AN ANALYSIS OF THE EFFECTS OF AGROFORESTRY SYSTEMS ON PRODUCTIVITY AND SOIL CHARACTERISTICS

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CERTIFICATE

I, Shiv Kumar Dhyani, hereby, declare that the subject matter of thesis entitled, "An analysis of the effects of agroforestry systems on productivity and soil characteristics" is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

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CHAPTER 1

INTRODUCTION

The concept of sustainability assumes vital significance in agriculture in view of the fact that modern agriculture has created a number of ecological and environmental problems. The sustainability in agriculture depends on the extent to which a balance could be created between human and livestock needs, and conservation of the environment. The existence of forests and grasslands in the surrounding areas is vital for a sustainable agriculture. However, forest and grassland ecosystems have been undergoing fast degradation in recent years owing to deforestation caused by shifting cultivation and other human disturbances in the whole of north-eastern hill region (Khan *et al.*, 1987; Singh & Prasad, 1987). Nearly 19 million t of soil is estimated to be eroded every year due to shifting cultivation in this region (Singh & Singh, 1980, 1981). This has resulted in a loss of 6 million t of organic carbon, 9.7 t of available P_2O_5, and 5,690 t of available K_2O (Borthakur *et al.*, 1985). Besides, a substantial amounts of Ca and Mg are also washed away and eventually, their deficiencies are being noticed in the crops grown on these soils (Prasad, 1987). The extent of degradation has already reached an alarming proportion in Meghalaya and according to a recent estimate, approximately 21 percent of the total geographical area of the state is in the form of wastelands (SPWD, 1995). Abandoned jhum-lands and barren hill ridges or rock outcrops form the major part of wastelands in the state. The ecological implications of land degradation in these areas are evident now. The natural resource degradation is bound to adversely affect the economic growth, particularly in the rural areas and may trigger the migration of the population to the urban centres. The removal of forest biomass alters bio-geochemical cycles and modifies physical characteristics of the site (Johnson *et al.*, 1991). This impact may be more pronounced in agricultural systems. However, not much information is available on the soil fertility status on the hill slopes that have been brought under cultivation after clearing the forest vegetation growing on them. It is an urgent need to put back the abandoned areas under some kind of permanent vegetation for reasons of ecological reconstruction of the degrading resource- base as well as for meeting the food and fodder requirement of ever increasing human and livestock population in this region.

The significance of tree-based land use systems in general and agroforestry in particular, has been realized in improving the economy of farmers having small land holdings as well as in the restoration of soil fertility level (Alpizar *et al.*, 1986; Lal, 1986; Fassbender *et al.*, 1988; Chauhan & Dhyani, 1989; Beer *et al.*, 1990; Fisher, 1990). The fertility restoration capacity of the soils can be improved under the influence of tree cover which protects the soil from erosion, contributes to soil organic matter (SOM) content and continuously replenishes the nutrients through effective recycling mechanism. In the recent past ICAR Research Complex for NEH Region has evolved agri-horti-silvi-pastoral land use as an alternative to shifting cultivation for high and sustained crop production systems in the hills (Prasad, 1990). Besides, different forms of inter-cropping including annual food crops in asoociation with trees, plantation crops and pastures not only optimize the natural resources but also ensure continuous food flow (Watson, 1990). Agroforestry is a special case of mixed cropping and it integrates the land-use systems and practices in which woody perennials are deliberately integrated with crops and/or animals on the same land-management unit (Leakey, 1996). The benefits accrued from agroforestry systems might be due to efficient nutrient recycling, nitrogen fixation by leguminous trees (if present), and accumulation of organic matter. It offers a practical means of achieving greater output and at the same time maintaining soil fertility which ultimately helps in increasing the productivity of agricultural crops and trees. This is so because maintaining high levels of available N and P, the two most limiting nutrients in soil, still remains a major challenge to ecologists and land managers. Investigating long term effects of cultivation on soils under different agroforestry systems is an important component of research efforts directed towards restoring the sustainability of agriculture in terms of maintaining soil fertility and optimum economic returns. Organic matter is the most dynamic constituent of soil and its input is a key factor governing the soil fertility. Besides, soil organic matter (SOM) greatly influences the physical, chemical and biological characteristics of soils (Lal & Kang, 1982; Adejuwan &

Adesina, 1990; Drechsel *et al.*, 1991). It is expected that inclusion of compatible and desirable trees in cropland situation would improve soil fertility (Okigbo *et al.*, 1980; Vergora, 1987; Young, 1989; Lal, 1989; Parrotta, 1990; Watson, 1990) through organic matter decomposition cycle. But it is impossible to answer the many questions on nutrient cycling until data are available for different agroforestry systems under different environments. In this context the need for quantitative determination of inputs, outputs and within-system transfers of nutrients and their storage in plant and soil compartments is evident. The collection of quantitative data on biomass production of the tree species, agronomic and biological productivity of crops and other plants and the influence of agroforestry systems on soil properties and nutrient dynamics, is a pre-requisite for a better understanding of the effects of agroforestry systems on productivity and soil characteristics. A review of literature reveals that studies on these aspects have been carried out with reference to natural forests, grasslands and agroecosystems by several researchers and a large amount of data is available, but no serious attempt has been made to study agroforestry systems on these lines.

The ICAR Research Complex for NEH Region has initiated a long term indepth study on various farming systems at Barapani Farm since 1987, wherein the analysis of agroforestry systems is also envisaged. The present study in conjunction with the efforts already made by the ICAR, may help in developing suitable agroforestry models for this region.

OBJECTIVES

The major objective of the present research is to **analyse the effects of a few agroforestry systems on crop yield and soil characteristics** in slopy land situation in Meghalaya. The specific objectives of the study are as follows:

1. To study the effects of agroforestry systems on agronomic productivity and biological productivity of crops, trees and weeds.
2. To study the effects of agroforestry systems on physical and chemical properties of soil.
3. To investigate nutrient dynamics under different agroforestry systems.

To achieve the above objectives, the following four agroforestry systems were selected for the study:

(1) Alder-based agroforestry system (AFS 1),

(2) Albizia-based agroforestry system (AFS 2),

(3) Cherry-based agroforestry system (AFS 3), and

(4) Mandarin-based agroforestry system (AFS 4).

Data on growth attributes, survival, timber volume, and above- and below-ground biomass production of the four tree species, distribution of tree roots in soil profile and fine root biomass of the four tree species, agronomic and biological productivity of crops and weeds and the influence of agroforestry systems on soil properties were collected in the four agroforestry systems. Besides, the uptake of nutrients and their retention and removal in vegetation compartment and soil pool were also estimated. Data collected on various aspects were analysed using appropriate statistical procedures and conclusions with regard to effects of agroforestry systems on crop and tree productivity, soil characteristics and nutrient dynamics were drawn.

The thesis is divided into 10 chapters. The data collected on various aspects such as survival, growth attributes and litter dynamics of the tree species, biomass and productivity of tree, crops and weeds, soil properties as influenced by the four agroforestry systems and nutrient cycling are presented in Chapters 4-9. Chapter 1 gives a general introduction to the entire study. Chapter 2 presents the review of literature published on the subject matter of the thesis and related aspects. Chapter 3 includes the details pertaining to the study site, description of the selected agroforestry systems and physico-chemical properties of soil at the study site. Survival and growth of the four tree species have been discussed critically in Chapter 4. The details relating to biomass and productivity of the four tree species and of crops and weeds in the four agroforestry systems have been presented in Chapters 5 and 6. Litter dynamics of trees and physico-chemical characteristics of soil as influenced by the agroforestry systems have been presented and discussed in Chapters 7 and 8. A comparative account of nutrient cycling in the four agroforestry systems has been discussed in Chapter 9. The results presented in chapters 4-9 have been critically discussed in detail in individual chapters, however, the major findings of the whole study have been briefly discussed in an integrated manner in Chpater 10 (General Discussion). This is followed by a brief summary and references.

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 agroforestry 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 agroforestry 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 up to 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.

CHAPTER 3

LOCATION, CLIMATE AND SOIL OF THE STUDY SITE, AND DESCRIPTION OF THE SELECTED AGROFORESTRY SYSTEMS

Location

The experimental study site is located at the ICAR Farm, Barapani (Meghalaya), between 25^0 39' and 25^0 41' N latitude and $91^0$54' and $91^0$63'E longitude. It is 22 km north of Shillong city. The altitude of the farm area varies between 952 and 1082 m above msl. The farm is an old abandoned jhum and land degradation due to soil erosion was the major problem at the time the area was acquired by the ICAR. In order to control soil erosion, and to retain maximum water in the area, and for safe disposal of excess water, mechanical measures such as construction of contour bunds and mini terraces on contours, were taken. The bunds have 3-3.2 m width and 50-60 m length.

Geology

The rock types in Barapani area are quartzites, phyllites and metamorphosed conglomerates of the Shillong series, with metadolorite (green stone). There are pink to buff quartzites, hard areanaceous black phyllites, medium hard redish and greyish phyllites, sandstones etc.

Climate

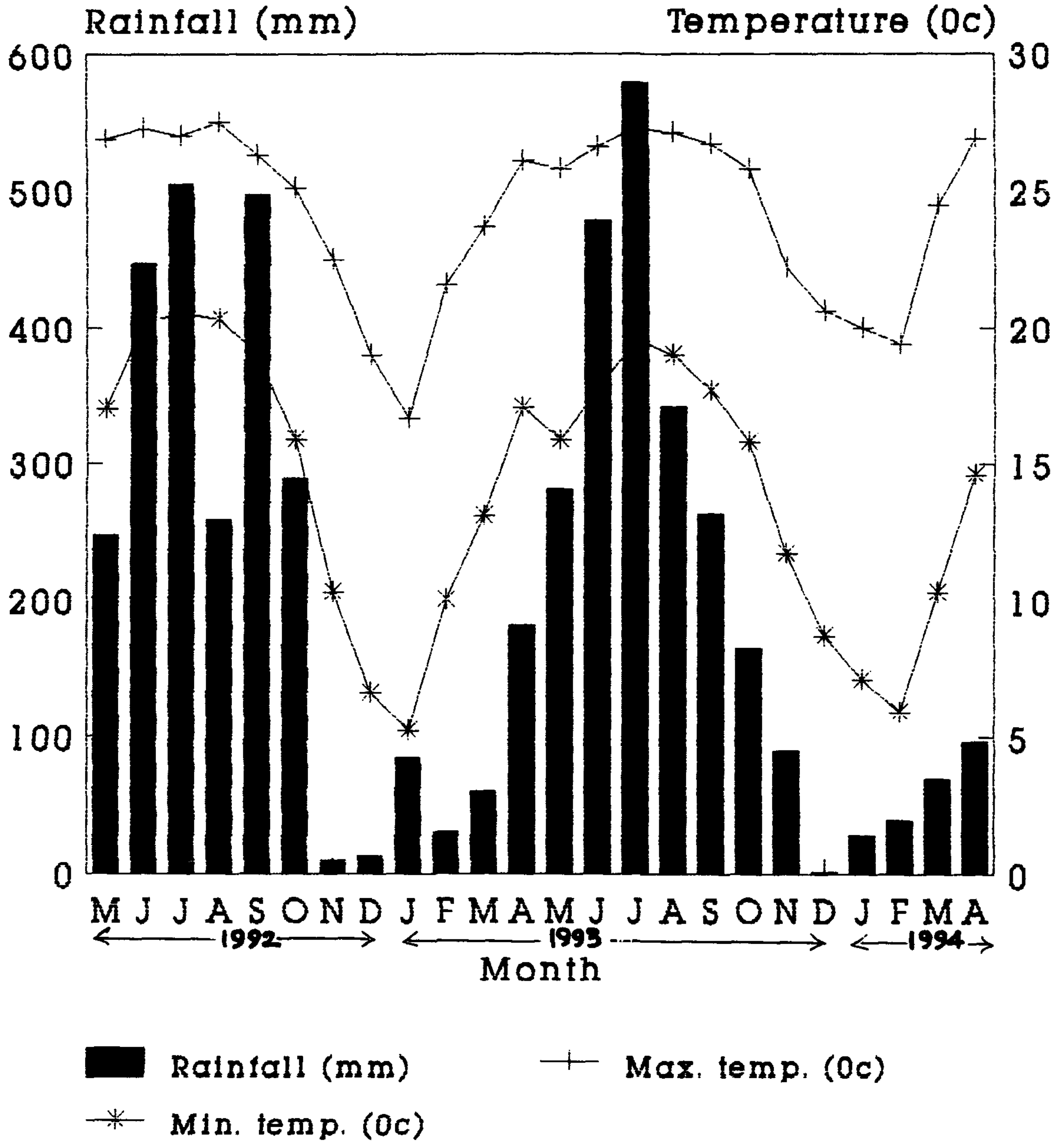
The climate of Meghalaya is monsoonic and is directly influenced by the south-west monsoon originating from the Bay of Bengal and the Arabian sea. Annual rainfall during past 30 years ranged from 1537 mm (in 1975) to 2788 mm (in 1953) with an average of 2138 mm. More than 90% of total annual rainfall is received during April to October. Mean rainfall recorded during winter (January-February), pre-monsoon (March-May), monsoon (June-September) and post-monsoon (October-December) periods accounts for 3.66, 19.21, 64.75 and 12.38 percent of the mean annual rainfall. The intensity of rainfall is more in June, July and August. Mean maximum temperature at the study site varied from 16.7^0C in January to 28.5^0C in April '92 (Fig.3.1). There is a gradual increase in tempe-rature during February to July and thereafter it starts declining. The mean minimum temperature is recorded during January. Relative humidity within the study area was quite high (more than 90% during rainy season). It was more than 60% even during the driest period of the year. Sunshine was less during rainy season and more during winter season. Moreover, there was some interception of light due to increased tree canopy cover during kharif (crops grown during the main monsoon season i.e. April to September (Table 3.1)), whereas, no interception of light occurred during rabi (crops grown during the winter season) when the trees become leafless.

In spite of high rainfall in the area, it is difficult to grow rabi crops on dry terraces due to poor water retention capacity of soils, prolonged low temperature, occasional frost, lack of irrigation facilities and synchronization of harvesting time with pre-monsoon showers.

Agroforestry systems

Agroforestry is an ideal scientific approach to tackle the problem of degraded lands and to bring about ecorestoration

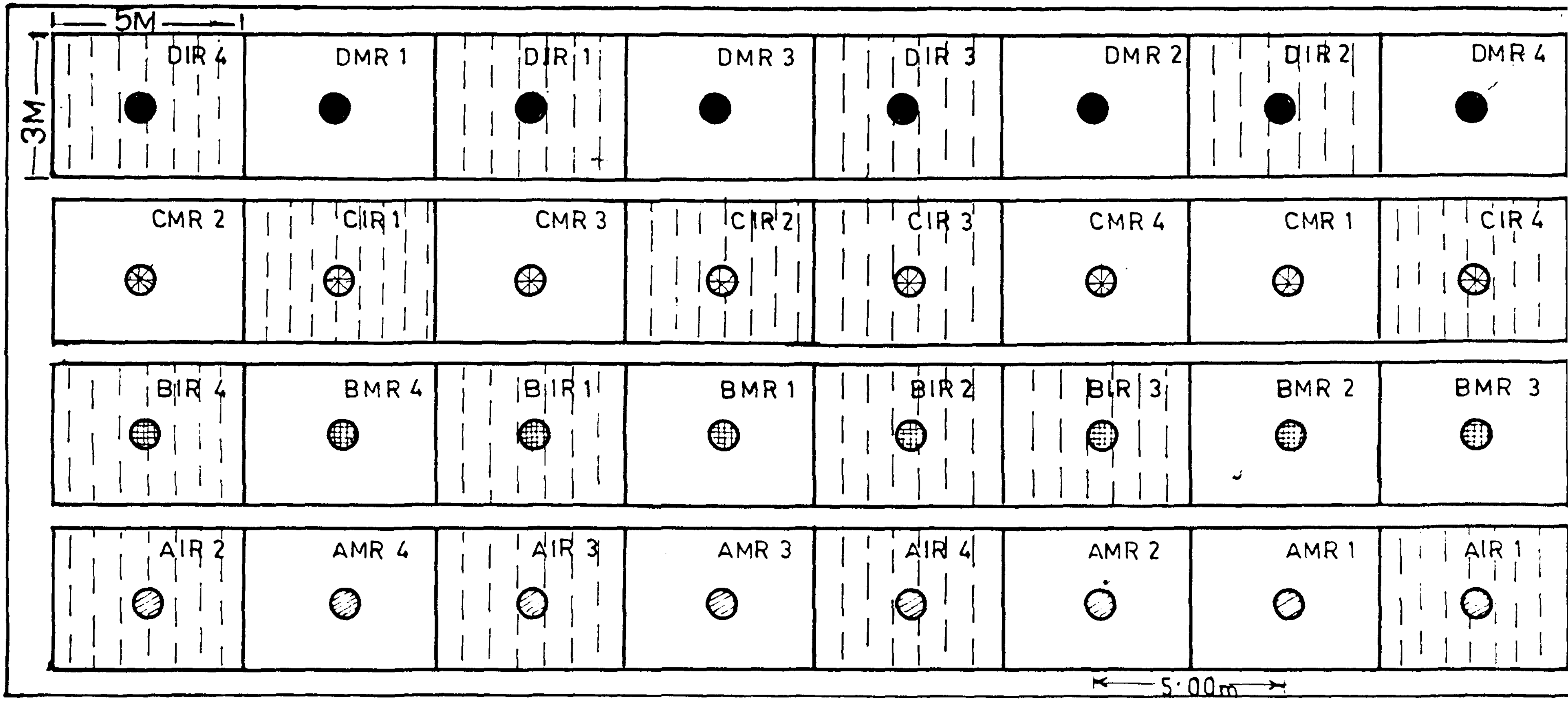
Fig. 3.1. Temperature and rainfall data for the study period (May '92 to April '94)



and maintenance of soil resources. Hence, the ICAR Research Complex for North-Eastern Hills Region identified Agroforestry as one of the major thrust areas. Several agroforestry systems viz. agri-horti, agri-silvi, silvi-horti, silvi-pasture and agroaquaculture were introduced by the ICAR in 1987 as a part of its agroforestry research activities. Over the years 9 agroforestry systems/models were developed and are being evaluated for their productivity and sustainability. An agri-horti system comprising mandarin (*Citrus reticulata* Blanco) as the tree component and three agri-silvi systems each having crops and one of the three multi-purpose tree species viz. alder (*Alnus nepalensis* D.Don), albizia (*Paraserianthes falcataria* (L) Nielsen syn. *Albizia falcataria* (L) Forsberg) and Himalayan wild cherry (*Prunus cerasoides* D.Don) which were found most suitable in terms of overall production, were selected for an indepth analysis of their effects on growth and productivity of crop and weed, and soil characteristics.

The experimental design was a split-plot with four replications. The four agroforestry systems (AFS) were main plot treatments and the two crop situations viz. inter-cropping, and monoculture, referred to as 'tree+crop' and 'tree only' respectively, were the sub-plot treatments. The size of the main plot was 40 x 3 m and it was divided into eight sub-plots of 5 x 3m (Fig. 3.2). **The four agroforestry systems are referred to above are as follows:**

(1) Alder-based agroforestry system (AFS 1),
(2) Albizia-based agroforestry system (AFS 2),
(3) Cherry-based agroforestry system (AFS 3), and
(4) Mandarin-based agroforestry system (AFS 4).



Species (4) — A — D

A — Alder (Alnus nepalensis)

B — Albizia (Paraserianthes falcataria)

C — Cherry (Prunus cerasoides)

D — Khasi mandarin (Citrus reticulata)

Crop situations (2) — I, M

I — 'TREE + CROP'

M — TREE ONLY

Replications (4) - $R_1 - R_4$

Fig. 3.2. Schematic drawing of agroforestry experiments showing arrangement of trees and intercrops in split-plot design.

A brief note on the importance of the above four tree species is given below.

Alder (*Alnus nepalensis* D.Don)

Alder is distributed throughout the Himalayas from Chamba in Himachal Pradesh to Mishmi hills in Arunachal Pradesh and Khasi hills in Meghalaya, commonly below 1800 m, occasionally up to 2700 m. It grows in moist, shady ravines near water and on clayey soils, usually in gregarious strips and on exposed soils forming pure patches. It is planted as an associate species with *Cryptomeria japonica* Don, *Cupressus cashmeriana* Royle, *Betula alnoides* Ham, *Michelia champaca* L. and with other timber trees. It is a good nurse tree in Cinchona and cardamom plantation in the Himalayan region. Production of large amounts of seed, easy dispersal, fast juvenile growth and occurrence of nitrogen-fixing root nodules have made it a successful pioneer species in freshly exposed soils in landslide affected areas.

Roots of *Alnus* species are nodulated with *Frankia* as an endophyte, and are efficient in biological nitrogen-fixation (Becking, 1977; Johnsrud, 1978; Akkermans & Van Dijk, 1981; Sharma & Ambasht, 1984).

Albizia (*Paraserianthes falcataria* (L)Nielsen)

An evergreen, slender tree with a straight and almost cylindrical bole, smooth bark and a spreading crown, leaves compound, with 8-12 pairs of pinnae, flowers small, fairly fragrant, pods 10-15 cm long, 15-seeded, thinly woody, pale brownish. Wood of the species is used for the manufacture of cheap matches, fruit packing cases, and is also suitable for paper and board making. The species is native to south-east Asia. Being a very fast growing tree, it is extensively planted in tropical regions (Singh *et. al.*, 1991). The species is not exacting as to its soil requirements. In India, it has been extensively used for reforestation and for shade in tea gardens. Biological nitrogen fixation also occurs in the root nodules (CSIR, 1990).

Himalayan wild cherry (*Prunus cerasoides* D.Don)

A handsome middle sized deciduous tree, with smooth, peeling bark, flowers pink, fading to white, appearing before or with the leaves. The wood is reddish brown, close grained and polished well. The species is well distributed from Kashmir to Manipur at 900-2300 m. It is recommended for stabilizing north-eastern hills (CSIR, 1990). It yields good timber, fuel and fodder. Its rootsuckers make excellent walking-stick and umbrella-crook. The bark yields tannin and gum. Fruit, though edible is not eaten; useful for cherry-brandy.

Mandarin (*Citrus reticulata* Blanco)

The north-eastern region is the original home of mandarin orange. It has been cultivated in the region for a long time. The variety grown in the region is commonly called Khasi orange. In Sikkim it is known as Sikkim orange. The major belts are confined mostly to the sub-montane tracts and up to an altitude of about 1000 m above m.s.l.

The four agroforestry systems have similarity in topography of the site (slope, soil depth, aspect), initial soil properties and age of the stand. The weed flora in these systems was commonly represented by grasses such as *Brachiaria villosa*, *Digitaria adscendens*, *Eleusine indica*, *Echinochloa colonum*, *E. crusgalli*, *Imperata cylindrica*; legumes like *Desmodium microphyllum*, *Mimosa pudica* and *Trifolium repens* and a few other broad leaved forbs, such as *Ageratum conyzoides*, *A. haustonianum*, *Bidens pilosa*, *Borreria hispida*, *Eupatorium odoratum* and *Galinsoga parviflora*. However, there were differences between the four systems, particularly in the tree components, density of the stands, canopy spread, light interception by the canopy, crop yield, and occurrence of certain exclusive weed species in a particular system and differences in abundance of weeds that are common to various systems. The major differences of the four systems are summarised in Table 3.1.

Agricultural operations in 'tree+crop' plots

The land of the 'tree+crop' plots was prepared for cultivation by hand hoeing (at least thrice) before being cropped. During hoeing the soil down to 15-20 cm depth was thoroughly mixed. Before hoeing the weed plants were slashed and the slash was spread over the terrace and allowed to decompose. In the same terrace different crops were grown in different seasons rotationally. During rainy season soybean and groundnut were grown, and in dry winter period linseed and mustard were grown. Crop duration, crop density and quantity of inorganic fertilizer applied to each crop under the four agroforestry systems during the study period are given in Table 3.2. All the weed biomass after intercultural operations was initially incorporated in soil for mulch, which

Table 3.1. Some salient characteristics of the four agroforestry systems.

Characteristics	Agroforestry systems (AFS)			
	AFS 1	AFS 2	AFS 3	AFS 4
1. Tree component	Alder	Albizia	Cherry	Khasi mandarin
2. Utilization	NFTS	NFTS	Wild fruit	Fruit tree
3. Crown width	Large (6-7 m) Dense foliage	Moderate(4-5m) Sparse foliage	Moderate(4-6m) Dense foliage	Restricted(1.5-2m) Dense
4. Age of stand(yr)	5	5	5	5
5. Density(ha^{-1})	500	500	500	400
6. Light interception by tree canopy during *kharif*	66	38	64	13
7. Crops grown				
Kharif	Groundnut and soybean crops were grown in all AFS			
Rabi	Linseed and mustard crops were grown in all AFS			
8. Crop yield(kg ha^{-1})				
Soybean	1590	1672	1346	1648
Groundnut	1590	1684	1352	1605
Linseed	689	729	536	704
Mustard	711	741	517	704

NFTS - Nitrogen fixing tree species

AFS 1- Alder-based agroforestry system,
AFS 2- Albizia-based agroforestry system,
AFS 3- Cherry-based agroforestry system, and
AFS 4- Khasi mandarin-based agroforestry system.

Table 3.2. Phenology and density of the crops grown and the quantity of fertilizers applied in the 'tree+crop' system under the four agroforestry systems.

Crops	Seed rate (kg/ha)	Fertilizer (N:P:K)	Crop planting date	Germination date	Flowering period	Harvest period
Soybean [*Glycine max*]	40	30:60:40	May '92 (1st wk)	May '92 (2nd wk)	Aug '92 (2nd wk)	October '92 (1st wk)
Linseed [*Linum usitatissimum]*	15	40:60:40	Oct '92 (2nd wk)	Nov '92 (1st wk)	Jan '93 (2nd wk)	March '93 (1st wk)
Groundnut (*Arachis hypogaea*) JL-24	30	30:60:40	May '93 (3rd wk)	June '93 (2nd wk)	July '93 (3rd wk)	Sept '93 (3rd wk)
Mustard [*Brassica campestris]*	7	40:60:40	Oct '93 (3rd wk)	Nov '93 wk, 1993	Dec '93 (3rd wk)	March '94 (3rd wk)

N- As Urea, P- as Superphosphate, K- as Murate of potash subsequently served as manure. Inorganic fertilizers (i.e., nitrogen, phosphorus and potassium) were top- dressed in the ratio of 30 : 60 : 40 for soybean and groundnut, and 40 : 60: 40 for linseed and mustard at the time of sowing.

Characteristics of the study site

The experimental plots have 25-38% slope and the soil depth varies between 22.5-45 cm. Soils have been formed predominantly from the weathering of sedimentary and metamorphic rocks, quartzites, conglomerates, phyllite, shale, sandstone etc., and they belong to Alfisol order. The soil is prone to increased erosion losses, mainly due to the continuous denudation caused by _jhum_ (shifting agriculture). The soil materials are continuously removed by erosion from the upper portion of the slope and get deposited on the lower parts of the slope or in the valleys. Thus soil depth on the upper reaches of the slopes decreases. Soils of the study site are clay loam to sandy clay loam. Initial study of fertility status of soils suggests, that they were deficient in available phosphorus (Table 3.3). This could be due to acidic reaction of the soil and presence of considerable amount of exchangeable Al. To evaluate the effects of the tree species on soil properties such as pH, organic carbon, exchangeable Al^{+++}, Ca^{++}, Mg^{++}, K^{+}, and Bray's P_2-P, soil samples were collected for analysis before the start of present study. Soils from two depths i.e. 0-20 cm (surface) and 20-40 cm (sub-surface) were sampled from each sampling place. The samples were bulked, air-dried, sieved and kept ready for analysis. Standard procedures were followed for determining soil properties (Jackson, 1973).

After five years of establishment of the agroforestry systems, chemical properties of the top soil such as pH, organic carbon, exchangeable Mg and Al^{+++} were hardly influenced by the tree species and intercropping, as the coefficient of variation (CV) was less than 20% (Table 3.3). However, the four systems differed in Bray's P_2-P, Ca^{++} and K^+, as their CV varied between 23.4-47.2%. Significantly high variability for nutrient status was found under the four systems in spite of the common crop sequence and adoption of uniform management practices.

Soil pH

A perusal of the data (Table 3.3) distinctly revealed that these tree species had shown differential behaviour with regard to soil pH over a period of time. By and large pH declined in the fifth year by 0.2 units under alder, cherry and albizia, and by 0.3 units under mandarin.

Organic carbon

The organic carbon content exhibited an increasing trend (3-20%) in the fifth year under alder, cherry and albizia, but a decline of 12% under mandarin.

Exchangeable Al

A marginal increase in exchangeable Al content by 25% in cherry to as high as 45% in mandarin was observed after five years.

Exchangeable Ca, Mg and K

The exchangeable Ca content of the soil ranged from 0.2 to 0.50 C mol(P^+) kg^{-1}, Mg from 0.68 to 0.8 C mol(P^+) kg^{-1} and

Table 3.3. Initial physico-chemical properties of the soil from the experimental plots.

Agroforestry systems	pH in H_2O	Organic Carbon (%)	Exchangeable nutrients (C mol(P^+) kg^{-1})			Bray's P_1-P (mg kg^{-1})	Exch.‡ Al^{+++}
			Ca^{++}	Mg^{++}	K^+		
Initial values (1987)							
Surface soils (0-15cm)							
	4.9	1.77	0.60	0.50	0.17	1.20	0.55
Sub-surface soils (15-30cm)							
	4.8	0.88	0.10	0.40	0.13	0.02	0.68
Values before the start of the present study (1992)							
Surface soils (0-15cm)							
AFS 1	4.7	2.13	0.20	0.70	0.14	6.00	0.71
AFS 2	4.7	1.83	0.35	0.75	0.19	5.44	0.74
AFS 3	4.7	2.13	0.50	0.80	0.25	7.44	0.69
AFS 4	4.6	1.56	0.19	0.68	0.19	3.60	0.80
Sole crop	4.8	1.49	0.58	0.52	0.18	1.80	0.68
Mean	4.7	1.82	0.36	0.69	0.19	4.85	0.72
SD(±)	0.07	0.30	0.17	0.10	0.04	2.20	0.05
CV(%)	1.50	16.60	48.10	15.34	20.70	45.17	6.67
Sub-surface soils (15-30cm)							
AFS 1	4.6	1.61	0.30	0.20	0.10	0.40	0.76
AFS 2	4.7	1.77	0.20	0.30	0.12	0.48	1.05
AFS 3	4.7	1.52	0.15	0.20	0.16	0.80	0.74
AFS 4	4.5	1.50	0.12	0.18	0.19	0.50	1.11
Sole crop	4.7	0.81	0.10	0.28	0.15	0.24	0.73
Mean	4.6	1.44	0.17	0.23	0.14	0.48	0.87
SD(±)	0.09	0.36	0.07	0.05	0.04	0.20	0.18
CV(%)	2.07	25.60	45.90	23.30	24.35	42.18	21.17

‡(C mol(P^+) kg^{-1})

AFS 1- Alder-based agroforestry system
AFS 2- Albizia-based agroforestry system
AFS 3- Cherry-based agroforestry system and
AFS 4- Mandarin-based agroforestry system

K from 0.14 to 0.25 C mol(P^+) kg^{-1} in the fifth year. Thus, there was an increase of 36-60% in exchangeable Mg under the four systems, and 12-47% in exchangeable K content under the three systems over initial values. However, in the alder system, K^+ content decreased by 18%. A substantial decline in Ca^{++} values was noticed under mandarin (68%), alder (67%) and albizia (42%), though under cherry the decline was only 17% as compared to initial values.

Phosphorus

There was a build up of available P by 7 to 15 kg ha^{-1} as compared to the initial value of 2.4 kg ha^{-1}. Maximum build up was observed under cherry system, followed by alder and albizia, and the minimum was in mandarin system.

The sub-surface (20-40 cm) soil properties viz. Bray's P^2-P, Ca^{++}, Mg^{++}, K^+ and Al^{+++} were similarly influenced by the four tree species as indicated by the high values of CV (Table 3.3).

The declining trend in pH of the surface soils was mainly due to rise in exchangeable Al level at the fifth year. The high accumulation of organic-C beneath alder, cherry and albizia was attributed to addition of greater amount of litter and root biomass as compared to mandarin. Another possibility for this high build up might be the lesser microbial activity due to high exchangeable Al and the low levels of P and cations such as Ca and Mg in the initial years. Exchangeable Al, a potential cause of infertility of acid soils, might have increased mainly due to leaching of cations owing to low canopy in the beginning coupled with regular use of nitrogenous fertilizers for the intercrops. The spectacular increase in Bray's P_2-P (available P) under the four systems may be attributed to solublization of native P (unavailable form) owing to root exudates and addition of large quantities of organic matter through roots. The increase in organic-C, Ca^{++}, Mg^{++}, K^{+}, Al^{+++} and P content in the sub-surface layer of soil under the tree species, could be ascribed to the litter input and decreased run-off losses of these nutrients under tilled condition.

Ca^{++} and K^{+} showed a strong positive correlation with soil pH. However, other variables such as organic-C and Mg^{++} showed moderate positive correlation with each other. Almost similar relationship between these variables was also observed in the sub-surface soil.

Weeds

Besides crops, and perennial woody plants, weeds also grew abundantly in the agroforestry systems. It is an established fact that weeds modify or suppress the growth of crop plants as a result of competition for nutrients, water and light etc. and cause tremendous loss to the crop yield. In the entire north-east India, weed growth is luxuriant particularly during the <u>kharif</u> (summer) season owing to abundant supply of moisture and favourable temperature. In fact, one of the important reasons for poor crop yield in this region is the abundant weed growth as weeds can grow all the year round in wet tropics (De Rouw, 1995). Patel and his associates (1988) observed that as high as 38% increase in yield could be obtained by weed control. Several studies have been made recently on weed-crop interference where competitive influences have been assessed not merely as an agronomic problem but also as an ecological problem (Kushwaha, 1985; Tripathi, 1985; Saavedra *et. al.*, 1989). Although the mortality and plasticity of plant populations in pure and mixed stands have been analysed by several workers (Tripathi & Harper, 1973; Tripathi & Gupta, 1980; Ibrahim, 1984; Beckett *et al.*, 1988), studies pertaining to weed control and weed biology under the complex system of agroforestry are scanty.

In agroforestry systems, soils and the weed growth are frequently disturbed by soil working, intercultural operation and chemical treatment, and hence, there may be a gradual elimination of some weed species and invasion of some new ones. At the same time, with the increasing age of the cultivated land, the original weed flora gradually undergoes perceptible changes. The crop fields at the ICAR Farm, Barapani, have been under intensive cultivation round the year on rotation basis since 1984, and therefore, the original vegetation (and weed community) at this farm has been under constant biotic stress (Boral, 1993).

In view of the above, weed flora in the 'tree+crop' and 'tree only' situations under the four agroforestry systems was analysed over a period of two years (1992-94). Every month six 50 x 50 cm quadrats were randomly laid in each agroforestry system and individuals of each species were identified and counted for density determination. Species recorded during sampling were broadly grouped into the following categories:

1. Grasses and sedges,

2. Legume forbs,

3. Non - legume forbs.

Based on the position of perennating buds or organs during unfavourable season, the plant species were classified into different life forms following Raunkaier (1934). Quantitative characteristics of the weed community such as frequency and density were calculated using the formulae outlined in Misra (1968).

In general, the numbers of weed species recorded in the 'tree only' situation were more than in the 'tree+crop' situation in both years. In the 'tree only' situation 21, 27, 19 and 22 species were recorded in alder-, cherry-, albizia- and mandarin-systems, respectively during 1992-93 whereas in 'tree+crop' situation, the corresponding numbers of weed species were 11, 12, 11 and 14 (Table 3.6). In 'tree only' situation no new species were recorded during 1993-94. In fact, four weed species viz., *Setaria glauca* under cherry- ('tree only') and mandarin-systems ('tree+crop' and 'tree only'); *Panicum montanum* under cherry- ('tree+crop') and albizia-('tree only'); *Crotalaria striata* under alder-, cherry- and albizia-systems ('tree only'); and *Commelina benghalensis* under cherry- ('tree only') and mandarin-systems ('tree+crop' and 'tree only'), which were present during the first year did not appear during the second year. However, two new species *Sida rhomboidea* in 'tree only' and *Murdannia spirata* in 'tree+crop' situation made their appearance during second year. A total of 31 species during 1992-93, and 29 species during 1993-94 were recorded under the four agroforestry systems. Of these, 18 species in 1992-93 and 16 species in 1993-94 were common in both, 'tree+crop' and 'tree only' situations. Two species in 1992-93 and 3 species in 1993-94 were exclusively present in 'tree+ crop' situation, while 11 species in 1992-93 and 10 species in 1993-94 were exclusively present in the 'tree only' situation under the four agroforestry systems (Table 3.4).

Table 3.4. Distribution of weed species under the four agroforestry systems during the study period.

Species common to 'tree+crop' & 'tree only' situations	Species present exclusively in 'tree only' situation	Species present exclusively in 'tree+crop' situation
Brachiaria villosa *Digitaria sanguinallis* *D. adscendens* *Eleusine indica* *Echinochloa crusgalli* *Setaria glauca* (only in 1st year) *Panicum montanum* (only in 1st year) *Desmodium microphyllum* *Trifolium repens* *Ageratum conyzoides* *A. haustonianum* *Ambrosia artemisifolia* *Bidens pilosa* *Blumea barberata* *Borreria hispida* *Commelina benghalensis* (only in 1st year) *Galinsoga parviflora* *Spermacoceae hispida*	*Arundinella bengalensis* *Cynodon dactylon* *Cyperus rotundus* *E. colonum* *Imperata cylindrica* *Crotalaria striata* (only in 1st year) *Eupatorium odaratum* *Lantana camara* *Mikania micrantha* *Phyllanthus urinaria* *Mimosa pudica* *Sida rhomboidea* (only in 2nd year)	*Chenopodium album* *Murdannia spirata* (only in 2nd year) *Oxalis latifolia*

Weed species exclusively present in different agroforestry systems during the two years are as follows:

AFS 1- Alder- system
Echinochloa crusgalli, *Murdannia spirata* in 'tree+crop' and *Ambrosia artemisifolia* in 'tree only' situations.

AFS 2- Albizia- system
Panicum maximum in 'tree only' situation.

AFS 3- Cherry- system
Commelina benghalensis and *Setaria glauca* in 'tree only' situation.

AFS 4- Mandarin- system
Oxalis latifolia in 'tree+crop' situation.

Out of the 31 species recorded during the first year, 11 were perennials and 20 annuals, whereas out of 29 species recorded during the second year, 11 were perennials and 18 annuals. The number of perennial species was higher in 'tree only' than in 'tree+crop' situation in both years. The ratio of annual to perennial species (A/P ratio) was greater in 'tree+ crop' than in 'tree only' situation under the four agroforestry systems (Table 3.5). With reference to the first year, the A/P ratio was higher during the second year in the alder- and cherry- sytems, it did not change in the albizia- system and it declined in the mandarin-system. It is interesting to note that mandarin-system had the least A/P ratio in both years, thus indicating that the proportion of perennial weeds in this system was greater as compared to other systems.

Table 3.5. The ratio of annual to perennial weed species under four agroforestry systems during the period of study.

Year	Agroforestry systems							
	Alder-		Cherry-		Albizia-		Mandarin	
	C1	CO	C1	CO	C1	CO	C1	CO
1992-93	10.0	1.63	5.0	2.0	10.0	1.38	6.0	2.14
1993-94	11.0	1.71	10.0	1.5	10.0	1.43	5.5	1.86

CO- 'tree only' situation; C1- 'tree+crop' situation.

The number of forbs was greater than the grasses and sedges in both years except under albizia-system in 'tree only' situation. Out of the four leguminous species recorded in the 1992-93 and three in 1993-94, only one was perennial. On an average 16-17% of the species were hemicryptophytes, ca. 20% were chamaephytes and 62-64.5% species were therophytes. 'Tree+ crop' situations were dominated by annuals as indicated by a high percentage (83-92%) of therophytes. On the other hand, the percentage of therophytes in the 'tree only' situation ranged from 58 to 68% (Table 3.6).

Table 3.6. Number and percentage of species in different life forms under the four agroforestry systems during the study period.

Systems & Year		A	P	Grasses & Sedges	Forbs		Life form (%)				
					Leg.	Other	Ph	Ch	H	G	Th
Alder (AFS 1)											
1992-93	C0	13	8	9	3	9	0	19.0	19.0	0	62.0
	C1	10	1	5	2	4	0	9.1	0	0	90.9
1993-94	C0	12	7	8	2	9	0	21.0	15.8	0	63.2
	C1	11	1	5	2	5	0	8.3	0	0	91.7
Albizia (AFS 2)											
1992-93	C0	11	8	10	2	7	0	26.3	15.7	0	57.9
	C1	10	1	4	1	6	0	9.1	0	0	90.9
1993-94	C0	10	7	9	1	7	0	23.5	17.6	0	58.9
	C1	10	1	4	1	6	0	9.1	0	0	90.9
Cherry (AFS 3)											
1992-93	C0	18	9	10	4	13	0	14.8	18.5	0	66.7
	C1	10	2	5	2	5	0	16.7	0	0	83.3
1993-94	C0	15	10	9	3	13	0	20.0	20.0	0	60.0
	C1	10	1	4	2	5	0	9.1	0	0	90.9
Mandarin (AFS 4)											
1992-93	C0	15	7	9	3	10	0	18.2	13.6	0	68.2
	C1	12	2	3	1	10	0	14.3	0	0	85.7
1993-94	C0	13	7	8	3	9	0	15.0	20.0	0	65.0
	C1	11	2	2	1	10	0	15.4	0	0	84.6

A- Annuals; P- Perennials; Leg- Legume;
Ph- Phanerophyte; Ch- Chamaephyte; H- Hemicryptophyte;
G- Geophyte; Th- Therophyte;
C0- 'tree only' situation; C1- 'tree+crop' situation.

Weed density

'Tree only' situation

Weed density under the four agroforestry systems ('tree only' situation) varied considerably and was influenced by the tree species (Table 3.7). The total weed population during 1992-93 was 10 to 14% higher as compared to 1993-94 under the four tree species. Cherry-system has maximum weed population followed by Mandarin-system, alder- and albizia-systems during 1992-93, while during 1993-94 weed population in the cherry-system was maximum followed by alder, albizia and mandarin systems. Peak density (number of weed plants m^{-2}) which was observed during June to September for different weed species varied among the four systems. The peak density was recorded in August for *Ageratum haustonianum* and it varied from 67 in albizia- to 101 in alder- system in 1992-93. During 1993-94 also weed density was lowest in the albizia- and highest in cherry- system. Weed density showed a declining trend during October through April. The maximum weed density was observed in cherry- followed by mandarin- and alder- systems, and minimum in albizia-system during 1992-93 and in alder-system during 1993-94. The total weed population was maximum during September in alder-, and during August in albizia-, cherry- and mandarin- sytems in 1992-93 (Fig. 3.3), whereas in 1993-94 it was highest during September in albizia-, and during August in the other three systems. Peak density of grass species like *Arundinella bengalensis*, *Imperata cylindrica* and *Digitaria sanguinalis* was very high, while the density of forb species was low.

'Tree+crop' situation

There was marked variation in weed density under the four agroforestry systems. Although most weed seedlings emerged

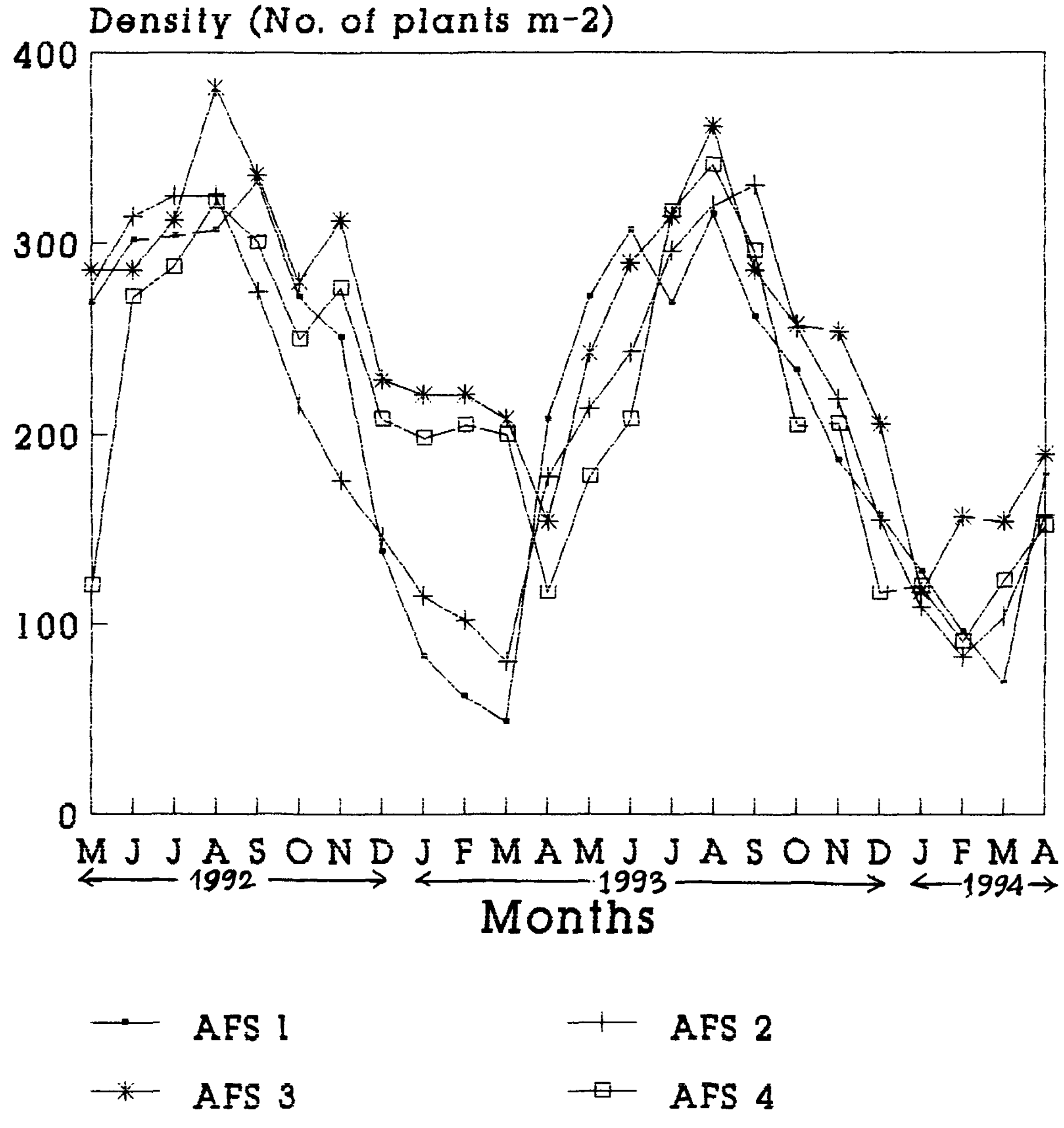
Table 3.7. Peak density (number of weed plants m^{-2}) of some important weed species in the 'tree only' plots and the month in which the peak density was attained.

System and weed species	1992-93		1993-94	
	Density	Month	Density	Month
AFS 1				
Ageratum haustonianum	101	Aug	78	Aug
Arundinella bengalensis	-	-	68	Aug
Digitaria sanguinalis	73	Jun	46	Jun
Eupatorium odoratum	15	Apr	-	-
Imperata cylindrica	78	Sep	42	Jun
AFS 2				
A. haustonianum	67	Aug	54	Aug
A. bengalensis	73	Jul	49	Aug
D. sanguinalis	51	Jun	29	Sep
I. cylindrica	53	Aug	89	Sep
AFS 3				
A. haustonianum	91	Aug	56	Jun
A. bengalensis	77	Aug	74	Aug
Ambrosia artemisifolia	-	-	19	Aug
Desmodium microphyllum	3	Jun	5	Aug
E. odoratum	19	Jun	17	Aug
I. cylindrica	88	Sep	74	Sep
Mimosa pudica	5	Sep	-	-
AFS 4				
A. haustonianum	78	Aug	-	-
A. bengalensis	59	Jul	64	Aug
A. artemisifolia	-	-	41	Aug
D. microphyllum	3	Jun	5	Aug
I. cylindrica	79	Sep	84	Sep
D. sanguinalis	-	-	67	Jul

-, species absence

AFS 1- Alder-based agroforestry system
AFS 2- Albizia-based agroforestry system
AFS 3- Cherry-based agroforestry system, and
AFS 4- Mandarin-based agroforestry system.

Fig.3.3. Monthly variation in total weed density under the four agroforestry systems in 'tree only' situation



AFS 1-alder-, AFS 2-albizia-, AFS 3-cherry-, AFS 4-mandarin-systems almost at the same time as the crop seedlings in 'tree+crop' situation, with the passage of time more weed seedlings were recruited which resulted in increase in weed population. Different weed species showed their peak density during different cropping periods (Table 3.8). Peak density of the most dominant weed species under the four systems was as below,

Crop & year	Agroforestry systems(AFS)	Peak density (Number of weed plant m^{-2}), species	Month
1992-93			
Soybean	AFS 1 Alder+crop	109, *A. conyzoides*	October
	AFS 2 Albizia+crop	68, *G. parviflora*	October
	AFS 3 Cherry+crop	50, *G. parviflora*	September
	AFS 4 Mandarin+crop	76, *I. cylindrica*	September
Linseed	AFS 1 Alder+crop	66, *G. parviflora*	March
	AFS 2 Albizia+crop	47, *A. haustonianum*	November
	AFS 3 Cherry+crop	48, *A. haustonianum*	March
	AFS 4 Mandarin+crop	46, *Bidens pilosa*	February
1993-94			
Groundnut	AFS 1 Alder+crop	77, *A. haustonianum*	August
	AFS 2 Albizia+crop	113, *A. haustonianum*	September
	AFS 3 Cherry+crop	105, *A. conyzoides*	September
	AFS 4 Mandarin+crop	112, *A. haustonianum*	September
Mustard	AFS 1 Alder+crop	37, *Bidens pilosa*	February
	AFS 2 Albizia+crop	59, *Bidens pilosa*	January
	AFS 3 Cherry+crop	38, *Bidens pilosa*	January
	AFS 4 Mandarin+crop	43, *Bidens pilosa*	March

Thus density of *A. conyzoides* and *A. haustonianum* during groundnut and soybean and, *B. pilosa* and *G. parviflora* during mustard and linseed cropping periods was quite high. The density of each species gradually changed with the change in season. The maximum weed population was observed under Cherry- in both years followed by mandarin-system. The minimum weed population was observed in alder- during 1992-93 and in

Table 3.7. Peak density (number of weed plants m^{-2}) of some important weed species in the 'tree only' plots and the month in which the peak density was attained.

System and weed species	1992-93		1993-94	
	Density	Month	Density	Month
AFS 1				
Ageratum haustonianum	101	Aug	78	Aug
Arundinella bengalensis	-	-	68	Aug
Digitaria sanguinalis	73	Jun	46	Jun
Eupatorium odoratum	15	Apr	-	-
Imperata cylindrica	78	Sep	42	Jun
AFS 2				
A. haustonianum	67	Aug	54	Aug
A. bengalensis	73	Jul	49	Aug
D. sanguinalis	51	Jun	29	Sep
I. cylindrica	53	Aug	89	Sep
AFS 3				
A. haustonianum	91	Aug	56	Jun
A. bengalensis	77	Aug	74	Aug
Ambrosia artemisifolia	-	-	19	Aug
Desmodium microphyllum	3	Jun	5	Aug
E. odoratum	19	Jun	17	Aug
I. cylindrica	88	Sep	74	Sep
Mimosa pudica	5	Sep	-	-
AFS 4				
A. haustonianum	78	Aug	-	-
A. bengalensis	59	Jul	64	Aug
A. artemisifolia	-	-	41	Aug
D. microphyllum	3	Jun	5	Aug
I. cylindrica	79	Sep	84	Sep
D. sanguinalis	-	-	67	Jul

-, species absence

AFS 1- Alder-based agroforestry system
AFS 2- Albizia-based agroforestry system
AFS 3- Cherry-based agroforestry system, and
AFS 4- Mandarin-based agroforestry system.

albizia- during 1993-94. The total weed population was maximum in July in alder-, in September in albizia-, and in April in cherry- and mandarin- systems during 1992-93 (Fig. 3.4), whereas during 1993-94 maximum weed density was recorded in September in cherry-, and in April in other three systems. Weed density was comparatively very low in the rabi crops (mustard/ linseed) than in the kharif crops (groundnut/ soybean). Though the differences in the weed density were not significant between the four systems, the trend was cherry >mandarin >alder >albizia in kharif, and cherry >mandarin >albizia >alder in the rabi crops during the two years.

Frequency

Generally, frequency of the weed species in 'tree+crop' plots increased with the age of the crop. High frequency was also recorded during peak density months. Some of the important weed species which were more frequent during later part of the crop growth under the four systems are as follows,

Soybean : *A. conyzoides, A. haustonianum, D. adscendens, G. parviflora, I. cylindrica.*

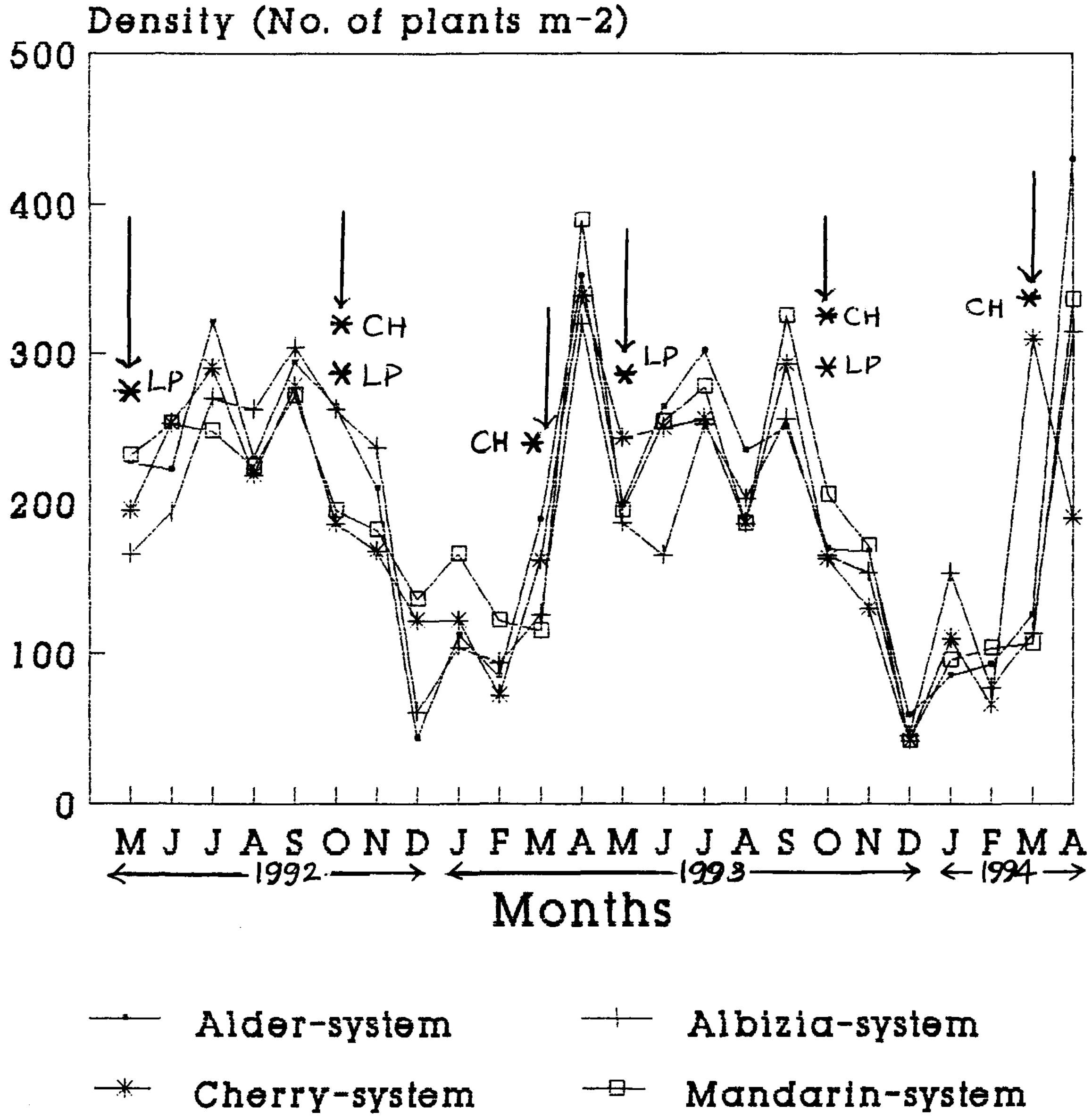
Linseed : *B. pilosa, G. parviflora, I. cylindrica.*

Groundnut: *A. conyzoides, A. haustonianum, D. adscendens, Borreria hispida, G. parviflora, Panicum montanum.*

Mustard : *B. pilosa, G. parviflora, A. haustonianum.*

On the other hand in 'tree only' plots weed plants did not show a rapid temporal change in their frequencies. *Ageratum haustonianum, Arundinella bengalenisis,* and *Imperata cylindrica* were the most frequent species showing 100% frequencies throughout the year (Table 3.9a,b).

Fig.3.4. Monthly variation in total weed density under the four agroforestry systems in 'tree+crop' situation



Note-The arrow and star mark indicate crop harvest (CH) and land preparation (LP) respectively.

Table 3.9a. Monthly variation in density (number of plants m^{-2}) of some important weed species in the 'tree only' plots under the four agroforestry systems during 1992-93.

Tree & weed species	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
							Months					
						1992-93						
AFS 1												
Ageratum haustonianum	51	60	86	101	91	53	68	46	30	23	13	47
Digitaria sanguinallis	69	73	25	34	31	51	31	3	-	-	-	19
Eupatorium odaratum	11	14	13	13	3	8	5	9	6	4	8	15
Imperata cylindrica	34	43	46	54	78	61	49	31	18	12	9	29
AFS 2												
A. haustonianum	45	49	66	67	60	38	39	36	27	23	18	27
A. bengalensis	47	54	73	59	41	37	29	26	28	29	13	34
D. sanguinallis	47	51	28	24	21	19	13	3	-	-	-	29
I. cylindrica	35	42	36	53	49	41	29	26	17	12	19	21
AFS 3												
A. haustonianum	49	54	78	91	58	41	69	44	37	55	49	33
A. bengalensis	29	55	68	77	49	55	71	53	49	47	40	31
E. odaratum	18	19	10	8	9	6	5	5	4	3	1	11
I. cylindrica	33	46	35	57	88	70	46	39	48	22	36	19
AFS 4												
A. haustonianum	23	65	66	78	62	48	55	38	29	42	29	25
A. bengalensis	21	57	59	58	45	42	43	48	40	34	55	23
Desmodium microphyllum	-	3	1	1	2	1	-	2	-	-	2	1
I. cylindrica	31	48	54	64	79	65	51	42	55	52	39	24

-, absence

Table 3.9b. Monthly variation in density (number of plants m^{-2}) of some important weed speies in the 'tree only' plots under the four agroforestry systems during 1993-94.

Tree & weed species	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
						Month						
						1993-94						
AFS 1												
Ageratum haustonianum	46	58	64	78	69	61	38	38	25	21	19	34
Arundinella bengalensis	39	46	56	68	34	51	43	28	23	19	13	38
Digitaria sanguinallis	44	46	28	30	38	28	20	5	-	-	-	11
Imperata cylindrica	31	42	20	21	23	6	16	28	32	20	11	29
AFS 2												
A. haustonianum	42	49	51	54	43	41	19	26	39	23	28	27
A. bengalensis	27	34	44	49	46	31	39	6	8	9	3	24
D. sanguinallis	27	22	25	28	29	27	21	7	-	-	-	19
I. cylindrica	38	47	65	69	89	61	58	21	20	34	29	38
AFS 3												
A. haustonianum	49	56	54	51	28	21	29	30	16	29	21	42
Ambrosia artemisifolia	13	6	11	19	7	11	13	-	-	-	-	9
A. bengalensis	39	54	60	74	61	53	55	48	17	51	49	36
E. odaratum	15	11	14	17	7	6	4	-	-	-	1	12
I. cylindrica	34	51	53	60	74	69	54	49	40	18	23	19
AFS 4												
A. artemisifolia	18	9	22	41	18	14	11	-	2	-	-	14
A. bengalensis	19	26	41	64	45	41	64	31	40	33	44	18
D. microphyllum	-	2	15	5	4	-	3	3	-	-	5	4
D. sanguinallis	38	49	53	45	34	22	14	9	-	-	-	23
I. cylindrica	36	44	67	58	84	51	37	30	33	24	28	36

-, absence

AFS 1- Alder-based agroforestry system

AFS 2- Albizia-based agroforestry system

AFS 3- Cherry-based agroforestry system, and

AFS 4- Mandarin-based agroforestry system.

The process of natural succession being interrupted during cropping many perennial species which invade a given habitat only later during succession, were unable to colonise the 'tree+crop' plots, while the 'tree only' situation developed a community of tall weeds due to less disturbance. This finding is in agreement with that of other workers (Quarterman, 1957; Nicholson & Monk, 1974; Pinder, 1975; Boral, 1993). Annual herbs such as *A. conyzoides, A. haustonianum, D. adscendens, B. pilosa* and *G. parviflora* which were dominant at different times in the crop fields, seem to be more successful colonisers on the slopy lands. These species produce seeds in large quantities and disperse them into the system before the crop harvest. On the other hand in the 'tree only' situation, the perennial species like *Arundinella bengalenisis, Eupatorium adenophorum* and *Imperata cylindrica* were the dominant and co-dominants. The belowground perennating organs of perennial species function as storage organs and means of vegetative propagation. In such species more energy is expended for competition rather than reproduction through seeds. Thus, these species under 'tree only' situation manage to dominate the community. Dominance of these species may also be attributed to lower rate of juvenile mortality during their early growth phase as they are attached with the parent plants and mobilize resources from parent to young one in sufficient quantities to sustain their life during establishment. On the other hand, forbs which largely depend on seed for their regeneration were less frequent and showed low density, which could be ascribed to the accumulation of litter under the trees, which adversely affected their seedling establishment.

Overall high values during May to October may be attributed to better seed germination and tiller growth due to conducive climate for plant growth. With the advent of dry winter period (November to March), due to prevailing conditions of low temperature and moisture stress only few species of weeds germinated and tended to establish. During this period in the 'tree+crop' situation, their density values remained low (Table 3.10a, b). The greater dominance of a given weed species or a group of weeds in a particular system as observed in the present study may be attributed to close affinity between the crop and its associated weeds, as has been envisaged by Tripathi and Misra (1971) and Streibig (1979).

Invariably weed yields were low in 'tree+crop' plots of the four agroforestry systems. This is due to more disturbance through soil working, intercultural operations such as weeding, and application of chemical fertilizers etc. At the same time crops, by severely competing with the weeds, provide an environment of reduced weed biomass (Vandermeer, 1989). Besides, weeds are usually intolerant of shade and hence, as the tree canopy increases causing greater inteception of light, weed growth decreases. In the present study, alder and albizia with maximum canopy spread have lower weed population/yield whereas mandarin with restricted canopy spread has the maximum weed density. The only exception to this is the cherry which has large canopy as well as maximum

Table 3.10a. Monthly variation in density (number of plants m^{-2}) of some important weed species in the 'tree+crop' plots under the four agroforestry systems during 1992-93.

Tree & weed species	Soybean						Linseed					
	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
						1992-93						
AFS 1												
Ageratum conyzoides	11	43	103	84	107	109	59	27	21	-	3	2
Bidens pilosa	29	18	11	-	3	7	4	-	46	37	49	34
Borreria hispida	6	8	31	9	10	9	17	-	-	-	-	18
Digitaria adscendens	38	43	28	37	31	19	22	-	3	-	-	27
Galinsoga parviflora	58	27	28	14	33	11	29	-	-	16	66	59
AFS 2												
A. conyzoides	16	36	34	23	45	20	11	27	22	-	5	2
A. haustonianum	22	44	41	48	54	26	47	11	14	-	18	29
B. pilosa	19	12	8	-	-	9	3	-	29	38	31	23
B. hispida	6	9	29	12	34	11	17	-	-	-	-	25
D. adscendens	47	51	28	24	21	19	13	3	-	-	-	29
G. parviflora	41	20	37	36	57	68	40	-	-	21	25	28
AFS 3												
A. conyzoides	19	49	41	33	39	31	23	28	19	-	-	5
A. haustonianum	14	44	48	27	11	16	17	11	17	-	48	43
B. pilosa	8	7	3	-	-	-	9	-	18	17	24	18
D. adscendens	27	4	25	14	31	27	21	3	-	-	-	30
G. parviflora	11	12	18	24	50	22	19	-	-	16	18	38
I. cylindrica	43	42	46	39	43	20	16	28	22	12	11	29
AFS 4												
A. conyzoides	-	11	8	11	-	26	1	3	2	-	-	-
A. haustonianum	28	25	31	31	57	42	24	49	36	-	30	45
B. pilosa	14	13	4	1	-	5	8	-	35	46	12	20
D. adscendens	50	59	20	23	21	14	34	3	-	-	-	33
G. parviflora	13	10	17	26	16	12	12	-	-	16	18	8
I. cylindrica	20	20	65	48	76	28	20	32	30	12	12	31

-, absence

Table 3.10b. Monthly variation in density (number of plants m^{-2}) of some important weed species in the 'tree+crop' plots under the four agroforestry systems during 1993-94.

Tree & weed species	Groundnut					Mustard						
	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
						1993-94						
AFS 1												
A. conyzoides	-	13	17	10	-	19	24	7	1	5	-	-
A. haustonianum	34	46	64	77	60	31	38	30	24	-	14	51
Bidens pilosa	6	8	31	-	3	7	4	-	26	37	29	34
B. hispida	6	8	31	9	30	19	17	-	-	-	-	18
D. adscendens	28	63	28	37	31	19	12	-	3	-	-	37
G. parviflora	28	27	38	14	33	11	10	-	-	16	26	19
AFS 2												
A. haustonianum	24	25	71	81	113	40	38	28	34	-	23	21
B. pilosa	18	27	-	-	8	7	4	-	59	37	14	36
D. adscendens	27	30	66	24	28	44	42	3	-	-	-	41
G. parviflora	18	21	21	22	11	12	12	-	-	12	34	18
AFS 3												
A. conyzoides	19	37	28	41	105	44	14	18	26	28	-	23
B. pilosa	31	35	21	41	-	9	7	1	38	20	14	28
D. adscendens	21	47	48	36	24	28	34	22	-	3	-	-
G. parviflora	41	46	39	39	41	20	8	12	-	-	18	38
Panicum montanum	8	5	11	17	21	9	2	-	-	-	3	-
AFS 4												
A. conyzoides	-	-	17	9	-	33	17	8	1	-	4	-
A. haustonianum	29	30	35	64	39	112	38	29	18	14	-	28
B. pilosa	8	3	1	-	-	5	11	11	-	37	43	21
D. adscendens	28	30	34	36	19	35	31	27	-	8	-	-
G. parviflora	21	46	39	39	40	33	7	2	-	-	14	18
P. montanum	6	4	13	18	9	18	9	21	-	-	4	8

-, absence

AFS 1- Alder-based agroforestry system

AFS 2- Albizia-based agroforestry system

AFS 3- Cherry-based agroforestry system, and

AFS 4- Mandarin-based agroforestry system.

population/yield whereas mandarin with restricted canopy spread has the maximum weed density. The only exception to this is the cherry which has large canopy as well as maximum weed density. Lower weed yields reported by Aken-Ova and Atta-Krah (1986), Yamoah *et al.* (1986a), Bashir Jama and Getahun (1991) and shift in weed compostition following alley cropping with various hedgerows species observed by Siaw *et al.* (1991) clearly show that weed infestation could be greatly reduced in agroforestry systems. Agroforestry has also been viewed as an example of three species competition in which a secondary species (e.g. tree species) controls the weeds and releases the main crop from the strong competition that could be offered by the weed (Vandermeer, 1989).

CHAPTER 4

SURVIVAL AND GROWTH OF THE TREE SPECIES

The measurements of girth or diameter, total height and volume of trees are necessary for making inventory of growing stock. These measurements are becoming increasingly important under agroforestry practices. As agroforestry practice involves growing trees and crops in close proximity, the presence of a plant can change the environment of its neighbours due to interactions at the tree/crop interfaces (Rao & Coe, 1991). The interactions between species in agroforestry situations (Anderson & Sinclair, 1993) are mediated by the environment through the 'response and effect' principle (Goldberg & Werner, 1983), which states that the plant and its environment modify one another. Thus the environment causes a response in plant function and growth, and the plant then has an effect upon the environment by changing one or more of its factors (Goldberg & Werner, 1983). The nature of the interactions within and between species therefore concerns the ways in which a plant can influence its neighbours by changing their environment, either directly, by addition or subtraction (e.g. nutrients), or indirectly. In recent times most studies on intercropping with tree species have focussed attention on the effect of the tree species on the crop yield (Singh & Dayal, 1974; Andrews & Kassam, 1976; Tustin *et al.*, 1979; Willey, 1979; Mishra & Prasad, 1980; Saxena, 1980; Szott, 1987; Vinaya Rai & Suresh, 1988; Ahmed, 1989; Singh *et al.*, 1989). But studies on the reciprocal effects of the crop on the tree are scanty (Samraj *et al.*, 1982; Redhead *et al.*, 1983; Suresh & Vinaya Rai, 1991). Therefore, the data on survival, height and diameter increment, crown width and timber volume of the four tree species under the 'tree+crop' and 'tree only' situations were recorded over a period of 2 years.

MATERIALS AND METHODS

Survival, growth and timber volume of trees:

Survival, height, diameter at breast height (dbh) and crown width of the tree species in each plot were recorded at six- monthly intervals, synchronising with cropping period. Height was measured using a dendrometer. The instrument is based on the trigonometric principles. In order to verify the measurements, a pole graduated in metres and centimetres was also used. Diameter at breast height (dbh) of trees was measured at 1.37 m above ground with a calliper. It was recorded by taking the mean of two diameter readings at right angles to each other.

The developmernt of tree depends on its crown, hence, crown measurement is of great interest. The measurement of crown involves measurement of its length and width, however, in agroforestry, measurement of crown width due to its shade effect is of greater importance than crown length, and hence it was recorded in present study. *Crown width* is defined as *the maximum spread of the crown along its widest diameter*. It indicates the functional growing space occupied by the tree. For measurement of crown width of trees, the tape was extended across the full length of the tree-crown first in one direction and then in the opposite side of the crown. The values thus obtained were added and average crown width was calculated. In case of irregular crowns, diameter was measured three or four times from different positions and the arithmetic mean of these readings gave the crown width.

The volume of tree depends mainly upon three variables, viz. diameter, height and form. Form is defined as *the rate of taper of a log or stem. Taper is the decrease in diameter of a stem of a tree or of a log from base upwards* (Chaturvedi & Khanna, 1982). Form of trees of the four species was studied by comparison of standard form ratios i.e. form factor, which is defined as *the ratio of the volume of a tree or its part to the volume of a cylinder having the same length and cross section as the tree.* The form factor may be represented as;

$$F = V_{/Sh}$$

Where F is the form factor,
V is the tree volume (m^3)
S is the basal area at breast-height (m^2), and
h is the height of the tree (m).

Form factors were compiled into tabular form giving average form factor values of trees of different diameter and height classes. These tables were used to estimate volume of standing trees by measuring their dbh and height.

Increments

Increment could be the increase in diameter, height, volume, biomass etc. of trees during a given period. Two parameters viz. current annual increment (CAI) and mean annual increment (MAI) were utilized to depict growth rate of the tree species. These parameters are described below.

Current Annual Increment (CAI)

It is the increment in growth which a tree puts on in a single year. In practice, CAI refers to average rate of increase in growth over the past one year.

Mean Annual Increment (MAI)

It is the mean volume or biomass or height of a tree at a given age divided by the age in years.

The two parameters were calculated taking into account the height, diameter and volume of the four tree species in the 'tree +crop' and the 'tree only' situations.

All the data were subjected to an analysis of variance and treatment differences tested for significance.

RESULTS

Survival

Survival of trees was not influenced by the presence of crops. But the species differed with regard to their survival. Alder and mandarin recorded 100% survival after six years of planting followed by cherry with 95%, and albizia with 90% (Table 4.1). Survival percentage of the four tree species did not vary under the two situations ('tree+crop' and 'tree only') during the entire period of study.

Diameter and height growth

There were significant ($P<0.1$) differences in diameter (dbh) and height growth among the four tree species in both years (Table 4.1). The maximim height growth at sixth year was recorded by albizia (12 m) followed by alder (11 m) and cherry (9 m), and mandarin (4.5 m) showed the minimum height. Alder had the highest dbh (19.7 cm) followed by albizia (14.7 cm)

Table 4.1. Survival, growth characteristics and timber volume of the four tree species in the 'tree+crop' and 'tree only' situations.

