Chapter 2

Background

and

Literature review
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2.1 The history of agroforestry in the world

Cultivating trees and agricultural crops in close combination is an ancient practice of farmers throughout the world. Tracing the history of agroforestry, King (1987) states that in Europe, until the Middle Ages, it was the general custom to clear-fell degraded forest, burn the slash, cultivate food crops for varying periods on the cleared area, and plant or sow trees before, along with, or after sowing agricultural crops. This "farming system" is no longer popular in Europe, but was widely practiced in Finland up to the end of the last century and in a few areas in Germany as late as the 1920s.

In tropical America, many societies have simulated forest conditions to obtain the beneficial effects of forest ecosystem. For example, in Central America, it has been a traditional practice among farmers to plant an average of two dozen species of plants on plots no larger than one-tenth of a hectare. A farmer would plant coconut or papaya with a lower layer of bananas or citrus, a shrub layer of coffee or cacao, annuals of different stature such as maize, and finally a spreading ground cover such as squash. Such a close mixture of various plants, each with a different structure, imitated the layered configuration of mixed tropical forests (Wilken, 1977).

In Asia, the Hanunoo of the Philippines practiced a complex and somewhat sophisticated type of "shifting" cultivation. In clearing the forest for agricultural use, they deliberately spared certain trees which, by the end of the rice-growing season and provided a partial canopy of new foliage to prevent excessive exposure of the soil to the sun. Trees were an indispensable part of the Hanunoo farming system and were either planted or preserved from the original forest to provide food, medicines, construction wood and cosmetics (Conklin, 1957). Similar farming systems have also been common in many other parts of the humid lowland tropics of Asia.

The situation was a little different in Africa. In southern Nigeria, yam, maize, pumpkin and beans were typically grown under a cover of scattered trees (Forde, 1937). The Yoruba of western Nigeria, who have long practiced an intensive system of mixing herbaceous, shrub, and tree crops, claim that the system is a means of conserving human energy by making optimum use of the limited space available from the dense forest.
The Yoruba also claim that this system is a modest means of maintaining the soil fertility as well as combating erosion and nutrient leaching (Ojo, 1966).

However, by the end of the nineteenth century, establishing forest or agricultural plantations became an important objective for practicing agroforestry. In the beginning, the change in emphasis was not deliberate. At an outpost of the British Empire in 1806, U.Pan Hle, a Karen in the Tonze forests of Thararrawaddy Division in Myanmar (Burma), established a plantation of teak (Tectona grandis) by using a method he called "Taungya" and presented it to Sir Dietrich Brandis, the Governor. Since then, the practice became increasingly widespread. It was introduced in South Africa as early as 1887 (Hailey, 1957) and was taken from what was then Burma, to the Chittagong and Bengal areas in colonial India in 1890 (Raghavan, 1960). The ruling philosophy of the Taungya system was to establish forest plantations whenever possible using available unemployed or landless labourers. In return, the labourers were allowed to grow agricultural crops in the land between the rows of tree seedlings. This is a simplified system whose details varied based on the country and locality. These practices were always undertaken by foresters. It appears that the foresters conducting the research never envisioned the system as being capable of making a significant contribution to agricultural development, or its potential as a land-management system (King, 1987).

Many factors and developments in the 1970s contributed to the general acceptance of agroforestry as a system of land management applicable to both farm and forests. In 1974, the FAO made a serious assessment of the forestry projects in developing countries as well as the policies advised to the Third World. After assessing the programme, it became clear that although there was notable success, there were also areas of failure.

FAO redirected its focus and assistance in the direction of the rural poor. Its new policies, while not abandoning the traditional areas of forestry development, emphasised the importance of forestry for rural development (FAO, 1976). It also focussed on the benefits that could accrue to both the farmer and the nation if greater attention was paid to the beneficial effects of trees and forests on food and agricultural production and advised land managers in the tropics to incorporate both agriculture and forestry into their farming system and "eschew the false dichotomy between agriculture and forestry" (King, 1979).
As a result, there was renewed interest in the concepts of inter-cropping and integrated farming systems. It was demonstrated that inter-cropping may have several advantages over sole cropping. Preliminary results from research in different parts of the world indicated that in inter-cropping systems, more effective use was made of the natural resources of sunlight, land, and water. Research also indicated that inter-cropping systems might have beneficial effects on problems of pests and diseases and that there were advantages in growing legumes and non-legumes in mixture. As a result, higher yields could be obtained per unit area even when multi-cropping systems were compared to sole cropping systems (Papendick et al., 1976).

It was evident that in spite of the growing awareness of the need for information on which agroforestry systems might be effectively based, very little research was being undertaken. Furthermore, the research that was being conducted was haphazard and unplanned. The IDRC Project Report therefore recommended the establishment of an international organisation, which would support, plan, and coordinate, on a world-wide basis, research combining the land-management systems of agriculture and forestry. This proposal was well received by international and bilateral agencies. Subsequently, the International Centre for Research in Agroforestry (ICRAF) was established in 1977. The ancient practice of agroforestry was institutionalised for the first time. This congruence of people, concepts, and institutional change has provided the material and the basis for the development of agroforestry.

Today, agroforestry is taught as a part of forestry and agriculture-degree courses in many Universities in both the developing and industrialised world. Instead of being merely the handmaiden of forestry, it is being used more as an agricultural system, particularly for small-scale farmers. Today, the potential of agroforestry for soil improvement and conservation is generally accepted. Indeed, agroforestry is becoming recognised as a landuse system capable of yielding both wood and food while conserving and rehabilitating ecosystems.

2.2 Traditional agroforestry

Agroforestry is frequently perceived as a solution for the problems of land and water degradation as well as an answer for shortages of food, cash income, animal fodder and building materials in many parts of the world (Rocheleau, 1988). While experts may disagree on whether famines, drought and resource degradation are natural disasters or
caused by misuse of the environment, there is a general consensus that future land use systems and technologies must give people more flexibility to respond to rapid shifts in economic and ecological conditions. In addition, new production systems must maintain or in many cases restore, the soil and water resources on which rural life depends.

In this context, several traditional agroforestry (TAF) systems have in fact sustained people for generations in a variety of environments. For example, the inter-cropping of *Acacia albida* with millet and sorghum in the West African Sahel, Kibanja system in Tanzania are among the best known examples of successful TAF practices. Less well-known but equally significant are the silvopastoral systems developed by people who depend on managing livestock and their fodder source in African savanna lands. At present, many of these TAF systems are literally losing ground in the face of destructive changes and increasing pressure on the people and their natural resources. The challenge is to maintain those agroforestry systems that are now under threat and to improve and adopt long-standing practices that can be effective under changing conditions. Where TAF systems have not been used or can no longer be used because of changing conditions, new systems need to be developed (Kaswamila1, 1999).

Traditional agroforestry in the Marshall Islands is a complex, sustainable system of land use integrating forest trees with agriculture. It does not generally exhaust the soils and thus continues to provide much food and other resources for the people in areas where it is still practiced. The early Atoll population depended entirely on food gathered from the sea and grown on land. They were experts in growing plants that were important for nutritional security and for providing materials for construction of canoe, handicrafts, flowers and medicine. They knew which varieties of edible plants grew well or poorly, how to propagate them and where they grew best on their Atolls. Such information had been passed down through the generations although some of it was lost in the last century. Although the traditional cropping system of agroforestry has significant value in nutrition, cultural preservation and rural economic stability, this long-lasting local system is changing due to greater contact with the outside world after World War II. This has led to increasing desire for consumer goods and cash incomes and access to markets. Pressure to cultivate cash crops and promote monoculture plantation agriculture and forestry has intensified, thereby resulting in an imbalance in nature. To overcome this situation, traditional agroforestry systems need to be revived. Inhabitants
of Marshall Islands have started re-establishing their traditional multi-spice agroforestry and landuse systems by growing food crops in-between forest trees (Verma, 2003).

The role of traditional agroforestry practice in socio-economic and environmental aspects has been considered in a biosphere reserve in the Republic of Benin. This study discusses the socio-economic determinants which explain the choice of people in Pendjari Biosphere Reserve to include local species in their traditional agroforestry systems. It also identifies the reasons for the difference in these systems and new agroforestry systems developed by researchers.

They collected data on the choice of the household to integrate indigenous trees into their farming systems whose products have traditionally been gathered from natural forests. Multinomial logistic regression analysis revealed that the choice of dwellers in Pendjari Biosphere Reserve to integrate indigenous trees in their farming system increased with land availability and decreased with availability in the natural vegetation. In the same way, the use of a species for the farmer and its market value determine whether the head of the household selects that particular species for his farming system. Taking into consideration the impact of gender on the choice of indigenous trees to be grown, the multinomial logistic analysis point out that women favour plant species more than men. All species which are integrated into the farming system are multipurpose species. For 80% of their research sample, this is being done to provide marketable products from farms that will generate cash for resource-poor rural and peri-urban households. However, according to 67% of the respondents in Pendjari Biosphere Reserve area, the expansion of these traditional agroforestry systems are facing a number of constraints, of which the most important is the lack of knowledge about the biological aspect of species. Complementary studies are needed for a better understanding about these systems (Fifanou, 2008).

The presence of trees in agrosystems is a fundamental property of agrarian landscapes in tropical Africa where many studies have been conducted. In this context, the structure and spatial distribution of traditional agroforestry systems has been considered in Togo. This study aims to analyse the spatial distribution of traditional agroforestry systems as well as their structure in Togo. Forest inventory and ethno-botanic investigations were carried out in several sites across the country. In each site, the tree inventory study identified three types of traditional agroforestry systems: homegarden, farm parkland and multistage farms of cocoa and coffee plantations in southwest of
Togo. The structure of these agro-systems varied according to latitudinal gradient and practices of the local communities. Some agroforestry species like *Parkia biglobosa*, *Vitellaria paradoxa*, *Vitex doniana* have a large distribution spectrum while others were restricted to specific climatic regions. The diversity index of Shannon increased from 0.51 bits in the north to 3.27 bits in the southwest region. There is a relationship between plant diversity of parkland and selection of species conserved in agro-systems by the local communities. Wherever this selectivity is high, the parklands are mono-specific. Tree density on farms decreased from forest area to the north Sudanian zone. Tree species conserved on farms provide many non-timber products such as food (leaves, fruits and flowers), forage, medicinal plants, fuelwood, and material for construction and craft. They are also a major source of income in rural areas (Wala et al., 2007).

