African Journal of Plant Science Vol. 3 (8), pp. 160-167, August 2009
Available online at http://www.academicjournals.org/AJPS
ISSN 1996-0824 © 2009 Academic Journals

Full Length Research Paper

Litter production, decomposition and physico-chemical properties of soil in 3 developed agroforestry systems of Meghalaya, Northeast India

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Accepted 28 May, 2009

The present study was conducted under 3 developed agroforestry systems that is, Khasi mandarin (*Citrus reticulata*), Alder (*Alnus nepalensis*) and Khasi pine (*Pinus kesiya*) in the state of Meghalaya, northeast India to study the litter dynamics and physico-chemical properties of soil. The findings of our investigation revealed that the soil texture in 3 systems varied from sandy to loamy sand and water holding capacity varied significantly ($P < 0.05$) between plots and depths. Porosity and soil temperature was higher at surface layer than into the subsurface layer. Soil was acidic in all the plots. Soil organic carbon as well as organic matter content was high in Khasi mandarin-based system than the other systems. Total Kjeldahl nitrogen concentration was low in all the soils. It was lowest in Khasi pine based system and a similar trend was observed in concentrations of available phosphorus and potassium. Monthly variation in litter mass varied markedly between different agroforestry systems. The leaf litter constituted 65 - 76% of total litter mass. The rate of weight loss of Alder leaf litter was much faster than other 2 species. Litter decomposition was fast during rainy season and slow during winter season. Rate of release of nitrogen and phosphorus from the decaying leaf litter of Alder occurred at much faster rate compared to Khasi mandarin and Khasi pine, however, potassium release was faster from Khasi mandarin. Total input of N, P and K through litter was higher in Khasi than other 2 species due to greater litter production.

Key words: Agroforestry systems, litter accumulation, nutrient release, soil properties, northeast India.

INTRODUCTION

Agroforestry is an ideal scientific approach for eco-restoration of degraded lands and sustainable resource management. The importance of tree based land use systems in restoring soil fertility and improving the economy of farmers having small land holdings has been realized during the last 2 decades (Chauhan and Dhyani, 1990; Fisher, 1990; Dhyani and Tripathi, 1999). Improvement in soil fertility under agroforestry systems occurs mainly through addition of plant biomass. However, in certain situations trees may have an adverse effect on soils. The magnitude of benefits or adverse effects depends on a number of site-specific factors and attributes of associated tree species. The fertility of soil improves under the tree cover, which checks soil erosion, adds soil organic matter, available nutrients and replenishes the nutrients through effective recycling mechanisms. The pressure on the agricultural lands has increased manifolds due to overpopulation, urbanization and industrialization process. These factors have not only affected the agricultural production but the environmental conditions have also got degraded. There is a global crisis of energy and man is striving hard to find out some alternative source of energy. Fuel wood is one of the established sources to meet energy requirement.

The agro-forestry has both productive and protective potential and it can play an important role in enhancing the productivity of the lands to meet the demand of ever-growing human and livestock population. The role of trees in soil conservation and erosion control is one of the most widely acclaimed and compelling reasons for including trees on farm lands prone to erosion hazards. The beneficial effects of trees in this regards extends beyond protecting the immediate farm lands under consideration, to impart stability to the ecosystem and reduce

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Table 1. Mean height, diameter (dbh) and density of tree component in different agroforestry systems.

Agroforestry system	Tree species	Age (years)	Mean height (m)	Mean dbh (cm)	Density ha^{-1}
Khasi mandarin	*Citrus reticulata*	14	6.40 ± 0.20	20.98 ± 1.03	800
Alder	*Alnus nepaulensis*	14	14.48 ± 0.53	25.15 ± 1.48	416
Pine	*Pinus kesiya*	14	15.82 ± 0.46	24.66 ± 1.28	416

±, Standard error.

duce the rate of siltation of downstream aquatic ecosystems, dams and reservoirs.

