Plant and Soil 84, 105–113 (1985). Ms. 5851

Chemical soil properties under five age series of *Alnus nepalensis* plantations in the Eastern Himalayas

EKLABYA SHARMA, R. S. AMBASHT and M. P. SINGH
Centre of Advanced Study in Botany, Banaras Hindu University, Varanasi-221 005, India

Received 12 March 1984. Revised September 1984

Key words Age series plantations *Alnus nepalensis* Eastern Himalayas Soil nutrients Soil properties

Summary Five age series stands of *Alnus nepalensis* D. Don monocultures have been selected from the Pankhasari range of the Kalimpong forest division in the Eastern Himalayas. Chemical soil properties such as organic carbon, total nitrogen, C:N ratio, available phosphorus and exchangeable cations (Ca^{+2}, K^+ and Na^+) were analysed in all these different ages of plantation stands from the surface to 1 m deep profiles to find out the long term effect of *A. nepalensis* on the soil quality of these erosion vulnerable slopes.

Organic carbon, available phosphorus and total nitrogen content per-hectare increased with increasing plantation stand age. Analysis of variance for nutrients showed significant variation in depth (total nitrogen, $P < 0.001$; organic carbon, $P < 0.001$; available phosphorus, $P < 0.05$; exchangeable Ca^{+2}, $P < 0.01$; and exchangeable K^+, $P < 0.01$) and between plantation stands (organic carbon, $P < 0.05$; and available phosphorus $P < 0.05$). High value of total nitrogen content (34.97 t ha^{-1}) was obtained in 46 yr old stand. Soil pH is low. It increased down the depth and in older plantations. These stands with high soil total nitrogen and organic carbon content show increased fertility of the stands. The cover of *A. nepalensis* in rocky, landslide and erosion prone slopes of the Eastern Himalayas, serves to protect and improve soil quality.

Introduction

Alnus nepalensis D. Don is a common tree in both natural and managed ecosystems in the Central and the Eastern Himalayas. It is planted as an associate species with *Cryptomeria japonica* Don, *Cupressus cashmeriana* Royle, *Betula alnoides* Ham, *Michelia champaca* Linn etc. and in monocultures. It is good nurse tree in *Cinchona* spp. and *Amomum subulatum* plantations in the Himalayan region. *A. nepalensis* is found to be a successful pioneer in freshly exposed soils in landslide affected areas, rocky and eroded slopes. *A. nepalensis* with actinorhizal root nodules is an efficient biological nitrogen fixer in the Eastern Himalayas[15]. Actinorhizal species have been shown to improve soil nitrogen status and act as pioneer species on denuded habitats[16]. The soil-improving properties of other *Alnus* species are well known. Studies have shown that *Alnus rubra* Bong. makes a significant contribution to fertility of forested sites in the Cascade Range, USA[18,19] and on some of the more fertile coastal soils[4].

On the erosion prone slopes of the Himalayas the conservation of soil nutrients against erosion is an important task. Forest plantation by suitable species is probably the best way of control against erosion of soil along with nutrients. *A. nepalensis*, a fast growing tree with nitrogen fixing capability, is a good species for plantation. Nitrogen, being easily washed down by torrential rains and through leaching, can be introduced into the system by Alnus through biological nitrogen fixation[15]. Thus a series of five different ages of *A. nepalensis* plantation stands were selected to study chemical soil properties and nature of the effect of stand age on a long range basis (7 yr to 56 yr old plantation stands).

