ECOLOGICAL INTERACTIONS BETWEEN TREE AND CROP COMPONENTS IN SELECTED AGROFORESTRY SYSTEMS OF MEGHALAYA

By

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**THESIS SUBMITTED IN
FULFILLMENT OF THE DEGREE OF
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CERTIFICATE

I, Jag Mohan Singh Tomar, hereby, declare that the subject matter of this thesis entitled, "Ecological interactions between tree and crop components in different agroforestry systems of Meghalaya" is the record of work done by me, that the contents of 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.

This is being submitted to the North-Eastern Hill University for the degree of Doctor of Philosophy in Botany.

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Chapter 1

INTRODUCTION

Agroforestry is an ideal scientific approach to tackle the problem of degraded lands and to bring about eco-restoration and maintenance of soil resources. The significance of tree-based land-use systems in general, and agroforestry in particular, has been emphasized by several workers such as Sanchez (1995), Puri and Nair 2004, Fisher (1990) and Dhyani and Tripathi (1999) in the restoration of soil fertility and in improving the economy of farmers having small land holdings. The fertility of soils can be improved under the influence of tree cover, which protects soil erosion, contributes to accumulation of soil organic matter content, addition of nitrogen through symbiotic N-fixation by leguminous or actinorrhizal trees and continuously replenishes the nutrients through effective recycling mechanisms. It offers a practical means of achieving greater output from the farmland and at the same time maintains soil fertility that ultimately helps in increasing productivity of agricultural crops and trees.

Agroforestry is a set of land use practices which aims to realize the benefits from growing woody and herbaceous species together, commonly by the integration of trees in the and already being used for growing crops or for pasture (Anderson and Sinclair 1993). The agroforestry systems may be of various kinds depending on the need and site specificity such as agri-silvicultural systems (improved *jhum* fallow, hedgerow intercropping or alley cropping, multi-species tree gardens, multipurpose trees/shrubs on farmlands, shade trees for commercial plantation, soil conservation hedges etc.), agri-silvi-pastoral systems (trees-livestock-crop, home garden, woody hedgerows for browse,

green manure, integrated farming systems etc.), silvi-pastoral systems (multipurpose trees on and around farmlands, live fence of fodder hedges and shrubs, trees and shrubs on pastures, integrated production of animals and wood products etc.), aquaculture with fruit trees and multipurpose tree etc. (Nair 1985). Although, agroforestry systems are man modified or natural systems, they do represent a move away from the markedly artificial systems of monoculture production towards mimicking aspects of natural ecosystem, with an emphasis on species diversities and resource conservation (Anderson 1987, Wood 1988). The aim of agroforestry practices is to enhance productivity and conserve resources. The capacity of trees to grow under different climatic conditions along with agricultural crops has potential to improve the soil quality and increase the productivity of land besides augmentation of biomass for fuel and/ or fodder including timber.

From the agroecological point of view, the objectives of agroforestry practices are to provide a balanced environment, sustainable yield, biologically-mediated soil fertility and natural pest regulation through diversified agroecosystems by use of low-input technologies (Gleissman 1998). By designing farming systems that make full use of sunlight, soil nutrients and rainfall, optimal productive potential of land can be achieved (Pretty 1994). It is therefore necessary to initiate synergisms, which subsidize agroecosystem processes by providing ecological services such as the activation of soil biological process, recycling of nutrients, enhancement of beneficial arthropods and antagonists. Resilience of any component to respond to sub-optimal level of resources at any growth stage in a tree-crop system either stabilizes or destabilizes the tree-crop association, which ultimately influences the yield of an agroforestry system (Singh et al. 1994).

Tree-crop interaction

Ecological interactions between trees and crops are beneficial for three main reasons (i) leguminous trees affect soil fertility through nitrogen fixation, greater organic matter production, and recycling of nutrients (Young 1986 a,b), (ii) combination of annual crops and trees increases biomass production because of differences in rooting behaviour (Huxley 1983), and (iii) tree acts as a protective barrier against soil erosion or as a windbreak (Wiersum 1984). The ecological interactions are helpful in determining the benefits which are likely to be realized from a given agroforestry system in a given situation. It also offers the scientific basis for designing more productive and sustainable land-use systems (Rao et al. 1991, Anderson and Sinclair 1993).

Biochemical interaction between the tree and crops may affect germination and yield of crops. Litter releases water-soluble chemical substances in soil that can have significant effect on crop production under integrated land-use systems. It has generally been observed that crops compete strongly for light under tree canopy that detrimentally influence the productivity of annual crops (Srinivasan et al. 1990). Production of allelochemicals from trees interferes with the growth and yield of associated crops (Rice 1974).

The nature of tree-crop interactions in an agroforestry system depends on the growth pattern and phenology of tree component. Trees with marked seasonality in growth and phenology may reduce competition for resources with crops, and thereby may enhance the crop yield. An increased rate of resource consumption by trees may cause decline in soil fertility unless the resources like nutrients and water are replenished at a fast rate. High production of agroforestry systems, therefore, can only be sustained if demand and supply of the resources are balanced.

Natural ecosystems generally have a synchrony between nutrients release and plant uptake, but the managed systems like agroforestry systems suffer from disruption of such a synchrony because of artificial combination of species having different growth pattern and phenology (Brown et al. 1994, Sanchez et al. 1989). In agroforestry systems, the altered microclimatic condition on the ground because of the overhead tree canopy, influences litter decomposition and nutrient dynamics in soil. Decomposition is impeded when soil is too warm or too wet, especially on sites where soil micro-fauna are directly responsible for decay of plant litter, as their population is adversely affected by such conditions. Micro-fauna plays a major role in converting coarse litter into finer particles, which are then attacked more effectively by microbes. Rate of litter decomposition as an important pathway for the transfer of minerals to the soil in natural ecosystem is a well established fact, but the quantification of the role of tree litter input to agroforestry systems is far from complete (Chaturvedi and Singh 1987, Beer 1988, Sharma et al. 1997).

The age-old method of crop cultivation in northeastern hill region, commonly known as slash and bun agriculture (locally called "*Jhum*") is widely practiced in the entire region. This primitive system of cultivation is similar to agroforestry systems, where varied mixtures of trees, shrubs, climbers and crops are grown together. In fact, most farmers grow agricultural crops along with the trees and rear animals to produce food, fiber, fuel and other products to meet their various needs. Due to a variety of reasons including location-specific problems and resource constraints the intervening fallow period between the two cropping spells has been shortened to an alarming level (Tripathi and Barik 2003).

Agroforestry systems have been reported to be more suitable than the traditional cropping practices in the rainfed foothill areas (Prasad 1987, Toky et al. 1989a). The cultivation of large cardamom in forest areas is a classic example of agroforestry in the northeast India (Borthakur 1992). Pineapple, areca nut, mandarin orange, betel vine, black pepper, jack fruit etc., are commonly grown in agroforestry practices in different agro-climatic zone of the northeastern hill region. Areca nut + betel vine/black pepper- and *Schima wallichii*-and *Pinus kesiya*-based systems are also practiced on the degraded steep slopes (Chauhan and Dhyani 1989a).

The land in the northeastern region has been degraded mainly due to over exploitation of forest resources for "*Jhum*" cultivation on hill slopes, improper land-use practices, inadequate infrastructure development, land tenure systems of different ethnic tribes, and mining activities (Patiram 2003). Farming activities on hill slopes is the major area of concern. Under these conditions agroforestry systems may be helpful in conserving soil and water resources (Prasad 1987, Bhatt et al. 2001).

Agroforestry lays high emphasis on technologies that stress on the role of trees in fertility improvement and conservation of soil. The choice of tree species is an important management decision in any tree-crop system. Proper combination of species with different growth forms, rooting patterns, phenology, growth requirements and chemical composition of leaf residues may lead to higher biomass production by enhancing complementary use of resources, reducing pest problems, and promoting greater synchrony between plant growth and nutrient release from decaying litter. This requires an in-depth analysis of the above aspects in order to develop a system in which spatial and functional niches of tree and crop components are displaced in such a manner that competitive interaction between the two are minimized and environmental resources

utilized to the fullest level for better yield. In crop-only systems resources remain under-utilized or unutilized because of many reasons such as inaccessibility of water and nutrients to crop roots due to their rooting pattern and excessive leaching and runoff losses.

A long-term research project on farming systems was initiated by the ICAR Research Complex for NEH Region, Barapani in 1983 to study various aspects of the farming systems. Dhyani (1997) and Dhyani and Tripathi (1999) studied soil, nutrient dynamics and productivity in different systems, but there was not much emphasis on ecological interactions between trees and crops in these studies. The effects of the tree on the crop in agroforestry systems or *vice-versa* is mediated either through alteration in physico-chemical properties of soil or change in microclimate near the crop canopy or both.

In present study, an ecological analysis of one traditional agroforestry system and two improved agroforestry systems has been undertaken. The traditional system was exemplified by *Pinus kesiya* + rice, maize and ginger, while the improved systems were represented by *Alnus nepalensis* + rice, maize and ginger, and *Citrus reticulata* + rice, maize and ginger. The ecological analysis of the above three systems were done taking into account the following major aspects:

- Microenvironment and Soil properties
- Phenology, growth and architecture of tree components
- Growth and yield of associated crops and
- Tree litter production, decomposition and NPK budget of the systems.

Chapter 2

REVIEW OF LITERATURE

The importance of tree-based land-use systems in general and agroforestry in particular, has been realized in improving the economy of farmers particularly those having small land holdings (Beer et al. 1988, Fisher 1990, Dhyani and Tripathi 1999). The fertility of soils can be improved under the influence of tree cover, which checks erosion, contributes to organic matter accumulation, adds nitrogen through symbiotic N-fixation if the tree happens to be leguminous or actinorrhizal, and continuously replenishes the nutrients through effective recycling mechanisms. It offers a practical means of achieving greater outputs and at the same time maintains soil fertility that ultimately helps in increasing productivity of agricultural crops and trees.

Agroforestry is a land-use system in which woody perennials are integrated with crops/ animals on the same land-management unit (Leakey 1996). Different authors have defined agroforestry differently (Nair 1989). However, the one proposed by Lundgren and Raintree (1983) is widely accepted. According to this definition, agroforestry is "a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboo, etc.) are deliberately used on the same land-management units as agriculture crops and/ or animals, in some form of special arrangement or temporal sequence". In other words, it is the system of resource management that simultaneously produces multiple items such as food, fodder, fuelwood, timber etc. on a sustainable basis.

Agroforestry is an interdisciplinary approach to landuse requiring the combination of social, ecological and economic factors (Sinclair 1992). When trees are grown in the cultivated land, several kinds of interactions take place between trees and crops. 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. Although a vast amount of knowledge has accumulated on monoculture stands both in agriculture and forestry (Huxley 1983), the studies on interactions under agroforestry systems are lacking. But a great deal of information is available on how the basic biophysical factors viz. light, water, nitrogen and certain other nutrients particularly phosphorus and potash contribute to crop yield under intercropping (ICRISAT 1986, Willey et al. 1986).

Understanding the way, by which system components respond to optimal or sub-optimal level of resources, forms the basis for selection of compatible and suitable components of agroforestry systems. Therefore, the choice of tree species is an important management decision in any tree-crop system. Mixing the species with different growth forms and growth pattern may lead to higher biomass production by enhancing complementary use of environmental resources, reducing pest infestation and by promoting greater temporal synchrony between the nutrient release from decaying tree litter and their uptake by crops.

Tree species differ widely in their growth form and growth behaviour. Tomilson and Gill (1973) and Halle et al. (1978) have studied the architecture and growth behaviour of tree species and the latter have described 23 architectural models of tree forms according to the branching activity that occurs during growth. The orientation of branches and leaves usually shape the geometry of crown, and this has been related to its

adaptive strategies for light interception (Bruning 1976). A greater branch angle down the tree increases the gap between the two first order branch complexes and causes opening in the canopy for more light interception. In large tropical trees, branching is confined mainly to uppermost part of the trunk, although lower branches often develop in open sites. Kramer and Kozlowski (1979) have reported that the time of growth initiation in temperate species is relatively constant.

Studies on light interception (Horn 1971), spacing (Nelson et al. 1981), extension growth related to successional status (Marks 1975, Boojh and Ramakrishnan 1982), branching pattern (Barker et al. 1973, Fisher and Honda 1979 a,b), and architecture (Shukla and Ramakrishnan 1986) of tree species have helped in understanding the development of forest communities. In early successional tree species, production and contribution of first order branches to the total framework of branch systems are much higher than in late successional species. On the other hand, late successional species show shorter growth period and densely packed canopies with shading leaves, which accounts for their slower growth rate (Toky and Khosla 1984). The architecture pattern of multipurpose tree species cultivated in agroforestry systems have been studied by Ramakrishnan et al. (1982) and Bisht and Toky (1992).

Mwihomeke (1989) compared the growth performance of 13 exotic and 10 indigenous agroforestry tree species in Tanzania and divided them into 4 groups based on the height growth. He concluded that the exotic tree species grew faster compared to most of the indigenous species. The amount of wood produced by them was directly proportional to the growth rate of stem diameter and height, as well as their survival rate. Nath et al. (1990) studied the growth attributes of 12 tree species up to 5 and a half years of age and found that *Eucalyptus* attained the maximum height of 15.8 m while

Pongamia pinnata could reach only up to 4.9 m, *Acacia auriculiformis* attained the maximum girth (68.4 cm) and *Cassia equisetifolia* had the minimum girth (26.6 cm).

Bhola (1995) studied the growth performance of seven nitrogen fixing trees up to 6 years age and reported that growth of *Leucaena leucocephala* in terms of height, diameter at breast height and crown area was best among the studied species. Nadagouda et al. (1997) compared the growth of seven tree species of 5 years age under high-density plantation and observed that *Eucalyptus* performed better than other species in respect of height and diameter growth. *Leucaena leucocephala* and *Azadirachta indica* were very close to *Eucalyptus*. The multipurpose trees such as *Alnus nepalensis, Parkia javanica, Paraserianthes falcataria, Michelia oblonga, Prunus cerasoides, Gmelina arborea* and *Acacia auriculiformis* show good growth in humid tropical climate of northeastern hills (Dhyani et al. 1994, Dhyani and Tripathi 2000). Increment in height and diameter is a good indicator of site condition (Foroughbakhch et al. 1987). Beneficial effects of crops on the tree growth in plantations under different edapho-climatic conditions have been reported by several workers (Singh et al. 1989, Atta-Krah 1990, Kass et al. 1992, Campbell et al. 1994).

Although much data is available on the biomass and productivity of natural and agricultural ecosystems of different agro-ecological zones of the country (Gupta and Singh 1982, Boral 1993, Puri and Nair 2004), limited data is available for agroforestry systems, particularly those from the northeastern India (Dhayani and Tripathi 2000, King 1968). Therefore, estimation of biomass and productivity of agroforestry systems is an essential pre-requisite for gaining a better insight into their functioning (Bhatt et al. 2001).

Several workers have reported that crop yield decreases as the age of trees cultivated in or around agricultural field increases (Bhatt et al. 2005, Dhyani et al. 1994, King 1968). Reduction in crop yield also depends on the nature of trees species (Dhillon et al. 1982, Dhyani 1997) and distance between crop field and trees (Karim et al. 1991, Dhillon and Thind 1996, Schroth and Lehmann 1995). Based on a study on rice in northeast Thailand with four tree species viz., *Parenarum anamense*, *Dipterocarpus obtusifolius*, *D. intricatus* and *Samanca saman*, Lee et al. (1992) concluded that plant height, tiller number, grain yield and aerial vegetative biomass production of the crop increased with increase in distance from the tree base. No reduction in dry matter production and grain yield was recorded under the 70 percent sunlight in soybean (Eriksen and Whitney 1984). Decrease in yield of crops under woody perennials compared to the monoculture, has been shown by several workers (Singh and Dayal 1974, Mittal and Singh 1983, Dhyani and Tripathi 1999). However, better yield of crops has been reported when they were grown with *P. falcataria, Senna spectabilis, Flemingia macrophylla, Dactyladenia barteri,* and *Erythrina poeppigiana* (Vinaya Rai and Suresh 1988, Basri et al. 1990, Kass et al. 1992). Studies on the effects of the crops on the tree are very few (Samraj et al. 1982, Redhead et al. 1983).

It was opined by Willey (1985) and Vandermeer (1989) that mixtures of species may have greater capacity to exploit resources and hence become more productive than monocultures. This hypothesis has been applied in agroforestry systems to understand the ecological basis of sustainability (Ong and Black 1994). Studies have suggested that in dry condition, *Leucaenea* strongly competes with millet, sorghum, groundnut and maize for water (Jama et al. 1995). Therefore, it was recommended that under such condition

tree and crops with different rooting pattern might be helpful in reducing competition stress (van Noordwijk and Purnomosidhi 1995).

In dry areas though farmers have been practicing agroforestry by keeping a few scattered mature trees in crop field (Shankarnaryan et al. 1987), recent attempts to promote agroforestry in such environments have been disappointing (Nair 1993, Rao et al. 1998, Ong and Leakey 1999). Despite substantial evidence of improved microclimatic conditions, soil nutrients and increased vegetative production beneath large isolated trees in most savanna ecosystems (Rhoades 1997), competition for water and nutrients is inevitable as tree and crop root systems are likely to have similar distribution in the soil profile (Singh et al. 1989, Schroth and Lehman 1995).

Researches on tree-crop interactions in agroforestry systems have focused on the importance of aboveground and belowground competition in declining yield (Snaydon and Harris 1981, Corlett et al. 1992a, b). Srinivasan et al. (1990) have reported that the crop yield is depressed by competition with trees for light. Alley cropping experiments at ICRISAT, India, and ICRAF, Kenya, in which annual crops were grown between woody hedges of *Leucaenea leucocephala*, produced contrary results. However, a marked decrease in crop yield was observed when alley width was reduced to less than 5m (Singh et al. 1989, Rao et al. 1990). The result suggested that reduction in crop yield was mainly due to root competition between trees and crops for water, and nutrients or both (Ong et al. 1991b). Lack of herbaceous growth under the tree species in agroforestry systems is very often attributed to competition for light, water and nutrients. Trees release various secondary metabolites into the soil, which may suppress germination, growth and yield of the under-storey crops (Kaletha et al. 1996). However, the magnitudes of toxicity have been reported to be species specific (Rice 1974).

The integration of trees into farmland has been suggested to check soil nutrient depletion in cropping systems since they help reduce leaching losses of nutrients from the system (Binkley et al. 1990, Schroth and Lehmann 1995). The trees are able to absorb nutrients from deeper layer of soil and then return them to the topsoil through litter making them available to the associated crops (Yamoah et al. 1986). The rate of litter decomposition and nutrient release depends on the chemical composition of litter, climatic condition and on the activity of soil micro-flora and fauna.

Various studies have been conducted on litter production of tree species in agroforestry systems (Hosur et al. 1977, Chaturvedi and Singh 1987, Singh et al. 1989, Das and Chaturvedi 2005) besides litter decomposition. Yamoah et al. (1986) observed variable rate of leaf litter decay depending on the species, litter quality and season (Ovington 1961). In general, decomposition in most species was rapid during the rainy season perhaps due to pronounced microbial activity under favourable temperature and moisture conditions and greater leaching by rainwater (Vossbrink et al. 1979, Pandey and Singh 1982). The higher weight loss during initial periods of decomposition occurs due to leaching of soluble materials.

Based on a study in the agroforestry systems in the mid hills of Himachal Pradesh, Toky et al. (1989b) reported that in agri-horti-silviculture and agri-horticulture systems, considerable amount of N, P, K, Ca and Mg was recycled through crop debris and tree leaf litter; compared to these systems, the recycling rate was almost half in the agri-silviculture system. Hosur et al. (1977) reported that nutrient returned through litter of 13-16 year old tree species followed the order of Ca > K > N in sissoo and catechu; Ca > N > K in Teak and casuarinas and K > Ca > N in bamboo and Eucalyptus. P and Mg input to soil through litter was low in all the cases.

The fine roots are important not only for water and nutrient absorption (Lyr and Hoffman 1967), but also for conservation of nutrients in the ecosystem (Khiewtam and Ramakrishnan 1993, Anuranachalam et al. 1996). Fine roots constitute a dynamic component in most forest ecosystems and play an important role in carbon cycling (Caldwell 1979, Agren et al. 1980, Ericsson and Persson 1980). Upon dying, they contribute significantly to the soil organic matter pool (Coleman 1976, Persson 1979). The importance of fine roots in soil organic matter dynamics and cycling of nutrients in the temperate deciduous forest ecosystem is well documented (McCalugherty et al. 1982, Fogel 1983, Hendrick and Pregitzer 1996). In the tropical forest ecosystems, Went and Stark (1968), and Redhead (1968, 1980) reported that the mycorrhizal hyphae and the fine root mats are responsible for the efficient and direct recycling of nutrients. Fine roots and the associated mycorrhizae contribute to the rapid and efficient cycling of nutrient elements on those sites where possibility of leaching of nutrients is high and their availability is low (Stark and Jordan 1978, Cuevas and Medina 1988). Therefore, the density of fine roots in a given environment relates to their absorption capacity and indicates their potential for conserving nutrients (Jordan 1983).

Dhyani and Tripathi (1999) reported that the proportion of below ground biomass in the upper soil layer in the 'tree only' situation was higher than in the 'tree + crop' situation. John et al. (2002) studied the fine and course roots biomass in different pine stands in northeastern region of India and found a high concentration of fine roots in the upper soil layer. Anderson (1987) and Cheng et al. (1990) reported greater concentration of belowground biomass in upper soil layer of the non-tillage system.

Studies have also been conducted to evaluate the effects of N and P fertilization (Lindell and Persson 1995), irrigation (Katterer et al. 1995) and soil acidification and

aluminium toxicity (Majdi and Persson 1993) on fine root biomass. Patiram (2003) reported that surface application of lime and N, P and K fertilizer had a beneficial effect on the root density. Based on the studies in different forest ecosystems, Lyr and Hoffman (1967) concluded that root biomass increases in the nutrient-rich zones of the soil. On the contrary, Gower (1987) reported significantly greater fine root biomass on a site having low soil phosphorus and calcium contents. In temperate coniferous forest, Vogt et al. (1985) observed an inverse relationship between fine root biomass and soil nitrogen level. Vogt et al. (1986) established a strong negative correlation between actual estimates of root production and rate of nitrogen cycling in the temperate needle-leaved and broad-leaved forests, and concluded that increase in nitrogen availability in soil due to fertilizer application generally caused decrease in root biomass and production in cold temperate forests. Contrary to the above finding, Arunachalam et al. (1996) reported an increase in fine root biomass with the increase in soil fertility level during regrowth of disturbed humid subtropical forests in northeast India.

In a study examining the resource sharing ability of multipurpose trees in an intercropping system, crop yield was found to be reduced by competition with the trees for light (Srinivasan et al. 1990). Wahna and Miller (1978) noticed that the dry weight of soybean decreased curvilinearly with the increase in shade. Eriksen and Whitney (1984) reported that shading caused 34% average reduction in dry matter and grain yield of soybean, cowpea and bush bean. Soyabean showed no reduction in dry matter and grain yield at 70% sunlight, bush bean was least affected by shading and cowpea was least shade-tolerant. Akyeampong et al. (1995) found that beans were not affected by 27% reduction in light but 42% decrease in light led to 37% decrease in the dry grain yield compared to control. Singh et al. (1989) reported that Leucaenea hedgerows in a 10 m

wide alley cropping caused 30 to 85% reduction in sunlight. Arora and Mohan (1986) reported that cowpea and sesame can be grown with peach trees until 6 years and beyond this, the yield declines to uneconomic levels due to shade cast by trees.

Tree-crop system has been known to influence the availability and utilization of available moisture both horizontally as well as vertically in the field. With the exception of areas with well distributed rainfall, or a zonal site with a continuous supply of ground water, competition for soil moisture is likely to occur in most agroforestry systems at some period of time.

Khybri et al. (1992) recorded minimum soil moisture under *Eucalyptus* followed in ascending order by *Grewia*, *Morus* and control plot, when grown with wheat and paddy. However, after *Eucalyptus* was harvested, the lowest soil moisture was recorded under *Grewia* and highest in control plot. The reduction in the crop yield due to competition for moisture between the trees and crops have been reported by Singh et al. (1989) and Corlett et al. (1989). Substantial reduction in crop yield even when the fields were fertilized at recommended rates, confirms that inadequate water was the limiting factor determining crop yields in hedgerows inter-cropping in semi-arid climates (Jama et al. 1995). The other factors that influence the competition was spacing between the trees and tree-crop combination (Srivastava and Rao 1993).

Dense forest cover that checks soil erosion, maintains organic matter and available nutrient level in the soil and ameliorates microclimate, is fast declining in north east India due to prevalence of shifting cultivation and other human activities (Prasad 1987, Singh and Prasad 1987). Hill slopes are facing serious problem of sediment loss and decline in soil fertility due to shifting cultivation in the absence of appropriate soil conservation measures and inadequate nutrient inputs (Singh et al. 1994). In such a

situation, agroforestry has a great potential for restoring soil fertility of degraded land and increasing agricultural production (Bhatt et al. 2005).

In Meghalaya, about 67% area of cultivable land is on hill slopes. About 85% of populations in the state of Meghalaya are dependent on agriculture. The most prevalent land-use systems in Meghalaya include pure horticulture crops, horticulture and forestry based intercropping and mixed farming (Singh et al. 1995). The traditional systems of agriculture in the state are primitive, labour-intensive and dependent on rainfall. The major problems that are adversely affecting agricultural production of the state include undulating topography, erratic rainfall, heavy soil erosion and continued land degradation. Under such circumstances, agroforestry systems can play an important role in soil conservation and improvement in moisture and nutrient levels through efficient cycling of nutrients, which in turn would enhance agricultural production and provide food, fodder, fuel and timber security to the people of the state (Chauhan and Dhyani 1989a, Singh et al. 1984, Bhatt et al. 2001). Thus agroforestry is an ideal scientific approach to tackle the problem of degraded lands and to bring about sustainable management of soil resources.

Chapter 3

STUDY SITE CHARACTERISTICS

Location

The study site is located at the ICAR Farm, Barapani (25^0 39' - 25^0 41' N latitude and 91^0 54' - 91^0 63' E longitude) in the Ri-bhoi district of Meghalaya, north- east India. The altitude of the farm area varies between 952 and 1082 m asl. Prior to the development of the farm, the area was under *jhum* cultivation, as a result of which the land was degraded due to soil erosion. In order to check soil erosion, increase water conservation in soil and safe disposal of excess water, contour bunds were prepared way back in 1987 for gradual conversion of slopes into bench terrace.

Geology

Geologically, Meghalaya represents the remnant of the ancient plateau of Pre-Cambrian Indian peninsula and forms a prominent geomorphic unit stretching across the Garo, Khasi and Jaintia hills in east-west direction. The central and northern parts of Meghalaya plateau are made essentially of highly metamorphosed crystalline rocks of Pre-Cambrian origin, which are often referred to as "Archaean Gnessic Complex". These are made up of gneisses (biotic gneiss, biotite granulite, quartz-sillimanite gneiss, cordierite, garnet and chondrodite) and Schistose (mica schist, quartz-sillimanite schist and metabasite) members of varying composition. The southern parts of the plateau have experienced tremendous tectonic impacts giving rise to the steep scarp, which today stands a loft facing the Sylhet plain of Bangladesh (Verma at al. 2001).

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 grayish phyllites, sandstones etc.

Physiography

Based on the physiography, the state may be divided into (i) western region, (ii) central and eastern region, (iii) northern undulating hills, and (iv) southern precipitous zone. The western region includes Garo hills and western parts of west Khasi hills and the central and eastern region includes Khasi hills, Ri- bhoi and Jaintia hills. The northern region has undulating hills towards the north with their altitude ranging between 300 m and 1600 m asl, while the southern part is a high precipitous zone. The central upland zone has the highest elevation of the plateau.

Climate

The climate of Meghalaya is monsoonic and is directly influenced by the southeast monsoon originating from the Bay of Bengal and the Arabian Sea. Average annual rainfall is 2138 mm. More than 90% of annual rainfall is received during April to October. Distribution of rainfall during different seasons are: winter (January-February)-3.66%, pre-monsoon (March –May)-19.21%, monsoon (June to September)-64.75 % and post monsoon (October -December) period-12.38 % of the total annual rainfall. Mean maximum temperature at the study site varied from 16.7^{0}C in January to 28.5^{0}C in April 2002 (Fig. 3.1). The temperature gradually increases from February to July and thereafter it starts declining. The mean minimum temperature (16.7^{0}C) is recorded during January. Relative humidity during rainy season exceeds 90% and remains more than 60% even during the driest period of the year.

In spite of high rainfall *rabi* crops are difficult to grow on dry terraces due to poor water retention capacity of soil, prolonged low temperature during winter with occasional

ground frost, and pre-monsoon showers with occasional hail-storm at the time of crop harvest in the month of March and April.

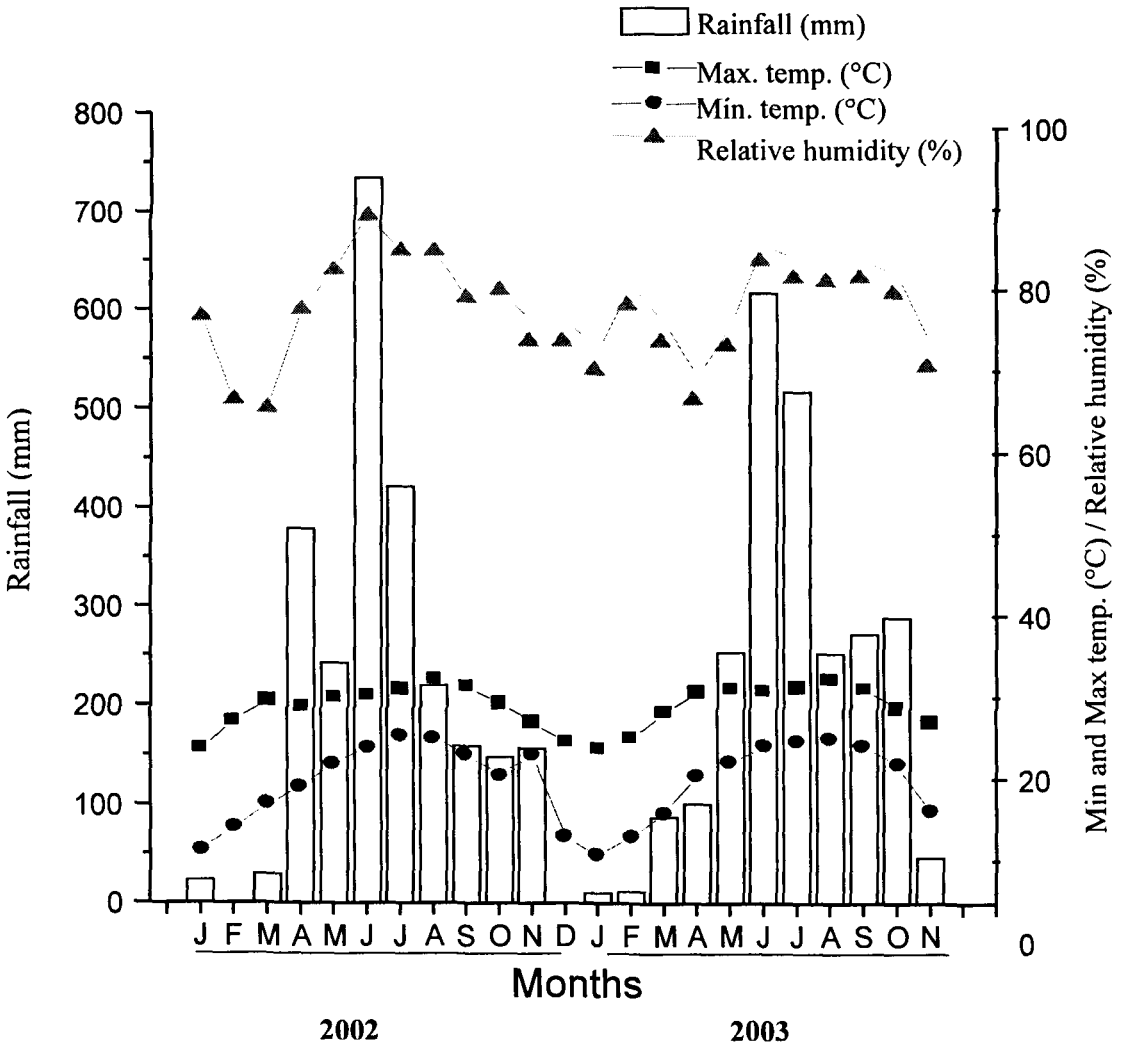


Fig. 3.1. Ombrothermic diagram of the study area for 2002-2003.

Tree Species for Agroforestry systems

Khasi mandarin (*Citrus reticulata* Blanco)

The northeastern India seems to be original home of mandarin orange. It has been in cultivation in the region for a long time. The variety grown in the region is commonly known as Khasi mandarin. It grows between 500m and 1500m above msl where annual rainfall ranges between 1000 and 3000mm, and summer and winter are mild. The mandarin is a major source of cash income to supplement subsistence farming at higher altitudes in the region. In Meghalaya, mandarin is cultivated in homestead garden various other landuse practices in combination with annual crops or with fodder or multipurpose trees. It has been observed that mandarin production in the region declined after its satisfactory performance for a few years. The decline in productivity of mandarin has been attributed to faulty management, including plantation on unsuitable land, cultivation of exhaustive intercrops, inadequate nutrient inputs, incidence of insect- pest and diseases etc. (Ghosh et al. 1980).

Alder (*Alnus nepalensis* D.Don)

Alder is found throughout the Himalayan region below 1800 m asl. It is distributed widely in the hills of Darjeeling, eastern Nepal, Sikkim, Bhutan, Arunachal Pradesh, Nagaland and the Khasi hills of Meghalaya. It grows in moist, shady ravines near water in gregarious strips and on exposed soils forming pure patches. Production of large amount of easily dispersed seeds, fast juvenile growth and nitrogen fixation ability in roots has made it a successful pioneer species for restoration of degraded lands throughout the Himalaya. The roots of *A. nepalensis* are nodulated with an efficient N_2 fixing *Frankia* as an endophyte. It is used as a chief associate/ shade/ nurse tree in Cinchona and large cardamom-based agroforestry systems in the region. This species has

also been widely used in the social forestry programme in the eastern Himalayan region, since it is a fast growing species and serves as a good source of fuelwood. Besides, it increases soil fertility by symbiotic N_2 fixation, nutrient recycling and protects the soil against erosion on steep slopes.

