Agroforest Syst (2007) 69:239–247
DOI 10.1007/s10457-007-9044-y

ORIGINAL PAPER

Evaluation and selection of multipurpose tree for improving soil hydro-physical behaviour under hilly eco-system of north east India

R. Saha · J. M. S. Tomar · P. K. Ghosh

Received: 31 July 2006 / Accepted: 10 January 2007 / Published online: 8 February 2007

Abstract Soil hydro-physical behaviour was studied under a 20-year old agroforestry plantation consisting of five multipurpose tree species (*Pinus kesiya* Royle ex-Gordon, *Alnus nepalensis* D.Don, *Parkia roxburghii* G.Don, *Michelia oblonga* Wall. and *Gmelina arboria* Roxb.) maintained under normal recommended practices at Indian Council of Agricultural Research (ICAR) Complex, Umiam, Meghalaya, India. The aim was to select tree species, which could act as better bio-ameliorant as well as provides higher economic return in highly degraded soil of northeastern hill region of India. A site without vegetation (no tree) nearby the plantation was also selected as control for comparison. Soil samples for various hydro-physical analysis, were taken from 0–15 and 15–30 cm soil depth at a distance of 1 m from respective tree species during wet and dry season of 2003–2004. No appreciable differences in relative contents of textural separates of sand, silt and clay were observed among various tree covers. Surface cover with constant leaf litter fall and extensive root system increased soil organic carbon, helped in better soil aggregation, improved water transmissivity and infiltrability and in turn, reduced soil erosion in the present study. However, due to variation in quantity of leaf litter fall and root biomass, these parameters differed among tree species. Of the tree species, *P. kesiya, M. oblonga* and *A. nepalensis* were found to be rated best for bio-amelioration of soils as these tree covers had more root and shoot biomass and more litter fall compared to other species. However, considering both timber production and improvement in hydro-physical behaviour, *M. oblonga* was found best among the tested tree species. The study, thus, suggested that inclusion of tree species *M. oblonga* in agroforestry system is a viable option for natural resource management and could sustain long-term soil productivity in a highly degraded soil of this region as well as for food security of the resource poor people of North East India.

Keywords Tree species · Bio-amelioration · Soil physical properties · Hilly eco-system

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Introduction

Shifting cultivation coupled with excessive deforestation [net loss of 1577 km^2 forest cover between 1999 and 2001 (Anonymous 2001)] are major constraints for sustainable crop production in hill slopes of northeastern India, resulting in more than 40% area falls under wastelands. High rainfall coupled with faulty land use practices, particularly the shifting cultivation has rendered the resource base in a fragile state, leading tremendous run-off and soil loss [200 t ha^{-1} yr^{-1} (Prasad 1987)] to soil erosion, severe siltation of river bed and floods, steep decline in soil fertility, poor soil physical health and uncountable loss of bio-diversity. Among various losses of resource base mentioned, soil hydro-physical constraints can severely limit crop production even if nutritional constraints are alleviated by additions of chemical amendments (Lal 1989a).

Presence of trees within a landscape affects its hydrological characteristics (Pereira 1979), just as deforestation increases the run-off (Lal 1981). Agroforestry, in this context, is the most viable option to tackle the problem of degraded lands and to bring about eco-restoration and maintenance of soil resources (Dhyani and Chauhan 1995). Agroforestry systems in the hills indicate superiority over traditional land use systems (e.g. shifting cultivation) under high rainfall, moderate to steep slopes and shallow soil depth condition (Singh et al. 1989). Moreover, it has been recognized as a carbon sequestration strategy because of its applicability in agricultural lands as well as in reforestation programs (Cairns and Meganck 1994). Trees being perennial in nature, a large quantity of litterfalls and fine-roots likely to influence physico-chemical properties of soils in long-term (Lal 1989a) as they enrich the soil with organic matter and nutrients by rapid turnover, intercept blocked nutrients and recycle them in the surface (Tufekcioglu et al. 1999; Allen et al. 2004). Fine roots represent a dynamic portion of below ground biomass, nutrient capital and a significant part of net primary production in any eco-system (Hendrick and Pregitzer 1993).

Over the years a number of agroforestry practices have been developed and are being evaluated for their productivity in India (Dhyani and Tripathi 1999). However, very little is known about the long-term effect of forestry and agroforestry systems on soil hydro-physical behaviour, particularly under hilly eco-system where level of soil degradation is very high. The present investigation thus attempted to evaluate the impact of multi-purpose tree species maintained under a 20-year old agroforestry (Agri-silvicultural) system on soil hydro-physical environment and to select a tree species, which can act as bio-ameliorant in degraded soils of NEH region in India.