Litter-fall is a major pathway for return of organic matter and nutrients from aerial parts of plant to the soil surface (Odiwe and Muoghalu, 2003). Litter production and decomposition rates have great importance in maintaining the fertility of soil. A substantial portion of nutrients accumulated by plants is returned to the soil as litter-fall followed by its decomposition. Standing crop of litter acts as an input–output system of nutrients and the rates at which litter falls and subsequently decays, regulate energy flow, primary productivity and nutrient cycling in forest ecosystems (Sundarpandian and Swamy, 1999; Pragasan and Parthasarathy, 2005). However, due to variations in canopy architecture and tree species, amounts and rates of litter-fall and decomposition show considerable spatial variation. Evaluation of litter production is important for understanding nutrient cycling, forest growth and interactions with environmental variables in forest ecosystems. Studies on litter production are also important for understanding nutrient cycling and carbon fluxes.

In northeast India where forestland has been degraded by shifting cultivation (Jhuming), agroforestry has a great potential of both restoring and maintaining soil fertility and increasing agricultural production. In the state of Meghalaya northeast India, about 70 - 80% of total population is dependent on agriculture (Verma and Bhatt, 2001). The major factors that are adversely affecting agricultural production are age-old practice of shifting agriculture, unduating topography and highly leached soils due to heavy rainfall. Under such socio-environmental conditions, practice of agroforestry can play an important role in checking soil erosion and improving soil fertility by conserving moisture and nutrients, which in turn may enhance the agricultural production. The scientific innovations can make traditional agroforestry systems more productive and profitable to the farmers for meeting their increasing demand. This requires in-depth analysis of ecological aspects of the system. In view of the above, the present investigation deals with an ecological analysis of selected agroforestry systems (AFS) with the emphasis on litter dynamics and to evaluate its effects on physico-chemical properties of soil.

Study sites and methodology

Indian council for agricultural research (ICAR) complex for north eastern hill region ($25^0$41' N latitude and $91^0$55' E longitude) which is located 22 km north of the capital city Shillong, Meghalaya has developed various model agroforestry systems on its research farm. This has provided an opportunity to do the ecological analysis of 3 selected agroforestry systems developed by ICAR on its research farm. The research farm is situated on hill slope (25^0 - 38^0) at an altitude of 1000 – 1100 m asl. The bunds and mini terraces on contours were prepared on hill slope to prevent soil erosion and safe disposal of excess rainwater. The climate of the study area is seasonal with distinct warm-wet and cold-dry seasons in a year. Annual rainfall is about 2300 mm, of which more than 90% is received during April to October; June and July being the wettest months of the year. Mean minimum and maximum temperature varied from 6^0C in January to 28.5^0C in August. Relative humidity ranged between 60% during winter and 90% during rainy season.

The existing experimental plots (1.5 m wide, 10 m long and 1 m height) were in the form of terraces made on hill slope having 22.5 to 45 cm thick soil. The soil depth at the upper reaches of the hill was less as compared to lower parts. Khasi mandarin (*Citrus reticulata*), Alder (*Alnus nepalensis*) and Khasi pine (*Pinus kesiya* Royle ex Gordon) based agroforestry systems were selected for detailed study. The Alder and Khasi pine based systems had a density of 416 trees ha^{-1} while in Khasi mandarin based system tree density was 800 trees ha^{-1}. The mean diameter at breast height (dbh) and mean height of seven individuals of each of the 3 species were measured as an index of tree growth and the data are given in Table 1.

METHODOLOGY

Soil samples were collected from 2 depths, that is, 0 - 15 cm and 15 - 30 cm from each of 3 selected agroforestry systems. Soil moisture content was determined gravimetrically by oven drying 10 g of fresh soil at monthly interval. The differences in weight between the initial and oven-dried samples expressed on dry weight percent gave the moisture content. Water holding capacity (WHC) was determined by Keen's box method as outlined by Piper (1942) and bulk density (the quotient of dry weight of soil to the total volume which occupy in the field) was determined using metallic cylinder (Allen et al., 1974). Soil pH was measured by digital pH meter in 1:2.5 (soil: water w/v) mixture (Anderson and Ingram, 1993). Organic carbon was determined by Walkley and Black's titration method (Jackson, 1973), Total Kjeldahl nitrogen by Semi-Kjeldahl distillation method and available phosphorous by molybdenum blue method (Allen et al., 1974).