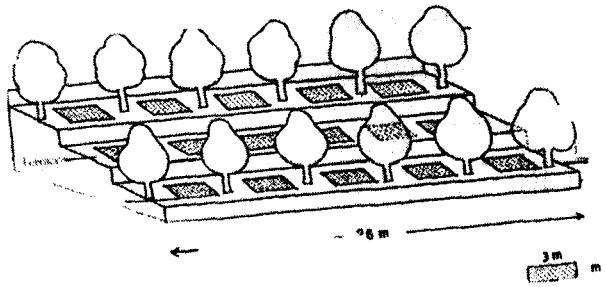
Khasi pine (*Pinus kesiya* Royle Ex. Gordon)

Khasi pine grows almost as pure stand in northeastern region between 800 and 2000 m asl on disturbed and exposed soils. According to Puri et al. (1989), Khasi pine was introduced in the hills of northeast India in pre-historic time. In this region, cash crops such as ginger, potato, vegetables etc., are grown in the Pine forests after thinning and cleaning the land. *Pinus kesiya* requires a seasonally dry climate and a well-drained soil for its successful establishment and development. It is fairly resistant to fire once over 3m tall (Kowal 1966). The seedlings can develop on mineral soil in open places and therefore, it becomes an efficient colonizer of abandoned fields. *P. kesiya* covers large area of Khasi hills, Jaintia hills, Naga hills, Lushai hills and Manipur. It also occurs in the Shan states of Upper Burma between 800-1900m and in Luzon in the Philippines between 450 and 2450m elevation. It is found in continental south-east Asia and its distribution extends into the Malay archipelago.

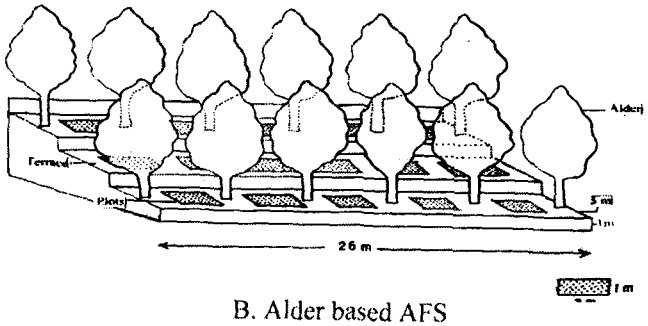
Experimental layout

The experimental plots were located on a hill slope (25-38%) where soil depth varied from almost 23cm at upper reaches to 45 cm at the foothills. The experimental plots were made on the terraces (1.5m wide, 10m long and 1 m in height). Three plots of 1m x 3m were developed for each of the three crops under a agroforestry systems. Besides, there were three control plots (plots with crops and without trees) for each crop. The

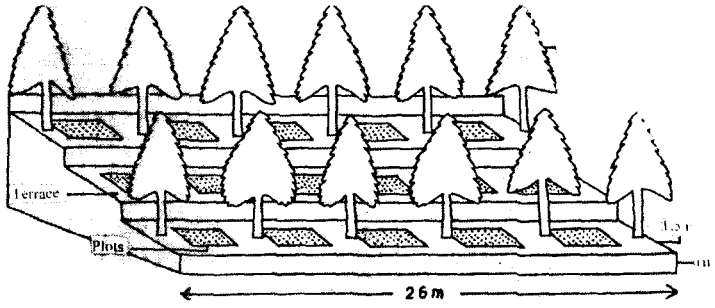
experimental plots were located between trees in a given terrace as well as between the terraces in each agroforestry system and control plots (Fig. 3.2a, b, c and d).



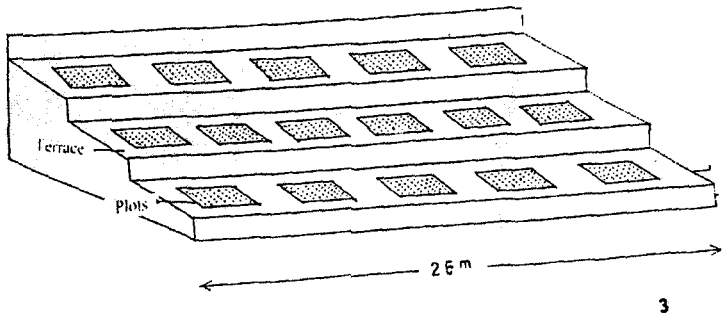
A. Khasi mandarin based AFS



B. Alder based AFS



C. Khasi pine based AFS



D. Control

Fig. 3.2 a-d. The layout of the experimental plots

The details of three agroforestry systems studied are listed below:

(i) Alder-based agroforestry system (Plate 1a-c)

(a) Alder-maize

(b) Alder-rice

(c) Alder-ginger

(ii) Khasi mandarin -based agroforestry system (Plate 2a-c)

(a) Khasi mandarin-maize

(b) Khasi mandarin-rice

(c) Khasi mandarin-ginger

(iii) Pine-based agroforestry system (KP-AFS) (Plate 3a-c)

(a) Pine-maize

(b) Pine-rice

(c) Pine-ginger

(iv) Control (without trees) (Plate 4a-c)

(a) Maize

(b) Rice

(c) Ginger

Plate 1a

Plate 1b

Plate 1c

View of maize (1a), rice (1b) and ginger (1c) under Khasi mandrin-based AFS

Plate 2a

Plate 2b

Plate 2c

View of maize (2a), rice (2b) and ginger (2c) under Alder-based AFS

Plate 3a

Plate 3b

Plate 3c

View of maize (3a), rice (3b) and ginger (3c) under Khasi pine-based AFS

Plate 4a

Plate 4b

Plate 4c

View of maize (4a), rice (4b) and ginger (4c) under control plot.

N, P and K fertilizer was applied as per the recommended dose for various crops in the bench terraces in all the plots. In Khasi mandarin-alder- Khasi pine-based systems, stylo and guinea grass were grown on the bunds of the bench terraces to check the erosion on the one hand and to provide fodder to the livestock on the other.

In all the systems trees were planted in alternate terraces with a spacing of 5m x 5m from plant to plant and row to row in 1990. Therefore, all three systems had a density of 400 trees ha^{-1}. The mean tree bole diameter at breast height (dbh) and mean tree height in the three systems are given in Table 3.1.

Table 3.1. Mean tree height (m) and dbh (cm) in different AFS.

Sl. No.	AFS	Age (yr)	Height	DBH
1	Khasi mandarin-based	14	6.40 ± 0.20	20.98 ± 1.03
2	Alder-based	14	14.48 ± 0.53	25.15 ± 1.48
3	Pine-based	14	15.82 ± 0.46	24.66 ± 1.28

(± SEM, n=5)

Agricultural operations

The experimental plots were prepared by hand hoeing the soil down to 15-30 cm depth and hand weeding was done before crop sowing. Maize, upland rice and ginger were grown during 2002 and 2003 cropping periods. Each crop was grown without and with FYM and recommended dose of fertilizer both in AFS and control plots.

Weed flora of the experimental plots

There was a profused growth of weeds in all the plots during rainy season. The dominant weeds in different AFS and control plots have been identified and presented in

Table 3.2. In all the plots, *Ageratum conyzoides*, *Borreria hispida*, *Bidens pilosa*, *Galinsoga parviflora*, *Commelina bengalensis* and *Drymaria cordata* were growing abundantly.

Table 3.2. Dominant weeds in different agroforestry systems and control plots.

Tree	**Crops**	**Weeds**
Citrus reticulata	Ginger, maize and rice	*Ageratum conyzoides, A. haustonianum, Bidens pilosa, Borreria hispida, Commelina bengalensis, Drymaria cordata, Eleusine indica, Euphorbia* sp., *Galinsoga parviflora, Imperata cylindrica, Oxalis latifolia, Polygonum* sp., *Setaria glauca, Solanum* sp., *Themeda* sp. and *Vernonia artimisifolia.*
Alnus nepalensis	Ginger, maize and rice	*Ageratum conyzoides, A. haustoninum, Arundinella benghalensis, Bidens pilosa, Borreria hispida, Commelina bengalensis, Drymaria cordata, Eleusine indica, Galinsoga parviflora, Imperata cylindrica, Mikania micrantha, Themeda* sp. and *Vernonia artimisifolia.*
Pinus kesiya	Ginger, maize and rice	*Ageratum conyzoides, Bidens pilosa, Borreria hispida, Commelina bengalensis, Crotolaria stricta, Curcuma* sp., *Cyperus rotundus, Drymaria cordata, Eleusine indica, Galinsoga parviflora, Mikania micrantha, Murdannia spirata, Oxalis latifolia, Panicum montanum* and *Paspallum* sp.

Control	Ginger, maize and rice	*Ageratum conyzoides, Bidens pilosa, Borreria hispida, Blumea barbellata, Commelina bengalensis, Desmodium microphyllum, Digitaria sanguinalis, Dioscorea* sp., *Drymaria cordata, Eleusine indica, Eupatorium odoratum, Galinsoga parviflora, Lantana camara, Murdannia spirata, Oxalis latifolia, Panicum montanum, Paspallum* sp., *Polygala* sp., *Polygonum* sp., *Setaria glauca* and *Trifolium repens.*

Chapter 4

MICRO-ENVIRONMENT, SOIL PROPERTIES AND WEED COMMUNITY

Investigating long-term effects of cultivation on soils under different agroforestry systems is important to predict their suitability for crop production. Several workers (Okigbo et al. 1980, Young 1986a, b, Vergora 1987, Lal 1991, Parrotta 1990, Watson 1990) have suggested that inclusion of compatible and desirable trees in crop field helps in improving soil fertility.

Trees influence microenvironment by altering quality and quantity of solar radiation, temperature regime, relative humidity and moisture, organic matter and nutrient contents in soil system. The interception of radiation and rainfall by tree canopy and input of organic matter and nutrients through litter decay are major functions of trees that change microclimate and improve soil productivity in agroforestry systems. Several studies have, however, demonstrated that crop yield is generally low under agroforestry systems compared to the monoculture though the magnitude of decline in yield varies widely depending upon the accompanying tree species. Such effect seems to be the consequence of tree - crop interactions (Ong and Black 1994, Rao et al. 1998).

Besides crops and trees, weeds are also an integral part of the system. They, on one hand, compete with the crop plants for environmental resources and cause loss to the crop yield, and on the other hand, enrich soil through addition of organic matter and nutrients after their death and decay. In the entire northeast India, weeds grow profusely almost everywhere during rainy season owing to abundant supply of moisture and

favourable temperature condition, which happens to be one of the important reasons for poor crop yield in wet tropics (De Rouw 1995). However, the yield could be increased significantly if they are managed effectively (Patel et al. 1988).

In this chapter data on certain micro-environmental variables such as soil moisture, soil temperature, and light intensity and physico-chemical properties of soil and characteristics of weed flora of the three agroforestry systems and control plots have been presented.

METHODOLOGY

Microenvironment

The following parameters were measured in different agroforestry systems and control plots to study the microenvironment:

(i) Light intensity: Light intensity was measured by a digital Lux meter (TES-1332A-Taiwan make) at crop height both in AFS and control plots. The intensity was measured just above the crop height at ten randomly selected points in each AFS and control plots. The data were recorded at 8.00 am and 2.00 pm at 15 days interval during the cropping period. The data obtained were averaged for each month.

(ii) Soil temperature: Soil temperature was measured at 0-15 and 15-30 cm depth with the help of a soil thermometer in AFS and control plots during the cropping period. The temperature was recorded at 8.00 am and 4.00 pm at 15 days interval at randomly selected ten points in AFS and control plots.

Soil analysis

Soil samples were collected from 0-15 and 15-30 cm depths at three randomly located points in all the three AFS and the control plot before the commencement and after termination of the experiments. The samples were brought to the laboratory and

mixed thoroughly depth wise to obtain a composite sample for each depth. A portion of these samples was sieved through 2mm mesh sieve and used for moisture content and pH determination. Another portion was air-dried and used for the analysis of physico-chemical properties. The following parameters were analyzed to study the physico-chemical and textural properties of soil in different AFS and control plots:

(i) Texture: Texture was determined by Bouyoucos hydrometer method (Allen et al. 1974).

(ii) Bulk density and porosity: The bulk density was determined using a metallic cylinder following Allen et al. (1974). After determining the bulk density, porosity was calculated by using the following formula:

Porosity (%) = 100 – [(bulk density/ 2.65) x 100]

(iii) Soil moisture content: Moisture content was determined gravimetrically by drying 10 g of field-moist soil at 105 ^{0}C for 24 hours in a hot air oven following Allen et al. (1974).

(iv) Water holding capacity (WHC): WHC was determined by Keen's box (copper cups of 5.6 cm internal diameter and 1.6 cm height) method (Piper 1942).

(v) pH: Soil pH was determined electrometrically by a digital pH meter (SYSTRONICS-335) in 1:2.5 w/v suspensions of soil and water (Anderson and Ingram 1993).

(vi) Soil organic carbon (SOC): SOC was determined by rapid titration method (Allen et al. 1974). Soil organic matter (SOM) was estimated by multiplying the soil organic carbon content by 1.724 assuming that soil organic matter contains 58% carbon (Allen et al. 1974).

(vii) Nitrogen, phosphorus and potassium content: Total Kjeldahl nitrogen (TKN) was determined by digestion and semi-micro distillation method following Allen et al. (1974).

Available phosphorus was determined by molybdenum blue method (Anderson and Ingram 1993), and available potassium was determined by flame photometer method (Jackson 1973).

Weed Community

Weed flora was sampled in each of the three AFS and control plots at monthly intervals by laying randomly 10 selected quadrates of 50 x 50 cm size during the cropping period. Species were identified with the help of regional flora (Kanjilal et al. 1934-1940, Balakrishnan 1981-1983, Haridasan and Rao 1985-1987). Frequency, density, abundance and importance value index of weed species were determined according to Misra (1968).

Statistical analysis

The data pertaining to the soil properties were analyzed using one-way, two-way and three-way ANOVA (fixed effect model) following Zar (1974).

RESULTS

Light intensity

It is evident from the data presented in Fig. 4.1 that light intensity varied significantly ($P< 0.01$) between months. The maximum value was recorded in the month of May and minimum in July under all the agroforestry systems and control plots. The maximum light intensity was recorded in Khasi mandarin-based (420 x 100 lux) followed by alder-based (350 x 100 lux) and Khasi pine-based (255 x 100 lux) AFS. In control plots, maximum light intensity (849 x 100 lux) was recorded in the month of December. The plots located between the rows received more light than those positioned between the trees in all the AFS (Table 4.1). Among the different AFS, Khasi mandarin-based AFS

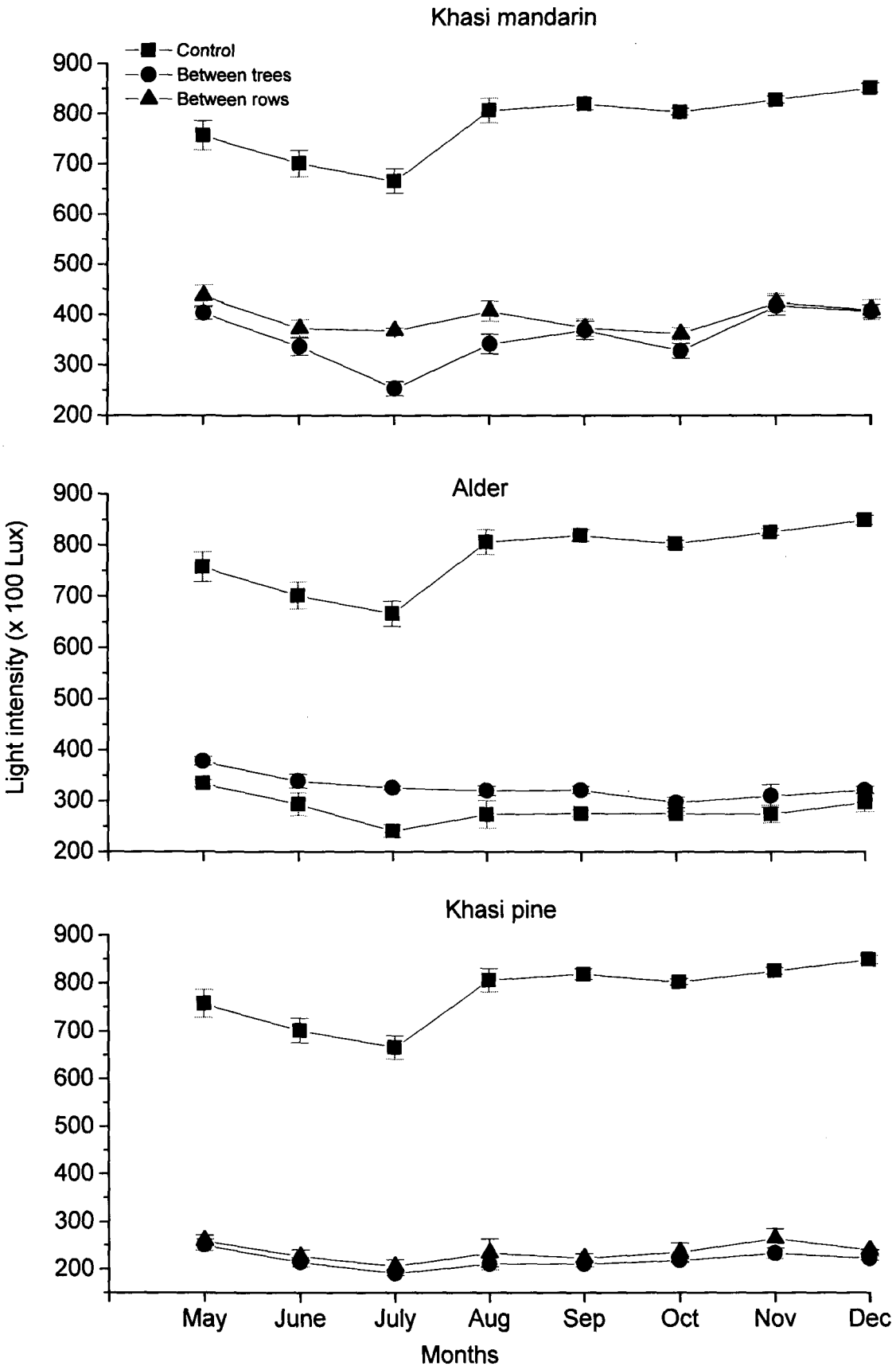


Fig. 4.1 Average light intensity at crop height under different AFS and control plots

received 42.91 to 55.46% of sunlight followed by alder-based (35.38 to 47.01%) and Khasi pine-based (26.48 to 33.71%) AFS.

Table 4.1: Light intensity (Lux x 100) at crop height* in different agroforestry systems (the values are mean of 2002 and 2003 cropping periods)

Months	Control	AFS		Absorbed or reflected by tree canopy (%)		Available to crops (%)	
		BT	BR	BT	BR	BT	BR
Khasi mandarin based AFS							
May	757.33	403.67	436.33	46.70	42.39	53.30	57.61
June	701.50	336.17	372.50	52.08	46.9	47.92	53.10
July	665.97	252.78	367.63	62.04	44.8	37.96	55.20
August	806.23	341.25	406.23	57.67	49.61	42.33	50.39
September	819.05	368.18	373.50	55.05	54.4	44.95	45.60
October	802.80	327.45	361.43	59.21	54.98	40.79	45.02
November	826.00	416.33	422.28	49.60	48.88	50.40	51.12
December	849.25	404.93	407.59	52.32	52.01	47.68	47.99
Alder based AFS							
May	757.33	334.17	377.83	55.88	50.11	44.12	49.89
June	701.50	293.45	338.85	58.17	51.7	41.83	48.30
July	665.97	240.98	325.67	63.82	51.1	36.18	48.90
August	806.23	273.55	319.95	66.07	60.32	33.93	39.68
September	819.05	275.06	321.33	66.42	60.77	33.58	39.23
October	802.80	274.95	296.88	65.75	63.02	34.25	36.98
November	826.00	274.42	309.97	66.78	62.47	33.22	37.53
December	849.25	296.97	321.23	65.03	62.17	34.97	37.83
Khasi Pine based AFS							
May	757.33	250.50	260.00	66.92	65.67	33.08	34.33
June	701.50	214.17	226.67	69.47	67.69	30.53	32.31
July	665.97	190.70	205.83	71.37	69.09	28.63	30.91
August	806.23	210.86	233.98	73.85	70.98	26.15	29.02
September	819.05	210.50	223.16	74.30	72.75	25.70	27.25
October	802.80	218.29	235.46	72.81	70.67	27.19	29.33
November	826.00	233.18	264.82	71.77	67.94	28.23	32.06
December	849.25	222.33	240.09	73.82	71.73	26.18	28.27

*Crop height varied from 50 cm to 231 cm
BT- Between trees, BR- Between rows

Soil temperature

Soil temperature varied significantly ($P<0.01$) between different AFS, but the difference between the upper and lower layers of soil was not significant (Fig. 4.2).

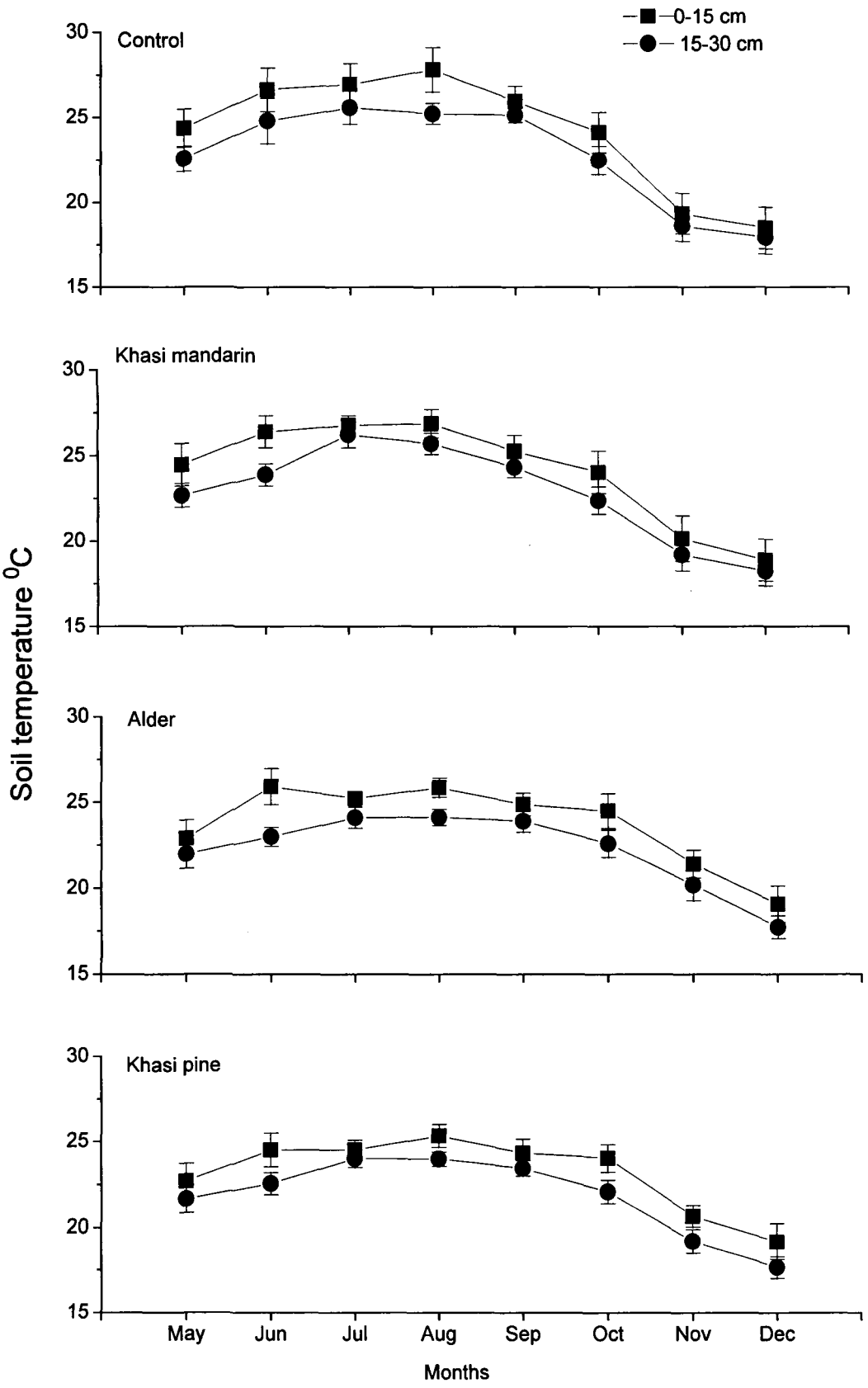


Fig. 4.2. Soil temperature in different AFS and control plots.

Among the three AFS, soil temperature in Khasi mandarin system was higher than other systems. It increased till August (26.8 ^{0}C) and then declined gradually and reached at the lowest level (18.8 ^{0}C) in the month of December. Similar monthly trends were observed in the alder-based and Khasi pine-based AFS including control plots (Fig. 4.2). The maximum soil temperature was recorded in the control plots (27.81^{0}C) followed by Khasi mandarin-based (26.8 ^{0}C), alder-based (26.8 ^{0}C) and Khasi pine-based (25.3 ^{0}C) AFS.

Texture

The soil was silt clay loam in all the AFS and control plots (Table 4.2). While clay content ranged from 30.20 to 36.70%, it was silt and sand which ranged from 28.52 to 35.20% and 31.62 to 41.30%, respectively. The proportion of different soil particles can be arranged as sand > clay > silt. Depth-wise variation in the proportion of different soil particles was significant ($P<0.01$).

Table 4.2. Texture of soil in different agroforestry systems and control plots.

AFS	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture Class
Khasi mandarin	0-15	39.30 ±1.63	29.20 ±0.50	31.50 ±0.87	Silty clay loam
	15-30	31.60 ±1.22	35.20 ±0.99	33.20 ±1.26	Silty clay loam
Alder	0-15	32.20 ±1.12	34.30 ±1.19	33.50 ±0.63	Silty clay loam
	15-30	36.20 ±0.54	30.20 ±0.59	33.60 ±1.04	Silty clay loam
Khasi pine	0-15	35.00 ±1.09	29.80 ±0.87	35.20 ±0.53	Silty clay loam
	15-30	33.10 ±1.36	30.20 ±0.63	36.70 ±0.35	Silty clay loam
Control	0-15	41.30 ±0.87	28.50 ±0.57	30.20 ±0.71	Silty clay loam
	15-30	33.90 ±1.16	32.50 ±0.84	33.60 ±0.92	Silty clay loam

n=3, ± SE

Bulk density and porosity

There were insignificant differences in the bulk density among the AFS and between soil depths. In all the plots, bulk density was higher at the lower layer (15-30cm)

than the upper layer (0-15cm) of the soil. Its value ranged between 0.91 g cm^{-3} (pine-.based AFS) to 1.03 g cm^{-3} (control) in the upper layer, and 0.93 g cm^{-3} (pine-based AFS) to 1.08 g cm^{-3} (control) in the lower layer of the soil (Table 4.3).

The porosity showed a reverse trend to that of bulk density and the values were higher in the surface layer than the subsurface soil layer. The values ranged from 61.13% (control) to 65.66% (pine-based AFS) in the surface layer and from 59.37% (pine-based AFS) to 65.03% (control) in the subsurface layer (Table 4.3). It did not show significant difference between soil depths and systems.

Soil moisture content (SMC)

During the cropping period, peak SMC was recorded in the Khasi pine AFS followed by alder-based and Khasi mandarin-based AFS, and it varied significantly ($P<0.01$) between systems and soil depths. In general, the values were high during rainy season (May to September) both in the surface and subsurface soil layers, and it decreased during October to December in all the AFS as well as in control plots (Fig. 4.3).

Water holding capacity (WHC)

Water holding capacity ranged from 56.14 to 67.09% in the upper layer and from 57.11 to 69.52% in the lower soil layer in all the experimental plots (Table 4. 3). There was significant ($P<0.01$) difference in WHC between different AFS and control plots but variation due to soil depth was non significant. The maximum water holding capacity was recorded in Khasi pine-based AFS in both upper (67.09%) and lower soil (69.52%) layers followed by the alder-based system (upper layer-66.72%, and lower layer-68.58%).

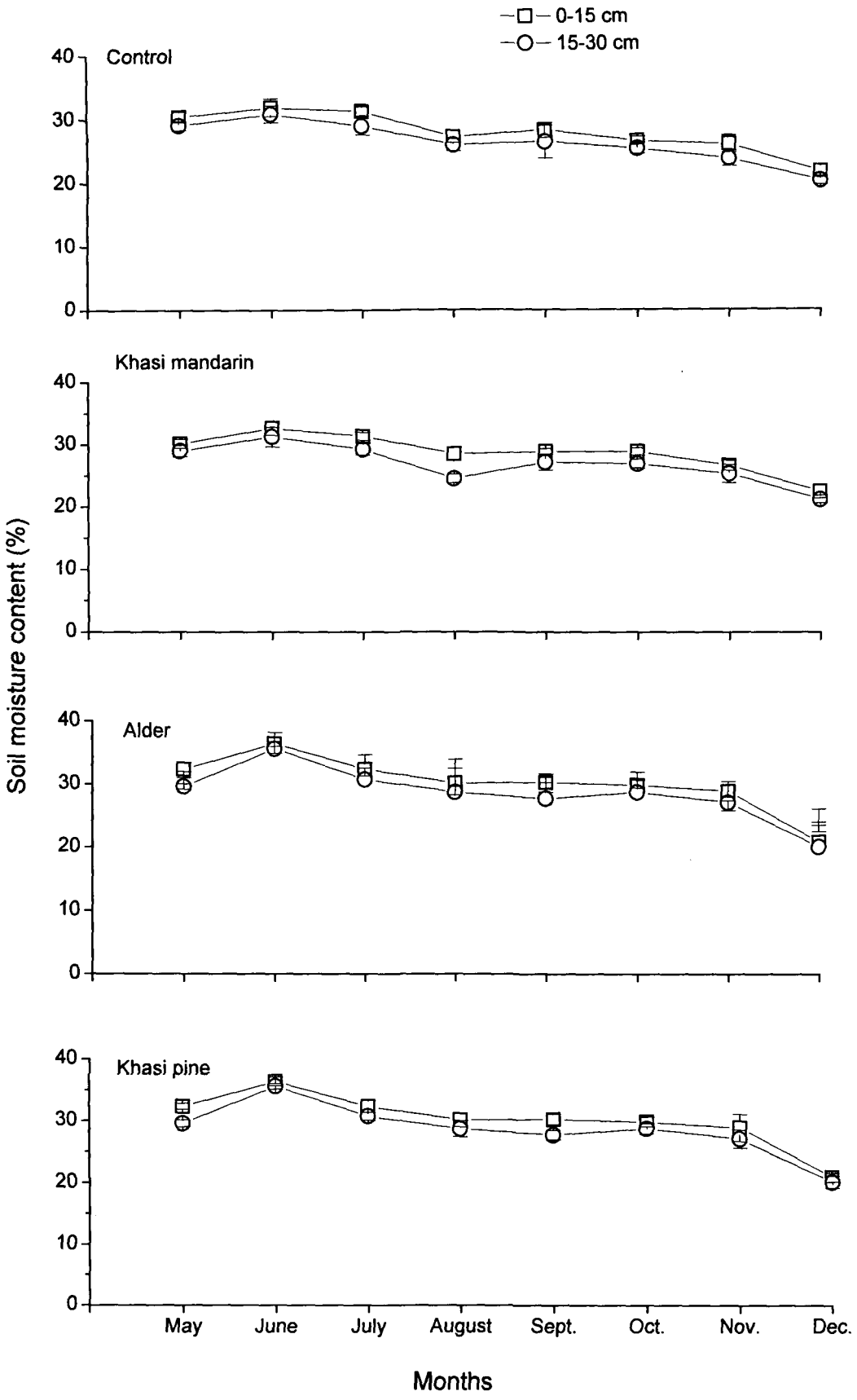


Fig. 4.3. Soil moisture content in different AFS and control plots

Table 4.3. Water holding capacity, bulk density and porosity of soil in different agroforestry system and control

AFS	Depth (cm)	Water holding capacity (%)	Bulk Density (g cm^3)	Porosity (%)
Khasi mandarin	0-15	61.52 ±1.85	0.98 ±0.02	62.89 ±0.77
	15-30	62.18 ±1.28	1.04 ±0.03	60.88 ±1.24
Alder	0-15	66.72 ±0.72	0.92 ±0.03	65.41 ±0.98
	15-30	68.58 ±0.65	0.97 ±0.01	63.52 ±0.45
Khasi pine	0-15	67.09 ±0.76	0.91 ±0.02	65.66 ±0.65
	15-30	69.52 ±0.65	0.93 ±0.02	65.03 ±0.88
Control	0-15	56.14 ±0.83	1.03 ±0.05	61.13 ±1.70
	15-30	57.11 ±0.90	1.08 ±0.05	59.37 ±2.06

n= 3, ± SE

Soil pH

The soil was acidic in all the AFS with pH ranging from 4.63 to 5.00 in the upper layer and from 4.69 to 4.94 in the lower soil layer (Table 4.4). The soil acidity decreased with the increase in soil depth. Among the different AFS, soils of Khasi pine-based AFS were more acidic followed by alder -based and Khasi mandarin-based AFS. The three-way ANOVA revealed significant variation ($P< 0.05$) between the AFS but depth-wise variation was non significant. The soil was more acidic without fertilizer application than with fertilizer application.

Soil organic carbon (SOC) and Soil organic matter (SOM)

Three-way ANOVA revealed that there was a significant ($P<0.01$) difference in the SOC between the two soil depths and among the AFS ($P<0.05$). In general, highest concentration (2.12%) of SOC was recorded in Khasi mandarin-based AFS followed by Khasi pine-based (2.09%) and alder-based (1.78%) based AFS and control (1.85%).

Concentration of SOC was higher in the surface layer (1.78% to 2.12%) than the subsurface layer (1.47% to 1.75%) in all the systems. SOM were also followed the similar trends in all the AFS and control plots (Table 4.4).

Total Kjeldahl nitrogen (TKN)

Total Kjeldahl nitrogen varied significantly ($P<0.05$) between the upper and lower layer of soil but difference between different AFS were non significant. Fertilizer application in Khasi mandarin AFS exhibited the highest concentration of TKN (0.25%), while it was lowest (0.19%) in Khasi pine-based AFS. Similar trends were also observed in the unfertilized plots (Table 4.4).

