CHAPTER 2

REVIEW OF LITERATURE

Forests and grasslands whose existence is so vital for agriculture, have shown fast degrading trend due to prevalence of shifting cultivation and deforestation practices in the whole north-eastern hill region (Prasad, 1987; Singh & Prasad, 1987). Of the 18.4 million ha of geographical area, about 2.99 million ha of cultivable land has been converted into wastelands. Of these, about 2.17 million ha abandoned areas are culturable wastelands and can be converted to pastures and/or can be used for fuelwood and timber production. The removal of forest biomass alters biogeochemical cycles and modifies physical characteristics of the site (Johnson *et al.*, 1991). This impact may be more pronounced in agricultural systems. There is a lack of information on the restoration and maintenance of soil fertility status on the hill slopes that have been brought under cultivation after clearing the forest vegetation growing on them. In Meghalaya, about 67% area of cultivable land on slopes is facing a serious problem of loss in soil fertility due to cereal cultivation in the absence of appropriate soil conservation measures and inadequate nutrient inputs (Singh *et. al.*, 1994). The most prevalent land use systems in Meghalaya include pure horticultural crops, horticulture-based intercropping, forestry, agroforestry and dairy farming (Singh *et al.*, 1995). Recent studies have nicely demonstrated the superiority of agroforestry systems for food, fodder, fuel and timber security over other land use systems in the state particularly due to its inbuilt capacity to restore and maintain the soil fertility (Chauhan & Dhyani, 1989; Dhyani & Chauhan, 1994; Singh *et al.*, 1994). This chapter presents a critical review of the existing literature on agroforestry systems relating to such aspects as biomass production, rooting behaviour, crop yields, ameliorative effects of the system on soil, nutrient recycling and nutrient balance.

Agroforestry definition(s)

Agroforestry is a traditional practice where trees are grown in association with crops and other vegetation. Nair (1989), in a review, has presented 13 definitions of agro-forestry given by various workers including the widely accepted one proposed by **Lundgren and Raintree (1983)**. As per the definition, agroforestry is "**a collective name for land use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/ or animals, in some form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economical interactions between the different components**". In other words it is a system of resource management that simultaneously produces multiple items such as food, fodder, fuelwood, timber etc. on a sustained basis.

Agroforestry takes an interdisciplinary approach to landuse requiring the combination of social, ecological and economic factors (Sinclair, 1992). As such, a great deal of literature *concerning the subject* and *particularly the* benefits to be gained by adoption of such practices is now available. But most of it is speculative rather than evidence (Anderson & Sinclair, 1993). When trees are added to cultivated land there are a number of possible outcomes of the interactions between tree and crop. Although a vast amount of knowledge has accumulated on monoculture stands in both agriculture and forestry (Huxley, 1983), evidence verifying the interactions under agroforestry systems is lacking. But a great deal of information is available on how the basic bio-physical elements viz. light, water, nitrogen and certain other nutrients particularly phosphorus and potash contribute to crop yield under intercropping (ICRISAT, 1986; Willey *et al.*, 1986). The performance of trees and crops under agroforestry system depends upon their relative ability to tap the resource pool of light, water and mineral nutrients and their responses to sub-optimal levels of these resources. In fact much of the current attention in agroforestry research is centred on alley cropping, which is a production system in which trees and shrubs (preferably fast growing leguminous species) are established in hedgerows on arable cropland, with crops cultivated in the alleys between the hedgerows (Kang *et al.*, 1981, 1990; Kang & Wilson, 1987). Such studies have also indicated that the biomass production per unit area is increased substanially by incorporating trees with arable crops.

