means, firewood and charcoal are frequently burnt in open fires or poorly-functioning stoves with considerable release of pollutants (especially from firewood) that may be fatal to human health. Such a condition has already lead to the deaths of more than one million people in a year worldwide. Of these, women stand most victimized since they are in direct contact with cooking activities (Jamnadas et al. 2011). Different tree species exhibit varying fuel quality as mentioned in "Multipurpose Trees MPTs".

Reduced access and increased prices of wood-based biomass have led to initiatives to promote agroforestry cultivation. The farmers who are involved in agroforestry practices growing their own fuelwood trees need less fuelwood to purchase from market as most of their needs can be fulfilled from their own sources. Moreover, there is less reliance on natural forest stands and requires lesser time in collection. This leaves more time for income-generating activities, especially for women who are usually the major fuelwood collectors (Thorlakson and Neufeldt 2012). Access to cooking fuel provides people with more flexibility in what they can eat, including foods with better nutritional profiles that require more energy to cook. The cultivation of woodlots allows the production of wood that is less harmful when burnt and has higher energy content. The use of better stoves – with greater efficiency – reduces greenhouse gas emissions relative to the energy generated for cooking purposes.

Pakistan is an energy deficient country. It has been reported that approximately 54% of national energy demand are covered by electricity conventional energy sources while the utilization of fuelwood, crop residues and dung fulfill the remaining requirements. It is important to mention here that fuel wood trees fulfill 26% of total energy requirements. By now, 95% energy requirements in rural areas are fulfilled by trees while in urban areas, this figure goes to 56% (Zaigham 2004). According to Zaman and Ahmad (2012), total wood consumption of Pakistan would be 59.44 million $m^3$ including timber consumption (16.62 million $m^3$) and fuelwood consumption (42.81 million $m^3$) by 2025 if population is 208.84 million. Currently, per capita fuelwood consumption is estimated at 0.205 $m^3$ while total fuelwood consumption is 34.95 million $m^3$ in Pakistan. Three main sectors are fuelwood consumers i.e., household, commercial (restaurants, hotels, tea shops, bakeris, milk shops etc. and industrial sector (mainly brick and tobacco curing industries). Zaman and Ahmad (2012) reported household sector as the largest fuelwood consumer (81.8%) followed by industrial fuelwood entrepreneurs (14.9%) and commercial sector (3.3%). Out of household sector, 75% households consume fuelwood for cooking purposes, 14% for water heating while the rest (11%) for room heating in winter. Moreover, rural community consume a major part of fuelwood for cooking purpose (90%) while in urban areas, only 10% inhabitants depend on fuelwood (Government of Pakistan 2011). In case of fuelwood consumption by industrial sector, major proportion goes to social ceremonies (27%), khoya production (24%), brick making (20%), charcoal making (8%), tobacco curing (3%) and other industries (18%).

Mainly *Acacia nilotica*(kikar), *Acacia modesta* (phulai), *Dalbergia sisso* (shisham), *Ziziphus jajuba* (ber), *Morus alba* (mulberry) are used for fuelwood consumption depending upon their calorific values, physical and chemical characteristics. Tree species with minimum moisture percentage are preferred that produce more heat as compared to other species with higher moisture content.

The selection of suitable tree species plays a key role in the production and exploitation of fuelwood in an agroforestry system. The selection mainly depends on community preferences, climatic factors, edaphic factors, landholding size, interaction with existing agricultural crops, and market demands. So, it is rather difficult to propose a specific fuelwood tree which can address global requirement but a few criteria can be made to select suitable species.

- Adaptation ability to local environmental conditions. In this case, indigenous species are preferred which are of community interest.
- Continuous pruning can supply unremitting fuelwood but for this, highly branched tree species should be preferred which can endure pollarding and pruning shocks.
- Multipurpose trees provide a number of useful benefits like branches can be used as fuelwood and leaves can be used as livestock fodder etc.
- Spineless wood of small diameter is easy to harvest and transport because that can be easily utilized for cooking and heating purposes.
- TCI (tree-crop interaction) is an important factor while selecting a suitable tree. The species which are compatible with agricultural crops should be preferred.
- Species with low moisture contents, higher density, and more ash and sulphur content possess good combustion quality.
- The consumers' demand is highly influential in selection.