Available phosphorus (P)

Available phosphorus concentration varied significantly ($P<0.01$) among the different AFS, irrespective of fertilizer application and soil depth. The concentration of available P was higher in the surface layer than the subsurface layer in all the systems (Table 4.4). Fertilizer application in Khasi mandarin-based AFS registered the highest concentration of available P (52.25 $\mu g\ g^{-1}$) followed by control (38.17 $\mu g\ g^{-1}$), alder-based (37.83 $\mu g\ g^{-1}$) and Khasi pine-based (26.75 $\mu g\ g^{-1}$) AFS, whereas, in the unfertilized plots, the concentration of available P was highest in Khasi mandarin-based AFS (41.75$\mu g\ g^{-1}$) followed by alder-based (29.92 $\mu g\ g^{-1}$), control (27.50 $\mu g\ g^{-1}$) and Khasi pine-based AFS (17.25 $\mu g\ g^{-1}$).

Available potassium (K)

Available potassium content varied significantly ($P<0.01$) among the different AFS and between fertilizer treatments and soil depths. Application of fertilizer caused an increase in the concentration of available K in the soil. Khasi mandarin-based AFS had

much higher (88.71μg g^{-1}) concentration of K than Khasi pine-based AFS (42.91 μg g^{-1}) in the fertilized plots. The concentration declined with the increase in soil depth (Table 4.4).

Weed Community

Altogether 33 weed species were recorded from the three AFS and the control plots. The species richness was maximum (21 species) in the control plots followed by Khasi mandarin-based (16 species), Khasi pine-based (15 species) and alder-based (13 species) AFS. Six species were common to all AFS as well as control plots which include *Ageratum conyzoides, Bidens pilosa, Borreria hispida, Commelina bengalensis, Drymaria cordata,* and *Galinsoga parviflora* (Table 4.5).

DISCUSSION

The tree canopies intercepted 52 to 71 per cent of light in different AFS and only 29 to 48 per cent was available to the crops. While 48% of the light was available to the crops grown in the Khasi mandarin-based AFS, it was only 39% and 29%, respectively in association of alder and Khasi pine-based AFS. In the control plots the crops received much more light than they did in the agroforestry plots. The maximum light intensity was recorded in the month of May and minimum in the month of July in all the AFS as well as control plots. The crops planted between the rows could get more light than those planted between the trees in all the AFS. It clearly indicates that the variation in canopy architecture of different tree species was responsible for the variation in light regime in

Table 4.4. Chemical properties of the soil in different AFS and control plots with and without fertilizer application (each value is the mean of two sampling period before crop sowing and after harvest)

Soil	Depths	Khasi mandarin		Alder		Khasi pine		Control	
Properties	(cm)	F (+)	F (-)	F (+)	F (-)	F (+)	F (-)	F (+)	F (-)
pH	0-15	5.00±0.05	4.92±0.06	4.92±0.06	4.82±0.04	4.89±0.02	4.62±0.02	4.98±0.04	4.91±0.02
	15-30	4.91±0.04	4.90±0.06	4.67±0.09	4.63±0.07	4.88±0.05	4.53±0.04	4.94±0.04	4.86±0.07
SOC (%)	0-15	2.23±0.08	1.98±0.07	2.06±0.02	1.78±0.10	2.15±0.11	2.09±0.28	2.04±0.05	1.85±0.07
	15-30	1.86±0.06	1.59±0.04	1.74±0.06	1.48±0.07	1.84±0.08	1.75±0.14	1.96±0.08	1.49±0.07
SOM (%)	0-15	3.85±0.13	3.41±0.12	3.55±0.04	3.07±0.18	3.71±0.19	3.61±0.49	3.52±0.08	3.20±0.12
	15-30	3.20±0.10	2.75±0.07	3.01±0.11	2.54±0.12	3.18±0.14	3.01±0.25	3.37±0.13	2.57±0.12
Total N (%)	0-15	0.25±0.01	0.19±0.01	0.21±0.02	0.18±0.01	0.19±0.01	0.16±0.01	0.20±0.01	0.19±0.01
	15-30	0.18±0.01	0.18±0.01	0.18±0.01	0.16±0.01	0.16±0.01	0.10±0.01	0.17±0.01	0.15±0.01
Av. P ($\mu g\ g^{-1}$)	0-15	52.25±1.46	41.75±1.04	37.83±1.58	29.92±1.02	26.75±0.79	17.25±1.28	38.17±1.56	27.50±0.72
	15-30	31.83±1.75	27.83±1.28	27.75±1.49	19.08±0.72	20.75±1.30	9.75±0.21	29.75±1.22	16.17±0.92
Av. K ($\mu g\ g^{-1}$)	0-15	88.71±2.36	72.11±2.30	67.34±4.87	50.18±1.23	42.91±3.44	33.02±0.79	62.75±1.97	48.32±0.80
	15-30	65.81±5.40	53.53±1.27	53.77±1.12	41.76±0.91	39.30±1.66	28.44±0.74	52.44±3.15	42.48±0.81

± SE

F (+) = with fertilizer, F (-) = without fertilizer

Table 4.5. Density (D), frequency (F) and abundance (A) of the weed species in different AFS and control plots.

Weed species	Khasi mandarin			Alder			Khasi pine			Control (open)		
	D	F	A	D	F	A	D	F	A	D	F	A
Ageratum conyzoides	18	70	12.57	15	70	10.71	13	70	9.29	43	80	26.63
Ageratum haustonianum	133	80	83.38	120	80	75.25	-	-	-	-	-	-
Arundinella benghalensis	-	-	-	102	90	56.89	-	-	-	-	-	-
Bidens pilosa	166	90	92.33	149	90	82.89	87	90	48.44	170	90	94.22
Blumea barberata	-	-	-	-	-	-	-	-	-	1	30	2
Borreia hispida	31	60	26	27	60	22.50	15	60	12.50	34	60	28
Commelina benghalensis	6	70	4.29	5	70	3.71	3	70	2.43	7	70	5
Crotolaria stricta	-	-	-	-	-	-	3	40	3.50	-	-	-
Curcuma sp.	-	-	-	-	-	-	24	90	13.11	-	-	-
Cyperus rotundus	-	-	-	-	-	-	61	80	38.13	-	-	-
Desmodium microphyllum	-	-	-	-	-	-	-	-	-	3	50	3
Digitaria sanguinalis	-	-	-	-	-	-	-	-	-	57	90	31.56
Dioscorea sp.	-	-	-	-	-	-	12	90	6.44	13	90	7
Drymaria cordata	16	80	10.27	14	80	8.50	9	80	5.38	26	90	14.67
Eleusine indica	1	20	3	1	30	2	-	-	-	2	50	2
Eupatorium odoratum	-	-	-	-	-	-	133	80	83.38	-	-	-

Euphorbia sp	0	10	1	-	-	-	-	-	-	-	-	-
Galinsoga parviflora	277	90	153.78	141	70	100.43	69	70	49.57	357	100	178.30
Imperata cylindrica	145	80	90.88	76	60	63.17	-	-	-	-	-	-
Lantana camara	-	-	-	-	-	-	6	80	3.63	9	80	5.88
Mikania micrantha	-	-	-	1	30	1.67	1	30	1.33	-	-	-
Murdannia spirata	-	-	-	-	-	-	-	-	-	116	70	82.71
Oxalis sp.	156	80	97.38				27	80	17	158	80	98.75
Panicum montanum	-	-	-	-	-	-	22	90	12.33	24	90	13.44
Paspallum sp.	-	-	-	-	-	-	117	80	73.38	119	80	74.50
Polygala sp.	-	-	-	-	-	-	-	-	-	62	90	34.67
Polygonum sp.	61	90	33.67	-	-	-	-	-	-	72	80	44.88
Setaria glauca	154	90	85.33	-	-	-	-	-	-	155	90	86.11
Trifolium repens	-	-	-	-	-	-	-	-	-	6	100	3.10
Solanum sp	4	50	4.40	-	-	-	-	-	-	-	-	-
Themida	4	50	4	3	40	3.50	-	-	-	-	-	-
Vernonia artimisifolia	3	40	3.25	2	40	2.50	-	-	-	-	-	-
Spilanthes maculanta	10	80	6.13	8	80	4.75	-	-	-	-	-	-

different AFS. Khasi mandarin, a semi-deciduous tree, has a horizontal branching pattern and has a medium size canopy, whereas Khasi pine is an evergreen tree, has pseudo-whorls branching pattern, and large compact canopy area. Similar results were reported by Jaswal et al. (1993) and Kumar (1996) with different tree species. Ovington (1961) measured the light intensity in different forest plantations in England and reported that conifers allow the least light to penetrate than deciduous species.

Soil temperature was significantly different in different AFS, but in control plots, however, it was higher than the AFS. In Khasi mandarin system it was higher than the other AFS. Monthly variation in soil temperature was similar in alder-based and Khasi pine-based AFS and control plots. Higher soil temperature in control plots was due to direct exposure to sunlight, while low soil temperature in AFS is attributed to shade cast by the trees.

Among the AFS, low soil moisture under Khasi pine-and alder-based AFS from October to December can be ascribed to active tree growth during this period which might have extracted larger volume of water from soil. The results are in line with the findings of Singh et al. (1989), Corlett et al. (1989), Rao et al. (1990), Ong et al. (1991b), Khybri et al. (1992) and Srivastava and Rao (1993) who reported less soil moisture in AFS compared to sole cropping.

Excessive leaching losses of bases due to high rainfall may be the reason for overall acidic nature of soil in all the experimental plots. But relatively more acidic soil in the pine and alder-based AFS could be related to the nature of tree species. In the later it could be due to N-fixation in alder, since soil under N- fixing trees commonly has a lower pH than the soil under non N- fixing tree stands (Binkley and Sollins 1990,

Franklin et al.1968), while in the former the increase in acidity was mainly due to presence of phenolic compounds in the conifer leaf litter (Das 1980).

The increase in organic carbon content in surface soil in all the systems was dependent on the amount and quality of litter input by trees in different systems (Majumudar et al. 2004). All the three tree species produced large quantities of litter during the dry period of the year, which decomposed during subsequent rainy season adding organic matter to the soil system. The litter of Alder and Khasi mandarin contains high amount of nitrogen, and therefore, they are capable of yielding high quality of organic matter (Dhyani 1997). Several studies have shown that soil fertility under trees is improved through increased input of litter (Campbell et al. 1988, 1994, Dunham 1991, Kesseler 1992, Dhyani 1997). Relatively higher concentration of organic carbon in the Khasi pine-based AFS than the alder-based AFS could be attributed to greater input of total litter, though its quality is poor than the alder litter. The higher content of soil organic matter in Khasi mandarin-based AFS is the result of regular application of manure and fertilizer to the plots and return of intercrop residues (Dhyani 1997).

An increase in total nitrogen, available phosphorus, potassium and improvement in WHC, porosity and reduction in bulk density of soils under Khasi mandarin-based AFS indicated an increased fertility level of the topsoil. Most of these parameters also improved in the alder-based and Khasi pine-based AFS as well, but their magnitude was lower than the Khasi mandarin-based AFS including control. The findings are conformity with those of Dhyani (1997) and Majumudar et al. (2004).

The species richness of weed species often shows close affinity with the crops (Tripathi and Misra 1971, Streibig 1979). Weed density was low in the Khasi pine-based

AFS as compared to the alder-based and Khasi mandarin-based AFS and the control plots. This could be the result of various ecological interactions including competition between trees, crops and weeds (Vandermeer 1989).

The weeds are usually intolerant to shade and hence, as the tree canopy increases causing greater light interception, weed growth decreases. This is evident in the present study as well. The weed density was lowest in alder-based and Khasi pine-based AFS than the Khasi mandarin-based AFS, where the tree canopy spread was less compared to the former two AFS. The control plots, which had no trees in them, had the maximum weed density. Lower weed yield reported by Aken-Ova and Atta-Krah (1986a) and Bashir and Getahun (1991) and shift in the composition of weed flora following alley cropping with various hedgerows species observed by Siaw et al. (1991) clearly show that weed infestation could be greatly reduced in AFS compared to sole cropping, i.e., control.

Chapter 5

PHENLOGY, GROWTH AND CANOPY ARCHITECTURE OF THE TREE SPECIES

The multipurpose trees (MPTs) form an integral component of different agroforestry interventions and models. The MPTs besides furnishing the multiple outputs like fuel, fodder, timber and other miscellaneous products, also help in the improvement of soil and other ecological conditions. Screening of multipurpose tree species is an important prerequisite for determining their suitability in agroforestry systems. A combination of desired characters of growth form and growth pattern is helpful in the selection of suitable species for AFS (Rai et al. 2001, Datta 1997, Dhyani and Tripathi 1999). A comparative analysis of desirable characteristic of tree species, therefore, provides useful baseline information for evaluating their competitive interactions in the AFS.

A study of phenological characteristics gives an idea of seasonal cycle of major events in growth cycle of trees. Each species has a precisely determined growth plan or architectural model adapted to the physical and biotic factors of ecosystems where it lives (Bisht and Toky 1992). It is affected by apical control of growth, shoot types, branching orientation, timing of meristematic activity and shedding of shoot as well as physical factors such as light, temperature, soil, water and nutrient availability. Architectural models of trees, stylistically drawn to represent the fully expressed form were developed by Halle et al. (1978). They developed several architectural models based on shoot extension, branching patterns, branch differentiation and position of flowers and named

these models after well known botanists. The canopy structure directly influences the amount of leaf surface area present to capture light for photosynthesis. The interrelated factors of tree form, vertical canopy structure, and leaf area influence the interception of light, photosynthesis and overall tree productivity (Bisht and Toky 1992).

In order to characterize the growth form and growth pattern of the three tree species viz. Khasi mandarin, alder and Khasi pine, data on their phenology, seasonal growth pattern, canopy architecture and biomass were collected. These have been presented and discussed in the present chapter.

METHODOLOGY

The Khasi mandarin, alder and Khasi pine trees were planted in alternate terraces with a spacing of 5m between the trees and 5m between the rows in 1990 (Fig. 2a, b, and c of chapter 3). The trees of all the three species were 13 years old when the present study was initiated in the month of January, 2002.

Phenology

Various phonological events such as leaf flushing, leaf fall, active shoot growth, flowering and fruiting were recorded from ten randomly selected trees at monthly interval from July, 2002 to June, 2003 in different AFS (Negi 1995).

Growth

Height and diameter at breast height (dbh) of the tree species were recorded every year in the month of January, 2002, 2003 and 2004. Height was measured by using Abney level, while dbh was measured at 1.37 m above the ground with the help of a measuring tape. Current annual increment (CAI) 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) is the mean height or diameter of a tree at a given age divided by its age in years.

These parameters were calculated according to the formula given by Chaturvedi and Khanna (1982).

CAI = Tree height or dbh in current year – Tree height or dbh in the preceding year

MAI = Mean height or diameter / Age of the tree

Canopy cover

The lateral spread of tree canopy was measured on the ground in north-south and east-west directions with the help of a measuring tape, and the canopy cover was calculated from the measurement of the projection of the crown diameter assuming that crown is a circle (Avery and Burkhart 1994).

Timber volume

The timber volume was estimated using dbh and tree height according to the formula given by Dhanda (2004).

$$\text{Volume} = 1/3\pi r^2 h$$

Where, r = radius of the bole, and
h = height of the tree

Aboveground biomass

Dry weight (Kg tree^{-1}) of leaves, branches and bole of tree species was determined by felling three trees of each species at 5 cm above the ground level. Leaves, branches, and bole were separated and weighed in the field. Three-sub samples of 1Kg of each of the plant parts were dried in hot air oven at 80 ^{0}C for 48 hours and weighed (Dhanda 2004). By using dry weight data of sub-samples, dry weight of above ground parts per tree was determined for all the three species.

Fine root biomass

In order to study lateral spread of fine roots (<2mm diameter) of the trees and their concentration at different soil depths, sampling was done at 0.5, 1.5 and 2.5 m away from the base of the tree trunk at two soil depths (0-10cm and 10-20cm) using a cylindrical metallic corer (diameter 10.0 cm). The fine roots (<2mm diameter) were separated from soil by wet sieving method as outlined by Bohm (1979). The roots were washed twice under tap water to ensure that all soil particles adhered to it are removed and thereafter the washed root were dried in a hot air oven at 80^0C to a constant weight.

Canopy architecture

The canopy architecture of each tree species was drawn to the scale on graph paper by measuring height, dbh, canopy spread and by observing the branching pattern of the first and second order branches.

RESULTS

Phenology

Khasi pine (*Pinus kesiya*), Khasi mandarin (*Citrus reticulata*) and alder (*Alnus nepalensis*) are evergreen, semi deciduous and deciduous in nature, respectively. Leaf flushing of alder and Khasi pine tree species was seen during the months of February and March. In case of Khasi mandarin, it was observed twice in a year, i.e., during February and March, and August and September. The maximum active shoot growth was observed during February to April in case of Khasi mandarin and Khasi pine, however, in alder it continued for more than four months. Flowering period was same in Khasi mandarin and Khasi pine (February and March), but in alder flowering occurred during September-October. Fruiting period and fruit ripening duration varied among the three species (Fig. 5.1).

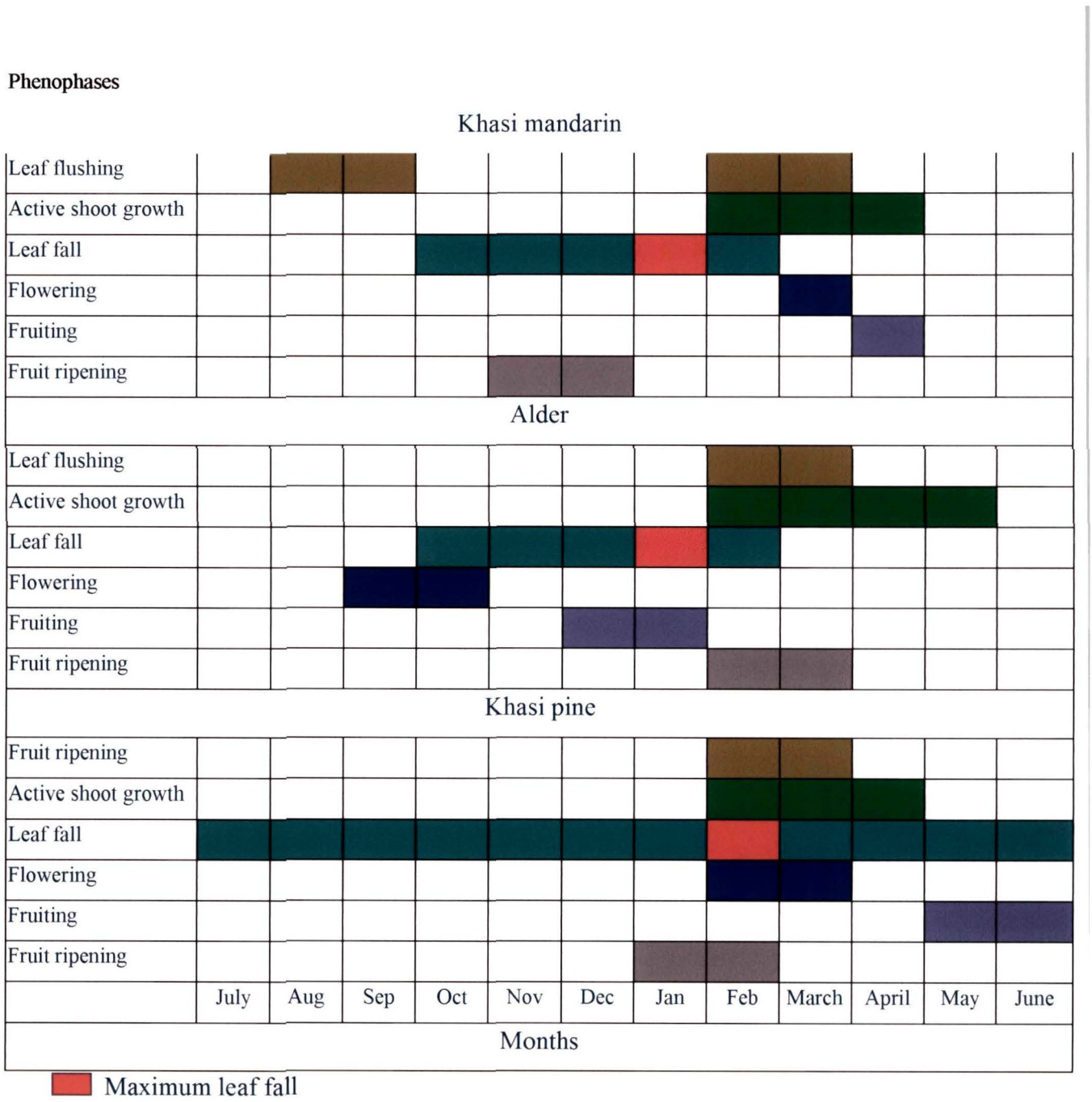


Fig. 5.1. Periodicity of different phenophases of the tree species under AFS.

The leaf fall started during post rainy period and it peaked during the dry winter in case of Khasi mandarin and alder tree. Khasi pine being an evergreen species, showed the leaf fall throughout the year but the maximum leaf fall was observed during November to April. The total annual leaf fall was maximum in Khasi pine (585 g m^{-2})

followed by alder (338 g m^{-2}) and Khasi mandarin (263 g m^{-2}). The details of leaf fall pattern have been discussed in Chapter 7.

Growth

The tree height and trunk diameter of the three species during the study period (2002-2004) were significantly ($P<0.01$) different. The mean height of *Alnus nepalensis*, *Pinus kesiya* and *Citrus reticulata* was 14.34, 13.85 and 5.72 m, respectively (Table 5.1). In terms of height growth, the species were ranked as *Alnus nepalensis> Pinus kesiya> Citrus reticulata,* and on the basis of diameter (dbh) increase, they may be ranked as *Pinus kesiya> Alnus nepalensis> Citrus reticulata.*

Table 5.1. Growth characteristics of trees in different AFS

Growth	Khasi mandarin			Alder			Khasi pine		
parameters	2002	2003	2004	2002	2003	2004	2002	2003	2004
Height (m)	5.58 ± 0.23	5.62 ± 0.23	5.97 ± 0.22	13.82 ± 0.61	14.24 ± 0.56	14.97 ± 0.58	13.53 ± 0.91	13.77 ± 1.08	14.24 ± 1.10
DBH (cm)	17.92 ± 1.21	18.23 ± 1.22	18.90 ± 1.17	23.15 ± 1.70	23.48 ± 1.68	23.78 ± 1.67	24.53 ± 1.65	24.68 ± 1.48	25.13 ± 1.66
Canopy cover (cm^2)	9.73 ± 0.32	11.27 ± 0.25	12.78 ± 0.23	41.75 ± 0.57	43.75 ± 0.53	49.18 ± 0.58	41.26 ± 0.99	48.93 ± 1.19	52.14 ± 1.14
Timber volume (m^3)/ tree	0.047	0.049	0.055	0.194	0.206	0.222	0.214	0.220	0.236
Fruit yield (kg/ tree)	47.25 ± 3.42	42 ± 3.63	40.5 ± 2.90	-	-	-	-	-	-

± SE, n = 6

The mean annual increment in height during 2002 to 2004 was 102, 98 and 40cm in alder, Khasi pine and Khasi mandarin, respectively. The CAI also showed the similar trend. However, annual diameter (dbh) increment was 1.77cm in Khasi pine, 1.67cm in alder and 1.31cm in Khasi mandarin, respectively. Khasi pine recorded the maximum diameter increment among the three tree species (Table 5.2).

Table 5.2. Current annual increment (*CAI) and mean annual increment (**MAI) in height and dbh of tree species

Growth	Khasi mandarin			Alder			Khasi pine		
parameters (cm)	2002	2003	2004	2002	2003	2004	2002	2003	200
Height – CAI	-	4.00	35.00	-	42.00	73.00	-	24.00	47.0
Height – MAI	39.00	40.00	42.00	98.00	102.00	107.00	96.00	98.00	102.(
Diameter – CAI	-	0.31	0.67	-	0.33	0.30	-	0.15	0.4
Diameter - MAI	1.28	1.31	1.35	1.65	1.67	1.69	1.75	1.76	1.7

*CAI is the increment in growth, which a tree puts on in a single year
** MAI is the mean height or diameter of a tree at a given time divided by the age.

Canopy cover and timber volume

The mean canopy cover was 47.44 m^2 for Khasi pine, 44.89 m^2 for alder and 11.26 m^2 for Khasi mandarin. The species differed significantly ($P< 0.01$) in timber volume. Like canopy cover, Khasi pine also had maximum mean timber volume ($0.22m^3$) followed by alder ($0.20m^3$) and Khasi mandarin ($0.05m^3$). The average edible fruit yield of Khasi mandarin was 43.25 Kg $tree^{-1}$. Alder and Khasi pine are the timber yielding trees species, and do not produce edible fruits (Table 5.1).

Aboveground biomass

The total aboveground biomass was maximum in Khasi pine (250.3 Kg $tree^{-1}$) followed by alder (97.1 Kg $tree^{-1}$) and Khasi mandarin (50.9 Kg $tree^{-1}$). The Khasi pine recorded 3 to 5 times increase in biomass compared to alder and Khasi mandarin, respectively. Bole contributed about 59% to 78% of total aboveground biomass, while leaves contributed only about 8% in all the tree species (Table 5.3).

Table 5.3. Aboveground biomass (Kg dry wt.) of leaf, bole, branch and the whole tree in different AFS

Tree species	Leaf	Bole	Branch	Total
Khasi mandarin	8.42 ± 0.81	12.06 ± 1.16	30.39 ± 3.14	50.87 ± 5.03
Alder	6.68 ± 0.51	14.50 ± 1.24	75.96 ± 2.43	97.14 ± 3.83
Khasi pine	22.42 ± 2.57	43.74 ± 2.07	184.1 ± 2.90	250.26 ± 7.42

± SE, n = 6

Fine root biomass

The fine root mass in 0-10 cm soil layer at distance of 0.5m, 1.5m and 2.5m from the tree trunk was 201.03 g m^{-2}, 162.98 g $m^{-2}$and 119.40 g m^{-2}, respectively in alder. In Khasi mandarin and Khasi pine, the corresponding values were 84.14 g m^{-2}, 128.38 g m^{-2} and 133.71g m^{-2} and 130.78 g m^{-2}, 131.98 g m^{-2} and 125.88 g m^{-2}, accordingly. Similar trend was observed in the 10-20 cm soil layer as well. In general, fine root biomass in alder and Khasi pine decreased with increase in distance from the tree trunk, but in Khasi mandarin it showed a reverse trend (Table 5.4).

Table 5.4. Distribution of tree fine root mass (g m^{-2}) at two soil depths from the base of the tree trunk

Tree species	Soil depth (cm)	Distance from tree trunk (m)		
		0.5	1.5	2.5
Khasi mandarin	0-10	84.14±9.12	128.38±4.06	133.71±6.30
	10-20	83.00±1.57	116.91±3.04	95.00±5.31
Alder	0-10	201.03±4.17	162.98±4.70	119.40±3.83
	10-20	175.03±5.48	124.49±5.80	115.78±6.23
Khasi pine	0-10	130.78±3.32	131.98±2.49	125.88±2.65
	10-20	90.00±6.23	101.62±3.79	100.19±1.26

± SE, n = 3

The maximum total fine root mass (trees and herbaceous fine root) was recorded in the upper soil layer (287.84 g m^{-2}) in alder-based AFS, 255.22 g m^{-2} in Khasi pine based AFS and 258.74 g m^{-2} in Khasi mandarin-based AFS. Similar trend was also observed in the 10-20 cm soil layer (Table 5.5).

Table 5.5. Total fine root mass (g m^{-2}) in soil at two depths in different AFS

Agroforestry systems	Soil depth	Tree	*Herbaceous	Total
Khasi mandarin	0-10	115.41±2.86	143.33±6.56	258.74±4.13
	10-20	98.30±0.80	96.25±6.89	194.55±6.14
Alder	0-10	161.14±1.32	126.71±2.77	287.84±1.98
	10-20	138.43±4.66	107.08±5.13	245.52±5.49
Khasi pine	0-10	129.55±0.15	125.67±1.79	255.22±1.66
	10-20	97.32±2.64	85.42±2.32	182.74±4.94

*Crop + Weed, ± SE, n = 3

Tree architecture

Khasi mandarin a semi-deciduous tree with compact medium size of canopy and horizontal branching produces oblate fruit with very sweet aromatic pulp. It performs best in the subtropical climate on well-drained soil. The tree is usually thorny with unifoliate leaves, relatively thick, ovate with acute tips, having entire or crenulate margins. Fragrant, white flowers are solitary or in short cymes, borne axillary on current flush of growth and also without leaves from previous flush of growth. Mandarin has a natural sympodial growth habit, forming a straight bushy canopy indicating that the species conforms to Roux's model of tree architecture (Fig. 5.2).

Alder is a deciduous tree with a straight trunk and large crown. The leaves, which are frequently damaged by insects, are alternate, elliptical, denticulate or sinuate. The upper leaf surface is dull or shiny dark green, the lower is pale with dot-like, yellow-

brown scales. The narrowly cylindrical clusters of tiny flowers or catkins occur as male or female separately on the same or different twigs in autumn. The tree attains its best growth on well-drained soils from lower to higher slopes of hills (Troup 1921). It shows continuous growth of monopodial trunk-branch differentiation and heterogeneous axes; orthotropic leader axis opens to give out leaves and or branches. Continuous growth, acrotonic branching, trunk and branch differentiation, orthotropic monopodium, heterogeneous axes and lateral inflorescence suggest that this species also conforms to Roux's model of tree architecture (Fig. 5.3).

Khasi pine is a tall evergreen tree with a straight and cylindrical bole and heavy horizontal or ascending branch. Branches are usually in pseudo-whorls, shoot dimorphic with long shoots and dwarf shoots; dwarf shoots borne in close spirals from axils of scale and bearing fascicles of needles. Branchlets stout, ending in a compound bud with many bud scales. Leaves dimorphic, spirally arranged; foliage leaves (needles) usually 3 per fascicle, 15-20cm long. Cones are ovoid, 5-9 cm long, often curved downwards. The trunk is monopodial and grows rhythmically, and develops tiers of branches; the formation of cones does not affect shoot construction. Thus, the normal architecture of pine is similar to Rauh's model (Fig. 5.4).

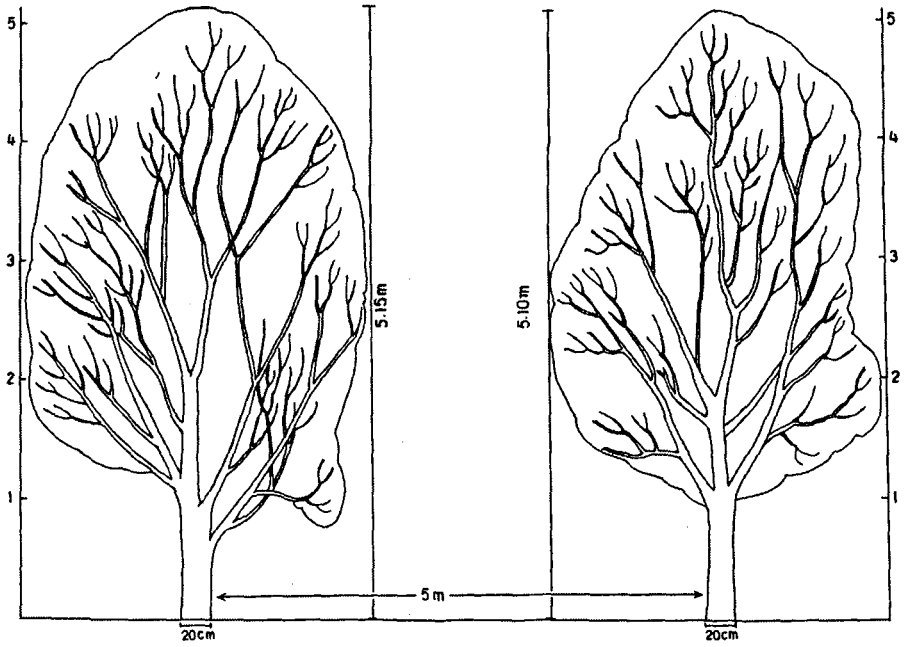


Fig. 5.2. Canopy architecture of Khasi mandarin tree

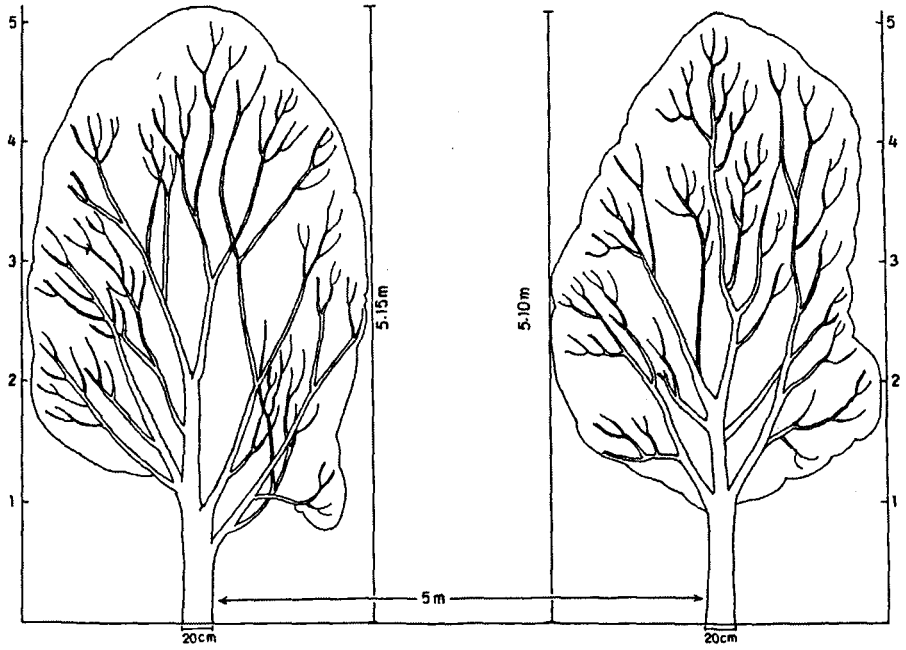


Fig. 5.3. Canopy architecture of alder tree

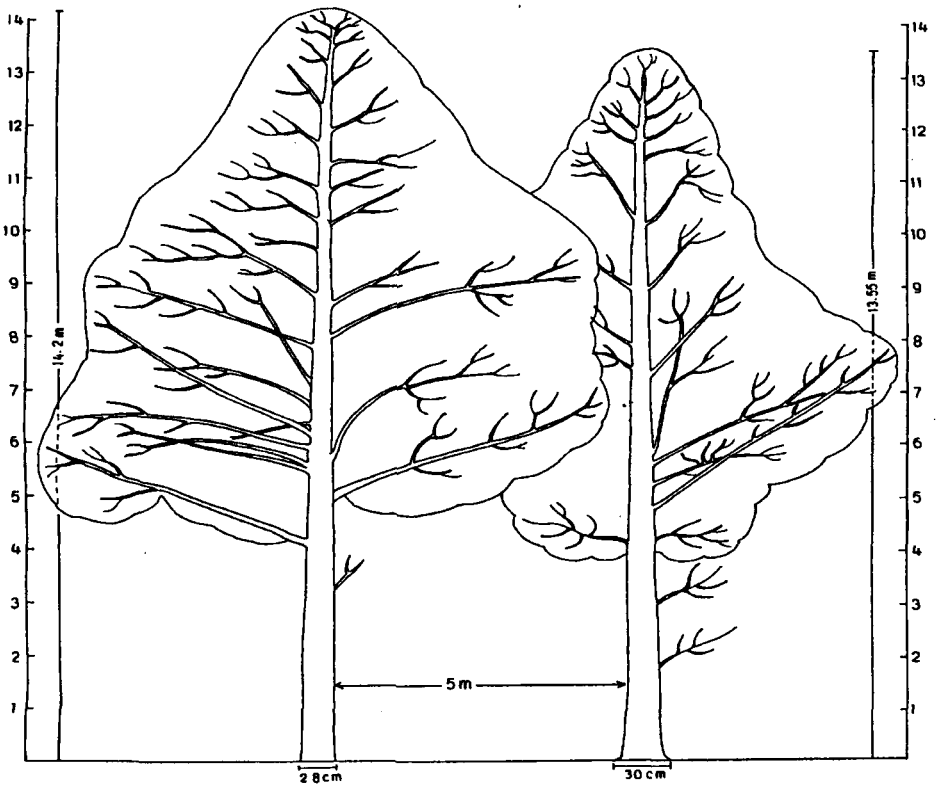


Fig. 5.4. Canopy architecture of Khasi pine tree

DISCUSSION

Alder and Khasi pine are fast growing temperate species, while Khasi mandarin is a bushy, short height fruit tree of the subtropical climate. Therefore, their growth showed large variation despite the fact that all tree species were grown in the same environment. Inter-comparing growth of these species, it has been observed that the alder had the maximum height, while dbh was highest in Khasi pine. This clearly brings out the differences in the growth pattern of the two species. Current annual increment (CAI) and mean annual increment (MAI) rates in height and dbh during the study period were greater in alder than in Khasi pine. Increment in height and stem diameter growth is a good indicator of site conditions (Foroughbakhch et al. 1987). Multipurpose tree species

help in ameliorating infertility of acid soils especially under intercropping with arable crops (Nair 1989).