Materials and methods

Experimental site

The study was carried out with different tree species planted under agri-silvicultural system in 1983 at Indian Council of Agricultural Research (ICAR) Complex for North East Hilly (NEH) Region, Umiam located at 25°41′21″ North (latitude) and 91°55′25″ East (longitude) with an altitude of 980 m above mean sea level. The station situated in the central part of Meghalaya in the East *Khasi* Hills of Northeast India. The mean annual rainfall of the area is 2439 mm with coefficient of variation of 15.96%. Most of the rains are confined to May–November months of the year. The daily temperature during a year varies widely between 2.5 (January) and 32.5°C (August). Five multipurpose tree species evaluated in this study were *Khasi* pine (*Pinus kesiya* Royle ex-Gordon), Alder (*Alnus nepalensis* D.Don), Tree bean (*Parkia roxburghii* G.Don), Champak (*Michelia oblonga* Wall.) and Gumhar (*Gmelina arboria* Roxb.). A control plot without tree plantation (natural fallow) was also maintained nearby the agri-silvicultural system since 1983. Soils are *Typic Paleudalf*, highly acidic (pH 4.5–6.5) in reaction and high in organic carbon content (2.97%) with an average slope of 32–53% (Majumdar et al. 2001).

Soil analysis

The experiment was laid out in a completely randomized block design with six treatments (five tree species and one control) replicated thrice. Detailed schematic diagram of a block under a particular tree species is presented in Fig. 1. Each treatment had standard plot size of 130 m^2 accommodating twelve plants per plot (Fig. 1). The periodical soil samples both in dry (February) and wet (July) season were collected in the

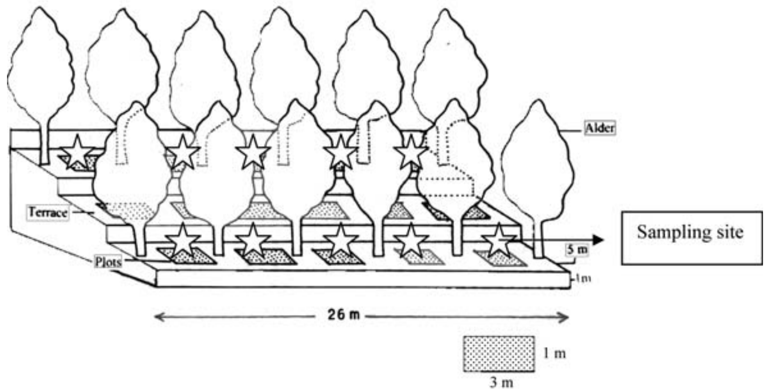

Fig. 1 Schematic diagram of the experimental plots showing the soil sampling sites

year 2003–2004 from 0–15 and 15–30 cm soil depth at different blocks under all the multipurpose tree species including control (natural fallow). For all the treatments except control soil samples were collected from three different locations each at a distance of 1 m from tree species as suggested by Dhyani and Tripathi (2000). Soil samples from control were collected randomly from three locations. Samples were brought to the laboratory and approximately 250 g (on an oven-dry basis) of each sample was taken for determining aggregate size distribution. The remaining portion was air-dried at room temperature and passed through 2-mm sieve for analysis of hydro-physical properties such as organic carbon, particle size distribution and erodibility indices. Bulk density, porosity and hydraulic conductivity were measured on the basis of undisturbed core samples collected from respective treatments.

Particle size distribution and bulk density were determined following the methods by Black (1965). Soil organic carbon was determined by Walkley and Black's wet-digestion method (Jackson 1973). The aggregate size distribution was determined by wet sieving method (Yoder 1936) using a set of sieves of 5.6, 3.4, 2, 1, 0.50, 0.25 and 0.125 mm diameter. Aggregates of 4–8 mm size were first separated from the bulk soil by dry sieving. About 50 g of this aggregate was put on the first sieve of the set and gently moistened from the below to avoid a sudden rupture of aggregates. After soaking the soil for 10 min the set was shaken in water for 10 min at 30 oscillations per min. The amount of soil retained on each sieve, after correction for sand content, was used for calculating the mean weight diameters (MWD) of the water-stable aggregates following van Bavel (1949). The percentage weight of water-stable aggregates retained on sieves >0.25 mm diameter was expressed as water-stable macro aggregates. Total porosity was determined in undisturbed water saturated cores assuming no air tapped in the pores. Soil infiltration rate was determined using double ring infiltrometer on a pre-wetted soil for 48 h (Richards 1954). Soil water characteristics curves at different suction gradients (–0.01 to –1.5 MPa) were determined using pressure plate apparatus (Black 1965). Plant available water content (AWC) was estimated as the difference between the volumetric water contents at –0.03 and –1.5 MPa, multiplied by depth of soil. Saturated hydraulic conductivity (*K*s) was estimated following the constant head method (Klute 1965). Moisture equivalent of the soils were measured as outlined by Piper (1950). Erosion ratio and erosion index were computed using the expressions given by Middleton (1930):

$$\text{Erosion ratio} = \text{Dispersion ratio} / (\text{Clay} / \text{Moisture equivalent ratio})$$

$$\text{Erosion index} = \text{Dispersion ratio} / (\text{Clay} / \text{Half of the water holding capacity of soil})$$