A large number of tree species have been identified as fuelwood crops. Fuelwood markets are dominated by such tree species as *Acacia nilotica, Tamarindus indica*, *Prosopis cineria*, *Salvadora oliodes* and other local species, inspite of the large scale tree planting efforts for fuelwood production by state agencies using exotics such as *Leucaena*, *Casuarina* and *Eucalyptus*.

Increasing efforts are being made all over the world to plant new species and improved varieties of trees that have good growth rates as well as have multiple uses. In Pakistan, many efforts are being made for introducing and cultivating fast growing and short rotation trees. The species most favored by farmers are kikar and shisham. They use the wood of these tree species for fuel, shelter, shade and fodder.

# Multipurpose Trees (MPTs)

Multipurpose trees are defined for their multiple benefits which can be driven from their different parts like food, fruits, nuts, fodder, timber medicines etc. This term is commonly used in agroforestry especially when the farmers are to decide about selection of suitable tree species. No doubt, all trees provide several benefits like soil improvement, shade, shelter etc. but MPTs have greater impact on farming culture because trees are planted not only for one purpose. The farmers are willing to get fodder, timber and fuelwood while planting trees as living fences, shelterbelts or alley cropping. In this part, scientific and local names, family and sub-family, origin, distribution, habitat and ecology of potential trees which can be used in agroforestry systems are given in this table with their uses, specific gravity, calorific values and productivity (Table 9.2).

**Table 9.2.** Multipurpose Trees for Agroforestry

| No. | Scientific name | Local name | Family-Subfamily | Origin | Distribution | Habitat & Ecology | Uses | Specific Gravity | Calorific Value | Productivity |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Acacia catechu | Katha | Leguminosae-Mimosoideae | Subcontinent | Malakand, Hazara, Rawalpindi, plain areas of Punjab | Drought tolerant, grows best on rocky, stony, sandy and loamy soils, required precipitation is 500-2700 mm/ year, upto 1200 m elevation, -5 to 40 °C | Fodder, food, agriculture implements, handy tools, timber | 1 | 5200 kcal/kg | 4-7 $m^3$/ha/yr |
| 2 | Acacia nilotica | Kiker | Leguminosae-Mimosoideae | Pakistan | Sindh, Punjab, Balochistan, KPK | Drought and salinity tolerant, requires precipitation 125-1300 mm/ year, semi arid, subtropical/ tropical climate, 1-45 °C | Fodder, fuel, charcol, agricultural implements, land stabiulization, nitrogen fixing | 0.75 | 4900 kcal/kg | 4-15 $m^3$/ha/yr |
| 3 | Acacia senegal | Gum Arabic | Leguminosae-Mimosoideae | Pakistan | Sindh and Balochistan | Drought resistant, usually below 1700 m elevation, intolerant to waterlogging, requires precipitation between 200-800 mm/year, arid to semi-arid, hot subtropical climate, -4-48 °C | Fodder, fuel, charcol, agricultural implements, land stabiulization, nitrogen fixing | | 3200 kcal/kg | 1-4 $m^3$/ha/yr |
| 4 | Albizzia lebbek | Kala Sirin, Black Siris | Leguminosae-Mimosoideae | Sub-Himalayan tract | Sialkot to Hazara, Bajaur, Buner, Malakand and plains of sindh & Punjab. | Well drained and loamy soils, pH 8.7 to 9.4, Summer precipitation of 400-1000mm/yr, sub-humid/sub-tropical/tropical climate, 4-40 °C, elevation 0-1600 m. | Fodder, fuel, apiculture, agricultural implements, land stabilization | 0.55-0.64 | 5100 kcal/kg | 5 $m^3$/ha/yr |