Parameters	'Tree only' situation				'Tree+crop' situation				C.D. at 0.05
	Alder	Albizia	Cherry	Mandarin	Alder	Albizia	Cherry	Mandarin	
Sixth year									
Survival(%)	100.00	90.00	95.00	100.00	100.00	90.00	95.00	100.00	-
Height(m)	11.01	12.05	9.06	4.50	13.25	12.60	9.28	4.53	0.88
DBH(cm)	19.7	14.7	12.8	10.9	20.9	17.2	14.1	12.7	1.64
Crown width(m)	6.40	4.52	3.92	1.68	7.75	5.56	4.69	1.58	-
Timber volume (m^3plant^{-1})	0.271	0.166	0.092	0.017	0.365	0.246	0.118	0.017	0.037
Seventh year									
Survival(%)	100.00	90.00	95.00	100.00	100.00	90.00	95.00	100.00	-
Height(m)	12.78	13.20	10.02	5.00	14.38	13.88	10.34	5.20	1.05
DBH(cm)	21.5	16.4	14.7	11.3	23.2	19.6	15.7	12.9	1.67
Crown width(m)	7.04	5.24	4.45	2.03	7.90	6.66	5.19	2.09	-
Timber volume (m^3plant^{-1})	0.373	0.225	0.136	0.026	0.490	0.348	0.166	0.026	0.185

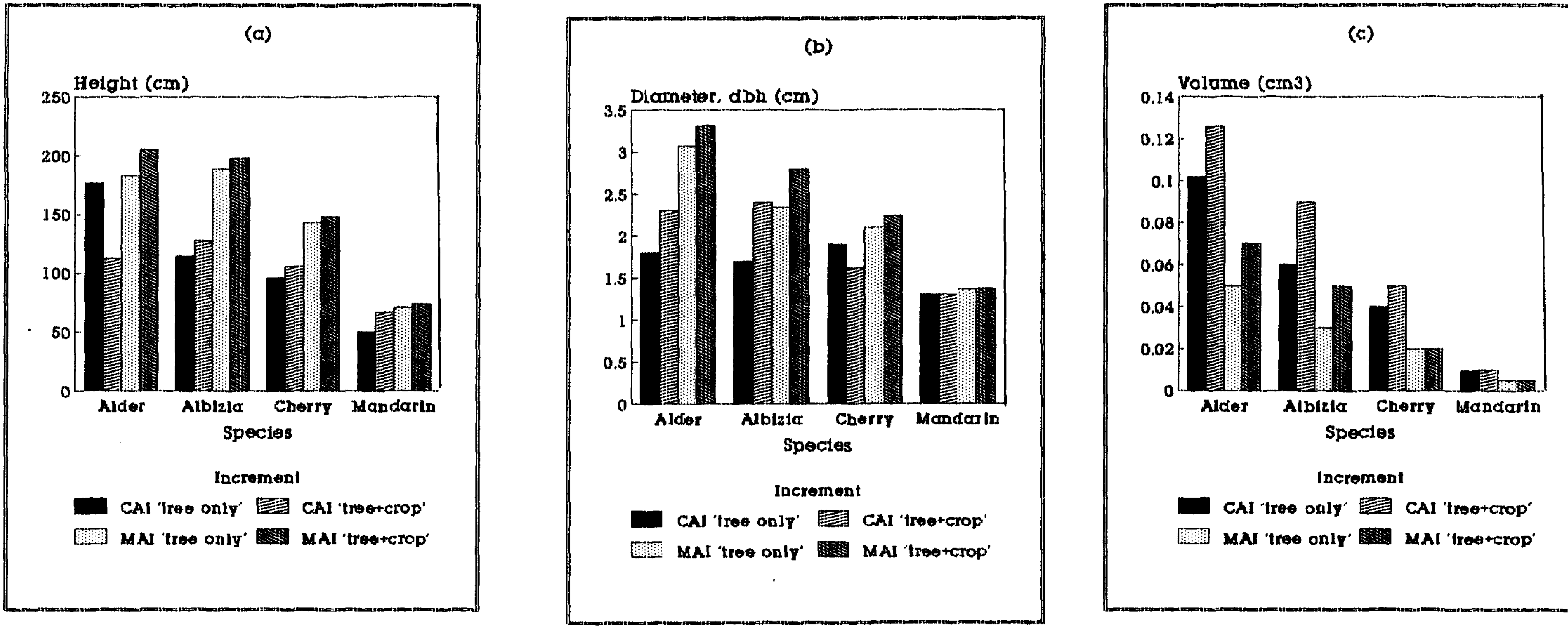
DBH- diameter at breast height.

and cherry (12.8 cm), while mandarin (10.9 cm) had the lowest value. At seventh year too, a similar trend was observed, but the values were greater by 10-16% in height, and by 4-15% in diameter (dbh) than in the sixth year. The mean annual increment (MAI) for height ranged between 0.7-1.9 m, the lowest being in mandarin and highest in albizia. MAI in diameter in the four tree species ranged between 1.4-3.1 cm. The current annual increment (CAI) in height ranged between 0.5-1.8 m in mandarin and alder, and for diameter 1.3-1.9 cm in mandarin and cherry, respectively. The MAI values were greater than the CAI in respect of height and diameter in the four tree species (Fig. 4.1a, b, c). In terms of height growth, the species ranked albizia> alder> cherry> mandarin; while for diameter, the ranking was alder> albizia> cherry> mandarin. The over all ranking was alder> albizia> cherry> mandarin.

Crown width and timber volume

Alder (6.4 m) had the maximum crown width, followed by albizia (4.5 m) and cherry (3.9 m), while mandarin (1.7 m) had the minimum width in the sixth year (Table 4.1). At the seventh year, crown width followed the trend similar to sixth year, but the values were higher by 10-21% in the four species. The four tree species differed significantly ($P<0.1$) in timber volume production. Alder had maximum survival (100%) and maximum timber volume (0.271 $m^3 plant^{-1}$), while mandarin had the least timber volume during the sixth year. In the seventh year, though the trend was same as in the sixth year, the values were higher by 36-53%. Mean annual increment of timber

Fig. 4.1. Current annual increment (CAI) and mean annual increment (MAI) of the tree species in 'tree+crop' and 'tree only' situations in height (a), diameter (b) and volume (c).



volume was lower than CAI in all the four tree species.

Effect of intercrops on tree growth and timber volume

The overall growth, in terms of increment in diameter (dbh) and height, was greater in the 'tree+crop' than in the 'tree only' situation . There was positive and significant ($P<0.1$) effect of intercropping on height growth of alder where it was greater by 20% in sixth year and 13% in seventh year than in the 'tree only' situation. But the height increment in albizia and cherry was marginally (2-5%) higher in the 'tree+crop' than in the 'tree only' situation in both years. The diameter (dbh) increment in all the four tree species was 6-17% more in presence of the crops than in the tree monoculture during the sixth year and 8-20% during the seventh year; the maximum % increase in the 'tree+crop' situation over the corresponding 'tree only' situation was recorded in alder and minimum in albizia. The crown width of alder, albizia and cherry was 12 to 27% more as compared to the corresponding 'tree only' situation. Among all the parameters, timber volume recorded highest increment in the 'tree +crop' than the 'tree only' situation in alder, cherry and albizia. The maximum increase in timber volume (48% and 55% during the sixth and seventh year respectively) was recorded in albizia followed by alder with 35 and 31%, and cherry 28 and 22% during the same years. In the case of mandarin, however, there was no appreciable difference between growth increments under 'tree+crop' and 'tree only' situations. The crown width in this species was slightly more (6%) in the 'tree only' than in the 'tree+crop' situations during the sixth year. Interestingly, the CAI and MAI values (Fig. 4.1a, b, c) indicated slight favourable effect of associating crops with mandarin on its growth. The MAI was generally higher than CAI for height and diameter but lower for timber volume in all the four species in the 'tree+crop' situation.

Effects of intercrops on periodic tree growth

In general the tree growth in terms of increment in diameter (dbh) and height was greater in the 'tree+crop' than in 'tree only' situation and seems to be positively correlated with rainfall (Fig. 4.2 a, b; 4.3a, b). During soybean and groundnut cropping period (May-October), there was a total rainfall of 2245 and 2111 mm in first and second year of cropping, respectively, and it was well distributed during the six month long cropping period. Height and stem diameter in all the four species rapidly increased during this period. However, the growth (height and diameter) slowed down over the next six months (November-April) largely due to low temperature and dry weather. During this period, there was quite low rainfall (ca 323-382 mm). Winter (rabi) crops viz. linseed and mustard were intercropped during this period. A positive correlation between growth and rainfall has also been reported for *Gliricidia sepium* in an alley cropping system in Sierra Leone by Karim and Savill (1991).

Growth of albizia, cherry and mandarin in terms of height increment in the 'tree+crop' (soybean) situation was only slightly greater (1-5%) than in corresponding tree monocultures. The height growth of alder in 'tree+crop'

Fig. 4.2. Mean height of the tree species as related to rainfall during cropping period in the 'tree only' (a), and 'tree+crop' (b) situations.

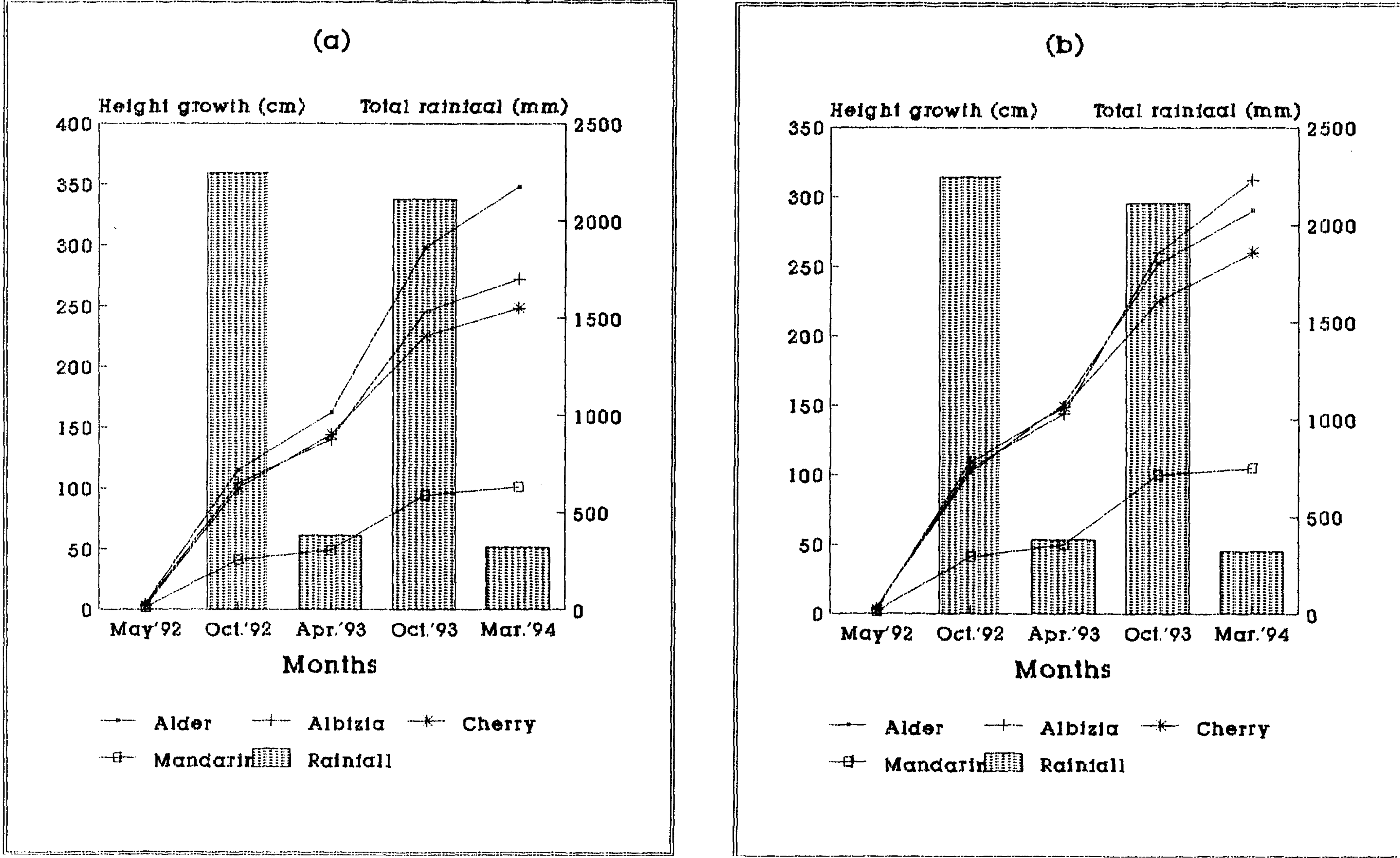
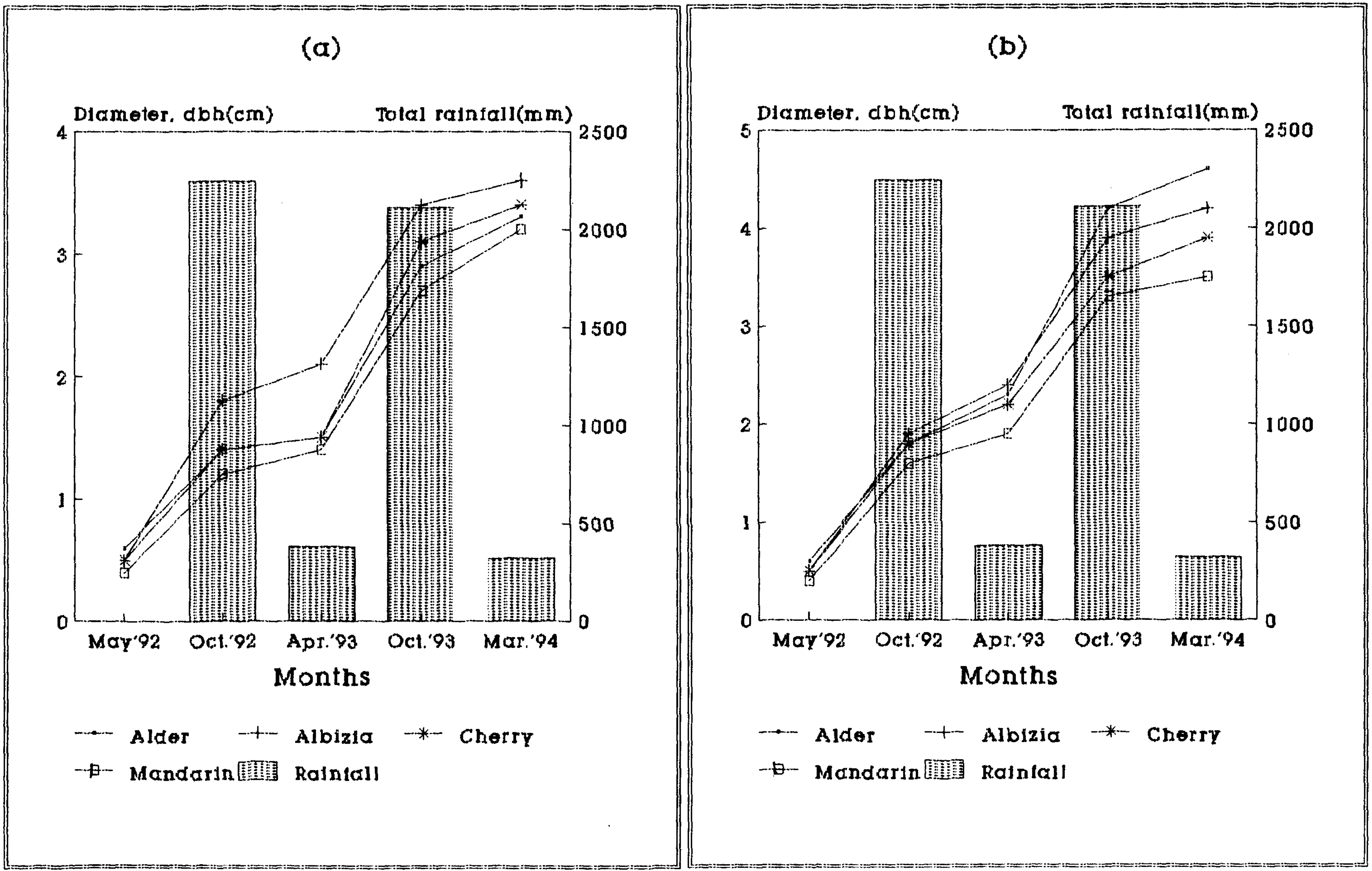


Fig. 4.3. Mean diameter of the tree species as related to rainfall during cropping period in the 'tree only' (a), and 'tree+crop' (b) situations.



situation was 14% lower than the 'tree only' situation. Overall, the four crops (soybean, linseed, groundnut and mustard) affected the height growth of alder adversely at 6, 12, 18 and 24 months. But in albizia and mandarin, the crops had favourable affecct on the height growth. Soybean and linseed crops had positive influence on height growth of cherry, but groundnut and mustard caused slight reduction.

Growth increment in diameter (dbh) was significantly ($P<0.1$) higher in the 'tree+crop' than in 'tree only' situation in all four tree species, though the magnitude varied between species. The most positive effect of intercropping on tree diameter growth was observed in alder, where the positive influence was greater by 42-64% for the four crops viz. soybean, linseed, groundnut and mustard. The corresponding influence was greater by 15-53% in cherry, and 15-45% in mandarin respectively. In albizia also intercropping caused significant ($P<0.5$) increase in dbh but the magnitude of increase was much less (13-20%) compared to the other tree species.

DISCUSSION

Survival and growth performance of alder, mandarin, cherry and albizia differed from one species to another. This could be explained by their differential genetic make up. The adoptability of alder, cherry and albizia species may be attributed to the soil and climatic conditions of this area which are similar to their native environment. The site of the present study, is characterized by low pH and high exchangeable aluminium (Chapter 3, Table 3.3), which is similar to as is commonly encountered in alder, cherry and mandarin's natural environment. However, albizia, a species native of South-east Asis, also performed reasonably well. Under optimum conditions albizia (*Paraserianthes falcataria*) is reported to attain a height of 12 m and above in third year (Duguma *et. al.*, 1994; Duguma & Tonye, 1994), however, it did not grow so well on the present site. In one of the studies, albizia was reported to attain maximum height growth among the ten multipurpose trees (Duguma *et. al.*, 1994). Relatively better growth of albizia could be attributed to its well developed and extensive rooting with profuse fine roots well distributed within the rhizosphere. Besides, secretion of root exudates might have helped this species in complexing exchange~able Al, a potential cause of infertility of acid soils in the region (Prasad *et al.*, 1985; Singh *et al.*, 1994], and eventually increasing the availability of P which might have contributed to its adaptability to local soil and climatic conditions. Apart from this, biological nitrogen-fixation also takes place in the roots of albizia, whereby an adequate supply of nitrogen is ensured for its growth and development under sloping land conditions, where inorganic-nitrogen is mostly subjected to leaching losses due to torrential and high rainfall in the area.

Increment in height and stem diameter growth is a good indicator of site conditions (soils) (Foroughbakhch *et. al.*, 1987). The present study site is having low pH and high exchangeable Al (Chapter 3). Various growth attributes viz. height, stem diameter, crown width and timber volume in all the tree species were better in the 'tree+crop' than in the 'tree only' situation (Table 4.1, and Fig. 4.1). Similar results have been reported by Roy and Gill (1991) while studying an agri-silvicultural system. The better growth performance and biomass production observed in the 'tree+crop' situation are mainly due to application of fertilizers and weeding opearation in the plots where crops were grown with trees. Use of fertilizers and amelioratives in the 'tree+crop' situation also provided congenial soil environment for optimum soil microbial activity, which in turn, might have caused rapid mineralization of organic matter and eventually adequate uptake of nutrients by the trees. Singh *et. al.*, (1995) have reported suitability of MPTS in ameliorating infertility of acid soils especially under intercropping. Nair (1989) has also confirmed the sustainable production per unit area by incorporating trees with arable crops. Beneficial effects of growing crops in tree plantations on the tree growth have also been reported by several workers under different soil and climatic conditions (Mann & Shanakrnarayan, 1980; Yamoah, 1986b; Tejwani, 1987; Singh *et. al.*, 1989; Atta-Krah, 1990; Basri *et. al.*, 1990; Evensen *et. al.*, 1990; Kang *et. al.*, 1990, 1991; Kass *et. al.*, 1992; Campbell *et. al.*, 1994).

In the case of all four species the mean annual increment (MAI) for height and diameter (Fig. 4.1a, b), was higher than current annual increment (CAI). The greater values of MAI indicates that the present site is suitable for good growth of the four tree species in general, and alder and albizia in particular. Alder and albizia, established well on the acid soils and showed fast growth with large crown diameter. Both species are known to be nitrogen fixing (Brewbaker, 1987) and play useful role in preventing soil erosion and land slips as well as conserving soil. Due to their multiple use (CSIR, 1990) these two tree species are widely used in afforestation and reforestation. They also provide shade, suppress weeds and improve soil fertility (Chapter 8) and thus in the humid lowlands of this region, albizia and alder appear to have potential for agroforestry technologies. The growth and development of the indigenous cherry, however, was slow over the first six years, though, it also established well and recorded cent per cent survival. The growth of mandarin, in terms of increment in height, diameter and timber volume was very poor compared to the other three tree species which fall under the MPTS category. This may be due to the fact that mandarin is primarily grown for its fruits, and the entire mandarin orange cultivation in the north-eastern region is based on seedling plants (Gupta, 1979) which are highly susceptible to diseases and pests.

CHAPTER 5

BIOMASS AND PRODUCTIVITY OF THE TREE SPECIES

The biomass of various components in an ecosystem depends on species composition and community structure. It fluctuates greatly with season . Though the green leaves are the main organ for the organic matter production, biomass also depends, to a large extent, on the root activities. This is because root is the only organ which absorbs water and nutrients from the soil pool. Besides, productivity depends on growth potential of the species, the availability of resources viz. light, nutrients and water, and the efficiency of resource use. From the viewpoint of ecological interactions, the determination of biomass and net annual production of trees in the 'tree+crop' and 'tree only' situations may be quite important.

Although studies on biomass and productivity of natural and agricultural ecosystems from different eco-climatic zones have attracted considerable attention (Harris *et al.*, 1975; Grier *et al.*, 1981; Singh & Singh, 1981; Vogt *et al.*, 1986; Uma Shankar *et al.*, 1993), only limited information is available on biomass dynamics and productivity of agroforestry systems. The major reasons for this are lack of reliable estimates of standing stock (above- and below-ground) of plant biomass and productivity.

In agroforestry systems the competition of tree roots with those of intercrops is considered most significant. Hence, the knowledge of root distribution in soil profile is essential for understanding the ecological niche of a tree species, and for its management in various silvicultural and agroforestry systems (Huxley, 1983). Fine roots in paricular, play an important role in the functioning of various ecosystems (Vogt *et al.*, 1986, 1991). They enrich the soil with organic matter and nutrients by rapid turnover, intercept leached nutrients and recycle them to the surface (Persson, 1979, 1982; McClaugherthy *et al.*, 1982; Hairiah & van Noordwijk, 1986). Therefore, fine root system is most important for nutrient cycling. However, relatively little is known about production and turnover of fine roots. Fine root system is still least studied and poorest understood portion of any agroforestry system although some information is available on the fine roots of various forest ecosystems and plantations. There is a large range in fine root biomass (Santantonio *et al.*, 1977; Harris *et al.*, 1978; Berish, 1982; Prasad & Mishra, 1984). Values range from 1.8-17.7 t ha^{-1} in coniferous forests (Vogt *et al.*, 1981; Persson, 1982), and 1.8-10 t ha^{-1} in tropical/sub-tropical forests (Jenik, 1969; Parthasarathy, 1987; Arunachalam *et al.*, 1996; Sundarapandian & Swamy, 1996). Information on the distribution of tree roots, especially fine roots, as well as the contribution of the aboveground parts to soil fertility (Gichuru & Kang, 1990) is quite helpful in the understanding of nutrient cycling in agroforestry systems.

The present chapter deals with biomass accumulation, net primary production and fine root dynamics of the four tree species in the 'tree only' and 'tree+crop' situations. The

specific objectives of the study were to determine
i) contrbution of different components of the agroforestry systems to stand and pattern of biomass accumulation,
ii) total net primary production, and iii) distribution and dynamics of fine roots of the four tree species in the two situations.

MATERIALS AND METHODS

Representative plants of the four tree species were harvested from the 'tree only' and 'tree+crop' situations and biomass of different compartments viz. leaves, branches and twigs, and stem was measured in July 1993 (sixth year) and July 1994 (seventh year) following the methods described in Misra (1968). Standing stock of roots was determined by collecting soil cores (Bohm, 1979, Buck, 1986) during winter (January), spring (April), rainy (July) and autumn (October) seasons. Soil cores were obtained by driving a sharp-edged steel tube auger (inside diameter 8 cm) into the soil to 0-10 cm, 10-20 cm and 20-30 cm depth, starting from the soil surface. Sample points were located 50 cm, 100 cm and 150 cm away from the trees. Twenty four soil cores were taken from each site. Individual cores were placed in polythene bags and returned to the laboratory for sorting.

In the laboratory, roots were separated from other organic material and mineral soil by passing the soil cores through a sequence of five sieves with hole sizes ranging from 12.7 to 2.0 mm. Root material was hand-sorted from the residue remaining on each sieve. Preliminary studies indicated that virtually no roots passed through the 2 mm sieve. The roots were distinguished into live and dead roots on the basis of colour and texture. Dead roots were dark and spongy, while living roots had characteristic colours and intact bark, and were firm. Roots were separated into two categories. Roots less than 2 mm in diameter were termed fine roots, and 2-5 mm in diameter were termed coarse roots. Root samples of each category were oven-dried at 70^0C for 24 hours and weighed. Annual fine root biomass (FRB) production was determined by summing up the positive increments in live root mass (biomass) and concurrent increment, if any, in dead root mass (necromass) in successive sampling (Persson, 1983). Root "turnover" i.e. the annual repalacement of the fine root material plus losses due to ageing and decay, was calculated (Persson, 1980) using the following equation,

$$T = FRB - (b_j - b_1)$$

Where, T is the root turnover, $(b_j - b_1)$ is the estimate of fine root biomass (FRB) at the last sampling (b_j) minus that on the first sampling (b_1).

To estimate the horizontal distribution of the woody roots at surface soils, excavation and tracing (Bohm, 1979) were undertaken for the tree species during July 1993 and 1994. Four trees for each species were selected randomly and the sub-surface soil from the base of tree was carefully removed until a large surface-oriented lateral root (>5 mm in diameter) was exposed. The root was then traced horizontally by progressive excavation to its termination up to at least 1 mm diameter. The parameters such as total root length, horizontal extent of roots, diameter at proximal and distal ends of the roots were measured.

The net change in the biomass component parts indicated annual biomass accumulation in each part, and the sum of the biomass of different components gave net biomass production of the tree species. Positive values of the differences of above- and below-ground biomass in progressive samplings were added to calculate annual production.

Root nodule biomass and production

Root nodule biomass estimations were carried out for the two NFTS viz. alder and albizia. Sampling in April, July, October and January representing spring, rainy, autumn and winter seasons, respectively, was done by the soil core method using 20 cm x 20 cm x 20 cm monolith. Most root nodules in both the species were present in the region between the soil surface to a depth of 20 cm. Cores were taken at 0.5, 1.0 and 1.5 m from the tree base. Nodule samples were oven-dried (48 hr, 80 ^{0}C) and weighed to constant weight.

Data analysis

Three factors were analyzed in split-split plot: species as main plots, 'tree+crop' and 'tree only' situations as sub plots and the four seasons as sub-sub plot. Biomass values of fine and coarse roots were analyzed as per split-plot to identify effects of season, effects of species, effects of the crops and effects of their interactions using 'F' test. Fine and coarse root biomass values are provided with standard deviations based on total number of samplings.

RESULTS

Seasonal distribution of root biomass:

Fine roots

The analysis of variance of fine root biomass, indicated that the variations due to species, crops ('tree only' and 'tree +crop' situations), and seasons (spring, rainy, autumn and winter) were significant ($P<0.01$) in both years (Table 5.1). The species x crops and species x seasons interactions were also significant ($P<0.01$), but crop x seasons, and species x crops x seasons interactions were not significant. Seasonal variations in fine root biomass (FRB) and necromass (FRN) of the four tree species were quite distinct. The maximum FRB and FRN values were observed during autumn (transition period after warm rainy season), and minimum during winter in both 'tree+crop' and 'tree only' situations (Fig. 5.1 and 5.2).

Table 5.1. Results of ANOVA for variations in fine root biomass (g m^{-2}) along species, situations, seasons and their interactions.

Source of variation	DF	Mean sums of squares (MSS)	F ratio
Replication	5	5512.407	2.94^{ns}
Species	3	339842.531	181.43**
Error(a)	15	1873.092	1.00^{ns}
Situations	1	14177.797	33.61**
Speciesxsituations	3	4592.275	10.89**
Error(b)	20	421.870	1.00^{ns}
Seasons	3	719702.229	1162.74**
Species x seasons	9	28229.868	45.61**
Situationsxseasons	3	620.367	1.00^{ns}
Species x situa- x tions x seasons	9	2275.464	3.68^{ns}
Error(c)	120	618.973	1.00^{ns}
Total	191		

Situations - 'tree only' and 'tree+crop'
** Significant at 1% level

Fig. 5.1. Seasonal variation in fine root biomass (g m−2) of the four tree species in the `tree only' situation.

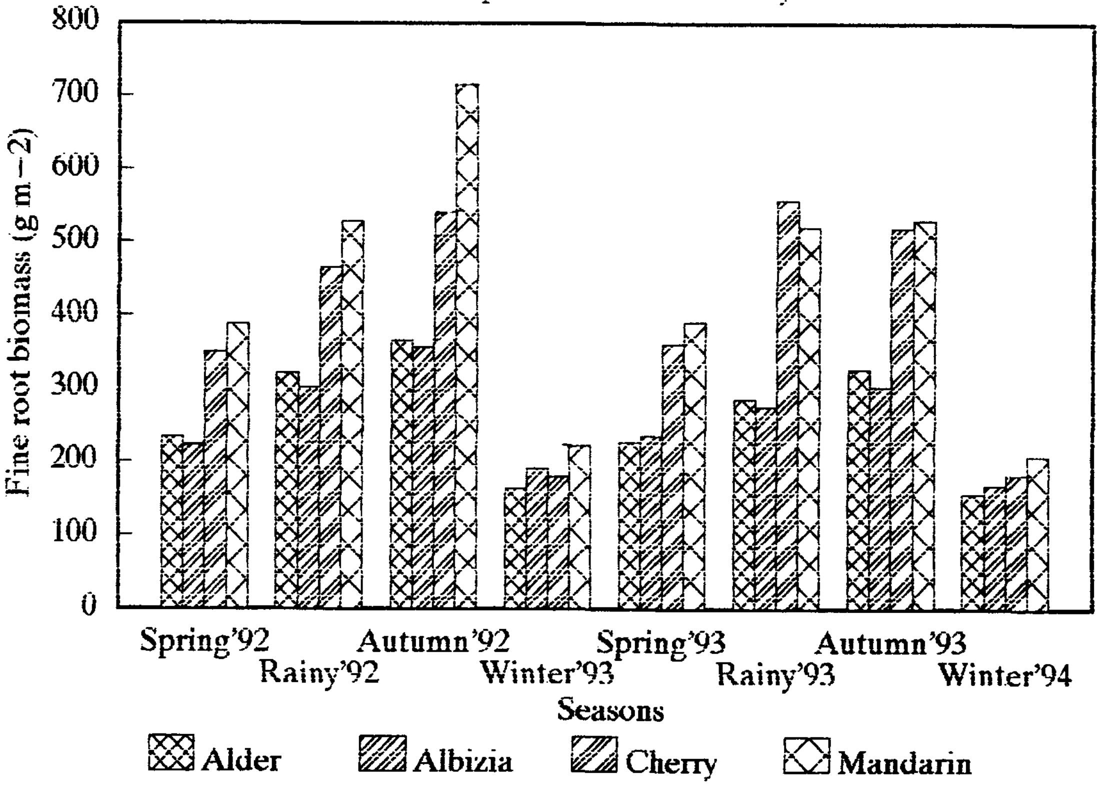
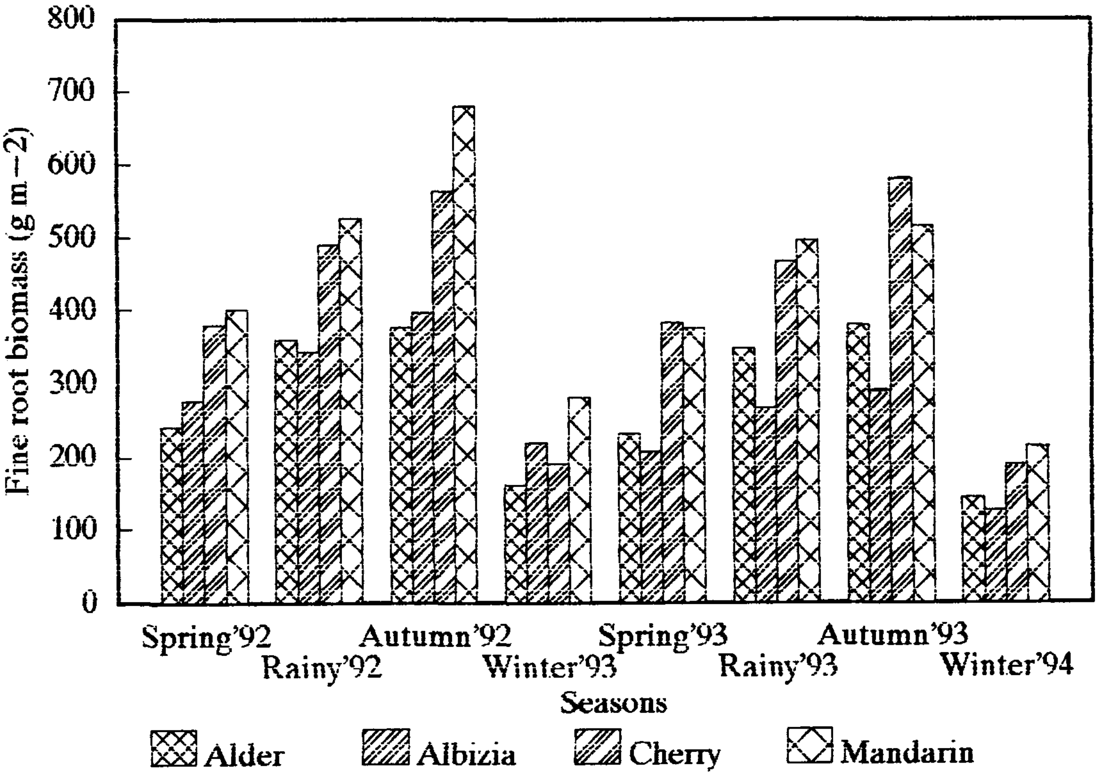


Fig. 5.2. Seasonal variation in fine root biomass (g m−2) of the four tree species in the `tree+crop' situation.



In general, FRB and FRN values for the tree species were 3-26% higher in the 'tree+crop' situation than in the corresponding 'tree only' situation, except for alder during winter and for mandarin in autumn, where the values were almost same. During the seventh year, there was distinct variation in FRB and FRN of the four species. In alder the fine rootmass (FRB + FRN) was greater in the 'tree+crop' than the 'tree only' situations in all seasons except during winter, where it was about 9% lower. In cherry, the trend was similar but during rainy season the FRB and FRN were 15% lower than in the 'tree+crop' situation. There was not much difference in FRB and FRN in mandarin in the two situations. In albizia, the FRB was invariably lower in the 'tree+crop' than in the 'tree only' situation in all seasons, and the magnitude varied between 3% during rainy to 25% during winter season. The necromass (FRN) was higher in 'tree+crop' situation during spring (15%) and rainy (33%) seasons, and lower by 28% during winter, and almost same during autumn. During the seventh year FRB was 3 to 11% lower as compared to the sixth year in alder, albizia and mandarin. But in cherry it was 20 to 30% higher during the seventh year than the sixth year in rainy ('tree only'), and autumn ('tree+crop' situation) seasons.

The FRB fraction was significantly ($P < 0.01$) greater than the necromass (FRN) in all the four tree species. The FRB/FRN ratio varied between 2 to 3. The maximum ratio of 3.2 was observed during spring and the minimum in rainy season where it was only 2. The trend was same in both the situations during sixth and seventh year.

Coarse roots

Seasonal variation in coarse root biomass (CRB) and necromass(CRN) followed the trend of fine roots. Total coarse root mass (CRM) i.e. CRB+CRN varied significantly ($P < 0.01$) among the four species and seasons. However, no significant difference was observed between the 'tree only' and the 'tree+crop' situations in the four species. The CRM was maximum during autumn and minimum in winter season in the two situations. The CRM ranged from 343 to 3774 kg ha^{-1} in 'tree only', and 263 to 3701 kg ha^{-1} in 'tree+crop' situation. The species-wise ranking for CRM was mandarin >cherry >alder >albizia, and in respect with season, it was autumn >rainy >spring >winter. In alder and cherry, there was no significant difference in the CRM during sixth and seventh year under the two situations. CRB represented about 64-69% of the total CRM in the four species.

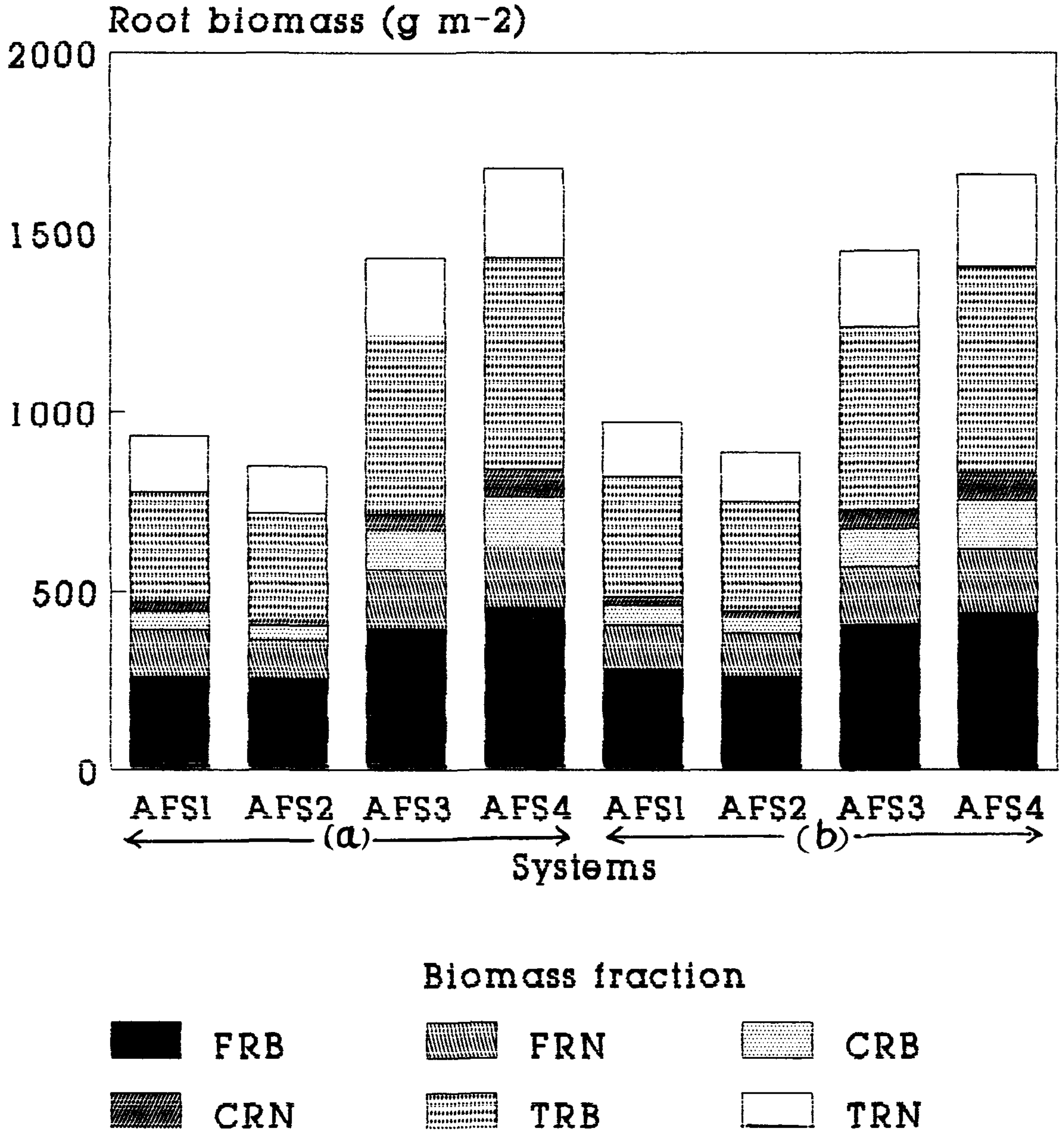
The total root biomass (TRB = FRB+CRB) was highest in mandarin (during autumn) and lowest in alder (during winter season) (Fig. 5.3). Fine roots reperesented about 76% of the total roots, and consequently, FRM/CRM ratio was <u>ca</u> 3, maximum (3.46) being in mandarin and minimum (3.19) in alder.

Vertical distribution

Fine roots

The soil profile (0-30 cm) was well exploited by the root system of the four tree species. The bulk of the fine root biomass (FRB) in alder, albizia, cherry and mandarin was concentrated in the upper 10 cm of the soil profile (Table

Fig. 5.3. Total root biomass and its fraction under the four systems in 'tree only' (a) and 'tree+crop' (b) situations



F-fine-, C-coarse-, T-total,
RB-root biomass, RN-root necromass

5.2). The fine root concentration decreased with increasing soil depth. At 10-20 cm soil depth, FRB ranged from 28% in alder to 34% in mandarin, while at 20-30 cm soil depth it was 19% (alder) to 28% (mandarin). In alder and albizia, more than 80% fine roots were concentrated in 0-20 cm soil layer, while in mandarin and cherry the fine root concentration in this layer was only 72-74%. There was no significant difference in the vertical distribution and quantity of FRB between the sixth and seventh year, although it varied from species to species. The FRB values during the seventh year were 8, 9 and 11% lower than the sixth year in alder, albizia and mandarin, but about 5% higher in cherry.

The distribution, seasonal trend and quantity of FRB in the 'tree+crop' situation were similar to that in the 'tree only' situation. At 0-10 cm soil depth, the FRB in the 'tree+crop' situation was greater by 5% in alder and cherry, and by 15% in albizia compared to the 'tree only' situation. However, in mandarin in both situations the values were almost same. Similar trend in FRB was also observed at 10-20 cm and 20-30 cm soil depths. Maximum FRB at 0-10 cm was observed during October in both years, while the minimum FRB was generally recorded in January. In the case of alder and albizia, the FRB in the 'tree only' situation was more than the corresponding 'tree+crop' situation. The tree species ranking based on the FRB was: mandarin >cherry >alder >albizia in the 'tree only' situation in both years, while in the 'tree+crop' situation there was a slight change in ranking and it became mandarin >cherry >albizia >alder in sixth year, and

Table 5.2. The vertical distribution of fine-root biomass(FRB), fine-root necromass(FRN), total root biomass(TRB) and total root necromass(TRN) in the four tree species in the 'tree only' and the 'tree+crop' situation in soil down to 30 cm soil depth. Estimates are pooled averages for two years.

Species	Soil depth(cm)	FRB g m^{-2}	FRN	TRB	TRN
		'Tree only' situation			
Alder	0-10	135.9±12.7	43.9±7.8	147.7±14.1	48.6±8.3
	10-20	72.1± 8.1	55.5±6.1	95.1±12.9	68.5±6.9
	20-30	51.8± 6.5	33.9±4.3	66.3± 8.1	41.0±5.3
	Total	259.8±15.4	133.4±8.2	309.1± 8.2	158.0±9.8
Albizia	0-10	126.3±11.8	36.5±4.9	136.5± 8.2	41.0±6.1
	10-20	78.0± 7.9	52.3±5.8	97.5± 8.8	63.0±5.4
	20-30	52.3± 6.4	20.7±4.4	61.0± 4.9	25.0±4.0
	Total	256.6±13.4	109.5±9.8	295.0±12.5	129.0±8.9
Cherry	0-10	172.4±13.8	44.0±4.4	218.0±13.4	62.8±6.8
	10-20	126.2±11.9	68.8±5.6	162.4±14.1	81.2±7.4
	20-30	96.8± 8.4	53.6±6.5	120.8±11.0	70.4±8.2
	Total	395.8±13.2	166.3±9.8	501.0±19.8	214.4±8.8
Mandarin	0-10	170.0±12.1	62.0±4.8	234.8±12.3	100.0±6.8
	10-20	150.0±12.6	52.8±6.8	195.6±10.8	78.0±8.0
	20-30	132.0±15.8	59.2±7.6	159.6±15.2	72.4±5.6
	Total	452.0±19.9	174.0±7.3	590.0±19.4	250.0±8.6
		'Tree+crop' situation			
Alder	0-10	148.3±14.2	47.5±4.8	167.0±14.2	53.0±4.8
	10-20	78.3± 6.9	54.0±6.1	100.5±11.2	67.5±5.6
	20-30	53.4± 5.2	25.5±4.6	67.5± 5.4	32.5±5.4
	Total	279.9±11.9	127.0±7.9	335.0±12.8	153.0±8.5
Albizia	0-10	133.5±15.8	39.5±3.5	143.0±10.5	44.5±4.6
	10-20	78.5±13.3	55.5±4.6	97.5±13.3	66.0±4.6
	20-30	53.0± 6.2	24.0±4.9	64.0± 7.1	29.0±5.7
	Total	265.0±16.8	119.0±6.0	304.5±17.9	139.5±7.9
Cherry	0-10	184.8±14.7	43.6±4.1	232.0±12.7	61.6±5.5
	10-20	123.6±10.0	64.4±7.2	155.6±11.8	80.0±6.2
	20-30	96.8±11.8	55.2±6.3	125.2±10.9	70.4±6.3
	Total	405.2±16.8	163.2±8.6	512.8±17.9	212.0±8.3
Mandarin	0-10	174.8±15.6	68.4±8.1	243.2±13.2	106.4±5.3
	10-20	152.8±14.3	56.0±7.0	201.2±14.8	80.4±8.0
	20-30	109.2±12.6	54.8±5.1	130.4±12.6	69.6±8.1
	Total	436.8±16.9	179.2±9.1	574.8±19.9	248.4±9.1

cherry >mandarin >alder >albizia in the seventh year. Fine root necromass (FRN) comprised about 51, 43, 42 and 38% of fine root mass in the 'tree only', and 45, 45, 40 and 41% in the 'tree+crop' situations in alder, albizia, cherry and mandarin, respectively. The maximum FRN was observed in alder and minimum in mandarin.

The coarse root mass (CRM = CRB+CRN) varied significantly ($P < 0.01$) among the four species and three depths. The CRM was maximum at 10-20 cm in alder and albizia in both the situations. But in cherry and mandarin, the maximum CRM was observed in the surface soil layer (0-10 cm). The CRM was maximum in mandarin (214 g m^{-2}), followed by cherry (153 g m^{-2}) and minimum in albizia (57.5 g m^{-2}). CRB represented about 64-69% of the CRM, and consequently, CRB/CRN ratio was ca 2 regardless of the presence of crop plants. Fine root represented 84, 87, 79 and 77% of the total root biomass (TRB) in alder, albizia, cherry and mandarin, respectively.

Horizontal distribution of fine roots

The maximum accumulation of FRB in all tree species was noticed near the tree trunk (0.5 m) in both years (Fig. 5.4). It was more than 60% in alder and albizia, and between 50-55% in cherry and mandarin. At 1 m away from the tree trunk, FRB was only 36-40% in alder and albizia, and 31-36% in mandarin and cherry. In alder and albizia the fine root distribution was restricted only up to 1 m distance from the tree trunk, but in mandarin and cherry, fine roots were found even at a distance of 1.5 m from tree trunk.

The seasonal and vertical distribution of fine roots in

Fig. 5.4. Lateral distribution of fine root biomass (g m−2) of the four trees in `tree only' situation.

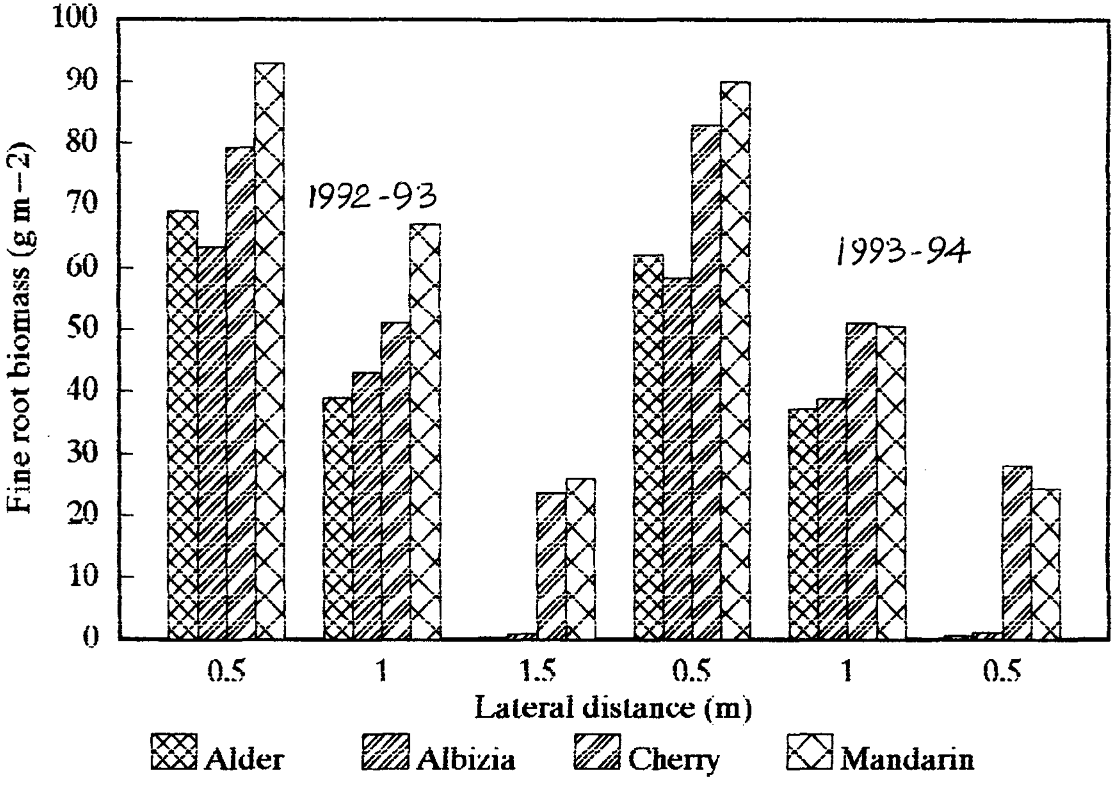
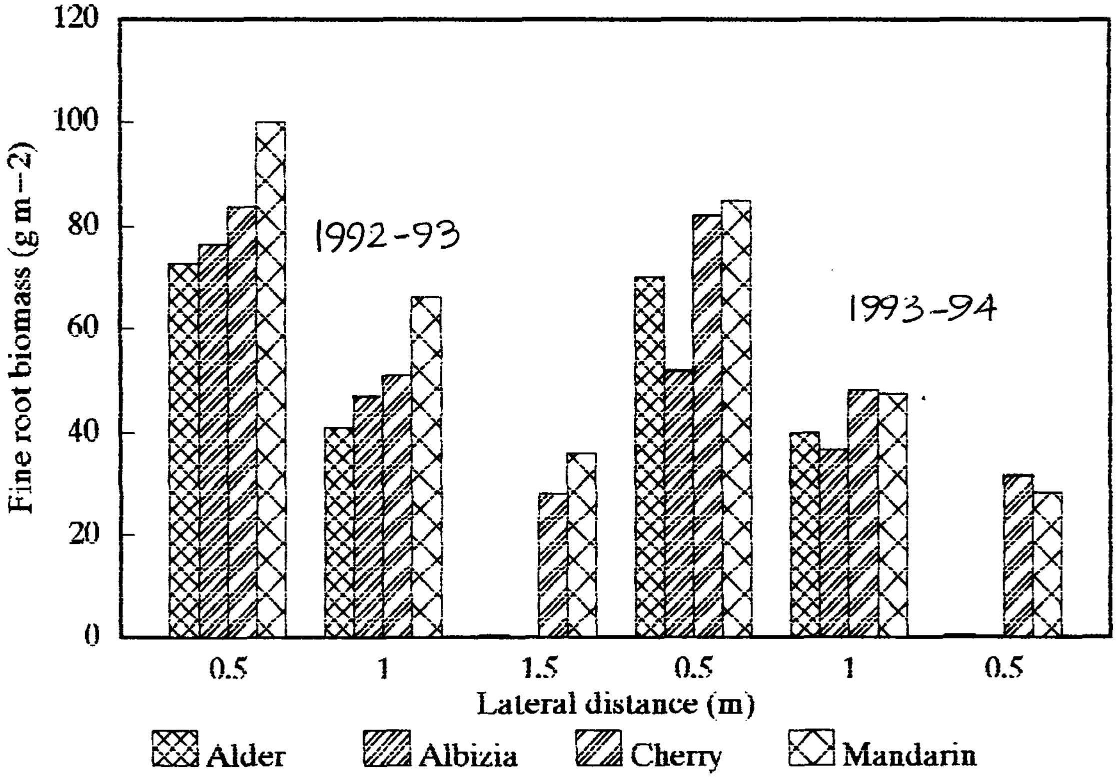


Fig. 5.5. Lateral distribution of fine root biomass (g m−2) of the four trees in `tree+crop' situation.



the 'tree only' and 'tree+crop' situations were same (Fig. 5.5).

Horizontal distribution of woody roots

Woody roots (>5 mm diameter) of all the species were mostly present within the upper soil layers (0-10 cm) near the tree trunk in both 'tree+crop' as well as in 'tree only' situations (Fig. 5.6). Further, with increase in lateral distance and depth, number of woody roots sharply declined, and the magnitude of decrease varied greatly from one species to another. Cherry and mandarin have much greater number of woody roots compared to the alder and albizia. Total root length of woody roots was less than 1 m in alder and albizia, and more than 1 m in cherry and mandarin (Table 5.3). Further, the thickest woody roots were recorded in cherry (2.5-5.6 cm diameter), followed by mandarin (2.0-4.2 cm diameter), alder (1.6-3.5 cm diameter) and albizia (1.1-2.1 cm diameter).

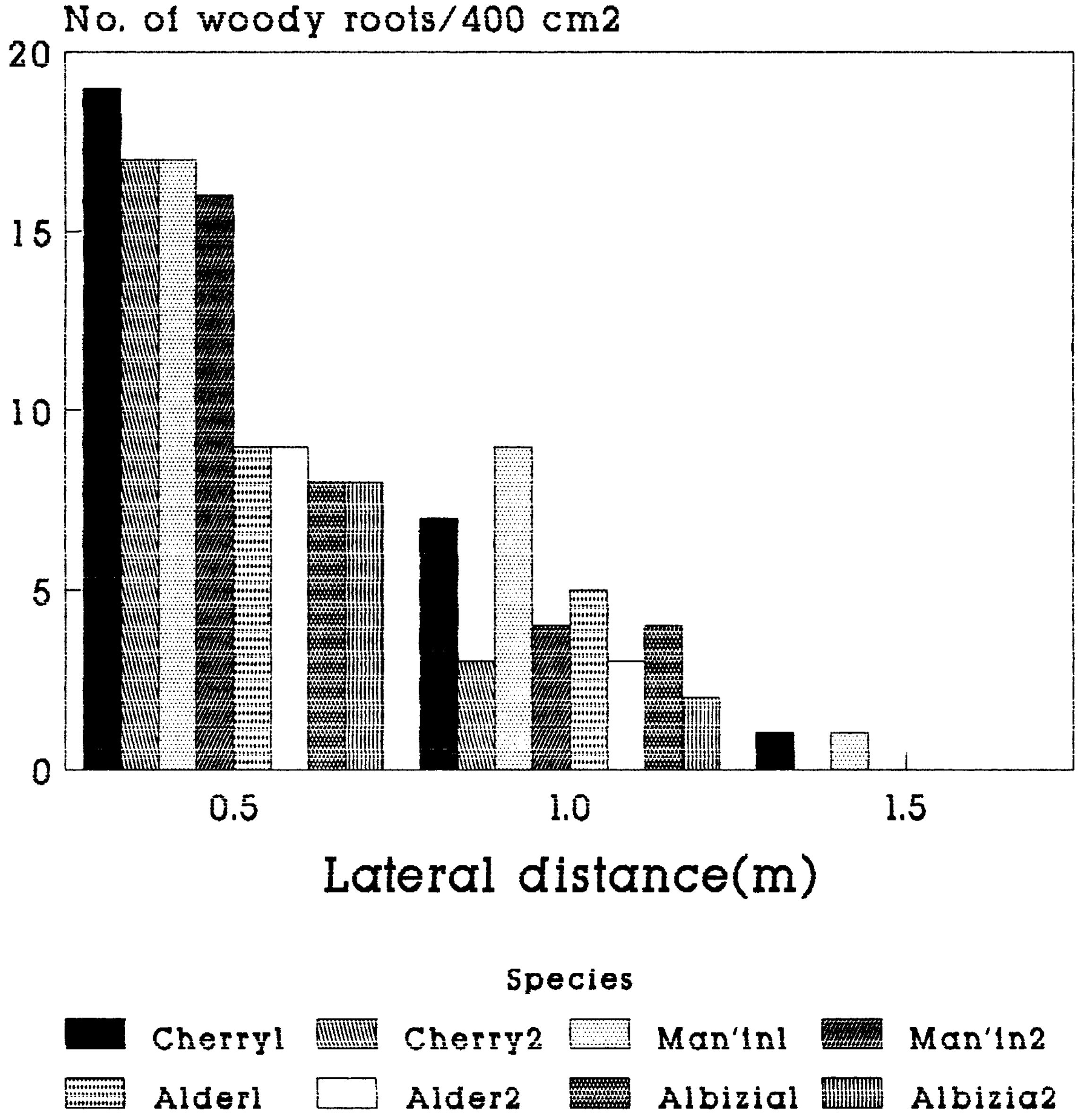
Table-5.3. Extent and distribution of woody roots of the four tree species (means ±S.D.; n=4).

Species	Root parameters (cm)			
	Total root length	Horizontal extent of root	Diam. at proximal end	Diam. at distal end
Alder	80.1±18.0	55.0±10.3	2.47±0.31	0.28±0.05
Albizia	77.0±13.6	75.0±12.1	1.57±0.25	0.28±0.03
Cherry	101.2±23.2	77.6±20.1	3.75±0.54	0.77±0.17
Mandarin	109.7±10.2	79.2± 7.0	2.81±0.52	0.42±0.10
CV(%)	17.40	15.70	34.00	52.90

Belowground production

Fine roots contributed on an average (pooled values for the two situations) 84, 86, 78 and 74% of the total root production in alder-, albizia-, cherry- and mandarin-systems,

Fig. 5.6. Lateral distribution of tree woody roots in the four agroforestry systems.



1- 'tree only' situation
2- 'tree+crop' situation

respectively. The total root production was maximum in mandarin (8.4 t $ha^{-1}yr^{-1}$), followed by cherry (7.2 t $ha^{-1}yr^{-1}$), and minimum in alder (4.6 t $ha^{-1}yr^{-1}$) and albizia (4.2 t $ha^{-1}yr^{-1}$) under both the situations. In general, production declined with the increase in soil depth, lateral distance and root-diameter (fine to coarse roots) (Table 5.4). The ratio between the total root production and the total biomass was maximum in alder (1.5), and it was ca 1.4 in mandarin, cherry and albizia in the 'tree only' situation. In the 'tree+crop' situation too the trend as well as the values remained more or less same.

Nodule biomass in alder and albizia

The active root nodule biomass in both species increased in the growing season from spring onwards and it peaked in autumn, after which i.e. during winter it again decreased (Table 5.5). Root nodule biomass was higher in alder than albizia in both the situations. It ranged between 217 to 245 kg ha^{-1} in alder and 176 to 222 kg ha^{-1} in albizia in the 'tree only' and 'tree+crop' situations, respectively. Nodule biomass was almost same in both years. The highest nodule biomass in alder (55.9 g m^{-2}) and albizia (34.4 g m^{-2}) was recorded during autumn. Annual root nodule production was comparatively greater in alder than in albizia in both the situations. It ranged between 215 to 229 kg $ha^{-1}yr^{-1}$ in albizia and 358 to 389 kg $ha^{-1}yr^{-1}$ in alder, respectively. In both the species maximum concentration (72-78%) of root nodule was found up to 0.5 m distance from the tree trunk and only 22-28% root nodules were recorded at 1 m away from it. No nodule was observed at 1.5 m distance from the tree trunk in both species in the two

Table 5.4. Production of fine and total (fine+coarse) roots in the four agroforestry systems. R= ratio between the root production and total biomass of fine and coarse roots.

Species	Soil depth(cm)	Production(g m^{-2} yr^{-1}) Fine roots	Total roots	R
		'Tree only' situation		
Alder	0-10	179.8±9.9	196.4±13.6	1.33
	10-20	127.7±8.4	163.7±11.8	1.72
	20-30	85.5±6.5	107.5± 9.2	1.60
	Total	393.3±8.8	467.5±14.6	1.51
Albizia	0-10	162.8±7.6	177.4±11.9	1.26
	10-20	130.3±8.6	160.4±12.3	1.67
	20-30	72.9±6.4	86.4±10.1	1.40
	Total	366.0±9.5	424.2±12.5	1.44
Cherry	0-10	216.9±8.2	280.8±12.8	1.26
	10-20	195.3±9.1	243.8±13.4	1.55
	20-30	150.4±7.5	191.6±15.1	1.55
	Total	562.5±9.5	716.2±15.2	1.43
Mandarin	0-10	231.9±8.9	334.8±13.3	1.36
	10-20	202.9±6.7	273.8±14.7	1.35
	20-30	191.4±8.9	232.0±12.7	1.45
	Total	626.3±9.9	840.7±13.2	1.42
		'Tree+crop' situation		
Alder	0-10	195.7±8.2	218.5±11.9	1.32
	10-20	132.5±6.0	168.0±12.6	1.69
	20-30	79.1±5.1	99.8± 9.2	1.48
	Total	407.4±6.9	486.4±19.2	1.46
Albizia	0-10	173.4±7.3	188.4±14.1	1.30
	10-20	134.0±5.7	163.3±11.7	1.70
	20-30	77.0±6.8	93.0±12.4	1.46
	Total	384.5±9.1	444.8±19.1	1.46
Cherry	0-10	228.6±5.7	294.2±14.3	1.25
	10-20	188.2±6.6	235.8±14.8	1.52
	20-30	152.0±8.5	195.8±13.7	1.57
	Total	568.8±9.5	725.8±16.8	1.41
Mandarin	0-10	243.0±8.8	349.4±13.4	1.40
	10-20	208.9±7.7	281.9±14.2	1.42
	20-30	164.4±6.1	200.6±12.6	1.51
	Total	616.4±9.9	832.0±23.3	1.45

Table 5.5. Root nodule biomass (g m^{-2}) of alder and albizia species in the 'tree+crop' and 'tree only' situations.

Seasons	Alder						Albizia					
	'Tree only'			'Tree+crop'			'Tree only'			'Tree+crop'		
	Distance from tree trunk (m)						Distance from tree trunk (m)					
	0.5	1.0	Total	0.5	1.0	Total	0.5	1.0	Total	0.5	1.0	Total
Spring	23.6 ±3.1	9.2 ±0.8	32.8 ±5.0	25.1 ±3.6	9.4 ±1.6	34.5 ±5.1	13.1 ±1.8	3.7 ±0.6	16.8 ±3.7	12.4 ±1.6	3.5 ±0.4	15.9 ±3.0
Rainy	29.8 ±4.5	11.6 ±0.9	41.4 ±6.4	31.7 ±5.3	12.3 ±2.3	44.0 ±5.8	17.1 ±2.6	4.8 ±2.0	21.9 ±3.4	12.8 ±2.8	3.6 ±0.8	16.4 ±3.1
Autumn	41.0 ±6.3	14.9 ±2.5	55.9 ±8.1	42.1 ±5.2	16.3 ±2.8	58.4 ±8.0	26.8 ±4.3	7.6 ±2.0	34.4 ±8.3	29.7 ±3.8	8.4 ±2.1	38.1 ±6.2
Winter	13.6 ±3.0	5.1 ±2.0	18.7 ±2.5	14.1 ±2.7	5.4 ±1.4	19.5 ±3.6	10.1 ±2.4	2.8 ±0.6	12.9 ±2.9	11.9 ±1.2	3.3 ±0.5	15.2 ±2.7

situations.

Net primary production

Total net primary production (TNP) of the four tree species ranged from 17.8-23.3 t $ha^{-1}yr^{-1}$ under the two situations (Table 5.6). The maximum TNP (t $ha^{-1}yr^{-1}$) was recorded for alder (22.3), followed by cherry (19.5) and mandarin (19.1), while the minimum was in albizia (17.8). The TNP was slightly (3-7%) greater in the 'tree+crop' situation than in the corresponding 'tree only' situation. In alder and albizia, root nodules also contributed 0.22 and 0.39 t $ha^{-1}yr^{-1}$ respectively to the belowground productivity.

The percent distribution of net primary production (NPP) in different components of the four tree species ranged from 14-23% in twig and leaf (foliage), 10-17% in branches, 21-38% in bole, 21-44% in belowground parts in the 'tree only' situation (Table-5.6); and almost the same in 'tree+crop' situation. In alder, cherry and mandarin 4-11% NPP was distributed in catkins, berries and fruits. In all the four tree species, NPP was high for foliage and bole and low for branches. The contribution of aboveground biomass to total biomass was quite high in albizia (76%) and alder (79%), while in case of mandarin and cherry it was only 56 and 63%, respectively. Thus belowground biomass in the latter two species contributed more to TNP than in the former species.

DISCUSSION

Belowground plant tissues (i.e., roots) contribute to soil organic pools and accumulation while they are alive, as well as after senescence while they are decomposing (Rovira *et*

Table 5.6. Distribution of total net primary productivity (t ha^{-1}yr^{-1}) of the four tree species in different plant parts in the 'tree+crop' and 'tree only' situations (values in parentheses are percent contribution to the total net primary productivity).

Parameters	'Tree only'				'Tree+crop'			
	Alder	Albizia	Cherry	Mandarin	Alder	Albizia	Cherry	Mandarin
Foliage(twigs and leaf)	5.00	3.68	2.93	2.60	5.20	4.27	3.28	2.81
	(22.5)	(21.0)	(15.0)	(14.0)	(22.7)	(22.7)	(15.7)	(14.0)
Catkins/fruits	0.9	-	1.25	2.10	0.95	-	1.41	2.32
	(4.1)		(6.4)	(11.0)	(4.1)		(6.8)	(11.8)
Branch	3.25	2.96	2.71	1.96	3.41	3.13	2.86	2.12
	(14.8)	(17.0)	(14.0)	(10.0)	(14.9)	(17.0)	(14.0)	(11.0)
Bole	8.13	6.74	5.40	4.05	8.44	6.94	6.03	4.11
	(37.0)	(38.0)	(28.0)	(21.0)	(37.0)	(37.0)	(29.0)	(21.0)
ANP	**17.28**	**13.38**	**12.29**	**10.71**	**18.00**	**14.34**	**13.58**	**11.36**
	(79.0)	(76.0)	(63.0)	(56.0)	(79.0)	(76.0)	(65.0)	(58.0)
Root biomass	4.67	4.24	7.16	8.40	4.86	4.44	7.25	8.32
Root nodules	0.36	0.22	-	-	0.39	0.23	-	-
BNP	**5.03**	**4.46**	**7.16**	**8.40**	**5.25**	**4.67**	**7.25**	**8.32**
	(21.0)	(24.0)	(37.0)	(44.0)	(21.0)	(24.0)	(35.0)	(42.0)
TNP	**22.32**	**17.84**	**19.45**	**19.11**	**23.25**	**19.01**	**20.83**	**19.68**

ANP = aboveground net primary productivity;
TNP = total net primary productivity;
BNP = belowground net primary productivity (accumulation of root biomass).

al., 1979). As the resources available at different soil depths are not the same, maintenance of a root system having a high surface area of absorbing roots well distributed throughout the soil profile is an important feature for management of a agroforestry system (Buck, 1986). In a root system, fine root biomass represents a varying proportion of the total accumulated organic matter of the stand. Studies on vertical distribution of tree roots have shown that most of them colonize the upper 50 cm of soil layers and majority of the fine roots are confined within the top 30 cm of the soil profile (Hermann, 1977; Persson, 1983). In this study the distribution of fine roots (<2 mm diameter) has shown that all four species have deep rooting systems, but they differed in the relative abundance of roots. This is because root distribution and density within the soil profile are primarily genetically determined, but is also a response to soil type, moisture, nutrient availability, organic matter distribution and soil management (Buck, 1986; Haissing & Riemenschneider, 1988; Myers *et al.*, 1994). The four tree species had 72-80% of the fine rootmass in the top 20 cm soil profile, the bulk of which was confined to 0-10 cm depth. The total fine root stock (1.2-1.7 t ha^{-1}) in the upper 10 cm soil layer falls within the range reported for a variety of forests in different agro-climatic regions (Berish, 1982; Cuevas *et al.*, 1991; Parrotta & Lodge, 1991; Vance & Nadkarni, 1992; Arunachalam *et al.*, 1996; Sundarapandiyan & Swamy, 1996). The mean standing crop of fine roots in alder (2.6-2.8 t ha^{-1}) and albizia (2.6 t ha^{-1}) is lower than the value of 4-5 t ha^{-1} reported by Singh and

Singh (1981) from a dry deciduous forest. However, the values recorded for cherry (5.6-5.7 t ha^{-1}) and mandarin (6.2 t ha^{-1}) are greater than the value reported by Singh and Singh (1981).

Root growth occurs independently of shoot growth (Persson, 1978) and the periodicity of root activity is dominated by environmental conditions. In the four tree species, the fine rootmass changed both seasonally and annually, which reflects the variation in production and decomposition processes through seasons (Ford & Deans, 1977; Srivastava *et al.*, 1986; Khiewtam & Ramakrishnan, 1993). Similar results are reported for several temperate and tropical forests (Harris *et al.*, 1977; Persson, 1978; Srivastava *et al.*, 1986; Parthasarathy, 1987). In the present study, fine roots followed an unimodal growth pattern indicating that autumn (post rainy season) period was most favourable for root growth. Besides, the rate of decomposition also declines during autumn due to decrease in soil moisture and ambient temperature. Autumn peak of the belowground biomass has also been reported in grassland ecosystems, and is attributed to the translocation of large amount of organic matter from shoot to the belowground parts. A low fine root standing crop occurred during spring and rainy season, when decomposition is most rapid due to high temperature and humidity. Soil moisture stress and low temperature in winter season are the factors responsible for limiting root growth (Lyr & Hoffman, 1967). Fine root production which accounted for 74-86% of the total root production in the four species, is higher than those reported by Harris *et al.* (1977) and

Persson (1978). Out of the four species, cherry and mandarin showed a high accumulation and uniform distribution of fine roots down to 30 cm soil depth. In these species, large number of woody roots were also found laterally distributed up to 1.5 m. These root characteristics help the species in establishing in the nutrient-poor soil. However, in this situation competition between tree and crops for belowground resources is expected (Jonsson *et al.*, 1988; Dhyani *et al.*, 1990; Ruhigwa *et al.*, 1992). Besides, the woody roots may pose physical hindrance, especially during soil workings and intercultural operations. At the same time the tree growth may also be affected adversely due to root injury resulting from these operations. This is the reason that in most of the mandarin orchards in this region, where farmers practice inter cultivation with cereals like maize, millets and vegetable crops, the growth of mandarin tree is hampered and incidence of insect pest and disease increases (Gupta, 1979). Alder and albizia showed a sharp decrease in fine root biomass below 10 cm soil depth. In these two species maximum roots were concentrated near the tree trunk. Many other workers (Roberts, 1976; Ford & Deans, 1977; Fogel, 1983) have also reported that in general, the root density declines with the vertical depth and distance from the tree.

Although mandarin and cherry would contribute more organic matter and nutrients due to their high belowground biomass productivity, yet the benefits of organic matter accumulation within the soil layers could be hardly utilized by the companion intercrops due to severe competition between tree and crop roots. A number of workers (Basri *et al.*; 1990; Evensen & Yost, 1990; Fernandes *et al.*, 1990) have also reported similar observations while working with hedgerow and crop combinations in acid soils. In alder and albizia systems, the root nodule biomass also contributes to the belowground productivity. The root nodule production was greater in alder (358-389 kg ha^{-1}) than in albizia (215-229 kg ha^{-1}). There are only a few estimates available for nodule biomass under field conditions, and a majority of them is for alder species (Akkermans & Van Dijk, 1976; Binkley, 1981; Sharma & Ambasht, 1986). In the present study the root nodule production in alder was comparatively lower than the value (492 kg ha^{-1}) reported by Sharma and Ambasht (1986) for a 7 year pure stand in the Eastern Himalayas. This is perhaps due to the fact that neither the site had an alder stand previously nor inoculation was carried out at the time of planting. Besides, the tree density was also low on the site. The results suggest that a significant proportion of organic matter and nutrients is being added to the soil system through roots in general, and fine roots in particular.

Though the four tree species were of same age, yet distinctly different patterns were observed in the annual partitioning of dry matter production. In alder and albizia, the trees channelled a large part of their net production towards biomass accumulation. In both species, production of new roots and foliage was rather small but it represented a significant fraction (44-45%) of the toal dry matter, thus ensuring adequate utilization of water, nutrients and sunlight. In contrast, in cherry and mandarin, 37-44% of annual net production did not accumulate as biomass, but instead was used to develop short-lived roots. On an annual basis, a large portion of these roots died and became an energy source for decomposers. Thus in case of cherry and mandarin, above-ground growth was reduced in favour of expending more energy belowground to develop and maintain root systems. This is desirable in slopy land situations, where the plants are exposed to water or nutrient stress. In such situations, this shift in production allocation from above- to below-ground may be an essential mechanism to avoid or alleviate stress (Dhyani *et al.*, 1996).

The total net primary production of the four tree species ranged between 17.6-22.8 t $ha^{-1}yr^{-1}$ under the two situations. The Miami model (Lieth, 1975) prediction of productivity of the warm temperate Himalayan zone was 19 and 23 t $ha^{-1}yr^{-1}$. These predicted values were within the estimated range of the four tree species. But, the values were lower than the likely net biomass production range of 25-35 t $ha^{-1}yr^{-1}$ reported for the highland tropics (Elsevier, 1981; Huxley, 1984). Kawahara *et al.*, (1981) reported the aboveground net primary production of 11.3 t $ha^{-1}yr^{-1}$ for albizia plantation in Philippines. The values in the present study for albizia are greater by 26%. In forest communities the biomass accumulation ratio (biomass/net production), which expresses the amount of biomass accumulated per unit of net production, is used in categorizing the production conditions (Whittaker, 1966; Whittaker & Woodwell, 1969). In the four tree species it ranged between 5.8-6.8 in the 'tree only' and 'tree+crop' situations. These values are higher than the ratio reported by Smith (1977) for a 8-10 year *Alnus rubra* stands.