All the data were statistically analyzed using analysis of variance (ANOVA) as applicable to

Table 1 General characteristics of experimental tree species under humid tropics

Tree species	Local name	Habitat	Preferred altitude for growing	Preferred rainfall range (mm)	Uses
Pinus kesiya Royle ex. Gordon	*Khasi* pine	Open degraded or seasonally dry exposed roots	1000–2000	2000–3000	Fuel wood, charcoal and building materials.
Alnus nepalensis D.Don	Alder	Open degraded sites	1000–2000	500–2500 (Humid)	Fodder, wind break, nitrogen fixation (soil N-enricher) and conservation/ wasteland reclamation
Parkia roxburghii G.Don	Tree bean	Slopy land	400–1500	600–1500 (Humid)	Pods edible, fodder and fuel wood
Mechelia oblonga Wall.	Champak	Foot hills	500–1200	500–1000 (Humid)	Timber, fuel wood, fodder and roadside plantation
Gmelina arborea Roxb.	Gumhar	Foot hills or valley upland situation	500–1200	500–1200 (Humid)	Timber, fodder, fuel wood and wasteland reclamation

complete randomized block design and treatments differences were tested for significance.

Crop growth behaviour study

The general characteristic of the tree species is given in Table 1. Diameter at breast height (DBH) of the tree species was recorded at 1.37 m above the ground level with the help of a measuring tape (Tomar 2006). The lateral spread of tree canopy was measured on the ground in north–south and east–west directions and the canopy cover was calculated from the measurement of the projection of the crown diameter assuming that crown is circle (Avery and Burkhart 1994). Annual litter production of the tree species were calculated on the basis of litter accumulated in litter trap throughout the year. The litter samples were separated into leaf, twigs, flowers, fruits etc., oven-dried at 80°C for 48 h and weighed. The roots were retrieved from the cylindrical metallic core (diam. 10 cm) following wet sieving method and the fine roots (<2 mm diam.) were washed with a gentle flow of tap water to overcome the soil contamination, oven-dried at 80°C for 48 h and weighed the root biomass of the trees (Bohm 1979). The timber volume of the tree species were estimated using diameter of breast height (DBH) and tree height according to the formula given by Dhanda (2004). The formula for timber volume calculation is:

$$\text{Timber volume} = 1/3\ \Pi\ r^2 h$$

where, r = radius of the bole and h = height of the tree.

Results

Mechanical properties of soil

The experimental soils are mostly silty clay loam in texture. Adoption of various multipurpose trees as such had no significant effects on soil texture although *A. nepalensis* and *P. kesiya* improved the clay content of the soil to the tune of 11–12.5% over control. Overall, the clay content varied marginally (30.4–36%) among the various treatments (Table 2). The plots under *G. arboria* had the lowest clay content (30.4%). The exact reason for this is not known. However, it may be due to soil variability and mixing effect of cultivation. A significant effect of tree species on bulk density (BD), organic carbon (SOC) and porosity of soil was observed. All the tree species

Table 2 Effect of various multi-purpose trees on soil physical properties (means ± SD)

Tree species	Particle size distribution				Organic C (g kg^{-1})	Bulk density (Mg m^{-3})	Total porosity (%)
	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)			
Pinus kesiya	19.8 ± 1.34	20.5 ± 1.51	24.2 ± 1.09	35.5 ± 0.63	3.54 ± 0.33	1.04 ± 0.12	54.3 ± 6.22
Alnus nepalensis	18.5 ± 1.85	18.2 ± 1.72	27.3 ± 1.21	36.0 ± 1.14	3.22 ± 0.47	1.09 ± 0.09	55.6 ± 5.87
Parkia roxburghii	15.4 ± 2.02	22.9 ± 1.86	28.1 ± 1.44	33.6 ± 1.35	2.31 ± 0.61	1.23 ± 0.20	52.2 ± 3.20
Michelia oblonga	16.4 ± 2.24	16.6 ± 2.36	32.2 ± 0.87	34.8 ± 0.96	3.36 ± 0.96	1.05 ± 0.32	55.5 ± 4.58
Gmelina arboria	18.0 ± 1.65	27.1 ± 2.44	28.4 ± 1.74	30.4 ± 2.24	2.86 ± 1.24	1.14 ± 0.09	52.4 ± 6.04
Control (No tree)	19.1 ± 2.46	22.7 ± 1.98	26.2 ± 1.62	32.0 ± 0.92	1.56 ± 0.92	1.32 ± 0.11	48.7 ± 8.09
LSD ($P < 0.05$)	1.25	0.91	1.52	2.01	0.39	0.15	5.06