| No. | Scientific name | Local name | Family-Subfamily | Origin | Distribution | Habitat & Ecology | Uses | Specific Gravity | Calorific Value | Productivity |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 | Albizzia procera | Sufed Sirin, White Siris | Leguminosae-Mimosoideae | Central/South India, Bangladesh, Burma | Punjab, KPK | Prefers moist sites, tolerant to saline/sodic conditions, summer precipitation of 500-1000mm/yr, subhumid/warm/subtropical climate, temperature 1-45 °C, elevation 0-1200 m. | Fodder, fuel, apiculture, agricultural implements, tannin, furniture, poles & construction. | 0.69 | 4800 kcal/kg | 10 $m^3$/ha/yr |
| 6 | Azadirachta indica | Neem, margosa tree | Meliaciae | India, Pakistan, Nepal, burma, Afghanistan, China & Sri Lanka | Sindh, Southern Punjab, Lower Balochistan | Rich loams to nutrient deficient soils that are not saline or waterlogged (water table >18 m), precipitation of 300-1150 mm/yr, arid/ hot tropical/subtropical climate, 1-45 °C, prone to frost damage. | Furniture, fodder, wood carving, medicinal, oil, tannin, timber and agricultural implements. | 0.68 | 4990 kcal/kg | 5-18 $m^3$/ha/yr |
| 7 | Bombax cieba | Simal, Silk Cotton Tree | Bombaceae | Pakistan, India, Nepal | Sub-Himalayan tracts and eastwards from Hazara. | Best in well-drained deep alluvial soils, precipitation 750-1700 mm/yr, humid warm subtropical/tropical monsoon climate, -5 to 40 °C, elevation of 1000 m, drought hardy but not frost tolerant,. | Fuel, ornamental, medicinal, canoes, furniture, carvings, seed cotton for pillows. | | 4900 kcal/kg | Diameter growth: 35 cm/ yr |

| No. | Scientific name | Local name | Family-Subfamily | Origin | Distribution | Habitat & Ecology | Uses | Specific Gravity | Calorific Value | Productivity |
|---|---|---|---|---|---|---|---|---|---|---|
| 8 | Cassia fistula | Amaltas, Indian Laburnum | Leguminosae-Caesalpinoideae | Pakistan | East of Indus, upwards to Himalayas, and throughout plains. | Moderately shade tolerant, grows on variety of soils, sub-humid cool to subtropical humid warm/tropical climate, precipitation of 500-3000 mm/yr, -5 to 45 °C, prone to frost damage. | Fuel, ornamental, agricultural implements, fine furniture, tool handles, support posts, cart wheels, tannin, medicines | | 5164 kcal/kg | 10-12 $m^3$/ha/yr |
| 9 | Dalbergis sissoo | Shisham, Tahli, Rose wood | Leguminosae-Papilionoideae | Sub-Himalayan tract of the subcontinent | Mostly along river banks and streams, in plains and foothills. | Frost hardy, dry subtropical/dry temperate climate, well drained sandy/sandy loam soils, elevation 900-1500 m, precipitation of 300-2000 mm/ yr, temperature range of 0 to 50 °C | Fodder, furniture, fuel, charcoal, railway carriages, sports goods, farm implements and medicinal. | 0.85 | 5000 kcal/kg | 7.7 $m^3$/ha/yr |
| 10 | Eucalyptus camaldulensis | Sufeda, Lachi, Red River Gum | Myrtaceae | Australia | Plains and hills. | Intolerant, frost hardy and may even tolerate drought, variety of soils even saline/sodic/waterlogged, semi-arid/warm hot/ subtropical winter/ monsoon climate, temperature -5 to 40 °C, elevation of upto 1400m, precipitation of 200-1250 mm/ yr. | Carriages, fuel, furnitutre, oil, charcoal, apiculture, shelterbelt, pulp & fiber board | 0.71 | 4900 kcal/kg | 10-25 $m^3$/ha/yr |