Forests are critical for indigenous communities as they are dependent on the forests. In Bangladesh, there are more than 36 ethnic groups, many of which still live and depend on forests for a variety of reasons including everyday meals. In this context, an exploratory study has been conducted in Lawachara National Park, a northeast protected area and an exceptionally biodiversity-rich region, to explore traditional agroforestry farming practiced by the indigenous communities in the park and its buffer zone area, socio-economic significance, possible environmental impacts and conservation prospects. They observed four ethnic communities (Khasia, Tripura, Garo and Manipuri) and identified traditional agroforestry practices such as betel-leaf-based agroforestry, upland rice-based shifting cultivation, lemon and jackfruit agroforestry and alley pineapple intercropping which played an important role in the livelihoods of ethnic communities by providing them with cash income, food, fuel, medicine and other non-timber forest products. The contribution of different farming practices to the livelihoods of these communities was estimated and found to vary from 45% to 80%, both in terms of cash generation and market value of consumed goods. For realising the conservation prospects of each farming practice, they considered the cultural practices, pesticide/fertiliser use, soil erosion, nutrient/moisture content in the soil and assessed the plant diversity, canopy coverage, undergrowths, faunal species richness (avifauna and mammals), etc. The study indicated that even though none of these were absolutely perfect for adoption in park management and biodiversity conservation, the betel-leaf based agroforestry practice could provide some basis for both conservation and livelihoods as it generates substantial revenue and retains almost all the old trees as
support, suitable for wildlife. Finally, they recommend an effective market chain for agroforestry products and large-scale adoption of a suitable agroforestry practice in place of an unsustainable one (Mukul, 2006).

Supari (*Areca catechu*) based agroforestry system has been practiced traditionally by the farmers of northern rural Bangladesh for decades. The study clarified the existing land-use systems in the study areas, components of agroforestry system and their interactions, indigenous cultivation and management of agroforests, production and marketing of products and income of farmers from their agroforests. Results of the study showed that farmers allocated a portion of their agricultural land along with homesteads for supari based agroforestry practices as they felt that the system was sustainable and profitable. The production system played an important role in the economy of farmers. Choice of species in the agroforestry system was highly influenced by farmers’ knowledge about ecology. Farmers did have more indigenous ecological understanding about above-ground interactions than below-ground interactions. Indigenous techniques in cultivation and management of different agroforestry components were described and discussed. Finally, perceptions of farmers were also described and discussed in the context of opportunities and constraints of this type of agroforestry (Nath *et al*., 2004).

Agroforestry while is still a new concept in Turkey at the academic and institutional levels, has been practiced in traditional forms for many years by villagers in nearly every part of the country. This study therefore undertook to observe and document traditional agroforestry practices in Turkey. The West Mediterranean region was selected for this purpose. According to this study, the nature of agroforestry systems and the objective of productions in the region are similar to other applications in the world. Many of the agroforestry production patterns are seen to be traditional. Results showed that agroforestry applications in the region can be placed in the following major categories:

(i) Agricultural systems (e.g. alley cropping, multilayer tree gardens, multipurpose trees on crop lands, plantation crop combinations, homegardens, trees in soil conservation and reclamation, shelterbelts and windbreaks)

(ii) Silvopastoral systems (e.g. trees on range land or pastures, protein banks, plantation crop with animals; and
Agrosilvopastoral systems (e.g. homegardens involving animals, multipurpose woody hedgerows, apiculture with trees, aquaforestry, multipurpose woodlots). These practices are also suitable for solving problems related to deterioration of family farms, increased soil erosion, surface and ground water pollution in West Mediterranean Region of Turkey. As agroforestry practices, shifting cultivation and Taungya were also found in this region, both the practices were not found to be applicable, as they lead to forest degradation (Tolunary et al., 2004).

Agroforestry has long been recognised as a system that is built on biological and genetic diversity. Traditional agroforestry systems are actually modelled around the complexity of forest ecosystems. This paper focusses on genetic diversity management and its implications on sustainable agroforestry systems. The paper analyses the role that inter and intra-specific diversity plays in agroforestry and highlights the importance of diversity management in tree component in ensuring sustainability and productivity of agroforestry systems. Through a review of current literature, the paper makes a comparative assessment of diversity within and between tree species in traditional agroforestry systems and modern agroforestry technologies, with a view to understand the functional elements within them and assess the role and place of diversity. A special emphasis in the paper is placed on the extent of diversity analysis in agroforestry research. The paper attempts to show that whereas agroforestry by definition and by tradition, has been a genetic diversity and conservation system, research of agroforestry over time has de-emphasised the diversity element, and shifted increasingly towards simple “technologies” that only involve a few tree species. Agroforestry research has tended to minimise the complexity that comes with diversity and has generally taken a reductionist approach in research on the system (Atta-Krah et al., 2004).

2.3 Agroforestry for sustainable development

Sustainability is one of the most widely debated topics in all land-use-related discussions today. It is a rallying theme for both environmentalists and production scientists. It is a concept that incorporates the long-term concerns of the society with the basic short-term needs of the World's poor (Thomas, 1990). Agricultural sustainability includes interaction among agriculture, household economies, environment, society and agricultural policies. Because of the complexity and temporal nature of this concept, definitions of sustainability are often vague and sometimes
contradictory. For example, BIFAD (1990) states: "Sustainability is increasingly viewed as a desired goal of development and environmental management. This term has been used in numerous disciplines and in a variety of contexts. The meaning is dependent on the context in which it is applied and on whether its use is based on a social, economic, or ecological perspective. Sustainability may be defined broadly or narrowly, but a useful definition must specify explicitly the context as well as the temporal and spatial scales being considered."

In their definition of sustainability, the Technical Advisory Committee (TAC) of the Consultative Group on International Agricultural Research (CGIAR) states that “sustainable agriculture should involve the successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resource” (CIMMYT, 1989). The World Commission on Environment and Development report, commonly known as The Brundtland Report, defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). While the BIFAD report explains the difficulty in arriving at a single definition of sustainability, the CGIAR's definition attempts to integrate economic growth and productivity with sustainable land-use practices and the WCED report defines sustainability in terms suitable for formulating development policies.

These and a plethora of other definitions and analysis suggest that sustainable agricultural practices should not have a negative impact on the environment but should rely predominantly on nutrient cycling and green manure for maintenance of soil fertility and promote system diversity for pest and disease control. Moreover, from the perspective of equitability, analysts of sustainable agriculture argue that sustainable agricultural production by resource-poor farmers today, and by their children tomorrow, can be achieved only if issues of land tenure and distribution, birth control, social security, economic development, and natural-resource exploitation are addressed. It is clear, then, that there is no universally accepted definition of sustainability. As Bellows (1992) puts it, many agricultural researchers and development workers, frustrated in their attempts to define sustainability, simply state that agricultural sustainability is "understood intuitively."
In production-oriented systems, sustainability can be considered as the maintenance of production over time, without degradation of the natural base on which that production is dependent. Since sustainability deals with productivity of the system over time, there are three main issues to be considered: productivity changes over time, the time-frame being considered, and the costs (e.g. ecological, social, economic, and agronomic) associated with management and maintenance of production.

In recent years, interest in agricultural sustainability has increased in response to perceived, unsustainable agricultural practices. In the United States, heightened awareness of the adverse effects of fertilisers, pesticides, and other agrochemicals resulted in renewed interest in the use of green manures, organic farming, and integrated pest control (USDA, 1980; Edwards et al., 1990). In developing countries, interest in sustainable agriculture arose mainly in response to what was perceived to be the non-sustainability and inequity of the green revolution technologies (Nair, 1990). Little wonder then that agroforestry, which also arose in response to these concerns, included sustainability as one of its cornerstones.

Thus, even before sustainability attained its present prominence in land-use disciplines, it was integral to the concept of agroforestry. Since the beginning of organised thinking of agroforestry in the 1970s, sustainability has consistently been a part of the definitions proposed for agroforestry (Nair, 1989). The sustainability attributes of agroforestry are mainly based on soil productivity and other such biophysical advantages. It could be argued that socio-economic and socio-cultural attributes of agroforestry are also important factors that contribute to its sustainability; but the added advantages in such socio-economic-cultural factors stem from the unique biophysical advantages of agroforestry. The latter includes beneficial effects such as erosion control, addition of organic matter, improvement of physical properties, $N_2$ fixation, improved nutrient cycling, synchrony in nutrient use and reclamation of degraded lands. Of course, possible adverse aspects such as competition for nutrients and moisture and increase in soil acidity, must also be considered in sustainability evaluations.

At present, there is no quantitative measure of sustainability. Several approaches are currently being discussed. One is to calculate the total factor productivity (TFP) of the system over a defined period of time (which could be the summation of total factor productivities of individual components); there could be separate indices for biological and socio-economic characteristics. Until such criteria and indices for assessment are
fully developed and widely accepted, we will have to contend with qualitative statements about the sustainability of agroforestry as is the case with other land-use systems. Again, it should be emphasised that the lack of definite quantitative parameter to express sustainability is no indication of whether or not a system is sustainable. Indeed, the value of agroforestry in terms of sustainability has almost been universally accepted and limited research data on the topic supports this contention (Nair, 1993).

The Campesinos (smallholder farmers) in Chile own more than 8 million hectares in rural properties with an average of 50 hectares per farmer. The main objective of the Campesinos is to provide food, care and money to cover their basic needs. They organise their lands for crops, prairies and livestock production, although the land is mainly forest land that is eroded, and only a small area is utilised to generate new forest plantations, which in the last five years have been less than 2 ha per property. This is one of the reasons why reforestation activity did not increase in this kind of smallholder properties, although in Chile there are more than 2 million ha without forest cover belonging to Campesinos which can be afforested. There is even a special law to promote reforestation in small farmers’ properties in Chile. The other reason is that the extension programme was trying to use the same reforestation strategy that was used in the past with the forest companies and large farming lands, which are not compatible with small farmers. Therefore, this strategy did not work. As a result, the Forest Research Institute (INFOR) along with the Institute for Agriculture Development (INDAP) studied an alternative model for reintroducing forests in Campesinos’ lands, using trees in a natural way, with an agroforestry arrangement, that allows them to receive their basic needs from crops, livestock and wood for energy and timber, but all on the same land; this was done in a way that is altogether compatible with natural resource conservation, land and water biodiversity, and encouraging Campesinos to remain on their farms. This new approach has been well received by the producers which has enabled new land to be used in agroforestry systems, such as silvopasture, windbreaks, alley cropping and riparian buffers and agroforestry systems developed a real alternative for a sustainable development for ‘small farmers’ in Chile (Alvaro, 2006).