Phenology not only reveals the growth behavior of tree species but also indicate the magnitude and duration of competition for light, which the under-storey crops are likely to face during the growth period. It has been observed that root activity of woody perennials increases tremendously during February-March before the appearance of new leaves, which causes mobilization of nutrients and water towards the active root zone. During this period, trees can adversely affect the growth of agricultural crops due to keen competition for belowground resources (Negi 1995). The duration and intensity of competition between trees and crops decide the compatibility of trees and crops in an AFS.

Gradual increase in temperature and low relative humidity during February-March marked the commencement of leaf flushing and bud initiation in all the tree species. It is clear from the study that the phenophases of these species were not overlapping with the cropping period. Therefore, crops grown during this period were not affected by the tree component. As shown in the Fig. 5.1, there is a wide variation in the duration and amount of active shoot growth, litter fall, flowering and fruit ripening of these three species. Thus, it indicates that different species have evolved different strategies for their survival and growth, even though they grow in the same environment. The variation in growth patterns among the species may be due to different adaptation to a moist climate.

Roots of woody perennial in AFS are expected to compete strongly with the crops for nutrients and moisture. Analysis of rooting pattern provides useful information for evaluating competitive interaction in AFS. Fine roots, apart from water and nutrient

absorption, add large amount of carbon to the soil through rapid turnover (Vogt et al. 1991).

Fine root biomass varied at the two soil depths among the three AFS. Total fine root biomass declined with increase in soil depth in all the three systems. Greater accumulation of fine root biomass in the upper soil layer in the tree-based farming systems has been reported by several workers (Dhyani et al. 1990, Parrotta 1990). Therefore, it is expected that root competition between crop and tree species may occur in AFS, unless some mechanism of root exclusion is practiced (Jonsson et al. 1988, Dhyani et al. 1990). This could be achieved by hoeing, tilling etc., prior to the planting of the crops and by trenching tree roots (Dadhwal and Tomar 1999) or lopping of branches in established systems.

Among various tree species studied, the maximum total fine root biomass was recorded in alder followed by Khasi mandarin and Khasi pine. In alder and Khasi pine the fine root biomass significantly ($P<0.01$) decreased with the increase in distance from the tree trunk, but it was reverse in the case of Khasi mandarin. Dhyani and Tripathi (2000) have reported similar findings. They have further observed that in alder, fine roots were concentrated near the tree trunk, whereas in Khasi mandarin it was found laterally distributed up to 1.5m from the tree trunk. Many other workers (Ford and Deans 1977, Fogel 1983) have also reported that in general, the root density declines with the vertical depth and distance from the tree trunk. Thus, on the basis of the present findings it may be presumed that alder fine roots were likely to offer more keen competition to crops than the other two tree species.

Chapter 6

CROP GROWTH, PRODUCTIVITY AND YIELD

Planting trees in agricultural fields alters the microclimate of the crop fields, which may be either beneficial (Samaraj et al. 1982, Singh et al. 2003) or harmful to the agricultural crops (Park et al. 1994, Cao et al. 1994). Trees may be directly influencing light, temperature and soil moisture regimes of the crop fields. Several authors have reported reduction in crop yields under the tree canopies. The growth and yield of crops is primarily determined by the availability of light, water and nutrients and their competitive ability and adaptive strategies under different environmental conditions (Dhyani 1997). Differences in the morphological traits and physiological attributes help plant species in adapting to various environmental conditions (Shanker 2005). A large amount of data is available on biomass and productivity of natural and agricultural ecosystems of different agro-ecological zones (Gupta and Singh 1982, Cheng et al. 1990, Boral 1993), but similar information on AFS is limited.

In AFS, the constituent species have marked differences in their morphological and physiological traits as well as their adaptive potential under varied climatic, edaphic and competitive stresses, and so, it is important to analyse their growth behaviour under varied conditions in order to assess their performance in mixed culture. An understanding of the accumulation of biomass, productivity and nutrient uptake by the crop plants and trees is an essential prerequisite to know the functioning of the agroforestry systems. Some data on biomass and productivity of crops, weeds and perennial woody plants have already been documented for some AFS of northeast India (Dhyani 1997, Dhyani and

Tripathi 1999), however, the data is inadequate to understand the production of major crops under AFS. Thus, the data on growth, yield and productivity and nutrient uptake and accumulation by maize, rice, ginger and weeds growing under three AFS were collected. They are presented and discussed in this chapter.

METHODS

Growth and yield of crops

The experiment was conducted under rainfed condition during 2002-2003 at agroforestry research farm of the ICAR Research Complex at Umiam, Shillong. The crop varieties used and the cultural practices adopted during the cropping are given in Table 6.1. Inter-cultural operations were carried out at monthly interval. Nitrogen fertilizer was applied in two equal splits, first as basal dose and the second after two months from the date of sowing, in the form of urea. P_2O_5 and K_2O were applied in the form of super phosphate and murate of potash at the time of sowing. Farmyard manure was applied at the rate of 5 t/ha one week before the crop sowing. The crop growth was measured in terms of shoot height, leaf area index, biomass, productivity and nutrient accumulation in each of the three AFS and control plots. Biomass and nutrient accumulation by associated weeds were also determined in all the systems.

Table 6.1. Cultural operations followed for the cultivation of maize, rice and ginger in different AFS

Crop	Spacing (cm)	Seed rate (Kg/ha)	NPK (Kg/ha)	Sowing date	Harvesting date	Days to maturity
Maize (Vijaya composite)	50x25	20	60:40:40	1st May	2nd Sep	124 days
Rice (Balun- 2)	25x10	60	60:40:40	3rd June	12th Oct.	132 days
Ginger (Nadia)	40x25	1500-1800	60:40:40	14th April	10th Dec.	240 days

Plant height

Ten plants of each crop were randomly selected from each plot to determine plant height at 30, 60, 90 days after germination and at harvest using the metallic scale.

Leaf Area Index

The leaf area of the sampled plants was measured by using leaf area meter (LICOR, USA). LAI was computed based on leaf area per plant and crop density m^{-2} (Beadle 1985).

Biomass production

For the estimation of biomass production, sampling was done in 1m x 1m plots at 30, 60, 90 days after germination and at the time of crop harvest. Plants were removed carefully to avoid major damage to the root system and were brought to the laboratory and washed thoroughly under tap water to remove the soil particles adhering to the roots and then separated into shoot (aboveground) and root (belowground) parts. They were oven-dried at 80 ^{0}C to constant weight (Coombs et al. 1985).

Grain yield and hundred-grain weight

Grains of maize and rice crops were collected from 1m x 1m sample plots at the time of crop maturity, cleaned and weighed. Three samples of 100 grains for each of the two crops were weighed for determining hundred-grain weight.

Straw yield

Straw yield was obtained by deducting the grain yield from the above ground biomass at the time of harvest.

Harvest index

The harvest index was calculated by dividing the economic yield by biological yield of the crops (Beadle 1985).

Yield parameters of ginger

(i) **Rhizome length and breadth**: Length and breadth of the rhizomes of ten randomly selected plants from each plot were measured and the mean value was computed.

(ii) **Rhizome yield**: The fresh weight of the rhizomes of ten selected plants was determined and the yield (g fresh weight per m^2) was calculated using mean rhizome fresh weight per plant and plant density.

Biomass and nutrient allocation in crops and weeds and their productivity

Biomass and nutrient allocation in shoot and root/rhizome of crops and weeds were studied by the methods described by Shukla and Ramakrishnan (1986). Net aboveground primary productivity was determined using peak biomass values (Singh and Yadava 1974).

N, P and K concentration in different plant parts of crops and weeds was determined according to the methods outlined by Allen et al. (1974), and nutrient accumulation was calculated using nutrient concentration and biomass data.

RESULTS

MAIZE

6.2 Growth

6.2.1 Height

The height of maize plant in the fertilized plots was significantly ($P<0.01$) higher in the control plots compared to AFS. Among the AFS, the crop in association of Khasi mandarin-based system registered the maximum height (222.8cm) and the minimum (152.6cm) in Khasi pine-based system. On an average, the height growth of maize plants in fertilized plots increased by 36, 191 and 126%, respectively, in association of Khasi

mandarin, alder and Khasi pine compared to height growth of same crop in unfertilized plots. The increase in maize plant height in the control plot was 21% higher due to fertilizer application. In all the AFS, planting of maize between the rows produced better results than when they were grown in between the trees (Table 6.2.1).

6.2.2 Leaf Area Index (LAI)

LAI was recorded maximum at 90 days after planting in all the AFS, irrespective of planting arrangement and fertilizer application. Among the fertilized plots of different AFS, highest LAI (3.51) was recorded in Khasi mandarin-based AFS followed by alder-(LAI 3.42) and Khasi pine-based AFS (LAI 2.53), whereas, in the unfertilized plots, it was found to be higher in the Khasi mandarin-(LAI 1.95) followed by alder-(LAI 1.89) and Khasi pine-based AFS (LAI 1.36). LAI improved significantly ($P<0.01$) after fertilizer application in all the plots. Maize, planted between the rows showed greater LAI than when planted between the trees (Table 6.2.2).

6.2.3 Biomass

In the control plot peak crop biomass was 3299.56 g m^{-2} on fertilizer application and 2318.67 g m^{-2} without fertilizer application. Among the AFS, highest biomass was recorded in Khasi mandarin-based AFS when the crop was fertilized and planted between the rows (2820.37 g m^{-2}) and lowest in Khasi pine-based AFS in between trees planting sequence (814.17 g m^{-2}). On an average, total biomass was recorded higher when crop was grown between the trees rows compared to when grown between the trees, regardless of fertilizer application (Table 6.2.3 and Fig. 6.1).

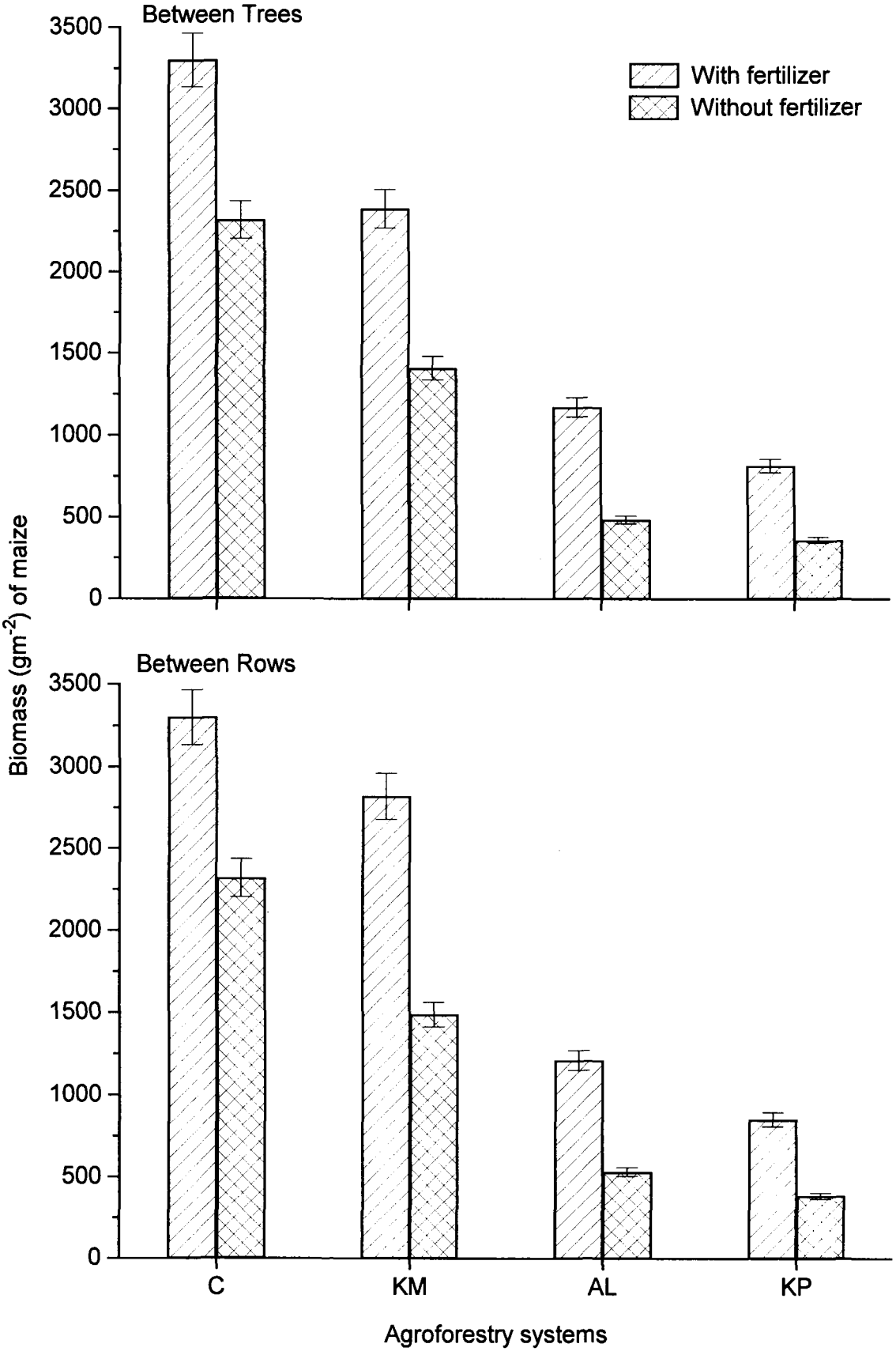


Fig. 6.1. Biomass of maize in different AFS and control plots

Table 6.2.1. Height (cm) of maize under different agroforestry systems (means of 2002 and 2003 cropping periods)

Days after emergence	Khasi mandarin-based AFS			Alder-based AFS			Khasi pine-based AFS			Control mean
	BT	BR	Mean	BT	BR	Mean	BT	BR	Mean	
					With fertilizer					
30	149.93	171.24	160.6	122.98	122.87	122.93	98.20	90.76	94.48	193.37
	±2.92	± 2.89		± 2.13	± 1.30		± 0.69	±12.98		±3.40
60	202.63	226.61	214.6	173.73	182.65	178.19	150.01	143.84	146.93	224.71
	±2.46	±4.20		±4.54	±1.97		±4.06	±2.36		±2.33
90	216.60	231.58	224.1	188.24	192.88	190.56	151.23	156.45	153.84	227.04
	±3.64	±3.26		±2.90	±1.72		±1.69	±13.31		±0.56
Harvest	215.39	230.25	222.8	187.87	190.46	189.16	149.31	155.89	152.60	231.29
	±1.02	±3.33		±1.82	±0.76		±1.40	±1.97		±4.70
					Without fertilizer					
30	116.14	132.92	124.53	34.87	38.55	36.71	38.19	34.83	36.51	149.82
	±2.16	±3.30		±2.06	±1.82		±1.94	±4.85		±7.25
60	159.02	175.46	167.24	53.02	59.74	56.38	68.99	64.70	66.85	195.14
	±5.50	±5.96		±1.16	±2.16		± 2.66	±7.89		±3.66
90	156.30	167.06	161.68	62.48	66.43	64.46	69.78	67.30	68.54	190.77
	±1.86	±2.63		±2.60	±0.43		±2.36	±4.23		±0.98
Harvest	160.60	165.65	163.13	64.05	65.84	64.95	68.64	66.13	67.39	190.54
	±2.09	±1.25		±1.55	±2.16		±0.97	±4.11		±2.33

Table 6.2.2. LAI of maize under different agroforestry systems (means of 2002-2003 cropping periods)

Days after emergence	Khasi mandarin-based AFS			Alder-based AFS			Khasi pine-based AFS			Control
	BT	BR	Mean	BT	BR	Mean	BT	BR	Mean	
					With fertilizer					
30	1.66	1.75	1.71	1.48	1.64	1.56	0.80	0.77	0.79	3.49
60	2.51	2.58	2.55	2.31	2.38	2.35	1.65	1.68	1.67	4.33
90	3.46	3.56	3.51	3.28	3.56	3.42	2.46	2.60	2.53	5.22
Harvest	1.97	2.12	2.05	1.77	1.84	1.81	1.34	1.41	1.38	3.95
					Without fertilizer					
30	0.96	0.96	0.96	0.84	0.95	0.90	0.46	0.59	0.53	1.87
60	1.26	1.36	1.31	1.24	1.31	1.28	0.71	0.71	0.71	2.24
90	1.92	1.98	1.95	1.84	1.94	1.89	1.31	1.40	1.36	3.17
Harvest	1.17	1.25	1.21	1.21	1.23	1.22	0.64	0.81	0.73	2.10

6.2.4 Root: shoot (R/S) weight ratio

There was a wide variation in the R/S ratio under different AFS and control plots (Table 6.2.4). In the case of fertilized plots, the R/S ratio was higher (0.115) in control plots than the AFS. Among the AFS, it was found maximum in Khasi mandarin-based AFS (0.096) followed by alder- (0.071) and Khasi pine -based (0.047) AFS, when maize plants were grown between the trees in the fertilized plots. When grown between trees under fertilized condition, the highest R/S ratio (0.096) was recorded in Khasi mandarin-based AFS and the lowest in Khasi pine-based AFS (0.039). In unfertilized condition, the maize plants in the control plots showed higher R/S ratio (0.11) than in the Khasi mandarin- (0.11), Khasi pine- (0.052) and alder-based AFS (0.036) when they were grown in between the rows.

Table 6.2.3. Biomass (g m^{-2}) of maize under different agroforestry systems

Days after emergence	Treatments	With fertilizer		Without fertilizer	
		Shoot	Root	Shoot	Root
		Khasi mandarin-based AFS			
30	BT	54.60±5.34	6.60±1.17	19.63±0.61	4.63±0.27
	BR	59.23±4.36	5.30±0.25	24.10±3.15	4.27±0.31
60	BT	889.53±57.25	53.90±5.79	233.23±18.13	25.63±5.71
	BR	1063.13±41.40	60.43±6.98	280.77±5.83	25.13±2.34
90	BT	1844.03±70.53	136.43±34.10	827.17±93.0	71.43±5.93
	BR	2240.00±80.53	123.53±26.70	819.77±55.94	82.97±7.70
124	BT	2180.07±45	208.50±20.74	1071.50±29.75	97.70±12.32
	BR	2607±88.44	213.37±9.66	1110.43±14.82	126.63±9.21
		Alder-based AFS			
30	BT	36.07±2.72	4.33±0.52	9.83±0.95	2.63±0.15
	BR	42.77±1.99	4.47±0.48	11.60±0.40	2.53±0.23
60	BT	263.67±14.88	22.83±1.68	81.07±8.27	3.97±0.12
	BR	325.33±10.38	22.67±1.24	86.00±2.26	5.10±0.67
90	BT	504.83±16.06	27.47±6.39	151.10±25.48	10.97±0.77
	BR	585.33±22.48	29.79±2.15	147.73±22.85	16.00±0.40
124	BT	832.37±15.77	59.27±8.63	470.60±24.0	13.87±2.47
	BR	949.23±17.16	61.63±5.33	512.73±35.0	18.60±1.07
		Khasi pine-based AFS			
30	BT	25.10±1.42	3.27±0.35	8.97±0.56	2.40±0.12
	BR	26.27±1.25	3.17±0.32	9.60±0.61	2.27±0.12
60	BT	250.03±30.71	6.67±0.59	51.17±9.19	3.13±0.24
	BR	248.23±17.67	6.47±0.94	63.93±6.02	3.30±0.26
90	BT	483.33±16.27	16.27±2.18	100.37±10.58	11.67±0.49
	BR	524.00±34.57	17.40±0.53	116.73±6.27	12.23±0.64
124	BT	777.60±22.35	36.57±9.33	341.17±13.21	17.17±1.53
	BR	819.53±17.81	32.20±5.81	366.90±28.55	18.90±2.73
		Control			
30	No tree	58.60±5.23	21.93±2.14	26.77±5.78	3.67±0.29
60	No tree	1173.40±27.49	86.17±5.58	297.33±24.87	24.17±2.74
90	No tree	2518.27±110.8	218.73±14.55	856.10±65.23	99.80±9.0
124	No tree	2986.43±124.20	313.13±55.44	1114.97±49.61	123.70±14.20

BT= Between trees, BR= Between rows

6.2.5 Net Primary Productivity (NPP)

Under fertilized condition, maximum NPP (g m^{-2} day^{-1}) was recorded in the control plots (16.55 g m^{-2} day^{-1}) followed by Khasi mandarin-(13.43 g m^{-2} day^{-1}) alder-(12.54 g m^{-2} day^{-1}), and Khasi pine-based AFS (9.13 g m^{-2} day^{-1}). Without fertilizer

application, the NPP was 8.31 g m^{-2} day^{-1} in the control followed by Khasi mandarin-(10.21 g m^{-2} day^{-1}), alder-(2.42 g m^{-2} day^{-1}) and Khasi pine-based AFS (7.56 g m^{-2} day^{-1}). The peak NPP values were recorded at 90 days after planting in all the AFS except in the Khasi pine-based AFS. In case of fertilized plots, maize planted between the rows showed higher productivity than those planted between the trees in Khasi mandarin AFS (Table 6.2.5).

Table 6.2.4. Root: shoot weight ratio (g m^{-2}) of maize under different agroforestry systems

Agroforestry systems/ Treatments		Days after emergence			
		30	60	90	124
Khasi mandarin-based AFS					
(a) With fertilizer	BT	0.121	0.061	0.074	0.096
	BR	0.089	0.057	0.055	0.082
(b) Without fertilizer	BT	0.270	0.110	0.086	0.091
	BR	0.177	0.090	0.101	0.011
Alder-based AFS					
(a) With fertilizer	BT	0.120	0.087	0.054	0.071
	BR	0.105	0.069	0.051	0.065
(b) Without fertilizer	BT	0.268	0.049	0.073	0.029
	BR	0.281	0.059	0.108	0.036
Khasi pine-based AFS					
(a) With fertilizer	BT	0.130	0.027	0.034	0.047
	BR	0.121	0.026	0.033	0.039
(b) Without fertilizer	BT	0.268	0.061	0.116	0.050
	BR	0.236	0.052	0.105	0.052
Control					
(a) With fertilizer		0.374	0.073	0.087	0.116
(b) Without fertilizer		0.137	0.081	0.140	0.111

BT= Between trees, BR= Between rows

6.2.6 Nutrient accumulation

Maximum NPK accumulation by the crop was recorded in the control plots followed by Khasi mandarin-, alder-and Khasi pine-based AFS. Like biomass production, NPK accumulation was also influenced markedly by planting arrangement. The maize plants grown between the rows showed greater accumulation of N, P and K than those

grown between the trees. Maize planted between the rows in the Khasi mandarin-and alder-based AFS recorded 162% and 48% greater N accumulation, respectively than when they were grown in the Khasi pine-based AFS under fertilized condition. Similar accumulation pattern was also noticed in P and K. Application of fertilizers caused an increase in NPK accumulation over no fertilizer application (Table 6.2.6, Fig. 6.2).

Table 6.2.5. Net primary productivity (g m^{-2} day^{-1}) of maize under different agroforestry systems and control

Days after emergence	Treatments	With fertilizer		Without fertilizer	
		Shoot	Root	Shoot	Root
		Khasi mandarin-based AFS			
30	BT	1.82	0.22	0.65	0.18
	BR	1.97	0.18	0.80	0.14
60	BT	29.65	1.58	7.12	0.68
	BR	33.46	1.84	8.55	0.69
90	BT	31.82	2.75	19.79	1.53
	BR	39.23	2.10	17.96	1.93
124	BT	9.88	2.12	7.18	0.77
	BR	10.79	2.64	8.93	1.28
		Alder-based AFS			
30	BT	1.20	0.14	0.33	0.09
	BR	1.43	0.15	0.38	0.08
60	BT	7.58	0.62	2.37	0.05
	BR	6.08	0.61	2.48	0.09
90	BT	8.04	0.15	2.33	0.23
	BR	8.9	0.24	2.06	0.36
124	BT	10.57	0.94	9.40	0.09
	BR	11.64	0.94	10.73	0.08
		Khasi pine-based AFS			
30	BT	0.83	0.11	0.30	0.08
	BR	0.88	0.11	0.32	0.08
60	BT	7.50	0.11	1.41	0.02
	BR	7.40	0.11	1.81	0.03
90	BT	7.78	0.32	1.64	0.28
	BR	9.19	0.36	1.76	0.30
124	BT	9.81	0.60	7.08	0.16
	BR	8.69	0.44	7.36	0.20
		Control			
30	No tree	1.95	0.73	0.89	0.12
60	No tree	37.16	2.14	9.02	0.68
90	No tree	44.83	4.42	18.63	2.52
124	No tree	13.77	2.78	7.61	0.70

BT= Between trees, BR= Between rows

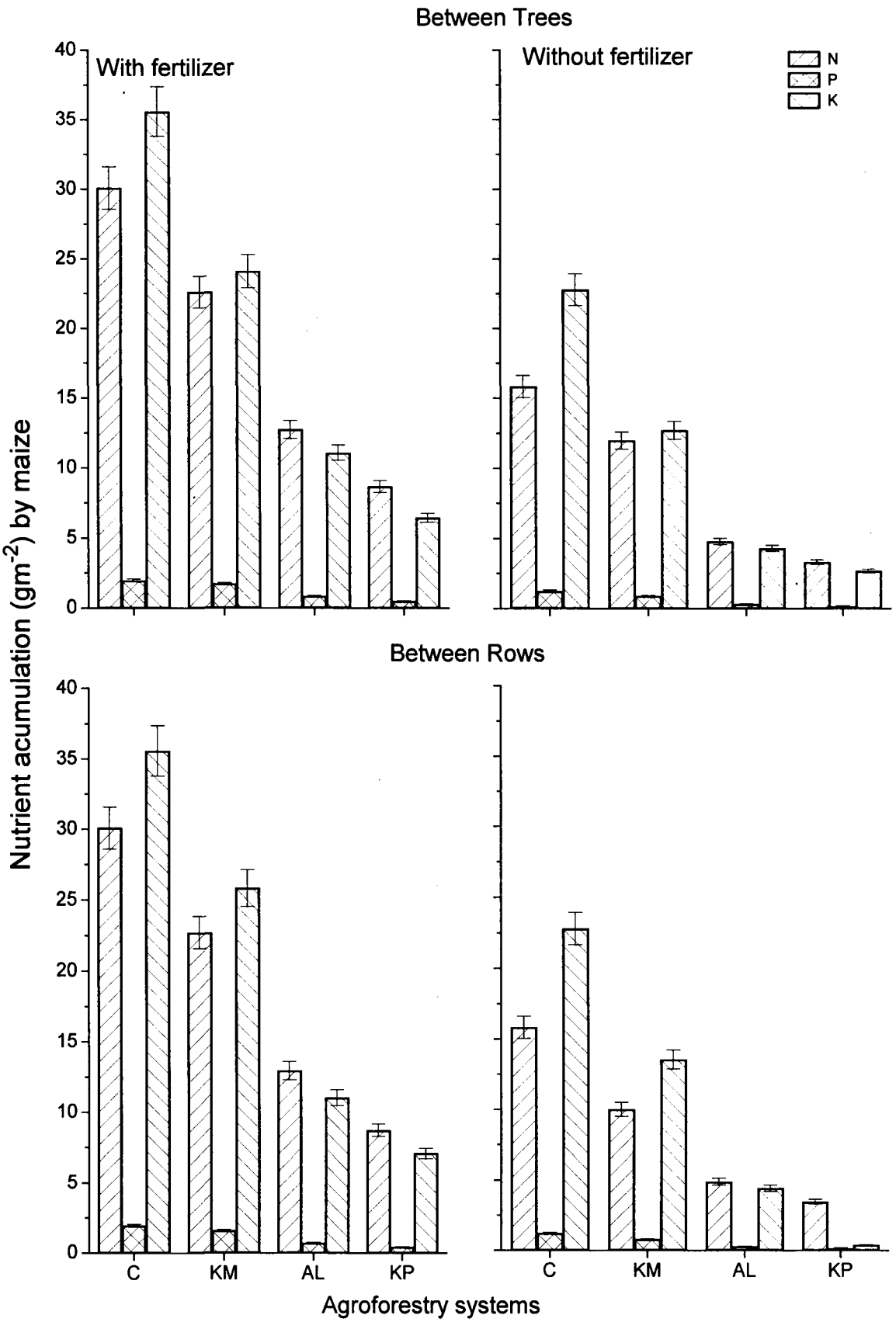


Fig. 6.2. Nutrient accumulation by maize under different AFS and control plots

Table 6.2.6. Nutrient accumulation (g m^{-2}) by maize under different agroforestry systems and control

Agroforestry systems/Treatments		N			P			K		
		AG	BG	Total	AG	BG	Total	AG	BG	Total
Khasi mandarin-based AFS										
(a) With fertilizer	BT	22.37	0.25	22.62	1.63	0.09	1.72	22.49	1.62	24.11
	BR	21.88	0.84	22.72	1.53	0.07	1.60	24.37	1.47	25.84
(b) Without fertilizer	BT	11.58	0.41	11.99	0.85	0.03	0.88	12.01	0.71	12.72
	BR	9.6	0.4	10.00	0.76	0.03	0.79	12.76	0.78	13.54
Alder-based AFS										
(a) With fertilizer	BT	12.35	0.4	12.75	0.82	0.02	0.84	10.65	0.44	11.09
	BR	12.58	0.36	12.94	0.69	0.02	0.71	10.59	0.43	11.02
(b) Without fertilizer	BT	4.69	0.09	4.78	0.3	0.01	0.31	4.19	0.11	4.30
	BR	4.81	0.09	4.90	0.28	0.01	0.29	4.32	0.12	4.44
Khasi pine-based AFS										
(a) With fertilizer	BT	8.39	0.26	8.65	0.47	0.01	0.48	6.16	0.28	6.44
	BR	8.51	0.19	8.70	0.42	0.01	0.43	6.86	0.21	7.07
(b) Without fertilizer	BT	3.2	0.1	3.30	0.18	0.01	0.19	2.55	0.12	2.67
	BR	3.37	0.1	3.47	0.17	0.01	0.18	2.27	0.12	2.39
Control										
(a) With fertilizer		28.95	1.14	30.09	1.86	0.1	1.96	33.25	2.34	35.59
(b) Without fertilizer		15.26	0.56	15.82	1.16	0.07	1.23	21.42	1.38	22.80

BT= Between trees, BR= Between rows, AG = Above ground, BG = Below ground

6.3 Yield

6.3.1 Grain weight

The maximum grain weight per 100-grains in the fertilized plots was recorded in Khasi mandarin-based AFS (30.69g) in between the rows planting and minimum in Khasi pine-based AFS (23.70g) when maize was planted between the trees. In the unfertilized plots, the grain weight was 25.70g in the control plots. Inter-comparing grain weight among planting arrangement, it was maximum in Khasi mandarin-based AFS (23.50g) followed by Khasi pine- (18.25 g) and alder-based AFS (17.70 g) when maize was grown between the rows in fertilized condition (Table 6.3.1).

Table 6.3.1. Grain weight (g/ 100 grain) of maize under different agroforestry systems (means of 2002 and 2003 cropping periods)

Agroforestry systems	Planting arrangement	With fertilizer	Without fertilizer
Khasi mandarin-based AFS	BT	30.03±0.14	23.38±0.50
	BR	30.69±0.24	23.50±0.36
Alder-based AFS	BT	25.12±0.41	17.11±0.95
	BR	23.96±1.59	17.70±0.31
Khasi pine-based AFS	BT	21.27±0.76	17.84±0.66
	BR	21.80±0.86	18.25±0.41
Control	No tree	30.02±0.62	23.70±0.76

BT= Between trees, BR= Between rows

6.3.2 Grain yield

The higher grain yield was recorded in the control plots (460.77 g m^{-2}) than all the AFS. In AFS, the grain yield ranged from 121.90g (Khasi pine-based AFS in the case of between the trees planting situation) to 443.18g m^{-2} (Khasi mandarin-based AFS in between the rows planting) with fertilizer application. Similar trend was observed in the unfertilized plots. In general, grain yield was better when maize was grown in between rows than when it was grown between the trees (Table 6.3.2).