2.1 Multipurpose woody perennials

The woody perennials in different agro-ecological zones under various agroforestry systems include *Acacia* *auriculiformis, Alchornea cordifolia, Cajanus cajan, Dactyladenia barteri, Calliandra calothyrsus, Senna siamea (syn. Cassia siamea), Senna spectabilis, Erythrina poeppigiana, Flemingea macrophylla, Inga edulis, Gliricidia sepium, Gmelina arborea, Leucaena leucocephala,* and *Paraserianthes falcataria* (Evensen & Yost, 1990; Fernandes *et al.*, 1990; Hawkins *et al.*, 1990; Kang, 1993; Kang *et al.*, 1990; Kass *et al.*, 1992). In India perennial woody plants have been included with crops for investigating their interactions with regards to crop productivity as well as their effects on soil fertility (Patil *et al.*, 1981; Jambulingam & Fernandes, 1986; Shakarnarayan *et al.*, 1987; Singh *et al.*, 1989). In north-eastern hills, Dhyani *et al.* (1994) have reported that multipurpose trees such as *Alnus nepalensis, Parkia javanica, Paraserianthes falcataria, Michelia oblonga, Prunus cerasoides, Gmelina arborea* and *Acacia auriculiformis* have shown good performance with regard to growth and biomass production.

2.2 Ecological interactions in agroforestry

Anderson and Sinclair (1993) reviewed the research literature in agroforestry with particular reference to ecological principles concerning interactions between species. It was distinctly indicated that the addition of a tree component to a field crop situation, is bound to have a number of possible outcomes of the interactions between crops. Raintree (1983) has demonstrated three types of relationships possible between two components under iso-resource conditions, viz. *supplementarity, complementarity* and *competition*. He also indicated that the relationships obtaining between components in an agroforestry association largely depends on factors such as crop and tree genotypes; the proportion and arrangement of the woody perennial; and limiting plant growth factors. The examples under agrofo-restry for supplementarity [multistorey intercropping with coconuts (Nair, 1989); sorghum under *Parkia clappertoniana*] and complementarity [*Acacia albida* with millet, sorghum, or groundnuts (Felker, 1978); other tree legumes such as *Leucaena, Cajanus, Gliricidia* and *Tephrosia* (Rachie, 1983); *Prosopis cineraria* (Mann & Shankarnarayan, 1980)] are well documented. Examples of competitive relationships among agroforestry components are too many (Raintree, 1983) and reviewed by a number of workers (Monteith *et al.*, 1991; Ong *et al.*, 1991a; VanDen Beldt *et al.*, 1990; Anderson & Sinclair, 1993).

There is a lot of information available on the effects of agroforestry systems (generally referred to as intercropping i.e. growing two or more crops concurrently on the same field) on crop production, particularly in the tropics. In India, the term intercropping is used for the practice of growing annuals or short-duration crops under perennial species. The effects of trees on crops are variable and differ from one agro-ecological zone to another. Crop yields under intercropping with *Leucaena*, *Inga edulis*, *Cajanas cajan*, *Eucalyptus* and many other forest trees were lower than monoculture (Singh & Dayal, 1974; Mittal & Singh, 1983), which has been attributed to the competition for light, nutrients and moisture. However, higher intercrop yields associated with different tree species are reported under varied agroecological zones by a number of workers with *P. falcataria*, *S. spectabilis*, *Flemingia macrophylla*, *Dactyladenia barteri* and *Erythrina poeppigiana* (Vinaya Rai & Suresh, 1988; Basri *et al.*, 1990; Evensen *et al.*, 1990; Kang *et al.*, 1991; Kass *et al.*, 1992). In alfisols and other high base status soils positive results of alley cropping, particularly with nitrogen-fixing leguminous woody perennials were also reported by Atta-Krah (1990); Kang *et al.* (1990) and Yamoah (1986b). Thus most studies on intercropping with tree species have focussed on the effect of the arboreal component on the arable in the mixed system (Tustin *et al.*, 1979; Mishra & Prasad, 1980; Saxena, 1980; Vinaya Rai & Suresh, 1988). However, studies on the effects of the crop on the tree are very few (Samraj *et al.*, 1982; Redhead *et al.*, 1983).