Occidental Mindoro National College of Philippines, in partnership with International Plan, conducted the Sustainable Upland Development Programme in Sitio Salafay, Monte Claro, San Jose, Occidental Mindoro, home to about 50 Buhid Mangyans. The
agroforestry project, as one of the livelihood components, was implemented to increase the productivity of the community and help conserve upland resources. Community people were organised and worked collectively in the project. Thus, ownership was communal. Their interest in the establishment of the project was further aroused by carefully and clearly explaining to them its importance not only in the improvement of their living conditions but also to their environment. Other activities conducted were the ‘Lakbay Turo’, showcasing 0.5 ha soil and water conservation techniques and construction of a community nursery and fish pond. The project contributed to the continuous schooling of children because it was able to augment the food that their individual farms provide. Prior to the establishment of the project, dropping out of classes was rampant. School children stopped schooling to hunt for food in their surroundings or just stayed at home because they had not eaten. The project also augmented the table needs of the families, based on the guidance of elders and on the degree of their participation. It also improved cooperation, camaraderie and belongingness among the participants. As to its long-term impact, it is envisioned that the community shall have real development suited to their culture and shall live in harmony with nature to accept that agroforestry will be a strategy for sustainable development in the area (Marigmen, 2007).

The Himalayan region is one of the world's richest ecosystems in terms of biological diversity. The Himalayas are home to hundreds of endemic plant species and some of the World's rare and threatened wildlife species. Approximately, 54 percent of Nepal's area is covered with some sort of vegetative cover (forested area 37%, shrub land 5% and grass land 12%). A total of 118 ecosystems with 75 vegetation types, and 35 forest types, have been identified in these realms. These rich biological resources have traditionally served as the foundation for the economic and cultural life of the Himalayan people. However, these resources are heavily threatened by increasing population growth, slash-and-burn agriculture, and the general over-exploitation of forest resources for fuel, fodder, manure, grazing, fishing and hunting. Conservation of Himalayan biodiversity is thus one of the important global responsibilities of mankind to ensure its safe future. This research critically examines the current status of Himalayan biodiversity conservation at different levels, conservation and management approaches of biodiversity conservation and institutions involved in conservation and management of this biodiversity. Unless species conservation provides a direct benefit to the rural people, it will be very difficult to attain the goals of sustainable
development. The goal cannot be attained in isolation. The challenge is to empower and motivate the larger sector of the society in this direction. Based on these facts and findings, recommendations are made for Himalayan biodiversity conservation to achieve sustainable development of the Himalayan region with emphasis on Nepal Himalayas (Dixit, 2004).

Agroforestry is a land use system in which tree species are deliberately grown alongside agricultural crops, and often in conjunction with livestock rearing. The advantages of agroforestry are that positive biological interactions between various components of the system result in increased yields and income. Nepal stands to benefit greatly from the introduction of agroforestry, as its natural forest reserves are at present diminishing rapidly. Nepal is a country with widespread poverty that can be reduced to a great extent by agroforestry farming methods. This is specially the case in mountainous areas. Various agroforestry systems are being introduced in Nepal, varying across the country with climatic and physiographic zones. Examples include home gardens, alley cropping, planting trees among agricultural crops, intercropping with horticultural trees, Taungya systems, silvofishery, silvopastoral systems, etc. This research identifies various agroforestry practices/models prevailing in physiographic regions of Nepal, explores research and development initiatives of Tribhuvan University/ International Development Research Center-Farm Forestry Project (1983-1997), and examines its impacts on rural development in selected areas of Terai, Inner Terai and Midhills of Nepal. Based on these experiences, recommendations were made for sustainable agroforestry development in Nepal (Bhandari, 2004).

Agroforestry can be presented as one of the means to reconcile the need for agricultural or forestry production and the protection of soils and the environment. The assessment of agroforestry experiences in Cameroon shows that some factors still hinder the maximum expression of its potentiality. Those factors include, among others: choice of the species planted; mastery of agricultural and forestry techniques and more globally, integration of agroforestry in the global agenda on sustainable development. This paper builds on the positive points of agroforestry as proven by field experiences, to advocate that it can play a better role in the constant search for more sustainable development strategies (Bitondo, 2003).

Farmers in the semi-arid tropical regions cultivate drought-hardy nutritious cereals. Poor yields along with low prices of these crops make dryland farming unprofitable.
Hence, an alternate agri-horti-silvi model with a participatory approach was attempted and developed for dryland farmers in India. This study aimed at conserving soil fertility and thereby bringing about sustainability in four semi-arid districts of India viz. Ranga Reddy and Mahaboobnagar in Andhra Pradesh and Beed and Sangli in Maharashtra on an experimental basis. Mango (*Mangifera indica*) orchards of three different age groups viz., < 2 years, 5-7 years and >10 years old were selected. Erosion barriers like preparatory tillage, bunds across the slope, and semi-circular basins around trees were prepared. Teak (*Tectona grandis L.*) plantations were planted along the boundaries. Cowpea, horsegram, sorghum, stylo and cenchrus were selected as intercrops, grown in between tree rows in different blocks with recommended doses of fertilisers (RDF), along with two other treatments viz., RDF alone or FYM without intercropping. Regular practices by farmers served as control. The estimated yields from the adopted technologies have 2 to 4 fold increase over control. Agri-horti-silvi systems provided higher net income to the rainfed farmers. The system also contributed to soil and water conservation in continuously degraded soils. Inclusion of fodder and livestock enhanced profitability to the system. Leguminous inter-crops enriched the soil fertility. Teak plantations in the boundaries served as windbreaks and provided income through valuable wood. The adoption rate was very high with sustainable income and could be implemented in other semiarid regions of the world (Reddy, 2002).

**Agroforestry as a sustainable cultivation system**

It is widely believed that agroforestry has considerable potential as a land management alternative for maintaining soil fertility and productivity in the tropics. In addition, low input costs in many agroforestry systems attract poorer farmers as well, who normally suffer most from the effects of erosion. Agroforestry is applicable to land types of wide range and has the potential to control erosion through soil cover provided by the tree canopy and litter. Field crop production mainly affects the upper soil strata, while agroforestry exploits the entire soil profile (Young 1989). The aim of agroforestry is to optimise the positive interactions of all components included and the physical environment (Lundgren and Raintree 1983). Improved agroforestry systems can provide alternatives to a land owner for short and long-term investments and allow the spreading of financial risks through diversification (Hoekstra 1987). This approach can reduce both the ecological and the economic risks of the farmer (Angelsen and Kaimowitz 2004).
Simple ways to fight erosion are a higher plant density and mixed cropping and better soil cover compared to monoculture. Trees provide double protection to the soil surface with the litter layer and leaf canopy. It has been found that litter cover can reduce the erosion rate by 95% as compared to bare soil and maintenance of a ground vegetation cover of 60% or more, provides a good way to reduce the erosion (Young 1989).

A change from traditional systems to improved agroforestry requires more time for planting and often, there are limited means to hire extra labour. However, a mixed cropping system also allows flexibility in the time of planting, e.g. for trees and food crops in the first year, food crops and spices between the tree rows in the second year, and food crops between the trees and spices in the third year. For adequate yields, planting has to be done at the onset of the rains, so as to allow the crops to successfully compete with weeds. All possible land preparations should be done before the rains. Digging of holes for seedlings can also be done prior to the onset of the rains (Beets 1990). Research results from Kenya show that when the change to a new recommended system calls for five times more effort for planting, the adoption of the new practice is not very rapid, even though the yields increased substantially (Keswani and Ndunguru 1982).

Organic matter management is critical for protecting the physical structure of soils, but it is not sufficient to be the only practice. Some soil types cannot support continuous cultivation of annual crops, which is a reason why economically attractive perennials and cover crops must be incorporated into the cultivation system (Scherr 1999). Annual crops should not be grown in badly deteriorated areas, and steep slopes should never be left bare (Gomez and Gomez 1983). There are small, simple things one can do to better manage sloping lands. In a case reported by Young (1989), a farmer in the Usambara Mountains maintained a good ground cover, allowed the weeds to grow, cut them, and left them at the site as mulch; he did the same with the maize residues and never burnt them. As a result, the soil loss on a 25° slope was only 0.01 t/ha/a, when normally it is in the excess of 10 t/ha/a on the steep slopes of the Usambara Mountains.

Some researchers estimate that the yields of any given crop in Tanzania are only 20-40% of the potential (Uliwa and Fischer 2004). However, for more profitable cultivation, the use of external inputs should be limited to the essential. That is done by optimising the use of internal resources, by using efficiently what is already available. There is no need for agriculture to expand into uncultivated lands, as the existing
farmlands already include a potential that is overlooked. There is no need for expensive commercial fertilisers and pesticides when there are natural ones available.

2.4 Agroforestry in Iran

2.4.1 Historical perspective and sustainability

A review of traditional agroforestry systems in Iran shows that many systems used natural forests and woodlands in their existing condition and livestock were generally free-grazing while the local people may have moved periodically from one area to another. Thereafter, agricultural activities blended with the systems and cultivation of crops was done on the forest floor. In almost all these practices, the tree component has generally been natural forest, frequently modified by regular burning or fruit orchards.

Except for the temperate forest in the north of the country, Iran has about 13 million ha of forest located in arid and semi-arid regions. In most parts of these forests, some agricultural systems are observed. In fact, from ancient times, human beings in forest areas have used some agricultural systems in natural forests. Although according to law, activities such as agronomy, animal husbandry, etc., in forest areas are forbidden, the Government has not been able to prevent and control the local people from using the forest for agricultural activities.

Gradually, for promoting agriculture and providing forage material, the original forest lands were cut or burnt and converted into farms. Meanwhile, trees and livestock components of the systems have received very little management and therefore many of the latter lands were eventually abandoned to regenerate as forest or remain as range. Subsequent to this, farmers and other native inhabitants began to plant trees as shelterbelts and windbreaks along crop borders and around homesteads for their subsistence. They also provided shade for grazing animals and provided a source for fuelwood, lumber and fence post. They also included multipurpose trees and other useful species in their systems to achieve all their subsisting purposes from a small piece of land.