Table 2. Physico-chemical properties of soil in different agroforestry systems.

Soil properties	Depths (cm)	Khasi mandarin (*C. reticulata*)	Alder (*A. nepalensis*)	Khasi pine (*P. kesiya*)
Water holding capacity (%)	0 - 15	62.20 ± 0.63	68.09 ± 0.48	50.21 ± 0.50
	15 - 30	62.78 ± 0.82	69.92 ± 0.50	55.11 ± 0.22
Bulk density (g m^{-3})	0 - 15	1.17 ± 0.04	1.14 ± 0.08	1.16 ± 0.04
	15 - 30	1.20 ± 0.04	1.17 ± 0.05	1.19 ± 0.04
Porosity (%)	0 - 15	55.85	56.98	56.23
	15 - 30	54.72	55.85	55.09
Textural class	0 - 15	Sandy	Sandy	Loamy sand
	15 - 30	Loamy sand	Loamy sand	Loamy sand
pH (range)	0 - 15	4.94 - 5.67	4.52 - 5.13	5.28 - 5.99
	15 - 30	4.71 - 5.60	4.17 - 5.22	5.30 - 5.41
Soil organic carbon (%)	0 - 15	1.33 - 2.60	1.15 - 2.36	1.12 - 1.79
	15 - 30	1.18 - 2.52	0.77 - 2.02	0.80 - 1.70
Soil organic matter (%)	0 - 15	2.29 - 4.49	1.99 - 4.08	1.93 - 3.09
	15 - 30	2.04 - 4.36	1.33 - 3.49	1.38 - 2.94
Total Kjeldahl nitrogen (%)	0 - 15	0.20 - 0.27	0.18 - 0.22	0.14 - 0.20
	15 - 30	0.13 - 0.18	0.14 - 0.20	0.10 - 0.14
Available phosphorous (µg g^{-1})	0 - 15	26 - 46	14 - 132	16 - 34
	15 - 30	3 - 48	16 - 27	16 - 22

±, Standard error.

Litter production and decomposition

The litter traps (1 m x 1 m) were set out in each agroforestry system to determine tree litter production. The accumulated litter in each trap was collected at monthly intervals for a period of 1 year. The litter samples were brought to the laboratory and separated into leaf litter, woody litter and miscellaneous litter (flowers and fruits, bark, unrecognizable remains of leaves and fine particles) fractions. The samples were dried at 80^0C temperature and weighed and result has been presented on dry weight basis. Initial leaf litter nitrogen, phosphorus and potassium concentrations were determined (Allen et al., 1974; Anderson and Ingram, 1993).

Nylon mesh (2 mm) litterbags (10 cm x 15 cm) were used to study litter decomposition and nutrient dynamics of leaf litter under field condition. Fresh leaf litters were collected, processed, separated and air-dried. Oven-dry weight (48 hr, 80^0C) of litter was also determined using a sub sample. 30 g air-dried leaf litter sample were kept in each litterbag. Sufficient numbers of litterbags were placed in each agroforestry system to enable replicated samplings at monthly intervals. At each sampling date, 4 litterbags of each species were retrieved and brought to the laboratory for analysis. The bags were washed under gentle flow of tap water to remove soil particles, fine roots and living organisms adhering on litter and then dried at 80^0C for 24 h. The dry weight of litter was taken and then powdered for N, P and K analysis. Nitrogen was determined by micro-Kjeldahl digestion-distillation method, phosphorus by molybdenum blue method and potassium by flamephotometry (Allen et al., 1974; Anderson and Ingram, 1993). Dry weight loss and nutrient release from the decaying litter was computed according to Singh et al. (1999) and Guo and Sims (1999).