Values for soil parameters are the means of three replications under soil depths (0–15 and 15–30 cm) and two seasons across the year

contributed lower BD (range 1.04–1.14 Mg m^{-3}) but maintained higher SOC (range 2.31–3.54 g kg^{-1}) and pore space (range 52.2–55.6%) than control plot (1.32 Mg m^{-3}, 1.56 g kg^{-1} and 48.7%, respectively). Among the tree species, *P. kesiya*, *M. oblonga*, and *A. nepalensis* had favourable effect on soil properties, particularly on BD (1.04, 1.05 and 1.09 Mg m^{-3}, respectively) and SOC (3.54, 3.36 and 3.22 g kg^{-1}, respectively) and porosity (54.3, 55.5 and 55.6%, respectively). Such positive effect on BD and porosity under *Dalbergia sissoo* and *Accacia nilotica* plantation was reported by Hosur and Dasog (1995). It has been observed that tree species differed in the relative abundance of roots (Table 5). This is because root distribution and its density within the soil profiles are primarily genetically determined, also these varied with soil type, moisture, nutrient availability, organic matter distribution and soil management (Myer et al. 1994). The retention of SOC depends on the quantity as well as quality of chemical composition (lignin/nitrogen ratio, carbon/nitrogen ratio, cellulose, hemi-cellulose etc.) of tree roots and litter and varies widely as a function of climate and soil type (Parton et al. 1987). The superiority of *P. kesiya*, *M. oblonga* and *A. nepalensis* to other tree species in improving soil properties was mainly due to higher fine root biomass and greater leaf fall of these tree species (Table 5) and quality litter production (range 473.75–621.50 g m^{-2}), leading to improvement in C status of soil. Data in Table 2 showed that there was 13.6–21.2% lower BD while 7.2–14.2% increase in porosity under various tree species as compared to control plots. Such improvement in physical properties by these trees could be ascribed to effect of living biomass of trees, as there was a constant addition of organic matter to the soil through decaying the large volume of dead roots as well as leaf litter (Balkrishnan and Toky 1993).

Soil structural properties

The water stable aggregates (>0.25 mm) increased significantly under various multipurpose trees as compared to control plots (Table 3). Soils under *P. kesiya* showed the highest water stable aggregate percentage (82.4%) followed by *M. oblonga* (78.5%), *A. nepalensis* (77.6%). Interestingly in the present study, the macro-aggregate predominated over micro-aggregates under tree cover, possibly due to higher root density and root activity under tree cover. This finding is in good agreement with the results of Drury et al. (1991) and Hosur and Dasog (1995). Among various tree species, *P. kesiya*, *M. oblonga* and *A. nepalensis* with mean weight diameter (MWD) of 2.65, 2.54 and 2.42 mm, respectively were most effective tree species for improving the size of stable aggregates as compared to only 1.25 mm in control without any tree cover. Lower the micro: macro aggregate ratio, better is the soil aggregation. Lower ratio obtained under *P. kesiya* (0.21), *M. oblonga* (0.27) and *A. nepalensis* (0.29) in the present study further confirms better soil aggregation under them. However, the ratios under remaining two tree species (0.40–0.61) comparatively wide,

Table 3 Effects of various multipurpose trees on structural properties of soil (means ± SD)

Tree species	Mean weight diameter (mm)	Aggregates			
		Macro (>0.25 mm)	Micro (<0.25 mm)	Ratio (Micro/Macro)	Stability
Pinus kesiya	2.65 ± 0.35	82.4 ± 6.32	17.6 ± 5.68	0.21 ± 0.15	75.6 ± 6.82
Alnus nepalensis	2.42 ± 0.43	77.6 ± 4.56	22.4 ± 3.30	0.29 ± 0.09	72.1 ± 6.94
Parkia roxburghii	1.90 ± 0.25	71.2 ± 9.25	28.8 ± 8.22	0.40 ± 0.11	63.4 ± 7.59
Michelia oblonga	2.54 ± 0.19	78.5 ± 8.87	21.5 ± 7.45	0.27 ± 0.26	73.2 ± 9.56
Gmelina arboria	1.86 ± 0.64	62.0 ± 6.35	38.0 ± 8.69	0.61 ± 0.11	67.9 ± 8.25
Control (No tree)	1.25 ± 0.34	55.8 ± 5.50	44.2 ± 6.02	0.79 ± 0.22	56.8 ± 7.44
LSD ($P < 0.05$)	0.09	2.38	3.05	0.04	3.20

