Summary

The present study was carried out in different land use systems at Sagalee and Kheel in the Papum Pare district of Arunachal Pradesh. The different land use systems under study were jhum cultivation system, terrace cultivation system, horticultural system, agroforestry system, abandoned jhum land and forest. The objectives of the study were to estimate the plant diversity and soil nutrient enrichment patterns involved in ecological interventions like terracing, agroforestry and horticulture in abandoned jhum lands. And to characterize the quality, decomposition and nutrient release patterns in various crop/plant residues and their recycling for soil organic matter and nutrient build-up in soil and also to evolve appropriate strategies for maintenance of soil fertility to ensure sustainable production in rehabilitated jhum lands.

Microclimatic variability and Soil physical properties

The results on micro environmental parameters suggest that there were radical changes in micro environment of forest when diverted to other land use system viz. jhum cultivation system, terrace cultivation system, horticultural system, agroforestry system or abandoned jhum land. Although, overall soil texture was sandy loam irrespective of land use systems, the fine textured soil (silt and clay) was greater in forest soil and lower in agricultural systems. The bulk density of soil was higher in agricultural systems and lower in forest. Soil pH varied considerably over seasons and land use systems. Soil moisture content varied significantly over different seasons and land use systems. It was highest during
rainy season and lowest during winter and the soil of terrace cultivation system had highest soil moisture content whereas the horticultural system in Sagalee and jhum cultivation system in Kheel registered lowest value.

**Soil nutrient dynamics**

Ammonium-N concentration was highest during summer and lowest during winter season irrespective of land use system, soil depth and sites. It varied significantly over different land use systems. The annual mean value was highest in horticultural system at Sagalee and in agroforestry at Kheel and least in abandoned jhum land in both the sites. The seasonal trend of nitrate-N was reverse to that of ammonium-N. Highest concentration of nitrate-N was recorded during autumn and least during summer. In most of the agricultural systems under study the nitrate–N concentration was higher in lower depth than surface layer in rainy or autumn season. Annual mean value was highest in jhum cultivation system in Sagalee and in terrace cultivation system in Kheel and least concentration was recorded in horticultural system in Sagalee and in forest at Kheel. The depth wise comparison suggests that there were nitrate leaching in terrace cultivation system at both Sagalee and Kheel. Phosphate-P represented a reverse trend from that of all other nutrients under consideration. It was negatively correlated with soil moisture content (r=-0.209, p<0.01), pH (r=-0.194, p<0.02), ammonium (r= -0.27, p<0.005) and nitrate concentration and positively correlated with organic C (r=0.646, p=<0.001) and total N (r=0.266, p=0.001). It was highest during winter and least value was recorded during autumn. Annual mean value was highest in terrace cultivation system
and least was recorded in horticultural system at Sagalee and in agroforestry system at Kheel and the altitudinal variation was not significant, although the values registered in Kheel were a little higher than that of Sagalee. The organic C was highest during winter and it gradually declined over summer, rainy and autumn seasons in all land use system, sites and depths. Annual mean value of organic C was highest in forest and lowest values were recorded in horticultural system in Sagalee and in abandoned jhum land at Kheel. However, in successive year the highest annual mean was recorded in terrace cultivation system and least was in jhum cultivation system in Kheel but the trend for Sagalee remained unchanged. The seasonal trend depicts the reduction of total-N from its peak concentration during winter over following summer and rainy season followed by slight increase in autumn particularly in open canopied agricultural systems in both Sagalee and Kheel. The annual mean of total-N ranges from 0.12±0.03% in horticultural system to 0.38±0.03% in forest at Sagalee (0-30cm depth). However, in Kheel the values range from 0.11±0.11% in abandoned jhum land to 0.35±0.15% in forest. The variation of the values over different land use system (F=282.206, p<0.001; F=189.69, p<0.001) and season (F=43.59, p<0.001; F=23.72, p<0.001) was significant in both Sagalee and Kheel. The general trend suggests that C/N ratio increases in the lower profile of soil. The overall mean value was highest in abandoned jhum land (10.13 and 11.45 in Sagalee and Kheel respectively) and lowest in forest (5.22 and 4.68 in Sagalee and Kheel respectively). Altitudinal variation was not significant, however. By and large, the result suggests that the land
use change from forest to agricultural land use caused increase in the C/N ratio of soil.