Table 6.3.2. Grain yield (g m^{-2}) of maize under different agroforestry systems (means of 2002 and 2003 cropping periods)

Agroforestry systems	Planting arrangement	With fertilizer	Without fertilizer
Khasi mandarin-based AFS	BT	432.61±3.30	222.44±6.47
	BR	443.18±8.57	226.98±8.36
Alder-based AFS	BT	186.91±4.02	88.02±4.86
	BR	195.18±5.01	96.75±6.21
Khasi pine-based AFS	BT	121.90±2.85	54.39±4.38
	BR	131.43±3.42	68.37±2.68
Control	No tree	460.77±9.68	297.00±2.18

BT= Between trees, BR= Between rows

6.3.3 Harvest Index (HI)

All the AFS recorded marginally higher HI values than the control. Among the AFS, harvest index in the fertilized plots was highest in Khasi mandarin-based AFS in the case of plants grown between the trees (0.180) and lowest (0.150) in Khasi pine AFS in between trees planting. In general, fertilizer application and planting arrangement did not affect the HI to any significant level (Table 6.3.3).

Table 6.3.3. Harvest Index (HI) of maize under different agroforestry systems (means of 2002 and 2003 cropping periods)

Agroforestry systems	Planting arrangement	With fertilizer	Without fertilizer
Khasi mandarin-based AFS	BT	0.180	0.160
	BR	0.160	0.150
Alder-based AFS	BT	0.155	0.180
	BR	0.160	0.185
Khasi pine-based AFS	BT	0.150	0.150
	BR	0.155	0.185
Control	No tree	0.140	0.130

BT= Between trees, BR= Between rows

RICE

6.4 Growth

6.4.1 Height

The plant height was significantly ($P<0.01$) higher in control plots than all the AFS. The maximum plant height was recorded in control plots (86.69cm) followed by Khasi mandarin-based (80.69cm), alder-based (65.33cm), and Khasi pine-based AFS (47.56cm). The plant height showed an increase of 31.00% in Khasi mandarin-based, 64.76% in alder-based and 55% in Khasi pine-based AFS due to fertilizer application, whereas the increase was only 42% in the control plots. The crop plants growing between the rows grew taller than those planted between the trees in all the AFS (Table 6.4.1).

6.4.2 Leaf Area Index (LAI)

The LAI was recorded maximum at 90 days after emergence in all the systems, irrespective of planting arrangement and fertilizers application. In the fertilized plots, LAI was maximum in the control plots (3.93) followed by Khasi mandarin-(3.66), alder-(2.41) and Khasi pine-based AFS (0.57). In the unfertilized plots among the AFS, it was observed higher under Khasi mandarin-(3.97) followed by alder-(0.46) and Khasi pine-(0.22) based AFS. The LAI of plants grown in between rows was higher than those grown in between trees in all the AFS including control plots (Table 6.4.2).

Table 6.4.1. Height (cm) of rice under different agroforestry systems (means of 2002 and 2003 cropping periods)

Treatments/ days after emergence	Khasi mandarin-based AFS			Alder-based AFS			Khasi pine-based AFS			Control mean
	BT	BR	Mean	BT	BR	Mean	BT	BR	Mean	
					With fertilizer					
30	26.79	27.49	27.14	28.9	30.16	29.53	23.38	27.28	25.46	28.67
	±0.62	±0.53		±2.64	±1.12		±0.69	±1.52		±1.30
60	75.05	75.82	75.44	45.345	49.18	47.26	37.50	43.90	40.70	77.41
	±2.79	±1.77		±1.70	±1.17		±2.22	±1.88		±4.99
90	79.70	81.68	80.69	63.41	62.39	62.90	45.24	49.88	47.56	86.69
	±4.70	±4.19		±1.00	±1.73		±1.05	±4.91		±3.14
At harvest	78.77	80.76	79.77	65.495	65.16	65.33	44.35	48.03	46.19	85.44
	±2.61	±1.35		±1.10	±0.49		±0.62	±7.12		±2.43
					Without fertilizer					
30	23.07	22.80	22.94	15.33	17.79	16.56	14.36	15.99	15.18	23.52
	±0.47	±0.94		±0.16	±3.10		±0.40	±0.65		±0.73
60	52.51	56.04	54.28	34.40	35.37	34.88	21.62	26.52	24.07	51.66
	±2.58	±3.85		±0.75	±1.12		±0.60	±2.20		±1.76
90	60.61	63.18	61.46	41.51	40.09	40.80	32.09	31.21	31.65	64.84
	±0.51	±1.76		±0.52	±1.19		±0.34	±1.58		±1.56
Harvest	59.76	62.02	60.89	38.52	40.79	39.65	30.08	29.36	29.72	59.78
	±1.01	±1.18		±3.95	±1.98		±0.30	±2.84		±0.93

BT= Between trees, BR= Between rows

Table 6.4.2. LAI of rice under different agroforestry systems (means of 2002 and 2003 cropping periods)

Treatments/ days after emergence	Khasi mandarin-based AFS			Alder-based AFS			Khasi pine-based AFS			Control mean
	BT	BR	Mean	BT	BR	Mean	BT	BR	Mean	
	With fertilizer									
30	0.19	0.23	0.21	0.07	0.11	0.09	0.07	0.08	0.08	0.32
60	3.07	3.20	3.14	1.39	1.68	1.54	0.27	0.49	0.38	3.41
90	4.80	2.52	3.66	2.30	2.52	2.41	0.45	0.68	0.57	5.53
Harvest	2.78	2.90	2.84	1.17	1.60	1.39	0.34	0.43	0.39	3.16
	Without fertilizer									
30	0.10	0.11	0.11	0.01	0.02	0.02	0.01	0.01	0.01	0.12
60	2.11	2.38	2.25	0.26	0.30	0.28	0.10	0.15	0.13	2.49
90	5.16	2.78	3.97	0.43	0.48	0.46	0.23	0.21	0.22	2.87
Harvest	2.02	2.17	2.10	0.15	0.20	0.18	0.11	0.13	0.12	2.28

BT= Between trees, BR= Between rows

6.4.3 Biomass

In control plots peak crop biomass was 1625.33 g m^{-2} with fertilizer and 797.07 g m^{-2} without fertilizer application. The rice plants grown in the Khasi mandarin and Khasi pine-based AFS registered maximum (1450.27 g m^{-2}) and minimum (1001.20 g m^{-2}) peak biomass respectively in the fertilized plots when planted in between the rows. In general, crops planted between rows gave higher yield than when planted between trees irrespective of fertilizer application (Table 6.4.3, Fig. 6.3).

6.4.4 Root: shoot (R/S) weight ratio

There was no regular trend in the R/S ratio under different AFS, irrespective of treatments. In control plots, the maximum R/S ratio was 0.29 with fertilizer and 0.20 without fertilizer application. Among the different AFS, maximum R/S ratio was registered in the Khasi pine-based AFS under "between rows planting" (0.25) and minimum in Khasi mandarin-based AFS under "between trees planting" (0.22) on fertilizer application. The "between rows planting" yielded higher R/S ratio compared to "between trees planting" irrespective of fertilizer application (Table 6.4.4).

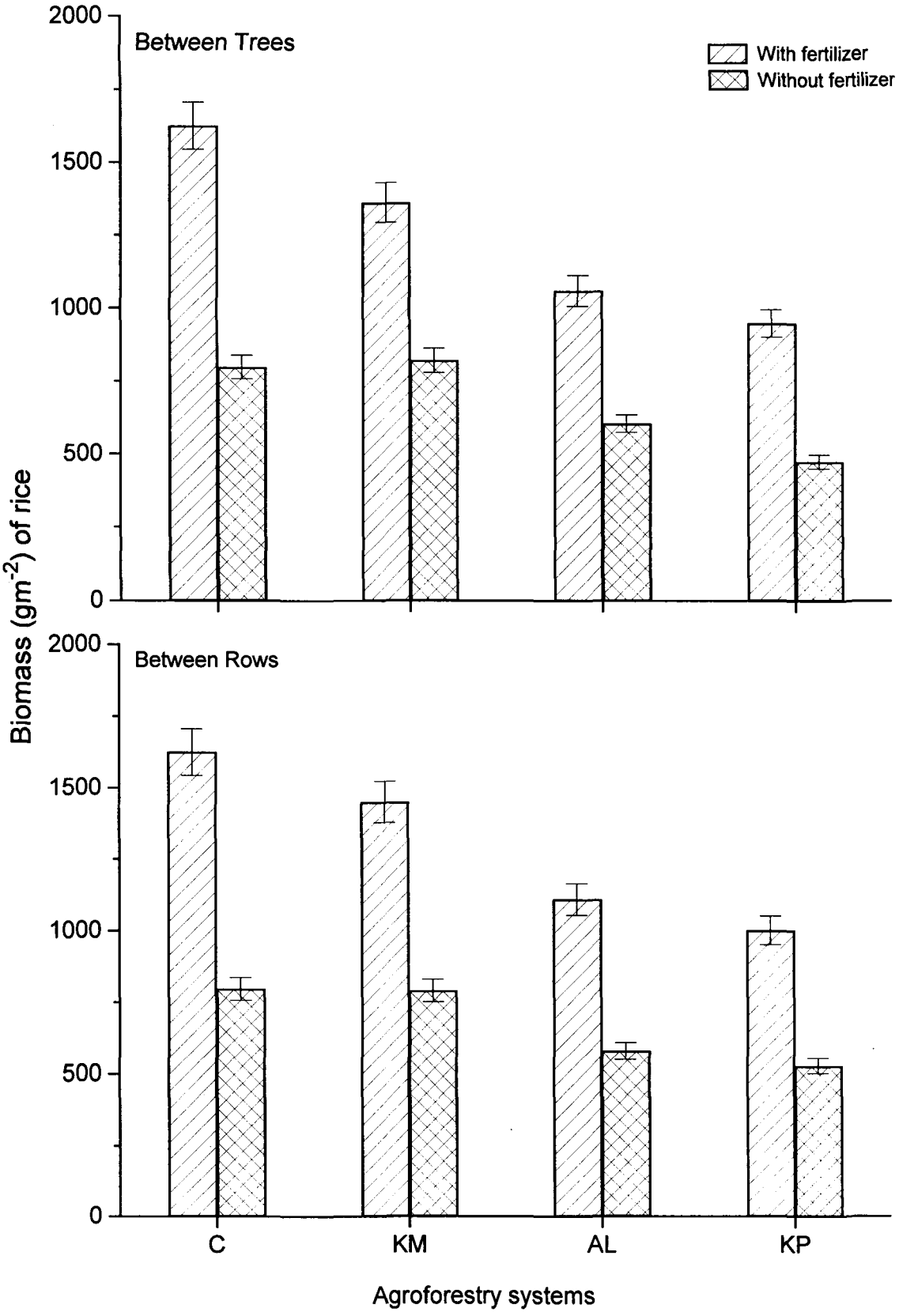


Fig. 6.3. Biomass of rice in different AFS and control plots

Table 6.4.3. Biomass (g m^{-2}) of rice under different agroforestry systems

Days after emergence	Treatments	With fertilizer		Without fertilizer	
		Shoot	Root	Shoot	Root
		Khasi mandarin-based AFS			
30	BT	77.07±5.48	26.27±4.72	64.0±6.74	18.13±1.04
	BR	65.2±6.67	21.33±0.48	58.0±4.62	17.2±1.01
60	BT	490.53±18.04	52.93±1.64	376.53±35.94	27.87±1.09
	BR	491.87±49.19	55.73±0.35	387.47±48.71	34.53±5.57
90	BT	636.67±37.61	79.87±5.20	426.13±32.15	44.0±0.80
	BR	648.8±6.08	78.67±2.91	450.53±35.60	45.2±1.06
132	BT	1120.2±29.73	240.4±3.89	698.53±47.81	121.2±5.61
	BR	1187.6±28.53	262.67±21.48	672.8±25.63	118.0±17.84
		Alder-based AFS			
30	BT	43.47±5.73	17.73±2.09	32.8±0.61	10.67±0.74
	BR	50.67±4.20	18.0±1.84	33.07±2.25	11.2±0.61
60	BT	238.93±15.77	37.6±1.62	90.4±4.18	12.67±0.71
	BR	215.87±15.64	39.07±1.39	91.87±2.31	14.27±1.35
90	BT	294.93±13.52	65.2±3.67	133.47±4.07	27.07±2.37
	BR	277.2±24.46	58.4±4.69	136.93±1.74	26.4±2.45
132	BT	866.4±82.83	191.07±10.66	499.07±38.54	104.0±11.0
	BR	888.93±57.42	221.33±44.25	486.67±42.55	93.07±9.45
		Khasi pine-based AFS			
30	BT	31.73±5.26	7.07±0.48	20.13±0.53	3.6±0.46
	BR	34.00±4.32	9.47±1.04	22.8±1.62	4.67±0.71
60	BT	114.4±6.06	27.6±0.69	58.13±2.10	12.93±0.35
	BR	149.73±13.0	42.4±2.45	73.2±4.17	18.93±1.57
90	BT	154.93±4.57	33.87±1.97	84.4±3.20	20.0±1.06
	BR	199.47±2.60	40.93±2.58	102.13±1.97	23.07±1.35
132	BT	766.13±51.66	179.2±14.05	383.6±22.46	88.8±3.63
	BR	799.2±3.13	202.0±5.15	420.27±30.49	108.0±5.30
		Control			
30	No tree	81.47±14.14	22.67±2.22	74.8±7.39	18.4±0.92
60	No tree	541.47±33.20	76.27±3.58	408.4±31.05	50.0±2.21
90	No tree	656.67±15.91	74.53±4.59	481.73±37.71	49.47±8.52
132	No tree	1253.33±52.31	372.00±32.12	664.4±25.66	132.67±14.73

BT= Between trees, BR= Between rows

Table 6.4.4. Root: shoot weight ratio (g m^{-2}) of rice under different agroforestry systems

Agroforestry systems/ Treatments		Days after emergence			
		30	60	90	132
Khasi mandarin-based AFS					
(a) With fertilizer	BT	0.341	0.108	0.125	0.215
	BR	0.327	0.113	0.121	0.221
(b) Without fertilizer	BT	0.283	0.074	0.103	0.174
	BR	0.297	0.089	0.100	0.175
Alder-based AFS					
(a) With fertilizer	BT	0.408	0.157	0.221	0.221
	BR	0.355	0.181	0.211	0.249
(b) Without fertilizer	BT	0.325	0.140	0.203	0.208
	BR	0.339	0.155	0.193	0.191
Khasi pine-based AFS					
(a) With fertilizer	BT	0.223	0.241	0.219	0.234
	BR	0.279	0.283	0.255	0.253
(b) Without fertilizer	BT	0.179	0.222	0.237	0.231
	BR	0.205	0.259	0.226	0.257
Control					
(a) With fertilizer		0.278	0.141	0.144	0.297
(b) Without fertilizer		0.246	0.122	0.123	0.200

BT= Between trees, BR= Between rows

6.4.5 Net Primary Productivity (NPP)

In control plots, the peak NPP values at the final harvest were 20.82 g m^{-2} day^{-1} with fertilizer and 4.08 g m^{-2} day^{-1} without fertilizer application. Among the different AFS, Khasi pine-based AFS recorded highest NPP values under "between trees planting" (16.61 g m^{-2} day^{-1}) and the lowest in Khasi mandarin-based AFS under "between trees planting' (14.33 g m^{-2} day^{-1}) in the fertilizer-applied plots at final harvest. There was a marked improvement in NPP at all the growth stages of crop, irrespective of fertilizer application and planting arrangement in different AFS (Table 6.4.5).

Table 6.4.5. Net primary productivity (g m^{-2} day^{-1}) of rice under different agroforestry systems and control

Days after emergence	Treatments	With fertilizer		Without fertilizer	
		Shoot	Root	Shoot	Root
		Khasi mandarin-based AFS			
30	BT	2.57	0.87	2.13	0.60
	BR	2.17	0.71	1.93	0.57
60	BT	13.78	0.89	10.42	0.32
	BR	14.22	1.15	10.98	0.58
90	BT	4.87	0.90	1.65	0.54
	BR	5.23	0.76	2.10	0.36
132	BT	11.51	3.82	6.48	1.84
	BR	12.83	4.38	5.29	1.73
		Alder-based AFS			
30	BT	1.45	0.59	1.09	0.35
	BR	1.69	0.60	1.10	0.37
60	BT	6.52	0.66	1.92	0.07
	BR	5.51	0.70	1.96	0.10
90	BT	1.87	0.92	1.43	0.48
	BR	2.04	0.64	1.50	0.40
132	BT	13.61	3.00	8.70	1.83
	BR	14.56	3.88	8.33	1.58
		Khasi pine-based AFS			
30	BT	1.06	0.24	0.67	0.12
	BR	1.13	0.32	0.76	0.16
60	BT	2.76	0.68	1.27	0.31
	BR	3.86	1.10	1.68	0.47
90	BT	1.35	0.21	0.88	0.23
	BR	1.66	0.28	0.96	0.14
132	BT	14.55	3.46	7.12	1.64
	BR	14.27	3.60	7.57	2.02
		Control			
30	No tree	2.72	0.75	2.49	0.61
60	No tree	15.33	1.79	11.12	1.05
90	No tree	3.84	0.61	2.44	0.32
132	No tree	14.21	6.61	2.34	1.74

BT= Between trees, BR= Between rows

6.4.6 Nutrient accumulation

The crop cultivated in different AFS showed reduction in nutrient accumulation compared to the control plots. Under different AFS, maximum NPK accumulation was

registered in the Khasi mandarin-based AFS followed by alder-based and Khasi pine-based AFS. The "between rows planting" of the crop showed greater nutrient accumulation than when the crop was planted between the trees. Rice planted between the rows in Khasi mandarin-and alder-based AFS recorded 97% and 24 % higher N accumulation, respectively than in the Khasi pine based-AFS under fertilized condition. Phosphorus and potassium also showed similar accumulation pattern. The N, P and K accumulation increased due to fertilizer application (Table 6.4.6, Fig. 6.).

6.5 Yield

6.5.1 Grain weight

The maximum (2.82g) grain weight per 100-grain was recorded in the control plots. In the fertilized plots, the grain weight was registered highest in Khasi mandarin-based AFS (2.60g in the "between trees planting" and 2.77g in the "between rows planting") whereas it was lowest in Khasi pine-based AFS (2.59g in the "between trees planting" and 2.60g in the "between rows planting"). The rice, planted between the rows, yielded greater grain yield than that planted in between the trees. Application of fertilizer and planting arrangement had significant ($P< 0.01$) effect on the grain weight in different AFS and control plots (Table 6.5.1).

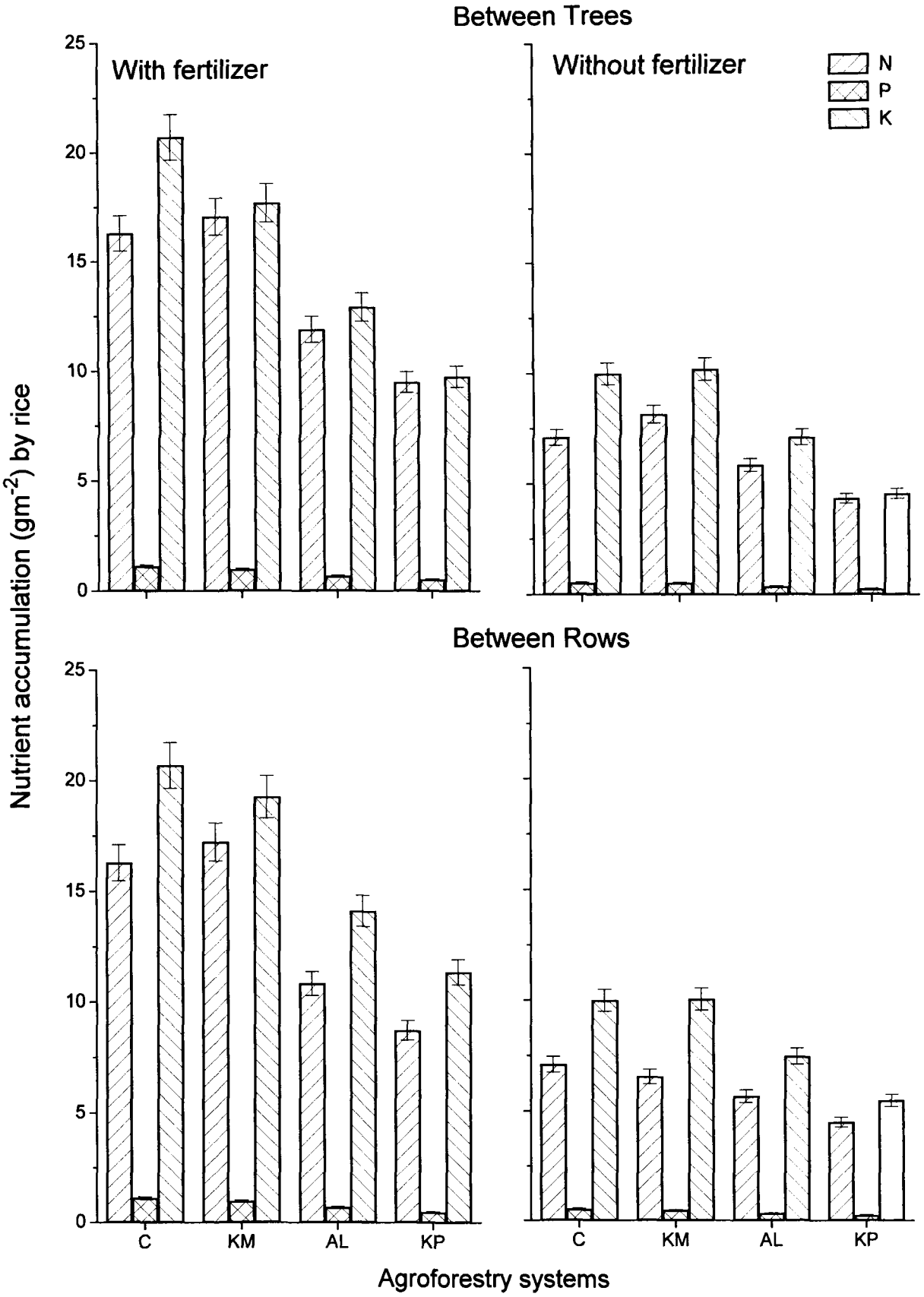


Fig. 6.4. Nutrient accumulation by rice under different AFS and control plots

Table 6.4.6. Nutrient accumulation (g m^{-2}) by rice under different agroforestry systems

Agroforestry systems/Treatments		N			P			K		
		AG	BG	Total	AG	BG	Total	AG	BG	Total
					Khasi mandarin-based AFS					
(a) With fertilizer	BT	15.32	1.72	17.04	0.87	0.10	0.97	15.75	1.91	17.66
	BR	15.65	1.58	17.23	0.86	0.11	0.97	17.08	2.19	19.27
(b) Without fertilizer	BT	7.44	0.7	8.14	0.47	0.05	0.52	9.28	0.91	10.19
	BR	5.93	0.62	6.55	0.43	0.05	0.48	9.14	0.91	10.05
					Alder-based AFS					
(a) With fertilizer	BT	10.71	1.16	11.87	0.59	0.08	0.67	11.34	1.53	12.87
	BR	9.41	1.43	10.84	0.52	0.17	0.69	12.32	1.79	14.11
(b) Without fertilizer	BT	5.34	0.51	5.85	0.32	0.04	0.36	6.31	0.79	7.10
	BR	5.09	0.58	5.67	0.26	0.07	0.33	6.69	0.78	7.47
					Khasi pine-based AFS					
(a) With fertilizer	BT	8.33	1.14	9.47	0.46	0.06	0.52	8.37	1.36	9.73
	BR	7.31	1.42	8.73	0.42	0.06	0.48	9.87	1.5	11.37
(b) Without fertilizer	BT	3.91	0.42	4.33	0.22	0.03	0.25	3.94	0.61	4.55
	BR	4	0.49	4.49	0.22	0.02	0.24	4.81	0.67	5.48
					Control					
(a) With fertilizer		14.45	1.84	16.29	0.95	0.17	1.12	17.67	3.03	20.70
(b) Without fertilizer		6.49	0.61	7.10	0.48	0.05	0.53	8.94	1.05	9.99

BT= Between trees, BR= Between rows, AG = Above ground, BG = Below ground

Table 6.5.1. Grain weight (g/ 100 grain) of rice under different agroforestry systems (means of 2002 and 2003 cropping periods)

Agroforestry systems	Planting arrangement	With fertilizer	Without fertilizer
Khasi mandarin-based	BT	2.60±0.03	2.41±0.02
AFS	BR	2.77±0.02	2.45±0.01
Alder-based AFS	BT	2.56±0.01	2.40±0.03
	BR	2.70±0.09	2.46±0.02
Khasi pine-based AFS	BT	2.59±0.02	2.32±0.03
	BR	2.60±0.02	2.21±0.02
Control	No tree	2.82±0.02	2.59±0.03

BT= Between trees, BR= Between rows

6.5.2 Grain yield

In the fertilized control plots, grain yield was maximum (285.53 g m^{-2}) followed by Khasi mandarin- (267.73 g m^{-2} in the "between trees planting" and 274.93 g m^{-2} in the "between rows planting"), alder- (155.80 g m^{-2} in the "between trees planting" and 157.46 g m^{-2} in the "between rows planting") and Khasi pine-based AFS (95.27 in the "between trees planting" and 100.80 g m^{-2} in the "between rows planting"). Crop planted between the rows showed better yield than that planted between the trees. In the fertilized plots of Khasi mandarin-based AFS, crop planted between the rows gave improved grain yield (2.7% increase) over that planted between the trees. Similar trend was observed in the alder-and Khasi pine-based AFS (Table 6.5.2).

Table 6.5.2. Grain yield (g m^{-2}) of rice under different agroforestry systems (means of 2002 and 2003 cropping periods)

Agroforestry systems	Planting arrangement	With fertilizer	Without fertilizer
Khasi mandarin-based AFS	BT	267.73±6.66	155.00±2.30
	BR	274.93±6.10	155.06±7.30
Alder-based AFS	BT	155.80±1.63	119.40±2.05
	BR	157.46±7.59	124.73±2.24
Khasi pine-based AFS	BT	95.27±3.07	69.80±0.31
	BR	100.80±6.71	80.13±4.65
Control	No tree	285.53±9.78	193.06±1.51

BT= Between trees, BR= Between rows

6.5.3 Harvest Index (HI)

Planting arrangement did not alter the harvest index much, but the fertilizer application. The highest harvest index was recorded in Khasi mandarin-AFS in the "between trees planting" (0.20) and lowest in Khasi pine-based AFS (0.10) in the fertilized plots (Table 6.5.3).

Table 6.5.3. Harvest Index (HI) of rice under different agroforestry systems (means of 2002 and 2003 cropping periods)

Agroforestry systems	Planting arrangement	With fertilizer	Without fertilizer
Khasi mandarin-based AFS	BT	0.197	0.188
	BR	0.190	0.192
Alder-based AFS	BT	0.146	0.199
	BR	0.141	0.210
Khasi pine-based AFS	BT	0.100	0.146
	BR	0.100	0.152
Control	No tree	0.177	0.240

BT= Between trees, BR= Between rows

GINGER

6.6 Growth

6.6.1 Height

The plant height of the crop in fertilized plots was significantly ($P< 0.01$) greater in the control plots than the AFS. Among the AFS, ginger plant in the Khasi mandarin-based AFS registered maximum (61.16cm) height, while in the Khasi pine-based AFS, it attained the lowest height (49.15cm). The height of ginger plants was 9.39% (in Khasi mandarin-based AFS) to 45.02% (in Khasi pine-based AFS) higher in the fertilized plots than in the unfertilized plots. Planting arrangement also affected the plant height markedly and it was greater in the "between rows planting" than in the "between trees planting" in all the AFS (Table 6.6.1).

Table 6.6.1. Height (cm) of ginger under different agroforestry systems (means of 2002 and 2003 cropping periods)

Treatments/ days after emergence	Khasi mandarin-based AFS			Alder-based AFS			Khasi pine-based AFS			Control
	BT	BR	Mean	BT	BR	Mean	BT	BR	Mean	
					With fertilizer					
30	43.64	45.79	44.72	34.63	40.92	37.78	31.59	37.96	34.78	42.95
	±1.40	±0.82		±0.79	±0.86		±0.67	±0.81		±1.30
60	57.50	59.82	58.66	50.41	51.31	50.86	47.97	45.98	46.98	55.71
	±0.84	±0.62		±1.32	±1.29		±1.02	±3.08		±1.60
90	60.47	61.84	61.16	56.42	53.11	54.77	49.52	51.69	50.61	59.68
	±0.69	±2.65		±1.62	±1.04		±0.97	±3.68		±2.60
Harvest	59.04	61.16	60.10	51.68	51.80	51.74	47.86	50.44	49.15	58.22
	±0.31	±1.97		±0.33	±1.53		±0.64	±0.52		±0.18
					Without fertilizer					
30	39.69	40.50	40.10	32.44	34.38	33.41	26.53	25.29	25.91	35.68
	±2.02	±2.52		±0.37	±0.73		±1.19	±1.43		±0.90
60	52.50	54.15	53.33	42.49	42.17	42.33	39.34	34.97	37.16	50.39
	±1.59	±1.73		±0.71	±1.23		±1.51	±1.63		±1.12
90	55.52	56.07	55.80	43.94	44.67	44.31	41.99	32.91	37.45	49.14
	±0.66	±0.68		±2.41	±1.33		±1.00	±1.39		±0.77
Harvest	54.56	53.54	54.94	41.67	42.62	42.15	40.49	34.78	37.64	47.65
	±0.50	±0.54		±1.18	±1.15		±0.86	±1.28		±1.51

BT= Between trees, BR= Between rows

6.6.2 Leaf Area Index (LAI)

The LAI was higher (0.65) in the Khasi mandarin-based AFS followed control plot (0.62), alder-(0.36) and Khasi pine-based (0.32) AFS in fertilized plots. The LAI was found higher under "between trees planting" than under "between rows planting" in all the AFS. The peak LAI was recorded at 90 days after planting in all the AFS irrespective of planting arrangement and fertilizer application (Table 6.6.2).

Table 6.6.2. LAI of ginger under different AFS agroforestry systems (means of 2002 and 2003 cropping periods)

Treatments/ days after emergence	Khasi mandarin-based AFS			Alder-based AFS			Khasi pine-based AFS			Control
	BT	BR	Mean	BT	BR	Mean	BT	BR	Mean	
	With fertilizer									
30	0.16	0.15	0.16	0.13	0.11	0.12	0.10	0.09	0.10	0.15
60	0.54	0.51	0.53	0.28	0.28	0.28	0.27	0.26	0.27	0.39
90	0.67	0.63	0.65	0.37	0.34	0.36	0.32	0.32	0.32	0.62
Harvest	0.41	0.40	0.41	0.27	0.26	0.27	0.26	0.25	0.26	0.39
	Without fertilizer									
30	0.08	0.08	0.08	0.08	0.07	0.08	0.04	0.04	0.04	0.10
60	0.31	0.24	0.28	0.21	0.20	0.21	0.16	0.16	0.16	0.21
90	0.33	0.32	0.33	0.26	0.25	0.26	0.22	0.21	0.22	0.30
Harvest	0.27	0.25	0.26	0.20	0.20	0.20	0.14	0.14	0.14	0.20

BT= Between trees, BR= Between rows

6.6.3 Biomass

The crop biomass was significant ($P<0.01$) in different systems, irrespective of treatments. The highest biomass was recorded in Khasi mandarin-based AFS (469.6g m^{-2}) and the lowest was in Khasi pine-based AFS (266.7 g m^{-2}) under "between rows planting". The biomass was higher under the "between rows planting" than under the "between trees planting" in the AFS and control plots. In different AFS, application of fertilizers showed an increase in the biomass to the extent of 30% in Khasi mandarin-based AFS, 13% in alder-based AFS and 12% in Khasi pine-based AFS (Table 6.6.3, Fig. 6.5).