RESULTS

Physico-chemical properties of the soil

There was no significant variation in soil texture of the selected systems and the soil was sandy to loamy sand in all the plots (Table 2). Depth-wise variation in proportion of different particle size also did not differ significantly. Water holding capacity varied significantly ($P < 0.05$) between plots and depths. Alder based system had maximum water holding capacity (WHC) than the other systems and in all the systems high WHC was recorded in subsurface layer than surface layer (Table 2). The bulk density among the different systems did not vary significantly and values ranged between 1.14 g cm^{-3} and 1.21 g cm^{-3} (Table 2) and it was higher in subsurface (15 – 30 cm) layer than the surface (0 – 15 cm) layer in all the plots. The porosity showed a reverse trend to that of WHC and bulk density, that is, values were greater in surface layer than subsurface layer. The surface soil layer had higher moisture content than the subsurface layer in all the systems. 2-way ANOVA clearly indicates significant ($P < 0.01$) effect of systems and depth on soil moisture content. It was generally higher in Khasi mandarin (25.83 ± 1.29 to 37.9 ± 1.81) followed by Alder (22.4 ± 1.11 to 33.12 ± 1.66) and Khasi pine based AFS (22.1 ± 1.10 to 37.5 ± 1.81). The soil temperature in surface layer ranged from 22 to 34.5^0C, with peak in August and trough in December.

The soil was acidic in nature (pH 4.52 - 5.99) in all systems, it was more acidic in Alder (pH 4.52) based agroforestry system. Khasi pine based system, though expected to have low pH recorded a higher pH range (5.28 - 5.99). 2-way ANOVA showed significant ($P < 0.01$) effect of agroforestry systems and soil depth on organic matter content. Soil organic carbon as well as soil organic matter content was high in Khasi mandarin fol-