Considering the gradual landuse alteration, the hierarchy of sustainability for these landuse systems can be as follows:

- Natural forest
- Forest and livestock
In any region, one of these landuse systems is in use. For example in Hyrcanian forests, considering the Government policies on timber production and the forest potential to produce a closed canopy, the priority is to preserve forest in its natural form and keep the livestock away. But in Zagros forests, which are sparse and their canopy cover is seldom closed, grasses and other herbaceous plants grow in great volume and can feed numerous livestock. Since the annual increment in Zagros forests is about 0.5 to 0.6 cubic m per ha which is not enough for timber harvesting, and forest grazing has been prevalent for thousands of years in this area, the priority of landuse in this region is grazing in the forests along with conservation and pasture management. The less sustainable landuse systems would be considered as priorities whenever the more complicated socio-economic and legal issues occur and consequently stage by stage, the natural resources will be displaced by agriculture.

2.4.2 Research history

For proper analysis of this project, a complete understanding of the studies conducted on various aspects of similar work in the country is essential. Although extensive research in agroforestry has been conducted throughout the world and inspite of the existing variety of traditional agroforestry systems in Iran, little research has been done so far and local references are not available for the scientific sector, farming communities (who are the backbone of rural development), students and readers. This prompted the authors to share the information on existing agroforestry systems and practices prevailing in Iran in the form of books and researches in recent years. A review of the relevant literature related to the study is presented in this section of which some are referenced below:

In 2002, for the first time in the country, the traditional agroforestry systems and the possibility of their improvement were assessed in Kohgiluye-va-Boyerahmad, one of the western provinces of Iran. For this purpose, the definition of agroforestry by the International Centre for Research on Agroforestry (ICRAF) was used to diagnose agroforestry landuse. Pilot characterisation of the systems indicated that predominant
methods of characterisation were not completely compatible and practical in the study site and so a new method was developed. A team of researchers performed diagnosis and design procedure in order to improve the characterisation method and organise the systems. In this way, thirty agroforestry systems, belonging to twelve different agroforestry practices were characterised. Four classification bases were employed for classification of the diagnosed systems. These include nature of components, ecological properties, level of applied technology and socio-economic criteria. The quantity and variety of the systems of the study area indicate that the landusers created these systems as a solution to satisfy their subsistence needs while protecting natural resources (Matinkhah, 2002).

It was also the first study on homegardens in Iran which concerned the characterisation of traditional homegardens of Kohkiluye-va-Boyerahmad province, in the Zagros region of Western Iran. These systems include the experiences of rural people in the use of various agroforestry components and which are at the same time applicable in new agroforestry planning. Four systems were characterised and compared to the homegardens of other countries. The study showed that these indigenous homegardens have the most compatibility with the need of their users and their climatic conditions (Matinkhah, 2002).

The experimental cultivation of alfalfa in Poplar trees understorey was conducted for the first time by Forest and Pasture Research Institute where alfalfa production was satisfactory. Poplar seedlings traditionally cultivated by growers with low spacing does not render thick trees. Farmers give high importance to the continuous flow of income before acceptance of a new practice. Thus, besides high return from wood, supplementary income is also one of the important factors for the acceptance of poplar-based agroforestry on the farms. Therefore, a need arises to evaluate the performances of intercrops along with poplar to increase the productivity. In this study, *Populus nigra sub sp. betulifolia* seedlings were planted in a randomised complete block design layout with 3 replications and 4 mixed poplar and alfalfa treatments with tree spacing including 3×4, 3×6, 3×8, and 3×10 m and 2 control treatments namely sole (pure) alfalfa and pure trees (3×4m). They investigated some important attributes during the period 1998-2008. Irrigation was assured during the growing seasons. Results showed that the best tree height was in the mixed treatments including 3×4, 3×8 and 3×6.66 m with 159, 158 and 142 cm respectively. Regarding the wood volume per ha, best yields
were in the same treatments with 18.4, 11.1 and 10.99 cubic m respectively. The highest dry weight production of alfalfa was in sole alfalfa, 3×10 and 3×8 m treatments with 7507, 4788 and 4265 kg per ha respectively. There was no significant difference among the spacing after 11 inter-cropping years for branch diameter and annual tree growth diameter (Asadi, 1999).

The influence of socio-economic factors on adoption of agroforestry among poplar farmers was analysed in 2006 in the northern part of Iran. The research findings revealed that there are significant and positive relationships among adoption level of agroforestry independent variables consisting of literacy level, level of annual income, level of awareness about agroforestry, level of access to needful inputs, level of access to credit facilities and contact with extension agents. The result of regression analysis indicated that 49.8% of the variations in level of adoption agroforestry were explained by the levels of awareness about agroforestry, access to credit facilities and annual income (Darvish et al., 2008).

The identification of Zagros forest vegetation units in support of Government management objectives has been studied in the western Iranian forests. In the coppice oak forests of this area, the present harvesting technique using traditional practices generally exceed regrowth potential, resulting in forest degradation and loss. To reverse this trend, more careful consideration is now being given to composition of species, site conditions, forest production potential and assessment of local wood and non-wood forest product requirements to develop improved forest management plans. The present study was carried out in the Doveyse forest, located in Kurdistan Province, northern Zagros. Clustering analysis of data from a systematic vegetation survey of the 660 ha forest site yielded four distinct plant ecological groups. Groups 1 and 2 included highly degraded sites that require conservation to rehabilitate or restore the productive forest. The results suggest that traditional utilisation can be continued on the more fertile sites within groups 3 and 4 under optimal management conditions. Site potential evaluations and classification of forest vegetation over the broader Zagros forest zone are recommended as an important step in the development of improved forest management plans in the region (Pourhashemi et al., 2004).

Some specialists at the University Research Institutions and the Department of Natural Resources at the Institute of Scientific and Applied Higher Education of Jihad-e-Agriculture, decided to prepare agroforestry courses at the technician and Bachelor of
Science levels. These courses were planned in technical and vocational systems, which attempted to consider the type of jobs in which students were employed. The graduates are employed in forestry departments, environmental departments and the private sectors (Mirzaee, 2007).

2.4.3 Agroforestry practices in different climatic zones

Traditional agroforestry systems have been applied since long ago in the country. Some of these applications in different vegetation regions of Iran consist of the following:

1. Agroforestry systems in Caspian coastal zone

Agroforestry systems in this area have the maximum species of woody perennials. In low plain areas, most of the forests have been replaced with agriculture, whereas some of the forest trees including; Maple, Alder, Caucasian wingnut, Box wood, Caspian locust, etc. are being observed on farm land sides. Desired lands are mainly allocated to rice plantation field or citrus orchards and tea plantation in hill sides. The prevailing livestock is cattle and the number of goat and sheep is less than the Zagros zone. On the other hand, silk worm breeding which is rare in Zagros zone is prevalent in this area. Most of the systems temporally consist of coincident components with a spatially bordering order which are located in a proper climate of humid temperate and their products are sold in city markets. Due to the existing policy in forest management and wood production, animal husbandry in forest zones of the area is restricted. In the mountainous area of this zone, natural forest management and in plain lands for a sustainable agriculture, management of agroforestry systems is recommended.

2. Agroforestry systems in Arasbaran zone

There are about 180 tree and bush species in this area. Therefore, the number of multipurpose trees (MPTs) is more than Zagros zone. Since the area is hilly (with a slope of 30 to 70 percent), to preserve the land stability, trees should be planted in crop fields. Due to poor forest management in the area, damage in tree cutting and animal husbandry is excessive. The agroforestry systems are located in a variant climate so that rainfall is varied from 350 mm in an altitude of 250 m in Aras riparian to 600 mm in altitude of 1800 m in mountains. The crop production is mostly for local or household consumption and animal husbandry is often semi mobile. There are many types of traditional systems in this area which can be investigated as a pattern to develop the agroforestry systems in this zone.
3. **Agroforestry systems in Zagros zone**

This area has a variable climate and the foundation of livestock, agriculture and forest production is quite complicated. The rural communities exist in the form of villagers and nomads. On the other hand, there are many conservation programmes for native vegetation in this area. The studies show that, there are many agroforestry systems in traditional forms, scattered throughout the area. Considering the nature of components, there are three groups of agroforestry systems in the area such as agri-silvicultural, agro-silvopastoral and silvopastoral systems which are totally traditional practices. A large number of farmers and livestock are linked with renewable natural resources. Diverse climatic conditions, rich vegetative cover and the feasibility of planting multipurpose trees and shrubs in farms and pastures, make this area suitable for agroforestry practices.

4. **Agroforestry systems in Iran-Touranian zone**

The climatic condition in this area is limited. Trees are mostly planted as windbreaks in agroforestry systems and some taller trees including Plane tree, White poplar and Willow are planted for wood production. Sometimes, the role of tree components is to create boundaries as live fences taking advantage of fruit trees which are the same as Mulberry, Oleaster, etc. and sometimes, the agroforestry systems appear in the form of citruses and date palm orchards in company with grasses underneath. Considering the strong sunshine, the tree shadow is very useful and favourable for inhabitants. A pervasive study seems to be essential in this area.

5. **Agroforestry systems in Persian Gulf and sea of Oman coastal zone**

There are a few studies on agroforestry systems in this area. Some native species of the area such as jujube can be used as multipurpose trees. The habitat condition is almost comparable to tropical zones all over the world specially India and Pakistan which are mainly rich in the field of agroforestry studies. While there are already many forms of traditional agroforestry systems in the area, it is possible to include them in modern agroforestry systems considering the knowledge on agroforestry in other countries.
2.5 Agroforestry in India

2.5.1 History of agroforestry

Agroforestry is an age old practice throughout the world, but its recognition as a science is nearly three decades old. The scientific and systematic research on tree-crop interactions in India started in the late 1970's and received major support and impetus with the establishment of the All India Coordinated Research Project (AICRP) on Agroforestry in 1983 by ICAR. Today, AICRP on Agroforestry has its network throughout the country. Under AICRP and through the individual efforts of State Agricultural Universities, location-specific agroforestry systems have been recommended to suit agro-climatic zones, landholdings and economic status of the region.