Though the use and management of trees and shrubs for nutrient cycling, soil erosion control and increased production of fodder, fuelwood, timber and poles have engaged sufficient attention in recent years, fruit trees have been seldom considered in these studies. However, farmers of our country have shown keen interest in the inclusion of fruit trees in agro-forestry systems (Nair, 1984, 1989; Tejwani, 1987; Campbell *et al.*, 1991; Pyakuryal & Dhakal, 1994). Recent reports by Chauhan and Dhyani (1989) and Singh *et al.* (1994) have documented the cultivation of cereals, rhizomatous crops, pineapple and vegetables with a number of fruit trees such as pear, plum, apple, arecanut, orange, guava, Assam lemon, coconut, jackfruit and banana in different agroclimatic zones of north-east India. Maize, finger millet, ricebean, ginger and turmeric in Sikkim and groundnut, soybean, ginger and turmeric in Meghalaya could be grown as intercrops with mandarin. There was no yield reduction of intercrops due to canopy architecture of mandarin up to 6 years, whereas there is sharp decline in crop yield under guava and other fruit species after three years of intercropping. Hence, farmers can be easily pursuaded to include fruit plants in their farming systems, and thus, well adapted fruit species could become an integral component of agroforestry models.

2.3 Effect on soil properties

Agroforestry has potential of achieving productive output whilst at the same time maintaining soil fertility and restoration of fertility on degraded soils (Young, 1986a, 1986b). The ameliorative capacity of trees on degraded agricultural lands is often emphasised (Young, 1989; Ingram, 1990), though it has not been adequately quantified (Fisher, 1990; Prinsley, 1992). There is lack of evident information from long term research on agriculturally modified forest soils (Nowak *et al.* 1991). The inclusion of compatible and desirable species of woody perennial under agroforestry can result in a marked improvement in productivity and sustainability (Okigbo *et al.*, 1980; Watson, 1990; Vergora, 1987). Now there is enough substantial information in agroforestry on soil fertility and soil productivity aspects (Nair, 1984, 1989; Wiersum, 1984; Lundgren & Nair, 1985; Lal, 1986; Young, 1987; Kang & Wilson, 1987), but little rigorous evidence and objective data on which to make choices.

2.3.1 Effect on soil fertility

Agroforestry practices may be classified as rotation, spatial mixed or spatial zones based on the components present and the type of association between the woody and non-woody components. The distinction between these practices forms a rational basis for the planning of agroforestry research (Huxley, 1986). Young (1991) in his excellent review on soil fertility aspects has dealt in detail the research questions on soil agroforestry interactios and indicated that there was lack of direct evidence on the favourable effects of agro-forestry on soil fertility. The main issue of soil fertility improvement under agroforestry system through addition of plant biomass (leaves, twigs, branches, litter) vis-a-vis other uses of the biomass (fodder, fuelwood, food etc.) and the proportion of space occupied by the tree component in the system largely depends upon factors like soil type, plant species and tree crop arrangement. Several studies have reported positive influences of trees on soil fertility under different agroclimatic situations (e.g. Bernhard-Reversat, 1982; Belsky *et al.*, 1989, 1993; Ernst & Tolsma, 1989; Campbell *et al.*, 1990, 1994; Weltzin & Coughenour, 1990; Dunham, 1991; Isichei & Muoghalu, 1992; Kessler, 1992). Further, many studies have concluded that soil fertility under trees is improved through increased input of litter and soil organic matter (Ingestad, 1987; Campbell *et al.*, 1988; Harrison *et al.*, 1990; Dunham, 1991; Szott *et al.*, 1991; Isichei & Muoghalu, 1992; Kessler, 1992). They emphasized that litter input and its quality is the main consideration for enriching the soil fertility under agroforestry systems. Lal (1976, 1985, 1989b) has reported that by and large alfisols, ultisols and some inceptisols under upland situations have low inherent fertility and weak structure, and are highly susceptible to crusting, compaction and accelerated soil erosion. In Meghalaya major sloping lands come under inceptisols (45.65%), ultisols (40%), alfisols (10.7%) and entisols (3.6%) facing the similar problems and posing a real menace for developing sustainable food production systems (NBSS & LUP, 1993; Singh *et al.*, 1994). These soils are also prone to mid-season drought stress. Farmers have developed certain tree-based indigenous landuse systems which have shown remarkable capacity for restoration of soil productivity by protecting soil loss, improving soil organic matter status and continuously replenishing nutrients through recycling mechanism. In addition, Nowak *et al.* (1991) have reported that trees have an ameliorative capacity on degraded agricultural land.