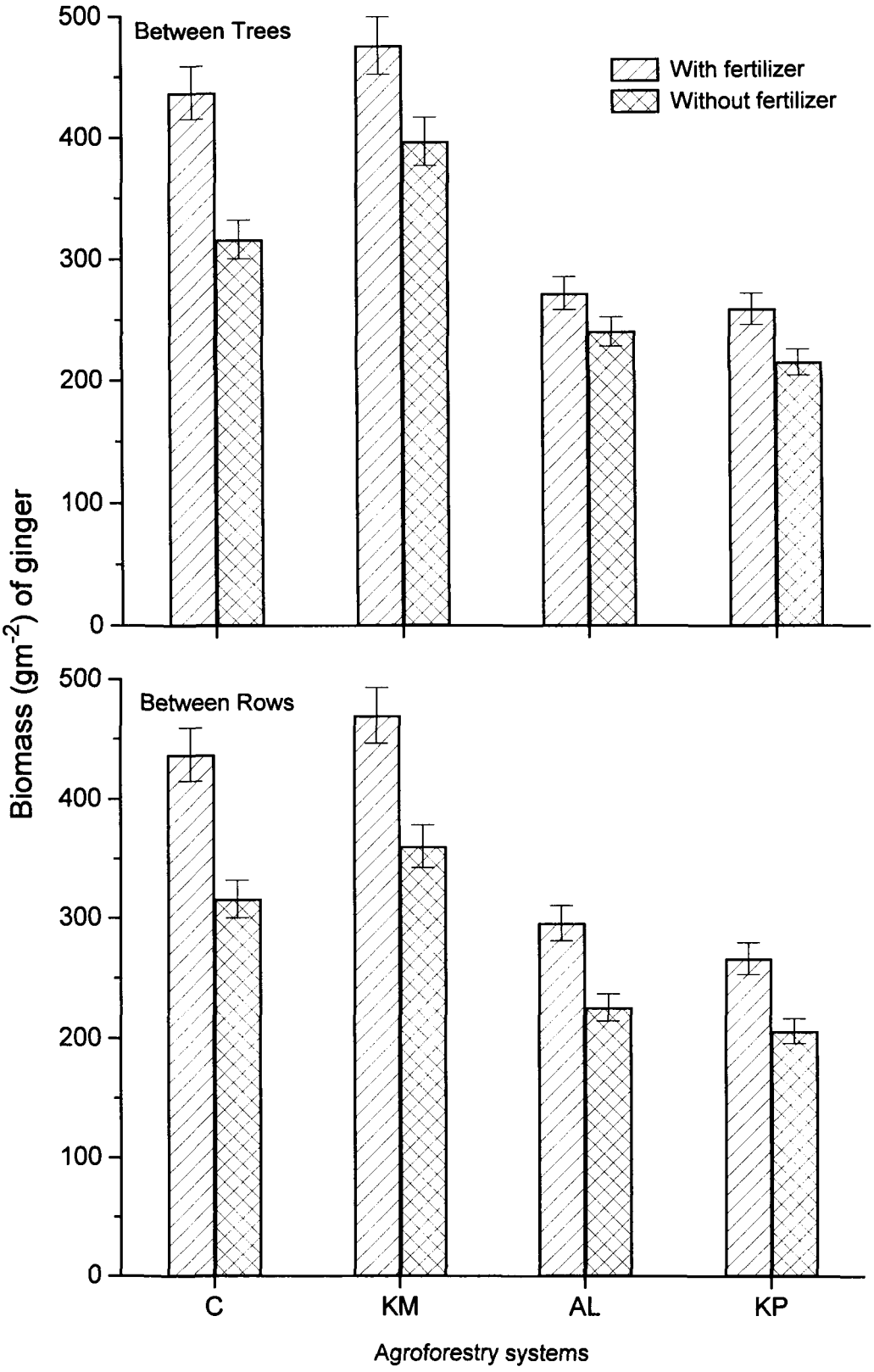


Fig. 6.5. Biomass of ginger in different AFS and control plots

Table 6.6.3. Biomass (g m^{-2}) of ginger under different agroforestry systems

Days after emergence	Treatments	With fertilizer		Without fertilizer	
		Shoot	Root/rhizome	Shoot	Root/rhizome
		Khasi mandarin-based AFS			
30	BT	4.64±0.42	31.81±1.58	3.68±0.17	26.25±0.99
	BR	4.69±0.47	30.27±1.48	4.13±0.19	25.63±0.61
60	BT	32.32±1.14	43.48±1.97	24.45±2.59	32.19±1.80
	BR	23.72±0.89	42.27±1.08	29.71±1.05	31.29±0.84
90	BT	112.40±5.73	245.36±7.90	92.53±5.07	210.80±7.85
	BR	121.33±12.50	247.55±7.15	78.80±3.56	204.67±6.47
240	BT	177.04±9.39	298.25±6.43	117.52±17.26	278.80±5.24
	BR	180.13±7.61	289.46±7.85	125.01±14.85	235.61±2.96
		Alder-based AFS			
30	BT	4.00±0.05	24.35±0.66	3.23±0.14	20.31±0.65
	BR	4.00±0.12	25.17±0.39	3.33±0.33	20.50±0.41
60	BT	24.93±0.71	28.36±0.36	19.79±0.15	23.17±0.98
	BR	25.73±1.75	27.94±0.76	19.06±0.99	22.85±0.74
90	BT	79.68±5.50	128.35±8.07	73.25±4.16	110.89±6.15
	BR	83.33±7.47	134.91±7.02	78.00±6.72	103.95±7.47
240	BT	103.68±5.85	167.82±4.25	87.49±5.69	152.44±6.30
	BR	104.67±4.53	191.47±5.25	87.20±3.85	138.85±2.29
		Khasi pine-based AFS			
30	BT	3.63±0.27	24.76±1.11	3.20±0.05	16.96±0.78
	BR	3.87±0.12	24.57±1.03	3.23±0.10	15.63±0.37
60	BT	23.47±0.67	27.73±1.06	14.85±1.07	18.35±0.38
	BR	23.76±0.73	28.72±2.27	17.12±2.18	18.03±0.28
90	BT	74.69±8.79	98.94±3.61	61.87±5.78	77.39±2.65
	BR	74.96±8.97	94.75±9.57	59.49±6.38	76.08±3.03
240	BT	92.13±3.58	166.19±3.22	77.33±4.30	137.11±3.25
	BR	103.23±5.58	163.49±2.98	85.33±7.15	121.14±2.99
		Control			
30	No tree	4.48±0.53	29.99±0.69	3.89±0.19	26.05±0.99
60	No tree	32.72±1.20	35.65±1.79	28.08±0.24	29.05±0.85
90	No tree	109.44±8.29	243.28±3.03	88.19±5.43	170.37±4.79
240	No tree	169.37±7.50	266.25±4.47	110.40±5.80	203.92±2.30

BT= Between trees, BR= Between rows

6.6.4 Root: shoot (R/S) ratio

There was a wide variation in R/S ratio under different AFS and control plots. The fertilized plots of Khasi mandarin AFS showed the highest R/S ratio while it was lowest in alder based AFS under between trees planting arrangement at 30 days after

planting. Application of fertilizer and planting arrangement did not show any marked effect on R/S ratio (Table 6.6.4a).

In general root/rhizome ratio was higher in unfertilized than the fertilized plots in all the systems. Among the AFS, "between trees planting" resulted in higher root/rhizome ratio than "between rows planting". Root/rhizome ratio was recorded highest (0.08) in Khasi pine AFS in "between trees planting" and lowest in Khasi mandarin AFS (0.04) in "between rows planting" under fertilized plots (Table 6.6.4b).

6.6.5 Net Primary Productivity (NPP)

The NPP was highest (0.67 g m^{-2} day^{-1}) in Khasi mandarin-based AFS and lowest (0.65 g m^{-2} day^{-1}) in the "between rows planting" under fertilized plots. Planting arrangement had no marked effect on net primary productivity. In general, NPP of ginger was lower at initial stage of growth and higher at 90 days after planting and thereafter it decreased (Table 6.6.5).

Table 6.6.4a. Root: shoot weight ratio (g m^{-2}) of ginger under different agroforestry systems

Agroforestry systems/ Treatments		Days after emergence			
		30	60	90	240
Khasi mandarin-based AFS					
(a) With fertilizer	BT	6.856	1.345	2.183	1.685
	BR	6.454	1.782	2.040	1.607
(b) Without fertilizer	BT	7.133	1.317	2.278	2.372
	BR	6.206	1.053	2.597	1.885
Alder-based AFS					
(a) With fertilizer	BT	6.088	1.138	1.611	1.619
	BR	6.293	1.086	1.619	1.829
(b) Without fertilizer	BT	6.288	1.171	1.514	1.742
	BR	6.156	1.199	1.333	1.592
Khasi pine-based AFS					
(a) With fertilizer	BT	6.821	1.182	1.325	1.804
	BR	6.349	1.209	1.264	1.584
(b) Without fertilizer	BT	5.300	1.236	1.251	1.773
	BR	4.839	1.053	1.279	1.420
Control					
(a) With fertilizer	No tree	6.694	1.090	2.223	1.572
(b) Without fertilizer	No tree	6.697	1.035	1.932	2.847

BT= Between trees, BR= Between rows

Table 6.6.4b. Root: rhizome weight ratio of ginger at the time of harvest under different AFS and control

Agroforestry systems	Planting arrangement	With fertilizer	Without fertilizer
Khasi mandarin-based AFS	BT	0.05	0.04
	BR	0.04	0.05
Alder-based AFS	BT	0.07	0.07
	BR	0.06	0.07
Khasi pine-based AFS	BT	0.08	0.07
	BR	0.07	0.09
Control	No tree	0.04	0.05

BT= Between trees, BR= Between rows

6.6.6 Nutrient accumulation

The maximum NPK accumulation by the crop was recorded in Khasi mandarin-based AFS followed by control plots alder- and Khasi pine-based AFS. Crop planted between the rows showed greater accumulation than those planted between the trees. Total N accumulation was maximum (4.72g m^{-2}) in Khasi mandarin-based AFS and minimum (2.54g m^{-2}) in Khasi pine-based AFS under "between trees planting" followed by the control and alder-based AFS in fertilized plots. Application of fertilizer caused marked improvement in total N accumulation in all the systems. Available phosphorus and potassium also showed similar trend in all the systems (Table 6.6.6, Fig. 6.).

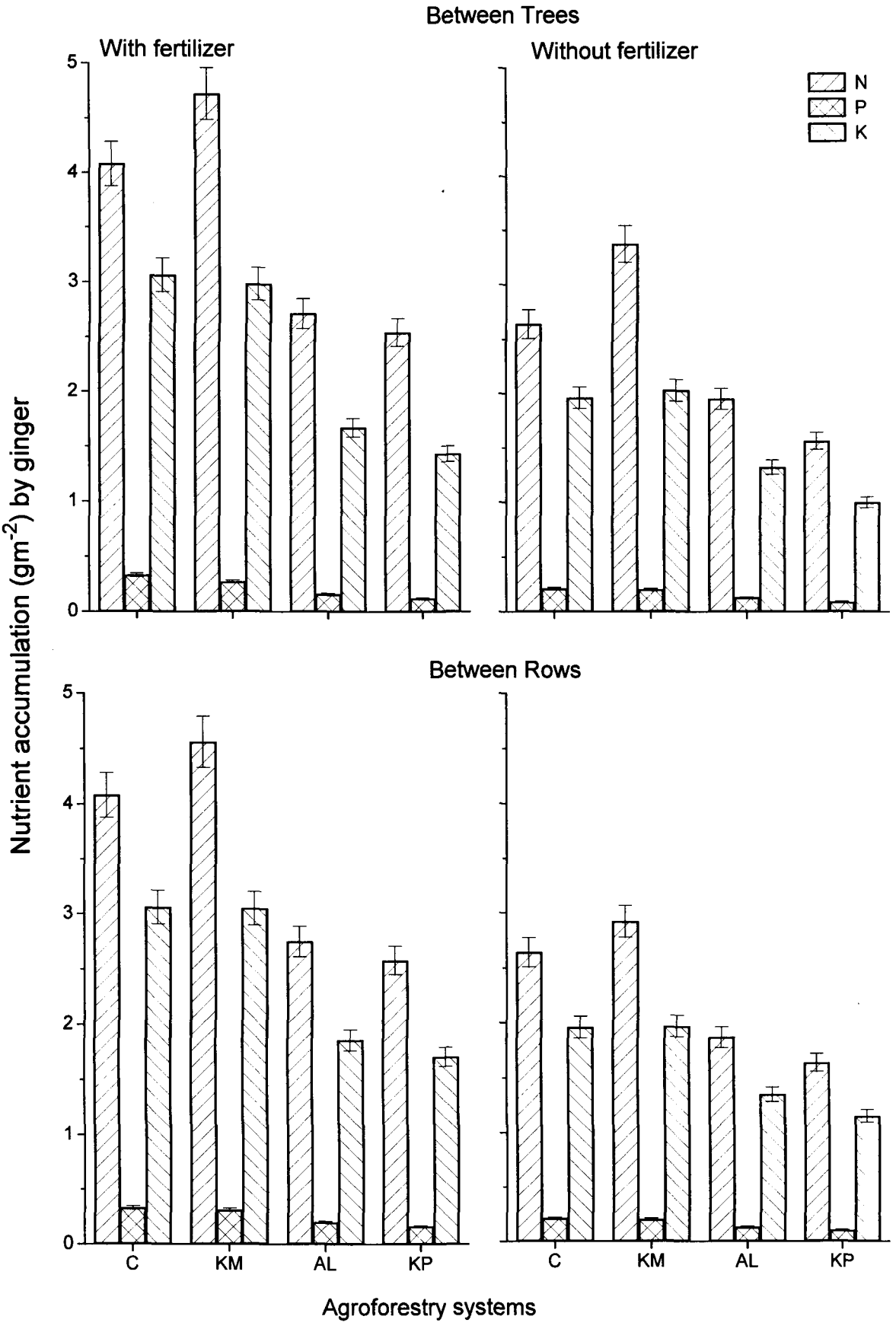


Fig. 6.6. Nutrient accumulation by ginger under different AFS and control plots

Table 6.6.5. Net primary productivity (g m^{-2} day^{-1}) of ginger under different agroforestry systems and control

Days after emergence	Treatments	With fertilizer		Without fertilizer	
		Shoot	Root	Shoot	Root
		Khasi mandarin based AFS			
30	BT	0.15	1.06	0.12	0.87
	BR	0.16	1.01	014	0.85
60	BT	0.92	0.39	0.69	0.19
	BR	0.63	0.40	0.85	0.19
90	BT	2.67	6.73	2.27	5.95
	BR	3.25	6.84	1.64	5.78
240	BT	0.43	0.35	0.17	0.45
	BR	0.39	0.28	0.31	0.21
		Alder based AFS			
30	BT	0.13	0.81	0.11	0.68
	BR	0.13	0.84	0.11	0.68
60	BT	0.70	0.13	0.55	0.09
	BR	0.72	0.09	0.52	0.07
90	BT	1.82	3.33	1.78	2.92
	BR	1.92	3.56	1.96	2.70
240	BT	0.16	0.26	0.09	0.28
	BR	0.42	0.38	0.06	0.23
		Khasi pine based AFS			
30	BT	0.12	0.82	0.11	0.56
	BR	0.13	0.82	0.11	0.52
60	BT	0.66	0.10	0.39	0.05
	BR	0.66	0.13	0.46	0.08
90	BT	1.71	2.37	1.57	1.97
	BR	1.71	2.20	1.41	1.93
240	BT	0.12	0.45	0.11	0.4
	BR	0.19	0.46	0.17	0.3
		Control			
30	No tree	0.15	1.00	0.15	1.00
60	No tree	0.94	0.19	0.94	0.19
90	No tree	2.56	6.92	2.56	6.92
240	No tree	0.40	0.15	0.40	0.15

BT= Between trees, BR= Between rows

Table 6.6.6. Nutrient accumulation (g m^{-2}) by ginger under different agroforestry systems

Planting arrangements/ treatments		N			P			K		
		AG	BG	Total	AG	BG	Total	AG	BG	Total
Khasi mandarin-based AFS										
(a) With fertilizer	BT	1.78	2.94	4.72	0.08	0.19	0.27	1.64	1.34	2.98
	BR	1.81	2.75	4.56	0.10	0.21	0.31	1.64	1.41	3.05
(b) Without fertilizer	BT	1.07	2.3	3.37	0.04	0.16	0.20	0.93	1.10	2.03
	BR	1.07	1.85	2.92	0.06	0.14	0.20	1.00	0.97	1.97
Alder-based AFS										
(a) With fertilizer	BT	1.09	1.62	2.71	0.05	0.11	0.16	0.9	0.77	1.67
	BR	1.08	1.67	2.75	0.06	0.14	0.20	0.93	0.93	1.86
(b) Without fertilizer	BT	0.76	1.19	1.95	0.04	0.09	0.13	0.73	0.59	1.32
	BR	0.81	1.06	1.87	0.04	0.09	0.13	0.71	0.64	1.35
Khasi pine-based AFS										
(a) With fertilizer	BT	0.98	1.56	2.54	0.03	0.09	0.12	0.76	0.67	1.43
	BR	1.07	1.51	2.58	0.06	0.1	0.16	0.9	0.81	1.71
(b) Without fertilizer	BT	0.6	0.96	1.56	0.03	0.06	0.09	0.59	0.41	1.00
	BR	0.8	0.84	1.64	0.04	0.06	0.10	0.66	0.49	1.15
Control										
(a) With fertilizer		1.72	2.36	4.08	0.11	0.22	0.33	1.59	1.47	3.06
(b) Without fertilizer		1.04	1.6	2.64	0.06	0.15	0.21	0.97	0.99	1.96

AG= above ground biomass, BG= below ground biomass

6.7 Yield

6.7.1 Fresh and dry weight of ginger rhizome

Highest fresh ginger rhizome yield was recorded in the Khasi mandarin-based AFS under "between trees planting" (1518.14g m^{-2}) and lowest in Khasi pine-based under "between rows planting" (704.64g m^{-2}). The planting of ginger between the trees gave greater rhizome yield compared to the planting between the rows. Application of fertilizer also showed marked increase in ginger rhizome yield. The yield of ginger planted between the trees in Khasi mandarin-based AFS increased to the extent of 17.8% in the fertilized plots than in the unfertilized plots. Dry weight of ginger rhizome followed the trend similar to the fresh weight in all the AFS, while it showed a reverse trend with respect to the planting arrangement (Table 6.7.1).

6.7.2 Yield attribute of ginger

Average number of fingers per rhizome was recorded maximum (6.9) in Khasi mandarin-based AFS under "between rows planting" and minimum (5.5) in Khasi pine-based AFS under "between trees planting". In the fertilized plots, the rhizomes produced greater number of fingers compared to the unfertilized plots (Table 6.7.2a). The average maximum finger length was recorded higher (7.32cm) in the Khasi mandarin-based AFS under "between rows planting" and minimum (6.32cm) in Khasi pine-based AFS under "between trees planting" (Table 6.7.2b). Average maximum finger diameter was highest (2.59cm) in Khasi mandarin AFS under "between rows planting" and lowest (2.41cm) in Khasi pine AFS under "between trees planting" (Table 6.7.2c).

Table 6.7.1. Weight of ginger rhizome (g m^{-2}) under different agroforestry (means of 2002 and 2003 cropping periods)

Agroforestry systems	Planting arrangement	With fertilizer		Without fertilizer	
		Fresh weight	Dry weight	Fresh weight	Dry weight
Mandarin- AFS	BT	1518.14±98.08	284.94±5.61	1288.29±20.91	257.70±4.92
	BR	1450.38±54.20	289.14±6.18	1184.06±28.40	224.87±2.72
Alder- AFS	BT	807.06±44.07	160.37±4.52	724.26±16.20	140.75±4.68
	BR	960.10±23.58	178.99±3.92	687.14±26.87	135.45±4.36
Pine- AFS	BT	722.69±16.55	147.13±3.35	560.24± 35.02	114.80±3.51
	BR	704.64±30.63	145.61±2.70	520.20±31.56	104.70±2.48
Control	No tree	1324.94±82.79	267.42±5.50	997.20±21.44	200.79±3.40

BT= Between trees, BR= Between rows

Table 6.7.2a. Average number of fingers per rhizome under different agroforestry systems (means of 2002 and 2003 cropping periods)

Agroforestry systems	Planting arrangement	With fertilizer	Without fertilizer
Khasi mandarin-based AFS	BT	6.77±0.18	5.69±0.24
	BR	6.92±0.15	6.06±0.30
Alder-based AFS	BT	6.53±0.13	5.60±0.16
	BR	6.24±0.09	5.92±0.12
Khasi pine-based AFS	BT	5.49±0.19	5.48±0.11
	BR	5.94±0.15	5.36±0.10
Control	No tree	6.27±0.21	6.22±0.34

BT= Between trees, BR= Between rows

Table 6.7.2b. Average maximum and minimum rhizome finger length (cm) under different agroforestry systems (means of 2002 and 2003 cropping periods)

Agroforestry systems	Planting arrangement	With fertilizer		Without fertilizer	
		Maximum	Minimum	Maximum	Minimum
Khasi mandarin-based AFS	BT	6.52±0.06	5.10±0.07	6.61±0.13	4.62±0.08
	BR	7.32±0.30	4.71±0.16	7.06±0.07	4.52±0.12
Alder-based AFS	BT	6.09±0.02	5.21±0.16	6.00±0.15	4.45±0.09
	BR	6.01±0.24	4.78±0.28	6.49±0.24	4.48±0.06
Khasi pine-based AFS	BT	6.34±0.13	4.61±0.11	6.17±0.08	4.48±0.09
	BR	6.25±.08	4.84±0.09	6.16±0.19	4.33±0.30
Control	No tree	6.66±0.07	4.87±0.15	6.51±0.29	4.73±0.07

BT= Between trees, BR= Between rows

Table 6.7.2c. Average maximum and minimum rhizome finger diameter (cm) under different agroforestry systems (means of 2002 and 2003 cropping periods)

Agroforestry systems	Planting arrangement	With fertilizer		Without fertilizer	
		Maximum	Minimum	Maximum	Minimum
Khasi mandarin-based AFS	BT	2.49±0.07	2.31±0.07	2.33±0.08	2.20±0.08
	BR	2.59±0.09	2.34±0.06	2.46±0.06	2.23±0.02
Alder-based AFS	BT	2.43±0.04	2.36±0.06	2.35±0.03	2.22±0.12
	BR	2.55±0.02	2.37±0.03	2.48±0.13	2.27±0.05
Khasi pine-based AFS	BT	2.41±0.02	2.36±0.02	2.36±0.10	2.22±0.07
	BR	2.67±0.07	2.47±0.09	2.46±0.17	2.36±0.07
Control	No tree	2.51±0.04	2.28±0.05	2.41±0.02	2.19±0.05

BT= Between trees, BR= Between rows

6.7.3 Harvest Index (HI)

Harvest index did not show any marked difference among the various agroforestry systems and with respect to planting arrangements. The harvest index in the control plots was 0.59 on fertilizer application and 0.62 in the unfertilized plots. Harvest index was highest (0.67) in the Khasi mandarin-based AFS under "between trees planting" and lowest (0.53) in Khasi pine-based AFS in the "between rows planting" in unfertilized plots. In general, unfertilized plots recorded greater HI than the fertilized plots in the AFS (Table 6.7.3).

Table 6.7.3. Harvest Index (HI) of ginger under different agroforestry systems (means of 2002 and 2003 cropping periods)

Agroforestry systems	Planting arrangement	With fertilizer	Without fertilizer
Khasi mandarin-based AFS	BT	0.599	0.677
	BR	0.610	0.633
Alder-based AFS	BT	0.587	0.588
	BR	0.611	0.578
Khasi pine-based AFS	BT	0.582	0.565
	BR	0.561	0.531
Control	No tree	0.594	0.624

BT= Between trees, BR= Between rows

6.8 Aboveground net primary productivity (ANP) of crops + weeds

Maximum total ANP of maize + weeds was recorded in the control plot (28.2 $gm^{-2}day^{-1}$). Among the AFS, the total ANP was highest in Khasi mandarin-based AFS (23.3 $gm^{-2}day^{-1}$) and lowest in Khasi pine-based (8.6 $gm^{-2}day^{-1}$) AFS under "between trees planting". Other two crops + weeds showed similar trend to that of maize + weeds in all the systems, irrespective of fertilizer application (Table 6.8).

6.9 Biomass (g m^{-2}) and net primary productivity of weeds

With the onset of monsoon (in May), the weed biomass started increasing and maximum value was recorded in the month of August, and minimum in December. Maximum weed biomass (499.8g m^{-2}) was recorded in the control plots with fertilizer application while in the plots without fertilizer; that was much lower (278.8 g m^{-2}). Among the AFS, Khasi mandarin-based system recorded maximum weed biomass under "between trees planting" than under "between rows planting", however, alder-based AFS and Khasi pine-based AFS recorded greater biomass under "between rows planting" than under "between trees planting". The application of fertilizers markedly increased the weed biomass production in all the systems (Table 6.9a).

Application of fertilizer significantly ($P< 0.01$) increased the ANP of weeds in all the AFS. Highest average aboveground net primary productivity of weeds was recorded in the control plots (4.61 g m^{-2} day^{-1}) followed by Khasi mandarin-(3.16 g m^{-2} day^{-1} in the "between trees planting"), alder-(2.29 g m^{-2} day^{-1} in "between rows planting") and Khasi pine-based (2.01 g m^{-2} day^{-1} in the "between rows planting") AFS (Table 6.9b).

Table 6.8. Above ground net primary productivity (g m^{-2} day^{-1}) of crops and weeds in different AFS (means of 2002 and 2003 cropping periods)

Planting arrangements/ treatments		Maize	Weed	Total	Rice	Weed	Total	Ginger	Weed	Total
		Khasi mandarin-based AFS								
BT	(a) F+	17.58	3.16	20.74	8.49	3.16	11.65	0.74	3.16	3.9
	(b) F-	8.64	1.52	10.16	5.29	1.52	6.81	0.49	1.52	2.01
BR	(a) F+	21.02	2.29	23.31	9.00	2.29	11.29	0.75	2.29	3.04
	(b) F-	8.96	1.47	10.43	5.10	1.47	6.57	0.52	1.47	1.99
		Alder-based AFS								
BT	(a) F+	6.71	2.04	8.75	6.56	2.04	8.6	0.43	2.04	2.47
	(b) F-	3.80	1.09	4.89	3.78	1.09	4.87	0.36	1.09	1.45
BR	(a) F+	7.66	2.27	9.93	6.73	2.27	9	0.44	2.27	2.71
	(b) F-	4.13	1.12	5.25	3.69	1.12	4.81	0.36	1.12	1.48
		Khasi pine-based AFS								
BT	(a) F+	6.27	1.64	7.91	5.8	1.64	7.44	0.38	1.64	2.02
	(b) F-	2.75	1.14	3.89	2.9	1.14	4.04	0.32	1.14	1.46
BR	(a) F+	6.61	2.01	8.62	6.05	2.01	8.06	0.47	2.01	2.48
	(b) F-	2.96	1.02	3.98	3.18	1.02	4.2	0.36	1.02	1.38
		Control								
	(a) F+	24.08	4.16	28.24	9.49	4.16	13.65	0.71	4.16	4.87
	(b) F-	8.99	2.32	11.31	5.03	2.32	7.35	0.46	2.32	2.78

ANP has been calculated on the basis of peak above ground biomass

(a) F+ = with fertilizer; (b) F- = without fertilizer

Table 6.9a. Weed biomass (dry weight g/m^2± SE) in different agroforestry systems (means of 2002 and 2003 cropping periods)

Agroforestry systems (AFS)	Months							
	May	June	July	August	September	October	November	December
Khasi mandarin-based AFS								
BT (a) F+	212.23±17.16	298.80±3.85	336.12±9.70	379.17±11.99	312.59±9.88	229.14±12.16	205.16±15.09	152.30±16.89
BT (b) F-	133.91±17.03	140.08±4.43	168.40±5.32	182.66±5.77	140.65±4.45	115.29±8.53	87.64±2.31	84.85±2.85
BR (a) F+	193.12±6.61	224.67±18.93	255.06±21.49	274.40±23.12	226.21±19.06	158.80±11.04	134.20±5.06	90.82±13.71
BR (b) F-	126.13±10.98	135.22±8.30	162.55±9.97	176.31±10.82	135.77±8.33	108.96±3.17	78.60±6.48	72.29±3.70
Alder-based AFS								
BT (a) F+	172.73±6.53	200.91±3.78	228.08±4.29	245.37±4.61	202.28±3.80	162.08±13.41	103.52±5.45	79.38±9.35
BT (b) F-	83.35±7.45	100.53±5.04	120.85±6.06	131.08±6.57	100.94±5.05	76.55±5.23	52.78±1.54	42.94±1.82
BR (a) F+	192.44±8.30	222.92±13.39	253.07±21.28	272.25±22.89	224.44±18.87	182.96±18.58	111.22±11.52	86.72±11.30
BR (b) F-	112.84±21.25	119.80±8.60	127.32±12.00	134.48±15.44	103.55±11.89	88.79±18.15	53.08±4.11	50.57±12.74
Khasi pine-based AFS								
BT (a) F+	159.62±12.16	166.89±6.61	188.33±7.33	196.97±9.43	159.64±10.18	141.62±5.64	89.24±5.24	81.10±5.31
BT (b) F-	97.93±2.90	109.46±3.49	114.77±4.06	117.89±2.14	81.80±1.64	82.15±4.69	41.92±2.48	50.55±6.18
BR (a) F+	166.29±7.86	197.93±11.12	224.71±12.55	241.57±11.94	199.29±11.39	160.96±6.41	98.65±7.32	77.94±7.92
BR (b) F-	96.69±8.60	104.69±1.53	115.96±3.74	122.16±5.67	94.07±4.37	79.47±3.51	46.74±0.08	43.14±1.69
Control								
(a) F+	298.51±10.45	387.09±11.35	435.59±10.39	499.79±2.18	411.89±9.55	310.99±13.24	234.34±19.11	197.96±9.91
(b) F-	225.45±6.02	246.47±12.47	257.16±3.97	278.76±13.61	214.65±12.77	192.83±13.72	100.20±12.53	123.54±6.08

(a) F+ = With fertilizer; (b) F-= Without fertilizer

Table 6.9b. Net above ground primary productivity (g m^{-2} day^{-1}) of weeds in different agroforestry systems (means of 2002 and 2003 cropping periods)

Agroforestry systems	May	June	July	August	Average NPP
Khasi mandarin-based AFS					
BT (a) F+	7.07	2.88	1.24	1.44	3.16
BT (b) F-	4.46	0.21	0.94	0.47	1.52
BR (a) F+	6.44	1.05	1.02	0.65	2.29
BR (b) F-	4.20	0.30	0.91	0.46	1.47
Alder-based AFS					
BT (a) F+	5.76	0.94	0.91	0.57	2.04
BT (b) F-	2.78	0.57	0.68	0.34	1.09
BR (a) F+	6.42	1.02	1.01	0.64	2.27
BR (b) F-	3.76	0.23	0.25	0.24	1.12
Khasi pine-based AFS					
BT (a) F+	5.32	0.24	0.71	0.29	1.64
BT (b) F-	3.26	0.38	0.18	0.11	1.14
BR (a) F+	5.54	1.05	0.89	0.56	2.01
BR (b) F-	3.22	0.26	0.37	0.21	1.02
Control					
(a) F+	9.95	2.95	1.62	2.14	4.16
(b) F-	7.51	0.70	0.36	0.72	2.32

BT= Between trees, BR= Between row (a) F+ = With fertilizer; (b) F-= Without fertilizer

DISCUSSION

It is evident from the above data that growth parameters such as height, LAI, dry weight and R/S ratio of maize, rice and ginger recorded at different stages of growth exhibited comparatively higher values in plots treated with fertilizers and FYM in all the AFS, as would be normally expected. Among the three-AFS, Khasi mandarin-based AFS was better than alder- and Khasi pine-based AFS for crop growth and yield. This may be related to the favorable microclimatic conditions for the crops under Khasi mandarin-based AFS. The canopy architecture of Khasi mandarin tree was such that it allowed greater light penetration (48%) than alder (39%) and Khasi pine (29%). Several workers have reported that the reduction in light intensity due to overhead tree canopy may cause adverse effect on crop growth. Srinivasan et al. (1990) while examining the resources-

sharing ability of multipurpose trees in an intercropping system reported reduced crop yield due to competition with the trees for light.

Poor growth and yield of the three crops under Khasi pine-based AFS could be attributed to the availability of low light intensity to the crops and certain adverse changes in soil due to chemical composition of pine needle. Kandpal and Negi (2003) reported that pine needle has a detrimental effect on crop growth. High C: N ratio and lignin content in pine needle slows down litter decomposition and nutrient release and increases the acidity of soil (Das 1980).

The performance of the crops grown with alder, which has an actinorrhizal association with N-fixing *Frankia*, was not as good when they grew with Khasi mandarin. This could be attributed to the concentration of fine root biomass of alder spreading in the shallow soil surface (0-10cm), which might have offered keen competition to crops for water and nutrients. Several workers have pointed out the similarity of root distribution between trees and crops in the soil profile indicating a considerable overlapping of the soil resources they use (Jonsson et al. 1988, Dhyani et al. 1990, Scroth and Lehmann 1995, Palm 1995). 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. 1991, Salazar et al. 1993). Besides comparatively low light intensity (29% of total sunlight), other unfavorable conditions such as poor availability of nutrients might have been responsible for poor crop growth performance under Khasi pine-based AFS. In general, the crops planted between the trees suffered more than those grown between the rows as 28-45% of light reached to the ground between the trees compared to 30-50% in between the rows.

Although variation in biomass accumulation by the crops in different AFS might be due to differences in their genetic make up, the combined or independent effects of edapho-climatic conditions, effect of trees, crop density, crop-weed interaction and biotic (weeding or other intercultural operations) interference might have also influenced the biomass production. Nutrient accumulation in above and below ground parts in maize, rice and ginger was maximum in the control plots followed by Khasi mandarin-, alder- and Khasi pine-based AFS. The higher nutrient accumulation in crops grown with application of fertilizers in different AFS was due to greater N, P and K availability to crops. The greater availability of nutrients in the Khasi mandarin-based AFS could be due to high moisture and higher initial N, P and K contents in soil as compared to the other two AFS, which could be the reason for better growth of crops and higher accumulation of nutrient in this system. The application of fertilizers and manures improved the status of soil nutrients in all the AFS. There was also marginal increase in soil pH. This might be the result of the nutrient inputs from the fertilizers and manures application in excess of nutrient removal from the system. The marginal increase in soil pH is caused by the addition of basic cations from the organic manure (Patiram and Singh 1993).

Not much variation in grain weight per 100-grains was recorded when maize and rice was grown either between the trees or between the rows. However, on fertilizers application, there was an increase in grain weight of crops in Khasi mandarin AFS, compared to the control. The grain yield was more in the case of "between the rows planting" than "between the trees planting" in all the three AFS. This trend might be due to greater availability of light to the crop plants growing between the rows compared to those growing between the trees. The crop plants grown between the rows received 11.1%, 16.4% and 2.1% higher light intensity compared to those grown between trees in

Khasi mandarin-, alder- and Khasi pine-based AFS, respectively. The better yield in Khasi mandarin-based AFS could be due to the favourable edapho-climatic conditions in this system compared to the other two systems. In the case of ginger too, the highest yield was recorded in the Khasi mandarin- followed by alder- and Khasi pine-based AFS. Since ginger grows better in partial shade, its productivity was more in the AFS than the control plots. Likewise, harvest index was also higher in the Khasi mandarin AFS compared to the alder- and Khasi pine-based AFS, which might be due to the microclimatic and edaphic differences created by the individual AFS.

In general, net primary productivity of an AFS largely depends on the tree species and crops grown, and the prevailing management practices. From the result of this experiment, it is clear that when net primary productivity (crops and weeds) in different AFS was considered, Khasi mandarin-based AFS was found to be more productive than the other two systems.

Chapter 7

TREE LITTER PRODUCTION, DECOMPOSITION AND NUTRIENT BUDGET

Litter production and decomposition are the crucial processes in organic matter and nutrient dynamics within an ecosystem (Buck 1986, Das and Chaturvedi 2005). A substantial amount of organic matter returns to the soil through litter fall, which exerts a great influence on physical, chemical and biological properties of soil (Ingestad 1987, Harrison et al.1990, Szott et al. 1991).

Litter decomposition plays an important role in enhancing soil fertility by releasing available nutrients to plants (Clarke 1977, Jorgensen et al. 1980) and by maintaining organic matter level in the soil. It is an important pathway of energy flow both in agriculture and natural ecosystems (Lavelle et al. 1993). The slower the rate of decomposition, slower will be the nutrient supply to the primary producers in the ecosystem. Atmospheric temperature, moisture, decomposition agents and litter quality are some of the important factors that influence decomposition rate (Hartemink and Sullivan 2001). Litter with high nitrogen content decomposes at faster rate and releases nitrogen quickly (Berg and Staff 1981) than those with low nitrogen concentration.