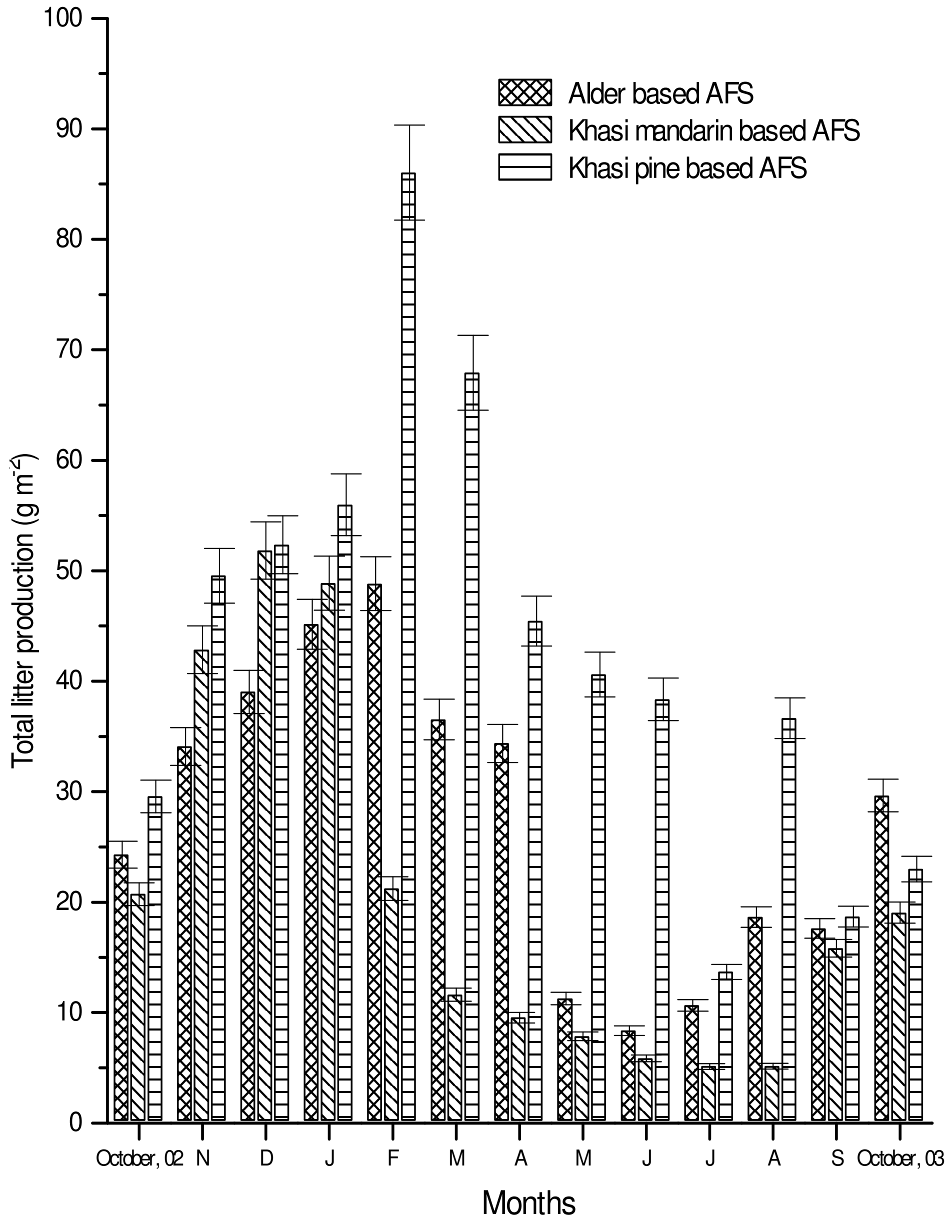

Figure 1. Total monthly litter production in different agroforestry systems.

followed by Alder and Khasi pine systems and surface layer had greater concentration of organic matter than the subsurface layer in all the systems. The concentration of TKN was low in all the soils; it was lowest in Khasi pine based system. The concentration of TKN was found to be high in surface layer than the subsurface soil layer. Alder based system, which was expected to have highest concentration of TKN, was in fact had lower concentration than the Khasi mandarin systems. Like TKN, concentration of available phosphorus was higher in the surface layer than the subsurface layer in all the systems, but variation between different AFS and between soil depths was not significant. The Alder based AFS showed wide variation in available phosphorus concentration (Table 2).

Tree litter input and accumulation

Monthly variation in litter mass on soil surface in different agroforestry systems varied markedly in different months depending on leaf fall pattern of tree species. In Khasi mandarin system, amount of litter present on soil was small during March-August and peaked during November - December. Contrary to this, Alder and Khasi pine based systems peak accumulation was recorded during the month of February (Figure 1). Total litter input was higher in Khasi pine (557.9 g m^{-2}) followed by Alder (358.5 g m^{-2})