Values for soil parameters are the means of three replications under two soil depths (0–15 and 15–30 cm) and two seasons across the year

maximum value (0.79) being under control plots. With respect to timber production among the three species found suitable for improving soil structural properties, the species *M. oblonga* recorded the highest timber volume (0.251 m^3 $tree^{-1}$). Although *G. arborea* and *Parkia roxburghii* had higher DBH, canopy spread and timber production, they contributed lower litter production and root biomass (Table 5). A higher stability of aggregates coupled with greater MWD under *P. kesiya*, *M. oblonga* and *A. nepalensis* were due to their impressive root system and root biomass (496.75, 462.00 and 435.50 g m^{-2}, respectively) resulting from accumulation of higher organic carbon, proliferation of rhizosphere and micro floral and faunal activities and root exudation below ground (Arunachalam et al. 1997).

Soil dispersibility

Dispersion ratio under various tree covers had significantly reduced. Regardless of tree cover, the dispersion ratio varied between 0.21 and 0.26, the highest (0.35) being with the control plot (Table 4). In the present study, soils under *P. kesiya*, *M. oblonga* and *A. nepalensis* had low dispersion ratio owing to better soil aggregation, as was evident from the macro-aggregates values (Table 3). The soil erodibility declined with the tree species to the extent of 23.1–43.6% with respect to control. It was observed that *P. kesiya* with the lowest erosion ratio (0.20) and erosion index (0.11) was very effective in checking soil erodibility, while with 0.22 erosion ratio values, *M. oblonga* and *A. nepalensis* were placed in the next best in order. Quite a good amount of litter fall (473.75–621.50 g m^{-2}) from these trees was observed (Table 5) which might have increased the cohesiveness in the soil system after its decomposition and also bound the soil tightly in lower horizons with the help of deep root systems (Deb et al. 2005). Grewal and Abrol (1986) reported that the litter fall to the ground and surface vegetation protected soil directly against erosive forces of raindrops and surface run-off by improving soil physical and hydrological parameters.

Table 4 Effect of various multipurpose trees on soil dispersibility and erodibility (means ± SD)

Tree species	Dispersion ratio	Moisture equivalent (%)	Erosion ratio	Erosion index
Pinus kesiya	0.21 ± 0.09	37.03 ± 0.58	0.20 ± 0.03	0.11 ± 0.01
Alnus nepalensis	0.23 ± 0.05	37.85 ± 1.22	0.23 ± 0.01	0.12 ± 0.02
Parkia roxburghii	0.26 ± 0.11	38.11 ± 0.96	0.30 ± 0.04	0.14 ± 0.01
Michelia oblonga	0.23 ± 0.03	37.65 ± 1.14	0.22 ± 0.03	0.11 ± 0.03
Gmelina arboria	0.25 ± 0.04	36.88 ± 1.02	0.24 ± 0.02	0.12 ± 0.02
Control (No tree)	0.35 ± 0.06	38.56 ± 1.19	0.39 ± 0.03	0.15 ± 0.03
LSD ($P < 0.05$)	0.06	2.82	0.05	0.03

Values for soil parameters are the means of three replications under two soil depths (0–15 and 15–30 cm) and two seasons across the year

Table 5 Growth performance, litter production and fine root biomass of various multipurpose trees in humid tropics of Meghalaya (means ± SD)

Tree species	DBH (cm)	Canopy spread (m)	Annual litter production (g m^{-2})	Total fine root biomass[a] (g m^{-2})	Timber volume (m^3 $tree^{-1}$)
Pinus kesiya	23.32 ± 8.24	6.26 ± 1.01	621.50 ± 27.67	496.75 ± 21.99	0.128 ± 0.02
Alnus nepalensis	21.20 ± 2.80	7.54 ± 1.03	473.75 ± 34.91	435.50 ± 28.59	0.212 ± 0.01
Parkia roxburghii	27.95 ± 2.71	9.41 ± 2.03	341.75 ± 37.75	415.50 ± 15.63	0.222 ± 0.02
Michelia oblonga	27.45 ± 7.28	7.24 ± 1.53	512.25 ± 46.35	462.00 ± 19.63	0.251 ± 0.02
Gmelina arboria	31.52 ± 5.60	7.75 ± 1.02	431.75 ± 27.99	419.00 ± 25.88	0.226 ± 0.01
LSD ($P < 0.05$)	3.51	1.16	5.13	2.77	0.66