The total net primary production was invariably higher in the 'tree+crop' situation than in the 'tree only' situation, thus indicating that agroforestry systems are more advantageous than the corresponding tree monocultures.

CHAPTER 6

BIOMASS AND PRODUCTIVITY OF CROPS AND WEEDS

Although a vast amount of data has been collected on the biomass and productivity of natural and agricultural ecosystems from different agro-ecological zones by several workers (Ovington *et al.*, 1963; Pearson, 1965; Singh, 1968; Whittaker, 1970; Singh & Yadav, 1974; Loomis & Gerkis, 1975; Kira, 1977; Singh & Joshi, 1979; Uhl & Murphy, 1981; Gupta & Singh, 1982; Cheng *et al.*, 1990; Koizumi *et al.*, 1990; Boral, 1993), no such data is available for agroforestry ecosystem. Besides quantitative estimation of nutrient uptake and retention, the determination of biomass and productivity of agroforestry systems is also an essential pre-requisite for gaining a better insight into Their functioning. For computing total biomass of the system , the biomass data for its various important components viz. crops, weeds and perennial woody plants must be available.

The biomass and productivity of the tree species have already been presented in Chapter 4. The present chapter comprises the aspects relating to the effects of the four agro-forestry systems on the biomass and productivity of crops and weeds.

MATERIAL AND METHODS

Crop yield

The experiment was conducted during 1992-94 at the agroforestry farm under rainfed condition. The details of phenology, density of the crops grown and the quantity of fertilizer applied in the 'tree+crop' under the four agroforestry systems are presented in Table 3.2. Groundnut [*Arachis hypogaea* L.] and soybean [*Glycine max* (L.) Merr.] during Kharif (summer), and linseed [*Linum usitatissimum* L.] and mustard [*Brassica campestris* L.] during Rabi (winter) were sown with the four tree species. The experiment was laid out in randomized block design with four replications. For crop yield assessment, only the crop rows within the pair of tree rows in each plot were considered. Crop yield was recorded by harvesting five consecutive crop rows from the tree row on either side. Thus a total of 10 rows were taken into account in each plot. The mean of the first two rows of crops proximal to the trees was the yield of row 1; similarly, the yield of row 2 was the mean of the next two rows, one on either side inner to the proximal row. The mean yield of five rows was computed in this manner. The data were subjected to an analysis of variance and treatment differences tested for significance.

Biomass sampling

Biomass was determined by 'harvest method' (Misra, 1968). The sampling was done at monthly interval over a period of two years (May, 1992 to April, 1994). On each sampling date four quadrats (50 x 50 cm) in each situation ('tree+crop' and 'tree only') were laid randomly and then all plants present in the quadrats were cut at ground level and kept species-wise in polythene bags. In the case of 'tree+crop' situation, the plant samples were collected from unweeded plots and a constant number of crop rows was included in the quadrat for each crop in order to avoid error due to crop rows and crop density. Surface litter was hand-picked after the aboveground vegetation of the quadrat had been cut and kept in polythene bags.

Belowground biomass was sampled by soil core method. Soils from a 10 x 10 cm area of each harvested quadrat was excavated from three depths viz. 0-10; 10-20 and 20-30 cm and kept in polythene bags. In the 'tree+crop' situation, crop and weed roots were excavated from the same harvested quadrat separately; crop roots from the crop rows and weed roots from the inter-rows of crop (Stinner *et al.*, 1984). The sampled materials were transported to the laboratory. The aboveground material of each species was sorted out into live and standing dead components. The quantity of standing dead parts being insignificant was transferred to the litter. The aboveground compartment was separated into crop, weeds (live) and litter components. Depending on necessity, the litter was cleaned with water to remove the adhering soil particles. Belowground biomass was extracted from the excavated soils following floatation method (McKell *et al.*, 1961). The excavated soil was soaked for about an hour and then repeatedly washed in a large tray with a fine jet of water using a 0.5 mm mesh sieve. Large particles retained on sieve were hand-picked. Based on morphology, root and rhizome from the belowground compartment were sorted out. All the collected samples of livegreen, litter and belowground compartments were oven-dried at 80°C till constant weight and then weighed.

Productivity measurement

Aboveground net primary productivity (ANP) of a few dominant species and of the whole community was computed by the method "sum of positive increment in biomass plus mortality", as outlined by Singh and Yadava (1974). The positive increment in livegreen component on successive sampling dates and the positive increment in standing dead component for only those months during which a positive increment in livegreen component occurred were summed up. Similarly, belowground net primary productivity (BNP) at each depth was measured by summing up the positive increment in biomass on successive sampling dates. The belowground productivity down to 30 cm depth was found out by summing up the productivity of each depth. Root and rhizome productivities were also measured during 1992-93 following the above method.

For assessment of annual TNP (total net productivity) of the four agroforestry systems, the productivity of tree species (Table 5.6, Chapter 5) were added to the ANP and BNP of the crop and weed plants growing in the corresponding agroforestry systems.

RESULTS

Crop yield as influenced by tree species

A total of four successive crops were raised during the study period. Crop yield as influenced by the tree species are presented in Table 3.1. Soybean and groundnut yield during Kharif, and linseed and mustard yield in Rabi were lower when grown in the 'tree+crop' situation as compared to the 'crop only' situation. The yield reduction in soybean and mustard due to presence of the trees was greater as compared to groundnut and linseed (Fig. 6.1). The reduction in yield for soybean ranged between 14-32% during 1992-93 and 15-31% during 1993-94. In case of groundnut, the maximum yield reduction of 26% in 1992-93 and 28% in 1993-94 was recorded in the cherry system, whereas the reduction in groundnut yield in the albizia system was only 9%. Similar trend was also observed in case of linseed and mustard yield. The yield reduction due to the presence of trees ranged 13 to 38% in linseed and 15 to 43% in mustard. Overall the maximum reduction in crop yield was observed in the cherry- followed by alder- and mandarin-system, whereas the reduction in the albizia-system was only marginal. Row-wise crop yield from the first row proximal to the tree to the 5th row away from it showed that proximity of tree had significant ($P<0.01$) effect on crop yield. In cherry-, alder- and mandarin-systems the crop yield in the first row was substantially low, and it improved as the distance from the tree increased. In contrast, proximity of the tree had no appreciable effect on crop yield in albizia-system, though, overall there was some reduction in intercrop yield as compared to sole crop (Fig. 6.2).

Aboveground biomass of crop and weeds

Monthly variations in aboveground biomass of crops and weeds are depicted in Fig. 6.3a to 6.6a. The aboveground biomass of the crops increased consistently with the increase in age of the crop plants. The peak aboveground biomass of the crops varied widely, the maximum being recorded for the soybean

Fig. 6.1. Intercrop and sole crop yield in the four agroforestry systems.

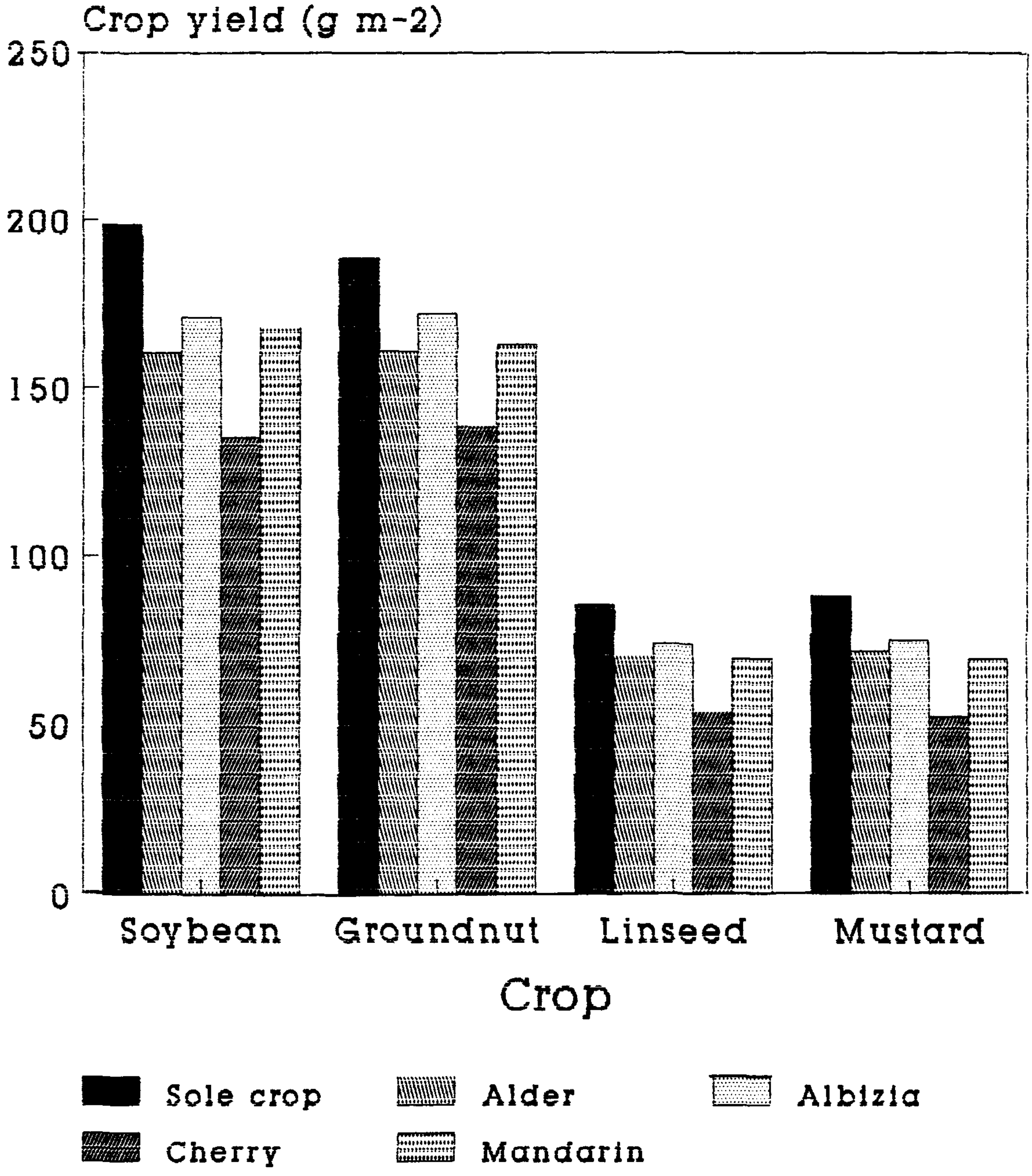


Fig. 6.2a- Soybean & groundnut yield in crop row 1 (nearest to tree) to crop row 5 (5th row from the tree) in the four systems.

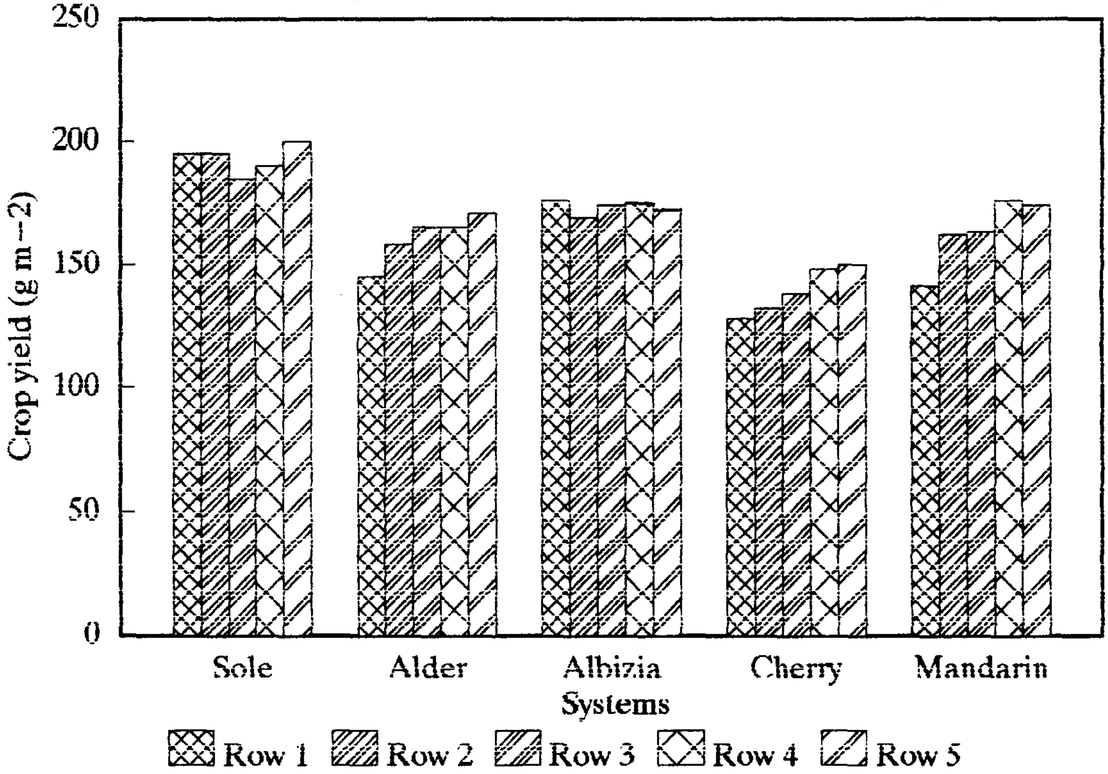


Fig. 6.2 (b). Linseed & mustard yield in crop row 1 (nearest to tree) to crop row 5 (5th row from the tree) in the four systems.

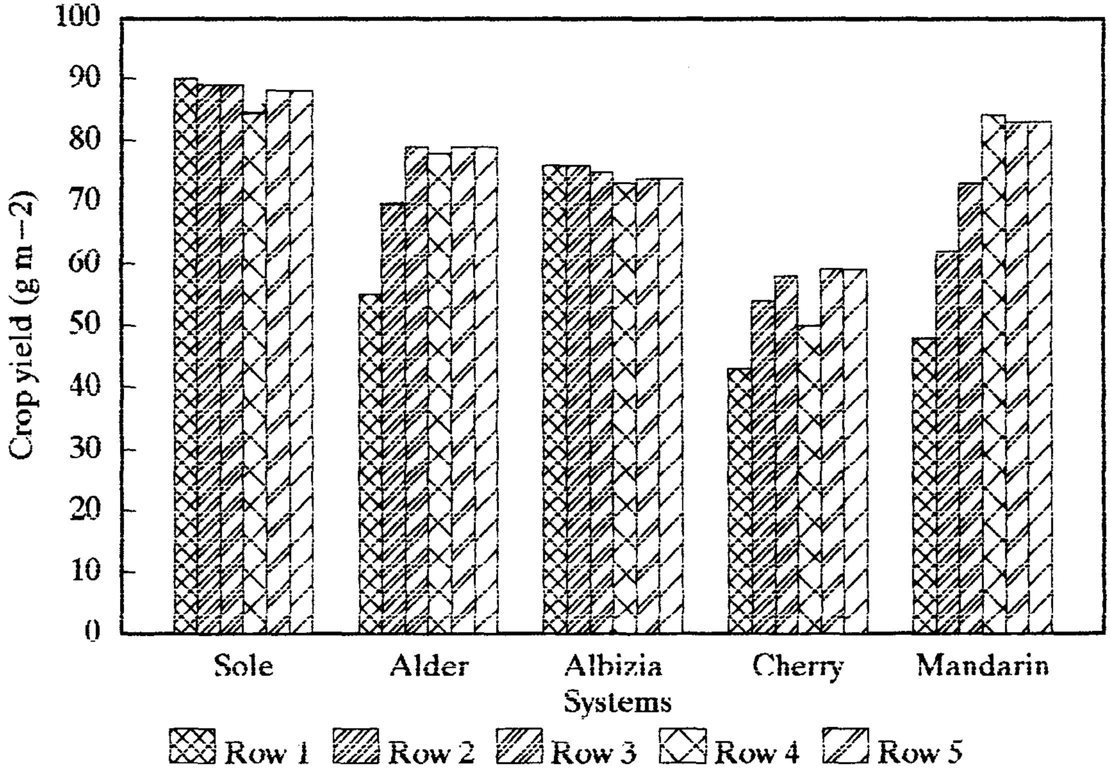


Fig. 6.3a. Monthly variation in aboveground biomass of crops, weeds and litter in alder-based system in 'tree+crop' situation.

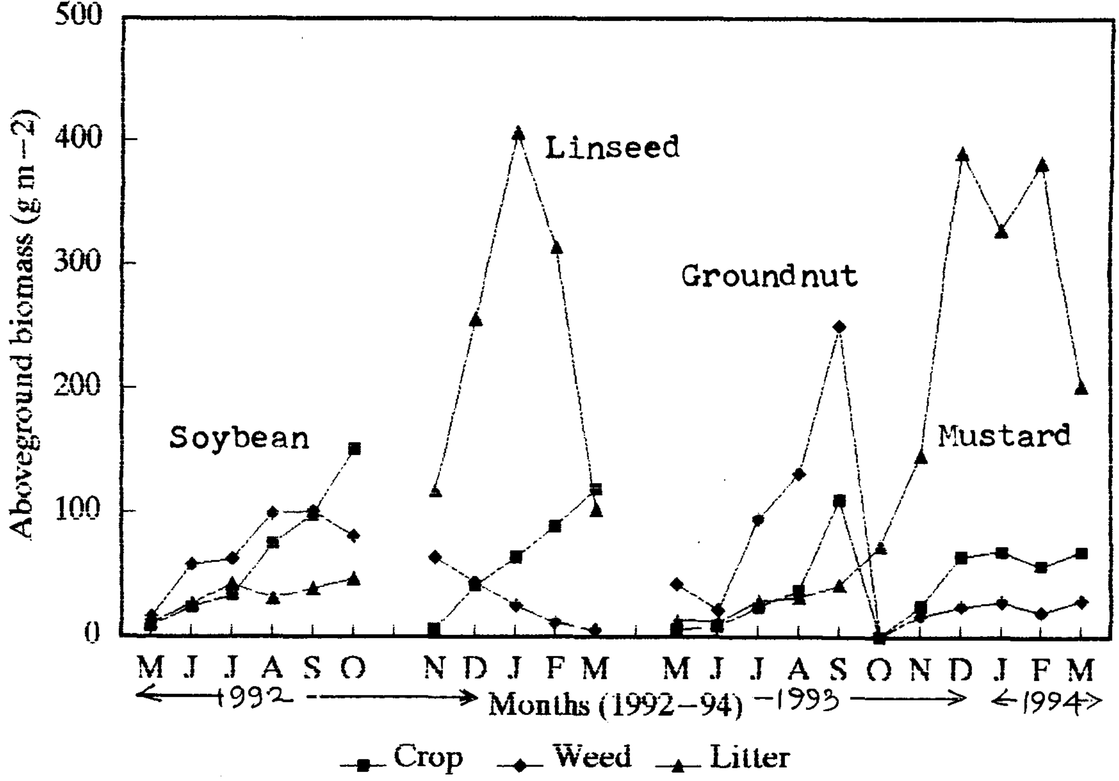


Fig. 6.3b. Monthly variation in aboveground biomass of weeds and litter in alder-based system in 'tree only' situation.

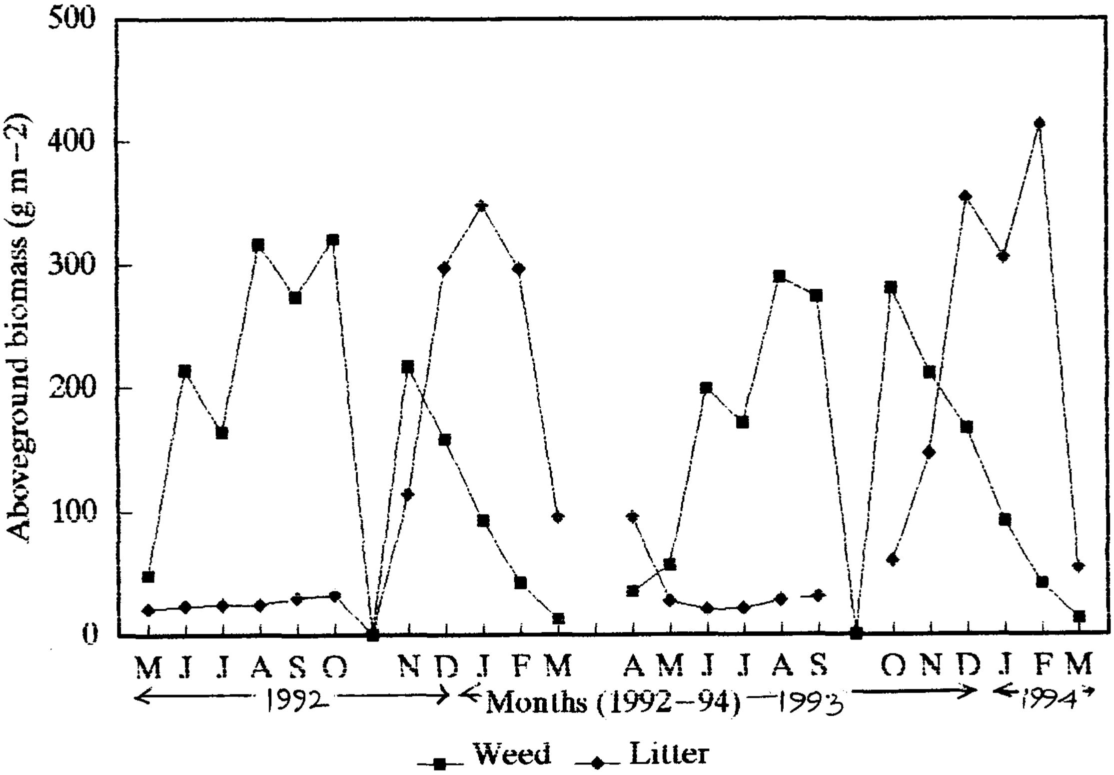


Fig. 6.4a. Monthly variation in aboveground biomass of crops, weeds and litter in cherry-based system in 'tree+crop' situation.

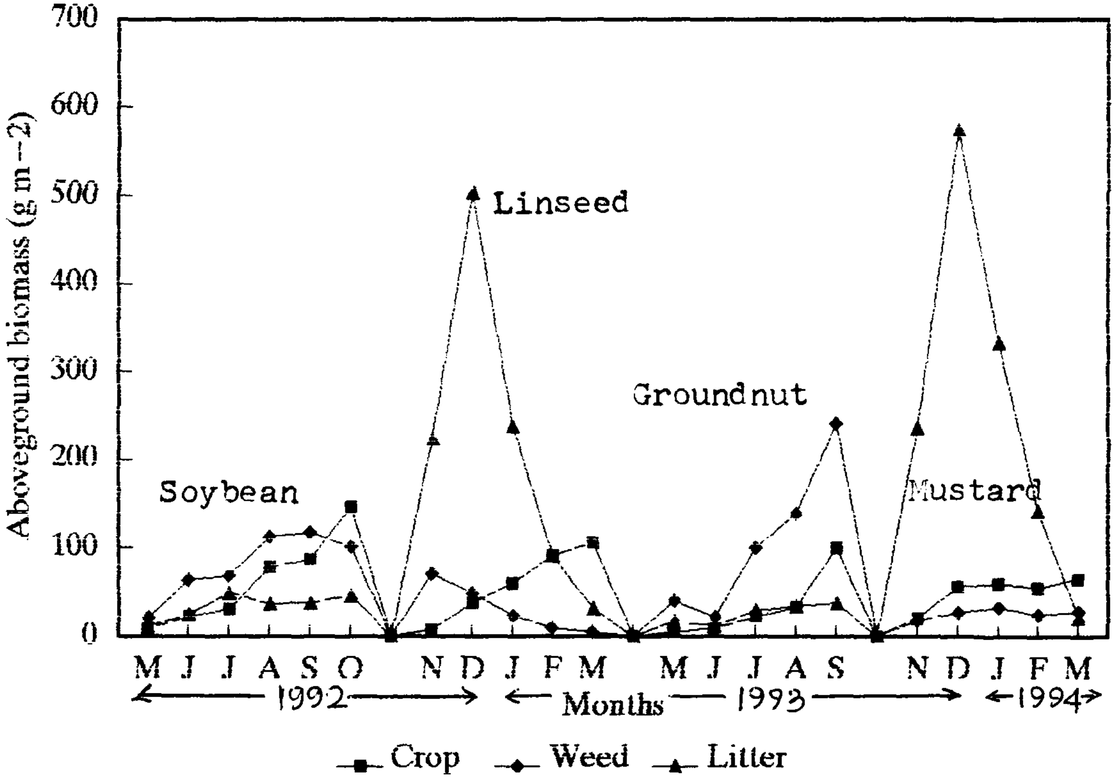


Fig. 6.4b. Monthly variation in aboveground biomass of weeds and litter in cherry-based system in 'tree only' situation.

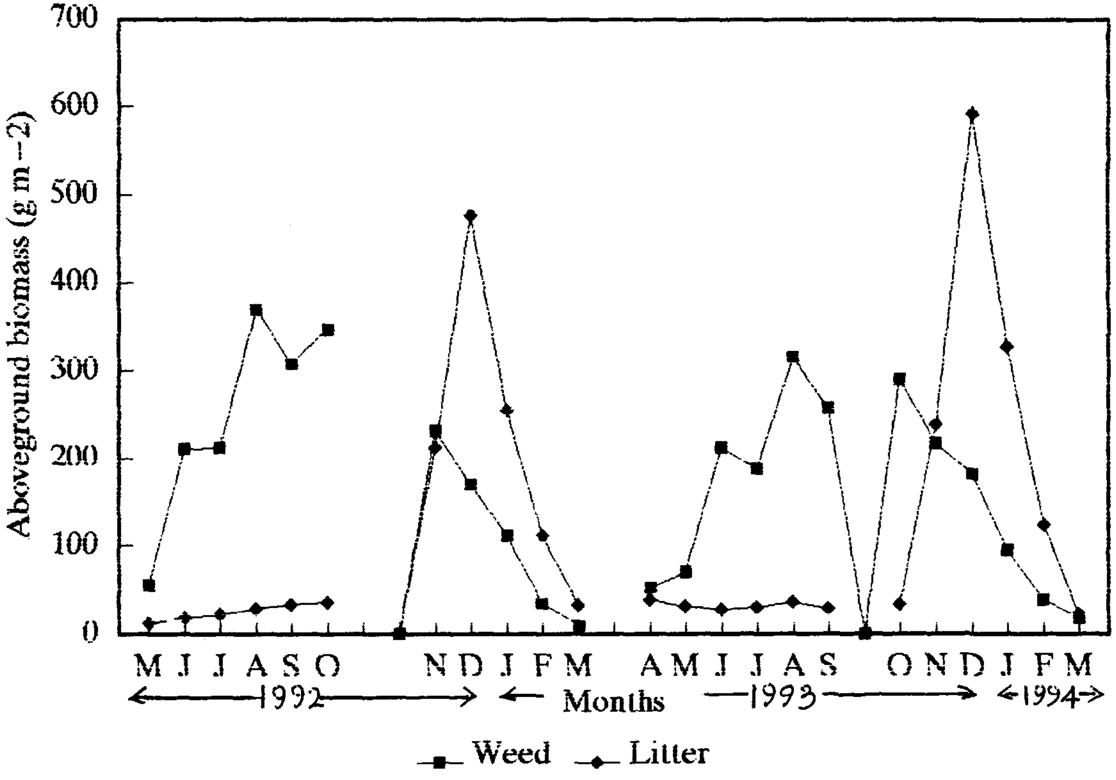


Fig. 6.5a. Monthly variation in aboveground biomass of crops, weeds and litter in albizia-based system in 'tree+crop' situation.

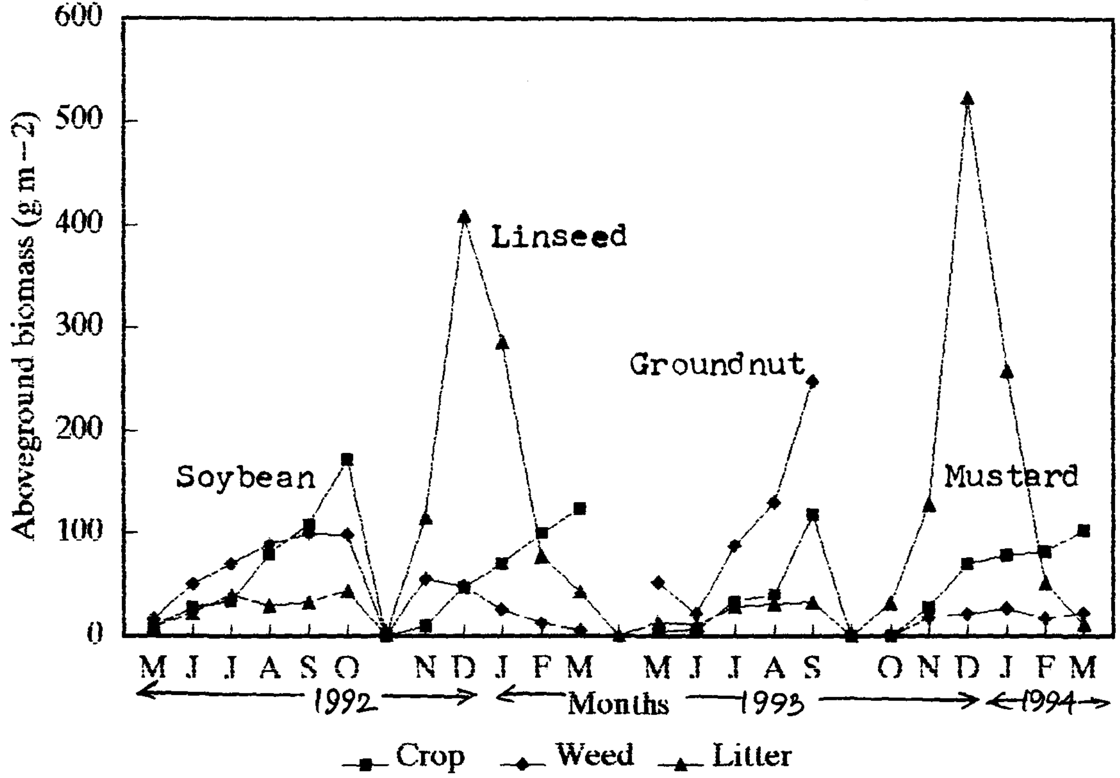


Fig. 6.5b. Monthly variation in aboveground biomass of crops, weeds and litter in albizia-based system in 'tree only' situation.

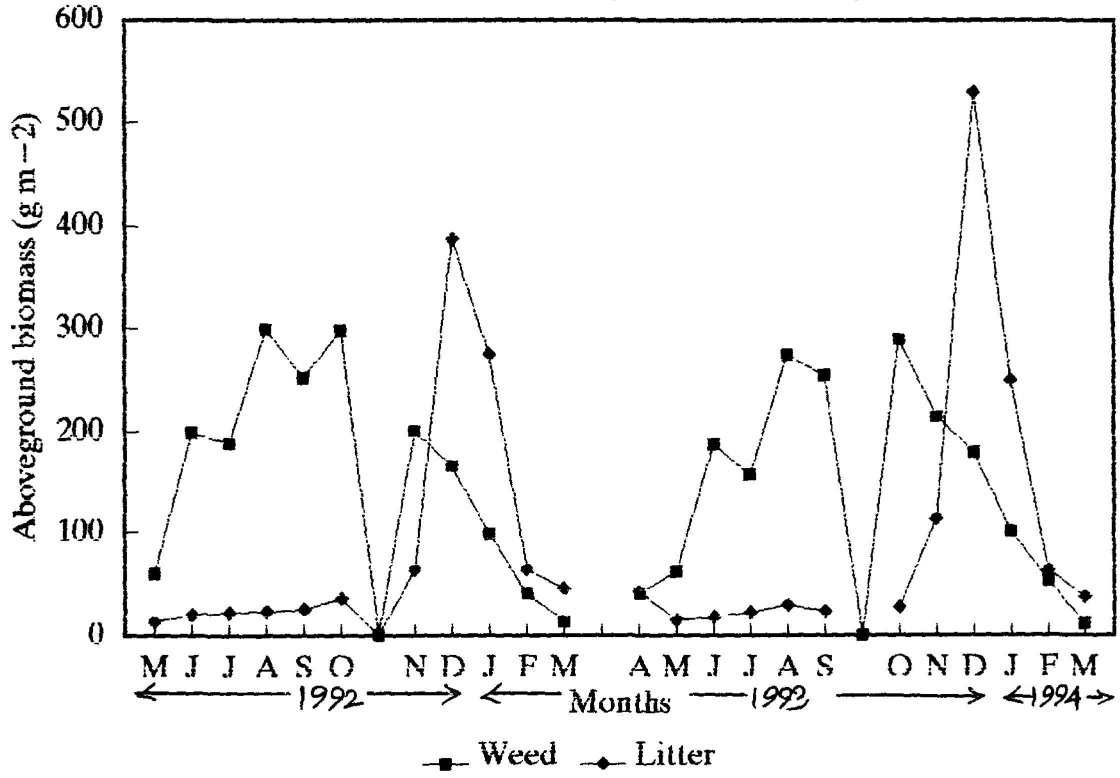


Fig. 6.6a. Monthly variation in aboveground biomass of crops, weeds and litter in mandarin-based system in 'tree+crop' situation.

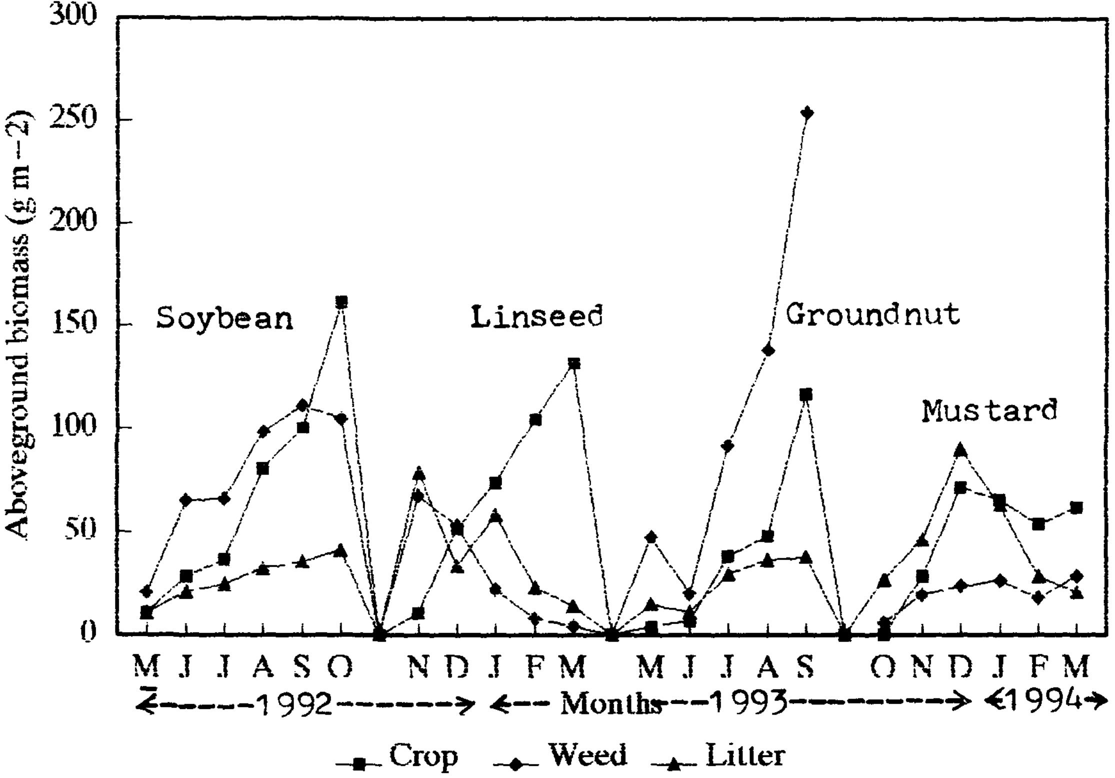
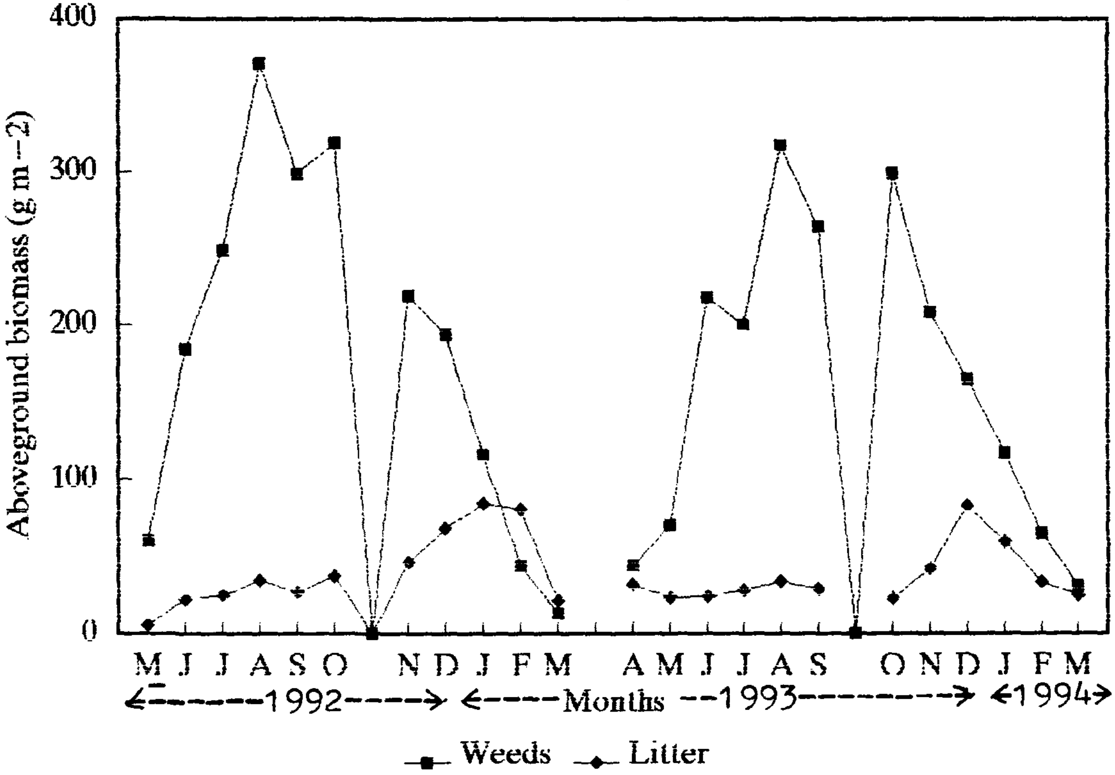


Fig. 6.6b. Monthly variation in aboveground biomass of weeds and litter in mandarin-based system in 'tree only' situation.



in October, ranging from 246 g m^{-2} in cherry- to 271 g m^{-2} in albizia-system. In the case of linseed aboveground biomass was maximum during March ranging between 106 to 132 g m^{-2} in the four systems. During the cropping period weeds also grew in the plots along with the crop plants and their biomass attained peak before the crop matured. At the time of crop harvest the weed biomass generally decreased. Though the biomass of weeds tended to be more than that of crops at early growth stage (at first sampling date after sowing), at later stages weed biomass was less than the biomass of soybean, linseed and mustard crop. However, the weed biomass was significantly greater than the groundnut biomass, throughout the growing period. Two peaks of weed biomass were recorded in a year. During 1992-93 maximum weed biomass (199-219 g m^{-2}) was recorded in September when growing with the soybean crop, and in December (144-153 g m^{-2}) during linseed cropping period. During 1993-94, the maximum weed biomass (242-254 g m^{-2}) was recorded again in September but when growing with the groundnut crop. The weed biomass was very low during the cultivation of the winter crops (linseed and mustard). Overall there was no significant ($P<0.05$) difference in the weed biomass under the four systems. In the 'tree+crop' situation maximum live biomass (crop + weed) was recorded in October during 1992-93, and it ranged between 432-470 g m^{-2} in the four systems. During 1993-94 the values ranged from 341 to 370 gm^{-2}.

Litter accumulation in 'tree+crop' situation was very high during Rabi, due to significantly high amount of litter contributed by the trees as the leaffall coincided with the winter crop cultivation period (November to February). During this period maximum litter accumulation (1206.5 g m^{-2}) was recorded in the alder- and minimum (241.2 g m^{-2}) in the mandarin-system. Litter accumulation in the 'tree+crop' situation was low (4.2 to 48 g m^{-2}) during kharif.

Monthly variation in live biomass and litter in 'tree only' situation in the four systems is depicted in Fig. 6.3 b - 6.6 b. The weed biomass ranged between 179 and 200 g m^{-2} in May 1992 under the four systems. Peak values of weed biomass ranging between 681-701 g m^{-2} during 1992-93, and 701-736 g m^{-2} during 1993-94 were recorded in October. The weed biomass peak was highest in the mandarin- and lowest in the albizia-system. The livegreen weed biomass in all systems decreased gradually from October to February and thereafter it increased. Minimum weed biomass was recorded in February. Differences in live biomass/ litter due to month and systems were significant at $P<0.01$ level (ANOVA). In 'tree only' situation also the amount of litter was considerably high during the leaffall period under the four systems ranging between 12 and 477 g m^{-2} during 1992-93, and 14 and 591 g m^{-2} during 1993-94.

Contribution of individual species to total aboveground biomass

The aboveground biomass contributed by the individual weed species varied with crop age and crop species. The important species whose contribution to the total aboveground biomass in different periods were high are as follows;

Soybean cropping period : *Ageratum conyzoides, A. haustonianum, Digitaria adscendens, Galinsoga parviflora, Imperata cylindrica.*

Linseed cropping period : *Bidens pilosa, Galinsoga parviflora, Imperata cylindrica.*

Groundnut cropping period: *Ageratum conyzoides, A. haustonianum, Digitaria adscendens, Borreria hispida, Galinsoga parviflora, Panicum montanum.*

Mustard cropping period: *Bidens pilosa, Galinsoga parviflora, Ageratum haustonianum.*

Biomass of most weed species increased with passage of time, however, it declined as the crop plants grew taller and matured. As a result the weed biomass at the time of crop harvest was generally lower than at the preceeding sampling dates (Table 6.1). Some of the weeds which contributed significantly high biomass in early stages were either absent at the time of harvest or their biomass was negligible. Overall *A. haustonianum* recorded highest biomass (154.99 g m^{-2} or 62.7%) in September 1993 during groundnut cropping in albizia-system. The general trend of biomass production by the dominant weed species under the four systems is described below.

Soybean cropping period

The weed biomass of *Ageratum conyzoides* and *Galinsoga parviflora* increased at the time of crop harvest than at early growing stage of the crops under alder-, albizia- and cherry-systems. But in the case of mandarin-system, *A. conyzoides* was present only at early growing stage of the crop and weed biomass of *G. parviflora* decreased at the time of crop harvest. The biomass of *A. conyzoides* was maximum (105.4 g m^{-2} or 52.4%) under alder-system, where the biomass was almost two fold greater at the time of crop harvest than at early growing

Table 6.1. Aboveground biomass (g m^{-2}) of dominant weed species growing with different crops during early growth stage (I) and at the time of crop harvest (II). Values in parentheses are biomass expressed as percentage of total aboveground weed biomass.

Agroforestry system	Crop	Growth stage/ Days after crop sowing	Weed species *A. cony*	 *A. hau*	 *Bid. pil*	 *Bor. his*	 *Dig. adsc*	 *Gal. parv*	 *Imp. cyl*	 *Pan. mon*
AFS 1	Soybean	I-(Jun'92)30	27.4 (30.9)	-	11.5 (13.0)	4.4 (5.0)	27.4 (31.0)	17.7 (20.0)	-	-
		II-(Sep'92)128	105.4 (52.4)	-	-	10.1 (5.0)	30.6 (15.2)	32.2 (16.0)	-	-
	Linseed	I-(Nov'92)25	25.0 (39.0)	-	-	-	9.6 (15.0)	12.2 (19.0)	-	-
		II-(Mar'93)12	-	-	23.4 (36.0)	-	-	31.2 (48.0)	-	-
	Groundnut	I-(Jun'93)30	5.7 (7)	20.4 (25)	8.2 (10.0)	-	27.7 (34.0)	12.2 (14.6)	-	-
		II-(Sep'93)112	-	84.7 (33.7)	5.0 (2)	42.5 (16.9)	44.0 (17.5)	46.7 (18.6)	-	-
	Mustard	I-(Nov'93)25	14.7 (19)	23.3 (30.4)	-	10.4 (13.6)	7.4 (9.6)	6.1 (8.0)	-	-
		II-(Mar'94)125	-	9.9 (14)	27.5 (39)	-	-	18.3 (26.0)	-	-
AFS 2	Soybean	I-(Jun'92)30	25.3 (25.5)	31.0 (31)	8.4 (8.4)	6.1 (6.4)	-	14.0 (14.2)	-	-
		II-(Sep'92)128	42.6 (21.4)	51.1 (25.7)	-	32.2 (16.2)	-	53.9 (27.1)	-	-
	Linseed	I-(Nov'92)25	35.8 (61)	15.4 (28)	1.1 (2)	9.4 (10.0)	-	13.1 (23.8)	-	-
		II-(Mar'93)125	4.2 (5)	15.3 (18)	26.3 (31.0)	-	-	21.2 (28.0)	-	-
	Groundnut	I-(Jun'93)30	-	18.4 (20.3)	19.9 (21.9)	-	22.2 (24.4)	15.4 (17.0)	-	-
		II-(Sep'93)112	-	154.9 (62.7)	10.9 (4.4)	-	38.3 (15.5)	15.1 (6.1)	-	-
	Mustard	I-(Nov'93)25	-	21.9 (32.7)	-	-	24.2 (36.0)	6.9 (10)	-	-
		II-(Mar'94)125	-	17.0 (22)	12.4 (16)	-	-	28.6 (37.0)	-	-

-, absence or biomass less than 1 g m^{-2}.

Species- *A. cony- Ageratum conyzoides, A. hau- A. haustonianum, Bid. pil- Bidens pilosa, Bor. his- Borreria hispida, Dig. adsc- Digitaria adscendens, Gal. par- Galinsoga parviflora, Imp. cyl- Imperata cylindrica, Pan. mon- Panicum montanum*

Contd. Table 6.1

Agroforestry system	Crop	Growth stage/ Days after crop sowing	*A. cony*	*A. hau*	*Bid. pil*	*Bor. his*	*Dig. adsc*	*Gal. parv*	*Imp. cyl*	*Pan. mon*
			Weed species							
AFS 3	Soybean	I-(Jun'92)30	22.7 (27.5)	19.8 (24.7)	3.3 (4)	-	1.8 (2.2)	5.5 (6.7)	19.4 (23.5)	-
		II-(Sep'92)128	43.5 (20.1)	12.1 (5.6)	-	-	34.6 (16.0)	55.6 (25.7)	47.8 (22.1)	-
	Linseed	I-(Nov'92)25	12.8 (18.4)	9.5 (13.6)	5.0 (7.2)	-	11.7 (16.8)	10.6 (15.2)	8.9 (12.8)	-
		II-(Mar'93)125	-	29.2 (39.2)	14.8 (19.8)	-	-	11.0 (14.8)	6.7 (9.0)	-
	Groundnut	I-(Jun'93)30	17.0 (21)	-	9.6 (11.9)	-	22.1 (27.3)	18.0 (22.2)	-	5.0 (6.2)
		II-(Sep'93)112	125.1 (51.7)	-	10.6 (4.4)	-	33.1 (13.7)	23.7 (9.8)	-	24.9 (10.3)
	Mustard	I-(Nov'93)25	23.0 (34.0)	-	-	-	14.9 (22.0)	8.1 (12.0)	-	8.1 (12.0)
		II-(Mar'94)125	-	-	25.0 (32.7)	-	-	22.6 (29.5)	-	3.8 (5.0)
AFS 4	Soybean	I-(Jun'92)30	5.2 (6.1)	12.0 (14)	6.2 (7.3)	-	28.3 (33.1)	14.4 (16.8)	3.6 (4.2)	-
		II-(Sep'92)128	-	65.6 (30.0)	-	-	24.1 (11.0)	14.0 (6.0)	87.5 (40.0)	-
	Linseed	I-(Nov'92)25	8.0 (11.0)	12.0 (17.9)	4.0 (6)	-	17.0 (25.3)	6.0 (8.9)	10.1 (15.0)	-
		II-(Mar'93)125	-	20.7 (32.6)	8.2 (13)	-	-	12.5 (19.6)	8.2 (13)	-
	Groundnut	I-(Jun'93)30	10.0 (10)	19.5 (20)	11.0 (11)	-	18.8 (18.9)	21.8 (21.8)	-	7.3 (7.3)
		II-(Sep'93)112	-	127.5 (50.2)	53.8 (21.2)	-	44.4 (17.5)	41.7 (18.4)	-	22.9 (9.0)
	Mustard	I-(Nov'93)25	9.3 (13)	15.8 (22.8)	6.0 (8.6)	-	14.7 (21.2)	-	-	11.4 (16.5)
		II-(Mar'94)125	3.7 (4.7)	-	40.2 (50.8)	-	-	13.0 (16.4)	-	3.9 (5.0)

-, absence or biomass less than 1 g m^{-2}.

Species- *A. cony- Ageratum conyzoides, A. hau- A. haustonianum, Bid. pil- Bidens pilosa, Bor. his- Borreria hispida, Dig. adsc- Digitaria adscendens, Gal. par- Galinsoga parviflora, Imp. cyl- Imperata cylindrica, Pan. mon- Panicum montanum* stage. *Bidens pilosa* was present only in early growing stage of the crop in all the four systems.

Linseed cropping period

A. conyzoides was invariably present at early growing stage of linseed under the four systems, but it was absent at the time of crop harvest. Biomass of *G. parviflora* increased at crop harvest in the alder-based system, but decreased in albizia- and mandarin-systems. This weed was absent at this stage in the cherry-system. *B. pilosa* was recorded only at early growing stage of the crops in the albizia-, cherry- and mandarin-systems and only at the time of crop harvest in alder-system.

Groundnut cropping period

The biomass of *B. pilosa*, *Digitaria adscendens* and *G. parviflora* was greater at the time of crop harvest than at early stage of crop growth. *B. pilosa* in the albizia-system showed 100% increase in biomass at the time of crop harvest over its biomass recorded at the early stage of crop growth. Similarly, biomass of *A. haustonianum* also increased under the three systems except in cherry-system where it was totally absent. In the albizia-system this species recorded three-fold increase in its biomass at the time of crop harvest.

Mustard cropping period

During mustard cropping period no weed species recorded a consistent increase or decrease in live green biomass. The biomass of *G. parviflora* increased at the time of crop harvest under alder-, albizia- and cherry-systems, but the species was absent in early growing stage of mustard under mandarin-system. On the other hand, biomass of *A. haustonianum* decreased under alder- and albizia-system at the time of crop harvest.

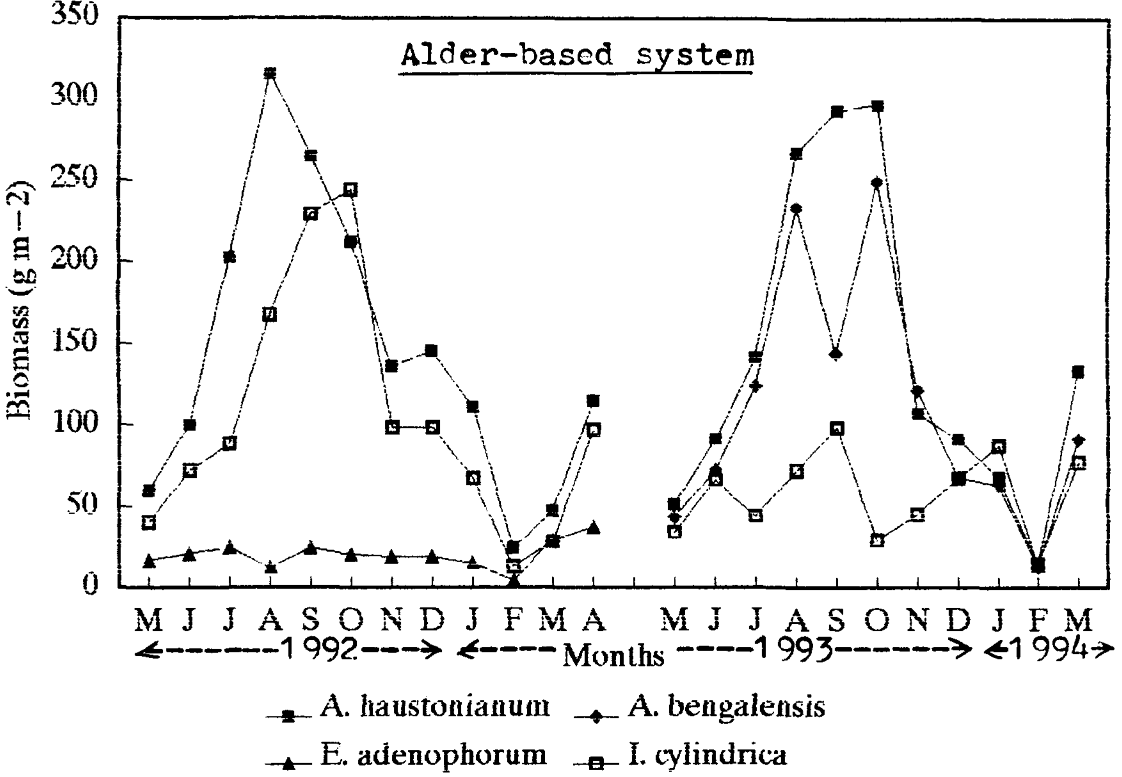
Aboveground live biomass of the dominant weed species viz. *Ageratum haustonianum*, *Arundinella bengalensis*, *Eupatorium adenophorum* and *Imperata cylindrica* in 'tree only' situation under the four agroforestry systems is shown in Fig. 6.7. Live biomass of *A. haustonianum* was consistently high throughout the year during 1992-93. It was followed by *I. cylindrica* under alder-, cherry- and mandarin-systems, and by *A. bengalensis* in albizia-system. All the weed species attained their peak during August to october after which their biomass declined constantly till February (Table 6.2).

Belowground biomass of four agroforestry systems

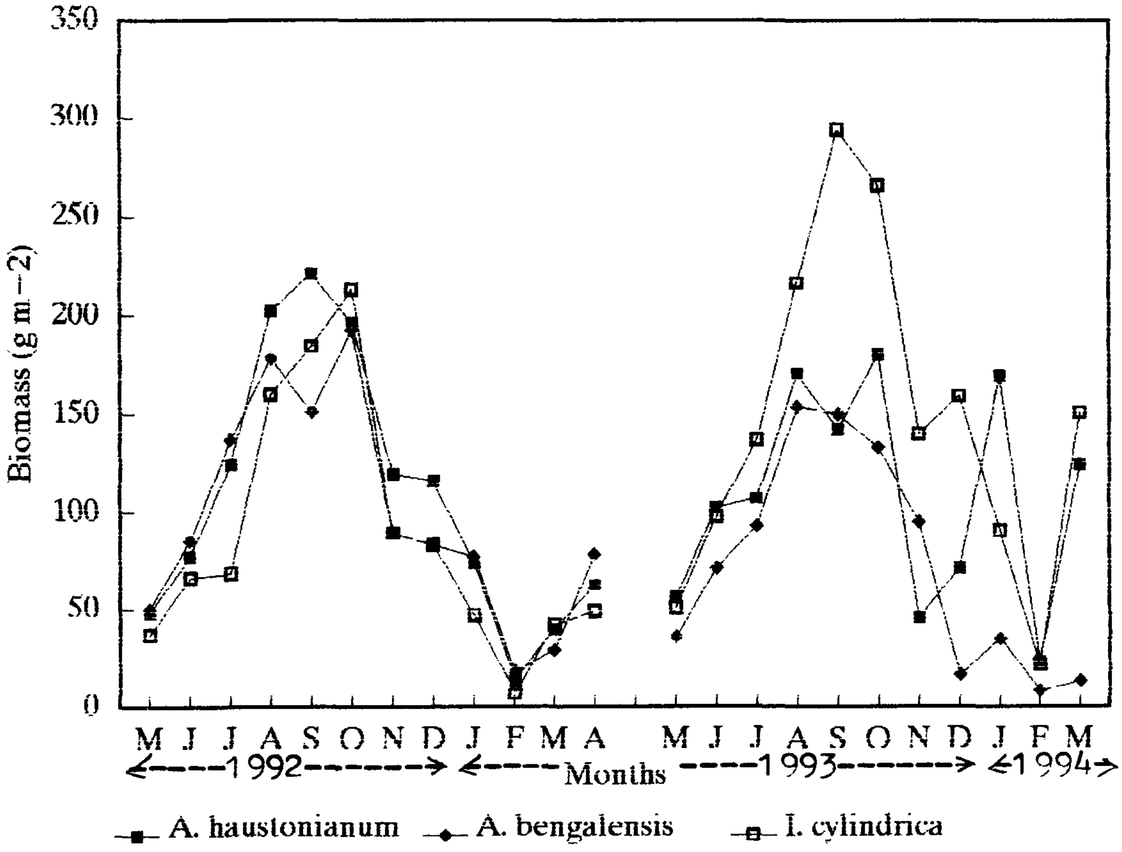
Monthly variations in belowground biomass of crop and weeds in 'tree+crop' situation under the four agroforestry systems are shown in Fig. 6.8. Though at the initial stages the belowground biomass of weeds was more than that of crops, at latter stages the crop plants outyielded weeds, the only exception being the linseed crop, which produced lesser belowground biomass than weeds throughout the growing period.

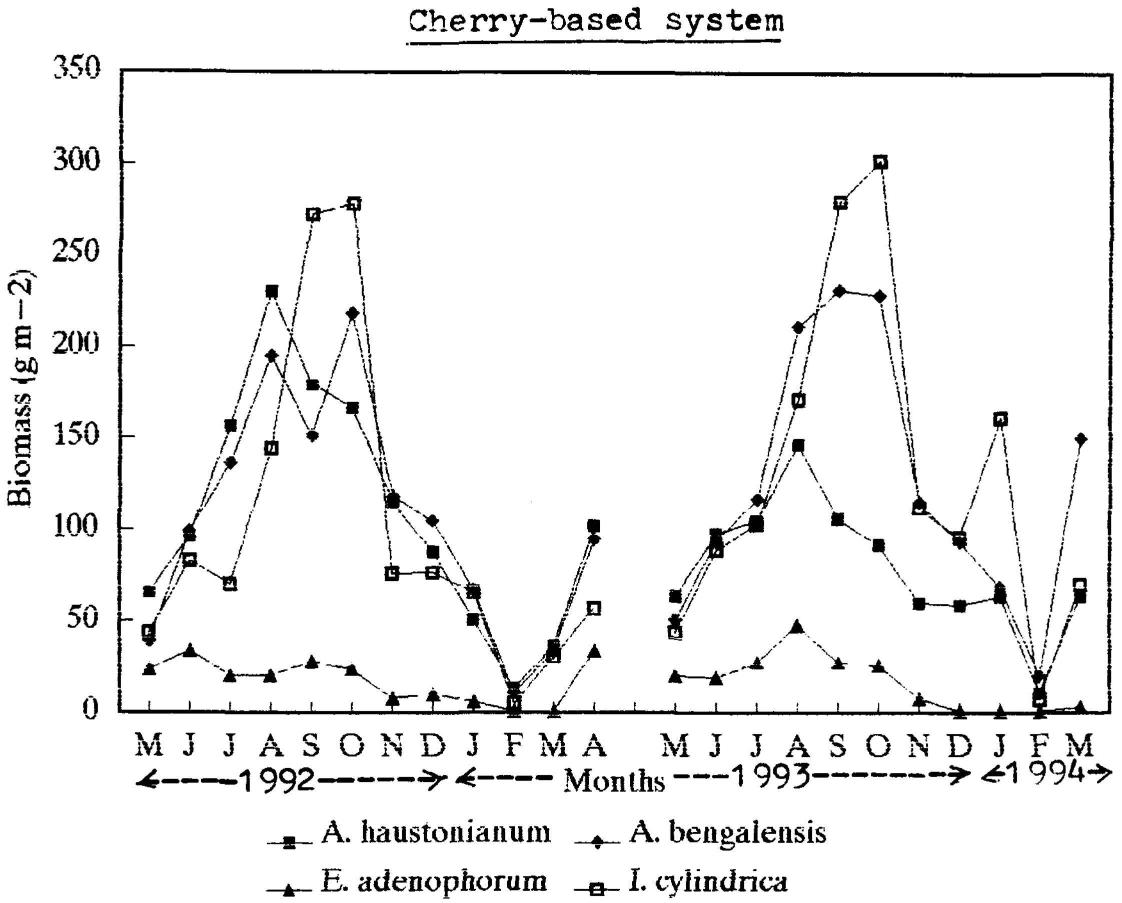
In general, the belowground biomass of crops was much greater than that of weeds. Maximum belowground biomass of weeds was recorded in the mandarin system (166.5 g m^{-2}) in August, 1992 during 1992-93 and in the cherry system (229.8 g m^{-2}) in September, 1993 during 1993-94. Total belowground biomass (crops + weeds) in the 'tree+crop' situation was maximum in October, 1992 in cherry system (352.5 g m^{-2}) during

Fig. 6.7. Monthly variation in livegreen biomass of few dominant weed species in `tree only' situation in the four agroforestry systems.



Albizia-based system




Cherry-based system
Biomass (g m−2)
0
50
100
150
200
250
300
350
M J J A S O N D J F M A M J J A S O N D J F M
←----1992-----→ ←---- Months ---1993-------→ ←1994→
A. haustonianum
A. bengalensis
E. adenophorum
I. cylindrica

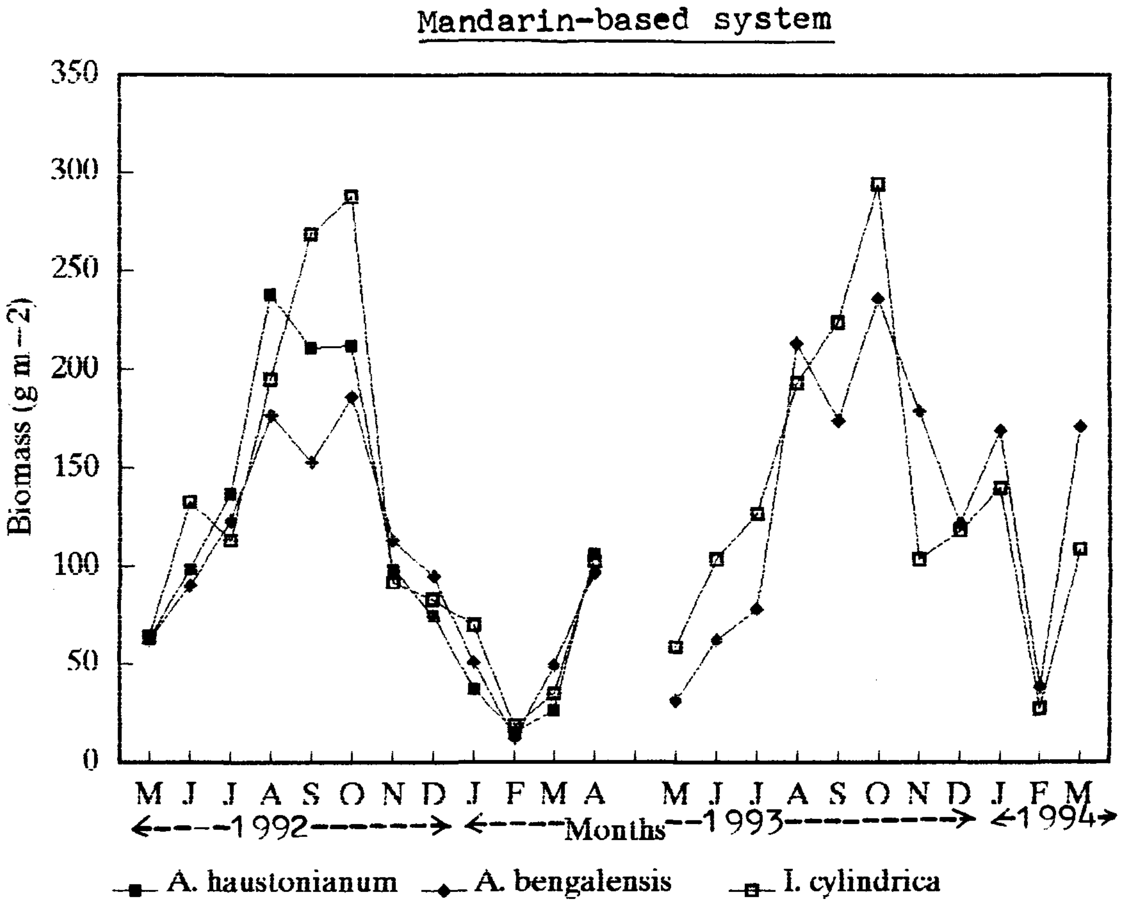
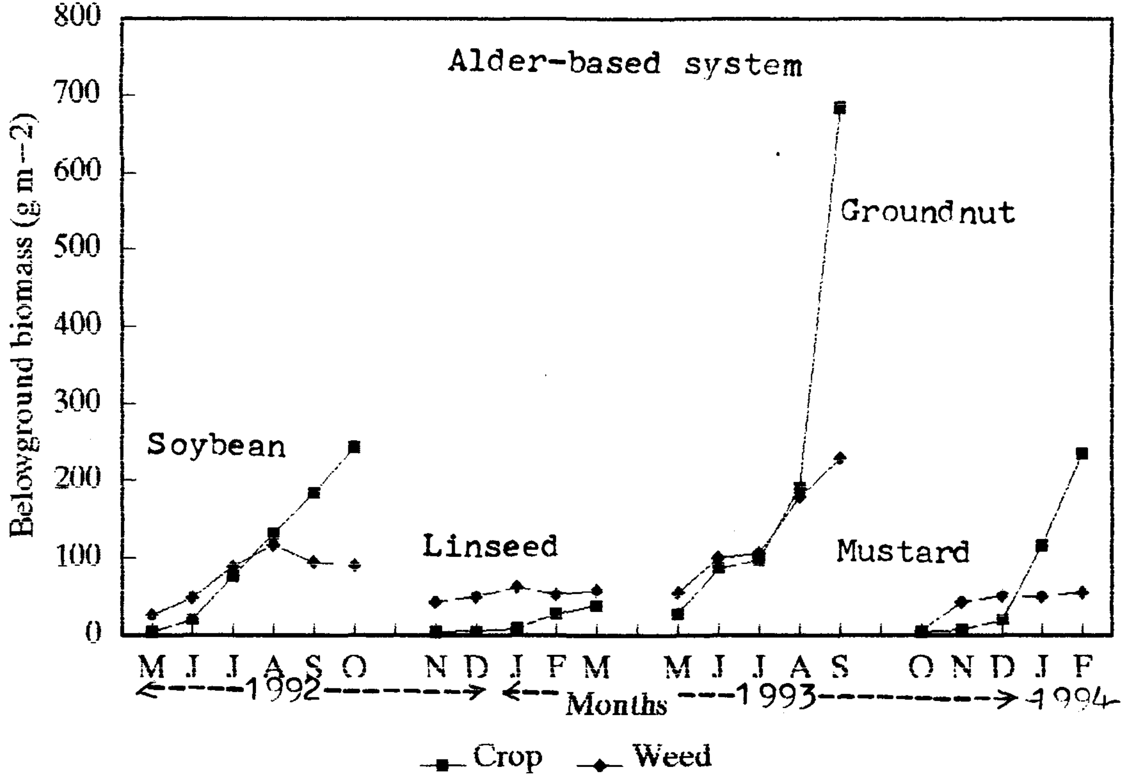

Mandarin-based system
Biomass (g m−2)
0
50
100
150
200
250
300
350
M J J A S O N D J F M A M J J A S O N D J F M
←----1992------→ ←----Months--1993---------→ ←1994→
A. haustonianum
A. bengalensis
I. cylindrica

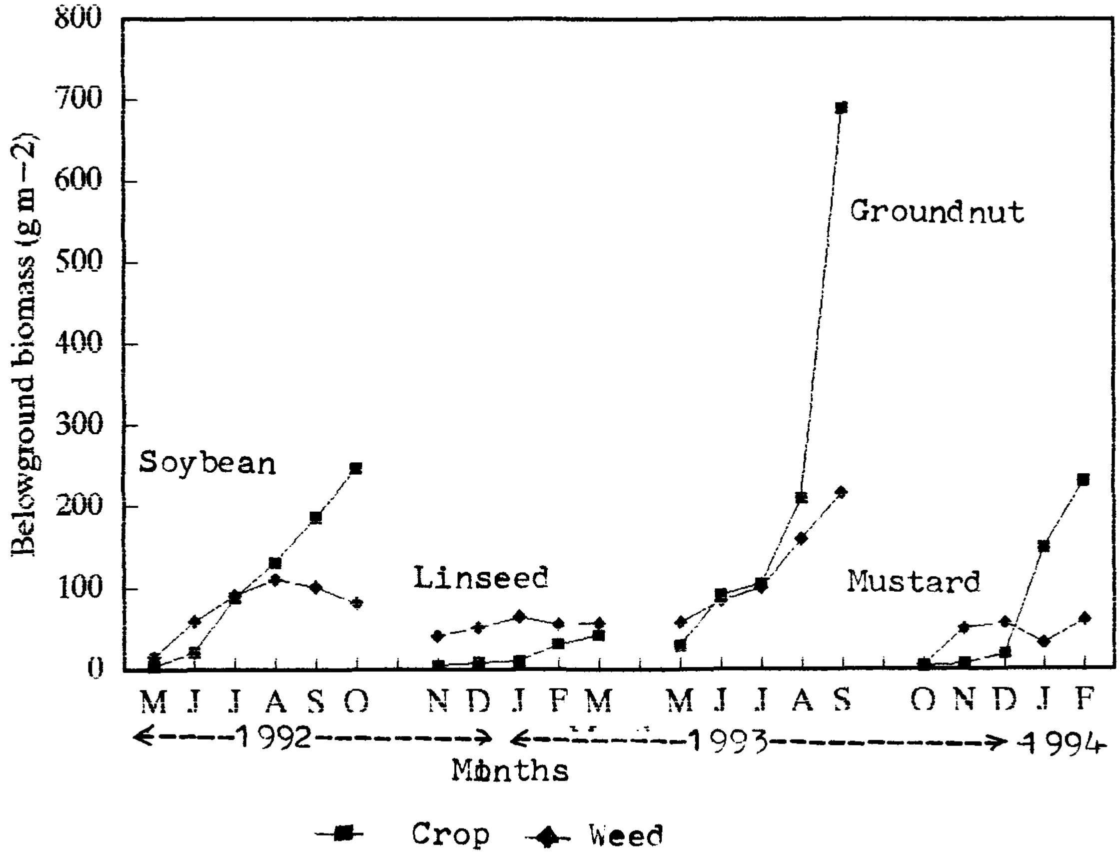
Table 6.2. Monthly variation in percentage contribution of few dominant weed species to the total aboveground biomass in the 'tree only' situation under the four agroforestry systems during 1992-93 and 1993-94.