India's long tradition of agroforestry has been influenced by numerous religious, social, and economic factors. Several indigenous agroforestry systems, based on people’s needs and site-specific characteristics, have been developed over the years. Agroforestry research was initiated in the country about two decades ago. Since then, considerable progress has been achieved. The interactions between and among the tree, crop, grass and animal components have been studied and several agroforestry technologies have been developed and tested on farmers' lands. Agroforestry research is now conducted under the auspices of AICRP of the ICAR at 31 centres distributed over India's tropical and temperate regions. In addition to research, the programme includes agroforestry training of farmers, technicians, and scientists at 28 centres throughout the country. Expectations from agroforestry are high in India in both rural and urban areas. These expectations include production benefits that are in harmony with the ecology, environment, traditions and heritage of the country.

2.5.2 Agroforestry studies

India has been in the forefront of agroforestry research ever since organised research in agroforestry started worldwide about 25 years ago. Considering the unique land-use, demographic, political, and socio-cultural characteristics as well as its strong record in agricultural and forestry research, India's experience in agroforestry research is important to agroforestry development, especially for developing nations. Agroforestry has received significant attention in India from researchers, policy makers and others for
its perceived ability to contribute significantly to economic growth, poverty alleviation and environmental quality, so that today agroforestry is an important part of the ‘evergreen revolution’ movement in the country. Twenty-five years of investments in research have clearly demonstrated the potential of agroforestry in many parts of the country, and some practices have been widely adopted. But the vast potential remains largely under-exploited, and many technologies have not been widely adopted. This situation is a result of the interplay of several complex factors. The understanding of the biophysical issues related to productivity, water-resource sharing, soil fertility, and plant interactions in mixed communities is incomplete and insufficient, mainly because research has mostly been observational in nature rather than process-oriented. Methods to value and assess the social, cultural and economic benefits of various tangible and non-tangible benefits of agroforestry are not available and the socio-economic processes involved in the success and failure of agroforestry have not been investigated. On the other hand, the success stories of wasteland reclamation and poplar-based agroforestry show that the technologies are widely adopted when their scientific principles are understood and socio-economic benefits are convincing. An examination of the impact of agroforestry technology generation and adoption in different parts of the country highlights the major role of smallholders as agroforestry producers of the future. It is crucial that progressive legal and institutional policies are created to eschew the historical dichotomy between agriculture and forestry and encourage integrated land-use systems. Government policies hold the key to agroforestry adoption.

2.5.3 Social forestry

In India, a conceptual distinction has been drawn between production forestry (so far confined mainly to reserved forests) and social forestry (scattered land wherever tree-growing is possible).

Social forestry is in effect an integral part of the Gandhian philosophy of economic growth and community development. Imagine an economy in which the present idle land and water resources, owned by individuals or communities, are harnessed for better purposes by putting to work unemployed people. The social benefits thus generated and the additional resources so created, may serve as stepping stones toward self-sufficiency.
The objectives of social forestry as defined by the National Commission on Agriculture (NCA, 1976) are: (a) supply of fuelwood to replace cow dung (b) supply of small timber (c) supply of fodder (d) protection of agricultural fields from wind and soil erosion and (e) creation of recreational amenities. Its main components are farm forestry, rural forestry and urban forestry. Broadly speaking, their objectives are almost identical and their differences although subtle, are worth examining.

2.5.4 Prospect and beneficial effect of agroforestry

Trees and forests were always considered as an integral part of the Indian culture. Planting of trees was regarded as a noble act during ancient times. Now due to increasing population and a wide gap between demand and supply, forests are ruthlessly exploited to meet the increasing demand of fuel, fodder and timber. Hence, in the light of ever increasing demand, the concept of multiple use of land with multipurpose tree species has become very important. In this context, agroforestry, which is a form of multiple land use system, should be adopted and encouraged. The reasons for higher production under agroforestry system include:

- Greater efficiency of tree species for photosynthesis;
- Improved soil structure and fertility with increasing effects on crop yield;
- Reduce losses from soil erosion and more closed cycling of organic matter and nutrients;
- Creating better micro climatic conditions for the growth of agricultural crops.

Different workers at various places have reported the beneficial effect of agroforestry. Most of the findings were in favour of this system with increased productivity and improved soil conditions. Higher yields of crops have been observed in forest-influenced soils than in ordinary soils. In the Tarai area of Uttar Pradesh, Taungya cultivators harvested higher yields of crops such as maize, wheat, pulses, etc. without fertiliser. Approximately, 20% higher yields of grains and wood have been reported in agroforestry areas of Haryana and western Uttar Pradesh than from pure agriculture (Dwivedi and Sharma, 1989). Experiments conducted at IGFRI, Jhansi indicate that the total yield of fodder is more when fodder grasses are grown with fodder trees than pure fodder grass cultivation. *Leucaena leucocephala* inter-cropped with agricultural crops and fodder grasses, increased the total yield of foodgrains, fodder and fuel (Pathak, 1989).
Nitrogen fixing trees grown in the agroforestry systems are capable of fixing about 50-100 Kg N/ha/year (Tewari, 1995). Experience in Punjab, Haryana, Uttar Pradesh, Gujarat and some parts of the southern States indicate that a tree and agriculture crop production system is more productive. The total production and value of fuel, fodder and small timber in degraded lands are reported to be many times more than the coarse grains usually produced on them (Gupta and Mohan, 1982). Sanchez (1987) stated that appropriate agroforestry systems improve soils, physical properties, maintain soil organic matter and promote nutrient cycling. Nitrogen fixing trees are mentioned as one of the most promising components of agroforestry system. The leaf litter after decomposition forms humus, releases nutrients and improves various soil properties. It also reduces the fertiliser needs. Growing of trees and fodder crops, including fodder trees is more economical, particularly on marginal lands. Observations taken in hot arid and semi-arid areas of Rajasthan indicate that marginal lands are incapable of sustaining stable and dynamic cultivation of agricultural crops. Silvopasture consisting of growing trees such as Prosopis, Albizia, Zizyphus and Acacia species may provide many times more returns per unit of land than agriculture under such conditions (Gupta and Mohan, 1982). Eucalyptus in agroforestry has been found to be more profitable than pure agriculture in Haryana. *Populus deltoides* increases the farm return by 50% in Tarai region of Uttar Pradesh (Chaturvedi, 1981).

### 2.5.5 Agroforestry promotion

The National Agriculture Policy (2000) clearly states that Agriculture has become a relatively unrewarding profession due to an unfavourable price regime and low value addition, resulting in neglect of farming and increasing migration from rural areas. Hence, the Policy emphasises that the farmers will be encouraged to take up farm/agroforestry for higher income generation by evolving technology, extension and credit support packages and removing bottlenecks in the development of agroforestry.

Rural people have been practicing tree planting on their farms and homesteads to meet the household requirements of fuel, pole, timber and medicinal plants. With the advent of social forestry, diversification in agriculture was encouraged to generate high income and minimise risks in cropping enterprises.

Planning Commission, GoI, in 2001 has recommended the following for promoting agroforestry:
• Rather than have a uniform strategy for the entire country, commercial agroforestry should be adopted in irrigated districts of the country;
• A separate strategy should be developed for rainfed areas for environmental security, sustainable agriculture (production and economy) and food accessibility;
• Suitable species for commercial agroforestry may include *Acacia nilotica*, Bamboo species, *Casuarina equisetifolia*, Eucalyptus species, *Populus deltoides* and *Prosopis cineraria* for different climatic, edaphic and agricultural conditions;
• Specific institutes have been identified for tree improvement and development of clones of specified species;
• Corporate private sector may be encouraged to take up research and development in tree improvement, development of better clones and micro and macro propagation of quality planting material;
• About 100 NGOs may be identified to carry out clonal propagation of seedlings for distribution to farmers at an appropriate price and carry out extension work. Extension activities should include organising farmers, providing them training in planting techniques, protection measures and other silvicultural operations;
• Technological development to diversify usage of agroforestry species will help to ensure a ready market; for example bamboo is being rediscovered as a potential raw material for development of bamboo composites as a suitable substitute for wood and wood composites;
• Bamboo technology mission should be started keeping in view the impending gregarious flowering, followed by mass mortality of bamboo, forest fire famine and insurgency. Circumstances require formulation of emergency plans for harvesting and processing of bamboo prior to their flowering;
• As more and more farmers are taking up agroforestry, export-import policies should be modified to encourage agroforestry product marketing;
• A system of market regulation needs to be put in place, including a mechanism of periodic review in order to protect the interest of both the producer and consumer of agroforestry produce;
• A suitable market information system needs to be introduced to inform farmers about major buyers, prevailing prices trends, procedure, etc.;
• All existing laws, executive orders relating to tree felling transport, processing and sale should be amended to facilitate agroforestry;
• Commercial agroforestry may be planned in irrigated districts covering 10 m ha. On an annual basis, one million ha should be brought under multipurpose tree species identified by the Task Force. The scheme of the National Bank for Agriculture and Rural Development (NABARD) for farm/agroforestry should be expanded and an investment of Rs. 100 crores per year should be ensured;
• It is proposed to cover 18 million ha of rainfed areas on watershed basis under agroforestry for conservation of soil and water and plantation of hardy species such as eucalyptus, bamboo and babul. On an annual basis, 1.8 million ha is proposed for afforestation under various schemes of the Rural Development, NAEB and 'food for work' scheme;
• Major States may establish an Agroforestry Co-operative Federation for increasing bargaining power of farmers in marketing of agroforestry products;
• Wood-based industries should continue supply of quality planting material to farmers and ensure suitable buy-back arrangement.

2.5.6 Agroforestry, a viable alternative for sustainability

In this era of global warming, fast degradation of land productivity and other environmental hazards, agroforestry is essential for sustainability of degraded natural resources. Agroforestry is found to be the most effective strategy for maintaining social, economic and ecological sustainability in India. The studies revealed that farmers have a good perception and a favourable attitude towards agroforestry. More than one-third of the farmers (39%) belonged to the high-adoption category when all the agroforestry practices were considered, followed by a smaller percentage of farmers, i.e. 36% and 25% respectively who belonged to low and medium-adoption level categories. The majority of farmers adopted an agri-silvi-horti-cultural system. The impact of the adoption of agroforestry on the social, economic and ecological conditions of the farmers is significant. Among the social parameters, celebration of festivals, migration and communication exposure and among the economic parameters, family income, livestock possession and employment status were found to contribute more to the total impact of agroforestry on farmers. From among the ecological parameters, dependency on forests, groundwater recharge and biomass production were found to contribute more to the total impact of agroforestry on farmers. The studies also revealed that the range
of crop diversity increased with the increase in area owned by the farmers. The approximate annual returns of agroforestry from one acre (0.40 ha) ranged from Rs.23916 (US$598) to Rs.31466 (US$786) as compared to original returns of Rs.2250 (US$56) to Rs.3000 (US$60). The results of the research clearly showed that agroforestry can achieve social, economic and ecological sustainability.