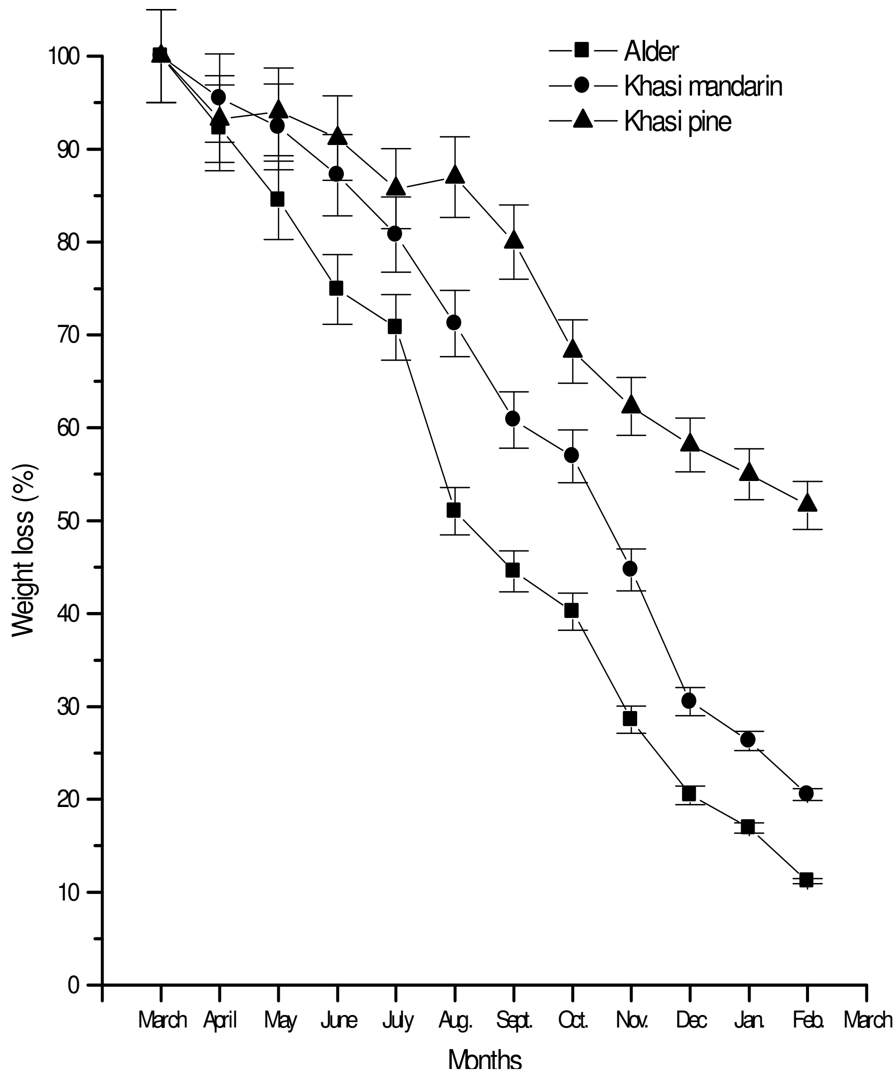

Figure 2. Weight loss (%) of leaf litter of selected agroforestry species.

and Khasi mandarin (265.5 g m^{-2}) based agroforestry systems. In all the 3-agroforestry systems proportion of fine litter (leaf) ranged between 65 - 76% of total litter mass followed by fruits/cones in Khasi mandarin and Khasi pine species.

Litter decomposition

The study on leaf litter decomposition (weight loss) pattern of tree species resulted that initially for about a month, rate of weight loss was slow in Alder compared to Khasi pine needle and Khasi mandarin leaves. In both the later species rapid loss continued till August, then it slowed down. However, after an initial lag period up to May, the rate of weight loss in Alder was much faster than other 2 species. At the end of study period (360 days from the placement of litter bag), Alder litter showed maximum loss (88%) followed by Khasi mandarin (79%) and Khasi pine (61%). In general, litter decomposition was fast during the rainy season (April to September) and slows during winter season (Figure 2).

Nutrient release pattern

The initial concentration of nutrients (N, P, K) differed significantly ($P < 0.01$) between leaf litters of different species. Initial nitrogen (N), phosphorous (P) and potassium (K) concentrations in alder leaf litter was significantly higher than the Khasi mandarin and Khasi pine leaf litter (Table 3). The rate of release of nitrogen and phosphorus from decaying leaf litter of Alder occurred at much faster rate compared to Khasi pine while Khasi mandarin closely followed Alder. The release of nutrients from Pine litter occurred at the slowest pace. However, potassium release was faster from Khasi mandarin than other 2 species. The release of nitrogen from leaf litter ranged from 8.6 mg m^{-2} in Alder to 126.89 mg m^{-2} in Khasi pine. The stock of phosphorus in leaf litter de-

Table 3. Initial nutrient concentration in leaf litters of Khasi mandarin, Alder and Khasi pine.

Agroforestry systems	Nitrogen (%)	Phosphorous (%)	Potassium (%)
Khasi mandarin (*C. reticulata*)	1.85 ± 0.05	0.22 ± 0.001	1.58 ± 0.04
Alder (*A. nepalensis*)	1.91 ± 0.12	0.26 ± 0.017	1.71 ± 0.01
Khasi pine (*P. kesiya)*	1.18 ± 0.08	0.096 ± 0.021	0.97 ± 0.05

±, Standard error.