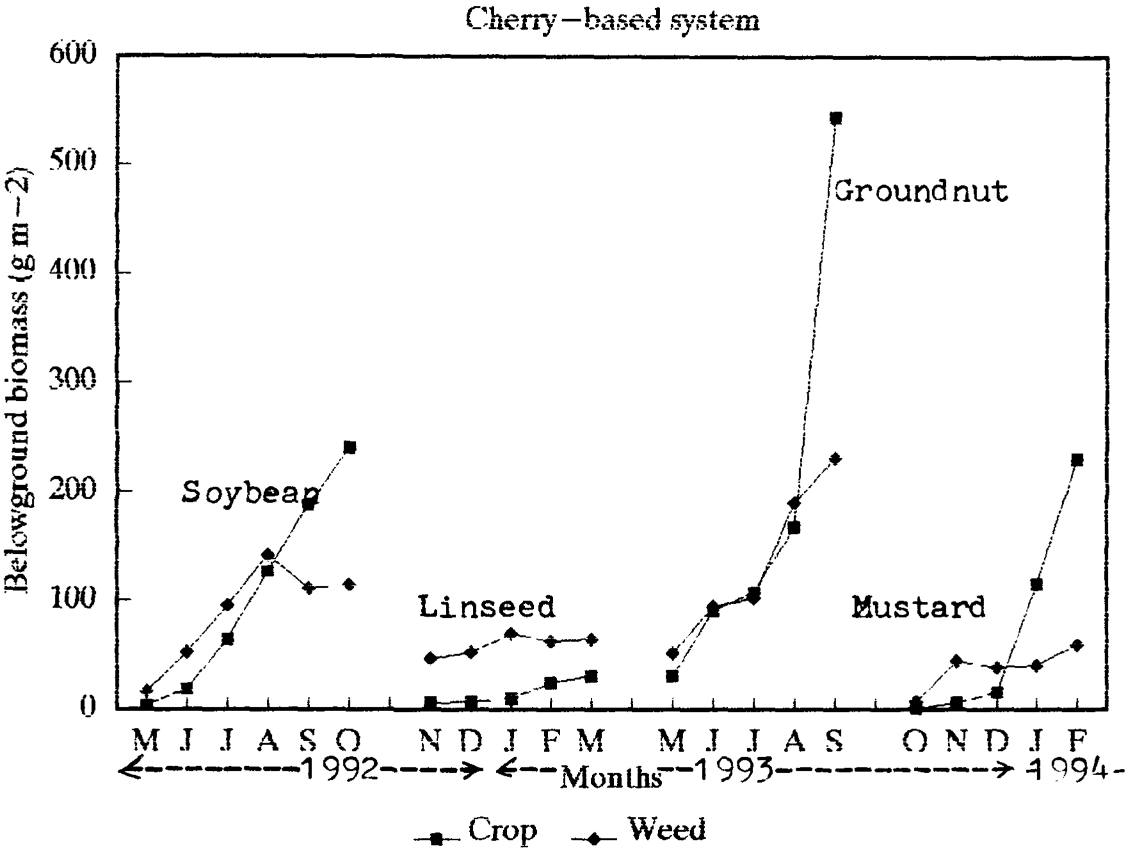
Weed species	Biomass (%)											
	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
1992-93												
AFS 1												
Ageratum haustonianum	30.4	31.7	55.8	52.6	43.5	31.1	43.3	53.5	57.7	58.9	43.3	36.2
Eupatorium odoratum	8.3	6.8	6.8	2.0	4.0	3.0	5.7	7.0	7.6	10.2	26.7	11.5
Imperata cylindrica	20.2	22.7	24.2	28.0	37.5	35.8	31.2	36.0	35.0	30.7	30.0	22.3
AFS 2												
A. haustonianum	25.8	25.0	32.5	33.0	34.9	28.1	35.5	39.6	37.5	35.9	36.0	24.3
A. bengalensis	27.0	27.6	35.9	29.1	23.8	27.4	26.4	28.6	38.9	45.3	26.0	30.6
I. cylindrica	20.1	21.4	17.7	26.1	29.1	30.4	26.4	28.6	23.6	18.7	38.0	18.9
AFS 3												
A. haustonianum	36.8	30.2	40.0	38.0	27.6	23.4	35.4	30.8	26.8	40.0	37.7	34.3
A. bengalensis	21.8	30.7	34.9	32.2	23.3	31.4	36.4	37.1	35.5	34.1	30.8	32.0
E. odaratum	13.5	10.6	5.1	3.3	4.3	3.4	2.6	3.5	2.9	2.1	0.8	11.5
I. cylindrica	24.8	25.7	17.9	23.8	41.9	40.0	23.6	27.2	34.7	16.0	27.7	19.7
AFS 4												
A. haustonianum	30.7	30.7	36.4	38.8	32.9	30.7	31.8	29.2	23.4	32.8	23.2	34.2
A. bengalensis	30.7	28.0	32.7	28.8	23.9	26.9	36.4	36.9	32.2	26.6	44.0	31.5
I. cylindrica	32.0	41.3	30.0	31.8	42.0	41.7	29.5	32.3	44.3	40.6	31.2	32.9
1993-94												
AFS 1												
A. haustonianum	27.1	30.2	38.1	39.6	42.0	41.8	32.5	37.0	31.2	35.0	44.2	30.3
A. bengalensis	22.9	23.9	33.3	34.5	20.7	34.9	36.8	27.0	28.7	32.0	30.2	34.0
I. cylindrica	18.2	21.8	11.9	10.7	14.0	4.1	13.7	27.0	40.0	33.3	25.6	25.8
AFS 2												
A. haustonianum	31.3	32.2	27.6	27.0	20.8	25.6	13.9	26.8	57.3	45.0	43.0	28.0
A. bengalensis	20.2	22.4	23.8	24.5	22.2	19.4	28.5	6.2	11.7	16.0	4.6	47.0
I. cylindrica	28.4	30.9	35.1	34.5	43.0	38.1	42.3	59.8	30.8	41.0	52.3	57.5
AFS 3												
A. haustonianum	32.2	30.9	27.6	22.6	15.6	13.0	18.2	23.2	21.9	29.6	21.9	35.3
A. bengalensis	25.7	29.8	30.6	32.7	34.0	32.9	34.6	37.2	23.5	51.8	51.0	30.2
E. odaratum	9.8	6.1	7.1	7.5	4.0	3.7	2.5	-	-	-	1.0	10.1
I. cylindrica	22.3	28.2	27.0	26.5	41.3	42.9	33.9	38.0	54.8	19.0	23.9	16.0
AFS 4												
A. bengalensis	17.1	20.0	20.7	30.0	24.3	32.0	49.6	42.4	53.3	57.9	57.1	19.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39.8	28.7	41.1	44.0	42.1	36.4	36.8

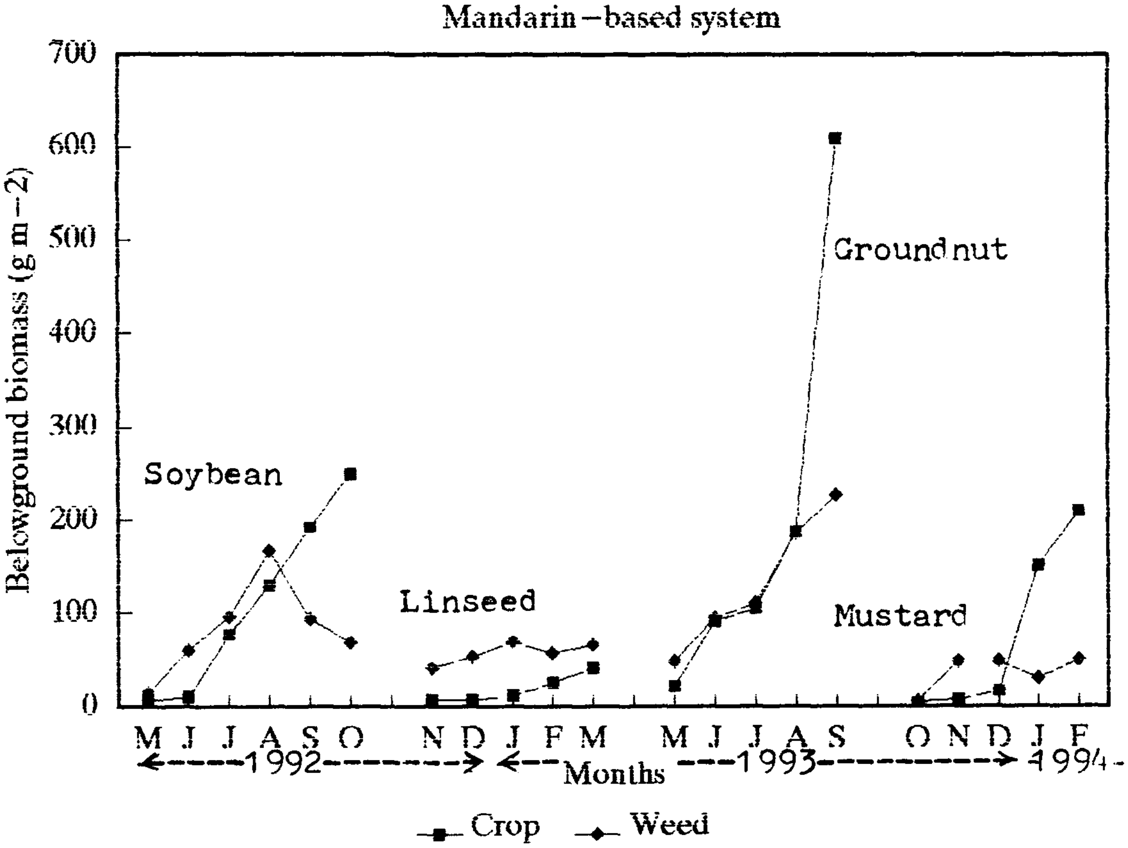
Fig. 6.8. Temporal variation in belowground biomass of crops and weeds in `tree+crop' situation under the four agroforestry systems.



Albizia–based system




Cherry–based system
Belowground biomass (g m−2)
600
500
400
300
200
100
0
Soybean
Linseed
Groundnut
Mustard
M J J A S O N D J F M M J J A S O N D J F
1992
Months
1993
1994
Crop
Weed


Mandarin–based system
Belowground biomass (g m−2)
700
600
500
400
300
200
100
0
Soybean
Linseed
Groundnut
Mustard
M J J A S O N D J F M M J J A S O N D J F
1992
Months
1993
1994
Crop
Weed

1992-93, and in September, 1993 in the alder system (912.4 g m^{-2}) during 1993-94. On the other hand, in the 'tree only' situation the maximum belowground biomass was observed in August in the albizia system (595 g m^{-2}) during 1992-93 and in the mandarin-system (612 g m^{-2}) during 1993-94 (Fig. 6.9).

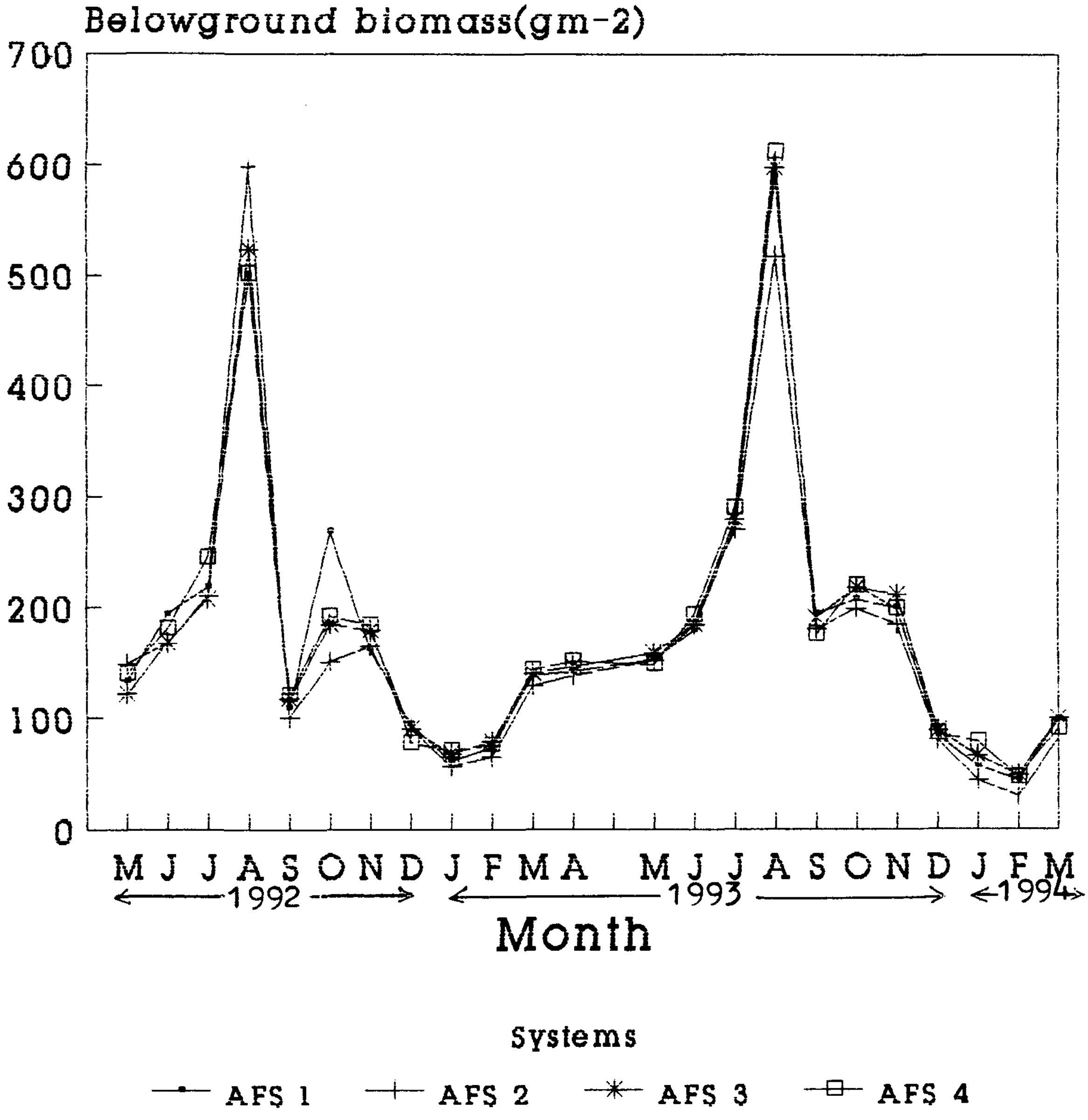
Vertical distribution of belowground biomass

Belowground biomass of weeds and crops in the 'tree+crop' situation was highest in the top 10 cm soil layer and it decreased with increase in soil depth. Time series data on belowground biomass showed that month to month fluctuation was greater in 0-10 cm depth as compared to 10-20 and 20-30 cm depths (Fig. 6.10). The month of peak belowground biomass varied among the four systems as well as between the two years. In the 'tree only' situation belowground biomass in 0-10 cm depth sharply increased from June '92 to August '92; March '93 to April '93; June '93 to August '93; and March '94 to April '94 in all the four systems, whereas in other months it decreased or remained almost unchanged. Data revealed that in the 'tree+crop' situation 66-68% of the total belowground biomass of weeds under the four systems was present in the top 10 cm soil layer, whereas in 'tree only' situation the top 10 cm soil contained as high as 82-84% of the total belowground biomass of the weed species (Fig. 6.11).

Distribution of belowground biomass between roots and rhizome

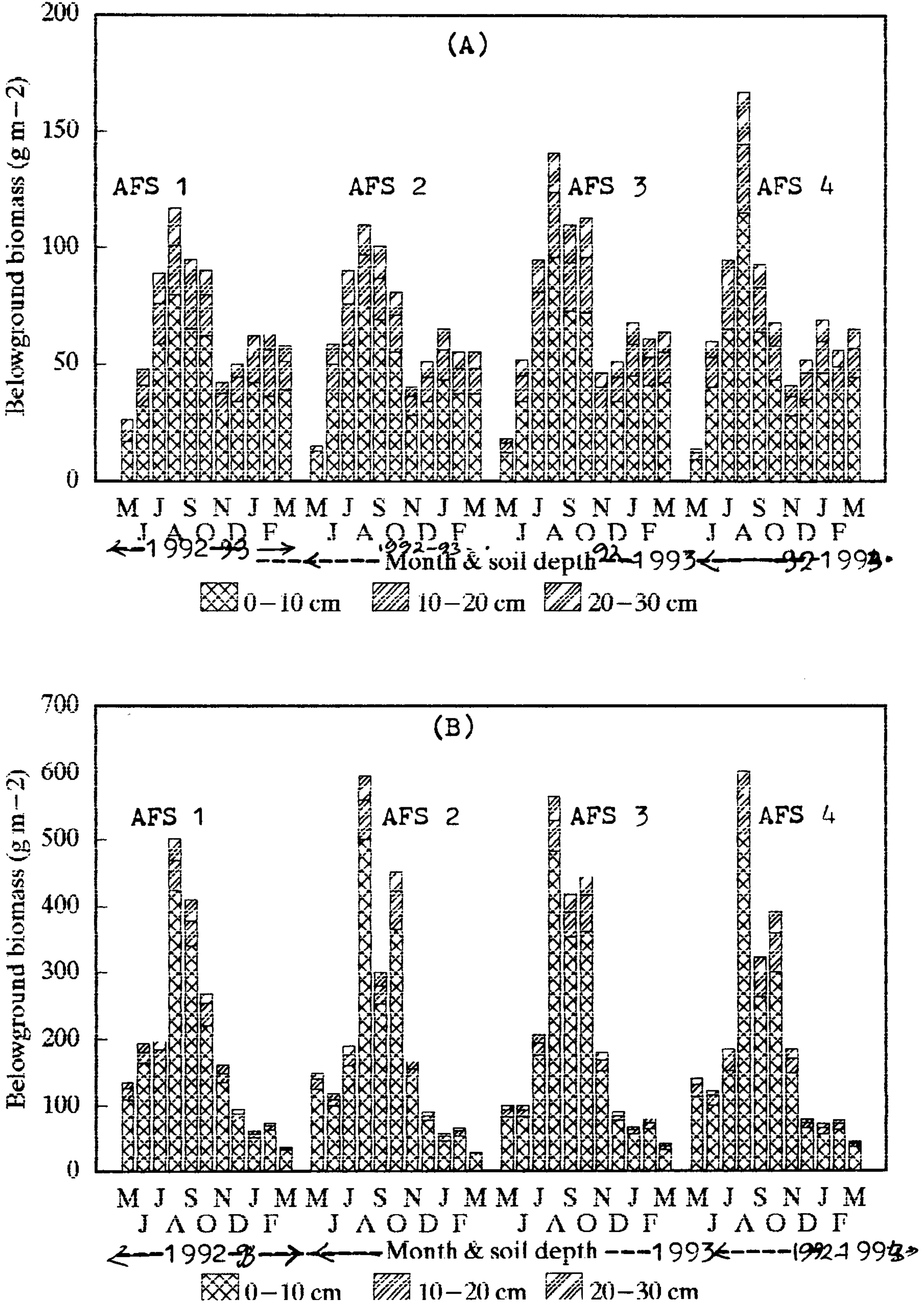
Root biomass in the 'tree+crop' situation was greater than the rhizome biomass, whereas in 'tree only' situation the reverse was true (Fig. 6.12). Maximum biomass of roots and rhizome was recorded during August in both the situations. In

Fig. 6.9. Temporal variation in below-ground biomass of weeds and trees in the 'tree only' situation.



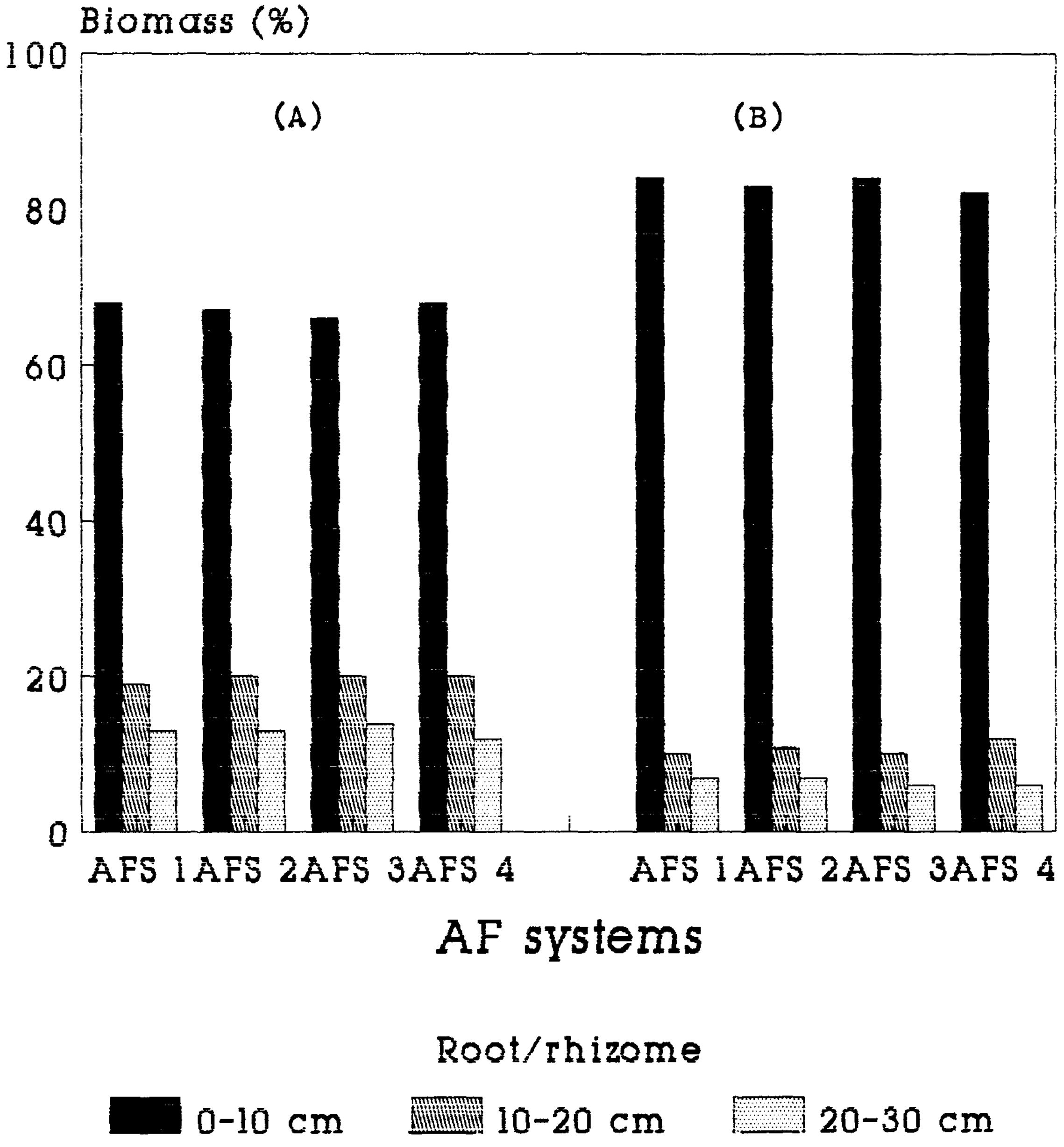
AFS 1-alder-, AFS 2-albizia-, AFS 3-cherry-, and AFS 4-mandarin-systems.

Fig. 6.10. Temporal variation in belowground biomass at three depths in 'tree+crop'(A) & 'tree only' (B) situations under the four systems.



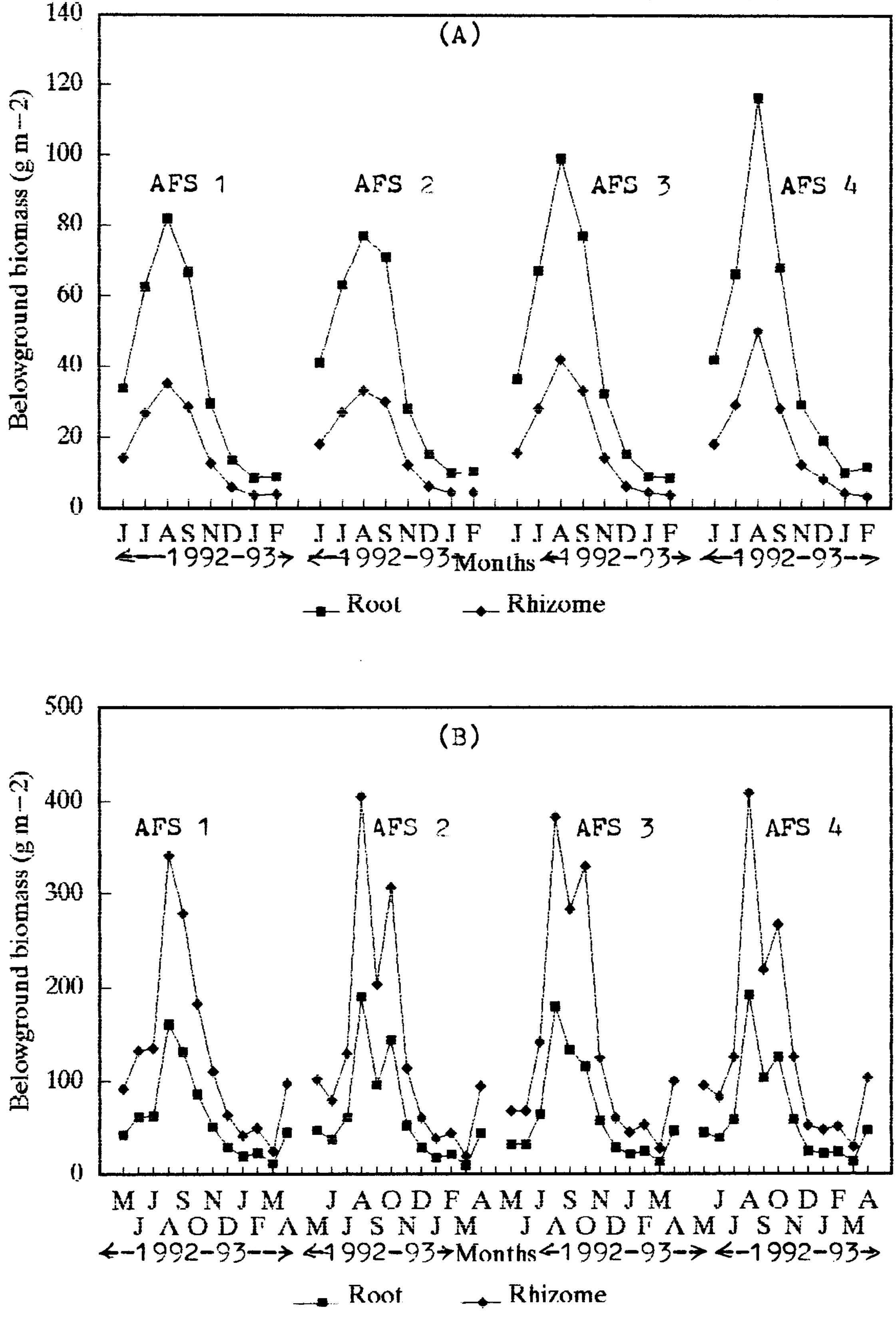
AFS 1−alder−, AFS 2−Albizia−, AFS−3−cherry
AFS 4−mandarin−based systems.

Fig.6.11. Distribution(%) of belowground biomass at three depths in the 'tree+ crop'(A) and 'tree only'(B) situations.



AFS 1-alder-, AFS 2-albizia-, AFS 3-cherry-, AFS 4-mandarin-based systems.

Fig. 6.12. Temporal variation in root & rhizome biomass in 'tree +crop'(A) & 'tree only'(B) situations in four agroforestry systems.



AFS 1—alder—, AFS 2—albizia—, AFS 3—cherry—,
AFS 4—mandarin—based systems.

the 'tree+crop' situation both root and rhizome biomass of weeds increased steadily during crop growing period, whereas in 'tree only' situation the root and rhizome biomass of weed species did not show any consistent trend with the passage of time. Rhizome biomass in 'tree only' situation increased rapidly during winter period and again during June-July while in other months rhizome biomass either decreased or showed only a negligible increase. Of the total belowground weed biomass, root and rhizome in the top 10 cm layer contributed 73 and 27% respectively in the 'tree +crop', and 28 and 72% in 'tree only' situation (Fig. 6.11).

ANP

Among the four crops, soybean showed highest rate of ANP (Table 6.3) under the four systems. The ranking for the rate of ANP of the crops under the four systems was soybean >mustard >linseed >groundnut. Overall ranking for the rate of ANP among the four systems was albizia >mandarin >alder >cherry, though the differences in the ANP rates were not significant ($P<0.05$). Rates of ANP of the crops, weeds and of secondary successional plants in the 'tree+crop' situation varied from month to month. ANP rates for weeds and crops varied widely. The ANP of weeds was maximum in June/July 1992 during 1992-93 and in July 1993 during 1993-94 (Table 6.3). For the crops maximum ANP was recorded in October 1992 during 1992-93 with soybean. The maximum ANP of weeds was greater than that of groundnut, linseed and mustard but it was lower than soybean. In the 'tree only' situation maximum ANP was recorded in August during both the years except in alder-

Table 6.3. Monthly variation in aboveground net primary productivity (g m^{-2}) in the 'tree+crop' situation under the four agroforestry systems. Values in parentheses are rates of net primary production (g m^{-2}day^{-1}).

Systems	Component	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
May'92 - Mar'93												
AFS 1	Crop[‡]	8.6	15.6	8.6	41.7	23.7	153.5	6.9	33.7	24.0	23.8	31.1
		(0.4)	(0.5)	(0.3)	(1.4)	(0.8)	(15.4)	(0.2)	(0.8)	(0.8)	(0.9)	(6.2)
	Weed	36.2	52.2	74.0	36.3	2.5	0	64.1	79.6	0	0	23.6
		(1.7)	(1.7)	(2.4)	(1.1)	(0.1)		(2.4)	(2.6)			(4.7)
	Total	**44.8**	**67.8**	**82.6**	**78.0**	**26.2**	**153.5**	**71.0**	**113.3**	**24.0**	**23.8**	**54.7**
AFS 2	Crop	9.2	17.2	6.2	46.9	28.9	168.9	9.3	37.1	23.1	29.2	24.9
		(0.4)	(0.6)	(0.2)	(1.5)	(1.0)	(16.3)	(0.3)	(1.2)	(0.8)	(1.0)	(5.0)
	Weed	15.8	83.8	69.6	19.5	10.3	0	55.1	92.5	0	0	43.2
		(0.8)	(2.8)	(2.2)	(0.6)	(0.3)		(1.8)	(3.0)			(8.6)
	Total	**25.0**	**101.0**	**76.8**	**66.4**	**39.2**	**168.9**	**64.4**	**129.6**	**23.1**	**29.2**	**68.1**
AFS 3	Crop	7.9	13.9	7.8	48.6	8.6	159.6	7.1	30.5	22.3	31.4	14.5
		(0.4)	(0.5)	(0.3)	(1.6)	(0.3)	(16.0)	(0.2)	(1.0)	(0.7)	(1.1)	(2.9)
	Weed	19.8	62.6	85.2	24.5	24.0	0	69.8	78.9	0	0	35.7
		(0.9)	(2.0)	(2.7)	(0.8)	(0.8)		(2.3)	(2.6)			(7.1)
	Total	**27.7**	**76.5**	**93.0**	**73.1**	**32.6**	**159.6**	**76.9**	**109.4**	**22.3**	**31.4**	**50.2**
AFS 4	Crop	10.4	17.8	8.2	44.1	19.2	162.1	10.4	41.3	22.1	30.7	21.4
		(0.5)	(0.6)	(0.3)	(1.4)	(0.6)	(16.2)	(0.4)	(1.3)	(0.7)	(1.1)	(4.3)
	Weed	20.1	65.3	80.5	32.1	20.8	0	67.4	86.0	0	0	26.3
		(1.0)	(2.1)	(2.6)	(1.0)	(0.7)		(2.3)	(2.7)			(5.3)
	Total	**30.5**	**83.1**	**89.7**	**76.2**	**40.0**	**162.1**	**77.8**	**127.3**	**22.1**	**30.7**	**47.7**

[‡] Soybean (May-October), Linseed (November-March)

[‡‡] Groundnut(May-October), Mustard (November-March)

contd..........

Table 6.3 contd.......

Systems	Comp-onent	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
May'93 - Mar'94												
AFS 1	Crop[‡‡]	4.8	3.6	15.8	12.6	74.0	0	24.8	39.9	5.1	22.3	38.6
		(0.9)	(0.1)	(0.5)	(0.4)	(2.6)		(0.8)	(1.2)	(0.2)	(0.8)	(19.3)
	Weed	42.8	38.8	113.2	16.9	39.6	0	76.8	47.7	0	0	21.1
		(8.6)	(1.3)	(3.7)	(0.6)	(1.4)		(2.6)	(1.5)			(10.6)
	Total	**47.6**	**42.4**	**129.0**	**29.5**	**113.6**	**0**	**101.6**	**87.6**	**5.1**	**22.3**	**59.7**
AFS 2	Crop	4.1	1.5	27.6	5.9	79.1	0	26.9	42.6	8.6	31.4	41.4
		(0.8)	(0.05)	(0.9)	(0.2)	(2.7)		(0.9)	(1.4)	(0.3)	(1.1)	(20.7)
	Weed	51.7	39.1	96.8	41.8	17.8	0	67.2	53.6	0	0	31.1
		(10.3)	(1.3)	(3.1)	(1.4)	(0.6)		(2.2)	(1.8)			(15.6)
	Total	**55.8**	**40.6**	**124.4**	**47.7**	**96.9**	**0**	**94.1**	**96.2**	**8.6**	**31.4**	**75.5**
AFS 3	Crop	3.8	5.4	12.2	11.4	66.7	0	20.3	35.9	2.9	24.4	34.4
		(0.8)	(0.2)	(0.4)	(0.4)	(2.3)		(0.7)	(1.2)	(0.1)	(0.8)	(17.2)
	Weed	40.1	40.8	118.8	19.1	23.1	0	67.8	59.1	0	0	32.4
		(8.0)	(1.4)	(3.8)	(0.6)	(0.8)		(2.3)	(1.9)			(16.2)
	Total	**43.9**	**46.2**	**131.0**	**30.5**	**89.8**	**0**	**88.1**	**95.0**	**2.9**	**24.4**	**66.8**
AFS 4	Crop	3.8	2.6	31.8	9.9	68.3	0	27.8	43.5	6.1	27.5	39.1
		(0.8)	(0.9)	(1.0)	(0.3)	(2.3)		(0.9)	(1.4)	(0.2)	(1.0)	(19.6)
	Weed	47.6	52.1	91.8	46.6	15.9	0	69.2	54.2	0	0	31.4
		(9.5)	(1.7)	(2.9)	(1.5)	(0.6)		(2.3)	(1.8)			(15.7)
	Total	**51.4**	**54.7**	**123.6**	**56.5**	**84.2**	**0**	**97.0**	**97.7**	**6.1**	**27.5**	**70.5**

[†] Soybean (May-October), Linseed (November-March)

[‡‡] Groundnut(May-October), Mustard (November-March)

AFS 1- Alder-based agroforestry system
AFS 2- Albizia-based agroforestry system
AFS 3- Cherry-based agroforestry system and
AFS 4- Mandarin-based agroforestry system

system during 1992-93 where the maximum ANP was recorded in April 1993 (Table 6.4). The maximum ANP in the 'tree only' situation was greater than that of weeds and crops in 'tree+crop' situation.

Table 6.4. Monthly variation in aboveground net primary productivity (g m^{-2}) in the 'tree only' situation under the four agroforestry systems. Values in parentheses are rates of production (g $m^{-2} day^{-1}$).

Month	Agroforestry systems							
	AFS 1	AFS 2	AFS 3	AFS 4	AFS 1	AFS 2	AFS 3	AFS 4
	1992-93				1993-94			
May	198.6	184.5	179.0	200.4	188.7	179.0	199.1	181.0
	(6.4)	(5.9)	(5.8)	(6.5)	(6.1)	(5.8)	(6.4)	(5.8)
Jun	116.2	122.7	142.5	122.6	113.3	138.0	117.9	128.0
	(3.8)	(4.1)	(4.8)	(4.1)	(3.8)	(4.6)	(3.9)	(4.3)
Jul	49.3	74.3	68.5	53.0	69.0	72.0	64.0	68.0
	(1.6)	(2.4)	(2.2)	(1.7)	(2.2)	(2.3)	(2.0)	(2.2)
Aug	233.9	230.0	214.5	237.0	303.0	239.0	263.0	332.0
	(7.6)	(7.4)	(6.9)	(7.6)	(9.8)	(7.7)	(8.5)	(10.7)
Sep	11.7	21.5	42.5	27.0	24.0	56.0	35.0	8.0
	(0.4)	(0.7)	(1.4)	(0.9)	(0.8)	(1.8)	(1.1)	(0.3)
Oct	71.5	68.0	47.5	51.0	13.0	17.0	25.0	19.0
	(2.3)	(2.2)	(1.5)	(1.6)	(0.4)	(0.6)	(0.8)	(0.6)
Nov	0	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0
Jan	0	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	0
Mar	68.3	71.4	75.4	67.7	260.9	239.5	257.0	234.2
	(2.2)	(2.3)	(2.4)	(2.2)	(8.4)	(7.6)	(8.3)	(7.6)
Apr	267.4	145.0	187.6	197.4	0	0	0	0
	(8.9)	(4.8)	(6.3)	(6.6)				

AFS 1- Alder-based agroforestry system
AFS 2- Albizia-based agroforestry system
AFS 3- Cherry-based agroforestry system, and
AFS 4- Mandarin-based agroforestry system.

Contribution of individual species to the ANP

Annual ANP of individual species varied widely between 1992-93 and 1993-94. In the 'tree+crop' situation contribution of weed species such as *Ageratum conyzoides*, *A. haustonianum*, *Digitaria adscendens* and *G. parviflora* was higher than other species. The highest annual ANP (Ca 37-38%) was contributed by either *A. conyzoides* or *A. haustonianum* (Table 6.5). However, in the 'tree only' situation the highest ANP (Ca 37-42%) was contributed by *A. haustonianum* during 1992-93 and by *I. cylindrica* during 1993-94 (Table 6.6). The maximum contribution of any given species to the total ANP was about 38% in the 'tree+crop' and 42% in 'tree only' situation. There were seven dominant weed species during 1992-93 and six during 1993-94, which contributed >1% to the total annual ANP of weeds in the 'tree+crop' situation. Likewise, the number of dominant weed species in the 'tree only' situation was six during 1992-93 and seven during 1993-94.

BNP

BNP of crops as well as weeds varied widely in different months in the 'tree+crop' situation under the four systems (Table 6.7). Among the four crops, groundnut had maximum rate of BNP in September 1993 during 1993-94, which was much higher than that of weeds. However, there was no significant difference in the rate of BNP among the four systems. The rate of BNP of the secondary successional plants in the 'tree only' situation also varied widely from month to month (Table 6.8).

Table 6.5. Aboveground net primary productivity ($g\ m^{-2}yr^{-1}$) of important weed* species in 'tree+crop' situation and their percentage contribution to the total weed ANP.

Species	Productivity and % Contribution							
/Systems	AFS 1	AFS 2	AFS 3	AFS 4	AFS 1	AFS 2	AFS 3	AFS 4
	May 1992 - April 1993				May 1993- April 1994			
Galinsoga parviflora	89.7 (24.3)	105.6 (27.1)	74.9 (18.5)	72.4 (18.1)	87.3 (22.0)	89.0 (22.3)	104.3 (26.0)	90.5 (22.5)
Ageratum haustonianum	-	87.6 (24.8)	78.9 (19.7)	100.1 (25.1)	123.2 (31.0)	152.3 (38.2)	-	119.4 (29.2)
Ageratum conyzoides	137.5 (37.3)	61.6 (15.8)	76.5 (19.1)	19.9 (5.0)	25.2 (6.4)	-	136.8 (34.1)	26.6 (6.5)
Digitaria adscendens	59.7 (16.2)	-	50.9 (12.7)	64.6 (16.2)	67.5 (17.0)	93.4 (23.4)	77.8 (19.4)	67.9 (16.6)
Bidens pilosa	57.5 (15.6)	44.0 (11.3)	28.0 (7.0)	39.8 (10)	54.6 (13.8)	64.2 (16.1)	70.6 (17.6)	74.4 (18.2)
Imperata cylindrica	-	-	93.1 (23.2)	99.6 (25.0)	-	-	-	-
Borreria hispida	26.2 (7.1)	36.3 (9.3)	-	-	36.1 (9.1)	-	-	-
Panicum montanum	-	-	-	-	-	-	30.0 (7.4)	32.7 (7.9)

*Those species which contributed >5% to ANP.
-, absence

AFS 1- Alder-based agroforestry system
AFS 2- Albizia-based agroforestry system
AFS 3- Cherry-based agroforestry system, and
AFS 4- Mandarin-based agroforestry system.

Table 6.6. Aboveground net primary productivity (g $m^{-2}yr^{-1}$) of important species* in 'tree only' situation and their percentage contribution to the total weed ANP.

Species	Productivity and % Contribution							
/Systems	AFS 1	AFS 2	AFS 3	AFS 4	AFS 1	AFS 2	AFS 3	AFS 4
	May 1992 - April 1993				May 1993- April 1994			
Imperata cylindrica	295.0 (29)	221.6 (24.2)	262.4 (27.4)	335.1 (35.0)	169.1 (17.4)	343.1 (36.6)	288.3 (30.0)	341.0 (35.2)
Ageratum haustonianum	431.7 (42)	287.2 (31)	319.8 (33.4)	310.7 (32.5)	334.8 (34.5)	257.3 (27.5)	225.8 (23.5)	-
Arundinella bengalensis	-	272.5 (29.7)	303.1 (31.7)	302.4 (31.6)	278.0 (28.6)	185.6 (19.8)	316.2 (32.9)	300.8 (31.0)
Digitaria adscendens	224.7 (22)	135.8 (14.8)	-	-	155.5 (16.0)	119.1 (12.7)	-	185.3 (19.1)
Eupatorium odaratum	64.4 (6.3)	-	47.9 (5.0)	-	-	-	46.1 (4.8)	-
Ambrossia artemisifolia	-	-	-	-	-	-	48.1 (5.1)	97.0 (10.0)
Desmodium microphylla	-	-	-	-	-	-	-	26.2 (2.7)
Mimosa pudica	-	-	10.5 (1.1)	-	-	-	-	-

*Those species which contributed >1% to ANP.
-, absence

AFS 1- Alder-based agroforestry system
AFS 2- Albizia-based agroforestry system
AFS 3- Cherry-based agroforestry system, and
AFS 4- Mandarin-based agroforestry system.

Table 6.7. Monthly variation in belowground net primary productivity ($g\ m^{-2}$) in the 'tree+crop' situation under the four agroforestry systems. Values in parentheses are rates of net primary production ($g\ m^{-2} day^{-1}$).

Systems	Component	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
May'92 - Mar'93												
AFS 1	Crop*	2.9	15.7	57.8	53.1	53.5	59.8	3.4	1.2	3.5	19.7	10.8
		(0.6)	(0.5)	(1.8)	(1.7)	(1.8)	(6.0)	(0.1)	(0.04)	(0.1)	(0.1)	(2.2)
	Weed	25.8	21.8	41.7	28.1	0	0	41.8	8.6	11.5	0	4.8
		(5.2)	(0.7)	(1.3)	(0.9)			(1.4)	(0.2)	(0.4)		(1.0)
	Total	**28.7**	**37.5**	**99.5**	**81.2**	**53.5**	**59.8**	**45.2**	**9.8**	**15.0**	**19.7**	**15.6**
AFS 2	Crop	3.6	16.3	68.2	43.4	54.9	60.1	5.4	1.4	3.5	19.3	11.9
		(0.7)	(0.5)	(2.2)	(1.4)	(1.8)	(6.0)	(0.2)	(0.04)	(0.1)	(0.7)	(2.4)
	Weed	14.9	43.8	31.1	19.9	0	0	40.3	11.1	12.9	0	1.2
		(2.9)	(1.5)	(1.0)	(0.6)			(1.3)	(0.4)	(0.4)		(0.2)
	Total	**18.5**	**60.1**	**99.3**	**63.3**	**54.9**	**60.1**	**45.7**	**12.5**	**16.4**	**19.7**	**13.1**
AFS 3	Crop	4.1	13.8	46.4	62.1	61.4	51.6	5.9	0.7	2.0	15.0	6.1
		(0.8)	(0.5)	(1.5)	(2.0)	(2.0)	(5.2)	(0.2)	(0.02)	(0.1)	(0.5)	(1.2)
	Weed	17.8	33.8	43.2	46.6	0	2.9	46.4	5.7	16.6	0	2.3
		(3.6)	(1.1)	(1.4)	(1.5)		(0.3)	(1.6)	(0.2)	(0.5)		(0.5)
	Total	**21.9**	**47.6**	**89.6**	**108.7**	**61.4**	**54.5**	**52.3**	**6.4**	**18.6**	**15.0**	**8.4**
AFS 4	Crop	5.0	5.1	65.5	54.3	61.6	58.6	6.1	1.2	4.1	13.4	15.9
		(1.0)	(0.2)	(2.1)	(1.8)	(2.0)	(5.9)	(0.2)	(0.04)	(0.1)	(0.5)	(3.2)
	Weed	13.7	46.4	34.6	71.8	0	0	41.4	11.3	15.8	0	9.3
		(2.7)	(1.6)	(1.1)	(2.3)			(1.4)	(0.4)	(0.5)		(1.8)
	Total	**18.7**	**51.5**	**100.1**	**126.1**	**61.6**	**58.6**	**47.5**	**12.5**	**19.9**	**13.4**	**24.9**
May'93 - Mar'94												
AFS 1	Crop**	28.4	58.0	10.4	92.9	394.4	2.6	4.1	12.6	134.9	79.9	-
		(1.3)	(1.9)	(0.3)	(3.0)	(13.6)	(0.08)	(0.1)	(0.4)	(4.3)	(2.8)	
	Weed	54.6	45.1	6.5	71.8	50.3	5.4	36.4	9.6	0	6.0	35.2
		(2.6)	(1.5)	(0.2)	(2.3)	(1.7)	(0.1)	(1.2)	(0.3)		(0.2)	(1.1)
	Total	**83.0**	**103.1**	**16.9**	**164.7**	**444.7**	**8.0**	**40.5**	**22.2**	**134.9**	**85.9**	**35.2**
AFS 2	Crop	27.8	61.8	15.2	105.5	479.4	3.0	2.9	11.7	131.5	81.6	-
		(1.3)	(2.1)	(0.5)	(3.4)	(16.5)	(1.0)	(0.1)	(0.4)	(4.2)	(2.9)	
	Weed	57.5	26.6	16.0	58.4	57.6	4.5	45.2	6.4	0	29.2	36.4
		(2.7)	(0.9)	(0.5)	(1.8)	(2.0)	(0.1)	(1.5)	(0.2)		(1.0)	(1.2)
	Total	**85.3**	**88.4**	**31.1**	**163.9**	**537.0**	**7.5**	**48.1**	**18.1**	**131.5**	**110.8**	**36.4**
AFS 3	Crop	29.7	60.1	18.3	59.2	377.0	1.1	4.1	10.2	98.9	114.7	-
		(1.4)	(2.0)	(0.6)	(1.9)	(13.0)	(0.04)	(0.1)	(0.3)	(3.2)	(4.1)	
	Weed	50.5	33.7	17.5	87.8	40.3	6.7	37.1	0	1.7	19.2	35.4
		(2.4)	(1.0)	(0.6)	(2.8)	(1.4)	(0.2)	(1.2)		(0.05)	(0.7)	(1.1)
	Total	**80.2**	**93.8**	**35.8**	**147.0**	**417.3**	**7.8**	**41.2**	**10.2**	**100.6**	**133.9**	**35.4**
AFS 4	Crop	22.3	69.4	13.0	82.9	422.1	4.1	2.2	10.1	134.1	59.2	-
		(1.2)	(2.3)	(0.4)	(2.7)	(14.6)	(0.1)	(0.07)	(0.3)	(4.3)	(2.1)	
	Weed	47.6	46.5	15.8	76.9	40.3	5.1	42.5	0.8	0	19.5	41.4
		(2.3)	(1.5)	(0.5)	(2.5)	(1.4)	(0.2)	(1.4)	(0.02)		(0.7)	(1.3)
	Total	**69.9**	**115.9**	**28.8**	**159.8**	**462.4**	**9.2**	**44.7**	**10.9**	**134.1**	**78.7**	**41.4**

* Soybean (May-Oct.), Linseed (Nov-Mar) **

Table 6.8. Monthly variation in belowground net primary productivity (g m^{-2}) in the 'tree only' situation under the four agroforestry systems. Values in parentheses are rates of production (g m^{-2}day^{-1}).

Month	Agroforestry systems							
	AFS 1	AFS 2	AFS 3	AFS 4	AFS 1	AFS 2	AFS 3	AFS 4
	1992-93				1993-94			
May	134.2 (4.3)	148.8 (4.8)	121.8 (3.9)	140.3 (4.5)	153.1 (4.9)	151.6 (4.9)	158.4 (5.1)	147.6 (4.8)
Jun	59.4 (2.0)	18.3 (0.6)	45.7 (1.5)	41.1 (1.4)	25.7 (0.9)	32.6 (1.1)	26.2 (0.9)	45.6 (1.5)
Jul	24.5 (0.8)	42.8 (1.4)	39.2 (1.3)	62.4 (2.0)	94.6 (3.1)	86.0 (2.8)	94.6 (3.0)	95.4 (3.1)
Aug	283.2 (9.1)	384.7 (12.4)	316.8 (10.2)	257.8 (8.3)	316.0 (10.2)	247.6 (8.0)	240.6 (7.8)	323.0 (10.4)
Sep	0	0	0	0	0	0	0	0
Oct	158.7 (5.1)	51.3 (1.6)	66.7 (2.2)	70.3 (2.2)	5.9 (0.2)	17.6 (0.6)	27.6 (0.9)	42.7 (1.4)
Nov	0	13.5 (0.4)	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0
Jan	0	0	0	0	0	0	0	0
Feb	12.1 (0.4)	7.4 (0.3)	11.1 (0.4)	6.2 (0.2)	0	0	0	0
Mar	64.6 (2.1)	64.6 (2.1)	62.4 (2.0)	67.4 (2.2)	54.6 (1.7)	51.6 (1.6)	50.1 (1.6)	43.6 (1.4)
Apr	3.8 (0.1)	8.9 (0.3)	6.3 (0.2)	7.2 (0.2)	27.6 (0.9)	48.7 (1.6)	32.5 (1.0)	46.8 (1.6)

AFS 1- Alder-based agroforestry system
AFS 2- Albizia-based agroforestry system
AFS 3- Cherry-based agroforestry system, and
AFS 4- Mandarin-based agroforestry system.

BNP was maximum in August in the 'tree only' situation under the four systems. The maximum rate of total BNP (crop+weeds) in the 'tree+crop' situation was higher during groundnut cropping period than the maximum rate of BNP of seconadary successional plants in the 'tree only' situation. Annual rate of BNP was maximum in the top 10 cm soil layer in both the situations and it decreased with the increase in depth (Table 6.9).

Table 6.9. Belowground net primary productivity(g $m^{-2}yr^{-1}$) of weeds in the 'tree+crop' and of plants in the 'tree only' situations in three soil depths under the four agroforestry systems.

Systems /depths(cm)		'Tree+crop' 0-10	10-20	20-30	'Tree only' 0-10	10-20	20-30
May'92 - April'93							
AFS 1	Root	91.7	19.8	18.6	149.7	37.3	30.5
	Rhizome	33.7	15.6	5.3	385.1	24.8	13.1
	Total	**124.8**	**35.4**	**23.9**	**534.8**	**62.1**	**43.6**
AFS 2	Root	85.7	19.3	18.2	170.0	46.6	31.1
	Rhizome	31.7	15.2	5.1	442.4	31.1	14.5
	Total	**117.4**	**34.5**	**23.3**	**614.4**	**77.7**	**48.2**
AFS 3	Root	104.2	24.2	22.8	156.8	40.2	30.1
	Rhizome	38.5	19.0	6.5	403.3	26.8	12.8
	Total	**142.7**	**43.2**	**29.3**	**560.1**	**67.0**	**42.9**
AFS 4	Root	120.9	27.3	23.6	149.5	46.2	29.2
	Rhizome	44.0	21.5	6.7	384.5	30.8	12.5
	Total	**164.9**	**48.8**	**30.3**	**534.0**	**77.0**	**41.7**
May'93 - April'94							
AFS 1	Total	217.6	61.6	41.7	565.7	65.7	46.1
AFS 2	Total	226.3	66.5	44.9	527.6	66.7	41.4
AFS 3	Total	218.7	66.3	44.9	526.7	63.0	40.3
AFS 4	Total	227.4	67.3	41.7	609.1	87.8	47.7

AFS 1- Alder-based agroforestry system
AFS 2- Albizia-based agroforestry system
AFS 3- Cherry-based agroforestry system, and
AFS 4- Mandarin-based agroforestry system.

In the 'tree+crop' situation 66-68% and in 'tree only' situation 82-84% of the total annual BNP of weeds and plants was recorded from the top 10 cm layer of soil. In the 'tree +crop' situation the root production was more than the rhizome production whereas in the 'tree only' situation the reverse was true. In the 'tree+crop' situation 73% and 27% of the total BNP of weeds was contributed by the root and rhizome, respectively in the top 10 cm soil layer, while in the 'tree only' situation the contribution by the root was quite low (only 28%) compared to the rhizome (72%) (Table 6.9).

Annual ANP and BNP of crops was much higher than weeds in the 'tree+crop' situation under the four systems. Annual ANP of weeds ranged between 368-401 g m^{-2} during 1992-93 and 397-409 g m^{-2} during 1993-94, and the values for the BNP during the corresponding periods were between 175-244 g m^{-2} and 301-336 g m^{-2}, respecively. The annual ANP and BNP of plants in the 'tree only' situation ranged between 917-1017 g m^{-2} and 641-740 g m^{-2} respectively, during 1992-93; and 938-972 g m^{-2} and 630-745 g m^{-2} respectively, during 1993-94 (Table 6.10). The total net primary productivity (TNP) in the 'tree only' situation was much greater during 1992-93 than that in the 'tree+crop' situation. But due to significantly greater production in groundnut-mustard crop sequence, the TNP was greater in the 'tree+crop' than the 'tree only' situation during 1993-94. Though there were no significant differences in the TNP under the four systems, the ranking was mandarin >albizia >cherry >alder during 1992-93 and albizia >mandarin >alder >cherry during 1993-94 in the 'tree+crop' situation. The ranking in the 'tree only' situation was alder = albizia >cherry >mandarin during 1992-93, and mandarin >alder >cherry >albizia during 1993-94.

Total productivity of the four systems

Annual ANP and BNP of trees were much higher than crop and weeds in the 'tree+crop' and secondary successional plants in the 'tree only' situation under the four systems. In the 'tree+crop' situation the annual ANP ranged between 1864-2490 g m^{-2} and constituted about 53-65% of the TNP, whereas the values for annual BNP varied between 1311-1677 g m^{-2}. TNP

Table 6.10. Annual† net primary productivity (g m^{-2}yr^{-1}) of plants growing in the 'tree+crop' and 'tree only' situations in the four agroforestry systems. Values in parentheses are rates of net primary production (g m^{-2}day^{-1}).

Systems		Productivity & Production					
		1992-93			1993-94		
Component		ANP	BNP	TNP	ANP	BNP	TNP
'Tree+crop' situation							
AFS 1	Crop	371.2*	281.4	652.6	241.5**	818.2	1059.7
		(1.3)	(0.9)	(2.2)	(0.9)	(2.9)	(3.8)
	Weed	368.5	184.1	552.6	396.9	320.9	717.8
		(1.2)	(0.6)	(1.9)	(1.4)	(1.1)	(2.6)
	Total	739.8	465.5	1205.2	638.4	1139.1	1777.5
AFS 2	Crop	401.0*	288.0	689.0	269.1**	920.4	1189.5
		(1.4)	(1.0)	(2.3)	(0.9)	(3.3)	(4.3)
	Weed	389.8	175.2	565.0	399.1	301.4	700.5
		(1.3)	(0.6)	(1.9)	(1.4)	(1.1)	(2.5)
	Total	790.8	463.2	1254.0	668.2	1221.8	1890.0
AFS 3	Crop	352.2*	269.1	621.3	217.4**	773.3	990.7
		(1.2)	(0.9)	(2.2)	(0.8)	(2.8)	(3.6)
	Weed	400.5	215.3	615.8	401.2	329.9	731.1
		(1.3)	(0.7)	(2.1)	(1.4)	(1.2)	(2.6)
	Total	752.7	484.4	1237.0	618.6	1103.2	1721.8
AFS 4	Crop	387.7*	290.8	678.5	260.4**	819.4	1079.8
		(1.3)	(1.0)	(2.3)	(0.9)	(2.9)	(3.9)
	Weed	398.7	244.0	642.5	408.8	336.4	745.2
		(1.3)	(0.8)	(2.2)	(1.5)	(1.2)	(2.7)
	Total	786.2	534.8	1321.0	669.2	1155.8	1825.0
'Tree only' situation							
AFS 1	Weeds	1016.9	640.5	1657.4	971.9	677.5	1649.4
		(3.0)	(1.9)	(4.9)	(2.9)	(2.0)	(4.9)
AFS 2	Weeds	917.4	740.3	1657.7	937.5	635.7	1573.2
		(2.7)	(2.2)	(4.9)	(2.8)	(1.9)	(4.7)
AFS 3	Weeds	957.5	670.0	1627.5	961.0	630.0	1591.0
		(2.8)	(2.0)	(4.8)	(2.9)	(1.9)	(4.7)
AFS 4	Weeds	956.1	652.7	1618.8	970.2	744.6	1714.8
		(2.8)	(1.9)	(4.8)	(2.9)	(2.2)	(5.1)

†Number of days: 'Tree+crop' situation = 298 days (1992-93) and 279 days (1993-94)
'Tree only' situation = 337 days (1992-93) and 335 days (1993-94)

*Soybean + Linseed, **Groundnut + Mustard

TNP = ANP + BNP

AFS 1- Alder-based agroforestry system
AFS 2- Albizia-based agroforestry system
AFS 3- Cherry-based agroforestry system, and
AFS 4- Mandarin-based agroforestry system.

values were 3474-3816 g $m^{-2}yr^{-1}$ under the four systems (Table 6.11). The corresponding values for annual ANP ranged between 2034-2722 g m^{-2}, for BNP 1162-1539 g m^{-2} and for TNP between 3400-3884 g m^{-2} in the 'tree only' situation. It is interesting to note that the contribution of ANP to the annual TNP was 62-65% in albizia- and alder-systems, while only 53-57% in mandarin- and cherry-systems. It is noteworthy that with soybean and linseed crop sequence (1992-93) the annual TNP in the 'tree+crop' situation was lower than that in the 'tree only' situation under the four systems, but with groundnut and mustard sequence (1993-94) the reverse was true. But overall, the TNP in the two situations did not differ among the four systems.

DISCUSSION

Although variation in biomass accumulation by the plants may be due to differences in their genetic make up, the combined or independent effects of edapho-climatic conditions, effects of trees, crop density, crop-weed interactions and biotic (weeding) interference can not be underestimated. On the other hand, the variation in plant biomass in the 'tree only' situation seems to be mainly due to edapho-climatic conditions and influence of tree species. In Barapani where the experimeantal sites are located, the active growing period was mainly during rainy season. Owing to this, only a single peak was attained during August-October and this was followed by a decline. The decline was due to the transfer of live biomass to the standing dead whereby a substantial amount of standing dead including leaf litter from the trees got

Table 6.11. Annual[+] net primary productivity (g $m^{-2}yr^{-1}$) of the four agroforestry systems in the 'tree+crop' and 'tree only' situations.

Systems		Productivity					
		'Tree+crop'			'Tree only'		
		ANP	BNP	TNP	ANP	BNP	TNP
AFS 1	Tree	1800.0	525.0	2325.0	1728.0	503.0	2231.0
	Crop	306.4	549.8	856.2	-	-	-
	Weeds	382.7	252.5	635.2	994.7	659.0	1653.4
	Total	**2489.1**	**1367.3**	**3816.4**	**2722.4**	**1162.0**	**3884.4**
AFS 2	Tree	1434.0	467.0	1901.0	1338.0	446.0	1784.0
	Crop	335.1	604.2	939.3	-	-	-
	Weeds	394.5	239.4	633.9	927.5	688.0	1616.5
	Total	**2163.6**	**1310.6**	**3474.2**	**2265.5**	**1135.0**	**3400.5**
AFS 3	Tree	1358.0	725.0	2083.0	1229.0	716.0	1945.0
	Crop	284.8	521.2	806.0	-	-	-
	Weeds	400.9	271.1	672.0	959.3	650.0	1609.3
	Total	**2043.7**	**1517.3**	**3561.0**	**2188.3**	**1366.0**	**3554.3**
AFS 4	Tree	1136.0	832.0	1968.0	1071.0	840.0	1911.0
	Crop	324.1	555.1	879.2	-	-	-
	Weeds	403.7	290.2	693.9	963.2	698.7	1661.9
	Total	**1863.8**	**1677.3**	**3541.1**	**2034.2**	**1538.7**	**3572.9**

[+] For trees the values are taken from Table 5.6 (Chapter 5).
[*] For crops and weeds mean ANP values during 1992-93 and 1993-94 are considered.

TNP = ANP + BNP
AFS 1- Alder-based agroforestry system
AFS 2- Albizia-based agroforestry system
AFS 3- Cherry-based agroforestry system, and
AFS 4- Mandarin-based agroforestry system.

accumulated during dry winter months. The increase in live biomass during rainy months was linked with increase in density and dry matter yield of various species. Biomass increment of crop and weeds was also rapid during rainy season while it was very slow during winter which is directly related to the soil moisture, ambient temperature and nutrient availability. Aboveground and belowground biomass of weeds was lower in the 'tree+crop' than in the 'tree only' situation, which may be attributed to changes in species composition resulting from soil working and other cultural practices.

Contribution of the individual species

Most of the total biomass of weeds in the 'tree+crop' situation and secondary successional plants in the 'tree only' situation was contributed by a relatively small number of species, which is in agreement with the findings of various other workers (Pearson, 1965; Singh, 1968; Singh & Yadava, 1974; Pradhan, 1990; Boral, 1993). The variations in species composition, density and vigour of the dominant species in different months were probably the reasons for their differential contribution. Unlike the plants in the 'tree only' situation, the relative contribution of dominant weed species varied with the cropping period and type of crop. Some of the weed species which were absent during one cropping season produced a significant amount of biomass during another season which may be attributed to activation of dominant weed seeds in the soil during soil working. Dominant species of grasses such as *Arundinella bengalensis* and *Imperata cylindrica* contributed a significant amount of biomass during peak growth period (in rainy season) in the 'tree only' situation but their contribution decreased during winter months despite the emergence of new tillers. Live biomass of these dominant species was transferred rapidly to standing dead so much so that in February/March most of the biomass was dead. This was due to decline in soil moisture and senescence of leaves/tillers. High amount of live biomass recorded for *Imperata cylindrica* and *Panicum montanum* even in most unfavourable period of plant growth was due to well developed root system which could survive moisture stress prevailing during this period of plant growth.

Crop yield as influenced by tree species

In agroforestry, crops can be combined successfully with trees in their initial stage, when the tree canopy has not yet fully developed (King, 1968). The crop yield reduction due to the presence of the tree becomes evident only from the 2nd or 3rd year (Maghembe & Redhead, 1983; Pamesh Shaw, 1987; Dhyani *et al.*, 1994). The reduction in crop yield depended on the tree species involved, as is reported by different workers (Sheikh & Haq, 1978; Dhillon *et al.*, 1982; Mittal & Singh, 1983). In the present study trees in alder-, mandarin- and cherry-system affected crop yield and as the distance from tree increased, yield also improved. Similar results were reported by several workers (Karim *et al.*, 1991; Khybri *et al.*, 1992; Sharma, 1992; Scroth & Lehmann, 1995; Dhillon & Thind, 1996). On the other hand, in albizia-system proximity of tree did not reduce the crop yield, though on the whole, there was some reduction in total yield of crops as compared to the sole crop condition. In a similar study by increasing tree distance, yields per row increased over the control in alley cropping with *Gliricidia* (Scroth & Lehmann, 1995).

The reduction in crop yield in the present study was due to severe competition between tree and crop roots. Several workers have stressed the similarity of root distribution in the soil profile between trees and annual crops, indicating a considerable overlapping of the soil resources they use (Jonsson *et al.*, 1988; Dhyani *et al.*, 1990; Ruhigwa *et al.*, 1992; Scroth & Lehmann, 1995; Jose & Gillespie, 1996). Root competition for water and nutrients has also been found responsible for yield depression at the tree-crop interface of agroforestry association (Lal, 1991; Szott *et al.*, 1991b; Salazar *et al.*, 1993).

The high competitiveness of the cherry and alder root systems may have been due to high nutrient and water consumption, as in these species vigorous leaf initiaion after dry winter takes place. From the results of this experimant it is clear that the root system of alder and chery was markedly more competitive than those of albizia, resulting in greater yield depression of the crops.

In the early growing stage the growth rate of the crops was slower than that of weeds, however, at later stages crops grew more rapidly than weeds in the four agroforestry systems. This is in agreement with the findings of Pandey *et. al.* (1969, 1971) and Govil & Pandey (1985). During crop peak growth period most of resources needed for organic matter build-up seemed to have been partitioned to the crop which caused considerable decrease in the aboveground biomass of weeds. The competition for resources between crops and weeds also adversely affected the crop yield.

Belowground biomass

Cultivation in the 'tree+crop' situation drastically altered the root-rhizome proportion of belowground biomass in the four systems besides reducing total belowground biomass of weeds. Higher proportion of belowground biomass in the upper 10 cm layer in the 'tree only' situation (82-84%) than in the 'tree+crop' situation (66-68%) may be attributed to more favourable physical and chemical conditions for root growth in surface layer of soil in the former situation than in the latter. Anderson (1987), Newell & Wilhelm (1987), and Chang *et al.* (1990) working on no-tillage and conventional tillage system which may be compared to the present 'tree only' and 'tree+crop' situations respectively, reported that higher proportion of belowground biomass was in the upper layer in the no-tillage system. Fluctuation in belowground biomass in the 'tree only' situation was mostly due to fluctuations in rhizome biomass, attributable to the retranslocation of photosynthates from senescing shoots to rhizomes particularly during unfavourable winter periods and again its translocation to newly growing shoots with the onset of favourable conditions.

Productivity of crops and weeds

Community composition is one of the most important factors determining the productivity of an ecosystem (Bourliere & Hadley, 1970; Singh & Joshi, 1979; Gupta & Singh, 1982). Net primary productivity of an agroforestry system largely depends on the species of tree and crop grown and management practices. Total net productivity of the crops could be ranked as: soybean >groundnut >mustard >linseed. The ANP of crops and weeds in the 'tree+crop' situation and that of secondary successional plants in the 'tree only' situation varied widely in different months and years. In the 'tree+crop' situation during winter cropping season annual weeds also grew and contributed to the total production. In the 'tree only' situation, on the other hand, despite decrease in total biomass during winter a considerable amount of above-ground production was recorded. This may be attributed to the differences in growth behaviour of the species which attained their peak biomass at different times.

The rate of BNP of the crops was associated with the genotype rather than the seasons. The higher rate of BNP of groundnut was due to rapid growth of pods at later stages. In the 'tree+crop' situation almost equal portion of the annual net productivity was contributed by crops and weeds during 1992-93. Of the total annual ANP, crop contribution was 47-51% in the four systems. But during 1993-94 it was only 35-40%, which shows that a significant contribution was made by the weeds (60-65%). The BNP of crops accounted for 54-62% of the total annual BNP during 1992-93 and 70-75% during 1993-94. Most of the total ANP was contributed by a small number of weed species. The higher ANP of crops, weeds and secondary successional plants than their respective BNP may be attributed to the application of fertilizers in the 'tree+crop' situation and long term protection from biotic interference in the 'tree only' situation. The dominant weed species like *Arundinella bengalensis* and *I. cylindrica* were quite tall (1.0-1.2 m) and their extensive shoot system could be responsible for greater values of ANP compared to BNP in the 'tree only' situation.

Total net productivity (TNP) of weeds in the 'tree+crop' situation was 2.4 to 2.6 times lower than that of secondary successional plants in the 'tree only' situation. The ranking for ANP among the four agroforestry systems was alder- >albizia- >cherry- >mandarin-system, for BNP it was mandarin- >cherry- >alder- >albizia-system, and for the TNP, it was alder- >cherry- >mandarin- >albizia-system in the 'tree+crop' situation. In the 'tree only' situation the ranking for ANP was alder- >albizia- >cherry- > mandarin-system, for BNP, it was mandarin- >cherry- >alder- >albizia-system, and for TNP, it was alder- >mandarin- >cherry->albizia-system in 'tree only' situation. Thus in both the situations mandarin- and cherry- system contributed greater BNP than alder- and albizia-system. The TNP of trees plus crops plus weeds in the 'tree+crop' situation, and trees plus secondary successional plants in the 'tree only' situation was more or less equal. This was expected as the trees were the major component under the four agroforestry systems in both the situations and they contributed 53-61% to the annual TNP. Besides, the crop production in the 'tree+crop' situation was hampered by the presence of trees as well as weeds, and so, their contribution was not high. In addition to this, the four crops selected for

this study produced comparatively far less biomass (above- and below-ground) than other crops like maize (Boral, 1993). However, the TNP of the present agroforestry systems was higher than that of agricultural systems (Boral, 1993), mixed grasslands (Singh & Yadava, 1974) and *Leucaena leucocephala* plantations (Brewbaker, 1987). In fact the TNP values obtained in the present study are one and half to three times greater than those reported by various workers under different agro-climatic situations (Table 6.12).

Table 6.12. Net primary productivity (g $m^{-2} yr^{-1}$) of different ecosystem types reported by various workers.

Site	Ecosystem type or land use	ANP	BNP	TNP	Climate/ rainfall(cm)	Reference
Central Minnesota	Maize field (crop+weed)	945.0	121.0	1066.7	-	Ovington *et al.*, (1963)
Kurukshetra	Mixed grassland	2407.0	1131.0	3538.0	799	Singh & Yadava (1974)
Mexico	Coffee, *Inga* spp.	840.0-950.0	-	840.0-950.0	Humid	Jimenez & Martinez (1979)
Philippines	Plantation (*Albizia falcataria*)	1130.0	-	1130.0	Humid	Kawahara *et al.*, (1963)
Colombia	Coffee+ shade tree	460.0-1300.0	-	460.0-1300.0	Humid	Bornemisza (1982)
Shillong	Pine(*Pinus kesia*) forest	1500.0	-	1500.0	-	Das & Ramakrishnan (1987)
Nigeria	Hedgerow inter-cropping with *Gliricidia sepium*	300.0-450.0	-	300.0-450.0	Moist sub-humid	Bahiru Duguma *et al.*, (1988)
Barapani	Agricultural system (1989-90)	3637.2	1829.6	5466.8	2,186	Boral (1993)
	(1990-91)	3453.2	1331.2	4784.3	2,158	- do -
	Protected 'jhum' fallow (1989-90)	1896.3	871.9	2768.2	2,186	- do -
	(1990-91)	1356.0	961.1	2317.1	2,158	- do -
Barapani	'Tree+crop' situation					
	AFS 1	2489.1	1327.3	3816.4	2,528	Present study
	AFS 2	2163.6	1310.6	3474.2	2,528	- do -
	AFS 3	2043.7	1517.3	3561.0	2,528	- do -
	AFS 4	1863.8	1677.3	3541.1	2,528	- do -
	'Tree+crop' situation					
	AFS 1	2722.4	1162.0	3884.4	2,528	Present study
	AFS 2	2265.5	1135.0	3400.5	2,528	- do -
	AFS 3	2188.3	1366.0	3554.3	2,528	- do -
	AFS 4	2034.2	1538.7	3572.9	2,528	- do -

-, Data not available

AFS 1- Alder-based agroforestry system
AFS 2- Albizia-based agroforestry system
AFS 3- Cherry-based agroforestry system, and
AFS 4- Mandarin-based agroforestry system.

CHAPTER 7

TREE LITTER DYNAMICS

Litter production is the dominant pathway joining the living biological component to the non-living soil component of the ecosystem through organic matter decomposition cycle (Swift *et al.*, 1979, 1981; Lamb, 1985). Litter acts as an input-output system on the soil surface and determines several functions of the ecosystem. Therefore, much emphasis has been placed on determining the nutrint flux accompanying litterfall and decomposition in forest and grassland ecosystems (Birk & Simpson, 1980; Boojh & Ramakrishnan, 1981; Singh & Ramakrishnan, 1982; Singh, 1984; Lindsay, 1988; Staff, 1988; Upadhyay, 1988; Pandey *et al.*, 1993). In agroforestry litter contribution is an important consideration, as its rate of production as well as decomposition affect mineral cycling (Buck, 1986). Several investigators have shown that litter addition improves soil quality (Ingestad, 1987; Harrison *et al.*, 1990; Szott *et al.*, 1991) and enrich and maintain the soil fertility under agroforestry systems. Knowledge of annual litter production, nitrogen content of the litter, and the local environmental conditions and how they affect decomposition rates are all important factors in managing agroforestry systems. They offer opportunities to manipulate the timing of nutrient release (Young, 1989).

In view of the above, data and information on litter production and rate of decomposition of litter in the four agro-forestry systems in a humid sub-tropical climate were collected and are presented in this chapter.

MATERIALS AND METHODS

Litter production :

For determination of the quantity of litterfall from the tree species, litter traps (1 m^2 size) were set out for each species in the 'tree+crop' and 'tree only' situations under the four agroforestry systems. Monthly collections from August to July were made during 1992-93 and 1993-94. The litter accumulated on the ground included branches, twigs, bark, flowers, fruits and leaves. Twig and leaf litter values were corrected by litterfall estimation. All the four tree species being deciduous, the values in this compartment were equal to annual litterfall. The litter samples were brought to the laboratory and were separated into the following fractions:

a) **Leaf litter-** species-wise leaves with petiole, foliar rachis and twigs were considered in this fraction,

b) **Woody litter-** the branches (>4 mm diameter) were included,

c) **Miscellaneous-** reproductive parts (flowers and fruits), bark, unrecognisable remains of leaves and fine particles.

The samples were dried at 70^0C to a constant weight and weighed. The results have been presented on dry weight basis. The data were statistically analysed employing ANOVA. The annual litter turnover was calculated by Olson's (1963) formula,

$$\text{Turnover ratio } (K_L) = \frac{L}{X_L}$$

Where, L = Annual litterfall,
X_L = Mean annual standing crop.

Litter decomposition

The litter decomposition studies were carried out using litter bag technique (Bocock *et al.*, 1960; Shanks & Olson, 1961; Anderson & Ingram, 1989). Nylon litter bags measuring 20 cm x 20 cm (0.04 m^2) with a mesh size of 1 mm were prepared. The litter samples collected were air-dried. Oven-dry weight (48 hr, 80^0C) of litter was determined using a subsample. The equivalent of 10 g oven-dry weight of each category of litter from air-dried stock was placed in each litter bag. In all five hundred twenty eight litter bags were prepared and kept randomly on the floor in the four agro-forestry systems in February 1993. Litter bags were randomly sampled initially at one month interval till 240 days and thereafter at two months interval till the end of the experiment. At each sampling time four bags of each category of litter of a species were brought to the laboratory carefully avoiding loss of material from litter bags. The litter samples were contaminated with clay which was removed by gentle rinsing with tap water over a fine soil sieve. Cleaned litter samples were oven-dried (48 hr, 80^0C), weighed and then ground to pass through a 2 mm mesh sieve. Subsamples (0.5-1.0 g) were combusted in a porcelain crucible at 480^0C for 12 hours after adding 2 ml saturated solution of magnesium nitrate to prevent P volatilization and the residual ash mass was determined. Ash was dissolved in 1N-HCl and was analysed for potassium using flame photometry and phosphorus by the molybdophosphoric blue colour method. Ground samples were analysed for total nitrogen by Kjeldahl digestion (Jackson, 1967). Decay constant on dry weight basis was calculated following the formula given by Olson (1963).

$$\frac{dx}{x} = kdt$$

Where, dx = difference (loss) in weight,
dt = time interval
x = initial weight, k = decay constant.

Nutrient input through litterfall was computed using nutrient concentration and production values of the litter. Nutrient accumulation in the litter was computed similarly using standing crop and nutrient concentration values. Rate of release of N, P, and K during decomposition was determined by weight loss and element concentration data of the samples obtained from litter bags.