In most of the situations, role of trees in influencing chemical properties of soils is expected after the trees have developed close canopy (Sanchez *et al.*, 1985; Anderson, 1987; Lal, 1989; Young, 1989a) although Young and Pinney (1989) suggested use of trees to increase soil fertility. In some situations, however, trees may have adverse effects on soils (Young, 1986). For example, fast growing multipurpose trees may place high demand for soil moisture; there may be nutrient losses from whole tree harvest; nutrient depletion may temporarily deprive adjacent crops; adverse chemical/ biological effects may result from certain tree species leading to allelopathy, acidification, accumulation of toxic exudates; trees may serve as alternate hosts of pests and pathogens; and may cause shade. But the magnitude of benefit or adverse effect will depend upon a number of site-specific factors and many attributes of trees.

2.3.2 Soil organic matter

Soil organic matter plays a significant role in maintaining fertility owing to decomposition of woody components, especially through improving water holding capacity, slow release of nutrients, enhancement of cation exchange capacity and providing favourable environment for soil faunal activity. Although there is now a large body of literature available on the ameliorative effects of trees on soil organic matter and soil nutrient status, there is much less information on the influence of trees on soil physical properties. But it is established that physical conditions of soil, independent of nutrient content, can substantially affect fertility (Lal & Greenland, 1979). Though a number of descriptive accounts are available for suggesting role of organic matter and its accumulation under agroforestry (Goh, 1980; Adejuwon & Adesina, 1990; Fassbender *et al.*, 1991) and traditional tree-based landuse systems (Alaban, 1982; Lal, 1986; Singh *et al.*, 1992), only in the cases of *Leucaena* and *Cassia siamea* there is evidence of soil carbon maintenance (Young, 1991). While a sharp reduction in organic matter status under agroforestry at initial stage has been reported in some situations (Lal, 1986; Dreschel *et al.*, 1991; Singh *et al.*, 1992; Dhyani *et al.*, 1994). The exchangeable Al content in soils- a potential cause of infertility of acid soils (Prasad *et al.*, 1985; Singh & Prasad, 1992) could be ameliorated through the use of multi-purpose tree species (MPTS). The beneficial effect of organic matter content in alleviating Al toxicity problems at the soil surface has also been reported by several workers (Hargrove & Thomas, 1981; Das & Singh, 1992; Singh *et al.*, 1994).

2.3.3 Fertilizers and amelioratives in agroforestry

In spite of the obvious ecological benefits of agroforestry practices, the system would remain unproductive unless fertilizers and amelioratives are added to atleast partially overcome critical acid soil constraints (Sanchez & Salinas, 1981). The acid soils of north-eastern region are deficient in available phosphorus. On these soils, the ability of agroforestry systems to significantly increase nutrients through enhanced nutrient cycling or nitrogen-fixation appears to be limited, mainly due to the low levels of nutrients and high levels of elements toxic to plant growth (Sanchez, 1987; Hawkins *et al.*, 1990; Palm *et al.*, 1991; Szott *et al.*, 1991b). Sanchez and Salinas (1981) opine that in certain cases the addition of fertilizer or amelioratives become an essential pre-requisite to overcome soil-related constraints as well as for maintaining balance between removal and addition of nutrients under agroforestry systems. Szott and Kass (1993) have recently reviewed the results of fertilization experiments on several agroforestry systems and advocated for fertilizer use in alley cropping, perennial shade systems and home gardens. Yamoah *et al.* (1986) and Fernandes *et al.* (1990) have reported that *Leucaena, Gliricidia, Flemingia, Sesbania sesban, Inga edulis and Cassia reticulata* can supply adequate nitrogen to the crops through prunings. On the other hand, Palm *et al.* (1991) and Szott *et al.*, (1991a, 1991b) have opined that in the case of infertile soil substitution for N-fertlization through inorganic fertilizers is a must.