[a] Total fine root biomass recorded in 0–30 cm soil depth

Soil moisture retention characteristics

Soil water retention characteristics ($\psi - \theta$ relationships) were determined at various suctions from –0.01 to –1.5 MPa. Data in Fig. 2 showed that all the tree species improved moisture retention capacity of soil at any given suction compared to control. At –0.03 MPa suction, highest soil moisture was retained by the soil under *P. kesiya* (0.386 m^3 m^{-3}) followed by *M. oblonga* (0.375 m^3 m^{-3}), *A. nepalensis* (0.362 m^3 m^{-3}), *G. arboria* (0.360 m^3 m^{-3}) and *Parkia roxburghii* (0.344 m^3 m^{-3}). The lowest soil moisture retention was in control plots (0.284 m^3 m^{-3}). Soil moisture retention at –1.5 MPa followed the trend similar to –0.03 MPa. Available water capacity among the various tree species varied between 0.183 and 0.220 m^3 m^{-3} and followed the order: *P. kesiya* > *M. oblonga* > *A. nepalensis* > *Parkia roxburghii* > *G. arboria* > control. Significant increase in available water under tree cover is attributed primarily to the continuous vegetative covers with litter fall of trees and also to their subsequent decomposition and decayed root biomass. This has resulted in increase the organic C content by 90.4% over control. Lal (1989b) has also reported similar improvement in water retentivity under various agroforestry systems.

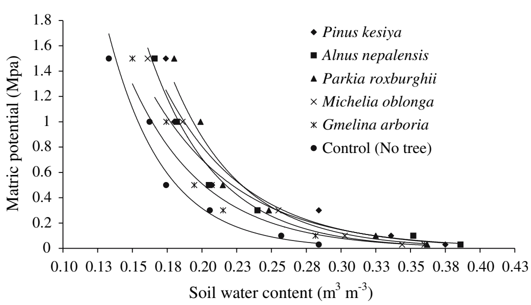

Fig. 2 Soil moisture characteristics curves under various multipurpose trees

Data on soil water retention characteristics (Table 6) showed that the saturated water content (θs) in *P. kesiya* was 33.2% higher than that under control plots. However, in other tree species, it was 17.9–23.1% higher. Tree species could influence infiltration rate of soil. Like water content, *P. kesiya* caused almost 2-fold increase (8.04 mm h^{-1}) in soil infiltrability over the control (3.84 mm h^{-1}). In other tree species, it varied between 5.36 and 7.28 mm h^{-1}. In case of cumulative infiltration, gradual increase with increase in time was observed in the present study (Fig. 3). There were significant differences among the tree species. The general trend observed in the present study was that of highest cumulative infiltration was observed under *P. kesiya* with least values under control plots at various time intervals. The greater improvement in saturated hydraulic conductivity was also observed in soils under *P. kesiya* (5.44 mm h^{-1}) followed by *M. oblonga* (4.82 mm h^{-1}). Within an established tree based cropping system, macropores dominates the pore space and facilitate rapid movement of water through the soil profile (Humbel 1975). Profile moisture storage up to 60 cm depth (Table 6) depicted that there was a sharp increase (about 78.6%) in moisture storage under *P. kesiya* in comparison to that of control during dry spell periods. In other systems it varied from 13.85 to 19.44 cm/60 cm. During wet season, the trend remains same but the variations within the treat-

Table 6 Effect of various multipurpose trees on soil water retention characteristics (means ± SD)

Tree species	Available water ($m^3\ m^{-3}$)	θs ($m^3\ m^{-3}$)	Infiltration rate ($mm\ h^{-1}$)	Hydraulic Conductivity ($mm\ h^{-1}$)	Profile moisture storage (cm/60 cm)	
					In dry season	In rainy season
Pinus kesiya	0.220 ± 0.03	0.566 ± 0.04	8.04 ± 1.28	5.44 ± 2.02	20.45 ± 3.22	24.60 ± 1.04
Alnus nepalensis	0.201 ± 0.02	0.523 ± 0.04	7.28 ± 0.95	4.82 ± 1.46	19.44 ± 2.50	22.68 ± 0.98
Parkia roxburghii	0.192 ± 0.01	0.511 ± 0.06	4.85 ± 0.56	3.23 ± 2.11	13.85 ± 3.61	18.52 ± 0.62
Michelia oblonga	0.210 ± 0.02	0.508 ± 0.09	6.10 ± 1.23	4.84 ± 1.54	18.54 ± 2.37	21.66 ± 1.10
Gmelina arboria	0.183 ± 0.01	0.501 ± 0.05	5.36 ± 0.82	3.50 ± 1.65	14.60 ± 2.11	19.41 ± 0.24
Control (No tree)	0.151 ± 0.02	0.425 ± 0.11	3.84 ± 1.46	2.12 ± 2.35	11.45 ± 2.05	15.34 ± 0.72
LSD ($P < 0.05$)	0.11	0.34	1.06	0.18	2.17	2.30