Materials and methods

Five different stands in the Pankhasari range of the Kalimpong forest division in the hills of Darjeeling (Eastern Himalayas) were selected (27° 7′ N, 88° 35′ E). These stands represented monocultures of *A. nepalensis* of 7, 17, 30, 46 and 56 years. The selection of these stands were done on the basis of available age series of *A. nepalensis* monocultures in close proximity. Ages of these alder stands were recorded in stand history maintained by West Bengal Forest Development Corporation. Each of the stand was divided into sample, buffer, measurement and study areas[12]. The studies on soils were done in the measurement area. All the stands were within 10 km distance. These stands fall beween 1670 m to 2040 m altitude above m.s.l. with a temperate climate. Normal annual precipitation is 3000 mm to 4000 mm. Mean maximum of 22.4°C, mean minimum of 15.4°C temperatures for the growing season (April to November) and mean maximum of 14.2°C, mean minimum of 6°C temperatures for the winter season (December to March) were recorded in 1981 to 1982. The selected stands occupy sloping topography (25° to 35° slope). Soils in the study stands were sandy loam in texture and dark brown to yellowish brown in colour. Soils exhibited little differences among stands. The geological formation belonged to Darjeeling Gneiss consisting of different grades of metamorphic rocks.

In July 1981, soil pits were excavated up to a depth of 1 m at five different monoculture stands of *A. nepalensis*. The pits were divided into five horizons *viz.*, (a) 0–20 cm, (b) 20–40 cm, (c) 40–60 cm, (d) 60–80 cm and (e) 80–100 cm. A bulk sample of each horizon was taken from each pit, air-dried and used for chemical analysis. Bulk density samples of soil were obtained from all the pits using bulk density tube sampler, oven dried (80°C for 48 hrs) and weighed. The calculated bulk density values were used to convert analytical data on kilograms or tons-per-hectare basis.

All chemical analyses were carried out with the air-dried, sieved (< 2 mm size) samples. Soil-water paste was prepared in 1:1 proportion for measurement of pH by glass electrode pH meter[2]. Some of the chemical analyses were carried out by the procedures outlined by Jackson[6]: (i) available phosphorus-dilute acid extracted and estimated by chlorostannous-reduced molybdophosphoric blue colour method, (ii) total nitrogen – by modified Kjeldahl method and (iii) exchangeable calcium, potassium and sodium extracted by ammonium acetate solution and determined by flame photometer. The organic carbon was determined by Walkley-Black titration method[14].

In calculation of kilograms or tons per hectare of the various nutrients, values were calculated separately for each horizon and then added to obtain data for each profile.

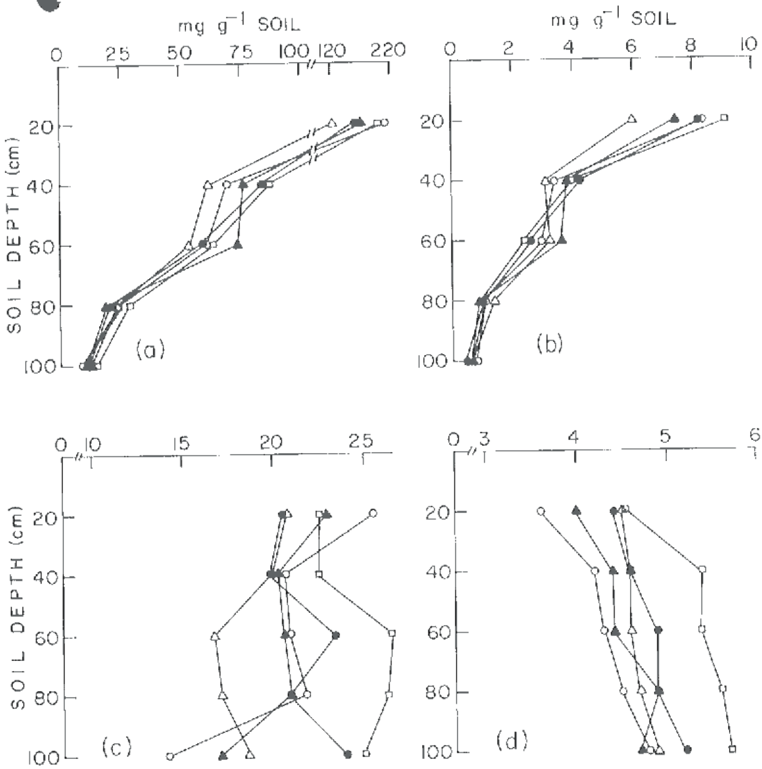

Fig. 1. Variation in (a) Organic carbon, (b) Total nitrogen, (c) C/N ratio and (d) pH of different plantations: (△) 7 yr, (▲) 17 yr, (○) 30 yr, (●) 46 yr and (□) 56 yr at different depths.