2.4 Nutrient cycling in agroforestry systems

One of the advantages commonly attributed to agroforestry practices is its potential for soil fertility improvement via a more efficient cycling of nutrients (Nair, 1984) through both above and below ground litter additions, retrieval behaviour of roots and quality and quantity of added weed biomass. It is often recommended to include nitrogen-fixing tree species (NFTS) and shrubs in such technologies (Nair *et al.*, 1984; Lundgren & Nair, 1985; Young, 1987).

2.4.1 Aboveground productivity

The litter inputs under different agroforestry systems varies greatly (5.2 to 20.9 t $ha^{-1}yr^{-1}$), which is mainly linked with tree and inter-crop characteristics, pattern of litter fall and its distribution (Budelman, 1989; Hawkins *et al.*, 1990; Szott *et al.*, 1991a; Szott & Kass, 1993). Sanchez (1987) reported nutrient cycling potential of agroforestry systems on alfisols and andepts of moderate to high fertility. Systems such as *Erythrina poeppigiana* shade trees over coffee in Costa Rica are a good example of this. The leaf litter (from both crops and trees) is returned to the soil, and its nutrient content per hectare per year is of the order of 150 to 300 kg N, 10 to 20 kg P, 75 to 150 kg K, and 100 to 300 kg Ca. When these systems are fertilized, the nutrients recycled in litter can exceed the annual fertilizer input (Aranguren *et al.*, 1982; Alpizar *et al.*, 1986, 1988; Glover & Beer, 1986; Russo & Budowski, 1986). Roskoski and van Kessel (1982) observed that *Inga jinicuil*, a shade tree in coffee plantations, fixes around 40 kg N $ha^{-1}yr^{-1}$. Similarly, presence of more favourable C/N ratios under *Alnus nepalensis* and addition of 249 kg N $ha^{-1}yr^{-1}$ (Singh *et al.*, 1989) by decomposing leaf of this species in large cardamom plantations have been recorded. Thus periodical prunings of leguminous shade trees may be an alternative to inorganic fertilization for increasing crop production and nutrient replenishment.

There is little information regarding the recovery of nutrients from organic or inorganic sources by trees in agroforestry systems (Szott & Kass, 1993). The superiority of organic materials for restoration and maintenance of soil fertility has been strongly advocated by Doran and Smith (1987). This may be attributed to the slow release characteristics of their N and P components. However, Myers (1988) reported lowest effectiveness under high rainfall environments mainly due to greater leaching and denitrification losses.

In addition to improvement in chemical characteristics of soil, the presence of litter at the soil surface also improves water infiltration and reduces runoff and evaporation thus influencing soil water fluxes and moisture regimes

(Shankarnarayan, 1984; Swift, 1987). Positive interactions between trees and crops due to improvement of the soil water status by trees via interception, stemflow and increased water infiltration (Lal, 1989) and conservation of soil moisture by reduced evaporation due to vegetation cover (Calder, 1977; Grewal & Abrol, 1986; Eastham & Rose, 1988; Calder *et al.*, 1991) have been observed.