**Dynamics of microbial population and biomass nutrients (C&N)**

The seasonal variation of fungi population was considerable. The population was highest during the summer season and least values were recorded during winter season in almost all the land use system and in both in Sagalee and Kheel. The mean fungal population ranged from $3.87 \times 10^3$ g$^{-1}$ soil in jhum cultivation system to $10.52 \times 10^3$ g$^{-1}$ soil in forest at Sagalee whereas in Kheel the values ranged from $6.14 \times 10^3$ g$^{-1}$ in terrace cultivation system to $21.72 \times 10^3$ g$^{-1}$ soil in forest. The bacteria population showed similar seasonal trend as that of fungi. The peak bacteria population was recorded during summer season and it declined during the following rainy season which again increased in the succeeding autumn and ultimately least population was recorded in the winter. Mean bacteria population in Sagalee was highest in forest soil ($21.45 \times 10^4$ g$^{-1}$ soil) and least in terrace cultivation system ($8.02 \times 10^3$ g$^{-1}$ soil). The same trend was observed in Kheel where the highest was recorded in forest ($24.01 \times 10^4$ g$^{-1}$ soil) and least was in abandoned jhum land ($12.03 \times 10^4$ g$^{-1}$ soil). However the trend changed a little in the successive year. Microbial biomass carbon (MBC) was highest during summer season and lowest during winter in almost all the land use systems and in both Sagalee and Kheel irrespective of year of sampling. The mean MBC was highest in forest (1834.10 μg g$^{-1}$) and lowest was recorded in jhum cultivation system (441.73 μg g$^{-1}$) in case of Sagalee, but
in case of Kheel the values ranged from 967.20 µg g⁻¹ in agroforestry system to 1768.70 µg g⁻¹ in forest. The values obtained in the second year sampling were a little higher than the previous year although the trend remained same. Almost same seasonal trend as MBC was observed in case of microbial biomass nitrogen (MBN). The least MBN was observed during winter season and highest was in summer irrespective of land use type, study area and year. The annual mean MBN was highest in forest (113.65 µg g⁻¹) and lowest was in abandoned jhum land (57.32 µg g⁻¹) in Sagalee. The same trend was followed in Kheel where the highest value was (363.33 µg g⁻¹) in forest and least was (104.26 µg g⁻¹) in abandoned jhum land. In Sagalee, the contribution of MBN to total N was 6.59 % in the horticultural system and 2.53 % in the forest. Similarly in Kheel the highest contribution MBN to total N was in abandoned jhum land (8.69 %) and lowest contribution (5.09 %) was in the agroforestry system. Generally the microbial contribution increased in the subsoil. However, when the whole soil profile of 0-30 cm considered together then the highest value was in horticultural system (4.05 %) and lowest in the forest (1.97 %) in Sagalee, but in Kheel it was recorded in abandoned jhum land (8.90 %) and agroforestry system, respectively.

**Plant community structure**

A total of 144 plant species (tree, shrub, herb and grass) belonging to 116 genera and 48 families were encountered irrespective of land use systems. The total number of species was higher at Kheel (143) compared to Sagalee (119). There were 17 tree species in forest at Sagalee where some of dominant species
(based on their IVI) were *Castanopsis indica*, *Cinnamomum bejolghota*, *Meliosma* sp. It declined in other land use systems and least number of species (3) was recorded in horticultural system in which the dominant species was *Citrus reticulata*. However, in Kheel 19 tree species were recorded in forest, which was maximum and some dominant species were *Duabanga grandiflora*, *Litsaea monopetala* etc. and lowest number of species (4) was recorded in abandoned jhum land in which *Meliosma wallichii* was dominant. Maximum number of shrub species (10) was recorded in abandoned jhum land and minimum was in terrace cultivation system (4) in Sagalee where *Schoepfia* sp. in forest, *Maliosma simplicifolia* in abandoned jhum land, *Urena lobata* in horticultural system, *Cupphia carthagensis* in terrace cultivation system and *Clerodendron colebrookianum* in jhum cultivation system were the most dominant shrubs. The number of shrub species in Kheel ranged from 3 (in terrace cultivation system) to 9 species (in abandoned jhum land) where most dominant shrubs were *Mollugo pentaphylla* in forest, *Eupatorium odoratum* in abandoned jhum land, *Crotalaria* sp. in agroforestry, *Combretum acuminatum* in terrace cultivation system and *Solanum torvum* in jhum cultivation system. Whereas maximum herbaceous species (12) were recorded in abandoned jhum land and minimum (6) was recorded in horticultural system in Sagalee and dominant herbs were *Hedychium* sp. in forest, *Ageratum conyzoides* in abandoned jhum land, *Spermacoce hispida* in horticultural system and *Ageratum conyzoides* in both terrace and jhum cultivation system. In Kheel, the richness of herbaceous species was highest in forest (12) and least (5) was
recorded in jhum cultivation system in which dominant species were *Lycopodium cernuum* in forest, *Spermacoce hispida* in abandoned jhum land, *Ageratum conyzoides* in agroforestry system, *Polygonum hydropier* in terrace cultivation system and *Ageratum conyzoides* in jhum cultivation system.