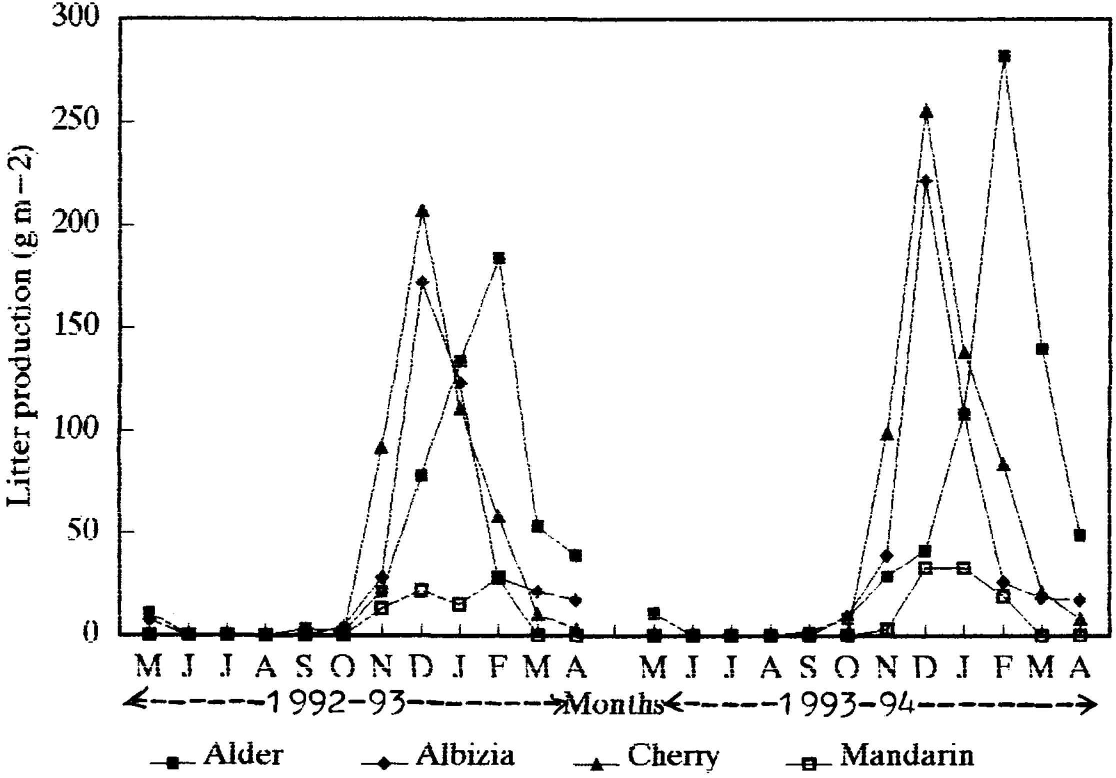
RESULTS

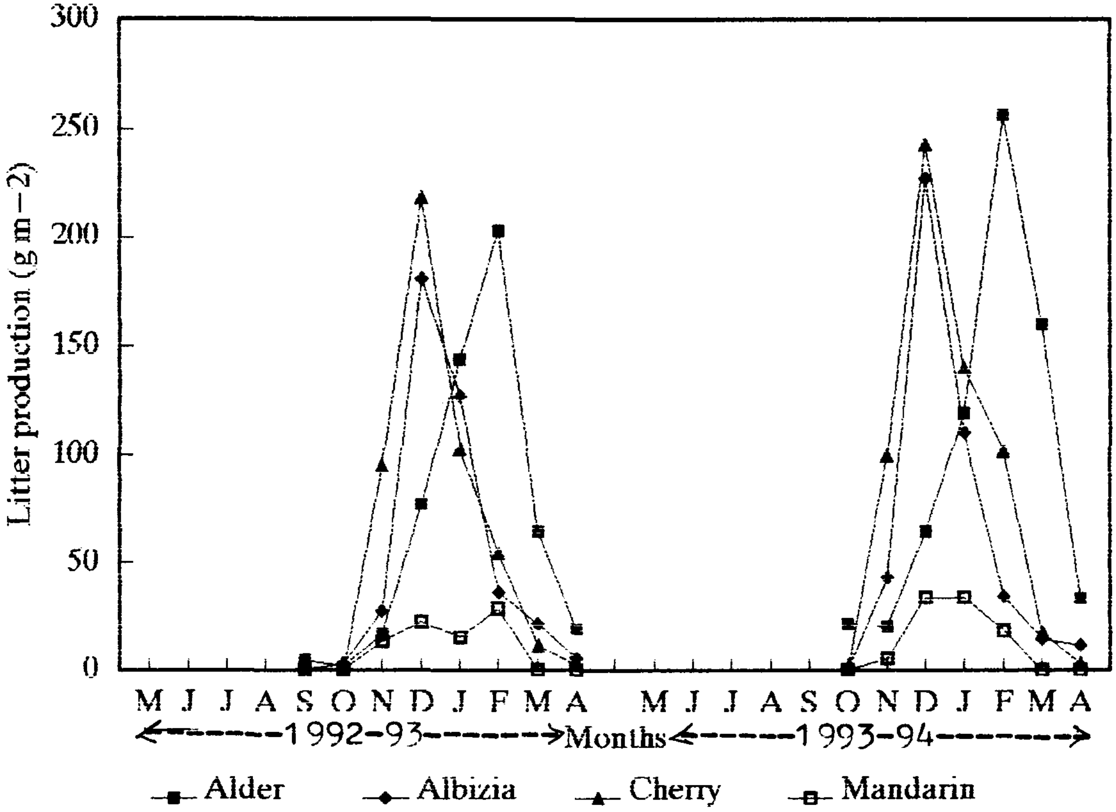
Litter production

The four tree species being deciduous, leaffall started in the months of September/October, attained peak in January/February, and declined therafter until April (Fig. 7.1). There was significant ($P<0.01$) variation in monthly leaf litter production in the four tree species in the 'tree+crop' and 'tree only' situations (Table 7.1). Leaf fraction constituted 64-79% of the total litter in the 'tree only', and 53-76% in the 'tree+ crop' situation, however, the differences between the two situations were not significant.

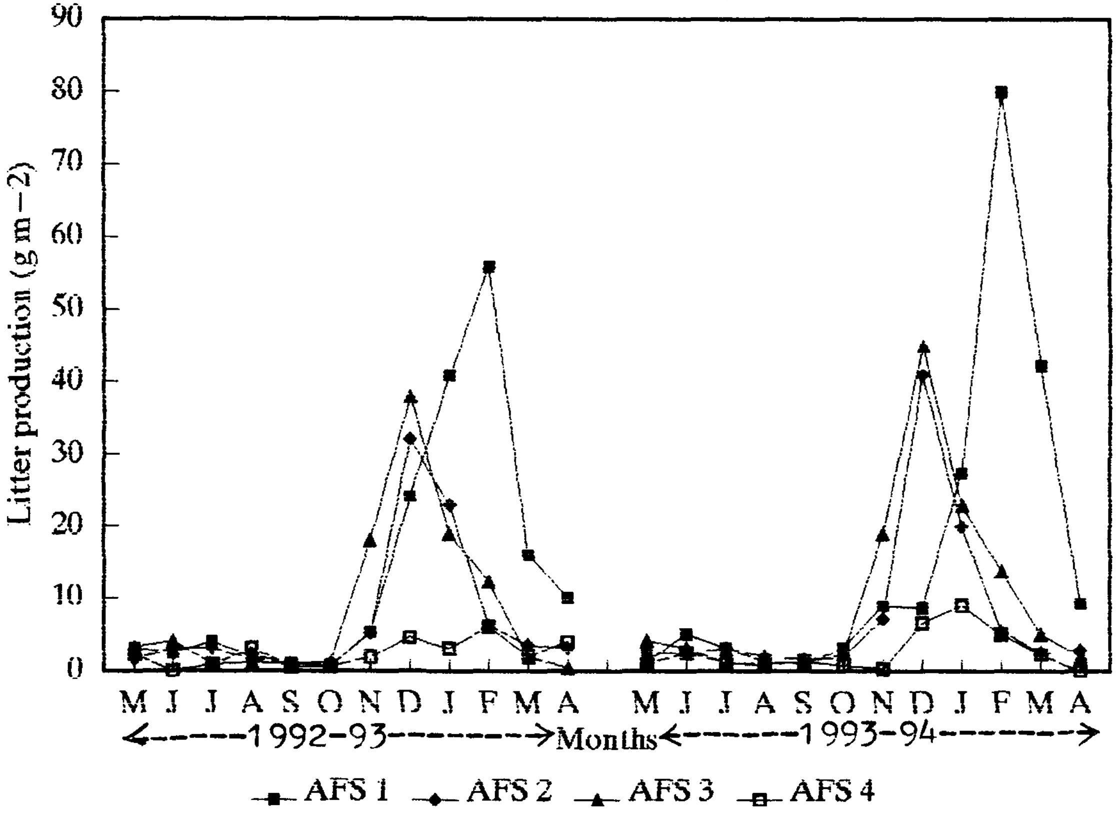
Woody litter fraction ranged 15-23% of the total litter in the two situations, although, during certain periods (June-August in alder, May-October in albizia and cherry, and March-October in mandarin) it made the major contribution to litter production, as during these period there was no leaffall. The miscellaneous fraction mainly comprising reproductive parts (flowers and fruits), bark and fine litter particles, exhibited significant ($P<0.01$) monthly variation in the two situations. In alder, albizia and cherry, 62-73% of total annual production of woody litter fraction occurred during

Fig. 7.1. Monthly litter production in the four agroforestry systems.

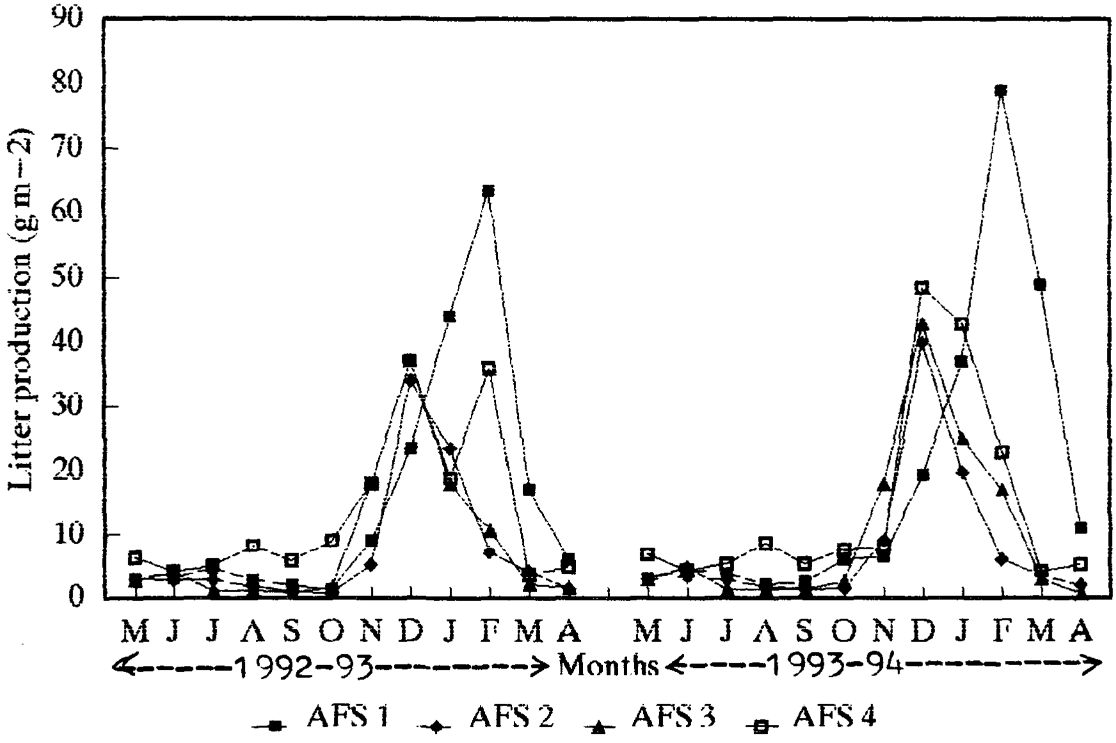

(a) Leaf litter in 'tree only' situation


(a') Leaf litter in 'tree+crop' situation

(b) Woody litter in `tree only' situation

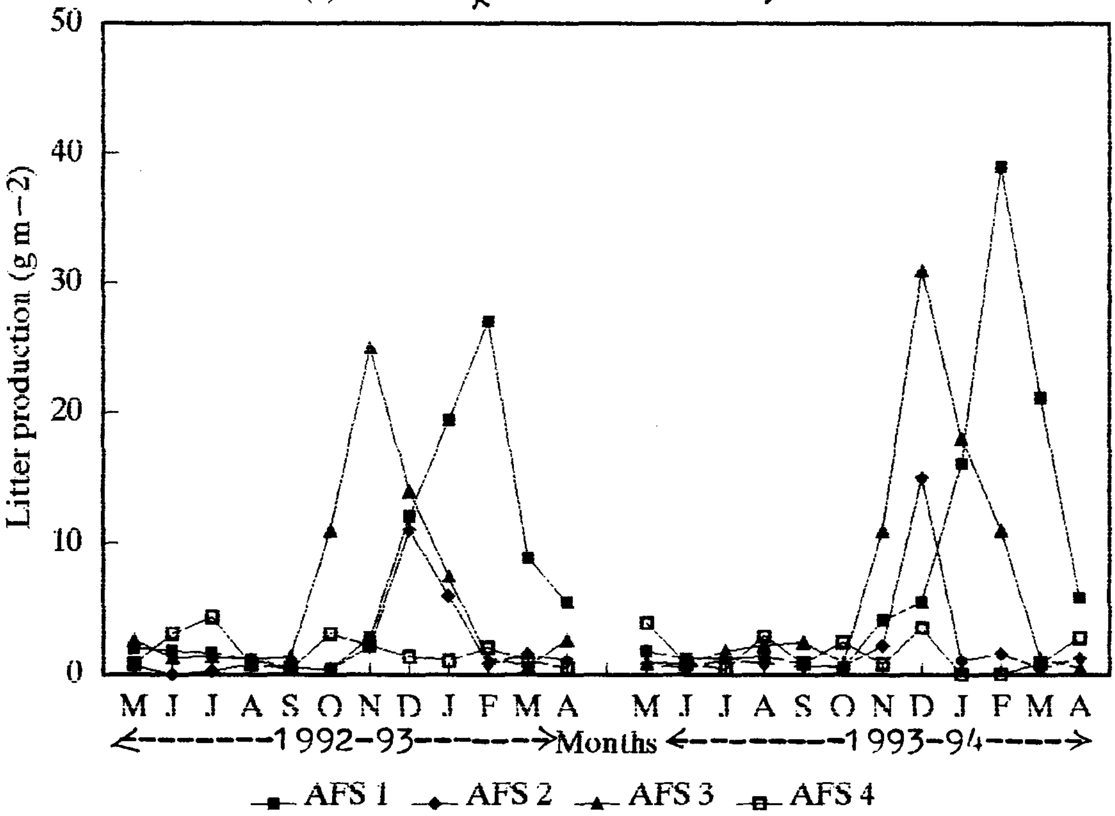


(b') Woody litter in `tree+crop' situation

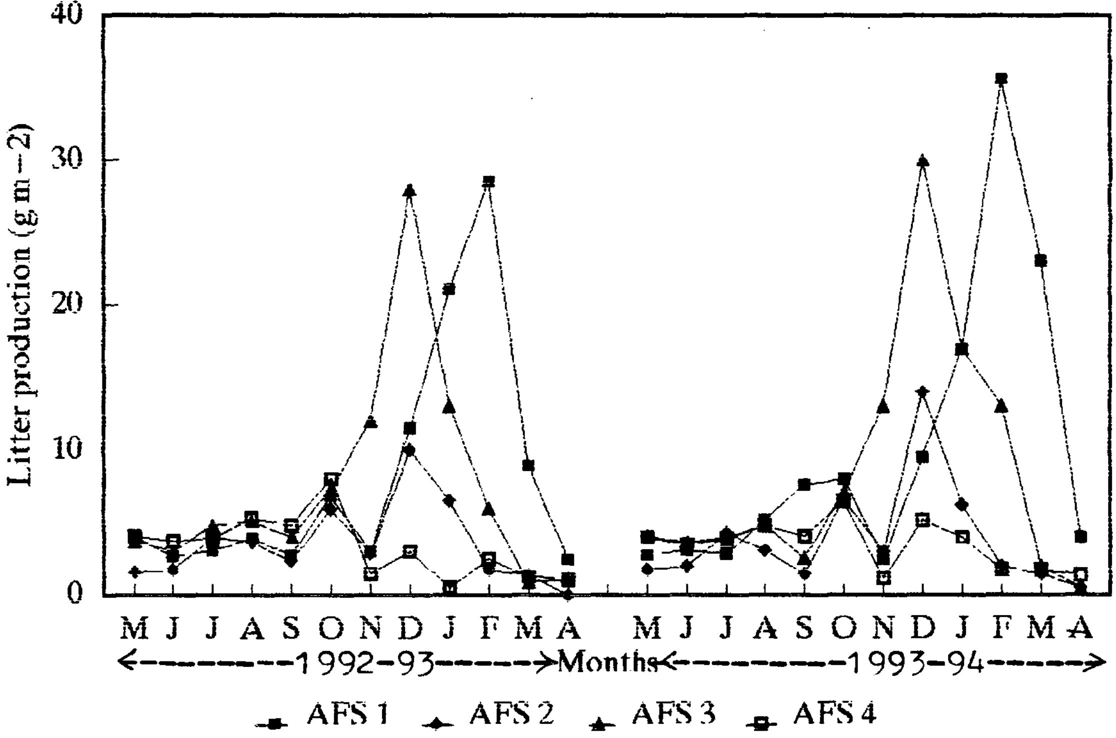


AFS 1—alder—, AFS 2—albizia—, AFS 3—cherry—,
AFS 4—mandarin—based systems.

(c) Miscellaneous litter in `tree only' situation

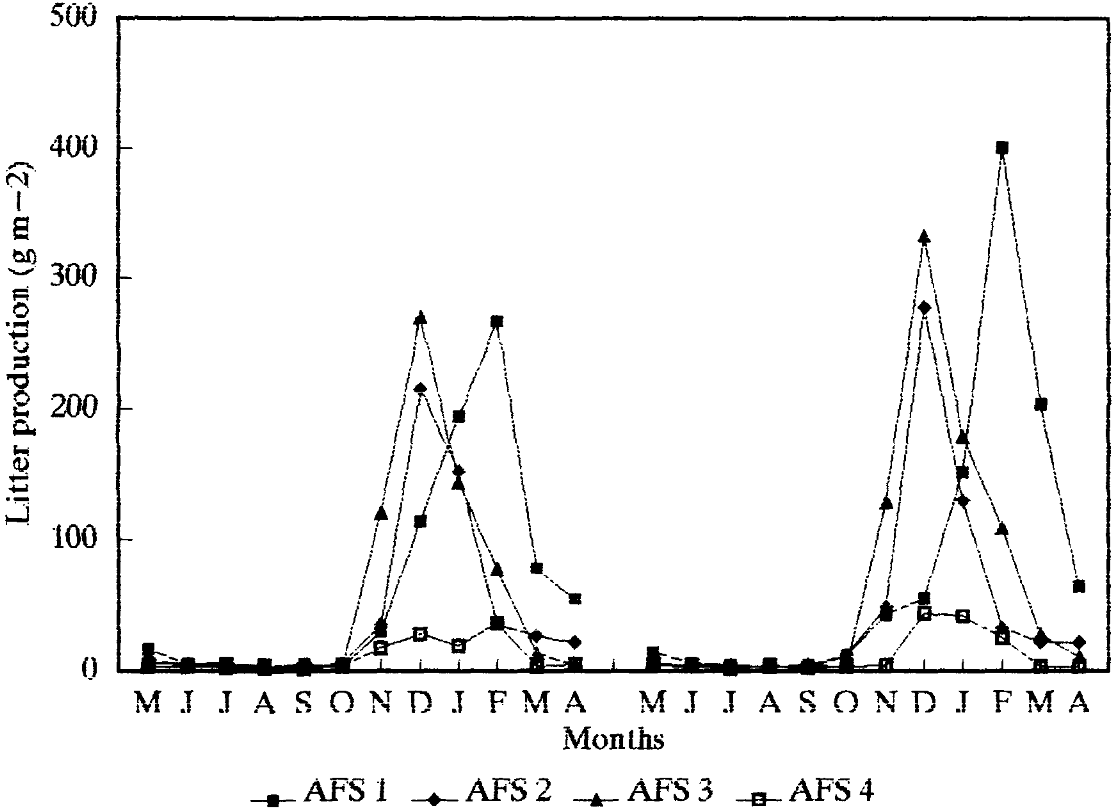


(c') Miscellaneous litter in `tree+crop' situation

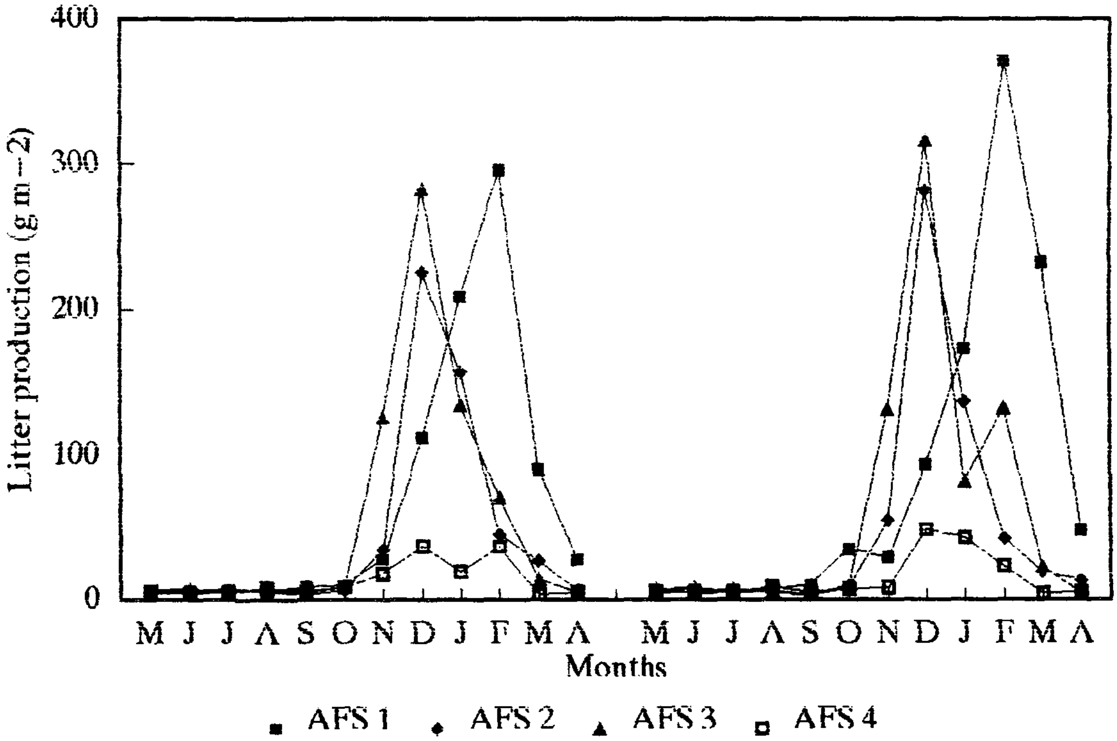


AFS 1−alder−, AFS 2−albizia−, AFS 3−cherry−, AFS 4−mandarin−based systems

(d) Total littermass in `tree only' situation



(d') Total littermass in `tree+crop' situation



AFS 1−alder−, AFS 2−albizia−, AFS 3−cherry−, AFS 4−mandarin−based systems

Table-7.1. Analysis of variance for the data on different fractions of litter in the four agroforestry systems.

Source of variation	df	Mean sums of squares (MSS)					
		Leaf litter		Woody litter		Miscellaneous	
		1992-93	1993-94	1992-93	1993-94	1992-93	1993-94
Replication	1	61.43*	0.30	0.02	0.09	0.05	0.80
Species	3	13984.99**	22895.95**	1072.65**	1644.91**	339.07**	533.27**
Error(a)	3	2.51	9.54	0.34	1.3	0.68	0.15
Situations	1	2.95	12.50	13.44*	55.15**	66.51**	137.70**
Species x Situations	3	3.81	20.04*	8.16*	20.98**	0.02	1.92
Error(b)	4	2.08	1.91	0.78	0.36	1.65	1.78
Month	11	30797.77**	39593.89**	1357.77**	1528.84**	238.29**	301.42**
Speci’ x month	33	5895.23**	10828.76**	354.81**	602.88**	97.47**	106.14**
Situations x months	11	66.44**	36.95**	5.44**	3.34	10.77**	9.89**
Species x month x situations	33	50.10**	134.42**	3.56**	5.12**	1.39	3.76**
Error(c)	88	5.81	15.35	1.57	2.55	1.14	1.62
Total	191						

* P < 0.05

** P < 0.01

winter season, whereas in mandarin, only 35-47% of the annual production of woody litter was contributed during winter months. In mandarin early fruit drop during rainy season contributed 40-42% to the total annual production of miscellaneous litter fraction. There were significant ($P<0.01$) differences in woody as well as miscellaneous fractions of litter (Table 7.1) in the 'tree+crop' and 'tree only' situations. This was mainly due to a significant amount of weed and crop residue contributing to litter production in the 'tree+crop' situation. The miscellaneous fraction made a small contribution in the 'tree only' situation ranging from 5-14%, but it contributed 8-25% in the 'tree+crop' situation.

Total litter (leaf + woody + miscellaneous fractions) production showed significant monthly variation among the four systems in both the situations (Table-7.2). It increased from October onwards attaining peak values during January (albizia

Table 7.2. Variation in total littermass (g m^{-2}) for species, situations, months and their interactions in the four agroforestry systems.

Source of variation	DF	Mean sums of squares (MSS) 1992-93	Mean sums of squares (MSS) 1993-94
Replication	1	0.083	16.981
Species	3	26386.516**	43353.875**
Error(a)	3	2.209	17.278
Situation[1]	1	182.520**	352.354**
Speciesxsitutation	3	2.156	19.767*
Error(b)	4	1.261	1.824
Months	11	51764.626**	64238.287**
Species x months	33	10646.609**	19645.287**
Situation x months	11	96.935**	107.379**
Species x months x situation	33	53.646**	127.466**
Error(c)	88	12.565	19.245
Total	191		

* $P < 0.05$ ** $P < 0.01$

[1] Situation = 'Tree+crop' and 'tree only' situations

and cherry) or February (alder). Mandarin exhibited slightly different pattern, where the total litter peaked in January (1993-94) or February (1992-93). The species showed maximum leaffall during winter (December to February) and minimum during rainy season (June to August) (Table-7.3). During June-August there was no leaffall. More or less this pattern of leaffall was observed during 1992-93 and 1993-94.

Mean daily leaf litter production (g $m^{-2}day^{-1}$) and seasonal variation in total litter production in the four agroforestry systems during the two years are presented in Table 7.4. The rate (g $m^{-2}day^{-1}$) was maximum during winter and minimum in spring season. The four systems showed significant ($P<0.01$) differences in the seasonal production of leaf litter, however, there was no leaf litter production during rainy season. Generally, the seasonal trend in leaf litter productuion for alder was: winter> spring> autumn, while for albizia and cherry, the trend was: winter> autumn> spring. In mandarin, there was no leaf litter production during spring and the highest production was recorded in winter. When seasonal total litter production was considered, the trend was winter> autumn> spring> rainy for cherry and albizia for both situations during 1992-93 and 1993-94, except for the albizia system in the 'tree only' situation during 1992-93, where the trend was: winter> spring> autumn> rainy. In mandarin system maximum litter production was recorded during winter season and minimum during rainy or spring seasons. For alder system, the seasonal trend in litter production was winter >spring >autumn >rainy in both the situations.

Table 7.3. Seasonal variation in the quantity (g m^{-2}) of different fractions of litter in the 'tree+crop' and 'tree only' situations in the four agroforestry systems. Values in parentheses are mean daily leaf litter production (g m^{-2}day^{-1}).

AF system	Litter category	'Tree only' situation				'Tree+crop' situation			
		Spring	Rainy	Autumn	Winter	Spring	Rainy	Autumn	Winter
					1992-93				
AFS 1	Leaf	103.0 (1.1)	-	26.0 (0.3)	396.0 (4.4)	82.5 (0.9)	-	22.0 (0.2)	424.0 (4.7)
	Wood	29.1	8.5	7.0	120.7	25.9	10.6	12.3	131.0
	Miscellaneous	16.4	4.5	3.7	58.5	15.5	9.7	12.6	61.0
	Total	**148.5**	**13.0**	**36.7**	**575.2**	**123.9**	**19.3**	**46.9**	**616.0**
AFS 2	Leaf	45.0 (0.5)	-	32.0 (0.4)	323.0 (3.6)	26.3 (0.3)	-	30.0 (0.3)	344.0 (3.8)
	Wood	8.0	7.5	6.7	61.2	8.5	7.5	6.9	64.7
	Miscellaneous	3.1	1.0	3.0	17.8	3.0	9.5	11.2	18.3
	Total	**56.1**	**8.5**	**41.7**	**402.0**	**37.8**	**17.0**	**48.1**	**427.0**
AFS 3	Leaf	13.0 (0.1)	-	92.0 (1.0)	376.3 (4.2)	13.4 (0.1)	-	95.0 (1.0)	375.4 (4.2)
	Wood	5.5	6.1	20.1	69.2	6.6	6.3	20.4	65.6
	Miscellaneous	4.4	4.0	13.5	46.5	5.8	13.0	23.3	47.0
	Total	**22.9**	**10.1**	**125.6**	**492.0**	**25.8**	**19.3**	**138.7**	**488.0**
AFS 4	Leaf	-	-	13.0 (0.1)	65.0 (0.7)	-	-	13.0 (0.1)	65.0 (0.7)
	Wood	8.1	3.9	2.9	13.6	8.5	4.2	5.3	21.0
	Miscellaneous	2.6	5.1	5.7	4.4	6.4	13.0	14.4	6.0
	Total	**10.7**	**9.0**	**21.6**	**83.0**	**14.9**	**17.2**	**32.7**	**92.0**

Contd.....

Table 7.3 contd.....

AF system	Litter category	'Tree only' situation				'Tree+crop' situation			
		Spring	Rainy	Autumn	Winter	Spring	Rainy	Autumn	Winter
					1993-94				
AFS 1	Leaf	200.0 (2.2)	-	39.0 (0.4)	431.0 (4.8)	193.0 (2.1)	-	41.0 (0.5)	439.3 (4.9)
	Wood	52.7	8.8	13.0	115.9	63.2	10.3	15.0	135.7
	Miscellaneous	28.8	3.8	5.5	60.6	29.8	11.2	18.1	62.0
	Total	**281.5**	**12.6**	**57.5**	**607.5**	**286.0**	**21.5**	**74.1**	**637.0**
AFS 2	Leaf	35.0 (0.4)	-	48.0 (0.5)	357.0 (3.9)	25.0 (0.3)	-	43.0 (0.5)	371.0 (4.2)
	Wood	7.9	7.3	8.9	66.5	8.5	7.9	11.9	65.8
	Miscellaneous	2.5	2.4	1.2	17.5	3.8	9.4	11.1	22.2
	Total	**45.4**	**9.7**	**58.1**	**441.0**	**37.3**	**17.3**	**66.0**	**459.0**
AFS 3	Leaf	39.0 (0.4)	-	99.0 (1.1)	478.3 (5.3)	20.0 (0.2)	-	100.0 (1.1)	485.0 (5.4)
	Wood	11.1	4.9	22.3	81.7	6.7	7.5	22.0	85.0
	Miscellaneous	2.6	4.8	14.3	60.0	6.6	12.4	22.7	60.0
	Total	**52.7**	**9.7**	**135.6**	**620.0**	**33.3**	**19.9**	**144.7**	**630.0**
AFS 4	Leaf	-	-	3.0 (0.1)	85.0 (0.9)	-	-	5.0 (0.1)	84.8 (0.9)
	Wood	3.2	4.4	2.2	20.5	8.9	6.2	3.8	18.7
	Miscellaneous	7.6	4.2	4.1	3.5	7.2	12.2	11.7	11.0
	Total	**10.8**	**8.6**	**9.3**	**109.0**	**16.1**	**18.4**	**20.5**	**114.5**

AFS 1- Alder-based agroforestry system
AFS 2- Albizia-based agroforestry system
AFS 3- Cherry-based agroforestry system, and
AFS 4- Mandarin-based agroforestry system.

There were marked differences in the annual production of leaf, woody and miscellaneous fractions of litter among the four tree species (Table-7.4). Alder followed by cherry and albizia recorded maximum values for the three litter fractions in both the situations, while mandarin had minimum values. The contribution by the leaf, woody and miscellaneous fractions of the litter to the total litter production among the four systems ranged 63-79, 15-23, and 5-14% respectively, in the 'tree only' situation, and 50-76, 15-25, and 5-25% in the 'tree+crop' situation. Annual litter production did not show significant differences between 1992-93 and 1993-94. The values in the 'tree only' situation varied between 1.3 and 7.7 t $ha^{-1}yr^{-1}$ during 1992-93, and 1.4 and 9.6 t $ha^{-1}yr^{-1}$ during 1993-94 in the four systems. The corresponding values in the 'tree +crop' situation were 1.6-8.1 t $ha^{-1}yr^{-1}$ during 1992-93, and 1.7-10.2 t $ha^{-1}yr^{-1}$ during 1993-94. Although the total litter and its production was slightly higher in the 'tree+ crop' than in the 'tree only' situation, the differences were not significant ($P < 0.05$).

Ground-floor littermass increased with age among the four species. It varied between 1.7-10.7 t $ha^{-1}yr^{-1}$ during 1992-93, to 1.9-11.9 t $ha^{-1}yr^{-1}$ during 1993-94 in the 'tree only' situation (Table 7.4). In the case of 'tree+crop' situation ground-floor littermass could not be determined as the litter was repeatedly incorporated in soil owing to cultural practices as well as soil working for raising crops.

Litter standing crop and turnover

Standing crop of total litter and its fractions varied

Table 7.4. Annual production of different fractions of litter (t ha^{-1}) and ground floor littermass* (t ha^{-1}) in 'tree+crop' and 'tree only' situations under the four agroforestry systems. Values in parentheses are % of the total litter.

Litter category	'Tree only' situation				'Tree+crop' situation			
	AFS 1	**AFS 2**	**AFS 3**	**AFS 4**	**AFS 1**	**AFS 2**	**AFS 3**	**AFS 4**
				1992-93				
Leaf	5.25 (68)	4.00 (79)	4.81 (74)	0.78 (63)	5.28 (66)	4.00 (76)	4.84 (72)	0.78 (50)
Woody	1.65 (21)	0.83 (16)	1.00 (15)	0.29 (23)	1.79 (22)	0.87 (16)	0.99 (15)	0.39 (25)
Miscelaneous	0.83 (11)	0.25 (05)	0.68 (11)	0.21 (14)	0.99 (12)	0.42 (7.5)	0.89 (13)	0.39 (25)
Total	7.73	5.08	6.51	1.27	8.07	5.29	6.71	1.57
Ground-floor littermass	10.76	8.76	10.15	1.72	-	-	-	-
				1993-94				
Leaf	6.70 (70)	4.40 (79)	6.06 (75)	0.88 (64)	6.73 (66)	4.39 (76)	6.05 (73)	0.89 (53)
Woody	1.90 (20)	0.92 (16)	1.20 (15)	0.30 (22)	2.24 (22)	0.94 (16)	1.21 (15)	0.38 (22)
Miscelaneous	0.98 (10)	0.26 (05)	0.81 (10)	0.19 (14)	1.21 (12)	0.46 (8)	1.02 (12)	0.42 (25)
Total	9.59	5.57	8.08	1.37	10.18	5.79	8.27	1.69
Ground-floor littermass	11.91	8.81	11.50	1.94	-	-	-	-

*Includes branches, twigs, bark, catkins/fruits and leaves.

AFS 1- Alder-based agroforestry system
AFS 2- Albizia-based agroforestry system
AFS 3- Cherry-based agroforestry system, and
AFS 4- Mandarin-based agroforestry system.

significantly (P<0.01) in different months in the four species and exhibited definite seasonal pattern. Mean standing crop of litter and its different fractions (leaf, woody and miscellaneous litter) was maximum in winter season in all the species under the two situations. But year to year variations were not significant. The annual fractional weight loss (K_L) of three litter fractions varied among the four species in the 'tree only' and 'tree+crop' situations. The lowest turnover rate for leaf litter was recorded for alder and highest for mandarin (1992-93) and albizia (1993-94) (Table 7.5). There was no consistent trend among the four tree species for the turnover rates of woody, miscellaneous and total litter. During 1992-93 the species ranking in respect of turnover of woody and miscellaneous litter in the 'tree only' situation was cherry >albizia >alder >mandarin while in the 'tree+crop' situation the ranking was: cherry >mandarin >albizia >alder. During 1993-94 the species ranking in terms of litter turnover was different. Overall, cherry recorded the highest turnover rate for total litter while alder recorded the lowest rate except in the 'tree only' situation during 1992-93 where mandarin litter showed the slowest turnover. In general, the leaf and miscellaneous litter showed faster turnover than the woody or total litter.

Weight loss pattern

Dry weight of enclosed leaf-, woody- and miscellaneous-litter fractions of the four tree species decreased steadily with the passage of time. However, the pattern of weight loss in case of different fractions of littermass varied markedly

Table 7.5. Turnover coefficient (k) for different fractions of litter in the ‘tree only’ and ‘tree+crop’ situations in the four agroforestry systems.

Litter category	‘Tree only’ situation				‘Tree+crop’ situation			
	AFS 1	**AFS 2**	**AFS 3**	**AFS 4**	**AFS 1**	**AFS 2**	**AFS 3**	**AFS 4**
1992-93								
Leaf	3.02	3.45	4.96	5.20	2.63	3.23	4.81	5.20
Woody	2.99	3.49	4.59	2.31	2.81	3.62	5.02	4.53
Misc.	3.20	3.83	4.56	2.90	3.06	4.33	6.41	4.47
Total	3.39	3.38	4.51	3.19	2.78	3.42	5.10	4.25
1993-94								
Leaf	2.35	4.78	4.66	2.93	2.86	4.43	4.42	3.15
Woody	2.30	4.72	4.96	2.86	2.87	4.78	4.36	4.48
Misc.	2.55	4.03	3.97	2.73	3.15	3.84	5.30	4.68
Total	2.41	4.32	4.57	2.99	2.79	4.28	4.52	3.78

Misc. Miscellaneous litter

AFS 1- Alder-based agroforestry system
AFS 2- Albizia-based agroforestry system
AFS 3- Cherry-based agroforestry system, and
AFS 4- Mandarin-based agroforestry system.

(Fig. 7.2). The loss in weight of leaf- and miscellaneous-fractions of litter occurred at a more rapid rate in alder and albizia than in other two species. In alder and albizia it took about 240 days for leaf litter and 300 days for miscellaneous litter for about 90% loss of material from litter bags, but in cherry and mandarin the decomposition was slow and a good percentage (20-59% in cherry and 25-64% in mandarin) of all the three fractions (leaf, woody and miscellaneous) of litter were retrieved from the bags even after 420 days. Woody litter decomposed very slowly, only 10% of total woody litter in the four tree species could decompose during first 60 days period. At 420 days, about 31-42% of woody litter in alder and albizia, and 59-64% in mandarin and cherry were retrieved from the litter bags.

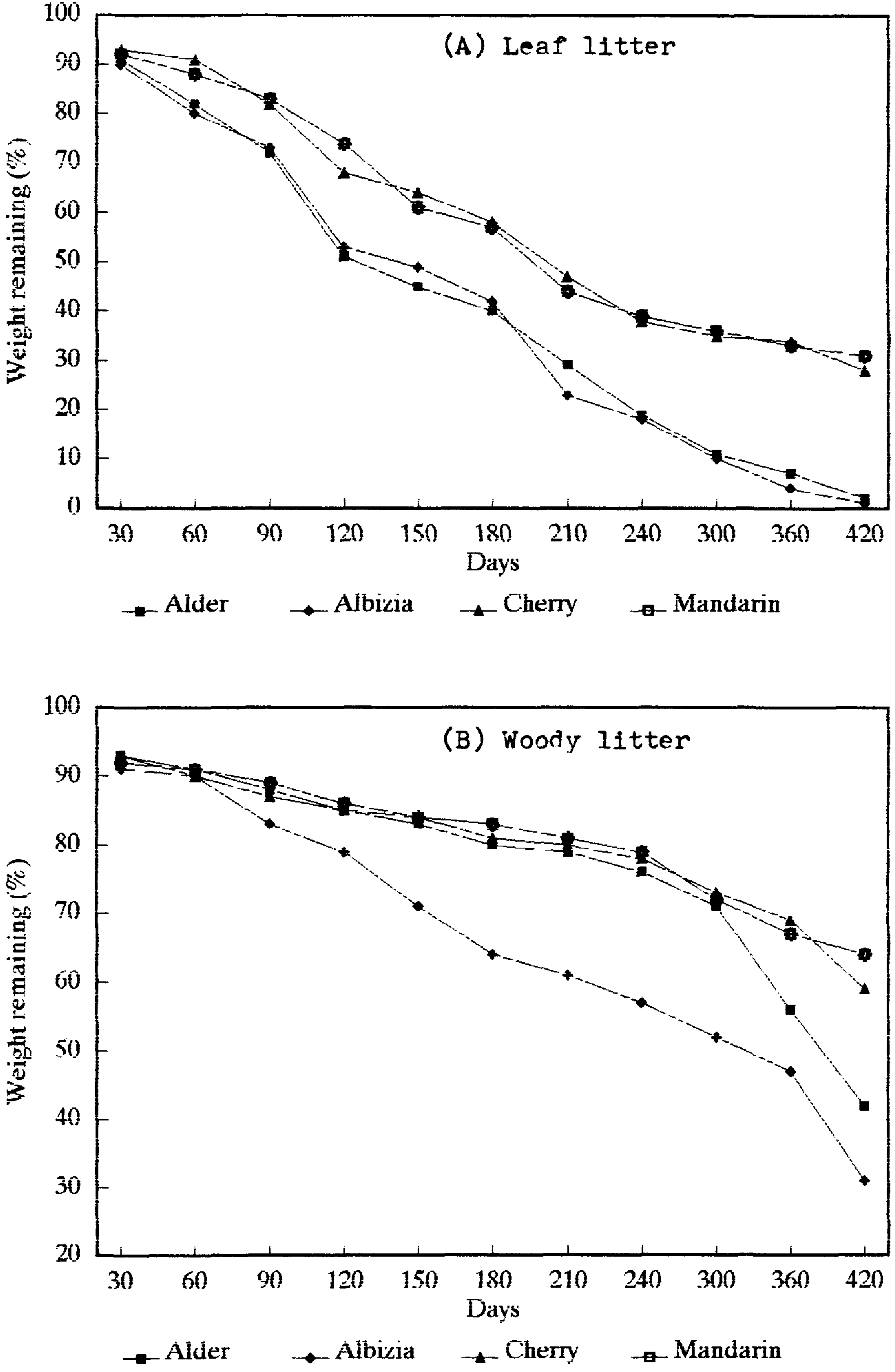
Decomposition time projection

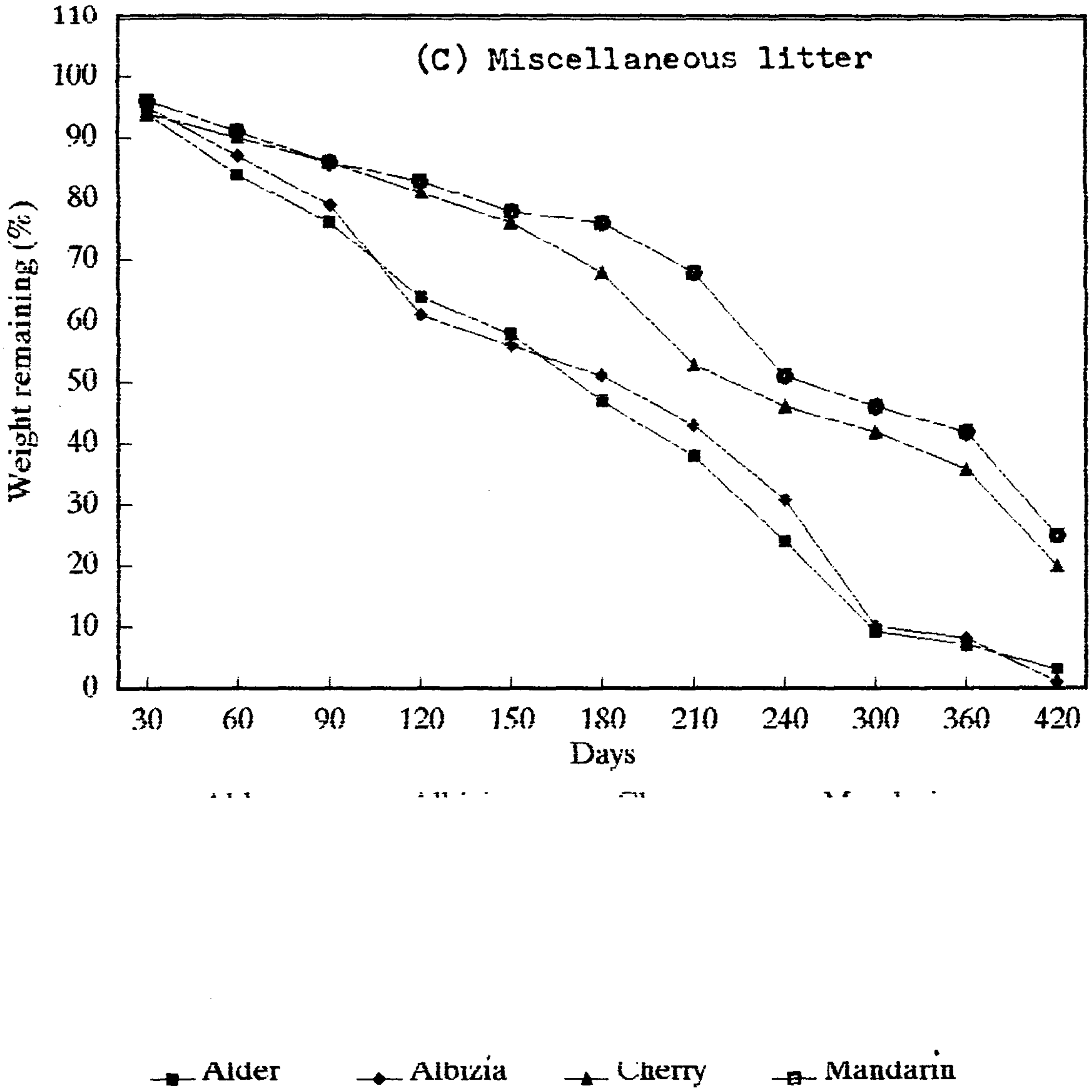
The daily instantaneous decay rates (k) of three litter fractions during the period of study are presented in Table 7.6.

Table 7.6. Daily instantaneous decay rate (k), and time required (days) for 50% (t_{50}), 95% (t_{95}) and 99% (t_{99}) weight loss.

Litter category	Species	Decay rate (k)	Time required in days t_{50}	t_{95}	t_{99}
Leaf	Alder	0.0163	42	184	306
	Albizia	0.0165	42	182	303
	Cherry	0.0120	58	250	417
	Mandarin	0.0115	60	261	435
Woody	Alder	0.0096	72	310	517
	Albizia	0.0115	60	260	435
	Cherry	0.0068	101	439	732
	Mandarin	0.0060	116	500	833
Miscellaneous	Alder	0.0160	43	186	310
	Albizia	0.0165	42	182	303
	Cherry	0.0130	52	225	375
	Mandarin	0.0125	55	240	400

Fig. 7.2. Mean percentage dry weight remaining in leaf (A), woody (B) & miscellaneous (C) fractions of littermass in four species.




(C) Miscellaneous litter
Weight remaining (%)
110
100
90
80
70
60
50
40
30
20
10
0
30
60
90
120
150
180
210
240
300
360
420
Days
Alder
Albizia
Cherry
Mandarin

The k values for the leaf and miscellaneous litter were almost equal and higher than for the woody litter. The k values for the leaf and miscellaneous litter were highest (0.0165 day^{-1}) in albizia and alder and lowest in mandarin (0.012 day^{-1}). Similar trend was observed for woody litter. The time required for 50% decay (half life) was minimum (42-60 days) for leaf- and miscellaneous- and maximum (60-116 days) for woody-litter among the tree species. When the same values were assumed for further projection, the time required for 95% decomposition of leaf and miscellaneous litter would be about 182-261 days, while woody litter would require about 260 days in albizia and more than one year in cherry and mandarin (Table 7.6). For 99% decay, leaf and miscellaneous litter of the four tree species would require 303-435 days while their woody litter would need 435-833 days. The litter decomposition rates among the four tree species varied and highest rate was obtained for alder and albizia which have the highest N content in the litter (Table 7.7).

Table 7.7. Nitrogen content and decomposition rates of leaf litter of the four tree species after 150 days.

Species	Nitrogen content(%)	Decomposed after 150 days (%)
Alder	1.91	55
Albizia	1.58	51
Cherry	0.94	36
Mandarin	1.02	39

Nutrient (N, P and K) changes

The N, P and K stock in the decomposing littermass at different sampling dates was calculated by multiplying the dry weight of the decomposing litter fraction with the corresponding concentrations of nutrient (Fig. 7.3). The stock of

Fig. 7.3a. Percentage N remaining in leaf litter.

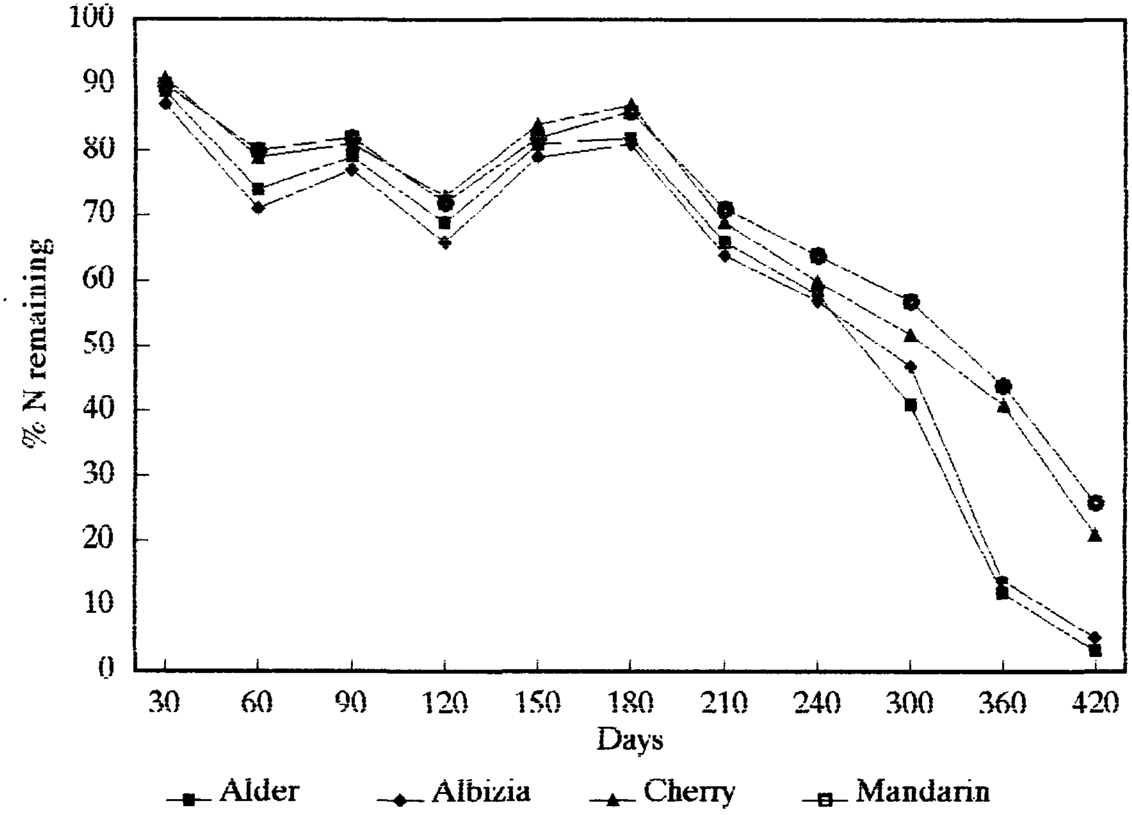


Fig. 7.3b. Percentage N remaining in woody litter.

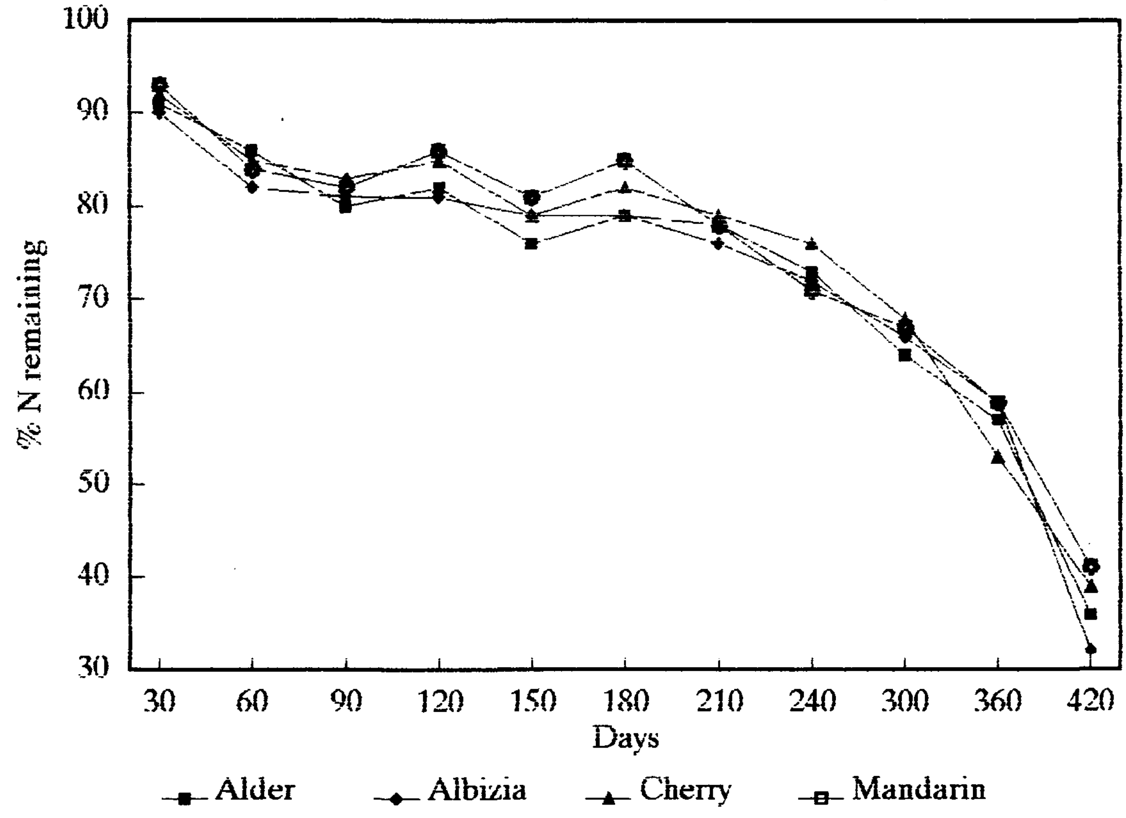
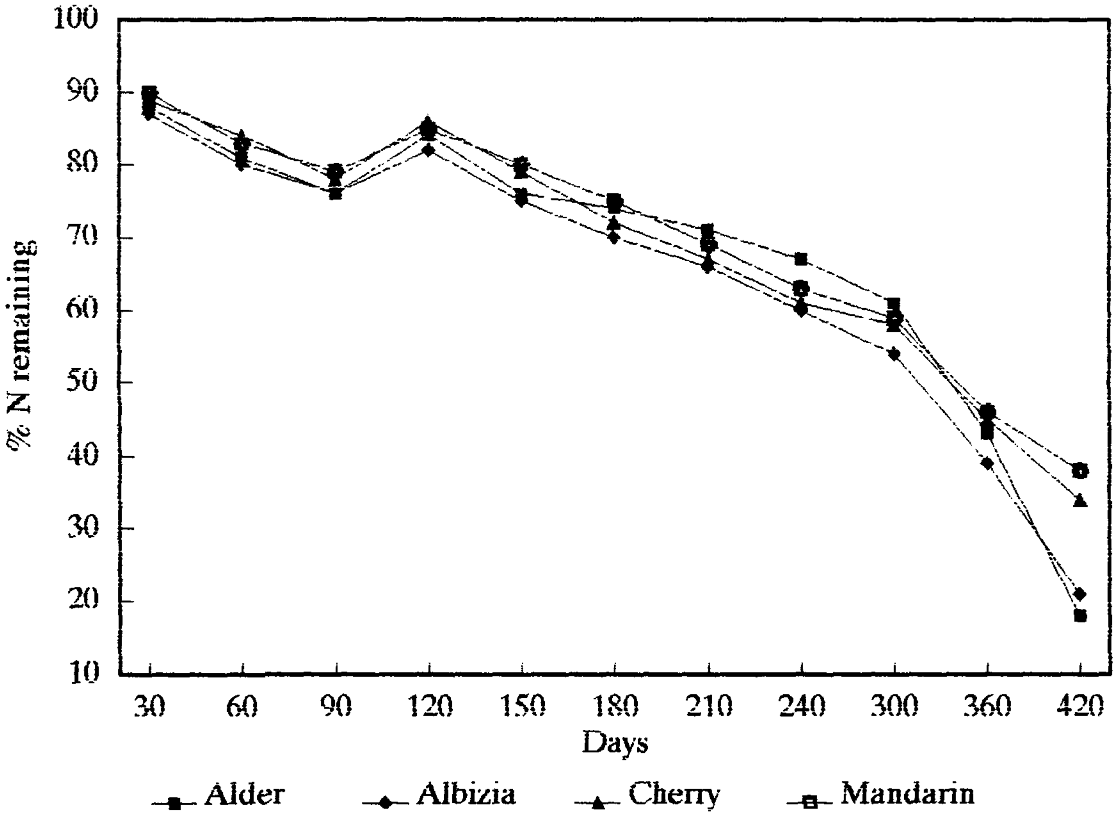


Fig. 7.3c. Percentage N remaining in miscellaneous litter.



nutrients indicated relatively higher amount of nutrient release during early stages of decomposition, irrespective of litter type and tree species.

The stock of nitrogen (N) in different fractions of litter of the four tree species showed fluctuation with time. The leaf litter showed a rapid decline in N stock up to 120 days, an increase up to 180 days, and thereafter, a constant decline till the end of the experiment. But in miscellaneous and woody fractions of litter there was a rapid decline in N stock up to 90 days followed by an increse at 120 days and thereafter till the end of the experiment a constant decline was observed. At the end of experiment (at 420 days) 97, 95, 79 and 74% of the initial N stock of leaf litter were released in alder, albizia, cherry and mandarin respectively. The percentage release of N from the miscellaneous litter ranged from 62% (mandarin) to 82% (alder) and from the woody litter it ranged from 59% (mandarin) to 68% (albizia).

The stock of phosphorus (P) in the leaf litter decreased constantly with time. In the other two fractions i.e. miscellaneous and woody litter, however, there was no constant decrease (Fig. 7.4). The amount of P increased at 150 and 180 days in miscellaneous litter, and at 180 days in woody litter. At 420 days, 82-93% of the initial P stock in leaf litter, and 63-79% in miscellaneous and woody litter of the four species were released.

The stock of potassium (K) in the three litter fractions decreased constantly with time and it did not show any increase during the entire period of experiment (Fig. 7.5). At

Fig. 7.4a. Percentage P remaining in leaf litter.

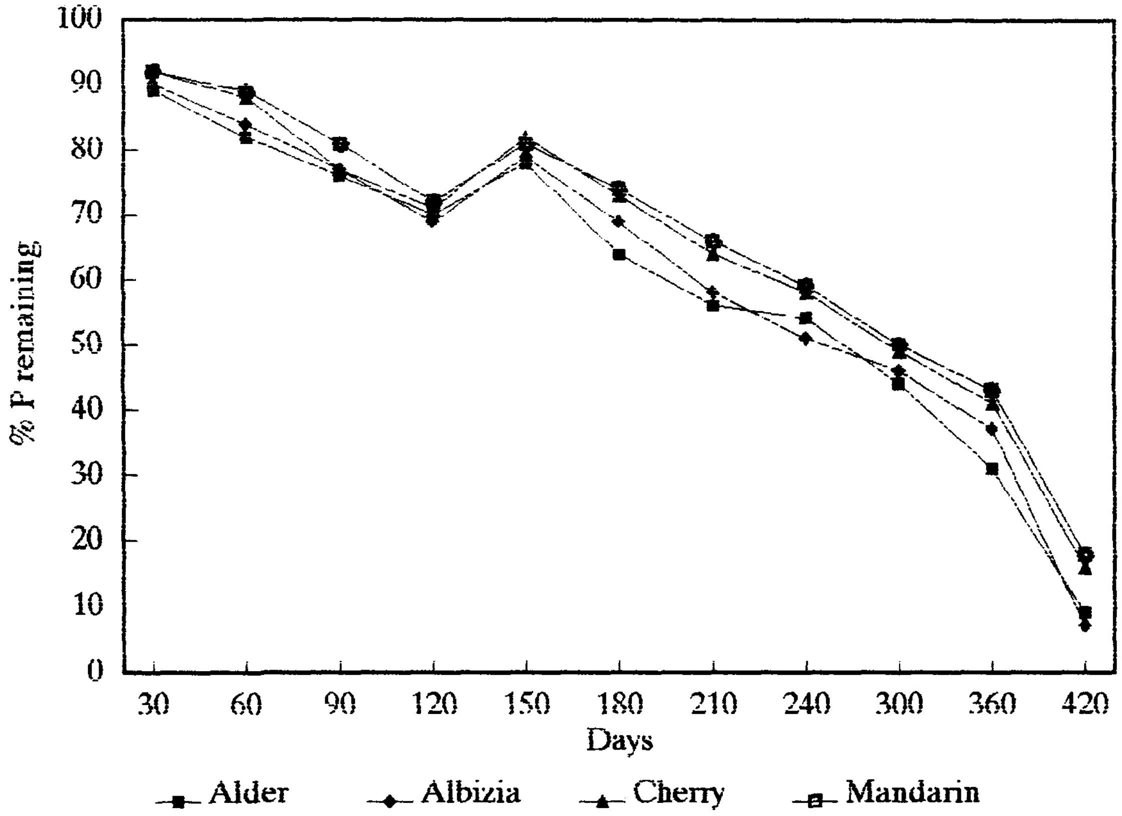


Fig. 7.4b. Percentage P remaining in woody litter.

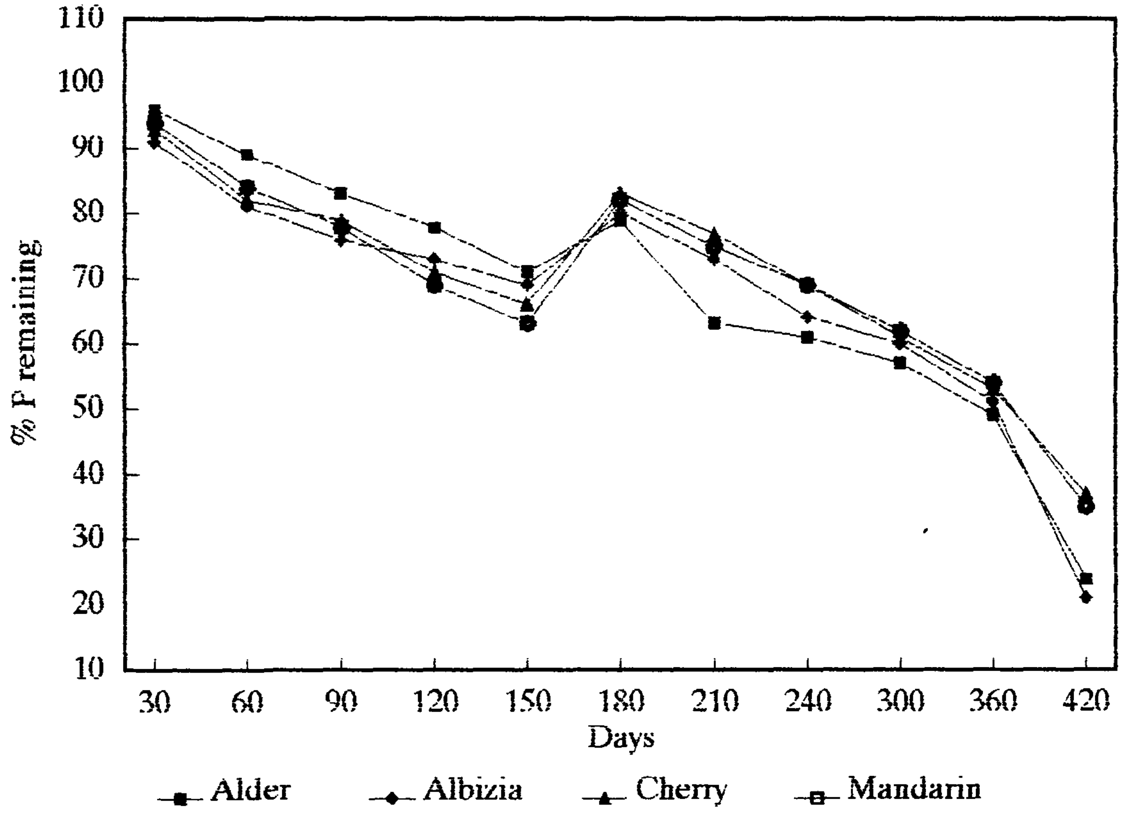


Fig. 7.4c. Percentage P remaining in miscellaneous litter.

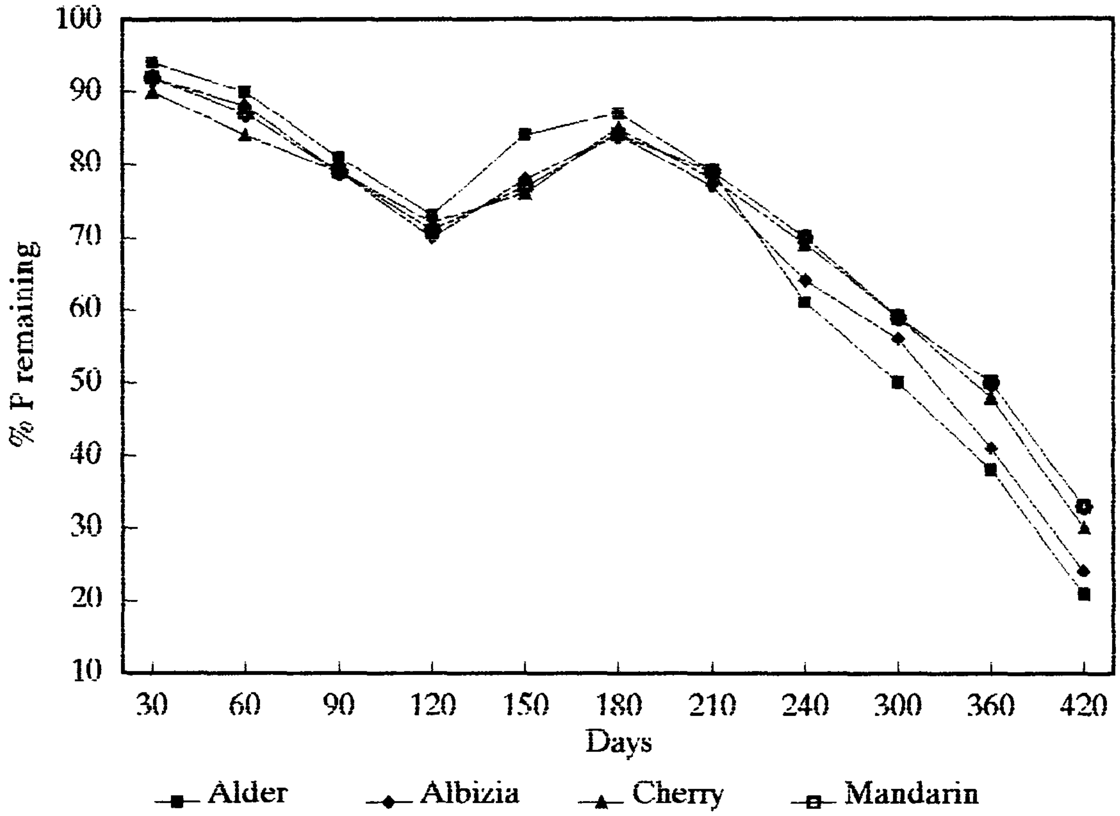


Fig. 7.5a. Percentage K remaining in leaf litter.

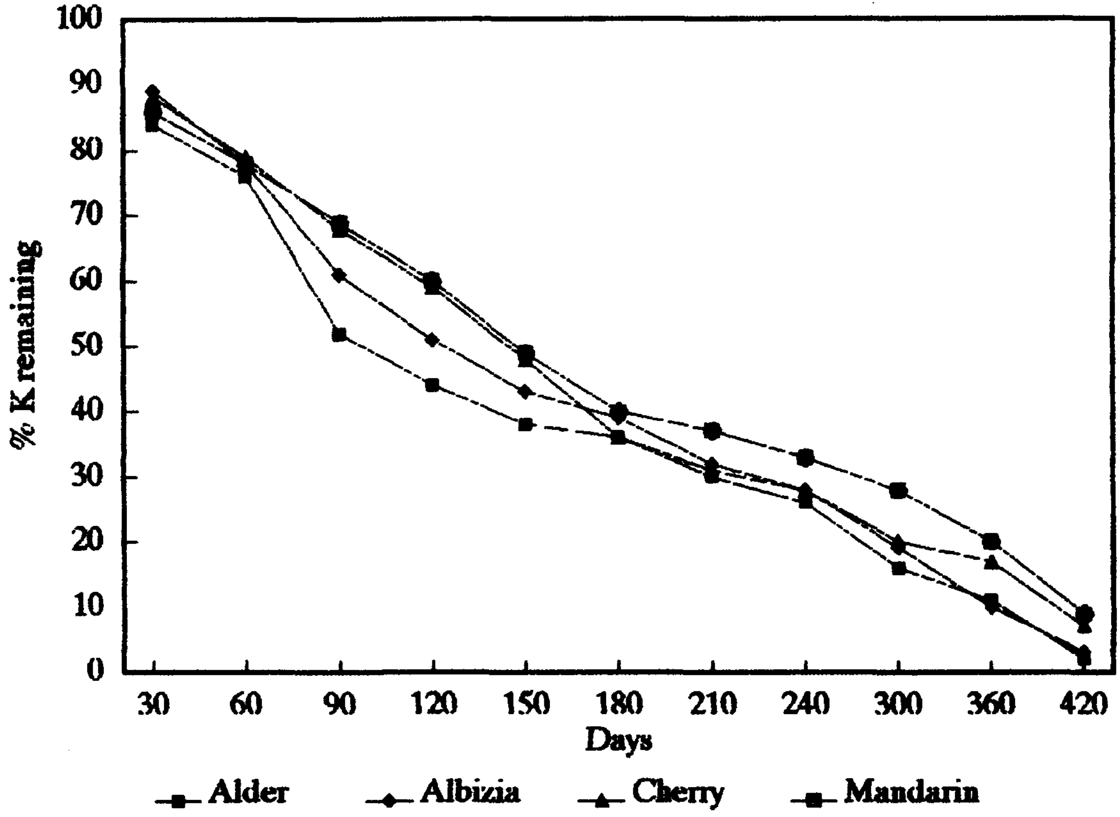


Fig. 7.5b. Percentage K remaining in woody litter.

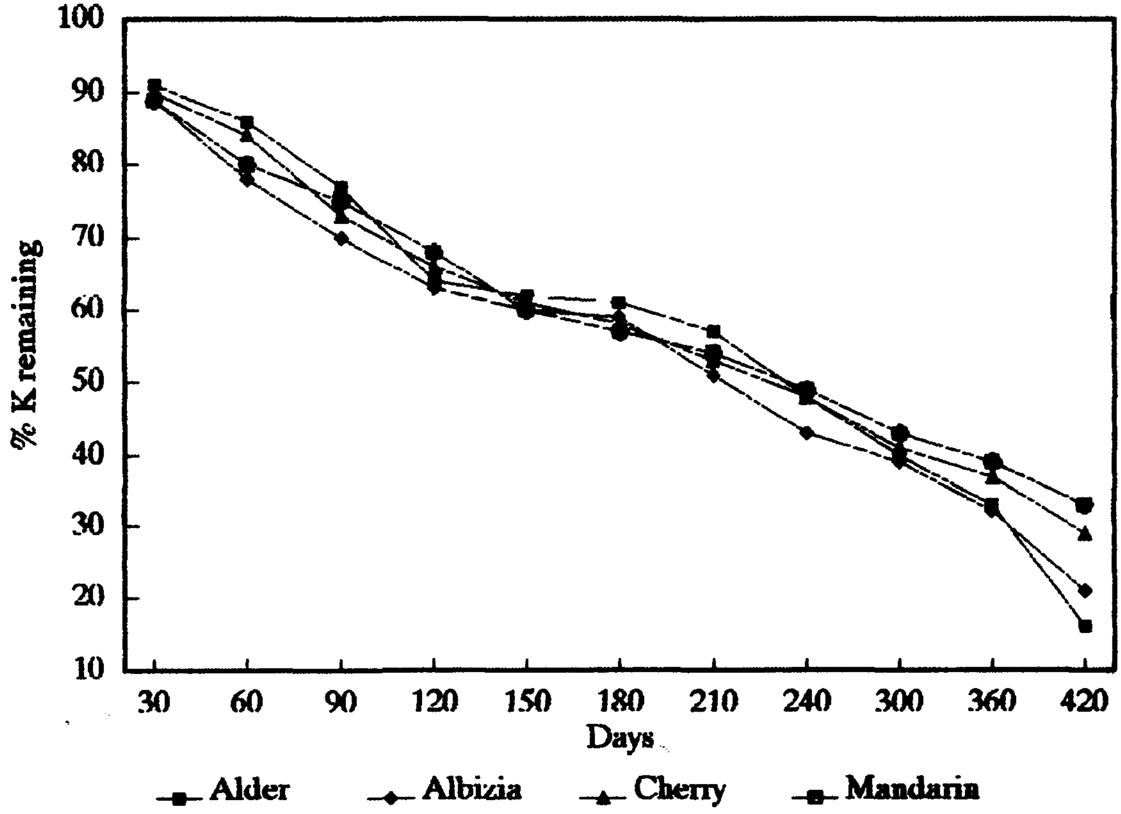
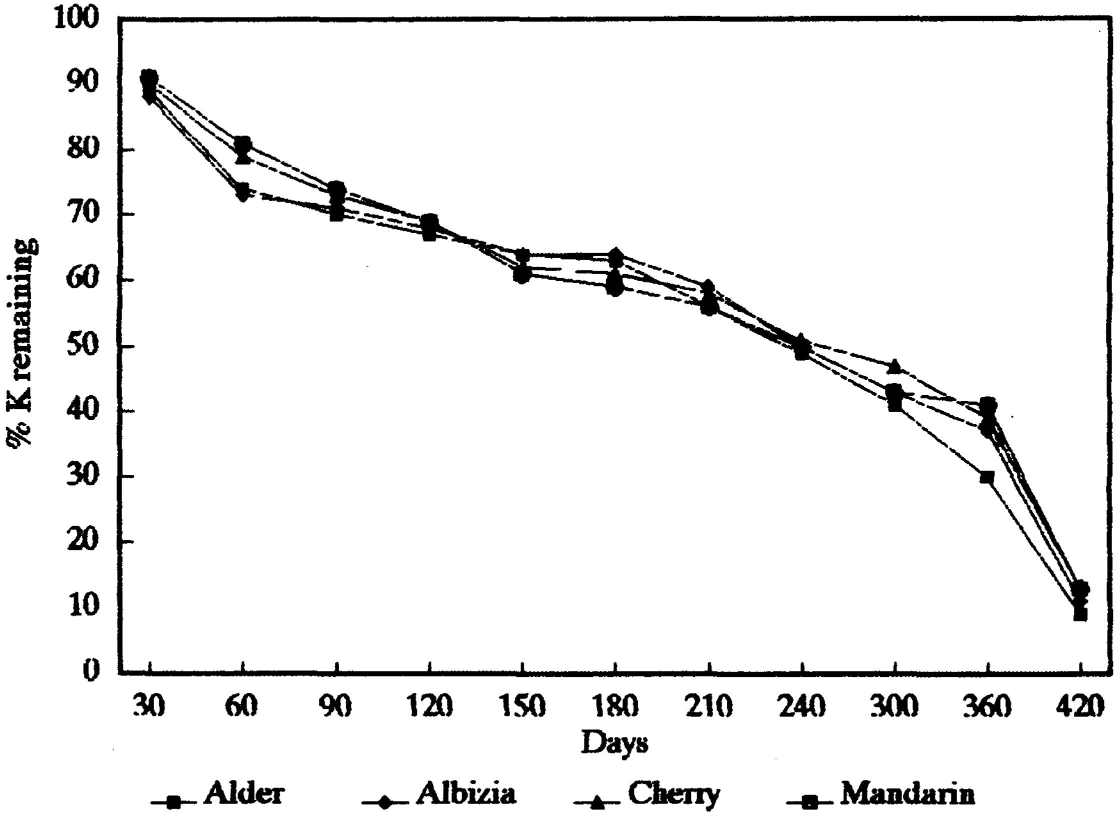


Fig. 7.5c. Percentage K remaining in miscellaneous litter.



the end of the experiment (420 days) 2-9% of the initial K stock of leaf litter, 9-13% of miscellaneous litter and 16-33% of woody litter remained undecomposed.