Thus, the integration of trees, especially nitrogen fixing trees (NFT) into agroforestry systems can make contribution to low input sustainable agriculture by restoring and maintaining soil fertility, and by combating erosion besides providing multiple outputs. About 650 tree species have the ability to contribute to symbiotic nitrogen-fixation (Brewbaker, 1987). The recorded rates of fixation for trees range from 20 to 300 kg N $ha^{-1}yr^{-1}$; the highest recorded is 500 kg N $ha^{-1}yr^{-1}$ for *Leucaena* (Young, 1991). *Sesbania* spp., *Acacia mangium* and *Acacia mearnsii* could also fix 100-300 kg N $ha^{-1}yr^{-1}$ (Dommergues, 1985; Young, 1989). *Alnus*, a non leguminous N-fixing species, has been reported to add 249 kg N $ha^{-1}yr^{-1}$ (Singh *et al.*, 1989). Because most of the NFT species are multipurpose and provide high quality fodder for livestock, nutrient rich mulch for crops, food, fuelwood and timber for human being and contribute to, micro-environment amelioration and ecosystem stability. They have been incorporated in all types of agroforestry systems, such as, in plantation crops combined with *Erythrina* or *Inga* spp. (Bornemisza, 1982; Roskoski & van Kessel, 1982), *Acacia albida* systems (Felker, 1978), *Leucaena* systems (Mulongoy, 1986; Sanginga *et al.*,

1986), *Albizia* (Prinsen, 1986), *Erythrina* (Pezo *et al.*, 1989) and others. The inclusion of NFT in agroforestry systems has led to the belief that nitrogen fixed in the root nodules may be used by the companion crop. Researches relating to legume-non legume plant interactions have been conducted for a long time. Sanginga and his associates (1986) found that maize yields in soil in which inoculated *Leucaena* had grown for 6 months, were increased from 1.5 to 2.5 t ha^{-1} with prunings removed and from 2.2 to some 4 t ha^{-1} with prunings returned to the soil. Similarly, Ladha *et al.* (1989) have indicated that nitrogen fixed by *Sesbania rostrata* can significantly increase subsequent grain yield of lowland rice. But such types of direct evidences of the advantages of intercropping are limited because the identification and quantification of the benefits of the fixed N to the associated crop have been realised recently. The benefits are likely due to:
1) underground transfer, whether by direct excretion of nitrogenous compounds and/or by root/nodule decay; 2) stimulation of non symbiotic N fixation; 3) more efficient use of nutrients, light, and water; and 4) the N-sparing effect. At present there is increasing worldwide interest in the use of nitrogen fixing trees in agroforestry systems particularly those providing fodder for livestock (Gutteridge & Shelton, 1993).

2.4.2 Belowground productivity

The role of roots in maintaining soil fertility in agroforestry is as important as that of aboveground biomass (Swift, 1984; Young, 1991). In addition to maintain continuous supply of essential nutrients to aboveground organs and anchorage to plants, roots are the primary agency in nutrint retrieval and contribute to soil organic pools (Vogt *et al.*, 1989). Organic matter accumulation through root turnover has been reported to the tune of 4 to 9.8 t ha^{-1} (Kummerow, 1981; Vogt *et al.*, 1989, 1991). The addition of the organic matter through fine roots is mainly dependent on tree species, root morphology, soil type, spacing and management techniques. In addition, the efficiency of utilization of nutrients supplied through organic residues largely depends on nature of organic matter, such as rate of decomposition and release of nutrients coupled with soil conditions (Carlisle *et al.*, 1967; Herrera *et al.*, 1987; Rout & Gupta, 1987; Beer, 1988; Cameron & Spencer, 1989; Dunham, 1989; Sharma & Pande, 1989; Eason, 1991). Rain forests have a lower ratio of roots to shoots than most ecosystems, yet in forests of Sri Lanka and Sarawak, roots were found to contain 12% to 28% of the N, P, K, and Ca in the standing plant biomass (Andriesse *et al.*, 1984, 1987). In agroforestry systems competition between tree and crop roots for nutrients depends on factors such as species of crops and trees, their rooting behaviour, soil physical conditions, effective rooting depth, climate etc. The competition will be reduced if tree and crop root systems mine nutrients from different soil layers (Huck, 1983). Since most crops have shallow rooting systems, trees with a predominance of deeper roots are preferred in agroforestry. However, in many situations major part of tree roots is distributed in upper soil profile, similar to that of crops, and hence competition between tree and crops for below-ground resources is expected (Jonsson *et al.*, 1988, Dhyani *et al.*, 1990; Ruhigwa *et al.*, 1992; Singh *et al.* 1994). In the humid zone on acid soils, competition between the hedgerows and crops for nutrients (in addition to light) was found very severe, as the woody species and crops have the tendency to concentrate their roots in the surface soil because of the subsoil's acidity and lower fertility e.g. in *Inga edulis, Senna spectabilis* and *Calliandra calothyrsus* and *Paraserianthes falcataria* (Basri *et al.*, 1990; Evensen & Yost, 1990; Fernandes *et al.*, 1990). The root competition in some cases can be minimised through trenching (Singh & Dayal, 1974; Dadhwal *et al.*, 1986), root exclusion or presence of root barriers (Corlett et al., 1992 a, b).