Results and discussion

Soil horizons under age series of *A. nepalensis* stands have more differences in the values of soil reaction (pH) and nutrients in the upper three horizons, but these differences are less in the lower two horizons (Figs. 1 and 2). The values are converted on a kilogram or ton per hectare basis, adjusted for horizon thickness and bulk density to get the magnitude and importance of some differences, more apparent. Values of soil nutrients on per hectare basis for 1 m profile of plantation stands are presented (Fig. 3) to show the effect of plantation ages on the stand soil properties.

Organic carbon

The 0–20 cm horizon, appearing dark brown in the field, had high organic carbon content and decreased down the depth sharply in all the plantation stands (Fig. 1a). It increased with the maturation of the stand, but the maximum value of 212 mg g^{-1} soil is obtained in

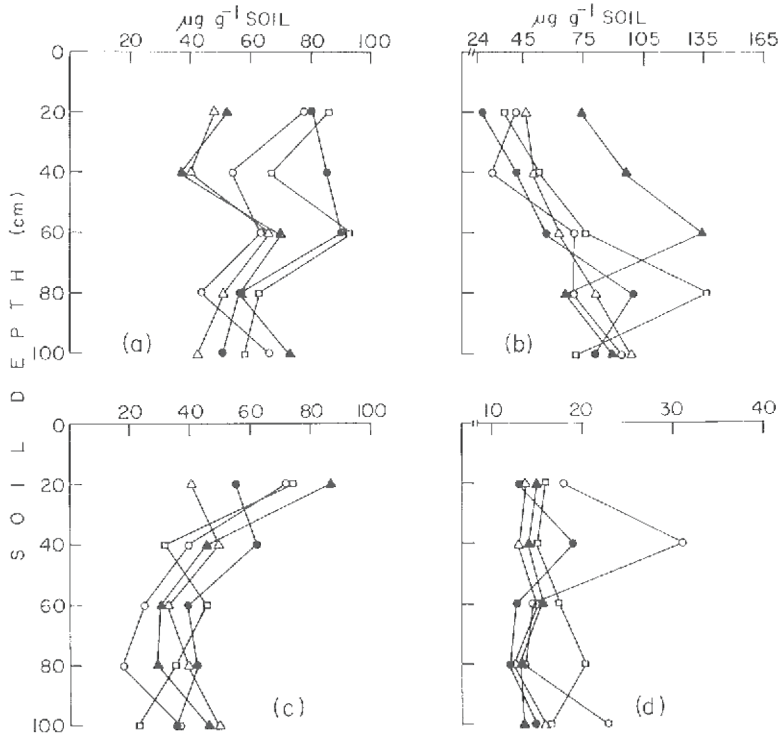

Fig. 2. Variation in (a) Available phosphorus, (b) Exchangeable calcium, (c) Exchangeable potassium and (d) Exchangeable sodium of different plantations: (△) 7 yr, (▲) 17 yr, (○) 30 yr, (●) 46 yr and (□) 56 yr at different depths.

0–20 cm horizon of 30 yr old plantation stand. High average value of organic carbon 234 mg g^{-1} soil in 0–30 cm horizon of 40 yr old red alder stand[4] is comparable to 212 mg g^{-1} soil in 0–20 cm horizon of 30 yr old *A. nepalensis* stand. The organic carbon contents of 60 100 cm depths are almost consistent in all the stands. Statistically, variations of organic carbon (t ha^{-1} horizon) between the soil depths and the plantation stands are significant at $P < 0.001$ and $P < 0.05$ levels, respectively (Table 1). Organic carbon is contributed to the soil through litter and root decomposition. The fast growing nature of *A. nepalensis* with maximum litter fall in winter and higher rate of decomposition in the rainy season continuously add organic carbon to the soil (Sharma and Ambasht, unpublished). In spite of the slope factor, surface runoff and removal of leaf litter for biofertilizer purpose by the local people, organic carbon content of the stands increased with advancing plantation stand age (Fig. 3).