Overall, during the entire period of experiment the nutrient release from the alder and albizia litter was greater than from the cherry and mandarin litter.

Nutrient concentration in ground-floor littermass

Nutrient (N, P and K) concentration in leaf, woody and miscellaneous fractions of ground-floor littermass showed definite seasonal pattern (Table 7.8). The maximum N concentration (%) in all the three fractions of litter was observed in autumn followed by winter, and minimum during rainy season. The leaf litter had significantly ($P<0.05$) higher concentration of N than the miscellaneous and woody litter. It ranged 0.6-1.4% among the four species. Maximum concentration of N in leaf litter was recorded in alder and albizia and minimum in cherry. N con centration in woody and miscellaneous litter ranged 0.41-0.76%. P concentration in litter did not show definite seasonal trend but it varied markedly between different fractions of the litter. The miscellaneous fraction usually had higher concent ration followed by leaf and woody litter. There was no significant difference in P concentration among the four species. K concentration in the leaf litter was higher than the other two fractions. The values ranged 0.40-0.82, 0.31-0.77, and 0.29-0.67% in leaf, miscellaneous and woody fractions of litter, respectively.

Table 7.8. Seasonal variation in ground-floor littermass(kg ha^{-1}) and N and P concentration (%) in litter fractions in the four agroforestry systems. (±SEM, n=10)

Agrofor. systems	Season	Littermass (kg ha^{-1})	Litter fractions	Concentration(%)	
				N	P
AFS 1	Winter	8170.3	Leaf	1.08±0.10	0.05±0.01
			Woody	0.58±0.03	0.04±0.01
			Misc.	0.69±0.02	0.06±0.01
	Spring	2894.1	Leaf	0.98±0.11	0.04±0.01
			Woody	0.52±0.01	0.03±0.01
			Misc.	0.60±0.01	0.05±0.01
	Rainy	190.6	Leaf	0.81±0.12	0.04±0.01
			Woody	0.44±0.11	0.03±0.01
			Misc.	0.61±0.06	0.04±0.01
	Autumn	655.0	Leaf	1.46±0.11	0.06±0.01
			Woody	0.71±0.12	0.04±0.01
			Misc.	0.76±0.09	0.06±0.01
AFS 2	Winter	6968.7	Leaf	0.99±0.13	0.05±0.01
			Woody	0.50±0.02	0.05±0.01
			Misc.	0.57±0.02	0.06±0.01
	Spring	845.8	Leaf	0.84±0.11	0.05±0.01
			Woody	0.51±0.03	0.04±0.01
			Misc.	0.70±0.12	0.06±0.01
	Rainy	176.2	Leaf	0.71±0.10	0.04±0.01
			Woody	0.54±0.05	0.03±0.01
			Misc.	0.60±0.09	0.05±0.01
	Autumn	819.3	Leaf	1.34±0.10	0.05±0.01
			Woody	0.69±0.09	0.04±0.01
			Misc.	0.74±0.09	0.06±0.01
AFS 3	Winter	8694.0	Leaf	0.79±0.10	0.06±0.01
			Woody	0.48±0.03	0.04±0.01
			Misc.	0.54±0.02	0.07±0.02
	Spring	575.0	Leaf	0.74±0.10	0.04±0.01
			Woody	0.43±0.03	0.04±0.01
			Misc.	0.49±0.04	0.05±0.01
	Rainy	161.0	Leaf	0.68±0.08	0.04±0.01
			Woody	0.43±0.05	0.03±0.01
			Misc.	0.47±0.04	0.04±0.01
	Autumn	2070.0	Leaf	0.91±0.08	0.07±0.02
			Woody	0.58±0.06	0.04±0.01
			Misc.	0.61±0.04	0.08±0.02
AFS 4	Winter	1425.9	Leaf	0.81±0.10	0.07±0.02
			Woody	0.49±0.03	0.05±0.01
			Misc.	0.53±0.03	0.08±0.02
	Spring	157.1	Leaf	0.71±0.08	0.05±0.01
			Woody	0.44±0.03	0.04±0.01
			Misc.	0.48±0.12	0.05±0.01
	Rainy	128.0	Leaf	0.59±0.08	0.05±0.01
			Woody	0.41±0.02	0.04±0.01
			Misc.	0.45±0.02	0.06±0.02
	Autumn	228.9	Leaf	0.97±0.06	0.07±0.02
			Woody	0.46±0.04	0.05±0.01
			Misc.	0.54±0.09	0.08±0.02

Misc. Miscellaneous litter

DISCUSSION

Litter production can vary as a result of species composition, plant age, spacing, local environmental conditions, and data collection period (Buck, 1986). Data on litter production (Table 7.4) clearly indicated that leaf litter was the major component contributing 50-79% of the total litter. Alder produced maximum leaf litter followed by cherry and albizia, while mandarin produced the least amount of litter. Low litter production in mandarin may be due to the greater longevity of its leaves, and greater production of litter in alder could be due to its more extensive canopy compared to the other tree species. The litter production values for alder in this study are within the range reported for various *Alnus* species in different parts of the world (2.6-9.9 t ha^{-1}) and also for *Alnus nepalensis* in Eastern Himalaya (3.2-5.8 t ha^{-1}) (Sharma & Ambasht, 1987). High variability of tree species with regard to litter production was also reported by Alaban (1982) and many other workers (Thojib, 1980; Budelman, 1989; Hawkins *et al.*, 1990; Szott *et al.*, 1991a; Szott & Kass, 1993; Dhyani *et al.*, 1994). The values obtained for the four tree species are within the range of reported litter production rates of 0.44 to 8.18 t $ha^{-1}yr^{-1}$ (Thojib, 1980; Reichle, 1981; Singh, 1984; Sanchez & Sanchez, 1995). The higher proportion of leaf fraction in the total litter is also reported by other workers (Singh, 1984; Jordan, 1983; Sanchez & Sanchez, 1995). In the present study, more than 80% litterfall was recorded during dry periods (November to April) and hardly any leaffall during wet season. Higher litter production during the dry periods has also been reported by Sanchez and Sanchez (1995). Moore (1980) reported that the water stress triggers *de novo* synthesis of abscissic acid in the foliage of plants, which in turn can stimulate senescence of leaves and other parts. Hence, changes in the endogenous hormonal balance can be a probable explanation for peak litterfall during dry period. In the present study a prolonged litterfall from November to early May could be attributed to the high wind valocity prevailing in this region during these months.

The litter standing crop represents the balance between input by litterfall and output by decomposition. Since the climate of study area shows distinct seasonal cycles, litter production as well as decomposition closely follow a seasonal pattern. Mean daily leaf litter production was maximum during winter and varied between 0.72 to 5.4 g $m^{-2}day^{-1}$. The highest litter production rate during winter was observed in cherry, followed by alder and albizia and minimum in mandarin. Maximum accumulation of litter on the ground during autumn and winter was due to increased litterfall and lower decomposition rate. Hardly any decomposition of litter from October till March was noticed primarily due to very little rainfall coupled with low temperature during this period. In contrast, during spring and rainy seasons when the environmental conditions are favourable for microbial activity, there was minimum littermass on the ground due to faster rate of decomposition.

A more rapid turnover of leaf-litter was recorded in mandarin- and cherry-system as compared to alder- and albizia-system. The main reason for the rapid leaf-litter turnover in mandarin-system may be due to its small tree canopy which allow more radiation to reach the ground surface, which might lead to increase in soil surface temperature. Under the small canopy trees there may be wide fluctuations in diurnal temperature, aeration, and wetting and drying cycles than under the trees which have large and wide canopies. These microclimatic differences might cause more rapid decay of leaf litter under the small canopy trees compared to those with large canopy. However, when turnover of total litter was considered, rates were faster in cherry than other species. The values of decay constant of different fractions of litter in the present study are similar to those reported for the tropical forests (0.7-6.0)(Swift *et al.*, 1981) indicating a rapid breakdown of litter at present site.

On the the other hand, litter-bag studies for decay pattern of total litter and its fractions indicated that decomposition of cherry and mandarin leaf- and miscellaneous- litter occurred at slower rate compared to alder and albizia. The ranking of the four tree species for turnover rates and decay pattern obtained through the litter-bag technique was different from that observed earlier which may be attributed to the buried or confinement condition of the litter in this case. It is well known that buried litter decomposes faster than surface litter (Wilson, *et al.*, 1986). The nutrient rich litter of alder and albizia decomposed more rapidly than cherry and mandarin litter. It took 240 days for leaf litter and 300 days for miscellaneous litter for 90% loss of material in alder and albizia, but in other two species a good proportion of all the three litter fractions remained undecomposed even after 420 days. The differences in decay constant (k) among the four tree species may be attributed to quality of liter. Litter of high quality (high in nutrients, low in lignin) decays and releases nutrients rapidly, than that of low quality (high in lignin and/or phenols) (Swift *et al.*, 1979). The slow rate of decomposition could be attributed to the time-lag in the colonization and establishment of the microbes on the litter (Alexander, 1977) on account of low moisture and high lignin contents in the leaves of cherry and mandarin. Overall, the rapid rate of decay after an initial lag phase was the net effect of a large number of processes such as utilization of readily available energy sources by microbes, loss of water soluble components and non-structural carbohydrates from leaf litter (Bloomfield *et al.*, 1993), and removal of leaf litter particles by animals, especially termites operating on the freshly fallen litter on ground (Swift *et al.*, 1979). A decline in the rate of weight loss after rapid phase of decay may be attributed to higher % of recalcitrant fraction like cellulose, lignin and tannin during the advanced stage of leaf decay. These substances are known to control decay rate by slowing resistance to enzymatic attack and by physically interfering with the degradation of other chemical fractions of the cell wall (Bloomfield *et al.*, 1993). Within the overall decay pattern, seasonal fluctuations were also observed. Woody litter comprising woody residues, branches and twigs decomposed at slower rates than the leaf and miscellaneous litter. The differences in the rate of decomposition may be attributed to differences in substrate quality. Woody litter had lower N and P concentration than the leaf and miscellaneous litter, and they did not show marked temporal variation. The perennial tissues have also been reported to have lower concentrations of nutrients especially N and P (Swift *et al.*, 1979; Young, 1989). Higher concentration of N in the leaf litter was responsible for its faster decomposition. A positive effect of N concentration on decomposition was also reported by several authors (Swift *et al.*, 1979; Pandey & Singh, 1982; Shukla *et al.*, 1990). Rout and Gupta (1987) and Parmelee *et al.* (1989) reported that the species/fraction with higher initial N concentration decomposed more rapidly than the species/fraction with lower N. Slow rate of decomposition of plant materials with lower N is related to the greater proportion of lignin fraction in the tissues (Fogel & Cromack, 1977; Meentemeyer, 1978; Swift *et al.*, 1979; Laishram & Yadava, 1988).

Decay of leaf litter of the tree species was accompanied by a rapid loss of nutrients at 60 days due to heavy rainfall. Subsequent increase in N and P concentration up to 180 and 150 days, respectively might have resulted due to microbial immobilization, nutrinet inputs from throughfall and atmospheric precipitation, and/or atmospheric nitrogen-fixation. Thus N and P release during leaf litter decay was influenced by immobilization and mineralization processes which are strongly influenced by seasonal cycle in climatic variables. Warm humid rainy season being more favourable for mineralization, was characterised by rapid rate of N and P release from the decomposing leaf litter than the dry-winter season when immobilization was the dominant process on ground-floor. In the present study alder had a high rate of litter production and contributed a litter which was easily decomposable by virtue of its high foliar N and low tannin content (Clein & Schimel, 1995). Relatively rapid release of N and P from alder and albizia litter (Fig. 7.3, 7.4) may be quite useful from the point of view of meeting requirements of intercrops during rapid growth phase. The high nitrogen content of alder and albizia litter can increase the amount and rate at which certain minerals can be utilized and recycled.

The daily decay rates (Table 7.6) of the three litter fractions were highest in albizia and alder and lowest in mandarin. The time required for 50% decay was minimum (42-60 days) for leaf and miscellaneous litter and maximum (60-112 days) for woody litter. The trend was similar for 95 and 99% decay. In the case of trees major portions of the nutrients were released from leaf- and miscellaneous-litter, though a slow rate of decay of woody litter contributes to the conservation of nutrients. Overall, the species ranking for rate of decomposition of total litter and its fractions was alder >albizia >cherry >mandarin.

Crops such as soybean, ground nut, linseed and mustard vary in their nutrient requirements during the growing season. It is therefore, beneficial if the release of nutrients from litter decay coincides with the time of active uptake of nutrients by the crop. The knowledge of the rate of litter decomposition offers opportunities to manipulate the timing of nutrient release (Young, 1989). At the present site, from October till March litter primarily serves as mulch material for protecting soil moisture. It also maintains optimum soil temperature, which eventually provides a conducive environment for crop seed germination, seedling establishment, better growth and yield. Besides, the accumulated litter is a reservoir of nutrients, which starts decomposing and releasing nutrients with the onset of favourable conditions during spring and rainy seasons. This is the period when kharif crops are grown and thus, the period of nutrient uptake by crops coincides with the release of nutrients from the litter decay. For agroforestry systems where annual crops are important components, tree species with a high quality of leaf-litter *e.g.* alder and albizia appear desirable not only because of the high nutrient content of their litter but also because the nutrient release synchronizes well with nutrient uptake period of crops. In this way, the ratio between nutrient uptake by plants and loss of nutrients through leaching is increased, making the plant-soil system more closed (Swift, 1984, 1985, 1987; Yamoah *et al.*, 1986a).

CHAPTER 8

PHYSICO-CHEMICAL CHARACTERISTICS OF SOIL AS INFLUENCED BY THE AGROFORESTRY SYSTEMS

Investigating long term effects of cultivation on soils under different agroforestry systems is an important component of research efforts to predict their suitability for sustainable production. Soil organic matter is the most dynamic constituent in soil and its input is a key factor governing soil fertility as it greatly influences the physical, chemical and biological characteristics of soils (Lal & Kang, 1982; Adejuwan & Adesina, 1990; Drechsel *et al.*, 1991). One of the reasons for enhanced interest in agroforestry is the belief that inclusion of compatible and desirable trees on crop land would improve soil fertility (Okigbo *et al.*, 1980; Vergora, 1987; Young, 1986a, 1986b, 1989; Lal, 1989; Parrotta, 1990; Watson, 1990). Besides, several studies have reported positive influences of trees on soil fertility (Bernhard-Reversat, 1982; Nair, 1984, 1989; Wiersum, 1984; Lundgren & Nair, 1985; Sharma *et al.*, 1985; Lal, 1986; Young, 1987, 1989; Kang & Wilson, 1987; Verinumbe, 1987; Campbell *et al*, 1988, 1990, 1994; Belsky *et al.*, 1989, 1993; Ingram, 1990; Dunham, 1991; Kessler, 1992; Duguma *et al.*, 1994). However, rigorous evidence and objective data in support of this are still scanty (Steppler & Lundgren, 1988; Lal, 1989; Fisher, 1990; Nowak *et al.*, 1991; Prinsley, 1992).

Therefore, an attempt was made to find out alterations in physico-chemical properties of soil under four agroforestry systems. Such a study will be helpful in assessing the role of agroforestry in soil fertility build up in an ecological region where predominant traditional farming systems are based on shifting cultivation which has an adverse effect on soil properties.

MATERIALS AND METHODS

Physico-chemical properties of soil

Since the changes in physico-chemical properties of soil are due to cummulative effects of cultural/agroforestry practices over a period of time and are not reflected in a short span of two years as in case of the present study, the soil properties as determined during 1987 when these agroforesry systems were started, were compared with those determined at the begining (1992) and at the end (1994) of the present investigation. The chemical properties of soil observed during 1987 are presented and discussed in Table 3.3 of Chapter 3.

To evaluate the long term effects of tree species in the 'tree only' and 'tree+crop' situation under the four agroforestry systems on physico-chemical properties of soil, soil samples from 0-15 cm and 15-30 cm depths were obtained from all plots at the time of commencement (1992) and at the end (1994) of the present study. On each site, 4 places were randomly chosen for collection of soil samples and finally 1 composite sample was prepared. Soil samples were also collected from adjoining sole crop plots to serve as control. The soil samples were taken from the two depths, 1.5 m away from tree base. Samples were separated from undecomposed plant residues, air-dried and gently ground to pass through 2-mm mesh sieve and also 80 mesh screen and kept ready for analysis. Soil samples were analysed for water holding capacity (WHC) following Piper (1942) and bulk density (the quotient of dry weight of soil to the total volume it occupies in the field) using a metallic cylinder (diameter 6.5 cm) following Allen *et al.* (1974). After determining the bulk density, porosity was calculated using the following formula,

$$\text{Porosity} = 100 - \frac{(\text{Bulk density}) \times 100}{2.65}$$

Chemical properties of soil *viz.* pH, organic-carbon (C), total nitrogen, exchangeable Al^{+3}, Ca^{+2}, Mg^{+2}, K^{+1}, and Bray's P_2-P were determined following standard procedures as outlined below:

Parameters	Procedures	Extractants	Reference(s)
pH	Glass electrode pH meter	1:2.5, Soil:Water	Jackson (1973)
Organic-carbon	Walkley & Black's titration method	-	Jackson (1973)
Available	Bray's P_2-P	0.1N HCl+ 0.03N NH_4F	Bray and Kurtz (1954)
Exchangeable K, Ca, Mg	Flame photometer and versenate titration method	1(N)NH_4OAC, pH - 7.0	Jackson (1973)
Total N	Modified Kjeldahl method	-	Anderson and Ingram (1989)

Statistical analysis

The effects of the agroforestry systems on soil characteristics were assessed by analysing the data using appropriate statistical methods. Simple correlation in all possible combination for each property was also worked out for interpretation of results.

RESULTS

Chemical soil properties

Soils of the study site were deficient in available phosphorus mainly due to acidic soil reaction and presence of considerable amount of exchangeable Al^{+3} (Table 3.3, Chapter 3). In spite of the common crop sequence and adoption of uniform management practices, some of the properties (e.g. Bray's P_2-P, Ca^{+2}, and K^{+1}) of topsoil (0-15 cm soil depth) showed significant variation after five years of establishment of agroforestry systems i.e. at the beginning of the present investigation in 1992. At the end of the experiments in 1994, soil properties such as Ca^{+2}, Mg^{+2}, K^{+1}, Bray's P_2-P, and Al^{+3} were further influenced ($P < 0.05$) by the agroforestry systems and sole crop. Soil organic-C, N, Ca^{+2} and Mg^{+2} contents were higher in the 'tree only' situation as compared to the 'tree+crop' situation, but reverse was true for K^{+1}, Bray's P_2-P, and Al^{+3} contents of soil. Available P was enhanced by more than 38 per cent, Al^{+3} by 18 per cent and K^{+1} by 11 per cent in the 'tree+crop' situation than in the 'tree only' situation.

A. Organic carbon, nitrogen and Bray's P_2-P

After five years of establishment of the agroforestry systems, soil organic-C showed an increasing trend under alder, albizia and cherry systems but declined under mandarin system and control (sole crop). At the end of the experiment (1994), organic-C content declined in the 'tree only' and 'tree+crop' situations as well as in sole crop. The initial mean organic-C (average of all treatments) which was 1.77 and 0.88 percent respectively, for topsoil and subsoil layers during 1987 increased to 1.82 and 1.44 percent in 1992 and then declined to 1.56 and 1.02 percent at the end of the experiment (Fig. 8.1). The organic-C was enhanced by 24-32 per cent as compared to the control in alder and albizia systems but only 10-21 per cent in cherry and mandarin systems.

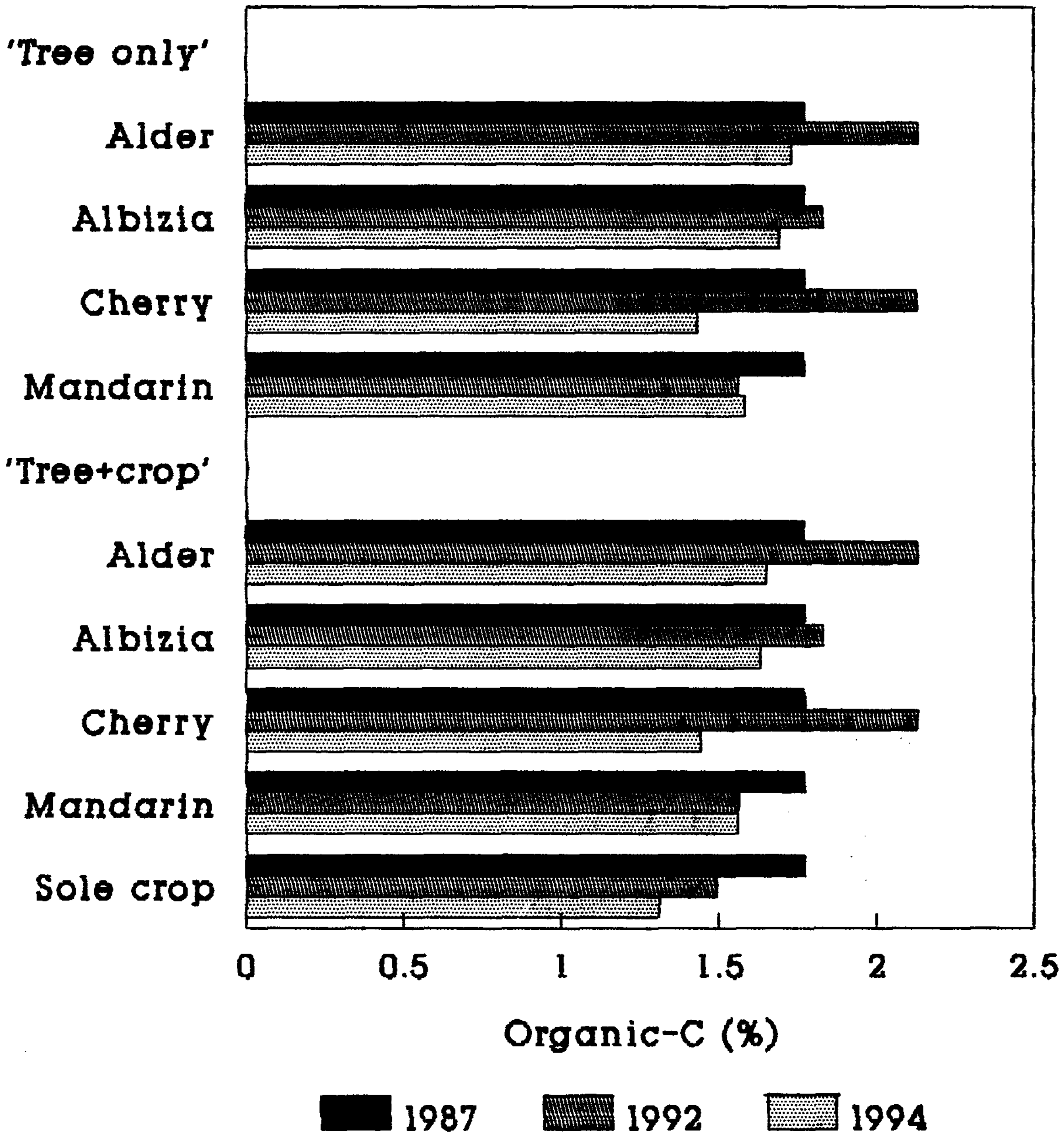
Soil nitrogen (N) content followed a trend similar to that of organic-C (Table 8.1). Over the values in the control (sole crop) total N contents of topsoil increased by more than 100 per cent in alder-, 82-100 per cent in albizia-, 54-63 per cent in mandarin- and only 36-54 percent in cherry-system.

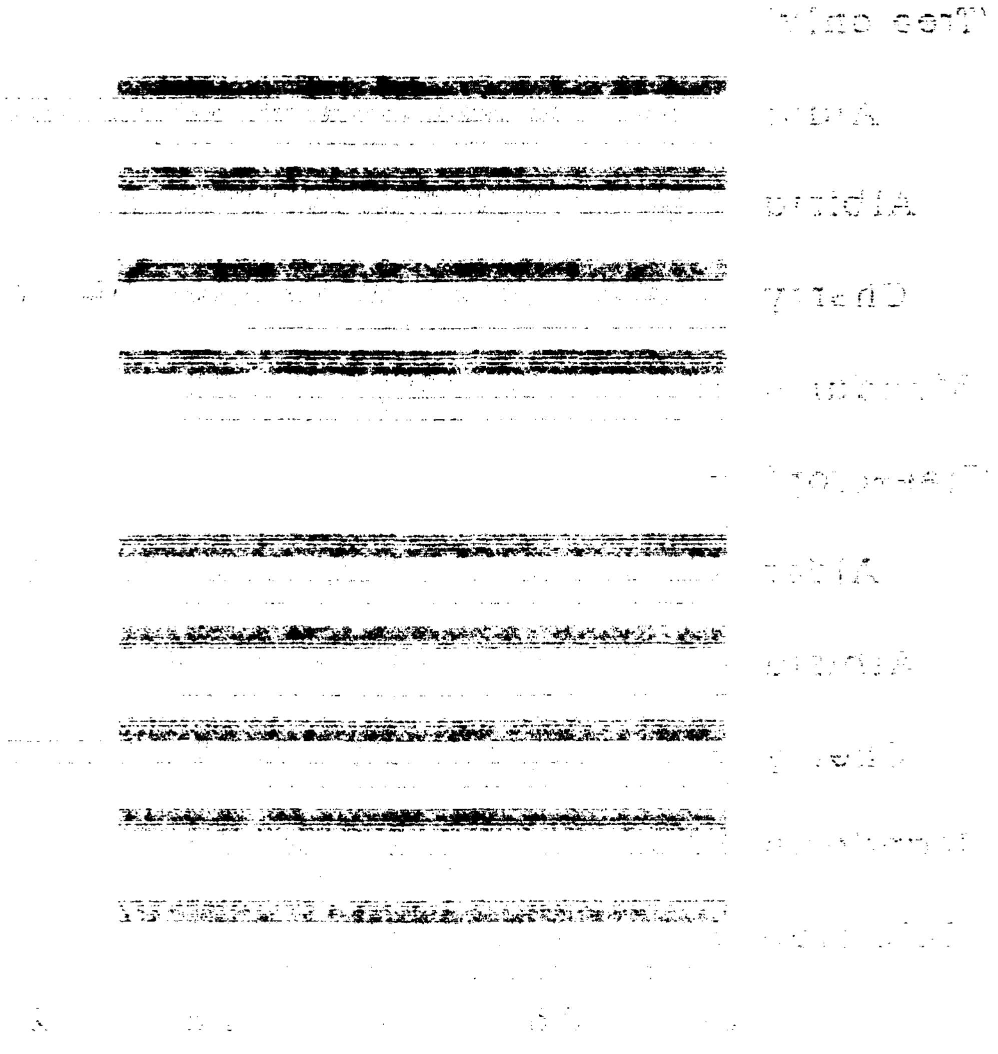
Table 8.1. Chemical properties of the topsoil (0-15 cm) at the end of the experiment in the 'tree only' and 'tree+crop' situations under the agroforestry systems.

Agroforestry systems	N-total (%)	C/N	Exchangeable nutrients (C mol(P^+) kg^{-1}) Ca^{++}	Mg^{++}	K^+	Bray's P_2-P ($mg\ kg^{-1}$)
'Tree only'						
Alder	0.25	6.90	3.10	2.28	0.34	9.40
Albizia	0.22	7.60	3.26	4.58	0.35	11.10
Cherry	0.17	8.40	2.30	2.14	0.21	8.50
Mandarin	0.18	8.70	2.84	2.30	0.27	8.80
'Tree+crop'						
Alder	0.23	7.10	2.91	2.05	0.41	12.10
Albizia	0.20	8.00	3.02	4.46	0.39	18.10
Cherry	0.15	9.60	2.11	1.90	0.23	10.50
Mandarin	0.17	9.20	2.52	2.00	0.27	11.80
Sole crop	0.11	12.20	0.53	0.51	0.19	5.80
Mean	0.19	8.60	2.51	2.46	0.29	10.67
SD+	0.04	1.61	0.83	1.28	0.08	3.39
%CV	23.20	18.63	33.23	51.90	27.02	31.80

Organic-C as well as total N contents were higher in the 'tree only' situation as compared to the 'tree+crop' situation of the four systems and the sole crop. Organic-C and total N

Fig.8.1. Effects of agroforestry systems and sole crop on organic-C contents of the topsoil.





contents in the sub-soil were quite low, but the trend was same as in the topsoil (Table 8.2).

The lowest C/N ratios (6.9 and 7.6 in the 'tree only' and 7.1 and 8.0 in the 'tree+crop' situations) in the topsoil were observed in the alder and albizia systems. The corresponding values for the subsoil were slightly higher (8.2 and 8.8 in alder, and 9.2 and 9.3 in the albizia systems). The maximum C/N ratio at the two depths was observed in the 'sole crop' plot (Table 8.1 and 8.2).

Concentration of Bray's P_2-P in topsoil changed drastically over a period of 7 years from 1987 through 1994 under the four agroforestry systems and sole crop. The mean P content in the topsoil which was low (1.20 mg kg^{-1}) during 1987 increased by four folds by 1992 and more than eight folds by 1994. Among the four systems, maximum increase in P content was observed in albizia and minimum in cherry. Besides, the 'tree+crop' situation has higher P content than the 'tree only' situation. Overall, an increase of 1.6 folds in the 'tree only', and 2.3 folds in the 'tree+crop' situation as compared to sole crop was recorded in the level of P during 1994 (Table 8.1). Similarly, the subsoil also showed an increase in P level in all the treatments (Table 8.2).

B. pH and exchangeable Al^{+3}

Mean soil pH in the topsoil declined under all the treatments from an initial value of 4.9 in 1987 to 4.7 in 1992 and then increased to 4.9 again in 1994. A perusal of data indicates that there was an increase in soil pH under all treatments as compared to 1992 except in the sole crop plot

Table 8.2. Chemical properties of the sub-soil (15-30 cm) at the end of the experiment in the 'tree only' and 'tree+crop' situations under the four agroforestry systems.

Agroforestry systems	pH in H_2O	Organic Carbon (%)	N-total (%)	C/N	Exchangeable nutrients (C mol(P^+) kg^{-1}) Ca^{++}	Mg^{++}	K$^+$	Bray's P_2-P (mg kg^{-1})	Exch.* Al^{+++}
'Tree only'									
Alder	4.8	1.11	0.13	8.20	0.95	0.61	0.29	0.93	0.28
Albizia	4.9	1.12	0.13	8.80	0.91	0.57	0.28	0.98	0.31
Cherry	4.7	1.04	0.09	11.20	0.61	0.43	0.25	0.78	0.71
Mandarin	4.8	1.08	0.11	10.00	0.82	0.51	0.25	0.80	0.55
'Tree+crop'									
Alder	4.9	1.09	0.12	9.20	0.85	0.57	0.28	1.00	0.33
Albizia	4.8	1.10	0.12	9.30	0.83	0.53	0.27	0.99	0.33
Cherry	4.8	0.94	0.08	11.70	0.52	0.40	0.23	0.86	0.74
Mandarin	4.8	1.01	0.10	10.00	0.78	0.43	0.24	0.88	0.58
Sole crop	**4.5**	**0.69**	**0.05**	**12.70**	**0.08**	**0.31**	**0.14**	**0.31**	**0.81**
Mean	4.8	1.02	0.10	10.12	0.70	0.48	0.25	0.84	0.51
SD±	0.1	0.13	0.03	1.47	0.27	0.09	0.04	0.21	0.20
%CV	2.5	13.37	25.60	14.52	38.54	20.20	18.25	25.48	40.38

where a gradual decline in soil pH was observed (Fig. 8.2). There was no significant difference in soil pH between the 'tree only' and 'tree+crop' situations. Soil pH was invariably higher in the alder, albizia and mandarin systems as compared to the cherry system and sole crop. The subsoil pH first declined from an initial 4.8 in 1987 to 4.6 in 1992 and then increased to a final value of 4.8 in 1994 (Table 8.2). However, the trend in the sub-soil was same as in the topsoil.

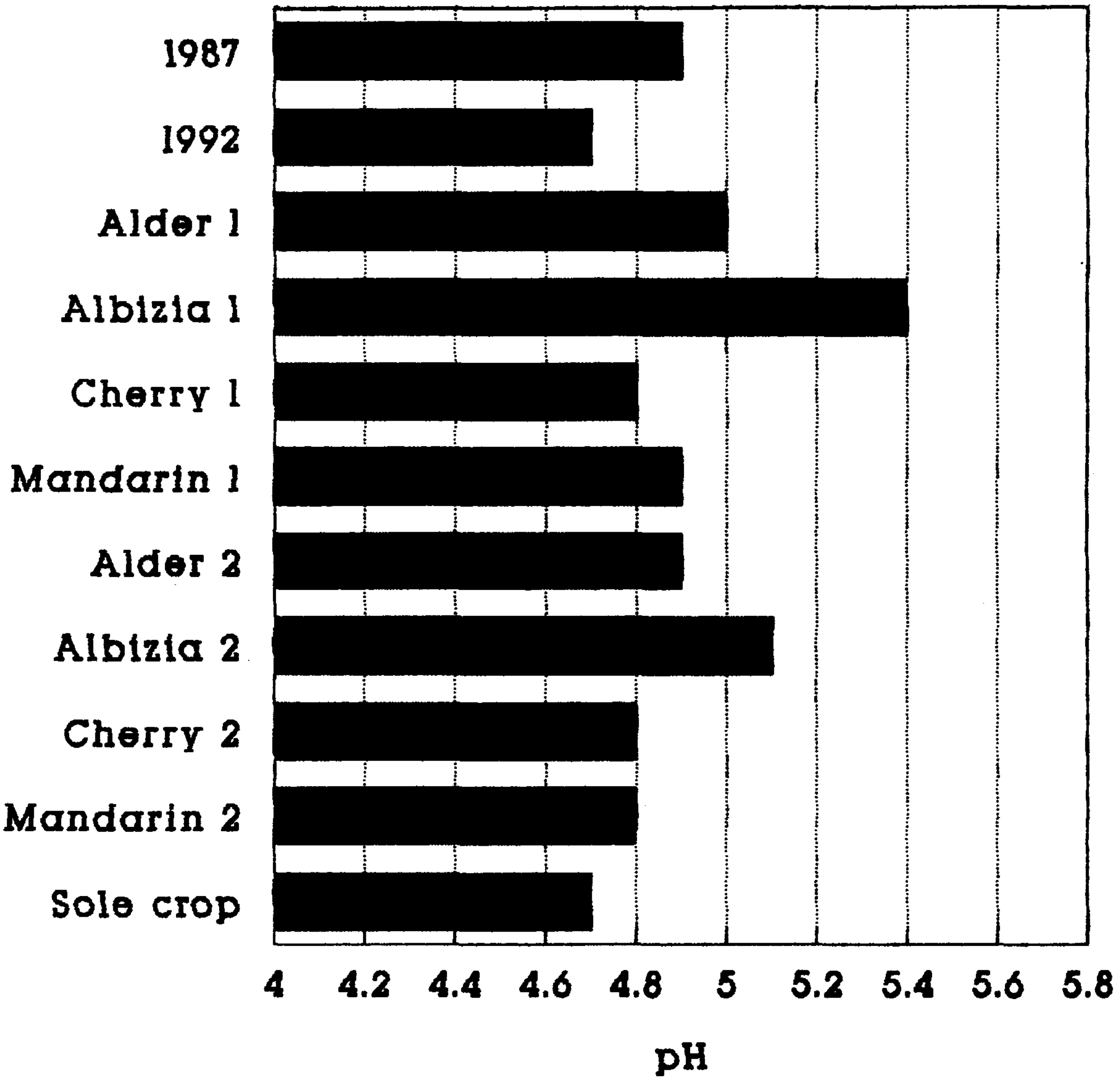
A marginal increase in exchangeable Al^{+3} (Fig. 8.3) content of soil was noticed in all the treatments during 1992. Mandarin system recorded the highest increase. At the end of the experiment (in 1994), exchangeable Al^{+3} in the topsoil was drastically reduced in alder and albizia systems but marginally under the mandarin system and only slightly in sole crop and cherry system. In 1994, exchangeable Al^{+3} content in the control (sole crop) and cherry system was still higher than the initial value of 0.55 C $mol(P^{+})\ kg^{-1}$ observed during 1987. The mean exchangeable Al^{+3}(C $mol(P^{+})kg^{-1}$) content in the sub-soil increased from 0.68 in 1987 to 0.74 in 1992, and then declined to 0.51 in 1994 (Table 8.2). The trend among the different treatments was same as in the topsoil.

The decrease in exchangeable Al^{+3} content was corroborated with significant increase in soil pH during the same period as is indicated by a highly significant relationship between exchangeable Al^{+3} and soil pH ($r=-0.77^{**}$ $P<0.01$) (Fig. 8.4).

C. Cations (exchangeable Ca^{+2}, Mg^{+2} and K^{+1})

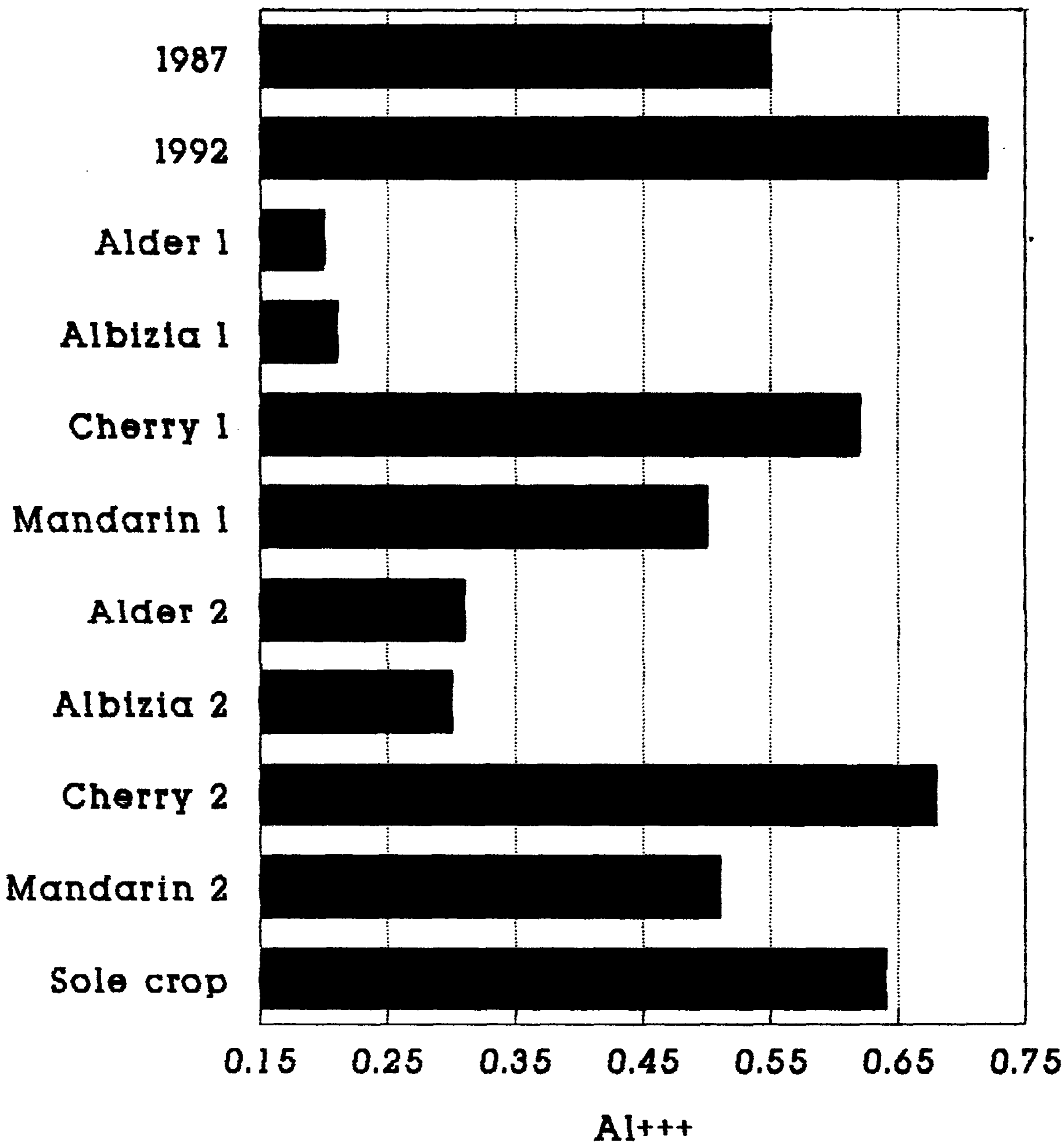
There were significant differences among the four agroforestry systems and the sole crop with regard to exchangeable

Fig. 8.2. Mean pH of the topsoil during 1987, 1992 and under the four systems at the end of experiment i.e. during 1994.



1- 'tree only' situation,
2- 'tree+crop' situation

Fig.8.3. Mean exchangeable Al+++ in top-soil during 1987, 1992 & under the four systems at the end of experiment (1994).



1- 'Tree only' situation,
2- 'Tree+crop' situation.

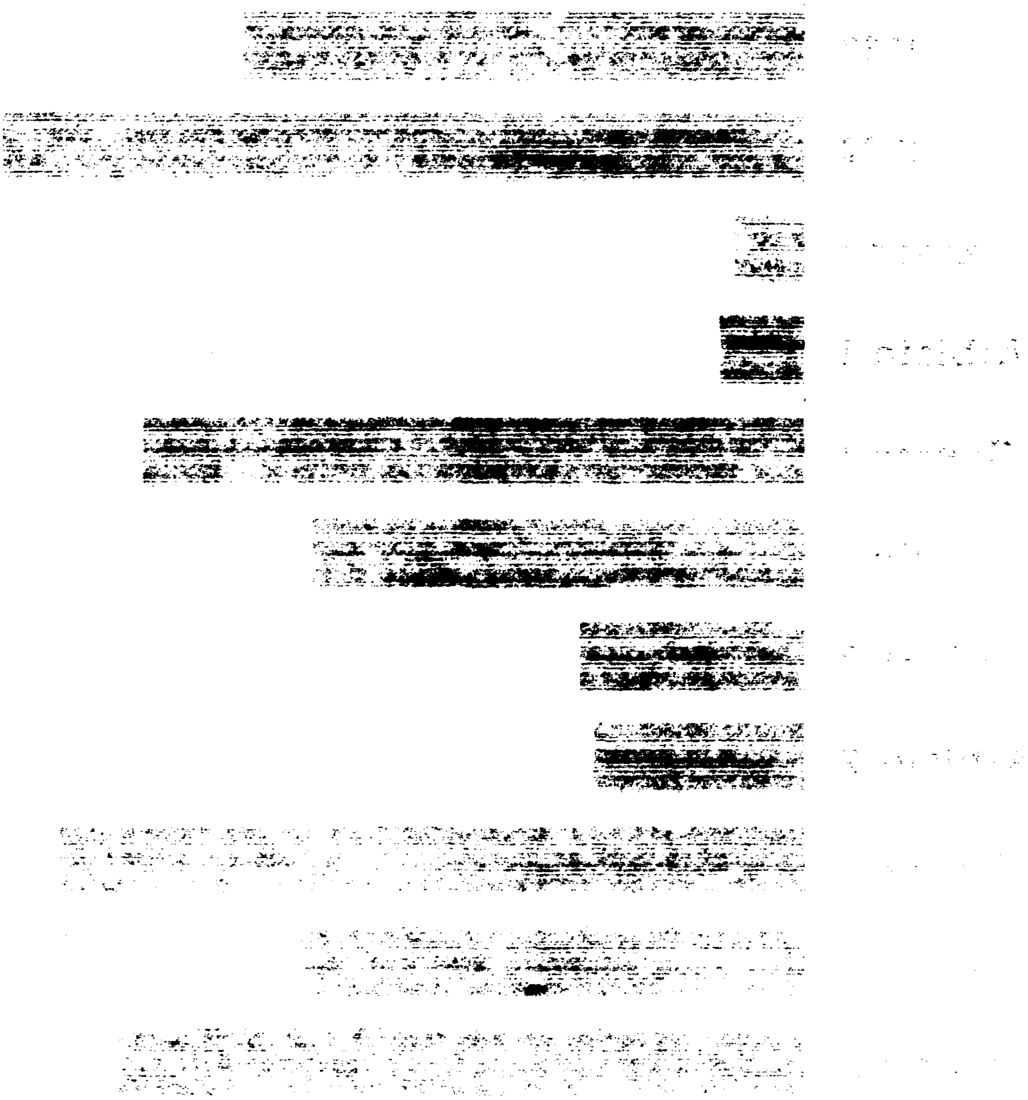
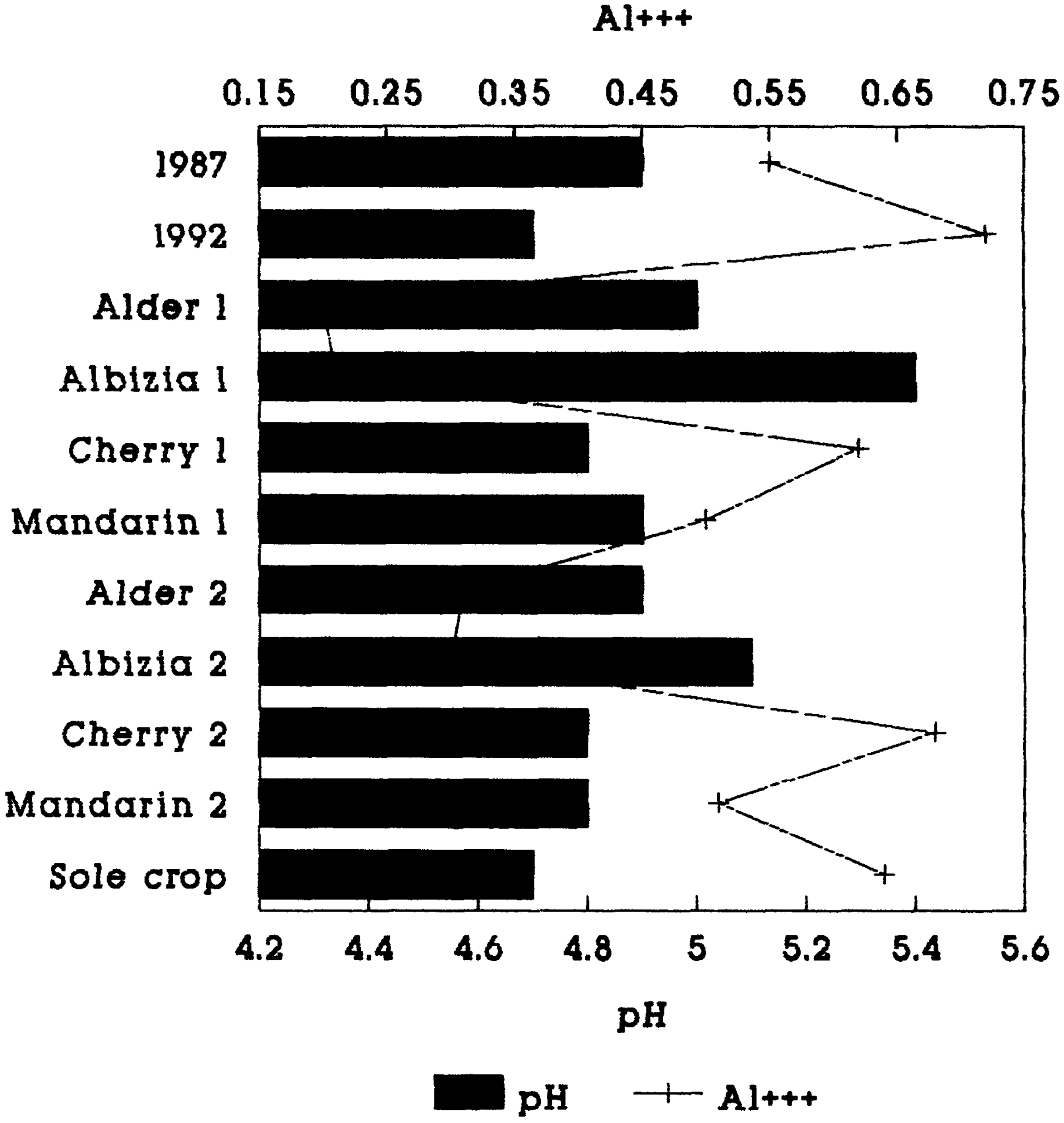


Fig.8.4. Mean pH and exch. Al+++ in top-soil during 1987, 1992 & under the four systems at the end of experiment (1994).



1- 'Tree only' situation.
2- 'Tree+crop' situation.

cations. Exchangeable Ca^{+2} contents of topsoil declined at the fifth year in 1992 and then it increased at the end of the experiment during 1994 under the four agroforestry systems. However, in the control (sole crop) a gradual decline in exchangeable Ca^{+2} contents of soil was observed (Table 8.1). The increase of exchangeable Ca^{+2} in the topsoil was more than 3-5 folds under the four systems in both the situations as compared to the control (sole crop). Maximum increase was recorded in the albizia system followed by the alder system and minimum in the cherry system. There was also a very high (5 to 11 folds) increase in exchangeable Ca^{+2} level at the subsoil under the four agroforestry systems compared to the sole crop (Table 8.2).

Trends in exchangeable Mg^{+2} content of soil were somewhat different from those of Ca^{+2}. The exchangeable Mg^{+2} contents of the topsoil recorded a gradual increase under all the treatments from an initial 0.50 C $mol(P^{+})kg^{-1}$ in 1987 to a final value of 2.46 C $mol(P^{+})kg^{-1}$ in 1994 (Table 8.1). The highest increase was recorded under albizia followed by alder and mandarin systems, while very little increase was observed in the cherry and sole crop. In the subsoil, however, there was a decline in 1992 and then an increase in 1994 (Table 8.2).

There were significant differences among the four agroforestry systems and the control (sole crop) with regard to exchangeable K^{+1} contents of soil (Table 8.1). In the topsoil, exchangeable K^{+1} increased in 1992 in the albizia, cherry and mandarin systems but declined in alder system. However, in

1994, it increased in alder, albizia, mandarin systems and sole crop (control) but declined slightly in the cherry system. There was more than two fold increase in K^{+1} content under alder and albizia, and about 30% in mandarin system in 1994 compared to 1992. Trend of exchangeable K^{+1} content in the subsoil was also well defined as in the topsoil (Table 8.2).

The total exchangeable cation (Ca^{+2}, Mg^{+2} and K^{+1}) contents of soil increased and were highest in the albizia- followed by the alder-system, while the lowest values were recorded in the sole crop plot. In the sole crop plot there was a slight reduction in total exchangeable cation contents in 1994 as compared to 1992. The increase in exchangeable cations in the topsoil seems to be directly related to increase in soil pH as there was a significant ($r = 0.66^{*}-0.96^{**}$, $P<0.05^{*}$, $<0.01^{**}$) positive correlation between these parameters (Fig. 8.5).

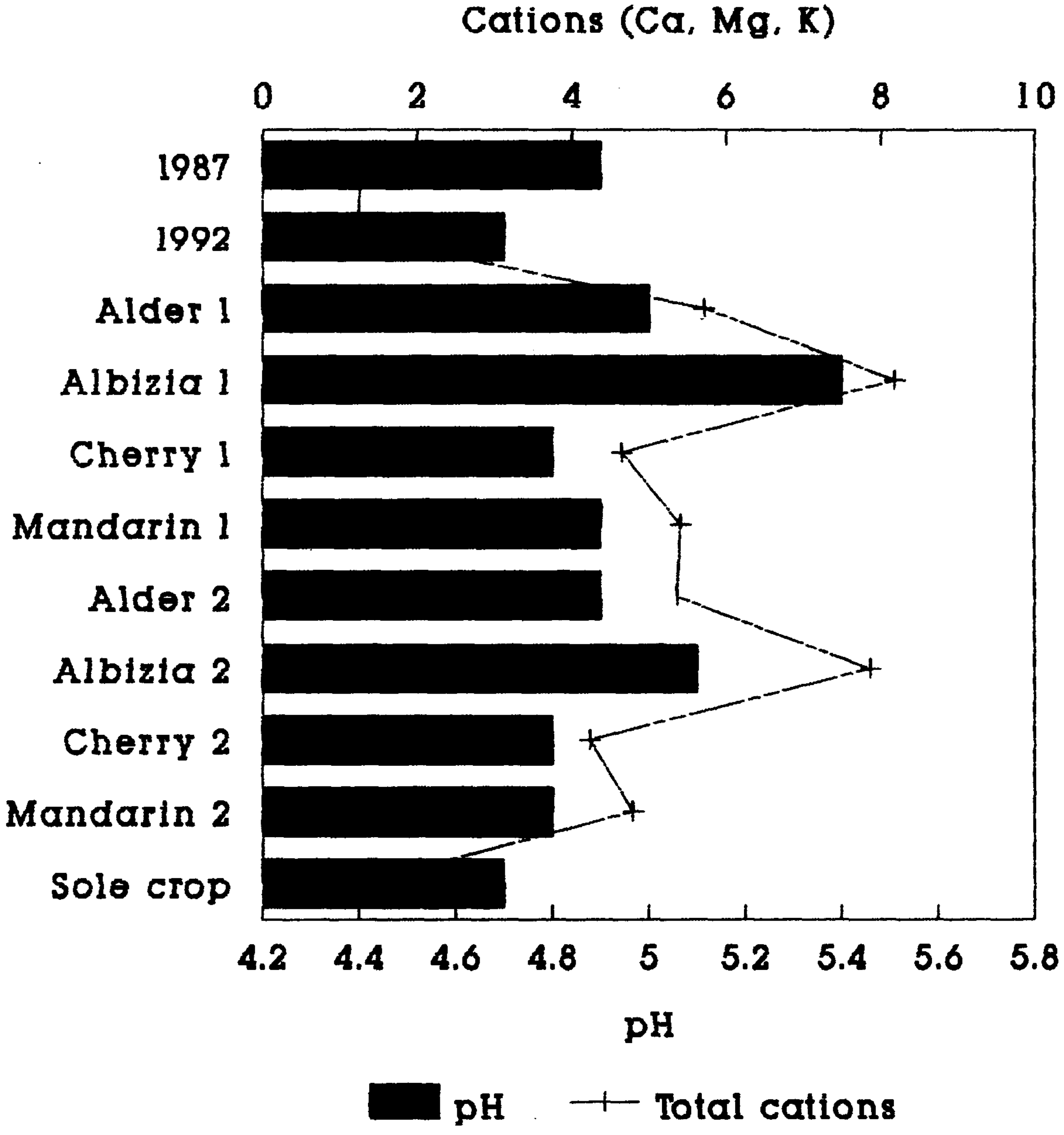
Physical properties of soil

Influence of the four agroforestry systems and the sole crop on physical properties of soil viz. water holding capacity, bulk density and porosity are presented in Table 8.3 and discussed below.

A. Water holding capacity (WHC)

At the beginning of the present investigation (1992), there was no significant ($P < 0.05$) difference in the WHC of soil under the four agroforestry systems and the sole crop. Although WHC was higher in the 'tree+crop' than in the 'tree only' situation and also in the subsoil than in the topsoil, the differences were not-significant ($P<0.05$). WHC varied between 39.3-42.8% in the topsoil and 41.4-45.6% in the

Fig.8.5. Mean pH and total exch. Cations in soil during 1987, 1992 & under the AF systems at the end of experiment (1994).



1- 'Tree only' situation.
2- 'Tree+crop' situation.

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Table 8.3. Changes in physical properties of soil in the 'tree only' and 'tree+crop' situations at the two soil depths (0-15 & 15-30 cm) under the four agroforestry systems.

Agroforestry	Initial (1987)						At the end of the experiment (1994)					
systems	WHC (%)		Bulk density (g cm^{-3})		Porosity (%)		WHC (%)		Bulk density (g cm^{-3})		Porosity (%)	
Soil depth	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
'Tree only'												
Alder	40.4	42.1	1.25	1.34	52.83	49.43	42.5	43.3	1.16	1.29	56.22	51.30
Albizia	40.6	42.0	1.21	1.36	54.33	48.68	42.9	43.2	1.14	1.31	57.22	50.56
Cherry	40.2	42.3	1.24	1.33	53.20	49.81	43.1	42.8	1.14	1.29	57.00	51.30
Mandarin	39.4	41.4	1.24	1.34	53.20	49.43	42.3	42.9	1.15	1.28	56.60	51.70
'Tree+crop'												
Alder	42.6	45.4	1.17	1.21	55.84	54.33	43.3	46.2	1.14	1.20	57.00	54.72
Albizia	41.9	45.6	1.19	1.20	55.10	54.71	43.6	46.3	1.12	1.18	57.73	55.47
Cherry	42.8	44.8	1.14	1.17	56.98	55.85	44.0	45.3	1.10	1.16	58.50	56.22
Mandarin	42.2	44.9	1.16	1.19	56.22	55.10	42.8	45.4	1.09	1.18	58.86	55.47
Mean	41.4	43.6	1.19	1.25	54.92	52.49	42.87	44.2	1.13	1.23	57.02	53.45
SD±	1.3	1.6	0.04	0.05	1.89	3.03	0.76	1.5	0.03	0.05	1.33	2.20

WHC- Water holding capacity

$$\text{Porosity} = 100 - \left(\frac{\text{Bulk density}}{2.65}\right) \times 100$$

subsoil during 1992. It improved marginally (7%) at the end of the experiment (1994) under the four agroforestry systems but declined by 3% in the sole crop plot.

B. Bulk density

The bulk density of soil in 1987 varied between 1.14-1.25 g cm^{-3} in the topsoil and 1.19-1.34 g cm^{-3} in the sub-soil. At the end of the experiment, bulk density was reduced by 6% under the four agroforestry systems but increased by 5% in the sole crop plot. However, because of variation caused by stones and pebbles in the samples the differences were not significant.

C. Porosity

In 1992, there were hardly any differences among the four agroforestry systems and sole crop with regard to porosity of topsoil. Porosity ranged between 52.83-54.33 per cent in 'tree only' and 55.10-56.98 per cent in 'tree+crop' situations as compared to 56.60% in the sole crop system. At the end of the experiment, porosity increased under the four agroforestry systems but declined under the sole crop, though the diffrences were not significant. Porosity at subsoil followed the trend similar to the topsoil.

DISCUSSION

The processes whereby trees improve soil fertility are many and difficult to separate. However, the mechanism that most probably played the major role in fertility build-up in the present study, is the improvement of soil organic matter (SOM) status by the trees under the agroforestry systems. In the four agroforestry systems litter, particularly leaves, twigs, flowers, fruits and bark which are produced by the tree component act as the raw materials for the generation of organic matter. Provided the foliage cover is maintained in such a way that surface wash is minimised, particularly on slopy land conditions, the organic matter produced will continue to accumulate even though some of it would normally be lost from the ecosystem (Jordan, 1985) through plant use and leaching. Alder, albizia and cherry are capable of generating large quantities of litter (Chapter 7) during the dry period when they shed their leaves, flowers etc.. The litter of alder and albizia contains high amount of nitrogen (>2%), and so they are capable of yielding high quality of organic matter. Alder, albizia and cherry also have heavy foliage cover in the rainy season which helps prevent the removal of the organic matter from the topsoil. Many other studies have also concluded that soil fertility under trees is improved through increased input of litter and SOM compartments under trees (Campbell *et al.*, 1988, 1994; Dunham, 1991; Isichei & Monoghalu, 1992; Kesseler, 1992). Levels of SOM also influences the levels of most nutrients (Campbell *et al*, 1988, 1994; Dunham, 1991; Kamara & Haque, 1992).

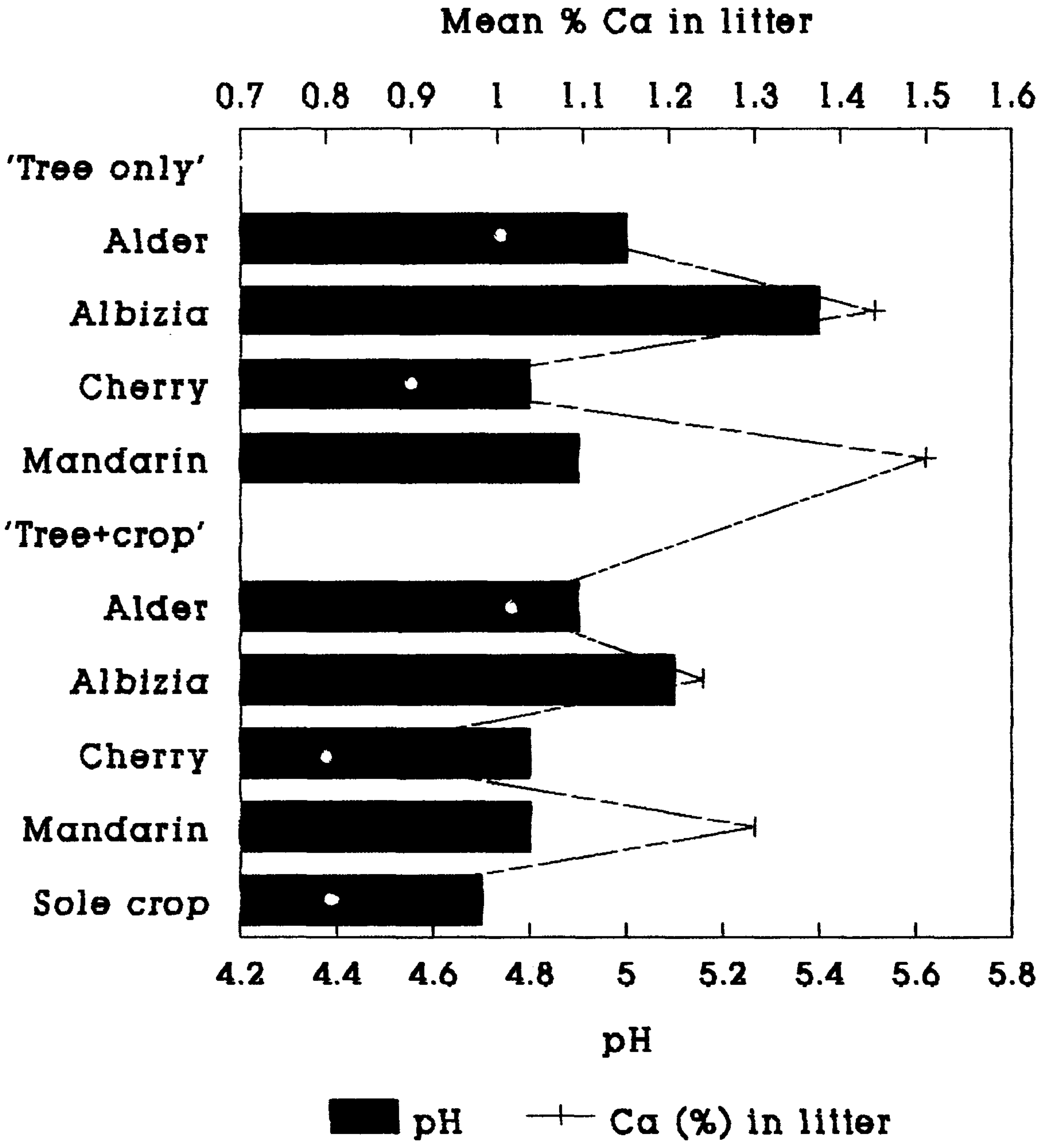
Effects of agroforestry systems on soil fertility

Generally, the effects of trees on soil properties are concentrated in the topsoil (Adesina, 1988). In the present study, highly significant differences in chemical characteristics of topsoil among the four systems indicate that different tree species had different influence on the soil properties.

Soil pH, exchangeable cations and Al^{+3}

The initial declining trend in soil pH (Fig.8.4) was mainly due to rise in exchangeable Al^{+3} level, whereas, soil pH rise at the end of the experiment was primarily due to sharp decline in exchangeable Al^{+3} coupled with a substantial increase in total exchangeable cations (Ca^{+2}, Mg^{+2} and K^{+1})(Fig. 8.5), particularly by Ca^{+2}-'pumping' of the trees (Drechsel *et al.*, 1991) since topsoil pH depends significantly ($r=0.70$, $P<0.05$) on the Ca levels of the litter (Fig. 8.6). Exchangeable Al^{+3}, a potential cause of infertility of acid soils, was increased initially mainly due to leaching of cations owing to low canopy (in initial years) coupled with regular use of nitrogenous fertilizers, particularly, in the 'tree+crop' situation. Sanchez (1976) also reported that progressive replacement of H^{+} ions by Al^{+3} ions in soil with low pH (<5.0) results in aluminium toxicity. On the contrary, at the end of the experiment, accumulation of high amount of soluble cations (10.49 C mol(P^{+}) kg^{-1}) in the topsoil caused sharp reduction in exchangeable Al^{+3}. However, the cherry system and control (sole crop) behaved differently. In these cases exchangeable Al^{+3} content of the soil at the end of the experiment though declined in comparison to 1992, it was still 13-20 per cent higher than in 1987. This was mainly due to lowest accumulation of total exchangeable cations (Ca^{+2}, Mg^{+2} and K^{+1}) in the cherry system as compared to other three systems. In the case of control (sole crop), marked deterioration of topsoil may be due to a degree of acidification which commonly occurs under agricultural use and can become

Fig. 8.6. Mean pH of the topsoil and Ca in litter under the four systems and sole crop at the end of the experiment.



severe with repeated application of fertilizers, especially ammonium sulphate. This is a common hazard associated with the agricultural use of soils of both moderate and strong acidity unless some amendments are used. Thus the exchangeable Al^{+3} content and total exchangeable cation status of the soil governed the soil pH under the four agroforestry systems and control (sole crop).

Organic carbon, nitrogen and available P

Maximum accumulation of organic-C occurred in the alder, cherry and albizia systems, which may be attributed to the addition of a relatively higher amount of aboveground litter (Chapter 7) and root biomass (Chapter 5) as compared to mandarin system. Another possibility for this high buildup might be the lesser microbial activity due to excessive exchangeable Al^{+3}, low P and cations such as Ca^{+2} and Mg^{+2} in the initial years (Fig. 8.3). At the end of the experiment i.e. in 1994, organic-C content sharply declined under all the four systems. Similar declining trend in organic matter status under agroforestry systems has also been confirmed by Lal (1986), Drechsel *et al.* (1991) and Singh *et al.* (1992). The declining trend of organic-C may be attributed to faster mineralization of organic matter resulting into release of nutrients particularly cations, N and P, owing to the enhanced microbial activity. The enhanced microbial activity was expected due to improvement in soil environment (readily available cations and P, porosity, good WHC and better soil tilth). By the end of the experiment, however, organic matter and exchangeable cation (Ca^{+2}, Mg^{+2} and K^{+1}) contents in the four agroforestry systems were significantly greater than those in the sole crop situation. The increase of organic matter in the topsoil seems to be responsible for increase in exchangeable cations and N since there are highly significant ($r = 0.86-0.95$, $P<0.01$) correlations between these parameters and organic-C. The average C/N ratio in the topsoil was lower under the two N_2-fixing tree species viz. alder and albizia species than under cherry, mandarin or sole crop. Narrow C/N ratio in N_2-fixing species is also reported by Drechsel *et al.* (1991). The soils under the four agroforestry systems seem to have high rate of mineralization, as the C/N ratios most favourable for mineralization lies between 10 and 20. The spectacular increase in Bray's P_2-P (available P) under alder, cherry and albizia may be attributed to solubilization of native P (inavailable form) owing to root exudates and addition of large quantities of organic matter through roots (Chapter 5). These soils have relatively low capacity to fix P, and consequently, even low rates of P applications can lead to a substantial build-up of available P (Lal, 1989). This confirms the high build-up of available P in the 'tree+crop' situation under the four systems and in sole crop.

Physical properties of soil

Although there is now a large volume of literature on the influence of trees on soil chemical properties, there is much less information on their influence on soil physical properties, especially under agroforestry systems. In the present study, the four agroforestry systems improved water holding capacity and porosity of topsoil and reduced bulk density (Table 8.3). The improvement in physical properties of soil might have occurred due to presence of litter at the soil surface. Years of leaffall and litter decomposition in the 'tree only' and 'tree+crop' situations improved the 'water holding capacity' and porosity of soil and reduced the soil bulk density. Improvement in soil friability and permeability through the action of root system and by addition of organic matter through litterfall is also reported by a number of workers (Shankarnarayan, 1984; Swift, 1987; Szabolcs, 1989; Garg, 1992; Garg & Jain, 1992; Rosecrance *et al.*, 1992; Chaturvedi & Behl, 1996; Jain & Garg, 1996). The surface litter and SOM also influences soil water fluxes and moisture regimes (Swift, 1987) through improvement in water infiltration and reduction in runoff and evaporation (Lal, 1989). The water infiltration improvement may also be the result of improvement in the macroporosity of the subsoil horizon (Juo & Lal, 1977). In The present study, the four agroforestry systems also improved the subsoil environment. On the other hand, continuous cropping caused a marked deterioration of topsoil in the control (sole crop) with rapid fall in organic matter content and reduction in water holding capacity (Lal, 1986), and increase in soil bulk density (Takahashi *et al.*, 1983).

The increase in soil total nitrogen, available phosphorus, exchangeable Ca^{+2} and K^{+1} and organic-C, and improvement in WHC and porosity and reduction in bulk densities under alder and albizia systems indicate increased fertility of the topsoil. Most of these properties were improved in the mandarin system as well but the magnitude was lower as compared to the alder and albizia systems though it was certainly higher than the cherry system and the control (sole crop). This was expected due to slow growth rate (Chapter 4), restricted canopy spread and low litter yield (Chapter 7) of mandarin. But its leaf litter has highest Ca^{+2} content (Fig. 8.6) which helped in improving topsoil pH. The cherry system behaved altogether differently than the other three systems. Cherry has comparatively high growth rate, wide canopy spread and high litter yield than mandarin system but due to low accumulation of exchangeable cations, exchangeable Al^{+3} was not influenced favourably, and consequently, soil pH did not improve appreciably. However, as all the four agroforestry systems are still young and at developing stage, it is difficult to generalize their long-term effects.

In conclusion, it could be stated that alder and albizia are the most useful tree species contributing to the soil fertility buildup. The positive effect of alder and albizia agroforestry systems on soil fertility has special significance and relevance to north-east India where the predominant practice of shifting cultivation or slash and burn agriculture which involves burning of trees, destroys the valuable organic matter and reduces soil fertility.

CHAPTER 9

NUTRIENT CYCLING IN AGROFORESTRY SYSTEMS

One of the advantages of agroforestry practice is its potential for soil fertility improvement via a more efficient cycling of nutrients (Nair, 1984) through above- and below-ground litter additions; retrieval behaviour of roots (Vogt *et al.*, 1989; Young, 1991) and quality and quantity of added weed biomass. This advantage finds its root partially in studies of nutrient cycling in natural forest ecosystems (Golley *et al.*, 1975; Bernhard-Reversat, 1982; Jordan, 1982; Brunig & Sander, 1983; Jordan *et al.*, 1983; Cuevas & Medina, 1986) or on the allied systems such as shifting cultivation and taungya system (Nye & Greenland, 1960; Jordan, 1972; Toky & Ramakrishnan, 1983a, 1983b), and in the assumption that trees in agroforestry systems will transfer nutrients to associated crops. The assumption is supported by observations of higher crop yields under some agroforestry systems (Sanginga *et al.*, 1986; Anderson, 1987; Sidhu & Hans, 1988; Sanchez & Palm, 1996). In recent years attempts have been made to collect data on nutrient cycling in agroforestry systems as well (Aranguren *et al.*, 1982; Maghembe *et al.*, 1983; Alpizar *et al.*, 1986, 1988; Glover & Beer, 1986; Russo & Budowski, 1986; Sanchez, 1987; Fassbender & Alpizar, 1987; Fassbender *et al.*, 1988; Sanchez & Palm, 1996).