Root systems of trees, including those of fruit trees, differ from annual plants by their perenniality. There are very few reports on fruit root distribution particularly under agroforestry systems, although considerable work has been done on the nature and extent of root development in various fruit trees (Ghosh, 1973). Atkinson (1983) reviewed the growth and development of the fruit tree root system and suggested that woody roots must be responsible for much of total water supply. Ford (1955) demonstrated very large differences for root development among different species. In mandarin, maximum quantity of feeder roots is concentrated upto 60 cm depth (Aiyappa *et al.*, 1968), whereas Ghosh and Chattopadhyay (1972) observed that in an 8-year old lemon tree majority of fibrous roots were confined in the uppermost 25 cm soil layer. In case of acid lime, 75-80% of root activity was located within a radial distance of 80 cm where the major part of the root system was confined (Kurien *et al.*, 1993). In Kinnow mandarin the root activity was greater near the surface soil (15-30 cm) than in the sub-soil layers (Badiyala, 1991). Ghosh (1974) while studying root concentrations in the three fruit trees at different soil depths indicated that sweet orange is predominantly surface feeder, whereas guava and mango roots exploit subsoil layers.

2.4.3 Nutrient recycling and weed biomass

Forest soils carry a high weed seed load due to presence of weeds in the forest and adjacent sites. Weeds being mostly the pioneer species, quickly colonize a site after the canopy is opened and light provided. Although the economic importance and nuisance value of weeds in agriculture have resulted in numerous studies, **"the realization that they are also excellent material for addressing basic evolutionary and ecological issues have stimulated further interest in the study of weeds during recent years"** (Tripathi, 1985). Since the weeds are usually intolerant of shade, an effective way of controlling them is through canopy closure and shading of the undergrowth. In fact weed control is often cited as one of the benefits of intercropping (Moody, 1980). The presumed mode of action is that one crop, by severely competing with the weeds, provides an environment of reduced weed biomass for the other crop (Vandermeer, 1989). Lower weed yields under hedgerows (Yamoah *et al.*, 1986a) with *Acacia albida* (Bashir Jama & Getahun, 1991), control of *Imperata* infestation in alley cropping (Aken-Ova & Atta-Krah, 1986), and shift in weed compostition following alley cropping with various hedgerows species (Siaw *et al.*, 1991) are some of the examples of reduced weed infestation in agroforestry systems. In the entire north-east India, there is tremendous weed growth in the kharif season. Heavy rainfall results in luxuriant growth of weeds and weed problem is one of the main reasons for poor yield of crops. Patel *et al.* (1988) observed that as high as 38% increase in yield could be obtained through weed control. While evaluating traditional landuse systems in general and agroforestry systems in particular in Meghalaya, it was observed that all the weed biomass is frequently being recycled in situ. Mishra and Ramakrishnan (1983) suggested that weeds have a useful role and are an essential ingredient of traditional agroecosystems in different parts of the world including north-eastern India. Thus, as pointed out by Tripathi (1977), weeds are desirable to some extent and play useful role in agroecosystems.

The review of literature pertaining to various aspects of agroforestry systems presented in the foregoing pages clearly shows that detailed ecological analysis of agroforestry systems has not been made under Indian conditions. Therefore, an attempt has been made to undertake ecological analysis of a few selected agroforestry systems that have potential to be suitable for the hill region of the subtropical humid climate, especially on the degraded alfisols on slopy lands.