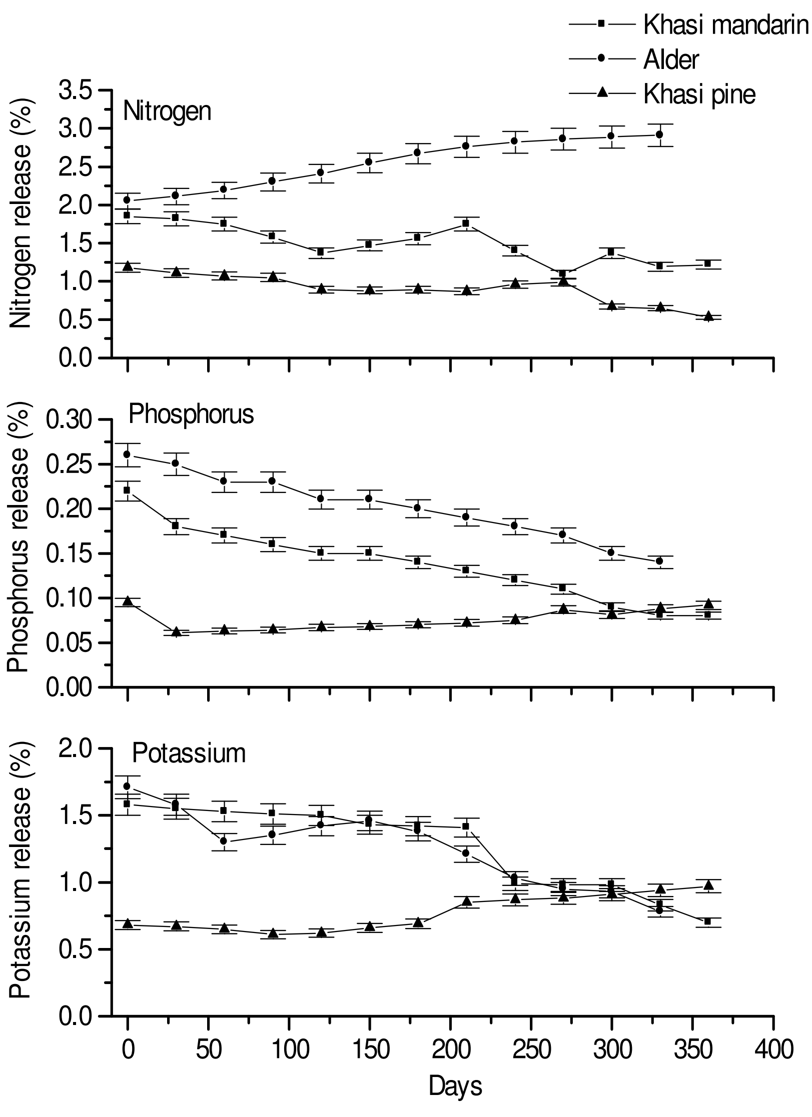

Figure 3. Release of nitrogen, phosphorus and potassium from leaf litter of Khasi pine, Khasi mandrin and Alder.

creased constantly with time and about 72, 81 and 34% of initial concentration was released from Alder, Khasi mandarin and Khasi pine leaf litter, respectively in 360 days (Figure 3). The percentage release of potas-sium from leaf litter ranged from 38% in Khasi pine to 69% in Alder. At the end of experiment 31 to 61% of the initial potassium stock of leaf litter remained undecom-posed.

Overall, during the entire period of the experiment (360 days) the nutrient release from the Alder was greater than the Khasi mandarin and Khasi pine leaf litter. During 360 days about 76% nitrogen, 81% phosphorus and 59% potassium of the initial content was released from de-caying Alder leaf litter. The values for N, P and K in Khasi mandarin were 65, 73 and 62% and in Khasi pine 45, 34 and 38%, respectively (Figure 3). The input and accumulation of N, P and K in leaf litters was higher in Khasi pine followed by Khasi mandarin and Alder based agroforestry systems. Though the initial concentration of N, P and K in leaf litter was low in Khasi pine but accumulation of these nutrients in litters was more than other 2 species due to greater litter-fall.