Among the major nutrients, nitrogen and phosphorus are the most important, especially in acid Alfisols where nitrogen and phosphorus are most frequently limiting. In the case of

Alfisols there is nearly always a substantial initial response to nitrogen fertilizer application. Phosphorus deficiency generally appears after a few years of cultivation, when its initial quantity present in soil is depleted. In agroforestry systems there is some recovery of nutrients due to input of organic or inorganic materials by trees. However, little information is available on this aspect. The recovery of organic form of nitrogen by the crop is generally lower than that of inorganic N brought about by the application of nitrogen fertilizers during the course of cropping. But organic inputs do have an important advantage over inorganic fertilizers in residual effect and sustainability (Doran & Smith, 1987). Much of the nitrogen available from organic mulches not used by crops is incorporated into active and less active pools of soil organic matter (SOM), while much of the fertilizer nitrogen not used by crops is subject to leaching and denitrification losses. Myers (1988) reported lowest effectiveness of inorganic fertilizers under high rainfall environments mainly due to greater leaching and denitrification losses. In addition, the efficiency of utilization of nutrients supplied through organic residues largely depends on nature of organic matter, rate of decomposition and release of nutrients coupled with soil conditions (Herrera *et al.*, 1987; Beer, 1988; Cameron & Spencer, 1989; Dunham, 1989; Sharma & Pande, 1989; Okeke & Omaliko, 1991).

In agroforestry systems, trees can provide nitrogen inputs by 2 processes- biological nitrogen fixation in the case of nitrogen-fixing tree species (NFTS), and deep nutrient capture. Although the magnitude of biological nitrogen fixation is methodologically difficult to quantify, the overall recorded rates of fixation for trees both leguminous as well as non-leguminous range from 20 to 300 kg N $ha^{-1}yr^{-1}$ (Dommergues, 1987; Young, 1989a; Giller & Wilson, 1991). The highest recorded value is 500 kg N $ha^{-1}yr^{-1}$ for *Leucaena* (Young, 1991). The advocation of inclusion of NFTS in agroforestry systems (Nair et *al.*, 1984; Lundgren & Nair, 1985; Young, 1987) has led to the belief that nitrogen fixed in the root nodules may be used by the companion crop (Morris, 1986; Giller *et al.*, 1991) though direct evidences to support it are still lacking. NFTS can also supply considerable nitrogen to crops through litter fall. On the other hand, there is ample evidence that trees such as cherry and mandarin, where nitrogen-fixation does bot occur, accumulate as much or more N in their leaves as do NFTS, presumably because of their greater root volume and ability to capture nutrients (Garrity & Mercado, 1994) from sub-surface soil. However, these non-NFTS are only cycling nutrients and not adding them to the system.

Deep nutrient capture- the second process through which trees can provide nitrogen inputs, is the uptake of nutrients by tree roots at depths where crop roots are not present. This is an additional nutrient input in agroforestry systems because such nutrients are leached and lost for crop use, but they become an input on being transferred to the soil through tree litter decomposition (Swift, 1987; Hartemink *et al.*, 1996).

The situation is quite different with phosphorus. Agroforestry systems cannot supply most of the phosphorus that crop requires. There is no process similar to nitrogen fixation for adding phosphorus to the system. The deep capture of phosphorus is likely to be negligible because of the very low concentrations of available phosphorus in the subsoil. In many agroforestry systems phosphorus does get accumulated in the tree biomass and returns to the soil when litter decomposes, but this is merely nutrient cycling and not an input. However, during phosphorus cycling, some less available organic forms of phosphorus in the soil may be converted into more available inorganic forms. The phosphorus cycle provides a valuable index to the levels and types of biological activity in an ecosystem, since photosynthesis and microbial turnover in decomposing litter need adequate levels of phosphorus in specialized biochemical forms. Unlike nitrogen, phosphorus cycle is closed, i.e. no substantial gains or losses occur from the system over a time scale of few years. Phosphorus is often the critical nutrient in agroforestry systems with low inputs. Hence, inorganic phosphorus must be applied in soils where P is depleted. Combining organic and inorganic sources of P may result in more effective use of nutrients. Uptake of other nutrients such as K, Ca and Mg by plants is proportional to soil solution nutrient concentration at the root surface, and is determined by the soil supply which in turn is determined for each nutrient by interactions between the nutrients and the soil properties.

In order to understand the nutrient cycling, it is useful to clarify some of the key terms that will be used in discussion. The terms are- nutrient inputs, nutrient cycling and nutrient capital.

Nutrient inputs are additions into the system from outside, such as biological nitrogen fixation by NFTS, chemical fertilizers, animal manure or leaf litter produced outside the system. *Nutrient outputs* are those actually lost from the system, through harvest and removal of crops, soil erosion, leaching, gas volatilization and other processes. The fewer the nutrient losses from the system, the fewer the inputs needed from outside the system to 'balance the budget'. *Nutrient balance* is the difference between nutrient inputs and outputs. *Nutrient cycling* is the transfer of nutrients already present in the soil-plant system from one component to another, e.g., the release of nitrogen from soil organic matter as ammonium or nitrate and its subsequent uptake by plants. Other processes involved in nutrient cycling are the return of crop residues such as stover and harvested weeds back to the soil, and also the transfer of nutrients from trees to crops in agroforestry systems through leaffall or root decomposition. The *nutrient capital* refers to the reserves of nutrients in the soil that can be released gradually over time.

In the 'tree+crop' situation of the agroforestry systems apart from trees, weeds also colonise the site and most of them die by the time of crop harvest. The remaining live weed biomass is put back in the systems after crop harvest. Thus, the amount of nutrients entering into and leaving the annual plants (crop and weeds) in the 'tree+crop' situation is larger than the 'tree only' situation, where the phenomenon of nutrient recycling (retranslocation/withdrawal) is prominent.

A review of literature reveals that a considerable attention has been paid to the cyclic flow of nutrients, particularly nitrogen in natural ecosystems (Yadava, 1980; Agarwal & Tiwari, 1987; Chaturvedi *et al.*, 1988; Pandey *et al.*, 1993; Uma Shankar et *al.*, 1993) however, studies pertaining to a complete cycling of nutrients such as nitrogen, phosphorus, potassium, calcium and magnesium in agroforestry are very few (Wetselaar *et al.*, 1981; Robertson *et al.*, 1982; Toky *et al.*, 1989). Besides, comparative studies on nutrient cycling between 'tree only' and 'tree+crop' situation in the agroforestry systems have not been undertaken so far. Therefore, a study of this nature was undertaken with the following objectives;

1. To ascertain the standing state and distribution of elements in soil and in different compartments of trees (boles, branches, leaves, fruits or catkins, and roots) and weeds in the 'tree only' and trees, and crops and weeds in the 'tree+crop' situation of the four agroforestry systems.

2. To evaluate the annual uptake of nutrients from soil, their transfer to various compartments and ultimate release to the soil.

MATERIAL AND METHODS

In the present study, only the soil and vegetation compartments were considered for nutrient cycling. Soil nutrients were determined as given in Chapter 8. After determining the biomass as described in Chapter 4, the dried plant samples of all the species were saved for the determination of plant nutrients. In the case of trees, The compartments (parts) such as boles, branches, leaves, fruits and roots were analyzed separately. Litter from the four tree species, categorised into leaf, woody and miscellaneous parts, was also analyzed separately. Nutrient contents in the samples of each compartment of trees (boles, branches, leaves, fruits or catkins, and roots) were estimated in the 'tree only' situation. In the case of 'tree+crop' situation, besides plant samples of different compartments of trees, the aboveground biomass of crops and weeds, litter, and belowground biomass were also analysed for nutrient concentration. Plant samples were ground to a powder and passed through a 0.5-mm sieve, and digested in triacid mixture (HNO_3, $HClO_4$ and H_2SO_4 in the ratio of 10:4:1) and analysed for P, K, Al, Ca and Mg. For estimation of total N, plant samples were digested with concentrated H_2SO_4 and catalyst ($CuSO_4$ + K_2SO_4). From the digested sample an aliquot of 10 ml was distilled with alkali in steam distillation unit and ammonia liberated was collected in boric acid (5 ml) which was titrated against N/10 H_2SO_4 (AOAC, 1990). The concentration of other nutrients was determined by following standard procedures as given below.

Nutrients	Procedure	References
P	Vandomolybdate yellow	Jackson (1973)
K	Flame photometer	Jackson (1973)
Al	Aluminon	Jackson (1973)
Ca and Mg	Versenate titration	Jackson (1973)
Total N	Modified Kjeldahl method	AOAC (1990)

The biomass and productivity were measured beforehand as described in Chapter 4 and 6. The mean nutrient concentrations were corrected to oven-dry weight basis. The standing state of nutrients (g m^{-2}) was computed from mean biomass values of different compartments (as given in Chapter 4) and the corresponding nutrient concentration (%).

The nutrient contents of some dominant weed species in the 'tree only' and 'tree+crop' situations were also determined following the methods described above. The species selected were, viz. *Ageratum conyzoides*, *A. haustonianum*, *Bidens pilosa* and *Galinsoga parviflora* in the 'tree+crop' and *Arundinella bengalensis*, *Imperata cylindrica* and *Digitaria sanguinalis* in the 'tree only' situations under the four agroforestry systems.

Uptake, transfer and release:

The uptake of nutrients in above- and below-ground compartments was calculated by multiplying the aboveground and belowground net primary productivity (Chapter 6) with the mean concentration of nutrients in the above or belowground biomass. The sum of the uptake of nutrients in the two compartments (above- and below-ground) yielded total uptake in the plants.

The nutrient content removed from the 'tree+crop' situation through the economic yield and through crop and weed biomass was estimated by multiplying the quantity of dry matter of these components with their respective mean concentrations. The quantities of nutrients recycled in the system through crop and weed residues after the crop harvest were estimated by multiplying the quantity of the dry matter of these components with their respective mean concentration of the nutrients. The biomass of the crop (edible and non-edible parts) and weeds removed at harvest was measured by subtracting the residues of crop and weeds left in the field (biomass recycled) after the harvest from the biomass of crop and weeds just before harvest.

For soil and vegetation compartments, the fractional annual turnover of each element was calculated by dividing the weight that left the compartment by the weight held in that compartment and expressed as percentage following Reiners and Reiners (1970).

$$\text{Annual turnover of nutrients in soil compartment} = \frac{\text{Annual uptake of nutrients by the vegetation}}{\text{Total amount of nutrients in the soil pool}} \times 100$$

$$\text{Annual turnover of nutrient in the vegetation compartment} = \frac{\text{Nutrients lost from the standing biomass}}{\text{Total amount stored in the vegetation pool}} \times 100$$

Thus, for the soil, amount of nutrients taken up by the vegetation was divided by total amount of active pool of nutrients in the soil, and for the vegetation the amount of nutrients lost from the standing biomass in the form of litterfall, lopping of branches, or fruits was divided by the total amount stored in the vegetation. This is a useful parameter to compare the enrichment quotients of soil and vegetation in different systems (Woodwell *et al.*, 1975).

RESULTS

Concentration of elements in plants

In general, the tree leaves had the highest concentration of elements followed by fruits and branches, and the bole had the lowest (Fig. 9.1). Concentrations of N, P and K were much higher in leaves and branches as compared to their litter but

Fig. 9.1(a) – Element concentration (% dry weight) in different compartments of alder trees.

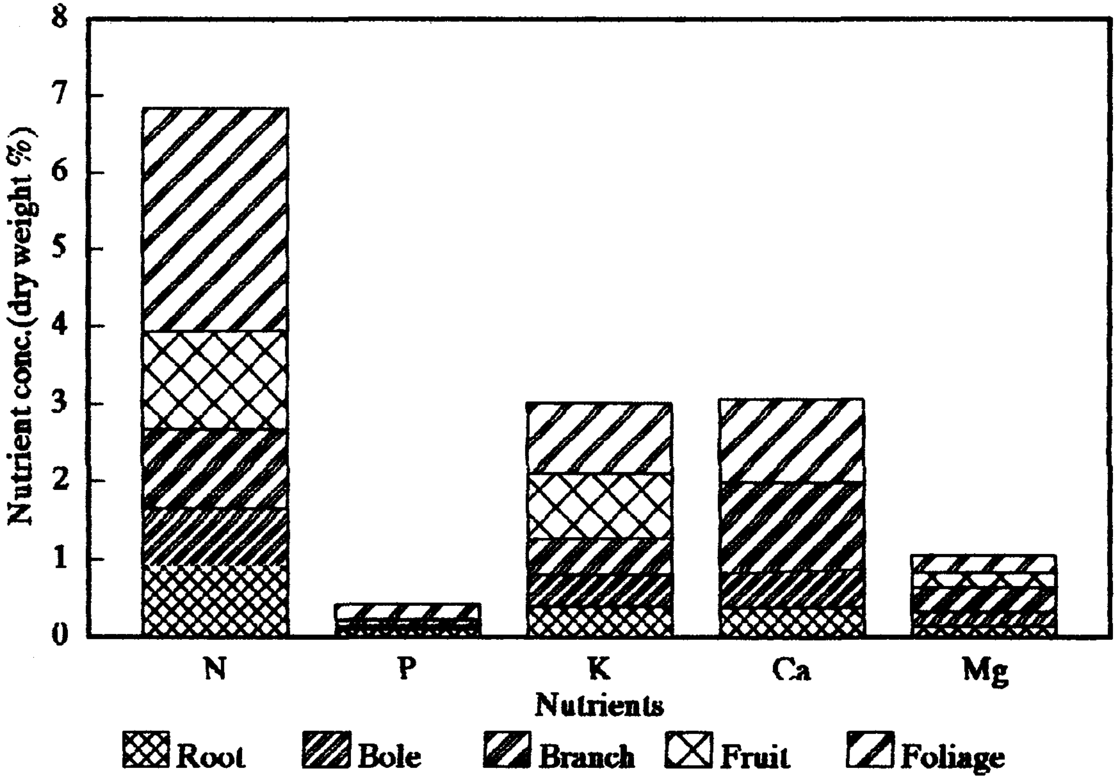


Fig. 9.1(b) – Element concentration (% dry weight) in different compartments of albizia trees.

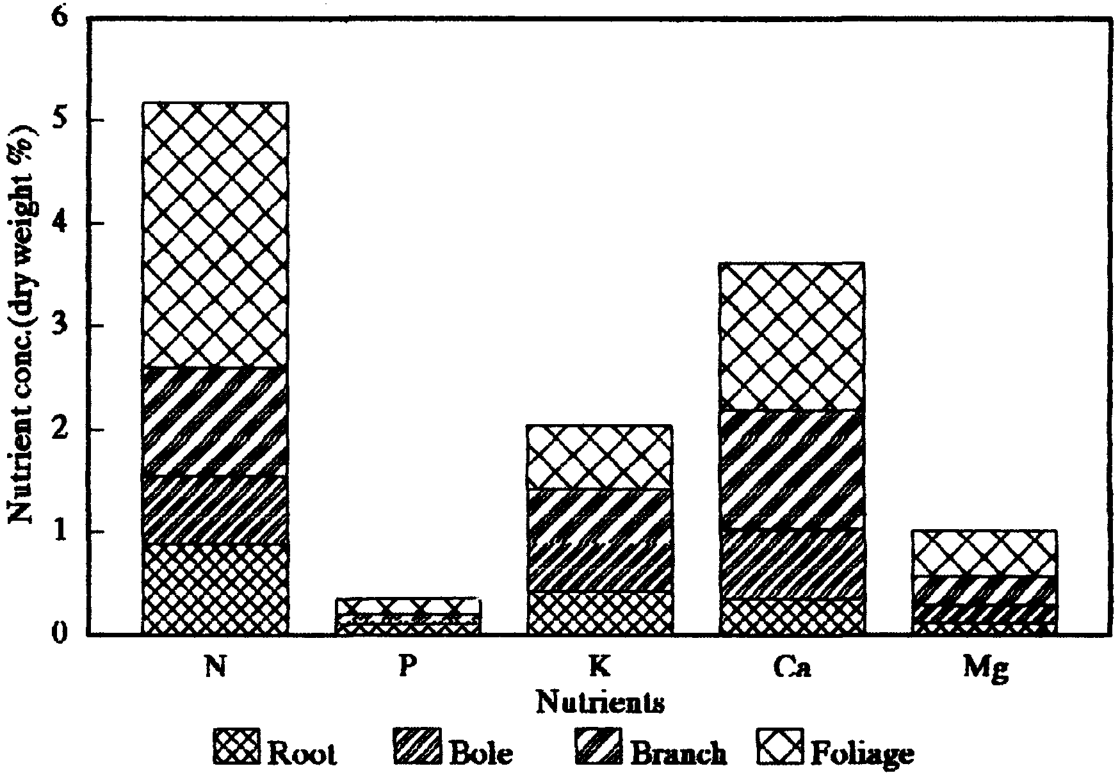


Fig. 9.1(c)—Element concentration (% dry weight) in different compartments of cherry trees.

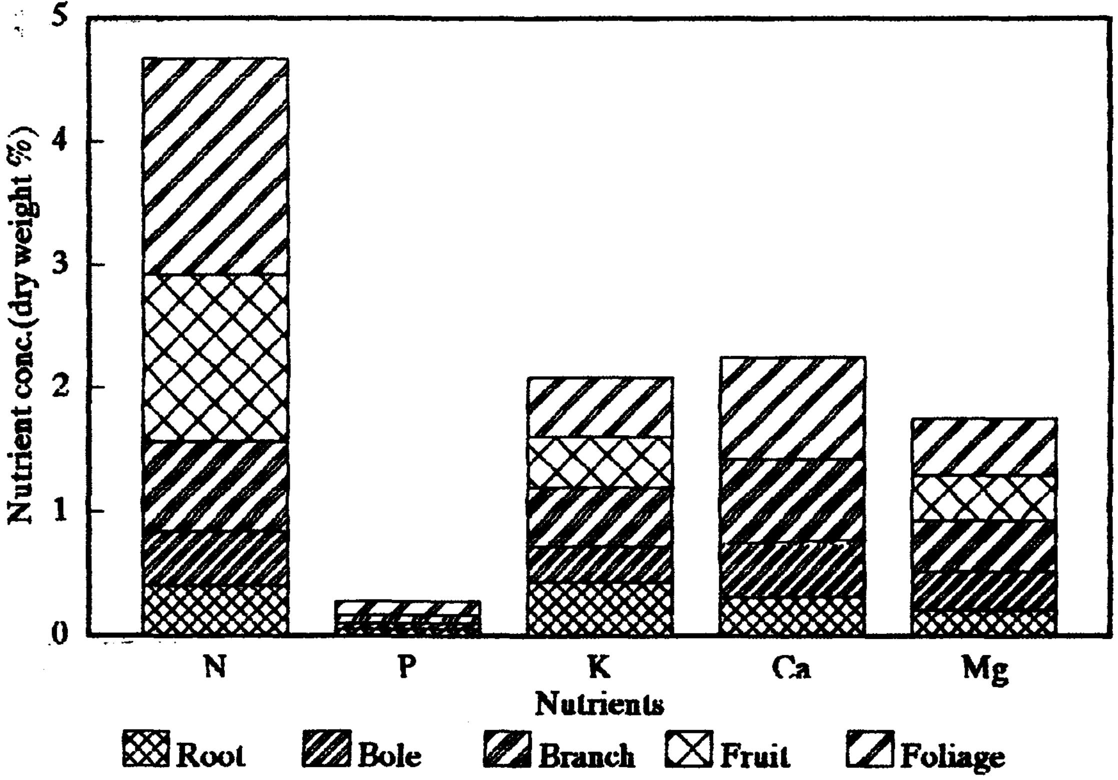


Fig. 9.1(d)—Element concentration (% dry weight) in different compartments of mandarin plants.

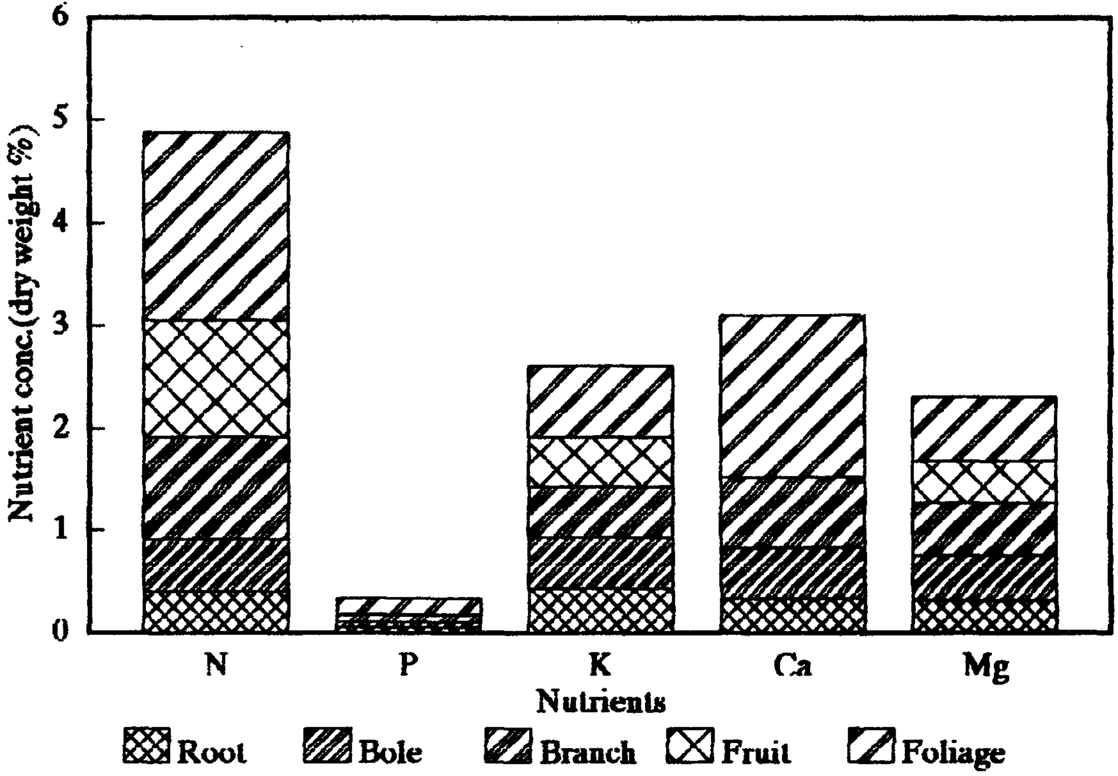


Fig. 9.1e. Element concentration (% dry weight) in different compartments of crops.

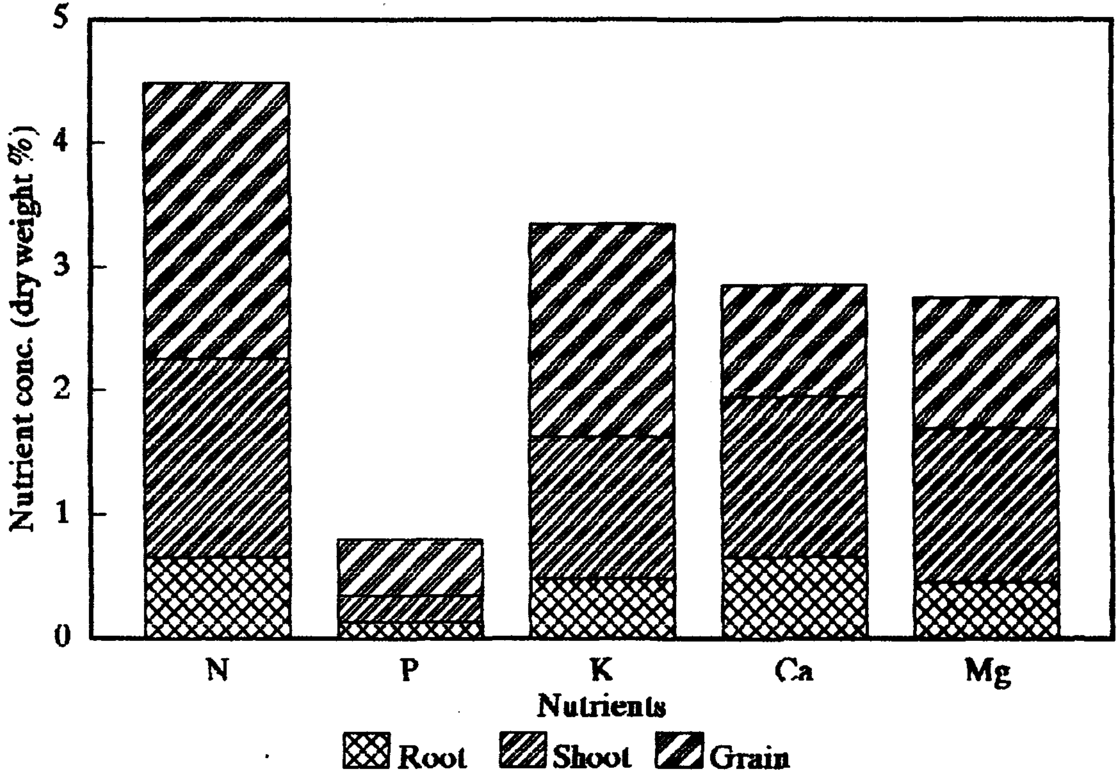
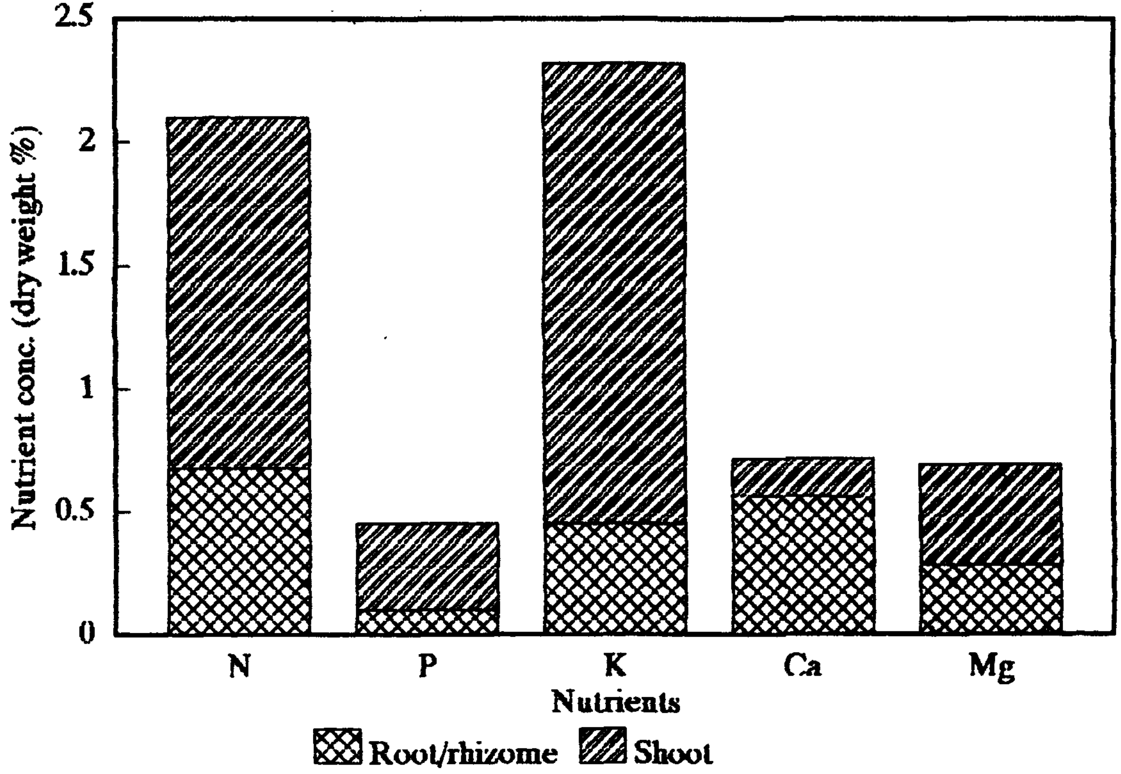


Fig. 9.1f. Element concentration (% dry weight) in different compartments of weeds.

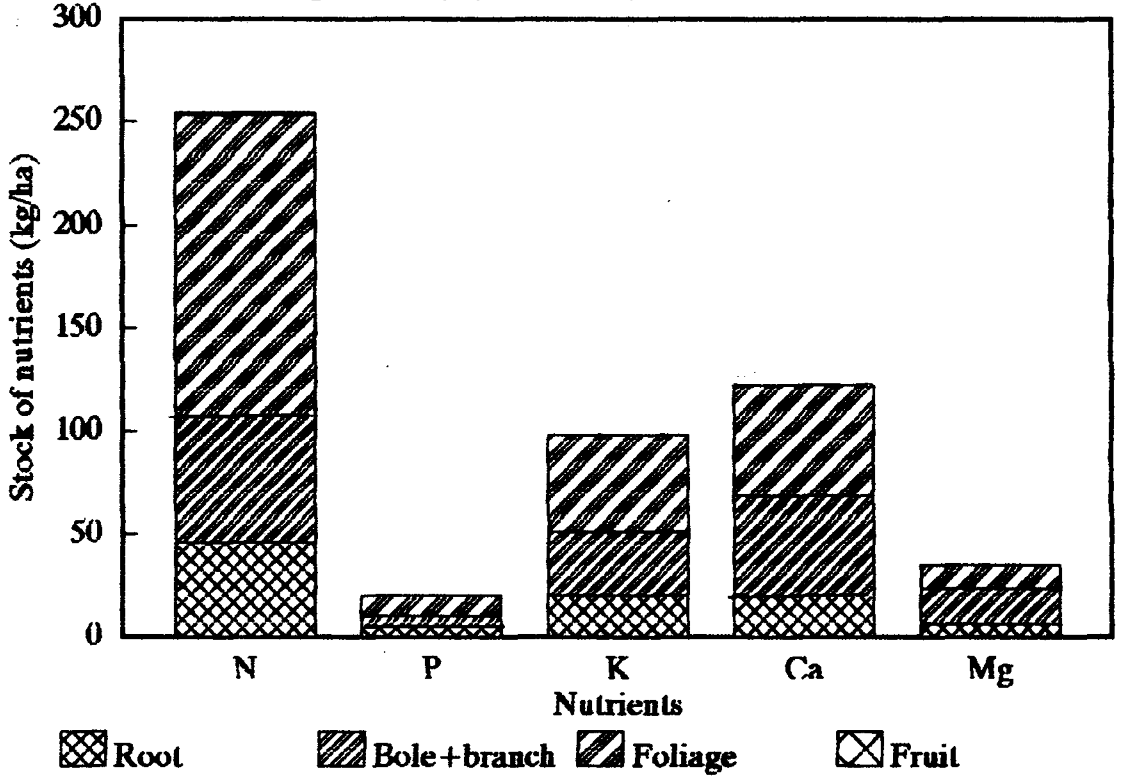


there was not much variation in the concentration for Ca and Mg in these compartments. The concentration of N was about 1.6-fold higher in the leaves of alder and albizia as compared to cherry and mandarin. Weeds showed a markedly higher concentration ($P < 0.05$) of P than trees and agricultural crops, while fruit and grains had a significantly ($P < 0.05$) higher concentration of K as compared to that in branches, bole, root and litter in trees, and shoot in crops. Among the cations, there was preponderance of Ca and K in the leaves and branches of trees. The concentration of Ca was 1.4- and 1.6-fold greater in the leaves of albizia and mandarin than the other two species. Crops had a markedly higher ($P < 0.05$) concentration of Mg than trees and weeds. Among the tree species alder had highest concentration of N, P and K in its leaves, catkins, litter and roots. But the concentrations of Ca and Mg was highest in the leaves of mandarin followed by albizia.

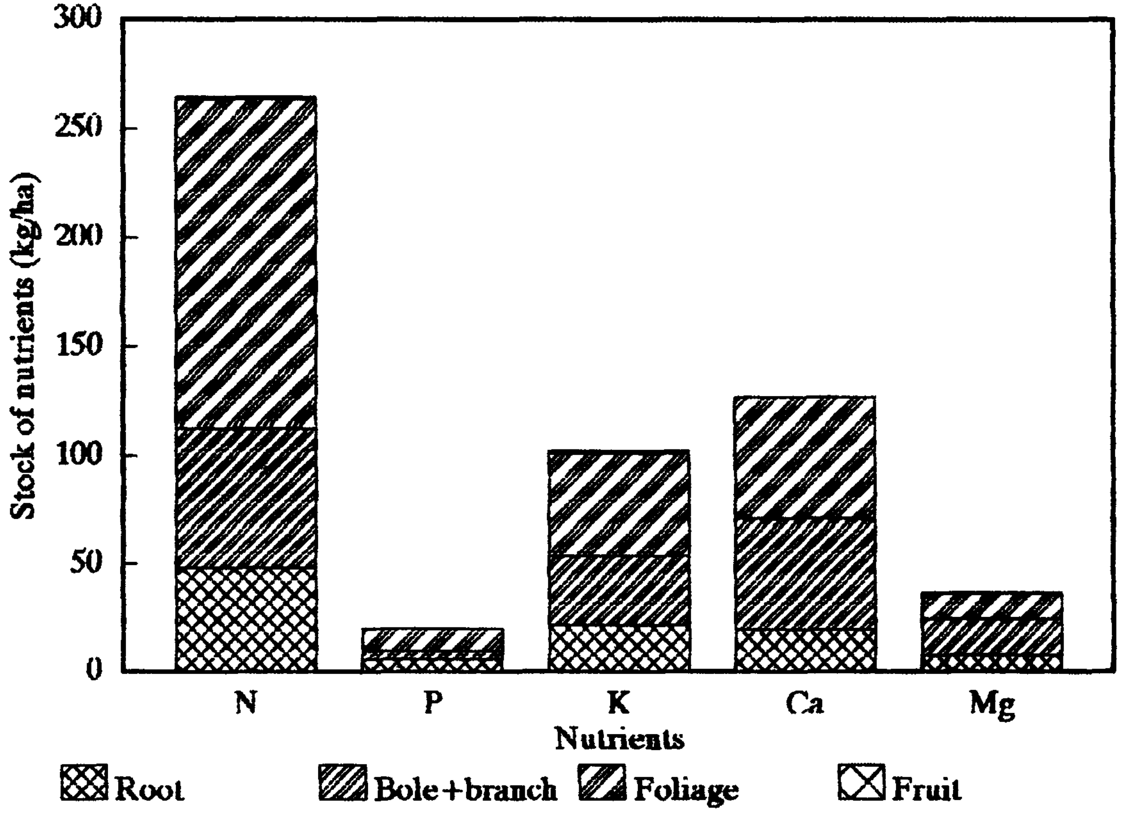
Stock of nutrients in standing biomass of trees

The patterns of distribution of some important elements in the bole, branches, leaves, fruit and roots of the four tree species in the 'tree only' and 'tree+crop' situations are shown in Fig. 9.2a-9.2h. It was interesting to note that trees when grown with crop had a larger stock of almost all elements as compared to when they grew in monoculture, though the differences were not significant ($P < 0.05$). Leaves followed by bole had higher stock of nutrients as compared to branches and fruits. Leaves of the four tree species contain 43 to 57% N, 37 to 54% P, 22 to 47% K, 33 to 46% Ca and 27 to

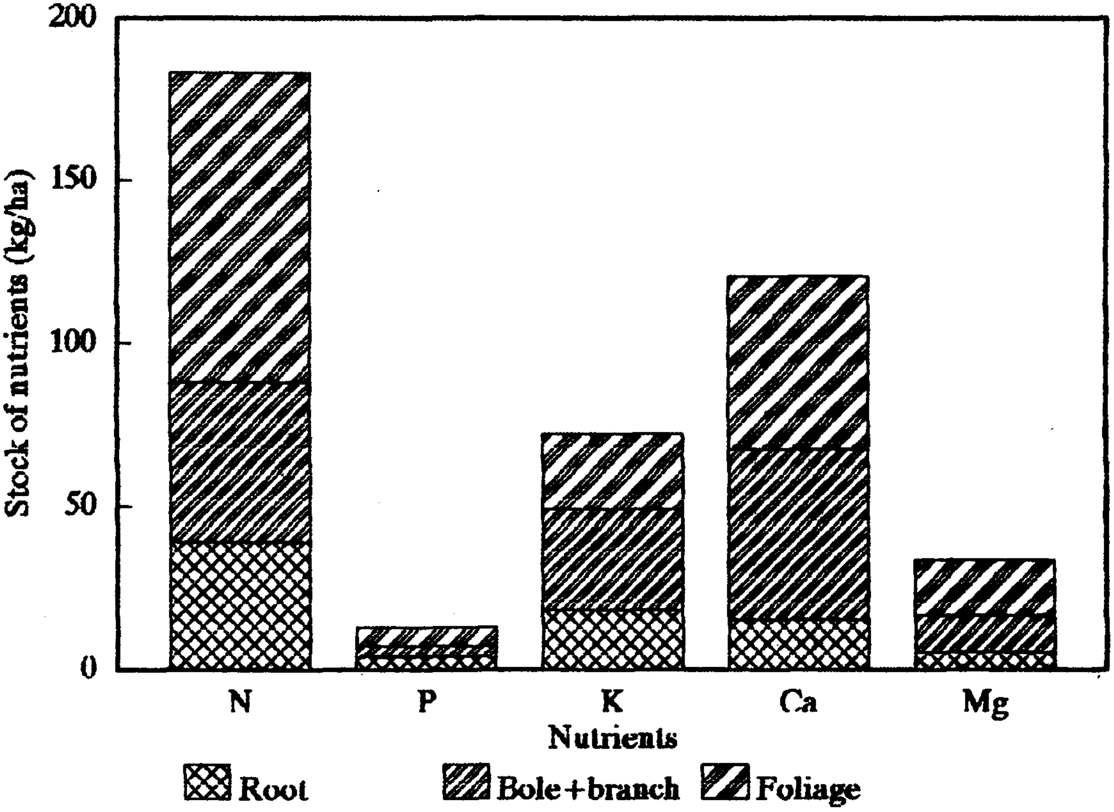
Fig. 9.2. Stock of nutrients in different compartments of trees in the four agroforestry systems— (a) alder 'tree only' situation.



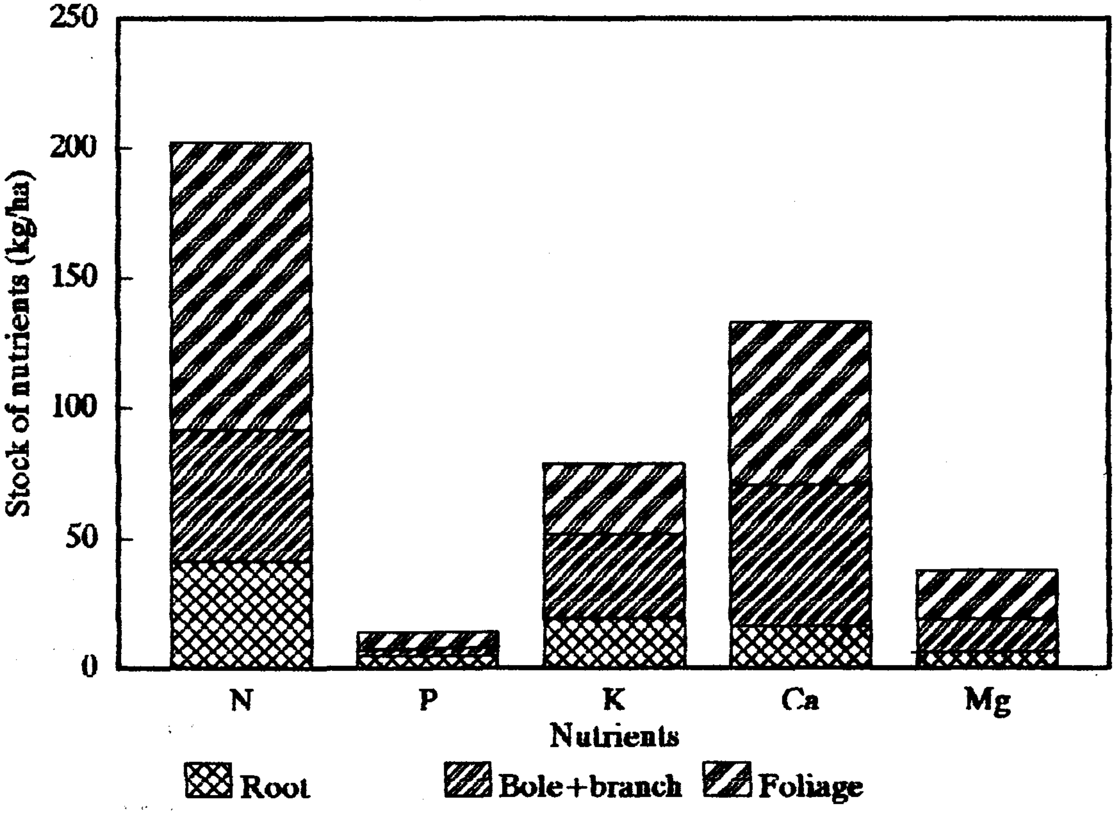
(b) alder 'tree+crop' situation.



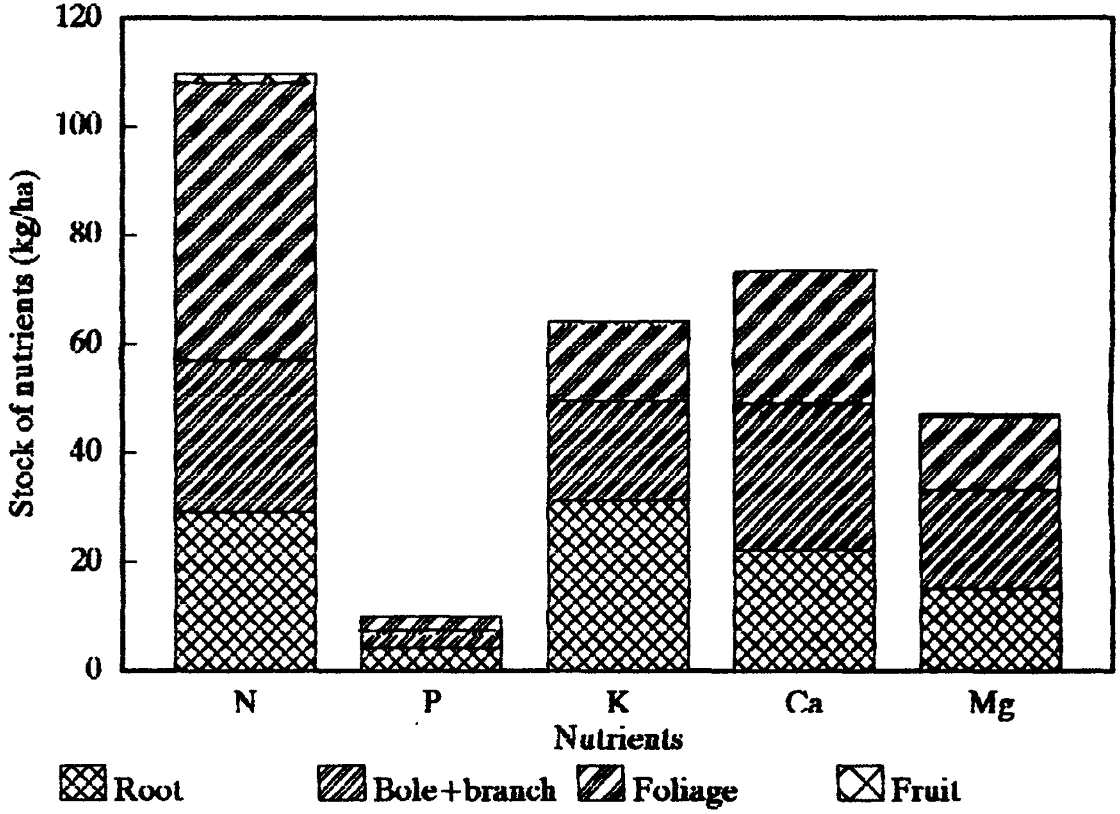
(c) albizia `tree only' situation.



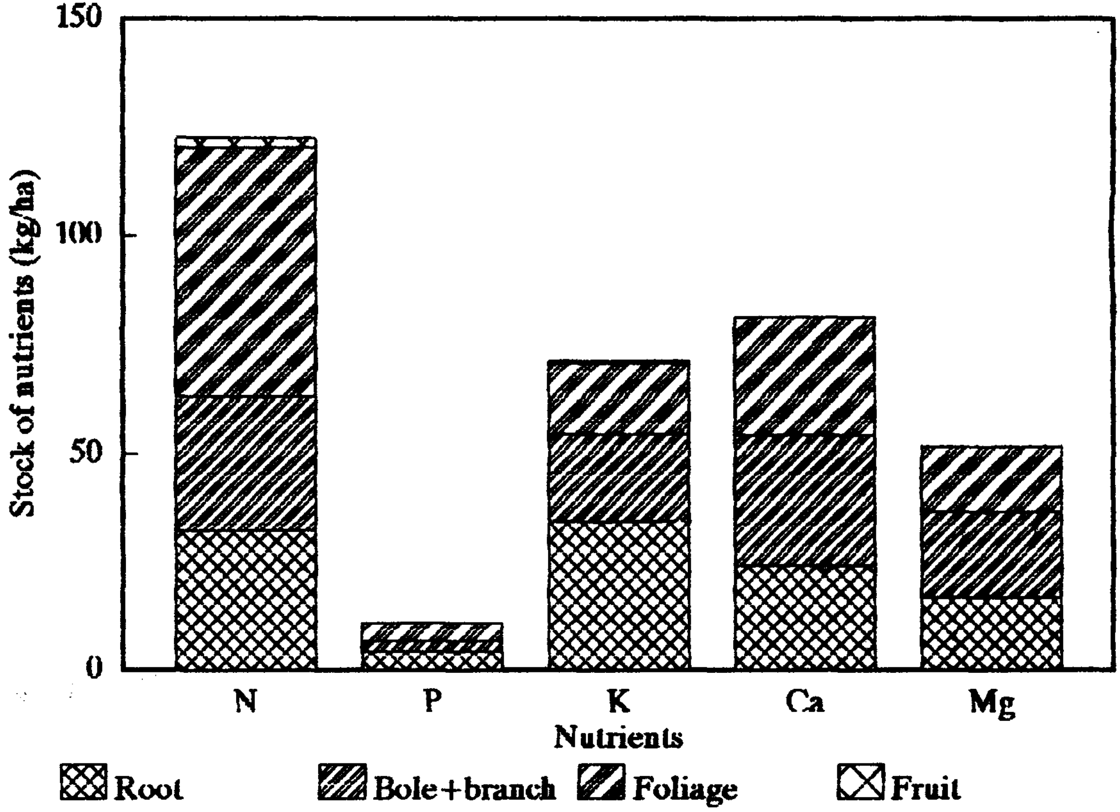
(d) albizia `tree+crop' situation.



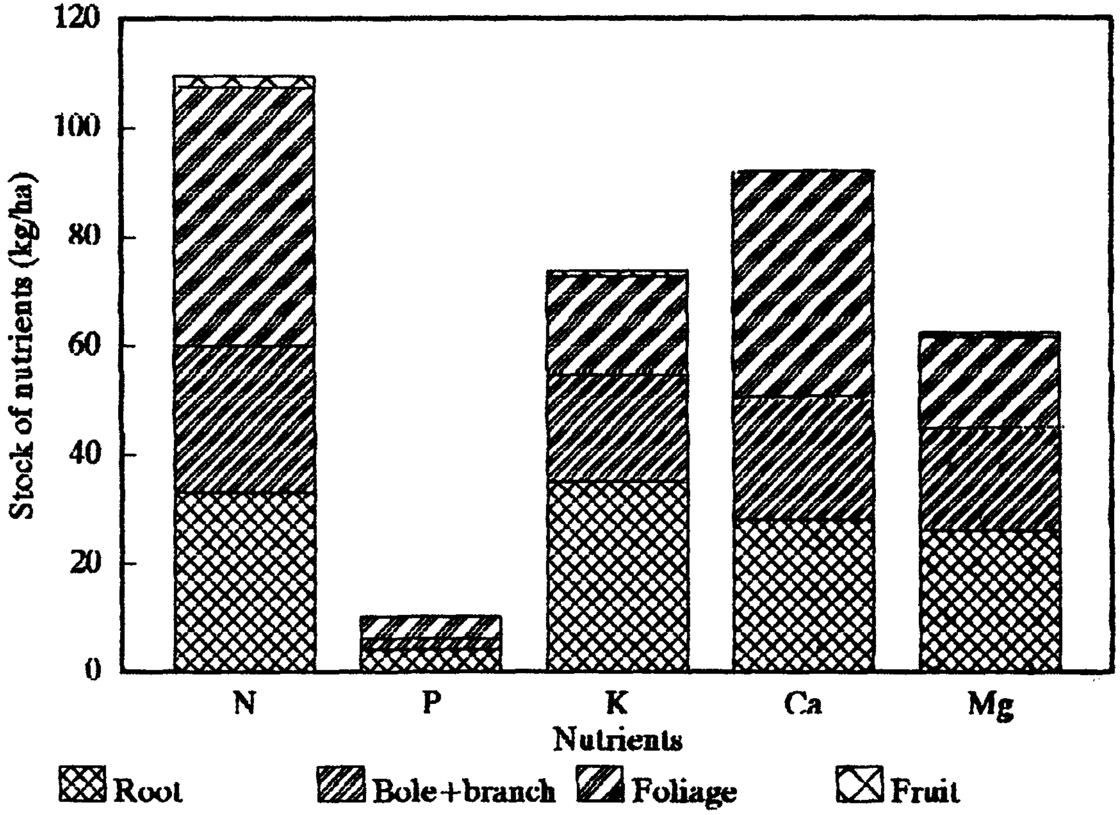
(e) cherry `tree only' situation.



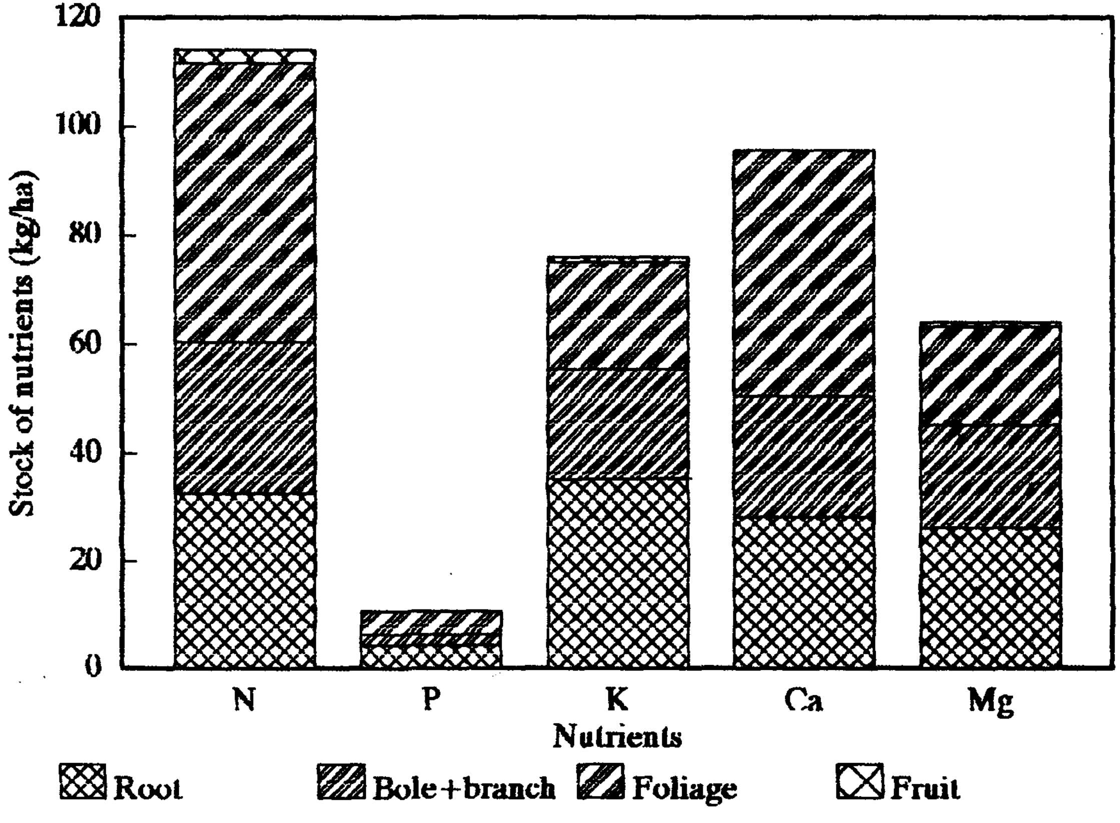
(f) cherry `tree+crop' situation.



(g) mandarin `tree only' situation.



(h) mandarin `tree+crop' situation.

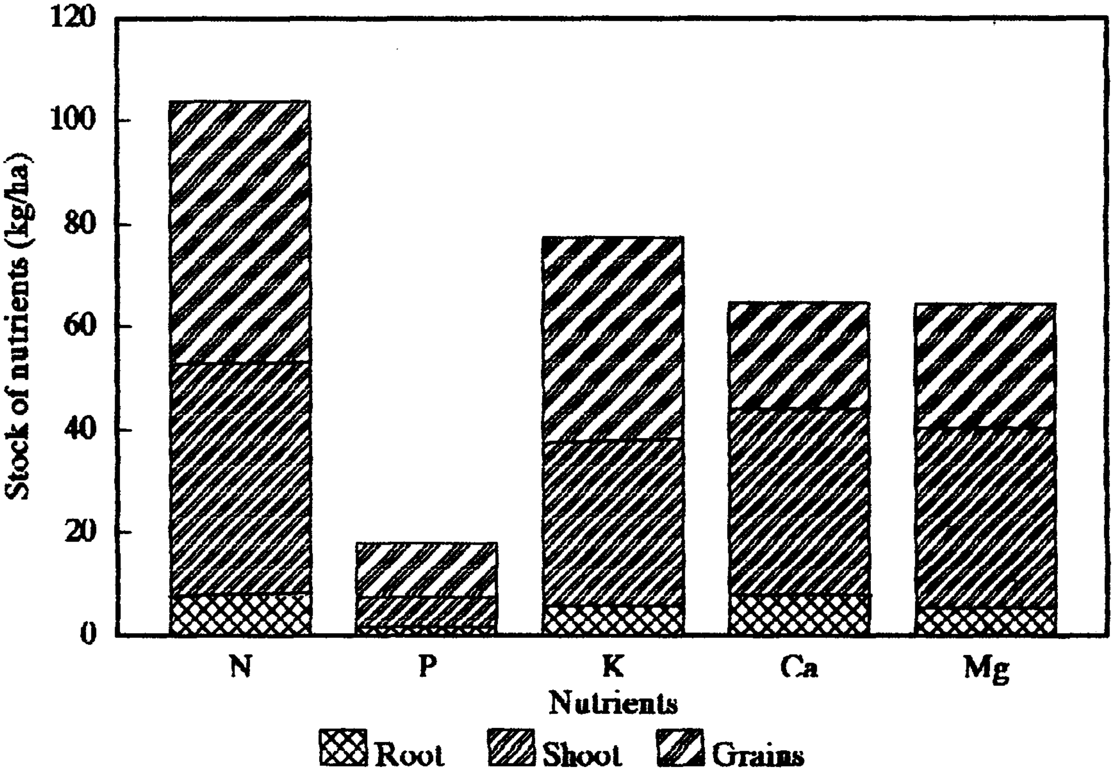


50% Mg. The maximum values for N, P and K were recorded by alder and minimum by mandarin. Maximum value for Ca was recorded in albizia and lowest in cherry, while for Mg the highest value was obtained in albizia and the lowest in mandarin. Surprisingly, roots (fine+coarse) had significantly ($P < 0.05$) greater stock of nutrients as compared to bole, branches and fruits. But there was no significant difference in nutrient stock of roots between the two situations. K followed by P was present in larger amounts in roots compared to N and Ca. The quantity of nutrients (2.4 N, 0.02 P, 1 K and 0.9 Mg kg ha^{-1}) partitioned in fruits in mandarin is removed from the system through harvest. In aboveground standing biomass of the four tree species accumulation of N was maximum followed by Ca and K whereas P was accumulated in the least quantity. Among the four tree species, alder contained maximum nutrients followed by albizia, while mandarin had the lowest.

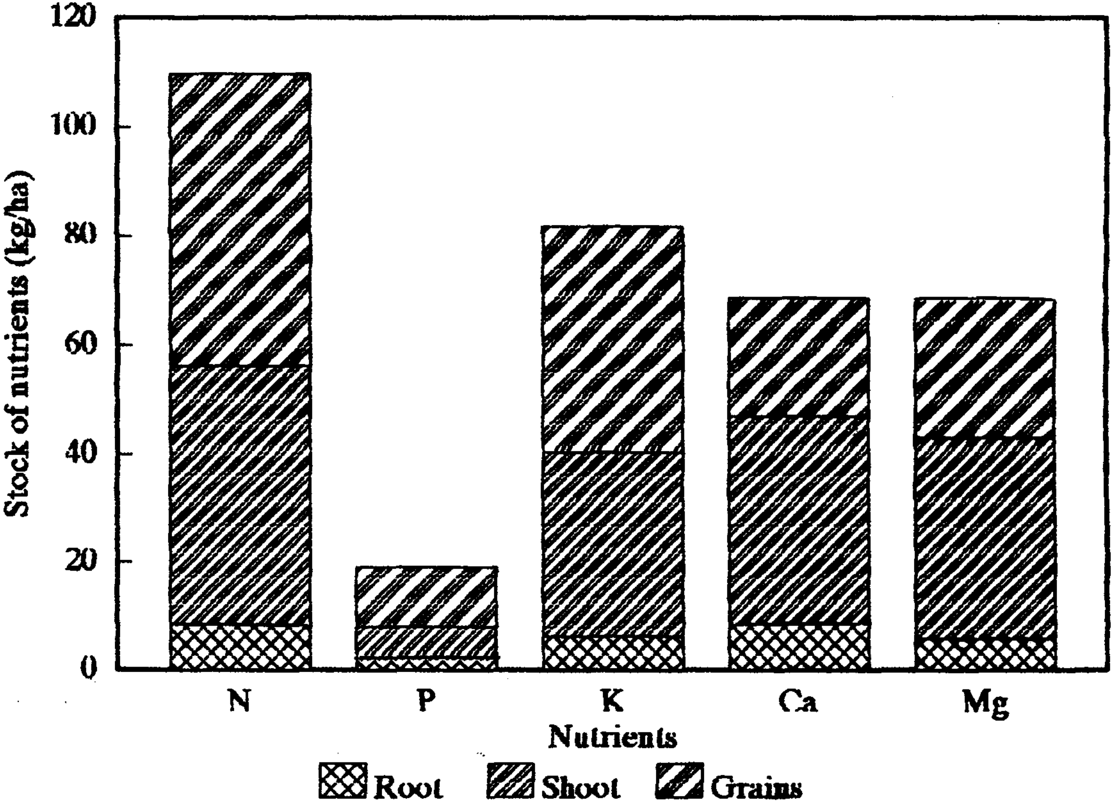
Accumulation of nutrients in crops and weeds

Agricultural crops viz. soybean, groundnut, linseed and mustard, and weeds contained a large amount of nutrients in their above- and below-ground parts (Fig. 9.3). Weed species such as *Ageratum conyzoides*, *A. haustonianum*, *Bidens pilosa* and *Galinsoga parviflora* in 'tree+crop' and *Arundinella bengalensis*, *Imperata cylindrica* and *Eupatorium adenophorum* in 'tree only' situations had significantly high amount of nutrients in their aerial parts (Fig. 9.4). In general, grain or seed had the highest stock of nutrients as compared to shoot and roots. A greater proportion of N, K and P was observed in grains, but Ca and Mg recorded higher proportion

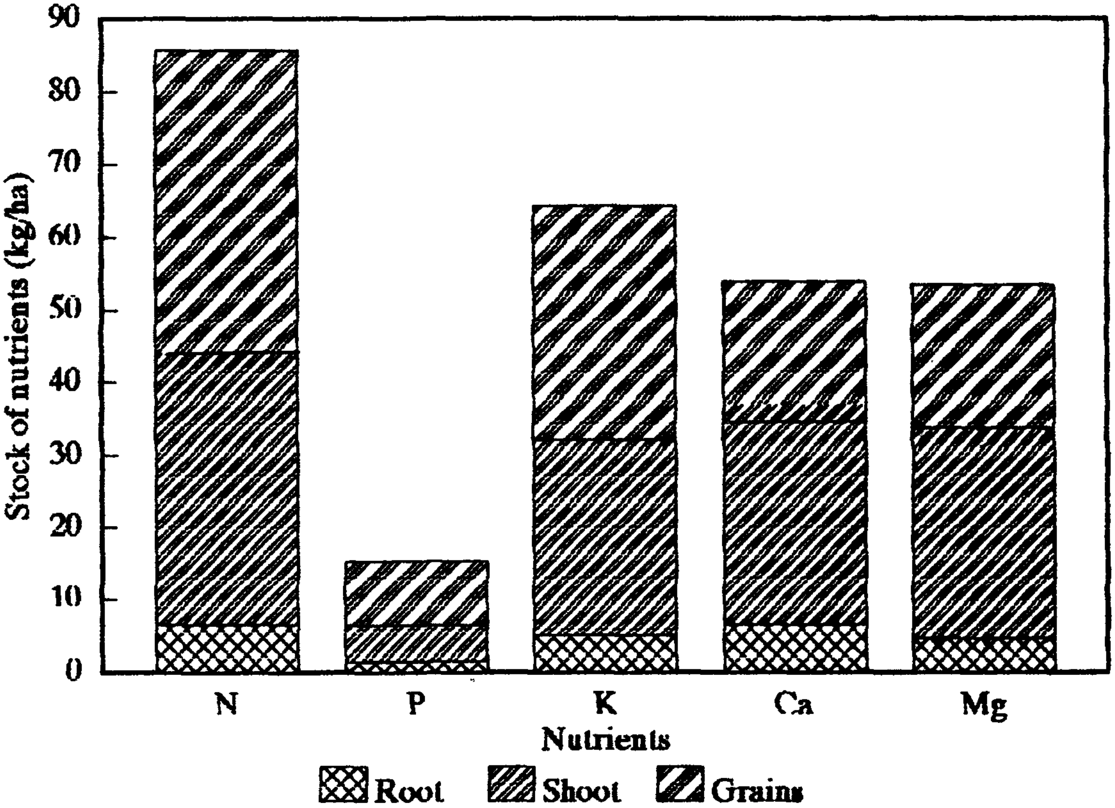
Fig. 9.3. Stock of nutrients (kg/ha) in different plant parts of the crops in four agroforestry systems – (a) crops in the alder system.



(b) crops in the albizia system.



(c) crops in the cherry system.



(d) crops in the mandarin system.

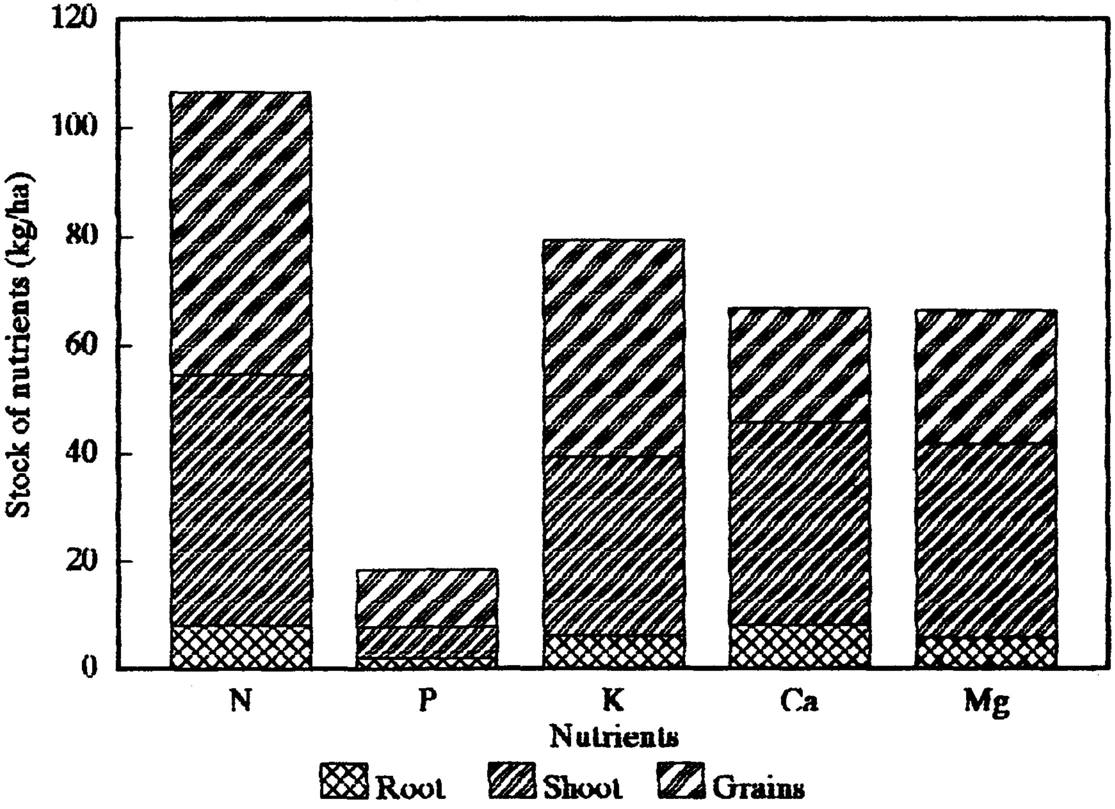
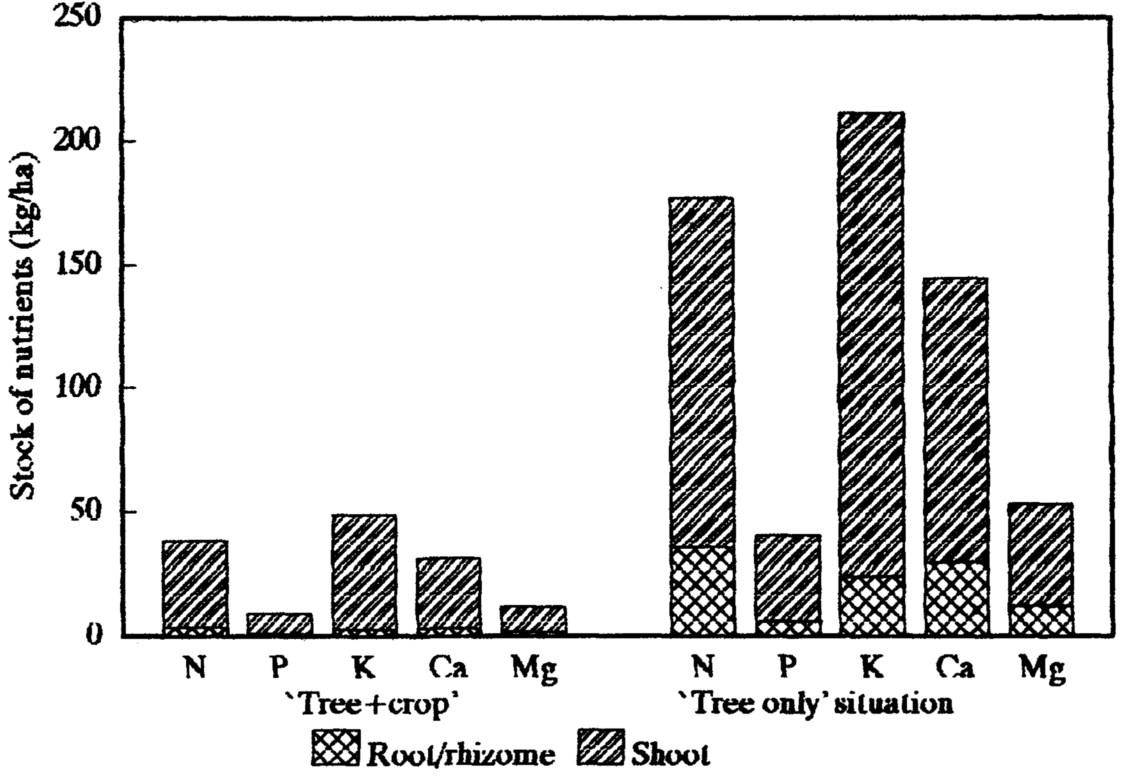
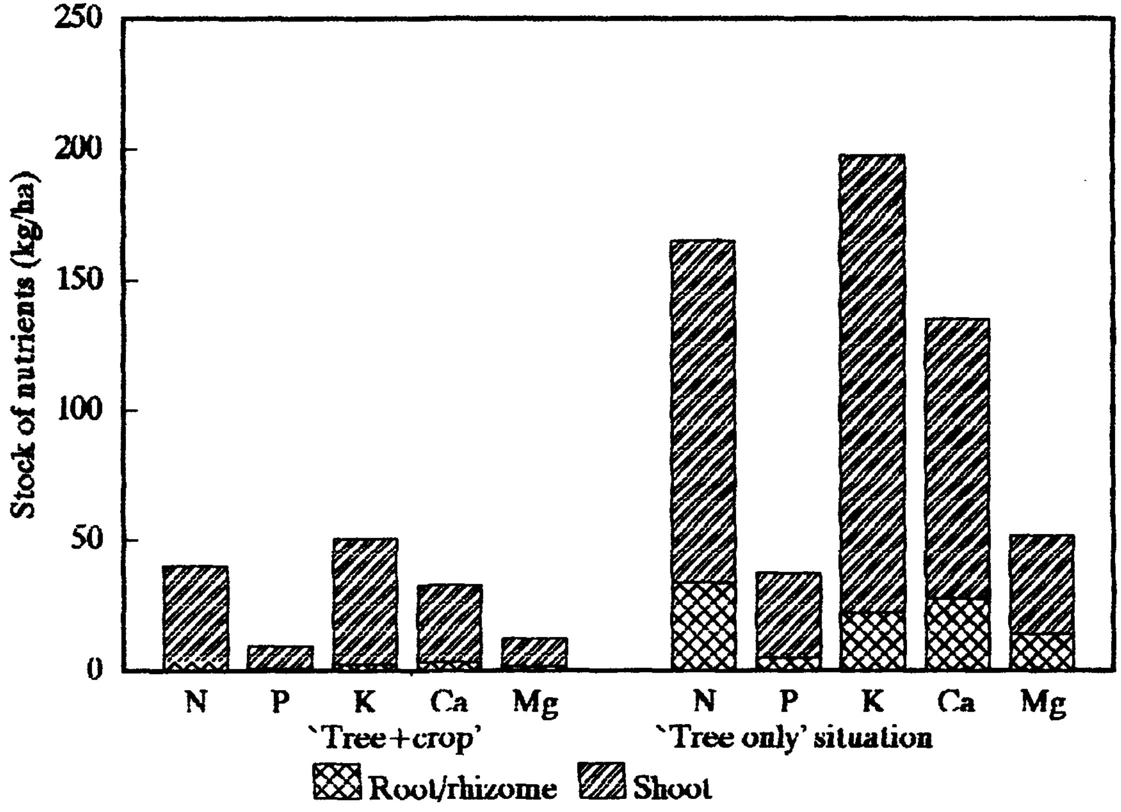


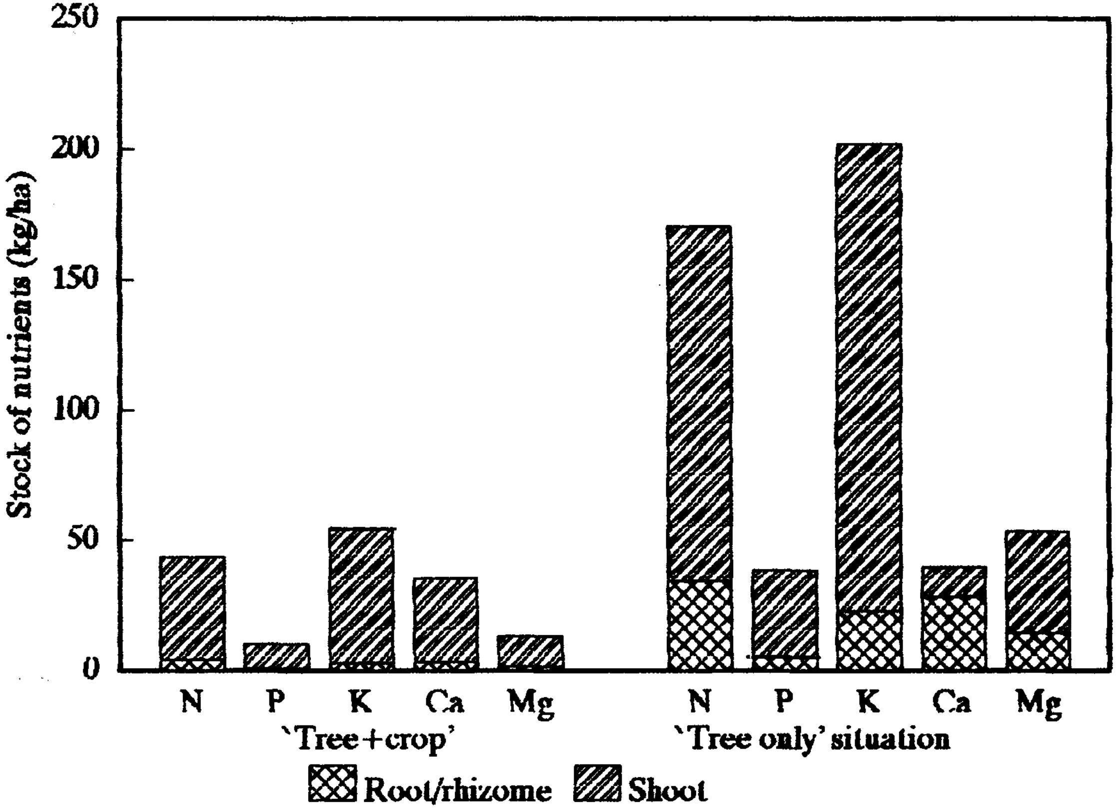
Fig. 9.4. Stock of nutrients (kg/ha) in different parts of weeds in the four agroforestry systems. (a) weeds in the alder system.