Values for soil parameters are the means of three replications under two soil depths (0–15 and 15–30 cm) and two seasons across the year

ments were much less. The improved soil aggregation process was evident from higher MWD, micro and macro aggregates (Table 3) and SOC (Table 2) under *P. kesiya* through their intensive root activity, which ultimately resulted in better movement of soil water within the soil profile.

Conclusion

On the basis of field observation from the present study, it is apparent that multipurpose tree species has significantly improved soil hydro-physical characteristics particularly decreasing bulk density and erosion ratio by 15.9 and 39.5%, respectively and increasing soil organic C by 96.2%, porosity by 10.9%, aggregate stability by 24.0% and available soil moisture by 33.2%. Such improvement in soil hydro-physical properties in tree-based system has a direct bearing on long-term sustainability, productivity and soil quality in hilly eco-system. Among the tree species tested, *P. kesiya*, *M. oblonga* and *A. nepalensis* were found suitable as bio-ameliorant in hilly terrain of northeast India in terms of organic matter build up through presence of leaf litter, better soil aggregation, transmissivity and infiltrability through extensive root system, improved soil conservation through constant surface cover with leaf biomass. However, considering both timber production and improvement in hydro-physical properties of soil under the humid sub-tropical climate of the northeastern Himalayan region, where, erosion is a major land degradative process, inclusion of *M. oblonga*, the locally available natural resources in agroforestry system, is a viable option for eco-restoration, maintenance of soil resources and could sustain long-term soil and timber productivity so as to improve food security of the poor tribal farmers of northeast India.

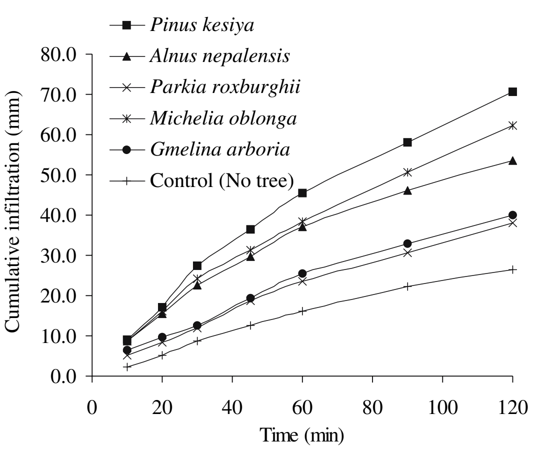

Fig. 3 Effect of various multipurpose tree species on cumulative infiltration

References

Allen S, Jose S, Nair PKR, Brecke BJ, Nkedi-Kizza P (2004) Safety net role of tree roots: experimental evidence from an alley cropping system. For Ecol Manage 192:395–407

Anonymous (2001) State of forest report. Published by Forest Survey of India, Ministry of Forest and Environment, Govt. of India, 130 pp

Arunachalam K, Arunachalam A, Tripathi RS, Pandey HN (1997) Dynamics of microbial population during the aggradation phase of a selectively logged subtropical humid forest in north-east India. Trop Ecol 38:331–341

Avery TE, Burkhart HE (1994) Forest mensuration. Mc Graw Hill Inc., New York, 408 pp

Balkrishnan, Toky OP (1993) Significance of nitrogen fixing woody legume trees in forestry. Indian Forester 119:126–134

Black CA (1965) Methods of soil analysis, Part 1. American Society of Agronomy, Madison, Wisconsin, USA, 770 pp

Bohm W (1979) Methods of studying root system, vol 33. Springer Verlag, Berlin, Heidelberg, New York, 188 pp

Cairns MA, Meganck RA (1994) carbon sequestration, biological activity and sustainable development: integrated forest management. Environ Manage 18:13–22

Deb S, Tangjang S, Arunachalam A, Arunachalam K (2005) Role of litter, fine roots and microbial biomass in soil C and N budget in traditionally managed agroforestry systems. In: Bhatt BP, Bujarbaruah KM (eds) Agroforestry in north east India: opportunities and challenges ICAR Research Complex for NEH Region, Umiam, Meghalaya, pp 491–506