2.6 Local knowledge on agroforestry management

Indigenous knowledge includes practices and decisions made by the local people. It is based on experiences passed on from one generation to the next, but nevertheless, it changes, adapts and assimilates new ideas (Oudwater and Marti, 2003). Failing et al. (2007) define local knowledge as the full variety of insights, observations and beliefs related to a particular decision that do not stem from conventional scientific expertise. Some of the holders of this knowledge are long-time community residents, some are Aboriginal people and some are resource users with specialised knowledge such as fishers, farmers or hunters.

It can be quite specific to location and may vary between individuals from different social groups according to differentiating factors such as age, gender, wealth, ethnicity and occupation. Local knowledge should not be seen as the simple counterpart to scientific knowledge. It includes cultural as well as technical knowledge and is interlinked with social and political knowledge and skills (Oudwater and Marti, 2003).

Research results in Turkey indicate that despite a heavy reliance on scientific knowledge as the primary source of information in resource management, many resources are in decline (Close and Hall, 2005). To combat this trend, researchers have been depending on the knowledge of local resource users as an important supplement to scientific knowledge in designing and implementing management strategies (Close and Hall, 2005).

In recent years, increasing evidence has been assembled to support the view that local knowledge is fundamental to the management of natural resources. However, this knowledge has been neglected in management plans due to the notion that local knowledge is fragmented and subjective, and thus lacking in scientific merit. This view is currently undergoing re-evaluation as the importance of local knowledge is being increasingly recognised, especially in light of the failures of management policies.
derived solely from the use of scientific knowledge (Close and Hall, 2005). Brush (2007) indicated about traditional agricultural knowledge in Colombia, Mexico and Costa Rica, as traditional agricultural knowledge shares the attributes ascribed to other forms of traditional and indigenous knowledge such as localness, oral transmission, origin in practical experience, emphasis on the empirical rather than theoretical, etc. Traditional agricultural knowledge also shares the ambiguity of distinguishing it from other types of knowledge, such as knowledge found in scientific and industrial communities.

Understanding the historical development of indigenous systems will provide valuable information for the design of ecologically desirable agroforestry production systems. For example, the agroforestry systems in Amazonia follow a trail that begins with the arrival of the first hunter-gatherers in pre-historic times, followed by the domestication of plants for agriculture, development of complex societies rich in material culture, decimation of these societies by European diseases, warfare and slavery, introduction of exotic species and finally, present-day scenario of widespread deforestation in which agroforestry is ascribed a potential role as an alternative land use (Miller and Nair, 2005). Farmers know the reason why they retain different tree species on their farms and they can also classify tree species that are suitable and unsuitable for agroforestry practice. The research results in Chiapas and Mexico indicated that farmers recorded and classified tree species suitable or unsuitable as shade species based on attributes such as leaf phenology, foliage density, crown shape and the amount and timing of litter decomposition as well as their overall impact on coffee yield (Pinto et al., 2005).

2.7 Multipurpose trees in agroforestry

Agroforestry involves raising trees in combination with other agricultural enterprises, including livestock. Different species of trees can be planted with many types of crops in a variety of patterns. For example, fast-growing trees can be planted when the land is fallow or they can be grown at the same time as agricultural crops. In addition to providing fodder, fuel, wood, and other products, trees in agroforestry systems promote soil and water conservation, enhance soil fertility and act as windbreaks for nearby crops.

Whereas woody perennials are central to the concept of agroforestry, the term “agroforestry species” usually refers to woody species and they have come to be known
as “multipurpose trees and shrubs” (MPTS). Hence, it has generally been accepted that the main scientific foundation of agroforestry is multipurpose trees and the success of agroforestry as a viable landuse option depends on tapping the potential of these multipurpose trees of which many are relatively known outside their native habitat (Nair, 1993).

2.7.1 MPTs studies

Work on MPTs was initiated by G.B. Pant University of Agriculture and Technology, Pantnagar in Uttarakhand from April 1983, under the AICRP on Agroforestry. Poplar and Shisham were the priority species allotted to the University. In 2004, College of Forestry, Hill Campus Ranichauri was also included as a sub-centre under AICRP with Grewia optiva and Morus alba as the priority species. At Pantnagar, about 100 tree species have been collected so far and are being evaluated for their survival, establishment and growth (Anon, 1999; Purohit et al., 2005). Based on their suitability, these species are being taken up for future research. The work on the priority species is being carried out under the following heads:

**Populus deltoides**

The work on poplar is being done under the following heads:

- Poplar improvement
- Evaluation of selected poplar clones
- Optimisation of management practices and planting density

Poplar improvement work is being carried out at Pantnagar on various aspects viz. germplasm collection, provenance testing under agroforestry, development of new clones and their testing for best selection and recommendation for farmers.

The germplasm is serving good purpose by supply of pure material for experimentation and also commercially for poplar growers. In another experiment, six promising clones of poplar are being evaluated for their growth performance in agroforestry systems with wheat and direct seeded rice. Results show that grain yield of wheat and rice was not influenced by different clones (Anon, 2004). In another experiment in a similar agro-ecological condition, growth of poplar planted at five different density viz. 200, 250, 333, 500 and 1000 trees/ha was evaluated under agroforestry. It was observed that the maximum mean DBH (14.98 cm) of poplar trees was attained with the lowest tree density of 200 trees/ha.
density. The height growth followed the reverse and the tallest mean tree height (13.27 m) was observed with maximum tree density. The maximum grain and straw yields were recorded in control (without tree) in both wheat and rice which decreased linearly with increase in tree density (Anon, 2004).

Management practices like pruning help in better growth of tree species apart from solving the problem of fuelwood scarcity and allowing more solar radiation to the understorey crops. In poplar-based agroforestry system, the effect of pruning was studied on growth of polar and understorey crops. Five different pruning treatments viz., unpruned, 25%, 50%, 75%, and pruning for equidistant balancing pattern were performed on the poplar. The results revealed that the pruning pattern did not influence the tree height growth significantly. However, tree pruning upto 75% of tree height showed adverse effect on tree growth. The fuelwood quantity obtained as a result of pruning treatment varied substantially. Pruning intensities however failed to influence the yield of rice significantly (Anon, 2004).

**Dalbergia sissoo**

Keeping in view the importance of *Shisham* (*Dalbergia sissoo*) as a potential tree, research experiments on *shisham* are being carried out on various aspects such as germplasm collection, provenance testing under agroforestry, development of new clones and their testing and clonal identification on basis of morphological and molecular marker. The selection of plus trees was made on the basis of superiority for height, dbh, straightness, health, etc.

**Salix alba**

Four clones of *Salix* were evaluated for their growth performance under agroforestry. The results revealed no significant difference in the growth of clones (Anon, 2004). Further, grain and straw yield of paddy were also not affected significantly due to different clones. In another experiment, no significant effect on height and dbh was observed in two different clones and four spacings.

**Bamboo**

The work on bamboo is being evaluated under coordinated approach in 13 different centres. A common framework for multilocaltrial trial is being followed at all the centres with two local and six common species. In addition, trials on nutrient and water management, comparison of growth of macro and micro propagated planting material
and development of bamboo-based cropping systems are also being undertaken at the centres with different species. All the experiments were initiated in the year 2005. Research trials were also taken up for production of quality planting material to be distributed to the farmers. Commercial plantation of bamboo was also established on 40 ha area in the university. The produce from this will help in generating needs for nearby paper and pulp industries.

In hill campus Ranichauri, the growth performance of different tree species of hilly regions is being evaluated. Work is also being done on development of package and practices of various fodder trees. Management practices are also being standardised for lopping and pruning. In addition, tree improvement work on *Grewia optiva* and *Morus alba* has also been initiated.

### 2.7.2 What are the best multipurpose trees for agroforestry?

It is important to select the most suitable trees since it is not easy to replace them once they have been planted. The following factors should be kept in mind while selecting tree species.

- **Environmental adaptation**
  
  A multipurpose tree must be able to adapt to the climate, soil and topography of the area and plant and animal life. This is especially important for exotic species i.e. species introduced from outside the project area or from outside the country.

- **Needs of farmers**
  
  The species should meet the needs of farm families. For this reason, it is important to involve farmers, both men and women while selecting species. They should identify desired tree products and planting locations based on local markets as well as conservation needs. The cost of acquiring seedlings or cuttings should also be kept in mind. Planting stock of most fruit trees for example, are expensive.

- **Ease of maintenance**
  
  Some species are more difficult to look after than others. Farmers should consider beforehand how much time they have to care for the trees. If they require additional skills and knowledge to grow a particular species, training or demonstration programmes should be organised.
• **Availability of genetic materials**
  Seeds or seedlings of the species being considered must be easy to obtain. If vegetative propagation is required, farmers should receive training on this technique. Seeds of *Gliricidia sepium* and *Sesbania spp.*, for example, might not be readily available. Farmers may need guidance on how to propagate the trees using root cuttings. They may not even have enough time to harvest the cuttings.

2.7.3 **Role of trees in agroforestry**

  ➢ **Alley cropping**
  When planted as hedgerows between rows of agricultural crops, some tree species reduce soil erosion. When planted on slopes, alley crops slow down run-off rainwater and trap sediment, which can form natural terraces after several years. Alley cropping means growing hedgerows of closely spaced trees (20cm or less) between rows of food crops. If the lands are slopy, farmers should plant the hedgerows along the contour i.e. the trees in each hedgerow should be planted at the same level of slope.

  Farmers should prune hedgerows regularly to prevent them from competing with nearby crops for sunlight and water. When pruned regularly, hedgerows can provide a reliable source of animal fodder and fuel. Farmers can cut the trees when they become competitive and carry the branches to pens where animals are sheltered. Longer cutting cycles of 4-6 months provide relatively more wood than shorter cycles. Short cycles produce relatively more foliage. Most species should not be pruned more often than every 30 days.