| No. | Scientific name | Local name | Family-Subfamily | Origin | Distribution | Habitat & Ecology | Uses | Specific Gravity | Calorific Value | Productivity |
|---|---|---|---|---|---|---|---|---|---|---|
| 11 | Eucalyptus citriodora | Sufeda, Lemon Scented Gum | Myrtaceae | Australia | Plains and hills. | Well drained soils, tolerates dry periods for 5-6months, semi-arid/warm hot/sub-tropical winter/monsoon, precipitation of 600-900 mm/ yr, 5-40 °C, elevation upto 2000 m, tolerates light frost, easily coppiced | Fuel, charcoal, perfume, furniture, shelterbelt, apiculture, fiber board, pulp and tool handles. | 0.78 | 4800 kcal/kg | 10-15 $m^3$/ha/yr |
| 12 | Eucalyptus microtheca | Sufeda, Flooded Box | Myrtaceae | Australia | Plains and hills. | Well drained soils, tolerates light frost, grows well in flood plains and swamps, stands dry period upto 7 months, precipitation: 200-1000 mm/yr, 0-40 °C and elevation upto 700 m | Fuel, poles and fence posts, charcoal, shelterbelt, apiculture & tool handles. | 0.89 | | 5-10 $m^3$/ha/yr |
| 13 | Eucalyptus tereticornis | Sufeda, Lachi, Mysore hybrid | Myrtaceae | Australia | Plains and hills. | Well drained soils including saline/ sodic/waterlogged soils, frost hardy and drought tolerant, precipitation: 800-1500 mm/yr, 0-40 °C, elevation: 1500 m. | Fuel, carriages, shelterbelt, furniture, fiber board, erosion control | 0.7 | 4900 kcal/kg | 12-25 $m^3$/ha/yr |
| 14 | Leucaena leucocephala | Subabul, Ipil Ipil | Leguminosae-Mimosoideae | Mexico | Plains and foothills. | Tolerant, adaptable growing even on steep and marginal lands, grows in saline and acidic soils, precipitation: 500-1000 mm/ yr, 2-45 °C and elevation upto 500 m. | Poles and construction, fuel, fodder, apiculture, agricultural implements, furniture and soil stabilization. | 0.56 | 4600 kcal/kg | 30 $m^3$/ha/yr |

| No. | Scientific name | Local name | Family-Subfamily | Origin | Distribution | Habitat & Ecology | Uses | Specific Gravity | Calorific Value | Productivity |
|---|---|---|---|---|---|---|---|---|---|---|
| 15 | Mangifera indica | Aam, Mango | Anacardiaceae | Pakistan, India, Nepal, Bhutan | River valleys of Chenab and Ravi, and in irrigated lands in Sindh. | Moderately shade tolerant, variety of well drained soils but does best on deep loamy soil, adaptable, humid hot/subtropical to tropical/monsoon climate with precipitation: 750-1500 mm/yr, -3.5 to 40 °C, elevation upto 600m | Fruit, chipboard, lumber and construction, ornamental, food and medicinal. | 0.55 | 4600 kcal/kg | average height for 7 years is 4 meter |
| 16 | Melia azedarach | Bakain, Persian Lilac | Meliaciae | Lower Himalayas (Pakistan and Nepal) | Plains of Punjab and KPK | Well drained soils of valleys and ravines, mature tree is frost and drought hardy, easily coppiced, tropical to subtropical temperate climate, precipitation 600-1000 mm/yr, -5-40 °C, elevation range of 900-1700 m. | Veneer and plywood, construction, boxes and crates, furniture, timber, agricultural implements, sports equipment, fodder, ornamental and medicinal. | 0.56 | 5100 kcal/kg | 17.5 $m^3$/ha/yr |
| 17 | Moringa oleifera | Sohanjna, Horseradish Tree | Moringeceae | Sub-Himalayan tract in Pakistan | Plains eastward from Rawalpindi | Intolerant, variety of soils does best in well drained soil, easily coppiced, endures drought periods and can grow on eroded sites. | Ornamental, food, fodder, seed oil, gum and medicinal. | | | |