**Biomass and productivity**

The monthly variation of standing live and standing dead biomass production data revealed that peak live biomass accumulation by weed was during the month of April in jhum cultivation system and during May in terrace cultivation system just prior to the initialization of agricultural activities and was least during the month of either December (in jhum cultivation system) or November (in terrace cultivation system). Whereas in the non-agricultural systems, the peak live biomass growth was during the month of July and least in January in case of forest and February in case of abandoned jhum land at Sagalee. The standing dead biomass however showed the opposite pattern of that of live biomass in almost all the land use systems. Seasonal variation of biomass accumulation by crop and weed communities in different land use systems at Sagalee reveals that the crop biomass production (275.18) was confined in rainy season in jhum cultivation system. However, the weed biomass was highest (191.36 g m\(^{-2}\)) during autumn and least during winter (155.67 g m\(^{-2}\)). But total biomass (crop + weed) was highest during rainy season (330.99 g m\(^{-2}\)) because of highest contribution of crop biomass. The crop biomass in terrace cultivation system was highest in autumn (462.32 g m\(^{-2}\)) when crop were mature and lower (353.49 g m\(^{-2}\)) during the rainy season. Weed biomass also
followed similar pattern which was highest during autumn (167.97 g m\(^{-2}\)) and least during rainy season (66.38 g m\(^{-2}\)). The weed biomass in horticultural system was highest (125.22 g m\(^{-2}\)) during autumn and least during summer (84.10 g m\(^{-2}\)). Whereas it was highest in autumn season in abandoned jhum land (387.00 g m\(^{-2}\)) and lowest in summer (246.50 g m\(^{-2}\)). In the forest ecosystem, it was greater during rainy season and lower during winter (169.00 g m\(^{-2}\)). The annual NPP was higher in the agricultural crops compared to the weeds in both the study area. In jhum cultivation system it was 682.11 g m\(^{-2}\) y\(^{-1}\) and in terrace cultivation system it was 1386.96 g m\(^{-2}\) y\(^{-1}\) in contrast to the productivity of weed community which ranged from 115.00 g m\(^{-2}\) y\(^{-1}\) (in forest) to 285.91 g m\(^{-2}\) y\(^{-1}\) (in terrace cultivation system) in Sagalee and in Kheel the annual NPP of crop in jhum cultivation system was 480.13 g m\(^{-2}\) y\(^{-1}\) and that in terrace cultivation system was 1374.80 g m\(^{-2}\) y\(^{-1}\). On the other hand, the annual NPP of weeds ranged from 170.94 g m\(^{-2}\) y\(^{-1}\) (in agroforestry system) to 257.78 g m\(^{-2}\) y\(^{-1}\) (in jhum cultivation system).

**Crop/plant residue quality and their effects on decomposition and nutrient release patterns**

C content in weed biomass varied from 29.6 (Centella asiatica) to 44.6 % (Hedychium sp.) and N concentration varied from 0.24 (Vitis sp.) to 2.76% (Ageratum conyzoides), which caused a wide variation in C/N ratios in weed biomass and thus influenced the residue quality. The C content in crop residues varied from 30.1 (Oryza sativa, root) to 43.3 (Zea mays, stem) and the range of N content was 0.5 (Eleucine coracana, root) to 4.1 % (Glycine max. leaf). The C/N ratio was within the range of 10.0 (Glycine max leaf) to 83.2 (Eleucine
The lignin/N ratio was lowest (5.2) in *Ageratum conyzoides* and highest (47.2) in *Fimbristylis dichotoma*. In crop residues it ranged from 2.2 (*Glycine max*, leaf) to 46.2 (*Eleucine coracana*, root). Weight loss was rapid in case of *A. conyzoides* and *G. max* residues. It took about 150 and 90 days respectively to decompose the *A. conyzoides* and *G. max* leaf litter completely which was the shortest period required for complete decomposition compared to all other residues in the present decomposition experiment. Slowest rate of decomposition was recorded for *C. indica* leaf litter. It took around 270 days to decompose about 80% of its initial mass. C release was rapid in some weed and crop residues. *A. conyzoides* leaf and root released about 40% of initial C content within 30 days. Whereas some of the residues *viz.* *C. indica*, *L. monopetela*, *E. coracana* root etc. showed very slow C release where only 5 to 10% of initial C content was released in 30 days. The N release by the crop/plant residues was different from that of C release. Initially the N was immobilized in the decomposing residues. The initial rise of N content in decomposing residues varied from 112% to 195%. After the initial phase of increase in N content, the decomposing residues gradually started releasing N. The releasing pattern of N after initial immobilization was different in different residues. The release was faster in case of *G. arborea* leaf, *G. max* stem, *O. sativa* root and leaf etc. whereas it was slower in case of *C. indica* leaf and *L. monopetala* leaf. Almost all the residues show faster decay rate during first 30 to 60 days, followed by a relatively slow rate of decomposition during 90 to 120 days. In the last phase, decomposition up to 80% of initial mass was
observed. However, there was a distinct variation among the decomposition pattern of weeds, tree leaf and crop residues.