  If planted in double lines rather than single lines, hedgerows can produce almost twice as much foliage and wood, without greatly increasing the competition with nearby crops for water, nutrients, and sunlight. Where farmers can plant in a north-south rather than east-west direction, this will reduce competition for sunlight. Whether farmers plant in single or double rows, depends on how much land is available and the slope.

  "Green manure" refers to foliage and twigs that are spread among food crops as mulch and organic fertiliser to improve their growth. To obtain green manure, farmers can prune the tops of the hedgerows every 6-8 weeks.
Desirable characteristics of species

- **Easily established**: require minimum labour for planting and maintenance.
- **Fast growing**: benefits are available to the farm family as soon as possible.
- **Good sprouting**: hedgerows continue to grow regularly after pruning.
- **Nitrogen fixing**: leguminous (nitrogen-fixing) species can contribute to crop nutrition.
- **Heavy and palatable foliage**: provide more green manure and acceptable fodder.
- **Deep root system**: nutrients and water are drawn from lower soil layers.
- **Easy to propagate**: generally, growing hedgerows from seed requires less labour than vegetative propagation.
- **Adaptable to close spacing**: hedgerows require dense planting.

➤ **Home gardens and other multistorey systems**

Homegardens, mixed plantings of annual and tree crops around dwellings, are a common type of multistorey agroforestry system. Multistorey means that there are at least two layers of plants growing at different heights in the system. In homegardens, the lowest level often consists of vegetables or root crops; the second level includes fast-growing trees or crops such as bananas, spices, and cacao; a third higher level may consist of large trees that provide fruit, timber and shade. Homegardens also provide a pleasant shaded living area. Many farmers already grow multipurpose trees in their homegardens for flowers, fruits, and seeds. If farmers want to grow a tree for its food rather than its wood or leaves, they should plant seedlings at least 5 m from each other.

Also, trees grown mainly for food should not be pruned regularly for fodder or fuel. Pruning can interfere with flowering and fruiting. Instead, farm families can collect fallen branches for fuelwood.

Women take many of the decisions on homegardens. They often select the species to be grown. Attempts to improve the use of trees in homegardens should involve discussions with women and men farmers to understand better how they can use trees and what products should be optimised. Other multistorey systems include those where trees in farmlands are left to grow amidst the food crops. In coffee or cacao plantations, growers plant fast-growing species to provide shade.
Desirable characteristics of species

• **Cast the desired amount of shade**: understorey crops need the right amount of light for optimum growth. Typically, the crown should be high, small, open, and foliage sparse.

• **Deep rooted**: they can draw nutrients and water from deeper soil layers and will not compete with shallow-rooted crops.

• **Roots should not spread laterally too far from the trunk**: to minimise competition with nearby crops.

• **Nitrogen fixing**: to grow well under adverse conditions and help improve soil fertility.

➢ **Living fences**

In many places, farmers plant multipurpose trees in rows along farm boundaries as "living fences". In addition to providing fodder and fuelwood, live fences provide privacy and protection from browsing animals.

Desirable characteristics of species

• **Tolerate minor "injuries"**: living fences are susceptible to frequent injuries from pruning or animals and should tolerate them well.

• **Fast growing**: provide benefits to farm families as soon as possible.

• **Compatible with annual and perennial crops**: should not have adverse effects on other tree species or crops they are associated with.

• **Provide fodder**: serve as a source of animal feed.

• **Fire resistant**: act as a fire break.

• **Thorns**: stiff branches, thorns, spines, nettles, or irritating latex help keep animals away.

• **Vegetative propagation**: ensures fast establishment while reducing the chance of spreading to pasture and cultivated areas.

➢ **Windbreaks**

Windbreaks are strips of trees, shrubs, and vines planted closely together along the edges of croplands perpendicular to prevailing winds. Especially in dry areas, windbreaks can provide protection to crops and soils from the detrimental effects of
wind. Table 2.1 provides a few examples of suitable species for living fences and windbreaks.

Table 2.1: Some examples of MPTS as windbreaks and living fences

<table>
<thead>
<tr>
<th>Species</th>
<th>Climate</th>
<th>Other uses</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acacia nilotica</em></td>
<td>arid, semiarid tropics</td>
<td>beverage, fuelwood</td>
</tr>
<tr>
<td><em>Azadirachta indica</em></td>
<td>semiarid tropics</td>
<td>timber, lumber, manure, essential oils, fuelwood</td>
</tr>
<tr>
<td><em>Casuarina equisetifolia</em></td>
<td>humid tropics</td>
<td>fuelwood, timber</td>
</tr>
<tr>
<td><em>Eucalyptus camaldulensis</em></td>
<td>humid tropics</td>
<td>fuelwood, timber</td>
</tr>
<tr>
<td><em>Gliricidia sepium</em></td>
<td>humid tropics</td>
<td>food, fuelwood, poles, fodder</td>
</tr>
<tr>
<td><em>Grevillea robusta</em></td>
<td>subhumid tropics, humid tropics</td>
<td>timber, fuelwood, building materials</td>
</tr>
<tr>
<td><em>Leucaena leucocephala</em></td>
<td>humid subtropics, humid tropics</td>
<td>fuelwood, poles timber fodder</td>
</tr>
<tr>
<td><em>Sesbania grandiflora</em></td>
<td>humid tropics</td>
<td>fodder, fuelwood, food</td>
</tr>
</tbody>
</table>

Windbreaks provide protection to crops over a distance equivalent to 15-20 times the height of the trees in the windbreak. For large areas, windbreaks should be planted at this distance from each other. For example, windbreaks comprising trees that grow to a height of 8m should be planted not more than 120-160m apart. Farmers should replace dead trees from time to time. As the trees in the windbreaks grow larger and compete with each other, farmers should remove some of them.

**Desirable characteristics of species**

- **Wind resistant**: withstand strong winds.
- **Deep spreading root system**: adds stability to the windbreak by making the trees less susceptible to wind damage.
- **Small open crown**: reduces the risk of wind damage.
- **Easy to propagate**: minimises labour inputs.

**Improved fallow systems**

In many regions, increase in population has resulted in faster rotation cycles of crop cultivation and shorter fallow periods. In some cases, fallow time is simply too short to allow the soil to recover. Blocks of fast-growing trees, particularly species that fix nitrogen in the soil, can help the soil recover as well as provide fuel, poles and fodder. Farmers can plant stump cuttings in the fields at the same time as the harvest of the last annual crops before the fallow period. The cuttings do not shade other crops until after 4-6 months.
Desirable characteristics of species

• **High nitrogen content in tissue:** hastens soils rejuvenation, since nitrogen is the most important deficiency of tropical soils.

• **Fast biomass production:** litter from the tree, especially foliage, can add important nutrients to the soil.

➢ **Trees and raising livestock**

Farm systems that combine tree plantations with livestock that graze in the understorey hem are generally found in drier areas, where natural grasslands and farm sizes are larger. In such systems, farmers graze sheep or cattle on forage grasses or in stands of trees.

In wetter areas, which tend to have smaller land holdings, alley cropping and other "cut and carry" methods for procuring fodder are more important.

<table>
<thead>
<tr>
<th>Species</th>
<th>Climate</th>
<th>Other uses</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acacia tortilis</em></td>
<td>semi-arid tropics</td>
<td>fuelwood</td>
</tr>
<tr>
<td><em>Albizia lebbeck</em></td>
<td>humid tropics, semi-arid tropics</td>
<td>fuelwood, timber</td>
</tr>
<tr>
<td><em>Calliandra calothyrsus</em></td>
<td>humid tropics</td>
<td>lumber, fuelwood</td>
</tr>
<tr>
<td><em>Dalbergia sissoo</em></td>
<td>semi-arid tropics</td>
<td>timber, fuelwood</td>
</tr>
<tr>
<td><em>Gliricidia sepium</em></td>
<td>humid tropics</td>
<td>food, fuelwood, poles</td>
</tr>
<tr>
<td><em>Leucaena leucocephala</em></td>
<td>humid subtropics, humid tropics</td>
<td>fuelwood, poles, crop shade, timber</td>
</tr>
<tr>
<td><em>Prosopis cineraria</em></td>
<td>semi-arid tropics, arid tropics</td>
<td>windbreak</td>
</tr>
<tr>
<td><em>Sesbania grandiflora</em></td>
<td>humid tropics</td>
<td>fuelwood, food</td>
</tr>
<tr>
<td><em>Zizyphus mauritiana</em></td>
<td>semi-arid tropics, subhumid tropics</td>
<td>food, shade</td>
</tr>
</tbody>
</table>

The advantages of integrating tree growing with livestock production are:

• Increasing the production of meat protein without sacrificing large tracts of agricultural land.

• Reducing surface soil erosion by preventing open grazing and reducing dependence on grasses.

• Using animal manure to fertilise the soils and inter-crops, reducing reliance on inorganic fertilisers

• Providing additional income through sale of livestock.
Desirable characteristics of species

- **High protein and nutrient content:** improve livestock nutrition.
- **Palatable:** livestock are selective about fodder to be consumed.
- **Free of toxic substances:** some fodder species contain toxic substances that can be consumed only in small amounts. *Leucaena spp.*, for example contain mimosine which in large doses can be harmful for animals. Therefore, it must be used in combination with other fodder sources.
- **Sprout well:** recover rapidly after pruning.

➢ **Stabilising stream banks and gullies**
Trees can help reduce soil erosion along streams and gullies. They should be planted at the medium to high-level water mark. Their roots serve to hold the soil in place and reduce the impact of storm water.

**Suitable species**
Some tree species suitable for stabilising stream banks and gullies are *Paraserianthes falcataria*, *Gmelina arborea*, *Leucaena leucocephala*, *Sesbania grandiflora*, and *Moringa oleifera*.