DISCUSSION

Agroforestry has now been well recognized as a successful tool in improving the economy of farmers and in restoration of soil fertility (Beer et al., 1990; Dhyani and Tripathi, 1999) by checking erosion on sloping sites and improving physical conditions and hydrological characteristics. Results presented in foregoing pages show that different agroforestry systems have different effects on soil. Soil of Alder based agroforestry systems was more acidic than other systems. Similar results were obtained by Binkley and Sollins (1990) who reported that the mixed stands with N_2- fixing trees commonly had lower pH than non N_2- fixing stands. Low soil pH in Khasi pine system is attributed to the chemical composition of pine needle and its slow decomposition rate.

Several studies have reported that soil fertility under tree situation is improved due to increased input of organic matter through litter (Dunham, 1991; Kesseler, 1992; Campbell et al., 1994; Dhyani, 1997). The leaf litter of Alder and Khasi mandarin with high concentration of N, P and K may therefore enhance fertility by adding high quality of litter to the soil system. The increase in soil total nitrogen, available phosphorus, potassium, water holding capacity, porosity and reduction in bulk densities of the topsoil are indicators of increased fertility under Alder based system. The Khasi mandarin based system was close to Alder based system in improving the soil fertility level. In Khasi pine based system, the poor quality of litter in terms of concentration of nutrients was compensated by greater amount of litter input.

Litter production varies according to habit of the tree species, its age and local environmental condition (Hawkins et al., 1990; Szott and Kass, 1993). Data on litter production indicates that major portion was contributed by leaf and several other workers reported similar findings from different forest stand (Singh, 1984; Sanchez and Sanchez, 1995; Pedersen and Hansen, 1999; Sundarpandian and Swamy, 1999; Zhou et al., 2007). The litter standing crop represents the balance between input by litter fall and output by decomposition. Since climate of the study site was humid subtropical with distinct wet and dry seasons, litter fall and its decomposition was related to seasonal cycle. Leaf fall was confined to autumn and winter seasons, while decomposition was most rapid during wet period. The minimum litter mass on the ground during rainy season is therefore attributed to fast rate of decomposition owing to greater microbial activity due to favourable temperature and moisture conditions.

The rapid rate of decay after an initial lag phase is the net effect of a large number of processes such as utilization of readily available energy sources by microbes and loss of water-soluble components from leaf litter (Bloomfield et al., 1993). A decline in rate after a phase of rapid weight loss as observed in case of Khasi pine may be attributed to higher percentage of recalcitrant fraction like cellulose, lignin and tannin during the advanced stage of leaf decay. The total input of NPK through the above ground litter was dependent on the nutrient concentration in the litter and its total production. Maximum nutrient input in Khasi pine based system was mainly to high litter production by this species. The rate of N, P and K release from litter was, however, much higher from Alder litter than Khasi mandarin and Khasi pine litters. The soil of Khasi mandarin based system had more organic carbon and greater concentration of nitrogen and phosphorus than the other systems therefore more suitable for the crop growth. Because of the canopy architecture of Khasi mandarin the soil was more exposed to sunlight. As a result of this soil temperature was high and moisture in surface soil was relatively low. These conditions of the above ground environment and soil might be responsible for better crop growth in Khasi mandarin than Khasi pine and Alder based systems. Chemical composition of pine litter that accumulates in large quantity on the soil surface may adversely influence associated crop growth by increasing soil acidity that impairs availability of nutrient to the plants.

ACKNOWLEDGEMENTS

The authors are thankful to Indian council of agricultural research, New Delhi for financial assistance in form of research project and director, ICAR NEH region, Meghalaya for providing developed agroforestry systems for present research work.

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