CHAPTER 10

GENERAL DISCUSSION

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

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

Survival and growth of trees

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

Biomass and productivity of the tree species

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

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

Biomass and productivity of crops

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

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

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

Belowground biomass

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

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

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

Litter dynamics of trees

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

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

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

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

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

Physico-chemical properties of soil under the four systems

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

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

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

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

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

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

Nutrient cycling in the four agroforestry systems

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

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

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