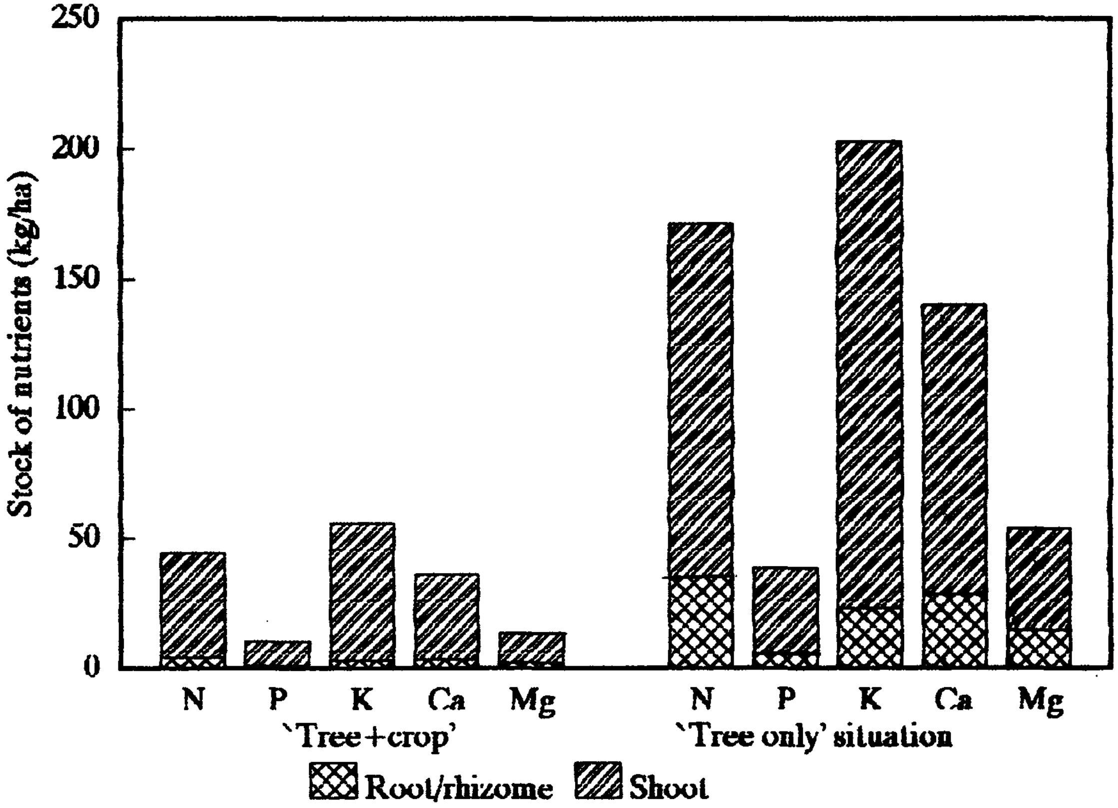
(b) weeds in the albizia system.



(c) weeds in the cherry system.



(d) weeds in the mandarin system.



in shoot. The amount of nutrients contained in crops and weeds was maximum under albizia system, whereas lowest stock was recorded under cherry system. This was largely due to better crop growth and higher grain yield in the former. In weed species, the shoot portion had 1.3-fold greater quantity of K than N.

In the 'tree only' situation, which was devoid of crops, perennial weeds stored a significantly higher stock of nutrients in their aerial parts. K, N and Ca were the predominant elements present in these weeds.

Overall, maximum stock of nutrients in crops and weeds was present in the alder-system closely followed by albizia-system, while the lowest stock was in the cherry system (Table 9.2).

Annual uptake of nutrients by trees

The annual uptake of nutrients in the four agroforestry systems has been presented in Table 9.1. Uptake of nutrients in the 'tree only' and 'tree+crop' situations was approximately the same. Among the four systems, alder-based system had the highest uptake of N, K and P, while cherry system had the least. In contrast, the uptake of Ca in albizia- and Mg in mandarin-system was the highest. The rate of uptake of N was 1.3-, 2- and 2-fold higher in alder system as compared to albizia-, cherry- and mandarin-systems, respectively. The corresponding values for P were 1.4-, 1.8- and 1.8-fold, and for K 1.3-, 1.5- and 1.3-fold higher respectively, in that order. The rates of uptake of Ca in alder and albizia were more or less equal, but the values in these systems were by

Table 9.1. Annual uptake of nutrients (kg ha^{-1}) by the vegetation in the four agroforestry systems.

Agrofor. systems	Components	'Tree+crop' situation					'Tree only' situation				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
AFS 1	Tree-Foliage	151.3	10.4	47.3	56.2	11.9	145.5	10.0	45.5	54.0	11.5
	Fruits	11.9	0.1	8.1	-	1.9	11.3	0.1	7.7	-	1.8
	Branches	35.1	2.4	15.3	38.9	10.6	33.5	2.3	14.6	37.1	10.1
	Bole	62.4	4.2	34.6	40.5	16.0	60.2	4.1	33.3	39.0	15.4
	Root	47.8	4.7	20.5	19.4	6.8	45.8	4.5	19.6	18.6	6.5
	Sub-total	308.5	21.8	125.8	155.0	47.3	296.2	21.0	120.7	148.7	45.4
	Crop-Grain	25.4	5.3	19.7	10.3	12.0	-	-	-	-	-
	Shoot	30.8	4.0	22.0	24.9	23.9	-	-	-	-	-
	Root	35.7	7.1	26.4	35.7	24.7	-	-	-	-	-
	Sub-total	92.0	16.4	84.5	70.9	60.7	-	-	-	-	-
	Weeds-Shoot	54.3	13.4	41.0	44.4	15.7	141.2	34.8	106.4	115.4	40.8
	Root	17.2	2.5	11.4	14.1	7.1	58.0	6.6	29.6	37.0	18.5
	Sub-total	71.2	15.9	52.3	58.5	22.8	199.2	41.4	136.1	152.3	59.2
	System Total	**472.0**	**54.1**	**262.6**	**284.4**	**130.7**	**495.4**	**62.4**	**256.8**	**301.0**	**104.2**
AFS 2	Tree-Foliage	110.2	6.4	26.5	61.5	19.2	94.9	5.5	22.8	53.0	16.6
	Branches	32.9	1.9	16.6	36.3	8.5	31.1	1.8	15.7	34.3	8.0
	Bole	45.8	2.8	33.3	47.2	12.5	44.5	2.7	32.4	45.8	12.1
	Root	41.1	4.2	19.2	15.9	5.1	39.3	4.0	18.3	15.2	4.9
	Sub-total	229.9	15.3	95.5	160.9	45.3	209.8	14.0	89.1	148.3	41.6
	Crop-Grain	27.1	5.6	21.0	11.0	12.8	-	-	-	-	-
	Shoot	34.3	4.5	24.5	27.7	26.6	-	-	-	-	-
	Root	39.3	7.9	29.0	39.3	27.2	-	-	-	-	-
	Sub-total	100.6	17.9	74.5	77.9	66.6	-	-	-	-	-
	Weeds-Shoot	56.0	13.8	42.2	45.8	16.2	131.7	32.5	99.2	107.6	38.0
	Root	16.3	2.4	10.8	13.4	6.7	46.8	6.9	34.4	38.5	19.3
	Sub-total	72.3	16.2	53.0	59.2	22.9	178.5	39.3	133.6	146.1	57.3
	System Total	**402.9**	**49.4**	**223.0**	**298.0**	**134.9**	**388.3**	**53.3**	**222.8**	**294.4**	**98.9**

Table 9.1 contd.....

Table 9.1 contd.....

Agrofor. systems	Components	'Tree+crop' situation					'Tree only' situation				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
AFS 3	Tree-Foliage	57.1	3.9	15.7	27.2	15.1	51.0	3.5	14.1	24.3	13.5
	Fruits	19.0	0.1	5.8	-	5.2	16.9	0.1	5.1	-	4.6
	Branches	20.9	1.7	13.7	19.7	11.7	19.8	1.6	13.0	18.7	13.8
	Bole	25.9	2.4	17.5	25.9	18.7	23.2	2.2	15.7	23.2	16.7
	Root	29.7	3.6	31.2	22.5	15.2	29.4	3.6	30.8	22.2	15.0
	Sub-total	152.6	11.8	83.9	95.4	66.0	140.2	11.0	78.6	88.4	63.7
	Crop-Grain	23.4	4.8	18.1	9.5	11.1	-	-	-	-	-
	Shoot	28.9	3.8	20.6	23.3	22.4	-	-	-	-	-
	Root	33.9	6.8	25.0	33.9	23.5	-	-	-	-	-
	Sub-total	86.2	15.4	63.8	66.1	56.9	-	-	-	-	-
	Weeds-Shoot	56.9	14.0	42.9	46.5	16.4	136.2	33.6	102.6	111.3	39.3
	Root	18.4	2.7	12.2	15.2	7.6	44.2	6.5	29.3	36.4	18.2
	Sub-total	75.4	16.7	55.1	61.7	24.0	180.4	40.1	131.9	147.7	57.5
	System Total	**314.2**	**43.9**	**202.8**	**223.7**	**146.9**	**320.7**	**51.1**	**210.5**	**236.1**	**121.2**
AFS 4	Tree-Foliage	51.1	4.5	19.7	45.0	18.0	47.3	4.2	18.2	41.6	16.6
	Fruits	26.5	0.2	11.4	-	9.5	23.9	0.2	10.3	-	8.6
	Branches	21.2	1.3	10.4	14.6	10.8	19.6	1.2	9.6	13.5	10.0
	Bole	21.4	2.0	21.0	20.1	18.1	21.1	2.0	20.7	19.8	17.8
	Root	32.5	4.2	34.9	27.5	25.8	32.8	4.2	35.3	27.7	26.0
	Sub-total	152.6	12.2	97.3	107.2	82.2	144.7	11.8	94.0	102.7	79.1
	Crop-Grain	26.2	5.4	20.3	10.6	12.4	-	-	-	-	-
	Shoot	33.2	4.3	23.7	26.8	25.8	-	-	-	-	-
	Root	36.1	7.2	26.6	36.1	25.0	-	-	-	-	-
	Sub-total	95.4	17.0	69.6	73.5	63.1	-	-	-	-	-
	Weeds-Shoot	57.3	14.1	43.2	46.8	16.6	136.8	33.7	103.1	111.7	39.5
	Root	19.7	2.9	13.1	16.3	8.1	47.5	7.0	31.4	39.1	19.6
	Sub-total	77.1	17.0	56.3	63.1	24.7	184.3	40.7	134.5	191.6	59.1
	System Total	325.1	46.2	223.2	243.8	170.0	329.0	52.5	228.5	294.1	138.1

AFS 1- Alder-based agroforestry system
AFS 2- Albizia-based agroforestry system
AFS 3- Cherry-based agroforestry system, and
AFS 4- Mandarin-based agroforestry system.

1.7- and 1.5-fold greater as compared to cherry and mandarin systems. Similarly, the rate of uptake of Mg in mandarin was 1.7-, 1.8- and 1.3 fold higher than alder, albizia and cherry systems, respectively. The pattern of uptake of nutrients was as follows: N > Ca > K > Mg > P.

Annual uptake pattern of nutrients in different compartments varied among the four tree species, except for P. For P, the pattern, **foliage > root > bole > branch > fruit**, was same in all the four tree species. The uptake pattern of nutrients in the various tree compartments is presented in Table 9.2.

Table 9.2. Annual uptake pattern of nutrients in the various compartments of trees in the four agroforestry systems.

Tree species	Nutrient	Tree compartments
Alder	N, K	Foliage > bole > root > branch > fruit
	Ca, Mg	Foliage > bole > branch > root
Albizia	N	Foliage > bole > root > branch > fruit
	K	Bole > foliage > root > branch
	Ca, Mg	Foliage > bole > branch > root
Cherry	N	Foliage > root > bole > branch > fruit
	K	Root > bole > foliage > branch > fruit
	Ca	Foliage > bole > root > branch
	Mg	Bole > root > foliage > branch > fruit
Mandarin	N	Foliage > root > fruit > bole > branch
	K	Root > bole > foliage > fruit > branch
	Ca	Foliage > root > bole > branch
	Mg	Root > bole > foliage > branch > fruit
	P	Foliage > root > bole > branch > fruit (same for all the four tree species)

In mandarin-system with fruit trees, a large quantity of nutrients (kg ha^{-1}), particularly N (24-26), K (11) and Mg (8-9) was present in fruits. Similarly, a significant amount of nutrient was also absorbed by fruits in cherry- and alder-based systems. Ca was either absent in fruits or present in negligible amount.

Overall, maximum uptake of N, P and K was recorded in the alder- followed by albizia- and least in the mandarin-system. However, the uptake of Ca was highest in albizia- and least in cherry-system. The uptake of Mg was highest in mandarin- and lowest in cherry-system. In general, in the 'tree+crop' situation, the uptake of nutrients by the trees was more than in the 'tree only' situation. In the latter situation, weeds and other plants also absorbed a large amount of nutrients in their aerial parts. The trees absorbed between 47-65% N, 43-54% Ca, 41-48% K, 34-48% Mg and 26-40% P in the 'tree+crop' situation. The corresponding absorption by trees in the 'tree only' situation was 44-60, 35-50, 37-47, 42-57 and 22-34% N, Ca, K, Mg and P in that order respectively. Interestingly, the quantity of nutrients (except for Mg) taken up annually in 'fodder tree-based systems' (alder-, albizia- and cherry-system) was significantly higher ($P < 0.01$) than in the 'fruit tree-based system' (mandarin system) (Table 9.1).

Annual uptake of nutrients by crops and weeds

Significant amounts of nutrients from the soil pool were taken up by the agricultural crops (soybean, groundnut, linseed and mustard) in the 'tree+crop' situation (Table 9.1). Of the total annual uptake of nutrients by the system, N accounted for 19-29%, Mg 37-49%, P 30-37%, K 31-33% and Ca 25-30%. Most of the annual uptake of nutrients was allocated towards the edible parts such as grains and pods, and thus removed from the system after crop harvest. The rate of nutrient uptake by the crops was highest in albizia-system, followed by mandarin-system, while the lowest uptake by crops was recorded in the cherry system. However, uptake of K by the crops was maximum in the alder-system.

Weeds growing alongwith the crops also contributed significantly to the nutrient uptake from the soil pool (Table 9.1 and 9.5). The high uptake of nutrients by weeds may be one of the reasons for the reduced crop yield. The nutrient uptake by weeds was highest in the cherry- and lowest in the alder-system.

In the 'tree only' situation too weeds absorbed a significant amounts of nutrient from the soil pool (Table 9.1). Weeds belonging to the family Poaceae such as *Arundinella bengalensis*, *Imperata cylindrica* etc. absorbed P more than the other weeds, whereas the dicot weeds such as *Ageratum conyzoides, A. haustonianum*, *Galinsoga parviflora* in comparison to other weeds absorbed more N.

Rates of nutrients returned to the soil

Important sources of nutrients in the 'tree+crop' situation are tree litter, crop residue, weed debris, decomposing roots, externally supplied manure (Farm Yard Manure, FYM) and inorganic fertilizers applied for the crops. In the 'tree only' situation, on the other hand, the sources are tree litter, standing and dead weed biomass and roots. In mandarin-system, manuring the established and bearing trees is essential, and hence, 10 t FYM and 70:120:80 Kg N:P:K ha^{-1} was applied in two split doses, first in March-April and second in

September-October each year. This is in addition to the fertilizer doses applied for the crops in 'tree+crop' situation. In the 'tree+crop' situation, 28-33% N, 85-86% P and 42-50% K were added to the alder-, albizia- and cherry-systems, respectively, in the form of inorganic fertilizers. In the mandarin-system the amount was as high as 63% N, 94% P and 74% K. The amounts of N, P and K in the 'tree only' situation in the mandarin system were 51, 89 and 64%, respectively.

Overall, no significant ($P < 0.05$) difference was observed in the quantity of nutrients recycled in the soil between the two situations. Annually, a considerable quantity of nutrients was added to the soil (Table 9.3). The amount (kg ha^{-1}) ranged from 111 to 182 for N, 16 to 20 for P, 77 to 96 for K, 82 to 161 for Ca, and 42 to 70 for Mg in the 'tree+crop' situation of the four systems. The corresponding amounts in 'tree only' situation was 113 to 185, 18 to 23, 80 to 137, 80 to 160, and 30 to 61 kg ha^{-1}yr^{-1} respectively, for the nutrients in that order. In the 'tree only' situation as there was no agricultural crop, the interspaces of trees were invaded by weeds. Hence, the input of nutrients except Mg, from the weeds was equal to or slightly higher than the combined inputs from crop residue and weed debris in the 'tree+crop' situation. In case of Mg, there was higher input from crop residue and therefore, the total amount (crop residue + weed debris) of Mg added to the soil in the 'tree+crop' situation was significantly higher than in the 'tree only' situation. Tree roots also added a considerable amount of nutrients to the

Table 9.3. Total amount of nutrients (kg ha^{-1}) added annually to the soil pool in the four agroforestry systems.

Agrofor. systems	Compartment	'Tree+crop' situation					'Tree only' situation				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
AFS 1	Litterfall	87.0	4.6	56.1	101.3	16.4	82.3	4.3	53.3	96.1	15.6
	Crop residue	20.9	3.1	15.2	17.9	15.7	-	-	-	-	-
	Weed debris	32.8	7.8	22.5	25.0	9.7	62.6	14.9	42.9	47.7	18.5
	Root decay	41.6	4.1	17.8	16.9	6.0	40.0	4.0	17.2	16.3	5.7
	Fertilizers	70.0	120.0	80.0	-	-	-	-	-	-	-
	System Total	**252.2**	**139.6**	**191.6**	**161.1**	**47.8**	**184.9**	**12.2**	**136.5**	**160.1**	**39.8**
AFS 2	Litterfall	51.0	2.8	25.2	81.9	10.0	49.0	2.7	24.2	77.7	8.5
	Crop residue	23.1	3.5	16.8	19.8	17.4	-	-	-	-	-
	Weed debris	33.4	7.9	22.8	25.3	9.8	58.4	13.9	40.0	44.5	17.2
	Root decay	34.8	3.6	16.2	13.5	4.4	33.4	3.4	15.5	13.0	4.2
	Fertilizers	70.0	120.0	80.0	-	-	-	-	-	-	-
	System Total	**212.1**	**137.7**	**161.0**	**139.5**	**41.5**	**140.8**	**20.0**	**80.0**	**135.3**	**30.0**
AFS 3	Litterfall	50.2	3.8	33.0	52.4	32.2	48.9	3.7	32.1	51.1	31.4
	Crop residue	19.8	3.0	14.4	17.0	14.9	-	-	-	-	-
	Weed debris	34.5	8.2	23.6	26.3	10.2	60.4	14.4	41.4	46.0	17.8
	Root decay	38.9	2.9	24.9	18.0	12.2	38.4	2.8	24.6	17.8	12.0
	Fertilizers	70.0	120.0	80.0	-	-	-	-	-	-	-
	System Total	**213.3**	**137.9**	**175.9**	**113.8**	**69.5**	**147.7**	**20.9**	**98.2**	**114.9**	**61.3**
AFS 4	Litterfall	11.3	0.9	9.0	15.3	6.2	9.1	0.7	7.3	12.4	5.0
	Crop residue	21.5	3.2	16.0	18.4	16.2	-	-	-	-	-
	Weed debris	35.2	8.4	24.1	26.8	10.4	60.7	14.5	41.6	46.2	17.9
	Root decay	43.2	3.3	28.0	22.0	20.6	43.7	3.4	28.2	22.2	20.8
	Fertilizers[*]	140.0	240.0	160.0	-	-	70.0	120.0	80.0	-	-
	FYM[**]	49.0	25.0	56.0	-	-	49.0	25.0	56.0	-	-
	System Total	**300.1**	**280.9**	**293.2**	**82.5**	**53.4**	**232.5**	**161.5**	**213.1**	**80.5**	**43.8**

Fertilizers[*] - @ 70-120-80 N-P-K for crops, and same rate for mandarin plants applied in two split doses each year.

FYM[**] - Farmyard manure @ 10 t ha^{-1} applied for mandarin plants.

AFS 1- Alder-based agroforestry system

AFS 2- Albizia-based agroforestry system

AFS 3- Cherry-based agroforestry system, and

AFS 4- Mandarin-based agroforestry system.

soil pool. The total N input into the soil by roots (fine + coarse) of the four tree species ranged between 35 to 43 kg ha^{-1} in the 'tree+crop' situation and 33 to 44 Kg ha^{-1} in the 'tree only' situation. The concurrent P addition by the roots was 3-4 kg ha^{-1}. Root nodules also contributed 3.4 kg N ha^{-1} in the alder and 2 kg in the albizia system. The alder-system recycled the maximum amount of N, P, K and Ca into the soil, while the amount of nutrients recycled in the mandarin system was the lowest. However, in the case of Mg, the cherry- followed by mandarin-system contributed higher amounts than the alder- or albizia-system. It is important to note that in the alder-, albizia- and cherry-systems the amounts of N and to some extent potassium (but not P), recycled through litterfall and roots are of the same magnitude as through the annual fertilizer application for the crops. But in the mandarin-system the input of nutrients by tree components was far less as compared to the rate of uptake from the soil pool. To maintain a balance in the soil, significant quantities of nutrients, particularly P and K in the three systems and N, P and K in the mandarin system, and P and K in the other three systems are to be added through manure and inorganic fertilizers (Table 9.3).

Nutrient loss from the four agroforestry systems

Depletion of nutrients from the four agroforestry systems was through pruning of branches and leaves from trees in the alder-, albizia-, and cherry-systems, and removal of straw/stalk and grains of the agricultural crops (Table 9.4). In the mandarin system, the depletion of nutrients was mainly

Table 9.4. Quantity of nutrients (kg ha^{-1}yr^{-1}) carried away from the four agroforestry systems in the form of prunings and harvests of crops and fruits.

Species	Compartment	'Tree+crop' situation					'Tree only' situation				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
AFS 1	Tree-Branches	8.8	0.6	1.3	9.7	2.6	8.4	0.6	3.7	9.3	2.5
	Leaves	37.8	2.6	11.8	14.0	3.0	36.4	2.5	11.4	13.5	2.9
	Sub-total	46.6	3.2	13.1	23.8	5.6	44.8	3.1	15.0	22.8	5.4
	Crop-Straw	29.3	3.8	20.9	26.6	22.7	-	-	-	-	-
	Grain	25.4	5.3	19.7	10.3	12.0	-	-	-	-	-
	Sub-total	54.7	9.1	40.6	37.0	34.7	-	-	-	-	-
	System Total	**101.4**	**12.3**	**53.7**	**60.7**	**40.4**	**44.8**	**3.1**	**15.1**	**22.8**	**5.4**
AFS 2	Branches	8.2	0.5	3.9	9.1	2.1	7.8	0.4	3.9	8.6	2.0
	Leaves	27.5	1.6	6.6	15.4	4.8	23.7	1.4	5.7	13.3	4.1
	Sub-total	35.8	2.1	9.5	24.5	6.9	31.6	1.8	9.6	21.9	6.1
	Crop-Straw	32.6	4.3	23.2	26.3	25.3	-	-	-	-	-
	Grain	27.1	5.6	21.0	11.0	12.8	-	-	-	-	-
	Sub-total	59.7	9.9	44.2	37.3	38.1	-	-	-	-	-
	System Total	**95.4**	**12.0**	**53.7**	**61.8**	**45.0**	**31.6**	**1.8**	**9.6**	**21.9**	**6.1**
AFS 3	Tree-Branches	5.5	0.4	3.4	4.9	2.9	5.0	0.4	3.3	4.7	3.5
	Leaves	14.3	1.0	3.9	6.8	3.8	12.7	0.9	3.5	6.1	3.4
	Sub-total	19.5	1.4	7.4	11.7	6.7	17.7	1.3	6.8	10.8	6.9
	Crop-Straw	27.4	3.6	19.6	22.2	21.3	-	-	-	-	-
	Grain	23.4	4.9	18.1	9.5	11.1	-	-	-	-	-
	Sub-total	50.8	8.5	37.7	31.7	32.4	-	-	-	-	-
	System Total	**70.3**	**9.9**	**45.1**	**43.4**	**39.1**	**17.7**	**1.3**	**6.7**	**10.8**	**6.9**
AFS 4	Branches	1.0	0.1	0.5	0.7	0.5	1.0	0.1	0.5	0.7	0.5
	Fruits	26.5	0.2	11.4	-	9.5	23.9	0.2	10.3	-	8.6
	Sub-total	27.5	0.3	11.9	0.7	10.0	24.9	0.3	10.8	0.7	9.1
	Crop-Straw	31.5	4.1	22.5	25.5	24.5	-	-	-	-	-
	Grain	26.2	5.4	20.3	10.6	12.4	-	-	-	-	-
	Sub-total	57.7	9.5	42.8	36.1	36.9	-	-	-	-	-
	System Total	**85.2**	**9.8**	**54.7**	**36.8**	**46.9**	**24.9**	**0.3**	**10.8**	**0.7**	**9.1**

AFS 1- Alder-based agroforestry system
AFS 2- Albizia-based agroforestry system
AFS 3- Cherry-based agroforestry system, and
AFS 4- Mandarin-based agroforestry system.

through harvest of fruits and carrying away of straw/stalk and grains of crops. In addition, 1-2% of nutrients in the 'tree+crop' and 4-22% in the 'tree only' situation were also lost through the removal of dead, diseased and dying branches of mandarin trees. A perusal of data (Table 9.4) indicated that a high amount of nutrients was exported through the various components. Among the elements, N was exported in maximum quantity. The trend of depletion of nutrients was N > Ca > K > Mg > P in the alder- and albizia- systems in both 'tree+crop' and 'tree only' situations, and in the cherry-system in the 'tree only' situation. However, in the 'tree+crop' situation in the cherry system the trend was: N > K > Ca > Mg > P. In contrast, the trend of nutrient depletion in the mandarin system was N > K > Mg > Ca > P in both the situations. Maximum loss (54 to 72%) of N was through the harvest of grains and removal of straw/stalk of crops. But in the 'tree only' situation the total loss of nutrients occurred due to pruning of branches and leaves. In the mandarin-system, 31% N, 2% P, 21% K and 20% Mg in the 'tree+crop' situation and 96, 78, 95 and 95% of N, P, K and Mg respectively in the 'tree only' situation were removed through fruit harvesting. The loss of nutrients was maximum from the alder-, followed by albizia-system and the lowest was from the cherry system. The losses were higher from the alder-, albizia- and mandarin-systems than from the cherry-system.

Stock of nutrients in the four agroforestry systems

In all the four agroforestry systems, the largest stocks were contained in the soil pool for all the elements except K

(Table 9.5). Even the alder-system which had the largest biomass, stored 91% of the system's N, 97% P, 93% Ca and 92% Mg in the soil. The trend was same in the other three agroforestry systems also. However, comparatively greater quantities of K (28 to 34% in the 'tree+crop' and 38 to 42% in the 'tree only' situation) were present in the live biomass than the other nutrients. Total stock of the elements decreased in the order: N > Ca > Mg > P > K for alder- and albizia-system in both the situations and cherry- and mandarin-system in the 'tree only' situation. In the cherry- and mandarin-system in the 'tree+crop' situation the order of decrease in nutrient stock was: N > Ca > P > Mg > K. In the 'tree+crop' situation, the difference in the stock of N, K and Ca in the soil among the four systems was negligible. But the difference among the four systems was greatest in respect of the quantities of Mg and P. However, in the 'tree only' situation the difference among the systems was worth noticing only in the quantity of Mg. In the 'tree+crop' situation, percentage of nutrients, particularly N and Ca stored in the woody components was higher than in the annual crops, except in the case of mandarin system. In contrast, the storage of P, K and Mg was generally more in crops than in the tree components. In the mandarin system quantities of all the elements were more in crops than in trees, but the reverse was true for Ca.

In the 'tree only' situation percentage of nutrients except for N in alder- and albizia-system stored in the weed components was more than in woody components. The results

Table 9.5. Density of elements (kg ha^{-1}) and their distributional pattern in different compartments of vegetation and soil in the four agroforestry systems.

Agrofor. systems	Compartment	'Tree+crop' situation					'Tree only' situation				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
AFS 1	**Aboveground**										
	Tree	215.9	14.7	80.6	107.4	29.5	207.5	14.1	77.4	103.4	28.3
	Crops	96.0	16.4	71.6	57.0	59.0	-	-	-	-	-
	Weeds	34.7	8.6	46.2	28.3	10.0	141.0	34.8	187.8	115.3	40.7
	Belowground(roots)										
	Tree	47.8	4.7	20.5	19.4	6.8	46.0	4.6	19.7	18.7	6.6
	Crops	7.7	1.5	5.7	7.7	5.4	-	-	-	-	-
	Weeds	3.5	0.5	2.3	2.9	1.4	35.7	5.3	23.6	29.4	11.9
	Soil (upto 30 cm)	4143.0	1537.0	552.0	3014.0	1257.6	4867.0	1300.0	504.0	3246.	1387.0
	Total system	**4548.6**	**1587.4**	**778.9**	**3236.8**	**1369.8**	**5297.3**	**1358.7**	**812.6**	**3513.**	**1474.7**
AFS 2	**Aboveground**										
	Tree	161.1	9.4	58.9	115.8	32.8	144.1	8.4	54.0	105.0	27.9
	Crops	101.5	17.4	75.7	60.4	62.6	-	-	-	-	-
	Weeds	36.6	9.0	48.1	29.9	10.6	131.7	32.5	175.3	107.6	38.0
	Belowground(roots)										
	Tree	41.0	4.2	19.1	15.8	5.1	39.3	4.0	18.3	15.2	4.9
	Crops	8.2	1.6	6.0	8.2	5.7	-	-	-	-	-
	Weeds	3.6	0.5	2.4	2.9	1.5	33.4	4.9	22.1	27.5	13.7
	Soil (upto 30 cm)	3820.0	2273.0	528.0	3086.0	2395.2	4430.0	1476.0	504.0	3342.	2472.0
	Total system	**4171.9**	**2315.1**	**738.3**	**3319.1**	**2513.4**	**4778.5**	**1525.8**	**770.7**	**3598.**	**2556.6**

Table 9.5 contd......

Table 9.5 contd...

Agrofor. systems	Compartment	'Tree+crop' situation					'Tree only' situation				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
AFS 3	**Aboveground**										
	Tree	89.4	6.6	36.6	56.9	35.5	80.5	6.0	33.1	51.54	31.9
	Crops	79.3	13.5	59.1	47.3	48.9	-	-	-	-	-
	Weeds	39.5	9.7	52.0	32.3	11.4	136.2	33.6	179.4	111.3	39.3
	Belowground(roots)										
	Tree	32.1	3.9	33.7	24.3	16.5	29.4	3.6	30.8	22.2	15.0
	Crops	6.5	1.3	4.8	6.5	4.5	-	-	-	-	-
	Weeds	3.9	0.6	2.6	3.2	1.6	34.5	5.1	22.8	28.4	14.2
	Soil (upto 30 cm)	2648.0	1298.0	368.0	2100.0	1104.6	3305.0	1158.0	368.0	2332.	1233.6
	Total system	**2898.7**	**1333.7**	**556.8**	**2270.9**	**1222.4**	**3585.6**	**1206.2**	**634.1**	**2546.**	**1334.1**
AFS 4	**Aboveground**										
	Tree	81.4	6.6	41.0	67.6	37.6	76.1	6.2	38.9	63.3	35.5
	Crops	98.3	16.8	73.4	58.6	60.6	-	-	-	-	-
	Weeds	40.4	9.5	53.2	33.0	11.7	136.8	33.7	180.1	111.7	39.5
	Belowground(roots)										
	Tree	32.4	4.2	34.9	27.5	25.8	32.8	4.2	35.3	27.7	26.0
	Crops	8.1	1.6	6.0	8.1	5.6	-	-	-	-	-
	Weeds	4.0	0.6	2.0	3.4	1.7	34.6	5.1	22.9	28.5	14.3
	Soil (upto 30 cm)	3162.0	1474.0	408.0	2645.0	1166.4	3706.0	1198.0	416.0	2934.	1348.8
	Total system	**3426.8**	**1513.3**	**618.7**	**2843.1**	**1309.4**	**3986.3**	**1247.2**	**693.2**	**3165.**	**1464.1**
	System mean	**3761.5**	**1687.4**	**673.3**	**2917.5**	**1603.7**	**4411.9**	**1334.5**	**727.6**	**3205.**	**1707.4**
	SD	**740.4**	**431.8**	**103.0**	**478.5**	**609.4**	**770.7**	**142.9**	**79.6**	**477.**	**564.7**
	CV(%)	**20.0**	**25.6**	**15.3**	**16.4**	**38.0**	**17.5**	**10.7**	**11.0**	**15.**	**33.4**

AFS 1- Alder-based agroforestry system
AFS 2- Albizia-based agroforestry system
AFS 3- Cherry-based agroforestry system, and
AFS 4- Mandarin-based agroforestry system.

clearly demonstrate that a relatively larger quantity of nutrients was present in the soil than in the vegetation. However, in the case of K which is highly susceptible to leaching, a major part (28 to 34% in the 'tree+crop' situation and 38 to 42% in the 'tree only' situation) was stored in the biomass (Table 9.5).

Element turnover in the four agroforestry systems

Annual turnover of different elements is given in Table 9.6. The turnover of the different elements in the vegetation did not follow a consistent trend. Percentage turnover of N, Mg, Ca and P in the soil was generally much lower than in the vegetation. For soil compartment, no significant difference in percentage turnover of N, P, K and Ca was observed among the four systems. However, the turnover rate of Mg differed significantly and it was maximum in the cherry- and minimum in the mandarin-system. There was wide variation in turnover rates of all the five elements in the vegetation compartment.

DISCUSSION

A knowledge of cycling of nutrients is essential to understand the way in which the fertility, which is lost due to removal of fuel, fodder, fruits and grains from the agroforestry systems, is restored by biological process or by external inputs. The nutrient cycles consist of stores, flows within the sytem, and gains and losses external to it. The nutrient ***stores*** are live plant parts, plant residues, soil organic matter and the available nutrients in mineral form in the soil solution. The main internal ***flows*** are from the plant components to plant residues via soil fauna to soil humus,

Table 9.6. Annual turnover of elements in soil and vagetation compartments of the four agroforestry systems.

Agrofor. systems	Compartment	'Tree+crop' situation					'Tree only' situation				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
AFS 1	Soil	11.4	3.5	47.6	9.4	10.4	10.2	4.8	50.9	9.3	7.5
	Vegetation	60.9	53.1	85.9	116.4	74.7	61.3	52.4	88.2	115.0	74.3
AFS 2	Soil	10.6	2.2	42.2	9.7	5.6	8.8	3.6	44.2	8.8	4.0
	Vegetation	53.8	51.7	60.7	91.0	51.6	55.9	53.2	62.7	94.8	52.5
AFS 3	Soil	11.9	3.4	55.1	10.6	13.3	9.7	4.4	57.2	10.1	9.8
	Vegetation	77.9	78.5	110.1	112.7	109.8	82.7	82.7	117.3	120.0	119.7
AFS 4	Soil	10.3	3.1	54.7	9.2	14.6	8.9	4.4	54.9	10.0	10.2
	Vegetation	47.6	18.1	50.9	23.7	43.2	44.7	16.2	46.4	20.7	39.8
	Soil										
	Mean	11.0	3.0	49.9	9.7	10.9	9.4	4.3	51.8	9.6	7.9
	CV(%)	6.6	20.0	12.4	6.4	36.2	7.2	11.6	11.0	6.5	36.2
	Vegetation										
	Mean	60.3	50.3	76.9	85.9	69.8	61.1	51.2	78.6	87.6	71.6
	CV(%)	21.8	49.2	34.6	50.0	42.6	26.0	53.2	39.4	52.4	49.1

AFS 1- Alder-based agroforestry system
AFS 2- Albizia-based agroforestry system
AFS 3- Cherry-based agroforestry system, and
AFS 4- Mandarin-based agroforestry system.

through the process of mineralization to mineral nutrients, and return to the plants via root uptake.

The objective in designing and managing agroforestry systems is to modify cycling in such a way as to make more efficient use of the nutrients, whether these originate from natural renewal processes or from inorganic fertilizers. It is, however, desirable to reduce the ratio between inputs and outputs. If this ratio can be reduced, nutrients would be re-used more often by plants before being lost from the system. The four agroforestry systems being discussed here are transitory between forests and agricultural systems. Major pathway for recycling of nutrients in these agroforestry systems is through crop residue and weed debris, tree litterfall, and external inputs through manure and organic fertilizers.

The amount of nutrients recycled through litterfall, crop residue and weeds varied significantly in the four systems. Highest amounts of nutrients were recycled from soil to vegetation and *vice versa* in alder- followed by albizia-system due to the fact that these tree species have greater biomass than the other two tree species. In addition, alder and albizia leaves have higher element concentrations than cherry and mandarin leaves (Table 9.1). It was observed that concentrations of most of the nutrients in live leaves were higher than in the litter. This is due to the fact that deciduous trees such as alder, albizia, cherry and mandarin translocate nutrients from leaves to perennial organs well before leaffall (Bernhard-Reversat, 1982; Tolsma *et al.*, 1987). In mandarin system, on the other hand, the nutrients recycled through litterfall, were minimum due to the fact that the trees have a small canopy. However, recycling process through crop residue and weeds in the 'tree+crop' and weeds in the 'tree only' situation is prominent in this system. Comparatively high budget of nutrients in standing biomass in alder- and albizia-systems also facilitates the nutrient cycling.

In all the four agroforestry systems, a significant amount of nutrients from the soil was taken up by the agricultural crops, and a large amount of it was allocated towards the edible parts and thus subsequently removed from the system. Loss of N, Ca and Mg is compensated from the large quantity stored in the soil or from crop residue, weed debris and roots. However, K and P may be in deficit unless compensated through external inputs. Therefore, the addition of P and K through organic and inorganic fertilizers becomes essential to maintain soil fertility for sustained plant productivity. The nutrient cycling pattern in agroforestry systems is diferent from that in the forest ecosystem where a major quantity of nutrients is recycled annually (Toky *et al.*, 1989). For example, Filku and Klinge (1973) estimated that in climax forests of Brazil, 7.3 t of litter ha^{-1} produced in one year, recycles 106 Kg of N, and maintains the soil fertility. A few other studies made on changes in soil nutrient budget during forest development have reported that soil fertility may increase (Aweto, 1981), decrease (Ramakrishnan & Toky, 1981; Werner, 1984), or remain relatively constant (Zinke *et* *al.*, 1978; Buschbacher *et al.*, 1988). In the present systems, though the quantities of nutrients recycled through litterfall, crop residue and weed debris are comparable with those reported by other workers (Maghembe *et al.*, 1983; Alpizar *et al.*, 1986, 1988; Grewal & Abrol, 1986; Fassbender *et al.*, 1988), the quantity lost through crop removal is significantly higher making the systems unstable unless external inputs are added. At the present site, outside nutrient input is necessary due to low fertility level of soil (Chapter 3), and removal of biomass through harvest. During the cropping period there may be competition for fertilizers among crops, trees and weeds, but after the crop harvest, the remaining fertilizers are utilized by trees and weeds. Alder, albizia and cherry produce leafy canopy prior to the onset of rains (monsoon) and loses these leaves during the later part or end of the monsoon season. This phenological trait of these trees enables the crops to benefit from the removal of overhead shade and accumulation of thick mulch of litter during **rabi** season, and as a result, they grow better.

The study indicates that boles and branches of trees in the agroforestry systems play a significant role in conserving the essential elements particularly potassium, which is more readily leachable.

There is greater uptake and return of nutrients in the alder- and albizia-systems making them remarkably efficient in nutrient cycling. Besides, the nutrient cycling in these two systems appear to be quite flexible due to the nitrogen fixation in the two tree species. Binkley *et al.* (1992), and

Sharma *et al.* (1992) have also reported generally higher uptake and return of nutrients in N_2-fixing trees. Thus, both alder and albizia make excellent associate in agroforestry systems, promoting greater availability and faster cycling of nutrients. Besides, the requirement of external inputs into these agroforestry systems is much lesser than the cherry- and mandarin-system.

CHAPTER 10

GENERAL DISCUSSION

The forest vegetation in the north-eastern hill region is being degraded due to disturbances of various kinds such as shifting agriculture, burning and cattle grazing. Degradation of forest vegetation has also caused accelerated soil erosion and land degradation. Results presented in the foregoing chapters show that agroforestry has potential to restore and maintain soil fertility. The four agroforestry systems (alder-, albizia-, cherry- and mandarin-based systems) selected for the present study differ from one another in the tree components, density of the stands, canopy spread, light interception by the canopy, crop yield, weed flora and density of weed species. These systems, however, have similarity in topography of the site (slope, soil depth, aspect), initial soil properties, age of the stand and agricultural crops grown. Ecological analysis of these agroforestry systems was done in terms of weed community organization, growth behaviour of tree species, biomass and productivity of tree, weed and crop components, litter dynamics, nutrient dynamics and effects of physico-chemical properties of soil. The experimental planning and methodologies also envisaged the comparison of the systems having both tree and crop components ('tree+crop' situation) with that having trees alone ('tree only' situation). The important findings are discussed below:

In general, the number of weed species recorded in the 'tree only' situation was more than in the 'tree+crop' situation. More than 60% weeds were annuals. The number of perennial species was higher in the 'tree only' than in the 'tree+crop' situation. The latter was dominated by annuals as indicated by a high percentage (83-92%) of therophytes, whereas in the former situation chamaephytes and hemicryptophytes were more prevalent. The perennial species which invade a given habitat only later during the succession, were unable to colonise the 'tree+crop' situation due to constant interruption through soil working and intercultural operations including weeding while the 'tree only' situation developed a community of tall weeds due to less disturbance. This finding is in agreement with that of other workers (Quarterman, 1957; Tripathi & Misra, 1971; Nicholson & Monk, 1974; Streibig, 1979; Boral, 1993). The therophytic weeds such as *Ageratum conyzoides*, *A. haustonianum*, *Bidens pilosa* and *Galinsoga parviflora* were abundant in the crop fields (Pradhan, 1990; Boral, 1993), especially on the slopy lands. They produce seeds in large quantities and disperse them into the system before crop harvest, which contributes to their prevalence in the crop fields. On the other hand, in the 'tree only' situation, the perennial species like *Arundinella bengalensis*, *Eupatorium adenophorum* and *Imperata cylindrica* were dominant. The belowground perennating organs of these weeds function as storage organs and means of vegetative propagation. In such species more energy is expended for competition rather than reproduction through seeds. Their dominance could also be attributed to the lower rate of juvenile mortality as they are attached with the parent plants and mobilize resources from parent to young ones in sufficient quantities to sustain their life during establishment. On the other hand, annual weeds which largely depend on seed for their regeneration were less frequent and showed low population density primarily due to an accumulation of litter under the tree canopy. The crops by severely competing with the weeds, also contributed to the reduction in density and growth of weeds. The lower weed population was observed in alder- and albizia-systems where the tree canopy was large and dense, whilst the mandarin-based system had the maximum weed density due to limited canopy spread of mandarin. The low weed biomass obtained in this study and similar observations made by others (Aken-Ova & Atta-Krah, 1986; Yamoah *et al.*, 1986a; Bashir Jama & Getahun, 1991) indicated that the weed infestation is reduced in agroforestry systems.

Survival and growth of trees

Albizia and alder owing to their fast growth and capacity to cause weed suppression seem to have great potential in agroforestry. Cherry and mandarin, on the other hand, showed slow growth, but cent percent survival. Albizia, which is an exotic tree grew reasonably well. Its success could be attributed to its well developed and extensive root system with profuse fine roots which are well distributed. Albizia being an NFTS has further advantage of getting some amount of nitrogen from root nodules for its growth and development. Performance of all the four tree species in terms of growth and biomass production was better in the 'tree+crop' as compared to the 'tree only' situation. This is mainly due to the addition of fertilizers, tilling and weed control measures in the 'tree+crop' situation. The tilled condition might have created a congenial soil environment for optimum soil microbial activity, thereby accelerating the mineralization of organic matter and making adequate nutrients available to the trees.

Biomass and productivity of the tree species

Alder and albizia channelled a large part of their net production towards biomass accumulation. In both species, production of new roots and foliage was rather small but it represented a significant fraction (44-45%) of the toal dry matter thus ensuring adequate utilization of water, nutrients and sunlight. But in cherry and mandarin, aboveground growth was reduced in favour of expending more energy belowground to develop and maintain root systems. This shift in production allocation from above- to belowground structures may be an essential mechanism to avoid or alleviate nutrient and water stress (Dhyani *et al.*, 1996) in slopy land conditions. All four tree species have deep rooting systems, though there were temporal and spatial variations in relative abundance of their roots. The distribution and density of roots within the soil profile are governed by genetic make up of the plant as well as soil environment (Buck, 1986; Haissing & Riemenschneider, 1988; Myers *et al.*, 1994). In the present study all the four tree species had 72-80% of the fine rootmass in the top 20 cm soil layer. The total fine root stock (1.2-1.7 t ha^{-1}) in the upper 10 cm soil layer recorded in this study is well within the range reported for different forests (Berish, 1982; Cuevas *et al.*, 1991; Parrotta & Lodge, 1991; Vance & Nadkarni, 1992; Arunachalam *et al.*, 1996; Sundarapandiyan & Swamy, 1996). The data on fine root mass indicated that autumn season was the most favourable period for root growth. The autumn peak of the belowground biomass may be attributed to the translocation of large amount of organic matter from shoot to the belowground parts. Fine roots accounted for 74-86% of the total root production in the four species. Cherry and mandarin showed a high accumulation and uniform distribution of fine roots down to 30 cm soil depth, whereas in alder and albizia the fine root production showed a sharp decreasing trend below 10 cm soil depth (sub-surface soil layers), and their maximum roots were concentrated near the tree trunk.

The total net primary production of the four tree species ranged between 18-23 t $ha^{-1}yr^{-1}$. It is worth noting that despite a high rate of root turnover and additional contribution of biomass by root nodules in alder and albizia, the total belowground productivity was almost equal to or slightly less than cherry and mandarin. The total net primary productivity was invariably higher in 'tree+crop' than in 'tree only' situation thus indicating that agroforestry systems are more advantageous than the corresponding tree monocultures.

Biomass and productivity of crops

In agroforestry systems the crop yield was reduced to some extent due to the presence of trees which compete with crop plants for belowground resources and cast some shade. Therefore, as the distance from the tree increased the crop

yield also improved. The similarity of root distribution in the soil profile between trees and annual crops, caused considerable overlapping of the soil resource use which sharpened competition between them (Jonsson *et al.*, 1988; Dhyani *et al.*, 1990; Ruhigwa *et al.*, 1992; Scroth & Lehmann, 1995). Root competition for water and nutrients has been found responsible for yield depression at the tree-crop interface of agroforestry association (Lal, 1991; Szott *et al.*, 1991b; Salazar *et al.*, 1993). However, in albizia-system proximity of tree did not reduce the crop yield significantly, though overall there was some reduction in total yield of crops as compared to the yield in sole crop condition. The normal crop yield near the tree in albizia might be due to its light shade as well as deep rooting system which did not interfere with the crop roots for uptake of nutrients and water.

The results indicate that the root systems of alder and cherry were markedly more competitive than those of albizia resulting in high yield depression at the tree-crop interface. The high competitiveness of the cherry and alder root system may be due to high nutrient and water consumption, as in these species a vigorous leaf initiaion takes place after dry winter.

Belowground biomass

The crop cultivation drastically altered the root-rhizome proportion of belowground biomass in the four systems. The proportion of belowground biomass in the upper 10 cm soil layer in the 'tree only' situation was higher (82-84%) than in the 'tree+crop' situation (66-68%) which may be attributed to more favourable physical and chemical conditions for root growth in the surface layer of soil. Anderson (1987), Newell & Wilhelm (1987), and Cheng *et al.* (1990) reported a higher proportion of belowground biomass in upper layer in the no-tillage system, which was comparable to the 'tree only' situation. Fluctuation in the belowground biomass in the 'tree only' situation was largely due to variations in rhizome biomass, which was caused by the retranslocation of photosynthates from senescing shoots to rhizomes particularly in unfavourable periods and again its translocation to newly growing shoots at different intervals of time. Increase in the belowground biomass during winter observed in the present study was probably due to retranslocation of photosynthates from shoots.

The ANP of crops and weeds in the 'tree+crop' situation and that of secondary successional plants in the 'tree only' situation varied widely in different months and years. In the 'tree+crop' situation during winter cropping season annual weeds also grew and contributed to the total production. In the 'tree only' situation despite decrease in total biomass during winter, there was a considerable aboveground production. This may be attributed to differences in growth behaviour of the species which attained their peak biomass at different times of the year. The annual TNP of tree plus crops plus weeds in the 'tree+crop' situation and tree plus weeds in the 'tree only' situation was more or less equal. This was expected as the trees were the major component in the four agroforestry systems in both the situations, contributing

53-61% to the annual TNP. The crop production in the 'tree+crop' situation decreased due to the presence of trees as well as weeds. Besides, the crops that were selected for the present study were characterised by low productivity. These are some of the reasons for the absence of any substantial difference between the TNP recorded for the 'tree+crop' and 'tree only' situations. The TNP of the four agroforestry systems is comparable to that of agricultural system (Boral, 1993), mixed grasslands (Singh & Yadava, 1974) and *Leucaena leucocephala* plantations (Brewbaker, 1987).

Litter dynamics of trees

Leaf litter constituted 50-79% of the total litter. Alder cherry and albizia produced large quantities of leaf litter due to their extensive canopies, while mandarin produced low amount of leaf litter due to greater longevity of the leaves and smaller canopy. High variability of tree species with regard to litter production has been reported by Alaban (1982) and many other workers (Budelman, 1989; Hawkins *et al.*, 1990; Szott *et al.*, 1991a; Szott & Kass, 1993; Dhyani *et al.*, 1994). The values recorded for the four tree species are within the range of reported litter production rates of 0.44 to 8.18 t $ha^{-1}yr^{-1}$ (Thojib, 1980; Reichle, 1981; Singh, 1990; Sanchez & Sanchez, 1995). In the present study, more than 80% litterfall was recorded during dry periods (November to April) and hardly any leaffall during rainy season. Higher litter production during the dry periods may be due to changes in the endogenous hormonal balance resulting in stimulation of senescence of leaves and other parts. Since the climate of the study area shows distinct seasonal cycles, litter production as well as decomposition too followed a seasonal pattern. Maximum accumulation of litter on the ground during autumn and winter seasons coincided with the period of peak litterfall and lower decomposition rate. At the present site hardly any decomposition of litter during the period of October till March was noticed, primarily due to prevailing dry and low temperature conditions. In contrast, during spring and rainy seasons which were favourable for soil microbial activity the littermass on the ground was minimum due to faster rate of decomposition.

A more rapid turnover of leaf-litter was recorded in mandarin and cherry as compared to alder and albizia. The rapid leaf-litter turnover in mandarin may be attributed to higher surface soil temperature, wider fluctuation in diurnal temperature, better aeration and shorter wetting and drying cycles under its small canopy compared to large and wider canopy of other tree species. These microclimatic conditions contributed to the rapid decay of leaf litter on the ground. In the litter-bag study the nutrient rich litter of alder and albizia decomposed rapidly than cherry and mandarin. It took 240 days for leaf litter and 300 days for miscellaneous litter for 90% loss of material in alder and albizia, but in other two species the litter remained more or less undecomposed after 420 days. The differences in decay constant (k) among the four tree species could be attributed to quality of litter. The slow rate of decomposition may be due to the time-lag in the colonization and establishment of the microbes on the litter (Alexander, 1977) on account of low moisture and high lignin contents in the leaves of cherry and mandarin. A decline in the rate of weight loss after rapid phase of decay may be attributed to the presence of higher % of recalcitrant fraction like cellulose, lignin and tanin in the leaf litter during the advanced stage of decay. These substances are known to control decay rate by slowing resistance to enzymatic attack and by physically interfering with the degradation of other chemical fractions of the cell wall (Bloomfield *et al.*, 1993). Within the overall decay pattern, seasonal fluctuations were also observed. Woody litter comprised woody residues, branches and twigs, which being of low quality on account of having lower concentration of nutrients especially N and P, decomposed at slower rates than the leaf and miscellaneous litter. The slow rate of decay of woody litter contributes to the conservation of nutrients. Higher concentration of N in the littermass particularly in leaf litter was responsible for faster decomposition. Slow rate of decomposition of plant materials with lower N is related to the greater proportion of lignin fraction in the tissues (Fogel & Cromack, 1977; Meentemeyer, 1978; Swift *et al.*, 1978; Laishram & Yadava, 1988).

The daily decay rates (Table 7.6) of the three litter fractions were highest in alder and lowest in mandarin. The species ranking for the rate of decomposition of litter was: alder >albizia >cherry >mandarin.

Crops such as soybean, groundnut, linseed and mustard vary in their nutrient requirements during the growing season.

At the present site, from October till March litter at the soil surface primarily serves as mulch material which improves water infiltration and reduces runoff and evaporation (Swift *et al.*, 1987; Benkobi *et al.*, 1993) and eventually provides a conducive environment for crop germination and development in rabi season. Besides, the accumulated litter is a reservoir of nutrients, which starts decomposing and releasing nutrients with the onset of rains. This is the period when kharif crops germinate and grow and thus the period of active uptake of nutrients by crops coincides with the release of nutrients from litter decay.

Physico-chemical properties of soil under the four systems

In the four agroforestry systems litter, particularly leaves, twigs, flowers, fruits and bark provides the raw material for the generation of organic matter. On mineralization, some of it would normally be lost through plant use and leaching. Alder, albizia and cherry generate large quantities of high quality litter during the dry period. Besides, they have heavy foliage cover in the rainy season which helps to prevent the removal of the organic matter from the topsoil. Thus the soil fertility under trees is improved through increased litter and SOM conent under trees (Campbell *et al.*, 1988, 1994; Dunham, 1991; Isichei & Monoghalu, 1992; Kesseler, 1992).

The initial declining trend in soil pH (Fig.8.4) was mainly due to rise in exchangeable Al^{+3} level, whereas soil pH rise at the end of the experiment was primarily due to sharp decline in exchangeable Al^{+3} coupled with a substantial increase in total exchangeable cations (Ca^{+2}, Mg^{+2} and K^{+1}), particularly by Ca^{+2}-'pumping' of the trees as the topsoil pH depends significantly on the Ca levels of the litter (Fig. 8.6). Exchangeable Al^{+3}- a potential cause of infertility of acid soils was reduced sharply due to accumulation of high amount of soluble cations (10.49 C mol(P^{+}) kg^{-1}) in the topsoil in the alder-, albizia- and mandarin- systems. However, in the cherry-system and the sole crop exchangeable Al^{+3} content was about 20 per cent higher than initial values. This was mainly due to lowest accumulation of total exchangeable cations (Ca^{+2}, Mg^{+2} and K^{+1}). In case of the sole crop, marked deterioration of topsoil may be due to acidification which commonly occurs under agricultural use and can become severe with repeated application of fertilizers, especially ammonium sulphate. This is a hazard with the agricultural use of soils of both moderate and strong acidity unless some amendments are used.

Initially, maximum accumulation of organic-C occurred beneath alder, cherry and albizia due to the addition of high amounts of aboveground litter as well as root biomass and lesser microbial activity due to excessive exchangeable Al^{+3}, low P and cations such as Ca^{+2} and Mg^{+2}. At the end of the experiment, organic-C content sharply declined under all the four systems. Similar declining trend in organic matter status under agroforestry systems has also been reported by Lal (1986), Drechsel *et al.* (1991) and Singh *et al.* (1992). The decrease in organic-C is attributed to a faster mineralization of organic matter resulting in the release of nutrients particularly cations, N and P, owing to the enhanced microbial activity which was expected due to improvement in soil environment (readily available cations, P, improved porosity, good WHC and better soil tilth). By the end of the experiment, however, organic matter and exchangeable cations (Ca^{+2}, Mg^{+2} and K^{+1}) in the soil of the four agroforestry systems were significantly more than in the sole crop soil. The increase in organic matter in the topsoil seems to be responsible for the increase in exchangeable cations and N since there are highly significant ($r=0.86-0.95$, $P<0.01$) correlations between these parameters and organic-C. The soils under the four agroforestry systems seem to have high rate of mineralization, as the C/N ratios ranged between 7 and 13 which are quite favourable for mineralization. The spectacular increase in Bray's P_2-P (available P) under alder, cherry and albizia may be attributed to solubilization of native P (unavailable form) and addition of large quantities of organic matter through roots (Chapter 5). These soils have relatively low capacity to fix P, and consequently, even low rates of P applications can lead to a substantial build-up of available P (Lal, 1989). This confirms the high build-up of available P in the 'tree+crop' situation in the four systems and in the sole crop plot.

Years of leaffall and litter decomposition in the agroforestry systems improved the soil water holding capacity and porosity, and reduced bulk densities as compared to the sole crop plot. Improvement in soil friability and permeability through the action of root system and due to the addition of organic matter through litterfall is also reported by other workers (Swift, 1987; Szabolcs, 1989; Garg, 1992;

Garg & Jain, 1992; Rosecrance *et al.*, 1992; Chaturvedi & Behl, 1996; Jain & Garg, 1996). On the other hand, in the sole crop plot continuous cropping caused a marked deterioration of topsoil with rapid fall in organic matter content, reduction in water holding capacity (Lal, 1986) and increase in soil bulk density (Takahashi *et al.*, 1983).

The increase in soil total nitrogen, available phosphorus, exchangeable Ca^{+2} and K^{+1} and organic-C, and improvement in WHC and porosity and reduction in bulk densities in the alder- and albizia- systems indicate an increased fertility of the topsoil. Most of these properties were improved in the mandarin system as well, however, the magnitude of improvement in this case was lower as compared to the alder- and albizia-systems, but certainly higher than the cherry-system and sole crop. The low magnitude of increase in soil fertility in mandarin was expected due to its slow growth rate (Chapter 4), restricted canopy spread and low litter yield (Chapter 7). However, its leaf litter had the highest Ca^{+2} content which helped it in improving topsoil pH. The cherry-system has comparatively higher growth rate, wider canopy spread and higher litter yield than the mandarin-system but due to low accumulation of exchangeable cations, exchangeable Al^{+3} was not influenced favourably, and consequently, the soil pH did not improve appreciably.

Nutrient cycling in the four agroforestry systems

The study on cycling of nutrients in the four agroforestry systems indicated the way in which the fertility, which was lost due to removal of twigs and branches, fruits, crop straw and grains from the system, was restored by addition of litter, crop residue, weed debris and roots.

The amount of nutrients recycled varied significantly in the four agroforestry systems. In alder- and albizia-system, highest amount of nutrients was recycled from soil to vegetation and *vice-versa*. This was due to higher nutrient budget in the standing biomass of these tree species as well as crops than other two species. In mandarin-system, on the other hand, the nutrients recycled particularly through litterfall, were minimum due to its small canopy and longevity of leaves. But in this system recycling of the crop residue and weed debris was more prominent. In all the four agroforestry systems, a large quantity of nutrients from soil was taken up by the crops and most of it was subsequently removed from the system through crop harvesting. In the present study, loss of N, Ca and Mg was compensated from the soil pool or from crop residue, weed debris and roots. However, K and P which remained deficit were added through inorganic fertilizers. Among the four agroforestry systems, cherry- and mandarin-systems have shown substantial negative nutrient balance unless compensated through the addition of inorganic fertilizers. The nutrient release from the nutrient-rich leaf-litter of alder and albizia synchronizes well with the uptake requirements of crops, thereby making the plant-soil systems more closed (Yamoah *et al.*, 1986a; Swift, 1987).

The present study, thus provides a good deal of information on the weed community structure, crop yield, growth and biomass production of the four tree species, influences of the agroforestry systems on soil characteristics, and nutrient cycling in the 'tree+crop' and the 'tree only' situations. From the data presented here, it could be concluded that alder- and albizia-systems are remarkably efficient from the point of view of biomass production, intercrop yield and nutrient cycling. besides, the two systems also have a positive influence on soil-fertility build-up on the slopy land conditions.

SUMMARY

Shifting cultivation which is still quite prevalent in north eastern hills, has caused severe land degradation. Recent studies on evaluation of fertility status under tree-based land use systems have shown their remarkable capacity for restoration of soil productivity by protecting soil, improving soil organic matter status and continuously replenishing nutrients through recycling mechanism. Agroforestry practices have great potential to improve soil fertility via a more efficient cycling of nutrients through above- and below-ground litter inputs and retrieval of nutrients from soil depths where crop roots are not present.

Agroforestry systems differ a great deal in soil working, intercultural operation and chemical treatment, species composition and community structure. Therefore, biomass, productivity and nutrient cycling differ to a great extent from one system to another. However, the analysis of the effects of agroforestry systems on primary productivity and soil characteristics particularly on slopy land situation has not been undertaken in our country. The present study encompassing the effects of four selected agroforestry systems on productivity, soil characteristics and nutrient cycling is a pioneering attempt. The four agroforestry systems selected for the study are alder-based (**AFS 1**), albizia-based (**AFS 2**), cherry-based (**AFS 3**), and mandarin-based (**AFS 4**). The study was carried out at the ICAR Farm, Barapani (Lat. 25^{0} 39'- 25^{0}

41' N , Long. $91^0 54'$- $91^0 63'$ E), which is 22 km north of Shillong, the capital of Meghalaya. The altitude of the farm area varies between 952 and 1082 m above msl. The experimental plots representing the four selected agroforestry systems are adjacent to each other and have similar toposequence. The climate is sub-tropical. The soil is clay loam to sandy clay loam and acidic in reaction. The study was carried out over a period of two years (May '92 -April '94) on the following aspects.

1. Weed populations in four selected agroforestry systems.
2. Survival, growth and biomass of the tree species.
3. Distribution and dynamics of fine roots of the tree species.
4. Biomass and net primary productivity of crops and weeds.
5. The litter dynamics.
6. Effects of the four agroforestry systems on physico-chemical properties of soil.
7. Standing state and distribution of elements in soil and in different compartments of trees, crops and weeds.
8. Nutrient cycling in different agroforestry systems encompassing the annual uptake of nutrients from soil, their transfer to various compartments and ultimate release to the soil.

The results of these investigations are summarised below:

Weed density

The number of weed species and weed yield were more in the 'tree only' situation than in the 'tree+crop' situation. The former situation was dominated by the perennial weeds but the latter had greater number of annuals. Alder- and albizia-systems had low weed population density whereas mandarin-system had the maximum weed density.

Survival and growth of trees

Survival percentage of the four tree species did not vary between the 'tree only' and 'tree+crop' situations. Alder and mandarin recorded 100% survival followed by cherry (95%) and albizia (90%). The maximum height growth was recorded for albizia, followed by alder and cherry, while mandarin showed the minimum height. Alder had the maximum diameter (dbh), canopy spread and timber volume followed by albizia and cherry, while the least values were recorded for mandarin. The mean annual increment (MAI) in timber volume was lower than current annual increment (CAI) in all the four tree species. The overall growth in terms of increase in diameter (dbh), height and biomass production was better in the 'tree+crop' than in the 'tree only' situation.

Biomass and productivity of the tree species

Biomass of differnt compartments viz. leaves, branches and twigs, and stem of the tree species was measured during 1992-93 and 1993-94 and the standing crop of roots was determined by collecting soil cores (0-10, 10-20 and 20-30 cm soil depth) during the four seasons. Horizontal distribution of the woody roots at surface soil was also studied. The maximum fine root biomass (FRB) and necromass (FRN) were recorded during autumn season and minimum during winter. The FRB and FRN were greater in the 'tree+crop' than in the 'tree only' situation. The FRB was significantly ($P < 0.01$) greater than the necromass (FRN) in all the four tree species. The FRB/FRN ratio was maximum (3.2) during spring and minimum during rainy season (2). Coarse root biomass (CRB) was maximum during autumn and minimum during winter season. The total coarse root-mass (CRM = CRB+CRN) ranged between 343-3774 kg ha^{-1} in the 'tree only', and 263-3701 kg ha^{-1} in the 'tree+crop' situation. The ranking for CRM was: mandarin >cherry >alder >albizia.

The total root biomass (TRB = FRB+CRB) was highest in mandarin (autumn) and lowest in alder(winter season). Fine roots represented about 76% of the total roots. Fine root concentration decreased with increasing soil depth. The maximum accumulation of fine root was found in the close proximity (upto 0.5 m distance) of the tree trunk. The total root production was maximum in mandarin, followed by cherry and alder and minimum in albizia. It ranged between 4 to 8 t ha^{-1}yr^{-1}.

The total net primary production (TNP) of the tree species ranged from 18-23 t ha^{-1}yr^{-1}. The maximum TNP (t ha^{-1}yr^{-1}) was recorded for alder (22), followed by cherry (20) and mandarin (19), while the minimum was in albizia (18). The percent distribution of net primary production (NPP) in different components of the four tree species ranged from 14-23% in twig and leaf, 10-17% in branches, 21-38% in bole, and 21-44% in belowground parts. In alder, cherry and mandarin 4-11% NPP was distributed in catkins, berries and fruits. In all the four tree species, NPP was high for foliage and bole and low for branches. The contribution of aboveground biomass to total biomass was quite high in albizia (76%) and alder (79%), but in mandarin and cherry it was only 56 and 63%, respectively. In alder (0.39) and albizia (0.22 t ha^{-1}yr^{-1}), root nodules also contributed to the belowground productivity.

Biomass and productivity of crops

Soybean and groundnut yield during kharif, and linseed and mustard yield during rabi was lower in the 'tree+crop' than in the 'crop only' situation. The reduction in yield due to presence of trees ranged 14-31% for soybean and groundnut, and 13-43% for linseed and mustard. The maximum reduction in crop yield was observed in the cherry- followed by alder- and mandarin-systems whereas the reduction in the albizia-system was only marginal. In cherry-, alder- and mandarin-systems the crop yield in the first row (nearest to the tree) was substantially low, and it improved as the distance from the tree increased. But in albizia-system, proximity of the tree did not influence crop yield, though there was some reduction in the intercrop yield as compared to the sole crop. The peak aboveground biomass was maximum in soybean during October (246-271 g m^{-2}), and in linseed during March (106-132 g m^{-2}). Weed biomass attained peak before the crop matured. Initially, the weed biomass was more than the crop biomass, but at later stages soybean, linseed and mustard crops outyielded the weeds. However, in the case of agroforestry with groundnut as the crop, the weed biomass was greater than the crop biomass throughout the growing period. In the 'tree+crop' situation maximum total live biomass (crop + weed) was recorded in October (432-470 g m^{-2} during 1992-93, and 341-370 g m^{-2} during 1993-94). Litter accumulation in the 'tree+crop' situation was very high during rabi, due to high amount of litter contributed by the trees as leaffall during the crop growing period.

Belowground biomass

Belowground biomass of crops (except linseed) was much greater than that of weeds. Total belowground biomass (i.e. crop+weeds) in the 'tree+crop' situation was maximum in October 1992 in the cherry system (356 g m^{-2}) during 1992-93, and in September 1993 in the alder system (912 g m^{-2}) during 1993-94. But in the 'tree only' situation the maximum belowground biomass was observed in August in the albizia- (595 g m^{-2}) during 1992-93 and in mandarin-system (612 g m^{-2}) during 1993-94. The percentage of total belowground biomass of weeds present in the top 10 cm soil layer was much greater in the 'tree only' situation (82-84%) compared to the 'tree+crop' situation (66-68%).

Annual ANP and BNP of trees were higher than those of crops and weeds. The ANP in the 'tree+crop' situation ranged 1864-2490 g m^{-2} and constituted about 53-65% of the TNP, whereas the BNP varied 1311-1677 g m^{-2}. The TNP values ranged 3474-3816 g $m^{-2}yr^{-1}$ under the four systems. In the 'tree only' situation ANP ranged 2034-2722 g m^{-2}, BNP ranged 1162-1539 g m^{-2} and TNP ranged 3400-3884 g m^{-2}.

Litter dynamics of trees

The leaf fraction constituted 64-79% of the total litter in the 'tree only', and 53-76% in the 'tree+crop' situation. Total litter production increased from October onwards and peaked during January (albizia and cherry) or February (alder). More than 80% litterfall in the four tree species was recorded during dry periods (November to April). In the 'tree only' situation, the leaf-, woody- and miscellaneous-litter fractions contributed 63-79%, 15-23% and 5-10% of the total litter production, respectively, whereas in the 'tree+crop' situation, the corresponding values for the three litter fractions were 50-75%, 15-25% and 5-25%. Annual litter production (t $ha^{-1}yr^{-1}$) in the four systems varied between 1.3 and 8.1 during 1992-93 and 1.4 and 10.2 during 1993-94.

Physico-chemical properties of soil under the four agroforestry systems

Physical properties of soil

Water holding capacity and porosity of soil improved marginally under the agroforestry systems but in the sole crop situation there was a decline. Bulk density decreased by 6% under agroforestry systems but it increased by 5% in the sole crop situation.

Chemical soil properties

Soil oraganic-C content declined significantly with duration of time after initial build-up. Total N content of topsoil increased by more than 100% in alder-system, 82-100% in albizia-, 54-63% in mandarin- and only 36-54% in cherry-system over the sole crop situation. Organic-C as well as total N contents were higher in 'tree only' situation as compared to the 'tree+crop' and sole crop situation . In the subsoil layer, organic-C and total N contents of soil were quite low but the trend was same as in the topsoil. The lowest C/N ratios (6.9 and 7.6 in 'tree only' and 7.1 and 8.0 in 'tree+crop' situations) were observed in alder- and albizia-systems. Concentration of Bray's P_2-P in topsoil increased by more than eight fold as compared to initial (1.20 mg kg^{-1})

values, the maximum increase being in albizia and minimum in cherry. Besides, the 'tree+crop' situation had higher P content than the 'tree only' situation.

Soil pH was invariably higher in alder, albizia and mandarin systems as compared to cherry-system and the sole crop situation. Exchangeable Al^{+3} decreased drastically in alder- and albizia-systems, whereas in the sole crop situation and other two systems the decrease was only marginal. The decrease in exchangeable Al^{+3} content was corroborated with significant increase in soil pH during the same period.

Exchangeable Ca^{+2} contents of topsoil first declined and then increased. However, in the sole crop situation there was a gradual decline in exch. Ca^{+2}. Maximum increase was recorded in albizia system followed by alder and minimum in cherry system. The exch. Mg^{+2} contents of topsoil recorded a gradual increase in all the cases. But in the subsoil layer, there was a decline in 1992 and then an increase in 1994. Exch. K^{+1} increased in alder, albizia, and mandarin systems, and also in sole crop situation, but in cherry system it showed some decrease.

The total exchangeable cation (Ca^{+2}, Mg^{+2} and K^{+1}) contents of soil increased in the agroforestry systems, the maximum being in the albizia-system folllowed by the alder-system.

Nutrient cycling in agroforestry systems

Tree leaves had the highest concentration of elements followed by fruits and branches, and the bole had the lowest. The concentration of N in the leaves was ca 1.6 times greater in alder and albizia than in cherry and mandarin. Weeds showed a markedly higher concentration of P compared to trees and crops. Further, fruits and grains had higher concentration of K as compared to branches, bole, root and litter in trees, and shoot in crops. Among the cations, there was preponderance of Ca and K in the leaves and branches of trees. Crops showed a markedly higher concentration of Mg than trees and weeds. The amount of almost all elements was greater in the 'tree+crop' situation than in the 'tree only' situation. Among the four tree species, alder contained maximum nutrients followed by albizia, while mandarin had the lowest. The crops grown in the agroforestry systems, such as soybean, groundnut, linseed and mustard, and weeds contained a large amount of nutrients in their above- and below-ground parts. Due to better crop growth and higher grain yield, a greater stock of nutrients was recorded under albizia system, whereas the lowest stock was recorded under cherry system. In weed species, the shoot portion had more K than N. In the 'tree only' situation perennial weeds stored more nutrients in their aerial parts.

Among the four systems, the uptake of N, K and P was highest in the alder-system and lowest in the cherry system. However, Ca content was highest in the albizia- and Mg in the mandarin-system. The pattern of uptake of nutrients was as follows: N > Ca > K > Mg > P. The trees absorbed between 47-65% N, 43-54% Ca, 41-48% K, 34-48% Mg and 26-40% P in the 'tree+crop' situation. The corresponding value in 'tree only' situation was 44-60, 35-50, 37-47, 42-57 and 22-34% N, Ca, K, Mg and P in that order respectively.

Significant amounts of nutrients from the soil pool were taken up by the agricultural crops (soybean, groundnut, linseed and mustard) in the 'tree+crop' situation. The rate of uptake by the crops was highest in the albizia system followed by mandarin system, while the lowest uptake by crops was recorded in the cherry system. In the'tree+crop' situation the nutrient uptake by weeds was also significantly high.

Tree litter, crop residue, weed debris, decomposing roots, externally supplied manure (FYM) and fertilizers applied for crops were the important sources of nutrient input to the soil. Annually, a considerable quantity of nutrients was added to the soil. The amount (kg ha^{-1}) ranged 111-182 for N, 16-20 for P, 77-96 for K, 82-161 for Ca, and 42-70 for Mg in the 'tree+crop' situation. The corresponding amounts in the 'tree only' situation ranged 113-185, 18-23, 80-137, 80-160, and 30- 61 kg $ha^{-1}yr^{-1}$ respectively, for the nutrients in that order. The alder system recycled maximum amount of N, P, K and Ca into the soil, the lowest amount was recycled in the mandarin system. However, the amount of recycled Mg, was more in the cherry- and mandarin-systems than in alder- or albizia-systems. A high amount of nutrients was exported through pruning of branches and leaves from trees in the alder-, albizia-, and cherry-systems, and through the harvest of straw/stalk and grains of agricultural crops in the case of 'tree+crop' situation. Maximum loss of N (54-72%) was through harvesting of grains and removal of straw/stalk of crops. But in the 'tree only' situation the loss of nutrients occurred only through pruning of branches and leaves. The loss of nutrients was maximum from the alder-, followed by albizia-system and the lowest was from the cherry system. The largest stocks for all the elements except K were contained in the soil pool. Even the alder system which contained the largest biomass, stored 91% of system's N, 97% of P, 93% of Ca and 92% of Mg in the soil.

It is concluded that alder and albizia tree species make excellent associates in agroforestry systems, promoting higher availability and faster cycling of nutrients. Besides, the requirement of external inputs into these systems is much lesser compared to the cherry- and mandarin-systems.

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