### 2.8 Arid zone agroforestry
Drylands, including arid zone lands, cover more than 60% area of the earth’s surface and are characterised by severe edapho-climatic conditions. The major distinguishing feature for defining and planning the arid zone is the low rainfall (below 500mm or Aridity Index <0.20) with more than 50% variability. This makes a great difference in terms of the nature of ecosystem, socio-economic environment and the challenges for sustainability. High wind and solar regimes further increase the effect of rainfall variability and the entire complex makes a fragile ecosystem in which a small disturbance may cause great loss to the sustainability and sometimes becomes irreversible. In the arid zone, closed forests are seldom available. In India, traditional animal husbandry and agroforestry practices have been used to manage parklands, rangelands, and reserved silvopastures near holy places, lay farming and run-off farming (traditional watershed management). Trees are managed mainly for their non-wood forest products (NWFP) and environmental services. Animals are an essential part
of these production systems. Traditional management of the entire arid zone ecosystem has been developed to minimise the risk of drought in diversified components and to efficiently utilise the scarce natural resources as well as the products of agroforestry for sustenance. With the advancement of science, efforts have also been made to enhance production in the arid zone. Some of the technologies like sand dune stabilisation, windbreaks and agri-horticulture have produced good results because they are developed in synergy with nature and people. But some other technologies imported from less environmentally stressed areas have proven to be unsustainable. For example, the use of tractors in agriculture, adversely affected natural regeneration of native trees especially *Prosopis cineraria*, besides increasing wind erosion. Irrigation with waters from the Gandhi canal network has caused problem of water logging and secondary salinisation. Several exotic species are either becoming invasive (e.g. *Prosopis juliflora*) or are proving to be economically unproductive (e.g. *F. albida, Jojoba*, etc.).

The overall impact of these imported technologies superimposed with high biotic pressure and a fragmented approach to desertification control is observed in terms of loss of biodiversity, increasing desertification and other problems. It is now imperative to think broadly and plan holistically for the future of arid zone agroforestry, the basis of sustainable livelihoods of arid zone. Policy makers and scientists need to recognise that sustainability of agroforestry in drylands depend on the degree of synergism with the 3 Ns, i.e., Nature, Native vegetation and Native people as well as self-sufficient input supply systems. Some of the future directions for arid zone agroforestry need to focus on the evaluation, improvement and encouragement of sustainable traditional agroforestry systems, exploring the possibilities of natural regeneration/rehabilitation of arid zone ecosystems, NWFPs as the basis of sustainable livelihood, rethinking of research priorities and policy improvement. This study discusses these topics with reference to the Indian and African arid zones which will be useful for planning conservation forestry irrespective of geographical boundaries.

### 2.9 Agroforestry in temperate zone

The preceding parts of this research mainly focus on agroforestry in the tropics. The main reason for the focus on the tropics is that agroforestry, as an approach to integrated land-use, was traditionally more relevant and had potential application in the tropics than in the temperate zone. In other words, traditional agroforestry systems are numerous and widespread in the tropics, and agroforestry offers a solution to many
land-use problems and constraints in those regions. As a consequence, during the past two decades of organised agroforestry, developments have been much more pronounced in the tropics than in the temperate zone. However, as in the tropics, there is a long tradition in the temperate zone too of meeting people's needs through both purposeful combinations of trees, animals, and crops, and efficient use of natural ecosystems. Although not comparable to the extent of activities and developments in tropical agroforestry, significant expansion in the scope of temperate-zone agroforestry is occurring, with similar expectation that the meshing of agriculture and forestry will generate new solutions for both old and new land-use problems. An overview of the systems and developments in temperate-zone agroforestry, and an evaluation of their prospects are briefly covered in this chapter because several recent comprehensive reviews are available (Gold and Hanover, 1987; Byington, 1990; Bandolin and Fisher, 1991).

**Characteristics of temperate-zone agroforestry**

As discussed here, the temperate zone primarily embraces the region between latitudes 30° and 60°. Some areas of slightly lower latitude in India and China will also be included in this zone because climatically and ecologically, they are similar to the rest of the temperate areas. However, the nature of agroforestry systems and the reason for which they are practiced in those two countries are more similar to those of the tropics than of the developed countries. As in other localities, the socio-economic conditions in India and China have strongly influenced the nature of agroforestry. Thus, the primary focus of this chapter is the developed countries of the temperate zone (North America, Europe, Southern Australia, and New Zealand). Most of Chile and Argentina will also be included, although with lesser emphasis.

Throughout this zone, the climate includes distinct warm and cold seasons. Precipitation may occur throughout the year or during summer or winter. This seasonality engenders some unique agroforestry qualities. Unlike the tropics where the same crops may be produced throughout the year, individual crops in the temperate zone are generally restricted to one or two seasons and fewer crops are grown each year. The temperate zone is also characterised by extreme physiographic diversity, ranging from dry wind-swept plains to moist rain forest conditions.
Agroforestry land-use occurs throughout the range of temperate-zone conditions but unlike the variety of systems and practices in the tropics, only a few agroforestry systems are practiced in these regions. The two most common systems have been the agri-silvicultural use of windbreaks and shelterbelts to prevent soil erosion in the plains and silvopastoral practices with livestock in diverse woodland and range eco-systems. Agri-silvicultural combinations of nut or fruit trees and herbaceous crops are increasingly common third system. Socio-economic conditions in the developed countries of the temperate zone have also strongly influenced land-use practices. Although small farms were historically dominant in the temperate zone and still are in many regions, there has been a significant trend in the 20th century towards large, family, corporate or communal farms where production is largely concentrated on a few crops for local and distant markets. Agroforestry applications on such farms have often focussed on one or two high-value crops and include high levels of mechanisation. A combination of trees and agriculture is viewed as a means to improve economic profitability. Thus, these temperate-zone agroforestry characteristics are in contrast to tropical agroforestry practices, which are most frequently found on small individual farms or on share-cropped and community lands. Production in tropical agroforestry is often for local markets and subsistence consumption, and a large variety of crops are both available and necessary in most family settings. Local systems and practices are often the rule as individual farmers and communities have adapted to their specific agro-ecological and socio-economic situations throughout many generations. Economic subsistence is imperative rather than opportunistic, although significant level of international funding and support for agroforestry in the tropics may have altered this imperative and emphasis on local systems.

Another significant attribute of temperate-zone agroforestry is the inclusion of a large number of tree species for which a substantial knowledge base is available and for which market values have been established. Forestry research in this region in the last 100 years has provided information on genetic variability, physiological characteristics, and cultural requirements for a wide variety of species, many of which are also important in wood products markets. Thus, the detailed information base and dependable markets are strong incentives for incorporating many temperate species in agroforestry systems, as opposed to the subsistence nature and lack of market and other support services that are so characteristic of tropical agroforestry systems.
Historical development of a permanent agriculture system based on the use of agroforestry in the temperate zone has been traced. In general, reasons for renewed interest in agroforestry include the end of cheap, subsidised fossil fuels, increased concern about soil erosion and marginal land use, an international awakening as to the dangers of indiscriminate use of pesticides, herbicides and other chemicals and a need to balance food production with other land uses. For the forestry profession in particular, the reasons for the interest in agroforestry arise from a need to revitalise rural economies, desire to increase timber exports and potential resolution to land use conflicts between agriculture and forestry. Through use of agroforestry management systems, an increase in both economic and silvicultural benefits can be obtained.

Two agroforestry management systems are reviewed which currently appear feasible for implementation in many industrialised countries of the temperate zone. These two systems include:

1. Animal grazing and inter-cropping under managed coniferous forests or plantations; and
2. Multicropping of agricultural crops under intensively managed, high value hardwood plantations (Michael et al., 1987).

Efficient temperate agroforestry systems often associate deciduous tree species with winter crops, resulting in a limited period of light competition, from tree bud burst in spring until crop harvest in summer. For a walnut wheat system, light competition occurs for a span of 3 months only from April to June. Climate change may affect the timing of phonological stages of both trees and crops. Temperature increase may result in a slower mean rate of completion for the chilling requirement and a higher mean rate of completion for the heat requirement of both trees and crops. Earlier investigations showed that a warming in early spring (February-April) by 1°C causes an advance in the beginning of the growing season of some tree species of 7 days. Differential responses of tree and crop phonologies to climate change may lead to a significant change in tree and crop complementarity for resource capture and use and therefore affect the total productivity of the system. Conversely, the adequate choice of tree and crop varieties with properly lagged phenologies could be a way to improve the efficiency of agroforestry systems (Talbot et al., 2007).

The ecological principles that define the competitive and complementary interactions among trees, crops, and fauna in agroforestry systems have received considerable
research attention during the recent past. However, these principles have not yet been adequately integrated and synthesised into an operational approach. This study reviews the ecological and ecophysiological bases for interspecific interactions based on data from site-specific research and demonstration trials from temperate agroforestry systems, primarily from temperate North America. The review shows that information on ecological interactions in several temperate agroforestry systems is inadequate. It is recommended that future research should focus on new species and systems that have received little attention in the past. Priority research areas should include cultural practices and system designs to minimise interspecific competition and maximise environmental benefits such as improved water quality. Potential for genetic modification of components to increase productivity and reduce competition also needs to be explored. Process-oriented models may be increasingly used to predict resource-allocation patterns and possible benefits for site and species combinations (Josef et al., 2004).

2.10 Evaluating Agroforestry Options

Agroforestry systems are much more complex than single-purpose farm or forestry enterprises. Each component of the system - trees as well as crops or livestock must undergo a series of evaluation procedures: testing against the farm or family goals, evaluating resources, investigating promising options from a longer list of possibilities, choice, planning and then implementing the plan and monitoring progress.

Evaluation of an agroforestry system requires collecting the following information:

- **Farm Accounts**: Income and expenditures for existing enterprises and potential ones, including fixed and variable costs.
- **Planting and Felling Areas**: The programme of harvest and planting for each year of the project.
- **Labour and Materials**: Includes the costs of seedlings, fertiliser, herbicides, and insurance, as well as planting, pruning, and thinning expenses.
- **Wood Yields**: Predicted wood-product values by log grade, including cost of harvest and transport.
• **Understorey Profiles:** Crop or livestock products, including harvested tree products (nuts, pinestraw), and how production will change through the tree rotation, effects of canopy closure and windbreak benefits.

• **Environmental Impacts:** Water yield, erosion reduction, carbon sequestration, wildlife.

• **Social Effects:** Family and farm goals, support of the rural community, improved visual aesthetics.

Since agroforestry systems in temperate climates have not been studied through several complete rotations, landowners will work on the basis of incomplete data during the evaluation process. Yield data from same-age tree plantations must be adjusted for an agroforestry system. Understorey competition for water and nutrients as well as light effects on both understorey and tree edges should be taken into account while projecting yields and expecting market values.