Agroforestry and other tree-based land-use systems have great potential to improve soil fertility than many other systems due to greater input of tree litter and more efficient nutrient cycling due to the presence of trees as an important producer component in the ecosystem. An estimation of annual litter production, chemical composition of the litter, and knowledge of the local environmental conditions that influence the

decomposition rate are important for an understanding of nutrient cycling in AFS. These informations offer an opportunity to manipulate the timing of nutrient release (Young 1989) and help in proper management of the system. Decomposition of applied leaf mulches (Budelman 1988) and nutrient cycling in different AFS such as large-cardamom and mandarin-based systems have been studied by Sharma et al. (1997).

In this chapter data on litter production and leaf litter decomposition of three tree species have been discussed and nutrient budget of three AFS has also been prepared.

METHODOLOGY

Litter production

Litter production was studied from October 2003 to October 2004. Five litter traps (1m x 1m x 0.5m height) were set out in each AFS with the help of polyethylene sheet and bamboo sticks. The litter accumulated in each trap was collected at monthly intervals during October 2003 to October 2004. The samples were brought to the laboratory and separated into leaf, branch and miscellaneous (flowers, fruits, bark, unrecognizable remains of leaves and fine organic matter particles) fractions. These were oven-dried at 80°C to constant weight and weighed. The data were statistically analysed using ANOVA test to determine the effects of tree species and month on litter production.

Litter decomposition

Litter decomposition was studied using nylon mesh litterbag method (Bocock et al. 1960, Upadhyay and Singh 1985, Anderson and Ingram 1993). Senesced leaves of Khasi mandarin, alder and Khasi pine were collected and air-dried. Sub samples of leaves were dried at 80 °C for 24 hr to determine moisture content in the air-dry leaf litter samples. Litterbags of 10cm x 15cm size, made of non-degradable nylon (2mm mesh),

were used for the decomposition study. For each species, 60 litterbags were prepared with twenty-gram air-dried leaves. The litterbags were randomly placed on the soil surface in each AFS in September 2002. At each monthly sampling date, four litterbags of each species were retrieved and brought to the laboratory for further analysis. The litter was washed under gentle flow of tap water to remove soil debris, fine roots and living organisms etc. and then dried at 80^0C for 24 hours. After dry weight determination, samples were powdered and stored for N, P and K analysis. Nitrogen was determined by micro-Kjeldahl digestion-distillation method, phosphorus by molybdenum blue method and potassium by flame photometry (Allen et al. 1974, Anderson and Ingram 1993).

Rate of N, P and K release during decomposition was computed using weight loss and element concentration in the litter obtained from litterbags during successive samplings. Monthly nutrient input through leaf litter fall was computed using nutrient concentration and production values of the leaf litter. Nutrient input through leaf litter for each crop was also computed using nutrient concentration and production values of leaf litter during the cropping period.

Nutrient budget

Annual nutrient budget of different AFS was prepared on the basis of nutrient storage in plant and soil compartments and their input to the system through tree and crop leaf litter, FYM and fertilizer and output from the system in the form of crop yield and weed biomass. Nutrient input was worked out by adding up the nutrient contents in tree leaf litter, FYM and chemical fertilizer during cropping season under each system, and accumulation in the harvested biomass of crops and weeds was considered as output or removal (Toky et al. 1989b, Mazumdar 1991).

Nutrient budget did not include:

(i) Nutrient inputs through rain water, dust etc. and runoff, leaching and volatilization losses.

(ii) Amounts of nutrients stored in the non-harvested tree parts such as bole, branch, and root were not included due to practical difficulty.

Economic analysis

The net return of the three studied crops was calculated by deducting the cost of cultivation from gross return whereas, B/C ratio was calculated by dividing the cost of cultivation by gross return of each system with or without fertilized application. B/C ratio was calculated on the basis of prevailing market price of each crop.

RESULTS

Litter production

Figure 7.1 shows the monthly variation in litter fall in three AFS during 2003-2004. The litter fall pattern was similar in all the three studied species. It increased from June to July and attained peak in the month of January in Khasi mandarin and alder, and during February in case of Khasi pine. Thereafter, it followed a declining trend till June in all the species. Maximum litter fall occurred during the winter season, a period characterized by low temperature and low rainfall. The minimum litter fall was, however, recorded during rainy season in all the systems. The total annual litter fall was 585.79 g m^{-2} in Khasi pine-based AFS followed by alder-based AFS (338.03 g m^{-2}) and Khasi mandarin-based (263.41 g m^{-2}) AFS. The share of leaf litter in the total litter production varied from 69% to 78% followed by miscellaneous litter (15% to 20%) and branches/ twigs (7% to 11%).

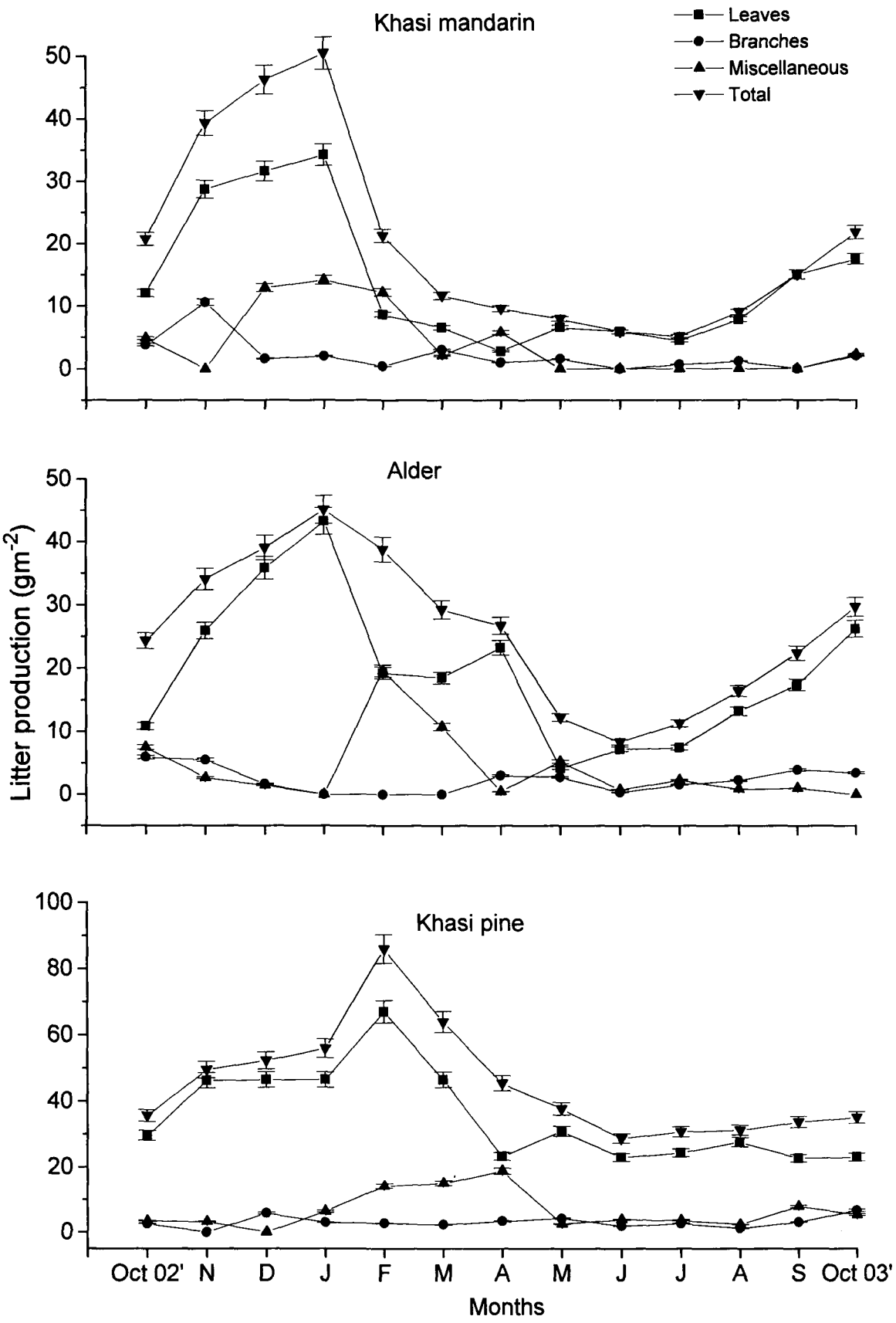


Fig. 7.1. Mean monthly litter production (gm^{-2}) in different agroforestry systems

Litter decomposition

The rate of leaf litter decomposition varied between the three tree species. Pine needle decomposed at a comparatively slower rate than Khasi mandarin and alder leaf litter. During 360 days only 55.3 % of pine leaf litter was decomposed, whereas the decomposition of Khasi mandarin leaf litter and alder leaf litter was 94.4 and 94.54 %, respectively. It was also observed that litter decomposition rate was fast during the rainy season (April to September) and slow during winter season in all three tree species. Rate of decomposition, expressed as mg dry matter loss per day, was maximum for alder (57.30 mg) followed by Khasi mandarin (52.43 mg) and Khasi pine (25.00 mg). Considering the rate of dry matter loss, Khasi mandarin may take 358 days, alder 349 days and Khasi pine 717 days for complete decomposition of leaf litter (Fig. 7.2).

Initial N, P and K concentration in leaf litter and changes during decomposition

There was a wide difference in concentration of mineral elements in the leaf litter of three tree species. Initial nutrient concentration (N=29.1, P=2.6 and K=17.1 mg g^{-1}) in alder leaves was higher than Khasi mandarin (N=18.5, P=2.20 and K=15.8 mg g^{-1}) and Khasi pine (N=11.8, P=0.95 and K=6.80 mg g^{-1}) tree leaves (Table 7.1). N concentration in alder leaves was much higher than other two species, while pine needle had the lowest concentration of N, P and K. The periodical changes in N, P and K concentration in leaf litter in different AFS are shown in Table 7.2. In all the tree species, nutrient concentration declined consistently up to 210-240 days and thereafter it increased in some cases, and remained either unchanged or decreased in other cases. For instance, the concentration of N, P and K in leaf litter decreased constantly with increasing period of decomposition in Khasi mandarin and alder, but P and K concentration increased in Khasi pine leaf litter after 240 days (Fig. 7.3).

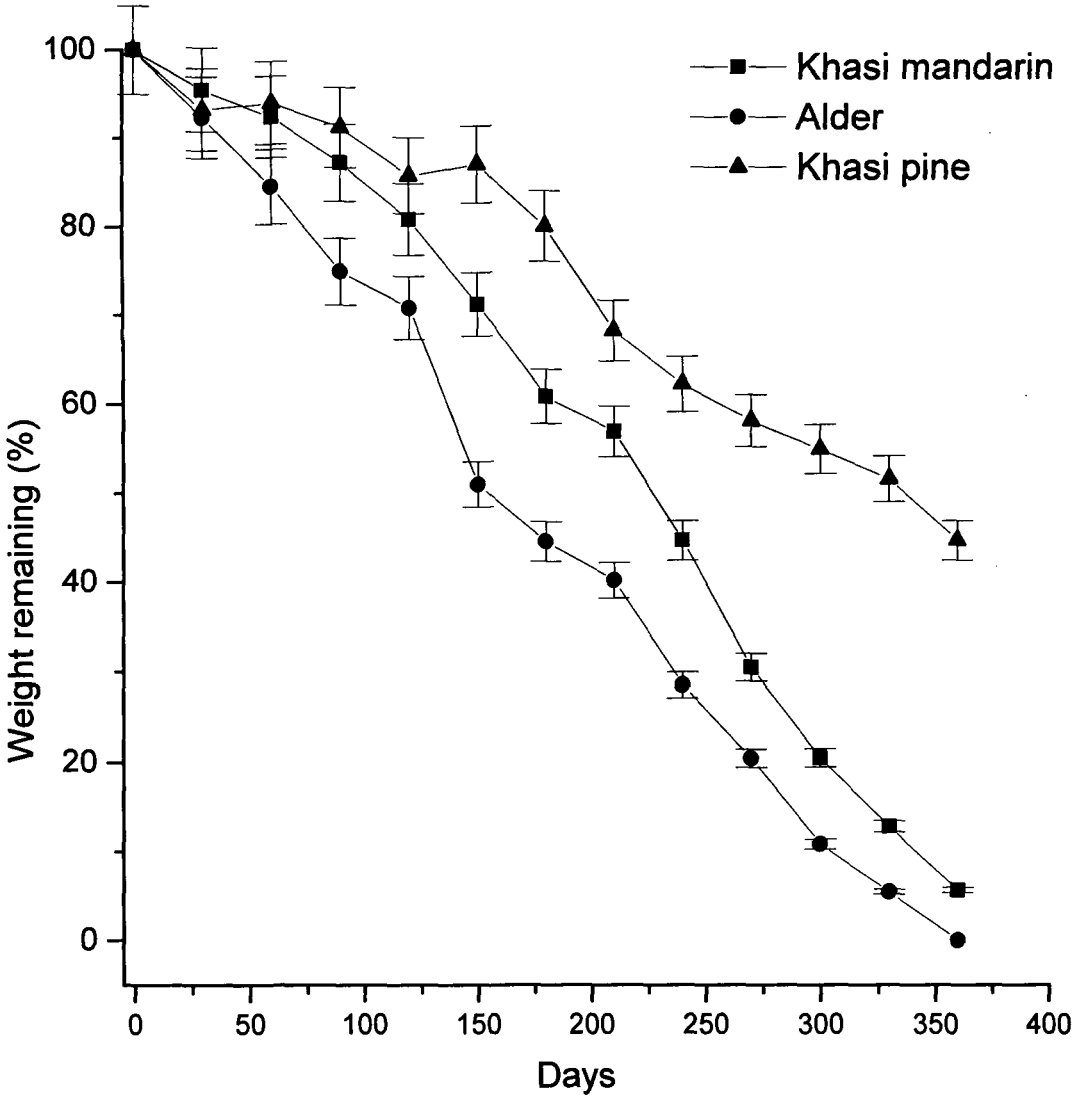


Fig 7.2. Mean percentage dry weight remaining in decomposing leaf litter of three tree species

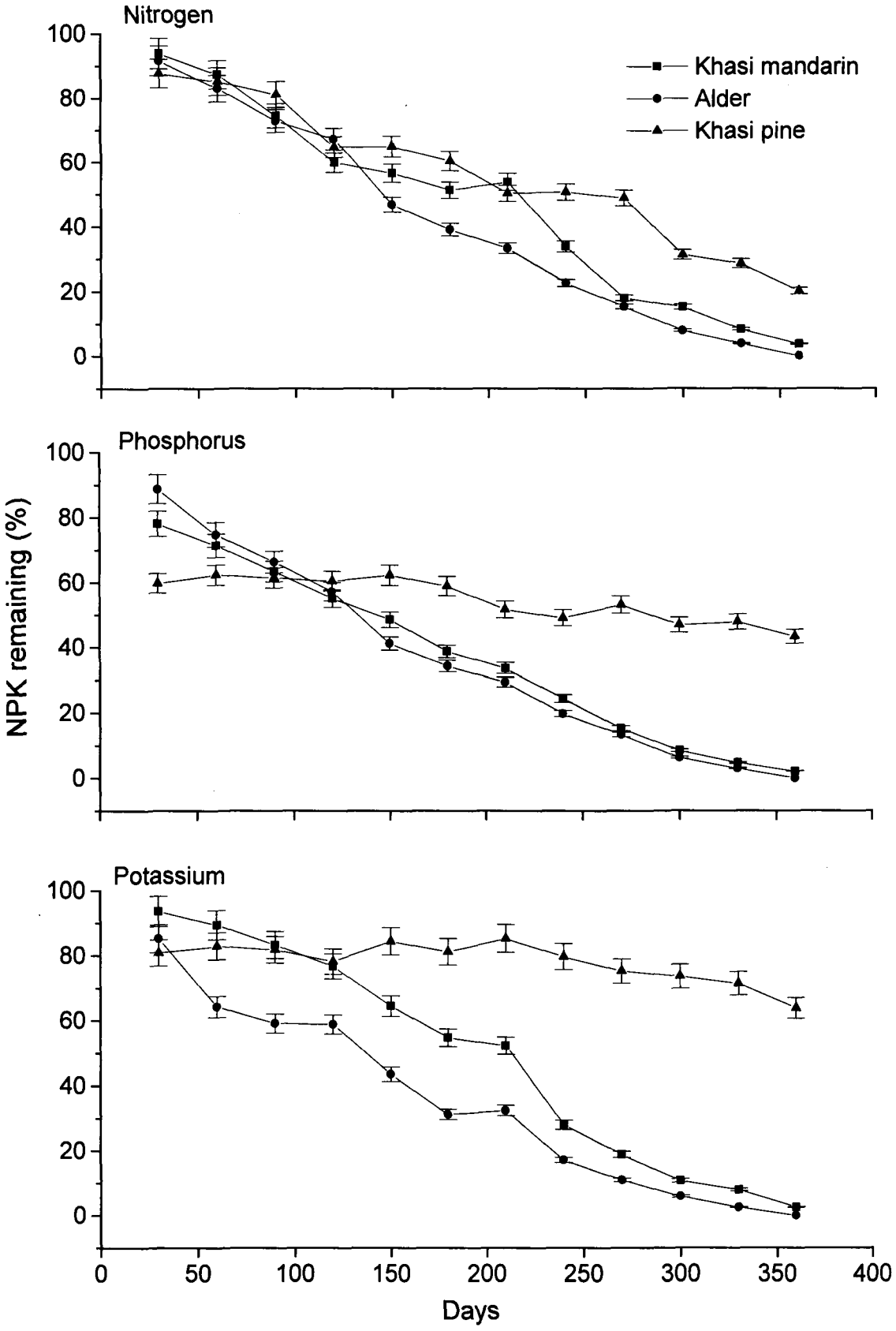


Fig 7.3. Percent NPK remaining in decomposing leaf litter of three tree species

Table 7.1. Initial N, P and K concentration (mg g^{-1}) in leaf litter of different tree species

Tree species	N	P	K
Khasi mandarin	18.50±0.51	2.20±0.59	15.80±0.11
Alder	29.10±0.26	2.60±0.79	17.10±0.07
Khasi pine	11.80±0.47	0.95±0.25	6.80±0.21

Table 7.2. Changes in nutrient concentration (mg g^{-1}) in decomposing leaf litter in different AFS

Days after Placement of litter	Khasi mandarin-based AFS			Alder-based AFS			Khasi pine-based AFS		
	N	P	K	N	P	K	N	P	K
Initial	18.50	2.20	15.80	29.10	2.60	17.10	11.80	0.95	6.80
30	18.20	1.80	15.50	28.90	2.50	15.80	11.10	0.61	5.90
60	17.50	1.70	15.30	28.60	2.30	13.00	10.70	0.63	6.00
90	15.80	1.60	15.10	28.20	2.30	13.50	10.50	0.64	6.10
120	13.70	1.50	15.00	27.60	2.10	14.20	8.90	0.67	6.20
150	14.70	1.50	14.30	26.70	2.10	14.60	8.80	0.68	6.60
180	15.60	1.40	14.20	25.50	2.00	12.00	8.90	0.70	6.90
210	17.50	1.30	14.50	24.10	1.90	13.80	8.70	0.72	8.50
240	14.00	1.20	9.90	23.00	1.80	10.30	9.60	0.75	8.70
270	10.90	1.10	9.80	21.90	1.70	9.20	9.90	0.87	8.80
300	13.70	0.90	8.30	21.10	1.50	9.30	6.70	0.81	9.10
330	11.90	0.80	9.80	20.50	1.40	7.80	6.50	0.88	9.40
360	12.20	0.80	7.00	-	-	-	5.30	0.92	9.70

N, P and K input through tree leaf litter

Total N, P and K input through leaf litter was highest in case of Alder (N=7360 P=657, and K= 4324 mg m^{-2}) followed by Khasi pine (N=5395, P= 434, and K= 3109 mg m^{-2}) and Khasi mandarin (N=3357, P=399, and K= 2867 mg m^{-2}). The total leaf litter input by Khasi mandarin was less though it had high concentration of N, P and K, which

was due to low litter production in this tree compared to Khasi pine (Table 7.3). The nutrient inputs (mg m^{-2}) through leaf litter during the cropping periods of different crops are shown in Figure 7.4. Alder leaves provided maximum amount of nitrogen for utilization by rice (1628 mg m^{-2}) and ginger (3628 mg m^{-2}) crops. In case of maize the nitrogen input through pine (1246 mg m^{-2}) was more than alder (938 mg m^{-2}) and Khasi mandarin (454 mg m^{-2}) trees. The maximum nutrient input by Khasi mandarin was recorded in ginger followed by rice, whereas, it was minimum in maize (Figure 7.4).

Table 7.3. Monthly input of N, P and K (mg m^{-2}) through leaf litter three agroforestry systems

Months	Khasi mandarin-based AFS			Alder-based AFS			Khasi pine-based AFS		
	N	P	K	N	P	K	N	P	K
October	223.30	26.60	190.70	316.00	28.20	185.70	349.00	28.10	201.10
November	531.51	63.20	453.90	755.10	67.50	443.70	546.60	44.00	315.00
December	585.34	69.60	499.90	1044.40	93.30	613.70	549.10	44.20	316.40
January	632.52	75.20	540.20	1260.0	112.60	740.40	549.40	44.20	316.60
February	159.66	19.00	136.40	560.20	50.10	329.20	815.10	65.60	469.70
March	120.81	14.40	103.20	537.80	48.00	316.00	549.10	44.20	316.40
April	51.62	6.10	44.10	676.90	60.50	397.70	274.80	22.10	158.40
May	120.99	14.40	103.30	122.80	11.00	72.20	364.10	29.30	209.80
June	108.41	12.90	92.60	210.70	18.80	123.80	270.50	21.80	155.90
July	82.14	9.80	70.20	218.50	19.50	128.40	287.30	23.10	165.60
August	143.38	17.10	122.50	386.70	34.60	227.30	325.00	26.20	187.30
September	276.39	32.90	236.10	506.90	45.30	297.90	267.40	21.50	154.10
October	321.90	38.30	274.90	763.90	68.30	448.90	271.40	21.90	156.40
Total	3357.94	399.30	2867.90	7360.00	657.60	4324.90	5395.20	434.40	3109.10

Nutrient budget

The total amount of N, P and K added through leaf litter, FYM and fertilizers was taken as input and their amount in crop and weed biomass was treated as accumulation, and the crop yield (grain/ rhizome) harvested was considered as output/ removal during

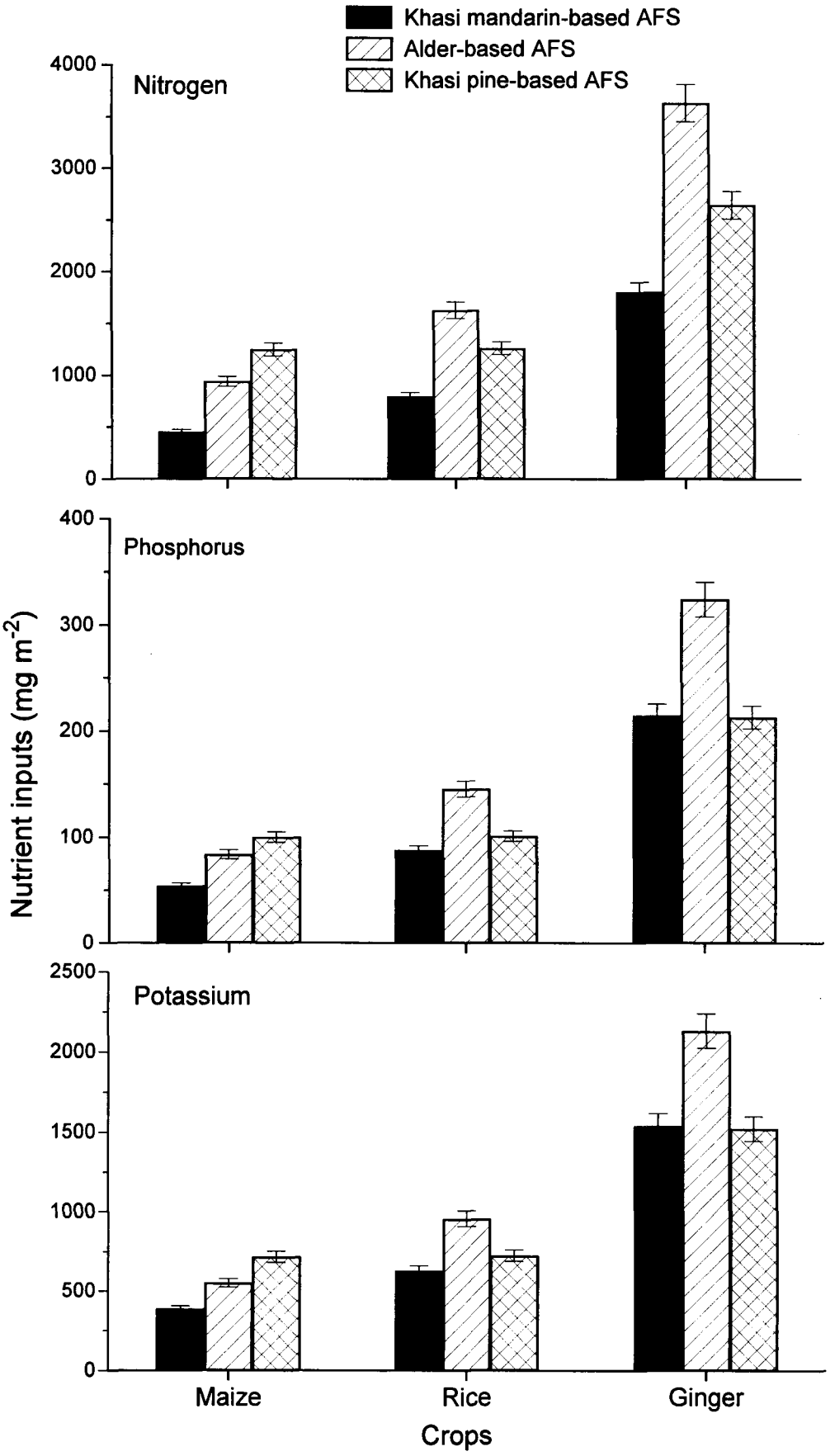


Fig 7.4. Nutrient inputs through leaf litter in different AFS during the croping periods

the cropping period. Addition and removal of N, P and K have been calculated separately for different AFS and control plots treated with and without fertilizer application (Table 7.4 and 7.5).

Nutrient Input

In general, N, P and K input was more in AFS than the control plots. Among AFS, it was highest in Khasi pine-based (N=127.73, P=38.25 and K=215.68 g m^{-2}) and lowest in Khasi mandarin-based (N=31.89, P=27.27 and K=24.58 g m^{-2}) AFS plots with fertilizer application. The trend was similar in the unfertilized plots where there was no nutrient input through FYM and fertilizer, but the values were lower than the fertilized plots (Table 7.4 and 7.5).

Nutrient Accumulation/ Removal

The N, P and K accumulation in the crop and weed biomass was maximum in the control plots than all the AFS. Among the AFS, maximum nutrient accumulation by crops and weeds was recorded in Khasi mandarin-based (N=55.54, P=3.23 and K=64.51 g m^{-2}) and minimum in Khasi pine-based AFS (N=26.92, P=1.20 and K=29.88 g m^{-2}). Alder-based AFS ranked in between these two extremes so far as nutrient removal was concerned (Table 7.4). A similar trend was also observed in the unfertilized plots in all the AFS and control plots, but the total accumulation was less than half of what was recorded in the fertilized plots (Table 7.5).

Nutrient Balance

Soil N, P and K levels in different AFS and control plots showed a negative balance at the end of the year after crop harvest. Among the different AFS, Khasi mandarin showed lower negative balance than the other two AFS.

In the fertilized plots, the least net loss or gain of N, P and K occurred in Khasi mandarin-based AFS, where it was (-) 1.59, 26.81 and 23.17 g m^{-2}, respectively as compared to alder [N= (-) 47.97, P= (-) 28.08 and K= (-) 27.47 g m^{-2}] and pine [N= (-) 72.53, P= (-) 38.11, K= (-) 215.29 g m^{-2}]. However in the unfertilized plots, the net loss of N, P and K was (-) 22, (-) 0.36 and (-) 0.95 g m^{-2} in Khasi mandarin-based AFS whereas in Khasi pine-based AFS there was a net gain of 80.71, 11.80 and 197.69 g m^{-2} of N, P and K, respectively (Table 7.4 and 7.5).

Table 7.4. Annual nutrient budget of different agroforestry systems and control plots with fertilizer application. (All values are g m^{-2} of oven-dry soil down to 30 cm depth)

Mineral nutrient	Initial nutrient status in soil	Input through leaf litter, FYM, & chemical fertilizer	Total nutrient storage in soil	Total accumulation in crop + weed* biomass	Final nutrient storage in soil	Change in soil nutrient level
Khasi mandarin based AFS						
Total N	636.30	31.89	668.19	55.54	666.60	-1.59
Total P	12.57	27.27	39.84	3.23	13.03	-26.81
Total K	22.70	24.58	47.28	64.51	24.11	-23.17
Alder based AFS						
Total N	541.50	47.97	589.47	35.53	541.50	-47.97
Total P	9.26	28.37	37.63	2.02	9.55	-28.08
Total K	16.90	28.20	45.10	39.58	17.63	-27.47
Khasi pine based AFS						
Total N	441.60	127.73	569.33	26.92	496.80	-72.53
Total P	6.48	38.25	44.73	1.20	6.62	-38.11
Total K	11.15	215.68	226.83	29.88	11.54	-215.29
Control plots						
Total N	567.00	19.42	586.42	67.70	567.00	-19.42
Total P	10.55	26.45	37.00	3.88	11.05	-25.95
Total K	17.76	17.68	35.44	86.93	18.54	-16.9

* Sum of the peak standing state of nutrients in above-and belowground biomass of three crops and peak standing state of nutrients in the aboveground biomass of weeds in three crop fields during one year (2003) period.

Table 7.5. Annual nutrient budget of different agroforestry systems and control plots without fertilizer application. (All values are g m^{-2} of oven-dry soil down to 30 cm depth).

Mineral nutrient	Initial nutrient status in soil	Input through tree leaf litter	Total nutrient storage in soil	Total removal by crop + weed*	Final nutrient storage in soil	Change in soil nutrient level
			Khasi mandarin based AFS			
Total N	545.4	12.47	557.87	27.37	535.70	-22.00
Total P	10.3	0.82	11.12	1.68	10.76	-0.36
Total K	18.86	7.15	26.01	35.04	19.06	-6.95
			Alder based AFS			
Total N	484.5	28.31	512.81	16.77	484.50	-28.31
Total P	6.69	1.92	8.61	0.86	7.27	-1.34
Total K	14.30	10.77	25.07	19.61	11.90	-13.17
			Khasi pine based AFS			
Total N	358.8	108.31	467.11	12.87	386.40	-80.71
Total P	3.73	11.80	15.53	0.57	3.73	-11.8
Total K	8.20	198.25	206.45	14.31	8.76	-197.69
			Control plots			
Total N	535.5	-	535.5	34.98	504.0	-31.5
Total P	6.45	-	6.45	2.22	7.41	0.96
Total K	14.10	-	14.10	49.97	14.50	0.40

* Sum of the peak standing state of nutrients in above-and belowground biomass of three crops and peak standing state of nutrients in the aboveground biomass of weeds in three crop fields during one year (2003) period.

Table 7.6. Cost benefit analysis of different AFS and control plots

Crop combination	Treatments	*Input (Rs./ha)	Out put (Rs./ha)	Out put/ Input	**Net monetary benefits (Rs.)
	#Khasi mandarin- based AFS				
Maize	With fertilizer	37040	91090	2.46	54050
	Without fertilizer	33380	75900	2.27	42520
Rice	With fertilizer	36221	76200	2.10	39979
	Without fertilizer	32360	69200	2.14	36840
Ginger	With fertilizer	55361	149300	2.70	93939
	Without fertilizer	51200	139700	2.73	88500
	°Alder based AFS				
Maize	With fertilizer	22020	29300	1.33	7280
	Without fertilizer	18360	22300	1.21	3940
Rice	With fertilizer	18201	25100	1.38	6899
	Without fertilizer	17340	22500	1.30	5160
Ginger	With fertilizer	40341	68800	1.71	28459
	Without fertilizer	36180	58000	1.60	21820
	°Khasi pine-based AFS				
Maize	With fertilizer	22020	28400	1.29	6380
	Without fertilizer	18360	24200	1.32	5840
Rice	With fertilizer	18201	26300	1.44	8099
	Without fertilizer	17340	24300	1.40	6960
Ginger	With fertilizer	40341	62600	1.55	22259
	Without fertilizer	36180	52400	1.45	16220
	Control plots				
Maize	With fertilizer	11460	32200	2.81	20740
	Without fertilizer	7800	20300	2.60	12500
Rice	With fertilizer	10641	16400	1.54	5759
	Without fertilizer	6780	10900	1.61	4120
Ginger	With fertilizer	29781	79200	2.66	49419
	Without fertilizer	25620	59400	2.32	33780

*The price of seeds/ rhizomes at the time of sowing was rice @ Rs. 8/- kg^{-1}, maize @ Rs.10/- kg^{-1} and ginger @ Rs. 12/- kg^{-1}

**The monetary benefit was calculated on the basis of cost of the produce at the time of crops harvest (rice @ Rs. 4/- kg^{-1}, maize @ Rs. 5/- $kg^{-1}$and ginger @ Rs. 6/- kg^{-1}).

#Khasi mandarin fruit yield @ Rs. 5/- kg^{-1} and °Firewood @ Rs. 2/- kg^{-1}

DISCUSSION

Data on litter production indicated that the leaf litter contributed maximum amount to the total litter production in all three species. This is in agreement with the

results of Jordon (1983), Singh (1984) and Sanchez and Sanchez (1995). The total litter production was greater in Khasi pine followed by alder and Khasi mandarin (Fig. 7.1). Lower litter production by Khasi mandarin may be due to the greater longevity of its leaves and small canopy than the other two tree species. However, greater production of litter by Khasi pine could be due to its more extensive canopy and continuous needle shedding. The temporal variation in litter fall was similar in all the three species showing a greater leaf fall during dry period (October to March). Several workers have also reported high variability among tree species with regard to litter production, which may be related to the age, spacing, local environmental condition and the period of data collection (Alban 1982, Buck 1986, Budelman 1989, Hawkins et al. 1990, Szott et al. 1991, Szott and Kass 1993). Moore (1980) reported that the maximum litter fall during the dry period could be due to water stress which triggers *de novo* synthesis of abscissic acid in the foliage of plants, which in turn can stimulate senescence of leaves and other parts. Prolonged litter fall during dry winter season in the present study could be also attributed to the high wind velocity which is a common feature in NE region of India.