| No. | Scientific name | Local name | Family-Subfamily | Origin | Distribution | Habitat & Ecology | Uses | Specific Gravity | Calorific Value | Productivity |
|---|---|---|---|---|---|---|---|---|---|---|
| 18 | Morus alba | Tut, Mulberry | Moraceae | Pakistan, China, Central Asia, Afghanistan | | Moderately intolerant, variety of well drained rich soils, semi-arid cool/cold subalpine/ subtropical winter/monsson climate, -10-40 °C, precipitation: 750-1250 mm/yr, elevation upto 3300 m, frost hardy and drought tolerant if irrigated | Silkworm food, fodder, fruit, shelterbelts, carriages, sports goods, veneer, plywood, furniture and medicinal. | 0.69 | 5100 kcal/kg | 8.5 $m^3$/ha/yr |
| 19 | Populus deltoides | Sufed Poplar, Northern Cottonwood | Salicaceae | North America | Plains and hills. | Sandy loams/alluvial soils, semi humid to semi arid/cool subtropical temperate climate, precipitation: 750-1250 mm/yr, -20-35 °C | Fuel, crates, packing cases, matches, pulp, reforestation, plywood, erosion control, fodder and roadside tree. | 0.46 | 5900 kcal/kg | 20-40 $m^3$/ha/yr |
| 20 | Populus euphratica | Bahan, Euphrates Poplar | Salicaceae | Middle East, Southern Russia, Subcontinent, East to China | Hot arid areas with river sources/sub surface water | Variety of sites including waterlogged/saline soils, arid/ semi arid/ sub tropical climate, -10-45 °C, precipitation: 750-1250 mm/yr, elevation: upto 4000 m, frost hardy, drought resistant and withstands inundation, also considered a riverain species | Timber, packing cases, crates, | 0.46 | 5000 kcal/kg | 8-15 $m^3$/ha/yr |

matches, erosion control, reforestation, plywood, pulp, fodder, roadside tree and medicines

| No. | Scientific name | Local name | Family-Subfamily | Origin | Distribution | Habitat & Ecology | Uses | Specific Gravity | Calorific Value | Productivity |
|---|---|---|---|---|---|---|---|---|---|---|
| 21 | Populus euramericana | Doghla Poplar, Hybrid Poplar | Salicaceae | Hybrid cultivar | | Intolerant, deep soils with abundant water, withstands freezing temperatures but does not tolerate temperature exceeding 40- 45 °C | Timber, packing cases, crates, matches, plywood, pulp, fodder, fuel, housing, furniture, chip board and shuttering poles. | 0.28- 0.52 | | 40 $m^3$/ha/yr |
| 22 | Populus nigra | Siah Poplar, Lombardy Poplar | Salicaceae | Western and Central Europe, | Northern areas, Azad Kashmir, | Well drained soils along water courses, arid/ cool-cold/subtropical climate, - | Fuel, packing cases, crates, matches, | 0.46 | 5000 kcal/kg | 10-15 $m^3$/ha/yr |
| | | | | Subcontinent, | Plains | 20-45 °C, precipitation: | erosion | | | |
| | | | | Middle East | Afghanistan, Middle East | throughout the country | Balochistan | 650-900 mm/yr, elevation range 900-3750 m, frost hardy | | Variety of dry sites mostly clays/sands, does well in high alkaline soil, hot arid/ semi arid to subtropical climate, -6-45 |
| 23 | Prosopis cineraria | Jand, Kandi | Leguminosae-Mimosoideae | Pakistan, India, | | Dry plains/hills of Sindh, Punjab, KPK and | | | | °C, precipitation: 75-650 mm/yr, |

| | | | | |
|---|---|---|---|---|
| elevation upto 450 m | control, reforestation, plywood, pulp, fodder, roadside plantation, general construction. Fodder, fuel, poles and construction, agriculture implements, apiculture, furniture, soil stabilization. | 0.61 | 5000 kcal/kg | 3-5 $m^3$/ha/yr |