Dhanda RS (2004) Measuring tree growth parameters and estimating timber volume in standing tree. In: Rai P, Handa AK (eds) Methodologies in agroforestry research. National Research Centre for Agroforestry, Jhansi, U.P., 119 pp

Dhyani SK, Chauhan DS (1995) Agroforestry interventions for sustained productivity in north-eastern region of India. J Range Manage Agroforestry 16(1):79–85

Dhyani SK, Tripathi RS (1999) Tree growth and crop yield under agrisilvicultural practices in north-east India. Agroforestry Syst 44:1–12

Dhyani SK, Tripathi RS (2000) Biomass and production of fine and coarse roots of trees under agrisilvicultural practices in north-east India. Agroforestry Syst 50:107–121

Drury CF, Stone JA, Findlay WI (1991) Microbial biomass and soil structure associated with corn, grasses and legumes. Soil Sci Soc Am J 55:805–811

Grewal SS, Abrol IP (1986) Agroforestry on alkali soils: effect of some management practices on soil initial growth, biomass accumulation and chemical composition of selected tree species. Agroforestry Syst 4:221–232

Hendrick RL, Pregitzer KS (1993) The dynamics of fine root length, biomass and nitrogen content in two northern hardwood ecosystems. Can J For Res 23:2507–2520

Hosur GC, Dasog GS (1995) Effect of tree species on soil properties. J Indian Soc Soil Sci 43:256–259

Humbel FX (1975) A study of soil-macroporosity based on permeability data: application of a filtration model to ferralitic soils of Cameroon. Cah ORSTOM Pedologie 13:93–117

Jackson ML (1973) Soil chemical analysis. Prentice Hall of India Pvt Ltd, New Delhi, India

Klute A (1965) Methods of soil analysis, Monograph 9. American Society of Agronomy, Madison,Wisconsin, USA pp 210–221

Lal R (1981) Deforestation and hydrological problems. In: Lal R, Russel EW (eds) Tropical agricultural hydrology. J Wiley & Sons, UK, 482 pp

Lal R (1989a) Agroforestry sytems and soil surface management of a tropical Alfisol: effect on soil physical and mechanical properties. Agroforestry Syst 8:197–215

Lal R (1989b) Agroforestry sytems and soil surface management of a tropical Alfisol: V water infiltrability, transmissivity and soil water sorptivity. Agroforestry Syst 8:217–238

Majumdar B, Venkatesh MS, Kumar K, Patiram, Satapathy KK (2001) Long term effect of different farming system on soil characteristics and distribution pattern of nitrogen fractions in an acidic alfisol of Meghalaya. J Hill Res 14:79–84

Middleton HR (1930) Properties of soils which influences soil erosion. United States Department of Agriculture Tech Bull No. 178:1–6

Myers RJK, Palm CA, Cuevas E, Gunatilleke IUN, Brossard M (1994) The synchronization of nutrient mineralization and plant nutrient demand. In: Woomer PL, Swift MJ (eds) TSBF. A Wiley-Sayce Publications, New York, pp 81–116

Parton WJ, Schimel DS, Cole CV, Ojizro DS (1987) Analysis of factors controlling soil organic matter levels in Great Plains grasslands. Soil Sci Soc Am J 51:1173–1179

Pereira HC (1979) Hydrological and soil conservation aspects of agroforestry. In: Mongi HO, Huxlay PA (eds) Soils research in agroforestry. ICRAF, Nairobi, pp 315–326

Piper CS (1950) Soil and plant analysis. Academic Press, NY, USA

Prasad RN (1987) Degradation of soil and water resources and crop production in NEH Region. Indian J Hill Farm 1:1–8

Richards LA (eds) (1954) Diagnosis and improvement of saline and alkali soils. Agriculture Handbook. United States Department of Agriculture, 60

Singh KA, Rai RN, Patiram, Bhutia DT (1989) Large cardamom (Amomum subulatum Roxb.) plantation: an age old agroforestry system in Eastern Himalayas. Agroforestry Syst 9:241–257

Tomar JMS (2006) Ecological interactions between trees and crop components in selected agro-forestry systems of Meghalaya. PhD thesis. North Eastern Hill University, Shillong

Tufekcioglu A, Raich JW, Isenhart TM, Schultz RC (1999) Fine root dynamics, coarse root biomass, root distribution and soil respiration in a multi-species riparian buffer in Central Iowa, USA. Agroforestry Syst 44:163–174

van Bavel CHM (1949) Mean weight diameter of soil aggregates as a statistical index of aggregation. Soil Sci Soc Am Proc 14:20–23

Yoder RE (1936) A direct method of aggregate analysis and study of the physical nature of erosion losses. J Am Soc Agron 28:337–351