Leaf litter decomposition studies indicated slower rate of decay of Khasi pine leaf litter compared to Khasi mandarin and alder. The nutrient rich leaf litter of alder and Khasi mandarin decomposed more rapidly than Khasi pine (Fig. 7.2). The decomposition rate was highest in alder (57.30 mg day^{-1}) and lowest in Khasi pine (25.00mg day^{-1}). Litter decomposition is influenced by three main factors i.e., climate, litter quality and nature and population of the decomposing organisms (Couteaux et al. 1994). During rainy season when environmental conditions are favorable for microbial activities, litter decomposed at a faster rate, as is evident by minimum litter mass on the ground during this season. The higher rate of decomposition and release of nutrients during rainy season

compared to the dry season has been related to soil moisture content (Arunachalam 1996). The rapid rate of decay after an initial phase is 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 (Anderson and Swift 1983, Bloomfield et al. 1993) and removal of leaf litter particles by animals (Swift et al. 1979). A decline in rate of weight loss after rapid phase of decay during rainy season may be attributed to higher percentage of recalcitrant fractions 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 physically interfering with the degradation of other chemical fractions of the cell wall (Bloomfield et al. 1993). Swift et al. (1979) have also reported that litter of high quality decays and releases nutrients rapidly than the low quality litter. The slower rate of decay of pine needles compared to other broad leaved species may be attributed to low N content and higher lignin and cellulose content (Das 1980).

Higher initial concentrations of N in the alder leaf litter could be the cause of its faster decomposition. A positive effect of N concentration on decomposition has been reported by several authors (Swift et al. 1979, Pandey and Singh 1982, Shukla et al. 1990). Higher rate of litter decomposition of alder has also been related to low tannin content (Clein and Schimel 1995). Relatively rapid release of N, P and K from alder and Khasi mandarin leaf litter may be useful from the point of view of meeting requirements of crops during their growth phase. The rapid decomposition and release of nutrients from alder make these nutrients available for uptake by associates and, with time, nutrient cycling is also expected to be accelerated. Sharma et al. (1994, 1997) have reported that the agronomic yield of large-cardamom increased more than two fold when grown in

association with alder compared to when it grew with non-N_2-fixing trees. The N, P and K release during leaf litter decay is influenced by microbial immobilization and mineralization processes which are strongly influenced by seasonal cycle of climatic variables. Warm humid rainy season being more favourable for mineralization, was characterized by rapid rate of N, P and K release from the decomposing leaf litter than the dry-winter season when the microbial immobilization is the dominant process (Arunachalam 1996, Dhyani 1997).

The C:N ratio of litter influences the immobilization and release of nutrients (Aber and Mellilo 1980). The C:N ratio in Khasi pine leaves was obviously higher than other two species. In general, N, P and K concentration in the decomposing tree leaf litter was significantly low both in alder and Khasi mandarin compared to its initial concentration but in Khasi pine it did not show any regular trend during the entire study period. Whereas, K concentration in alder and Khasi mandarin decreased during the course of decay, the reverse trend was found in Khasi pine leaf litter during the experimental period (Fig. 7.3). Subsequent increase in K concentration in Khasi pine leaf litter up to 210 days might be due to the release of immobilized nutrients by soil microbes.

The input of N, P and K through litter was high in 'Khasi pine + ginger' and 'Khasi pine + rice agroforestry systems was due to longer crop duration (132 days) as compared to maize which had 124 days growth period. The loss of N from the control plots was less than the alder and pine systems, but more than the Khasi mandarin-based system. It indicates that the production of biomass in different systems (Chapter 6) played the major role in N use efficiency i.e. greater biomass production reduced the chances for N loss through runoff, leaching and volatilization. The low quantity of available

phosphorus even after the application of fertilizers indicates that the applied phosphorus had been adsorbed on the active surface of iron and aluminum in the acidic soil (Patiram 1990). Potassium is comparatively a mobile nutrient, which is lost through leaching from the surface soil to the lower horizons. Some amount of K might have been converted to non-exchangeable forms. Similar trend in respect of N, P and K was also observed in the unfertilized plots. Similar results were reported by Patiram and Prasad (1983) in potato-rice system of Meghalaya.

In case of Khasi mandarin-based AFS, a positive balance of N, P and K as compared to the other systems in soils of the unfertilized plots as well as in the fertilized plots needs more intensive study of storage and flux of these mineral elements before reaching to any definite conclusion. Probably high organic matter contents in soil of Khasi mandarin-based agroforestry systems helped in retention of these elements in the soil system.

Economic analysis of three AFS has been compared with control. Among the three crops, ginger was found to be most remunerative compared to maize and rice. On an average, farmers could gain a net monetary benefit of Rs. 34,000 to Rs. 50,000 $ha^{-1}year^{-1}$ through ginger cultivation alone. It could further increase if it is cultivated in the partial shade of various tree-crops as evidenced from the data given in Table 7.6. The B/C ratio was highest (2.4) in Khasi mandarin-based AFS, compared (1.41-1.42) in other systems, irrespective of crops and fertilizer application. It could be attributed to comparatively higher net return from the fruits of Khasi mandarin. Net monetary gain was also satisfactory for maize cultivation either in AFS or under control. In all the systems economic return was poor in rice. Based on the economic analysis it may be concluded that ginger cultivation under AFS is more economic compared to cereals. In an

earlier study, Singh et al. (2003) also reported that ginger cultivation with Khasi mandarin was most profitable with benefit cost ratio of 2.58. Similarly, cultivation of ginger in association of *Parkia roxburghii* was reported to be most profitable compared to other food crops (Singh et al. 2004). Bhatt et al. (2001) also worked out the economics of various AFS and reported that ginger cultivation in agrihorticulture, agrisilviculture and multistoried AFS was most profitable in terms of monetary returns followed by soyabean, groundnut and turmeric. Although alder and Khasi pine produced, respectively, 100 and 140 q of firewood ha^{-1} which could also add to net monetary benefits, nevertheless the out put/ input ratio was low for both the systems due to low yield of rice and maize. Bhatt et al. (2001) also reported poor economic return of paddy and maize in the under storey of *Machilus bombycina*-based AFS. Comparatively higher monetary gain in agri-horticulture system has also been reported by Tomar and Bhatt (2004) compared to agri-silviculture system, which is similar to the present findings. Agri-horticulture AFS exhibited the highest net monetary benefits not only for ginger but also to the cereals, which is in conformity with the earlier findings of Bhatt and Misra (2003) who have reported that rice could be grown successfully in the understorey of guava and Assam lemon.

Chapter 8

GENERAL DISCUSSION

Agroforestry is an integrated land-use system involving suitable combination of trees and other woody perennials with agricultural crops and/or livestock. Its importance has been realized in improving the economy of farmers and in restoration of soil fertility in the hilly and mountainous regions (Anderson 1987, Garrity 1993, Sanchez 1995, Puri and Nair 2004) by checking erosion on sloping lands and improving physical, chemical and biological properties of soil as well as hydrological characteristics. In northeastern region of India, large-scale deforestation associated with shifting cultivation has led to widespread land degradation, which has adversely affected agricultural production (Borthakur 1992, Bhatt et al. 2001). Farming activities in the hills, particularly on the slopes, are the major areas of concern as they have resulted into severe soil erosion, decline in fertility and loss of flora and fauna. Therefore, an alternative system with low external inputs, such as agroforestry, has great potential for increasing agricultural production in the region on a sustainable basis.

It is well known that in the northeastern region of India, indigenous ethnic tribes grow crops and trees together in different combinations depending on the agro-climatic conditions of their habitat. In such traditional systems, a wide variety of crops are grown together in different combinations using different crop rotation practices depending on the edapho-climatic condition of the area. The needs of the farmers also influence the composition of mixed cropping. A number of crops involving cereals, vegetables, condiments and other cash crops are grown with multipurpose tree species like Khasi

mandarin, alder, Khasi pine, Makrisal, coconut, areca nut, jack fruit etc. (Chauhan and Dhyani 1989a).

Therefore, it is pertinent to study different AFS both from agronomic and ecological aspects to determine their suitability and sustainability. The present study was carried out in three AFS viz. Khasi mandarin-based, alder-based and Khasi pine-based AFS where three major crops namely maize, rice and ginger were grown with each of the three tree species. These systems were developed at the ICAR Research Complex for NEH region, Barapani. The ecological analysis of the above three AFS was done in terms of micro-environment, soil properties and weed community composition, tree phenology, growth and canopy architecture, crop growth, productivity and yield, and litter production, decomposition and nutrient budget.

Micro-environment, soil properties and weed community

In different AFS the tree canopies intercepted 54 to 73 percent of light and only 27 to 46 percent light was available to the crops when compared with the control plots without trees. Crops grown under the canopy of Khasi mandarin- based AFS could get on an average 48% of light and remaining 52% light was absorbed and/or reflected by the tree canopy. This value was much greater as compared to the alder-and Khasi Pine-based AFS. The maximum light intensity was recorded in May and minimum in July in all the experimental plots. The crops planted between the rows in alternate terraces could get more light than those planted in between the trees in the same terraces. Kohli and Saini (2003) have also reported that an AFS optimizes the microclimatic condition for crop growth and yield under similar conditions. The tree orientation and distance also influence the growth behaviour of crop but the effect of sun angle can change their influence over time because of altered sunrays and tree canopy resulting from changing

elevation and angle of sunrays. Greater availability of light to the crops in the Khasi mandarin-based AFS was due to medium size of canopy and semi-deciduous nature of the species whereas, lower light regime under Khasi pine is attributed to the large compact canopy and evergreen nature of the species. Jaswal et al. (1993) and Kumar (1996) have reported similar results with different tree species. Ovington (1961) measured light intensity in different forest plantations in England and reported that conifers allow the least light to penetrate than the deciduous tree species.

The effect of tree canopy architecture was seen on the soil environment. Among different AFS, soil temperature in Khasi mandarin system was higher than the other systems because of greater penetration of solar radiation. On the contrary, maximum soil moisture content was recorded in the Khasi pine-based AFS throughout the cropping period where tree canopy intercepted maximum light intensity. Besides light interception, the plots underneath the pine trees were covered by litter almost throughout the year thereby checking evaporation losses of water from the soil surface. Pandey and Sharma (2003) have also observed higher soil moisture content under tree canopies compared to open field conditions. The low soil moisture level under Khasi mandarin-based AFS and alder-based AFS during post rainy season from October to December is ascribed to greater evapotraspiration losses of water due to fast tree growth, thin litter layer on the ground and greater exposure to sun rays. Shanker et al. (2005) have reported that ecological advantages of growing trees with crops depend equally on both the resource use efficiency of the tree and the ability of the tree to provide a conducive microclimate to the understorey crops.

Excessive leaching of bases due to heavy rainfall in the area is the main reason for the overall acidic nature of soil in all the experimental plots. But relatively more acidic

soil under the alder-based and Khasi pine-based AFS could be related to the chemical nature of litter of these species. In the former, it could be due to N-fixation in the roots, since soil under N- fixing trees is reported to has lower pH than under non N- fixing tree (Binkley and Sollins 1990, Franklin et al. 1968). In the later i.e. in the Khasi pine, the increase in soil acidity was mainly due to presence of phenolic compounds in the conifer leaf litter (Berg 1986). Soils under coniferous forest are generally acidic in nature as reported by Majumudar et al. (2004)

All the three tree species produced large quantities of litter particularly during the dry period. On an average the maximum litter was produced by Khasi mandarin (50.37g m^{-1}) and alder (45.10g m^{-1}) in the month of January. In case of Khasi pine, the maximum litter was obtained in the month of February (86.04g m^{-1}). The litter so produced was decomposed during subsequent rainy season adding organic matter and nutrients to the soil system. The leaf litter of alder and Khasi mandarin being high in N concentration were capable of yielding high quality of organic matter (Dhyani 1997). Relatively higher amount of organic carbon in soil of Khasi pine-based AFS than the alder-based AFS could be attributed to greater amount of Khasi pine leaf litter though it had low N, P and K concentration than the alder leaf litter. Gradual buildup of organic residues in the soil of Khasi pine-based AFS may also be attributed to slower decay rate of pine needles.

In an earlier study, Majmudar et al. (2004) also observed that the organic carbon content in soil is dependent on the amount and quality of litter and its decay input by trees in different systems. Pandey and Sharma (2003) observed 29 to 43% greater organic carbon across irrigated soil with fertilized condition under different tree canopies as compared to open field. Studies conducted by several workers (Campbell et al. 1988,

1994, Dunham 1991, Kessler 1992, Dhyani 1997) have concluded that soil fertility under trees improved due to increased input of litter.

An increase in total nitrogen, available phosphorus and potassium in the soil and improvement in its WHC and porosity, and reduction in bulk density, under Khasi mandarin based-AFS clearly indicated an improvement in the fertility level of the top soil. Most of these parameters also improved in the alder-based AFS and Khasi pine-based AFS, but the magnitude of improvement was lower than the Khasi mandarin-based AFS and the control plots. Similar increase in soil fertility under different AFS was also reported by other researcher (Dhyani 1997, Majumudar et al. 2004).

In the crop fields, the species richness of the weed community often show close affinity with the crops (Tripathi and Misra 1971, Streibig 1979). Weed density was high in control plots followed by Khasi mandarin-, alder- and Khasi pine-based AFS. This could be the result of various ecological interactions including chemical properties of Khasi pine needle, competition between trees, crops and weeds (Vandermeer 1989).

The weeds are usually intolerant to shade and hence, as the tree canopy increases causing greater light interception, weed growth decreases (Dhyani 1997). This is evident in the present study as well, since alder-based AFS and Khasi pine-based AFS with maximum canopy spread had lower weed density than the Khasi mandarin-based AFS, where, the canopy was relatively small and open that permitted greater light intensity on the ground. The control plots without overhead tree canopy had the maximum weed density as compared to the other AFS. A lower weed growth under different AFS was also reported by Aken-Ova and Atta-Krah (1986), Bashir and Getahun (1991). In an another study (Siaw et al. 1991) weed community composition following alley cropping with various hedgerows species, was greatly reduced in AFS.

Phenology, growth and canopy architecture of the tree species

Alder, Khasi pine and Khasi mandarin showed wide variation in their growth characteristics. Though all three species grew well in the study area, CAI and MAI in height were greater in alder tree than in the Khasi pine, and CAI and MAI in diameter were maximum in Khasi pine as compared to the other two species. This differential behavior under same edapho-climatic condition could be explained on the basis of intrinsic differences between the two species.

Fine roots are generally concentrated in the upper soil layer both in natural forest and agro-ecosystems (Dhyani et al. 1990, Parrotta 1990, John et al. 2002. This was true for all the three AFS, where about 55% of the total fine roots were present in upper 10cm soil layer. Therefore, root competition between crop and tree species can be expected when they are intercropped, unless some mechanism of root exclusion is practiced (Jonsson et al. 1988, Dhyani et al. 1990). This could be achieved by hoeing, tilling etc., and trenching tree roots prior to the planting of the crops (Dadhwal and Tomar 1999) or lopping of tree branches in the established systems (Rai et al. 2001).

The root activity of woody perennials increases tremendously during February - March before the flushing. During this period, trees may strongly compete with crop plant for water and nutrients (Dhyani and Tripathi 1999). Coincidence of growing season of agricultural crops with the leaf flushing and bud initiation of integrated trees indicates the possibility of competition for resources between trees and crops (Negi 1995). The duration and intensity of competition between trees and crops decide the compatibility between tree species and crop in AFS.

Gradual increase in temperature during February and March after winter season marks the on set of leaf flushing and bud initiation in majority of tree species. As active

growth for all the tree species takes place during February to March, therefore, they might have utilized maximum resources. Whereas, underneath crops i.e. maize, rice and ginger were also sown in the May with the on set of monsoon. Therefore, the initial growth stages of crops were coincided with the active growth stage of all the tree species. This might be the reason for lower productivity of rice and maize under AFS as compared to control. The ginger rhizome yield however, was not affected due to its shade tolerant nature.

Crop growth, productivity and yield

It is evident from the growth data that crops in the plots treated with fertilizers and FYM in all the AFS performed better. This was obviously the effect of recommended dose of fertilizer application in conjunction with FYM. Among the three- AFS, Khasi mandarin-based AFS was better than alder-based AFS and Khasi pine-based systems so far as crop growth and yield was concerned. This may be related to better light regime for the crops under Khasi mandarin system. For instance, in Khasi mandarin-based AFS, light penetration was greater (48%) than alder (39%) and Khasi pine-based AFS (29%). Srinivasan et al. (1990) while examining the resources sharing ability of multipurpose trees in an intercropping system reported reduced crop yield due to competition with the trees for light. Reduction in availability of light not only adversely affects photosynthetic activity, but also influences other physiological activities of plants (Jha and Gupta 2003). Besides low light intensity, poor growth and yield of crops under Khasi pine could be attributed to other changes in soil properties caused by accumulation of pine needles on soil (Das 1980). Detrimental effect of pine needle on crop growth has also been reported by Kandpal and Negi (2003).

The performance of crops grown with N-fixing alder was not as good as with Khasi mandarin. This could be attributed to high concentration of fine roots of alder in upper soil layer, which might have offered keen competition to the crops for water and nutrients. Several workers have reported that similarity in root distribution pattern of trees and crops in the soil profile cause considerable overlapping of their niches for the utilization of soil resources (Jonsson et al. 1988, Dhyani et al. 1990, Scroth and Lehmann 1995). Root competition for water and nutrients has been found to be responsible for yield depression in crops under various AFS (Lal 1991, Szott et al. 1991, Salazar et al 1993). In Khasi pine-based AFS comparatively low light intensity (29% of total sunlight) and low availability of nutrients due to lowering of pH (pH 4.88) might have been responsible for poor growth performance of crops under this system. The crops planted between the trees in the same terrace suffered more than those grown on the terraces between the rows because of lower light intensity (up to 16%) in the former situation compared to the latter.

The application of fertilizer and manure helped in increasing soil nutrient level and pH of the soil in all the AFS. A marginal increase in soil pH has been reported due to the addition of basic cations released into the soil after application of organic manure (Patiram and Singh 1993). Therefore, the greater nutrient accumulation in the crops grown in the fertilized plots in different AFS was obviously due to their greater availability to the crops. Greater nutrient availability in the Khasi mandarin-based system due to high average soil moisture content (30.7%) and higher initial N, P and K contents in soil as compared to the other AFS might have been the reason for the better performance of the crops in this system.

Not much variation in grain weight per 100 grains was recorded when maize and rice was grown either between the trees or between the rows. However, with fertilizer application, there was an increase in the grain weight of the two crops in Khasi mandarin AFS than the control. The grain yield, however, was greater in the "between rows planting" than "between trees planting" in all the three systems. This could be due to high quantum of light availability to crops planted between the rows as compared to those planted between the trees. Crops grown between the rows in Khasi mandarin, alder and Khasi pine-based AFS received 11.1, 16.7 and 7.14% higher light intensity, respectively, than when grown between the trees. On an average, grain yield and harvest index was higher in Khasi mandarin based AFS than the other two AFS. In the case of ginger also, highest yield was obtained in the Khasi mandarin AFS followed by alder-based and Khasi pine-based AFS. Since ginger grows better in partial shade, its productivity was more in agroforestry systems than in the control plots. Jaswal et al. (1993) have also reported greater rhizome yield of ginger grown underneath of medium density plantation of *Populus deltoides* in Central India. The higher ginger yield was also recorded by Bhatt et al. (2001) in the under story of Assam lemon, guava and *Machilus bombycina*. In an another studies Singh et al. (2004) also recorded higher yield of ginger in the under story of *Parkia roxburghii* under agri-silvi systems.

The net primary productivity of AFS depends on the growth performance of the tree and crop components as well as the management practices. Thus, based on total aboveground net primary productivity during cropping periods in 2002 and 2003, the three AFS could be ranked as: Khasi mandarin (131.95g m^{-2} day^{-1}) > Alder (g m^{-2} day^{-1})> Khasi pine (60.95g m^{-2} day^{-1}). So far as the ANP of weeds was concerned, it was higher in the controls (4.16 g m^{-2} day^{-1}) followed by Khasi mandarin-based AFS (2.73 g m^{-2} day

$^{-1}$), alder (2.16g m^{-2} day^{-1}) and Khasi pine-based AFS (1.83g m^{-2} day^{-1}) in the fertilized plots.

Litter production, decomposition and nutrient budget

The tree leaf litter contributed maximum to the total litter fall in all the three systems. The total litter production was greater in Khasi pine-based AFS followed by alder and Khasi mandarin-based AFS. Lower litter production in Khasi mandarin was due to its small size of canopy than the other two tree species. Higher litter production in Khasi pine could be due to its more extensive canopy. The temporal variation in litter fall was similar in all the three species and all of them showed a greater leaf fall during dry period (October to March) of the year. Moore (1980) reported that the maximum litter fall during the dry period could be due to water stress which triggers *de novo* synthesis of abscissic acid in the foliage of plants, which in turn can stimulate senescence of leaves and other parts. Variability among tree species in litter production has been related to the age, spacing of trees, local environmental condition and the period of data collection (Alban 1982, Buck 1986, Budelman 1989, Hawkins et al. 1990, Szott et al. 1991, Szott and Kass 1993).

The nutrient-rich leaf litter of alder and Khasi mandarin decomposed more rapidly than the Khasi pine needles. The decomposition rate was highest in alder (57.3 mg day^{-1}) and lowest in Khasi pine (25.0mg day^{-1}). In the tropics, litter decomposes at a faster rate during the rainy season when the environmental conditions are favorable for microbial activities. Arunachalam (1996) have reported that during the dry period, litter decomposition rate is drastically retarded and the number of sarcophagus animals in the litter is reduced. The nutrient content especially N and proportion of resistant materials like cellulose, lignin and tannin influence in the rate of decomposition of litter

(Arunachalam 1996). These substances are known to control decay rate by slowing resistance to enzymatic attack and physically interfering with the degradation of other chemical fractions of the cell wall (Bloomfield et al. 1993). Swift et al. (1979) have reported that litter of high quality decays and releases nutrients rapidly than that of low quality. Higher initial concentrations of N in the alder leaf litter could be the cause of its faster decomposition and slow rate of decay of pine needles may be attributed to low N content and higher lignin and cellulose content (Das 1980, Berg 1986).

A positive effect of N concentration on decomposition has been reported by several workers (Swift et al. 1979, Pandey and Singh 1982, Shukla et al. 1990). Higher rate of litter decomposition of alder has also been attributed to the low tannin content (Clein and Schimel 1995). Relatively rapid release of N, P and K from alder and Khasi mandarin leaf litter may be useful from the point of view of meeting nutrient requirements of crops during the active growth phase. The rapid decomposition and release of nutrients from alder leaves increases the chance of their availability to the associated plants. Sharma et al. (1997, 2002) have reported that the agronomic yield of large cardamom increased more than two fold when it was grown in association with alder compared to when it was with non-N_2-fixing trees.

N, P and K input through litter was more in the "Khasi pine-ginger AFS" and "Khasi pine- rice AFS" than Khasi pine-maize AFS, (124 days). The N loss from the control plots was less than the alder and pine AFS. It appears that the production of biomass in different systems played the major role in this regard as greater biomass production minimized the chances of N loss from the system. Analysis of nutrient budget in the three AFS revealed a positive balance of N, P and K in case of Khasi mandarin

based AFS, even in the unfertilized plots, indicating that this AFS appears to be better and probably more sustainable as compared to the other two systems.

Based on economic analysis, it has been observed that Khasi mandarin- based AFS was more profitable compared to other systems due to income from Mandarin fruits. It was also eco-friendly to the understorey crops. Among various crops, net monetary gain was greater through ginger cultivation followed by maize and rice. Thus an agri-horticulture system was found to be most economic in terms of monetary benefits compared to other agri-silviculture systems. Other workers (Bhatt and Misra 2003, Singh et al. 2003, Tomar and Bhatt 2004) have also reported that agri-horticulture system is more profitable for eastern Himalayan region compared to other AFS.

SUMMARY

The present study was conducted in the Khasi mandarin-based, alder-based and Khasi pine-based AFS at the research farm of Agroforestry Division, ICAR Research Complex for NEH Region, Barapani located between $25^0$41' N latitude and $91^0$55' E longitude. Barapani, 22 km north of Shillong, the capital town of Meghalaya. The farm is situated on hill slopes at an altitude of 1000-1100m asl, where bunds and mini-terraces on contours have been created to prevent soil erosion and safe disposal of excess rain water. The climate of the study site is monsoonic with average annual rainfall of 2300 mm, and maximum and minimum temperature of 16.7^0C and 28.5^0C, respectively.

The experimental plots were made on the terraces (1.5m wide, 10m long and 1 m high) on a hill slope (25-38%) where soil depth varied from about 23cm at upper reaches to 45 cm at the foothills. Three plots of 1m x 3m were developed for cultivation of maize, rice and ginger under each of the three AFS viz. Khasi mandarin (*Citrus reticulata*)-based AFS, alder (*Alnus nepalensis*)-based AFS and Khasi pine (*Pinus kesiya*)-based AFS. Besides, these control plots (without tree species) were maintained for each crop. Ginger was sown in April, maize in the last week of April and rice in mid May during 2002-2003. All trees were 13 years old their with a density of 400 trees ha^{-1}. In all the systems, trees were planted in alternate terraces with a spacing of 5m between the trees and 5m between rows. The crops were grown in the fertilized and unfertilized plots in each AFS. N, P and K fertilizer was applied as per the recommended doses (60:40:40) for all the crops in the bench situation in each plot. The experimental plots were prepared by hand hoeing the soil down to 15-30 cm depth and hand weeding was done before crop sowing.

On an average thirty-three species of weeds were recorded in the AFS and the control plots. The weed species richness was maximum (21 species) in the control plots followed by Khasi mandarin (16 species), Khasi pine (15 species) and alder-based AFS (13 species). *Galinsoga parviflora, Borreria hispida, Ageratum conyzoides, Drymaria cordata, Commelina bengalensis* and *Bidens pilosa* were the dominant weed species in all the experimental plots.

Light intensity and soil temperature varied significantly between months and both recorded high values in Khasi mandarin-based AFS followed by alder and Khasi pine-based AFS in between the tree rows. Water holding capacity (WHC) varied significantly ($P<0.05$) between the plots with maximum values in Khasi pine-based AFS. The WHC of soil was high in 15-30 cm soil layer than the surface layer (0-15 cm). The surface soil layer had higher moisture content than the subsurface layer in all the experimental plots. It peaked during June, followed by a gradual decline until December. The soil texture was silt clay loam in all the plots. Depth-wise variation in the proportion of different soil particles was significant ($P<0.01$), but differences among the three AFS were not significant.

The soil pH ranged from 4.63 to 5.00 in upper layer and from 4.69 to 4.94 in lower layer. In fertilized plots, the soil of Khasi pine-based AFS was more acidic (pH 4.89) than the alder-based AFS (pH 4.92) and Khasi mandarin-based AFS (pH 5.00). Soil organic carbon as well as soil organic matter content was greater in the Khasi mandarin AFS followed by alder-based AFS and Khasi pine-based AFS. The surface layer had greater concentration of organic matter than the subsurface layer in all the systems. The concentration of total Kjeldahl nitrogen (TKN) was low in all the soils but it was lowest in the Khasi pine-based AFS. It varied significantly between soil depths. The concentrations of available phosphorus and potassium also showed a similar trend to nitrogen in different systems.

The growth habit of Khasi mandarin and alder are bushy conforms to Roux's model of tree architecture. The trunk of Khasi pine is monopodial and grows rhythmically, and develops tiers of branches; the formation of cones does not affect shoot construction. Thus, the normal architecture of pine is similar to Rauh's model.

Khasi pine, Khasi mandarin and alder are evergreen, semi deciduous and deciduous in nature, respectively. Leaf flushing in alder and Khasi pine was seen during the months of February and March, while in case of Khasi mandarin it occurred twice (February and August) in a year. The active shoot growth was observed during February to April in case of Khasi mandarin and Khasi pine, however, in alder it continued for over four months (February to May). Leaf fall started during post-rainy period (October to February) and peaked during the dry winter (January) in case of Khasi mandarin and alder tree, but in Khasi pine it occurred throughout the year with peak in February. In terms of height growth, the species ranked as *Alnus nepalensis*> *Pinus kesiya*> *Citrus reticulata,* and in terms of growth in basal diameter (dbh) they were found in the order of *Pinus kesiya*> *Alnus nepalensis*> *Citrus reticulata.*

The total aboveground biomass was maximum in Khasi pine followed by alder and Khasi mandarin. Bole contributed about 59 to 78% of total aboveground biomass while leaves contributed only about 8% in all the tree species. The fine root biomass in alder and Khasi pine decreased with increase in distance from the tree trunk, but in Khasi mandarin it showed a reverse trend. The maximum total fine root mass (trees and herbaceous fine root) was recorded in the upper soil layer in Khasi pine AFS.

The height, leaf area index and biomass of maize and rice were significantly greater in the control plots than the AFS, irrespective of fertilizer application. Maximum net primary productivity, NPK accumulation and grain yield of the two crops was recorded in the control plots followed by Khasi mandarin, alder and Khasi

pine-based AFS. When planted between the rows they showed better growth and greater net primary productivity and N, P and K accumulation than those planted between the trees, irrespective of fertilizer application.

The shoot height, leaf area index and biomass of ginger was significantly higher in the control plots than the AFS. Among the AFS, the best growth of the crops was in Khasi mandarin system and lower in Khasi pine-based AFS. Maximum net primary productivity and NPK accumulation of the maize crop was recorded in the control plots followed by Khasi mandarin, alder and Khasi pine-based AFS. Planting arrangement also affected plant growth; it was batter in "between rows planting" than "between trees planting" in all the AFS but yield and other yield attributes like rhizome length and diameter was better when it was grown between the trees.

Maximum total annual net production of crops + weeds was recorded in the control plot followed by Khasi mandarin, alder and Khasi pine-based AFS under "between trees planting" arrangement, irrespective of fertilizer application. Weed starts growing with the onset of monsoon and attain maximum biomass (499.8 g m^{-2}) in the month of August and minimum (278.8 g m^{-2}) in the month of December. Highest average aboveground net primary productivity of weeds was in the control plots (4.61 g m^{-2} day^{-1}) followed by Khasi mandarin- (3.16 g m^{-2} day^{-1} in the "between trees planting"), alder- (2.29 g m^{-2} day^{-1} in "between rows planting") and Khasi pine-based (2.01 g m^{-2} day^{-1} in the "between rows planting") AFS.

The litter fall in all the tree species was highest during the winter season, a period characterized by low temperature and low rainfall, and minimum during rainy season. The total annual litter fall was 585.79 g m^{-2} in Khasi pine-based AFS followed by alder- (338.03 g m^{-2}) and Khasi mandarin-based AFS (263.41 g m^{-2}). Leaf litter contributed maximum (69% to 78%) to the total litter production followed by miscellaneous litter (15% to 20%) and branches/ twigs (7% to 11%).

The rate of leaf litter decomposition varied between the species but seasonal trend was similar in all the cases as it was fast during the rainy season (April to September) and slow in winter season. The rate of weight loss was much faster in alder (52.0 mg day^{-1}) followed by Khasi mandarin (52.5 mg day^{-1}) and Khasi pine (25.0 mg day^{-1}). For complete decay, the alder, Khasi mandarin and Khasi pine leaves took 349 days, 358 days and 717 days, respectively.

There was a wide difference in concentration of N, P and K in the leaf litter of the all three species. Nutrient (NPK) concentration in alder leaves was higher than in Khasi mandarin and Khasi pine. Nitrogen concentration in alder leaves was much higher than the other two species. The pine needle had the lowest concentration of N, P and K. Total N, P and K input through leaf litter was highest in case of Khasi pine (N=127.73, P=38.25 and K=215.68 g m^{-2}) and lowest in Khasi mandarin-based (N=31.89, P=27.27 and K=24.58 g m^{-2}) AFS. Khasi mandarin though had high concentration of N, P and K as compared to Khasi pine its total input was less due to low litter production.

The N, P and K accumulation in the crop and weed biomass was maximum in the control plots than the AFS. Among the AFS, maximum NPK accumulation by crops and weeds was recorded in Khasi mandarin-based AFS and minimum in Khasi pine-based AFS. The total accumulation of NPK in the unfertilized plots was less than half of the amount accumulated by the crops and weeds in the fertilized plots.

Though soil N, P and K level in different AFS and control plots showed a negative balance at the end of the year after the crop harvest, Khasi mandarin showed lower negative balance than the other two AFS.

CONCLUSIONS

The Khasi mandarin-based AFS was found to be better both from ecologic and economic aspects than alder and pine-based AFS on account of the following reasons:

(i) The canopy architecture of Khasi mandarin was such that the under canopy was more exposed to sunlight as a result.

(ii) It helped in nutrient enrichment of soil as is evident from higher organic carbon and nitrogen, phosphorus and potassium contents in soil than the other systems.

(iii) The nutrient release from decaying leaf litter was relatively faster than Khasi pine and relatively slower than alder.

(iv) The nutrient loss from the soil was minimum as compared to other systems.

(v) The net economic return was higher than the other systems.

The lower crop growth and yield obtained in the alder-based AFS than the Khasi mandarin-based AFS was little surprising, since nutrient release from decaying litter was very fast and it is also known to enhance soil fertility level due to its symbiotic nitrogen fixation ability. Therefore, the reduction in crop yield could presumably be due to root competition between annual crops and alder for nutrients and water, since high concentration of tree fine roots was observed in the upper layer of the soil where most of the crop roots are also confined. Relatively low light intensity on the ground on a account of dense over head canopy could have been another reason for low crop yield in this system. However, further in-depth studies are required to reach to a definite conclusion.

The lowest crop growth and yield in Khasi pine-based AFS might have been occurred due to:

i) The low light availability to crops due to greater light interception by tree canopy.

ii) The amount of available phosphorus and potassium in the soil was about half as compared to other two systems. Further, increased soil acidity due to accumulation of large quantity of pine litter on the soil surface might have also reduced the availability of nutrients to the plants.

iii) The rate of nutrient release from decaying pine needles was the slowest among the three species.

Considering the planting arrangement, the crops grown in between the rows gave better yield than the crops grown between the trees. Based on economic analysis, Khasi mandarin- based agri-horticulture system was more profitable as compared to alder- and Khasi pine- based agri-silviculture systems. It was also eco-friendly to the understorey crops. Among various crops, net monetary gain was greater in ginger cultivation followed by maize and rice.

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