| No. | Scientific name | Local name | Family-Subfamily | Origin | Distribution | Habitat & Ecology | Uses | Specific Gravity | Calorific Value | Productivity |
|---|---|---|---|---|---|---|---|---|---|---|
| 24 | Prosopis juliflora | Mesquite | Leguminosae-Mimosoideae | West Indies, Central and South America, Southwestern United States. | Dry plains/hills of Sindh, Punjab, KPK and Balochistan | Variety of dry sites mostly clays to sands, does well on high alkaline sites, drought and frost hardy, -2-45°C, precipitation: 150-750 mm/ yr, elevation upto 1200 m. Large tap root and extensive root system. | Fodder, fuel, poles and construction, agriculture implements, apiculture, furniture, soil stabilization. | 0.7 | 4500 kcal/kg | 3-5 $m^3$/ha/yr |
| 25 | Syzigium cumini | Jamun, Jaman, Black Plum | Myrtaceae | Subcontinent | Plains and lower hills of Punjab, KPK and Azad Kashmir. | Well drained soils from sands to loams, semi humid warm hot/subtropical winter/monsoon climate, - 5-40 °C, precipitation: 1250 mm/yr, and elevations upto 1500 m, frost hardy and if irrigated then tolerates drought | Construction, fruit, fuel, paper pulp, apiculture, medicinal, tannin, shelterbelts , roadside planting and shade. | 0.7 | 4800 kcal/kg | 12 $m^3$/ha/yr |
| 26 | Tamarindus indica | Imli, Tamarind | Leguminosae-Caesalpinoideae | Tropical Africa | Sindh, Punjab | Variety of soils but does best in deep alluvium soils and dry sandy sites as well, | Implement hot humid/d r y tropi | 0.91- | 496 9 | height |

| | | | | | |
|---|---|---|---|---|---|
| cal to subtropical climate, 0-40 | handles, fuel, charcoal, furniture, wheels, axles, | 1.28 | kcal/kg | increased @ 0.8m/yr | |
| | | | | °C, precipitation: 250-1250 mm/yr, elevation upto 600 m | food, fodder, apiculture, ornamental and medicinal. |

| No. | Scientific name | Local name | Family-Subfamily | Origin | Distribution | Habitat & Ecology | Uses | Specific Gravity | Calorific Value | Productivity |
|---|---|---|---|---|---|---|---|---|---|---|
| 27 | Tamarix aphylla | Frash, Ghaz, Khaggal, Tamarisk | Tamaricaceae | Middle East, Pakistan, Central Asia, North Africa | Plains of Punjab, KPK, Sindh, Balochistan and Thal area. | Well drained sandy soils including saline/sodic sites, arid o hot subtropical winter monsoon climate, -1-50 °C, precipitation: 100-500 mm/yr, does not grow on elevation of more than 600 m, frost hardy | Carpentry, agriculture implements, fuelwood, shelterbelts, charcoal, tannin, erosion control, sand dune stabilization. | 0.68 | 4835 kcal/kg | 5-10 m$^3$/ha/yr |
| 28 | Terminalia arjuna | Arjun | Combretaceae | Subcontinent | Plains, gardens, roadside plantation | Shade tolerant, variety of moist well drained sites, also grows on saline/sodic/waterlogged soils, humid hot tropical/subtropical monsoon climate, 0-45°C, precipitation: 750-3800 mm/yr, elevation: 600m. | Fuel, implements, erosion control, wheels, fodder, ornamental, timber and medicines. | 0.9 | 5000 kcal/kg | 10-12 m$^3$/ha/yr |
| 29 | Zizyphus mauritiana | Ber, Chinese Date | Rhamnaceae | South Asia | Throughout the country | No particular soil requirement, warm temperate to subtropical to | tropical climate, -5-50 °C, precipitatio | n 600-1500 mm/ yr, elevation upto 600m. | | Fuel, charcoal, agricultural implements, fruit. |

| | | |
|---|---|---|
| 0.93 | 5900 kcal/kg | aver age heig ht for 7 years is 5 meter |

## Conclusion

Agroforestry is the purposeful growing or deliberate retention of trees with crops and/or animals in interacting combinations for multiple products or benefits from the same management unit. Furthermore, it is classified in three main classes or agroforestry systems i.e. agrisilviculture, silvipastoral and agrisilvopastoral systems. Poor soils adversely affect the biomass production and yield of agricultural crops. Large area of the world has been classified as degraded soils and bringing such area under cultivation is a big challenge for farmers. However, promotion of agroforestry practices on these areas can provide manifold benefits to farmers like soil reclamation, improving soil fertility through nitrogen fixation and increasing tree cover. Moreover, planting multipurpose trees can also fulfill food and fuelwood requirements of local inhabitants/ farmers.