**Organic amendments of soil and plant productivity**

Crop residues are tremendous natural resources, which were earlier regarded as waste material, which can be used for nutrient supplement in the agriculture. Use of crop/plant residues may be beneficial or harmful to the crop grown which depends on residue quality and mode of its application. A study was carried out to understand the dynamics of crop/plant residues, nutrient release and their effect on plant productivity and soil properties. Two crop/plant crop residues (paddy straw and *A. conyzoides* residues, with low and high quality respectively) were used in three different modes viz. direct mulching, used after composting, and vermicomposting in different plots cropped with *Zea mays*, *Phaseolus vulgaris* and *Abelmoschus esculentus* separately in three *in situ* experimental plots. The different treatments affected the seed germination of the three test crops significantly (*F*=3069.28, 17693.67; *p*<0.001). Mulching with the crop residues increased the germination of *P. vulgaris* 100%, and effect on *Z. mays* was moderate but it did not affect the germination of *A. esculentus*. Compost and vermicompost application had moderate effect on germination of all the test crops and the variation was significant (*F*=17693.67, *p*<0.001). Plant height and basal cover were highest in vermicompost treated plots and lowest in control or in mulched plots. The biomass allocation in above ground part of *Z. mays*, *P. vulgaris* and *A. esculentus* were highest (1134.05, 1091.85 and 175.15 kg h\(^{-1}\) respectively) in vermicompost treated plots and
lowest values were recorded in control plots (601.25, 539.40 and 70.30 kg h⁻¹ respectively) and the values varied significantly (F=142715.11, p<0.001) although different plant response was significantly different in different plots (F=1189020, p<0.001). The productivity of aboveground biomass was highest in the plots amended with vermicompost (459.00, 523.80, and 85.80 Kg ha⁻¹ month⁻¹ in three test plants respectively) and lowest rate of biomass production was recorded in control (296.40, 252.90 and 34.20 Kg ha⁻¹ month⁻¹ respectively). In vermicompost treated plots, both the available form of N (10.70 to 14.30 and 5.70 to 10.00 µg g⁻¹ ammonium and nitrate respectively) and N mineralization rate (27.00 to 37.00 µg g⁻¹) were highest and minimum available N (5.10 to 8.70 and 4.00 to 6.30 µg g⁻¹ ammonium and nitrate respectively) and mineralization rate (14.00 to 17.50 µg g⁻¹) were recorded in control plots throughout the period of experiment. The significant positive correlation between biomass accumulation and nutrient mineralization pattern but negative correlation between productivity and available nitrogen was observed. The study suggests that different type of amendment were suitable for different crops and the pre-treatment of crop/plant residues like vermicomposting are invariably beneficial for crop growth and soil properties.

**Major observations**

- The land use changes from forest to agricultural land deteriorated the soil physico-chemical and biological properties.
- Land use changes affected the quality and quantity of biomass and nutrient dynamics in different land use systems.
Soil microbial biomass and weed biomass have a major role in nutrient conservation in the sloping land agriculture which can be used for sustainable land use.

Among the different agricultural system under study the agroforestry and terrace cultivation system was found better so far as soil nutrient status, plant composition and productivity are concerned.

The horticultural system had poor soil nutrient status in the study area.

The terrace cultivation system was the most productive system among the different agricultural system under study although monoculture of paddy was practiced once in a year in the system.

Some weed residues, e.g. *A. conyzoides* with high quality residue, have the potential for using in agriculture as nutrient supplement for agricultural crops after proper treatment like composting.

Among the different organic amendments the vermicompost showed best result in general but the suitability was different for different crops.