Total nitrogen and C:N ratio

Total nitrogen content of *A. nepalensis* plantation soil-pool is very

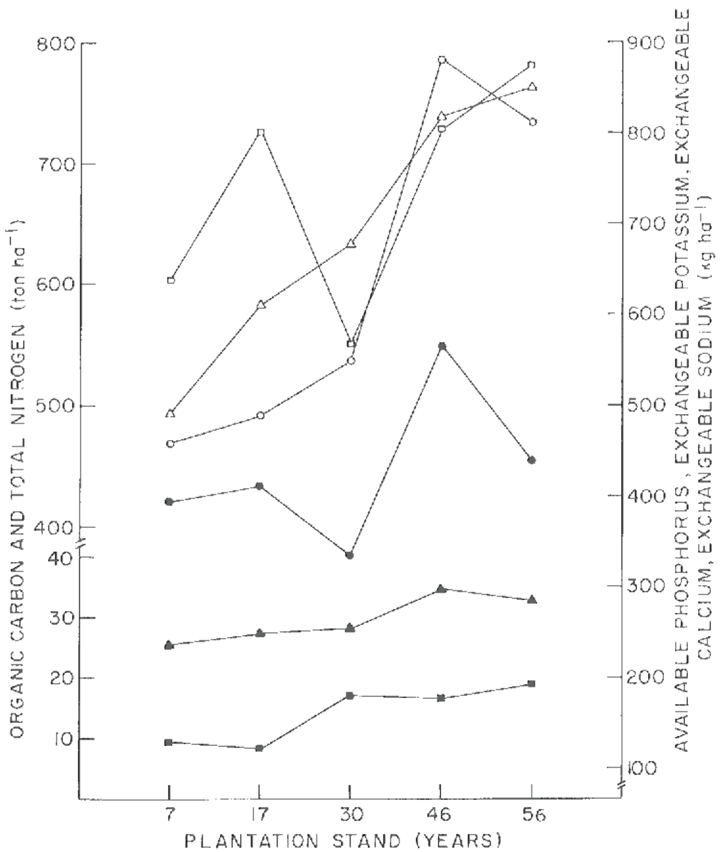

Fig. 3. Quantity per hectare of Organic carbon (△), Total nitrogen (▲), Available phosphorus (○), Exchangeable potassium (●), Exchangeable calcium (□) and Exchangeable sodium (■) of five different ages of plantation stands.

high (Fig. 3). In the uppermost (0–20 cm) horizon the total nitrogen content increased with the stand age (7 yr, 6 mg g^{-1}; 17 yr, 7.4 mg g^{-1}; 30 yr, 8.3 mg g^{-1}; 46 yr, 8.2 mg g^{-1} and 56 yr, 9.1 mg g^{-1} soil) and it decreased down the depth in all the plantations (Fig. 1b). The total nitrogen content of the lower horizons is also high, as the runoff effect is mostly confined to slope surface only and underground decomposing roots add total nitrogen to the lower horizon soils through leaching. The significant variance ratio (F) is obtained for total nitrogen content for soil depth ($P < 0.001$) only (Table 1).

Soil total nitrogen content (34.97 t ha^{-1}) under the stand of 46 yr old *A. nepalensis* up to a depth of 100 cm is high as compared to other ecosystems (25 yr old *Pinus patula* stand in the Eastern Himalayas[17], 0–100 cm soil depth, 25.34 t ha^{-1}; 18 yr old *Cryptomeria japonica* stand in the Eastern Himalayas[10], 0–100 cm soil depth, 24.5 t ha^{-1};

Table 1. Variance ratio (F) for soil chemical properties

Source of variation	Organic carbon t ha^{-1} horizon	Total nitrogen t ha^{-1} horizon	Available phosphorus $\mu g\ g^{-1}$ soil	Exchangeable potassium $\mu g\ g^{-1}$ soil	Exchangeable calcium $\mu g\ g^{-1}$ soil
Soil depth	99.12***	97.40***	3.73*	5.61**	4.18*
Plantation stand	4.67*	2.93^{ns}	4.06*	-	1.61^{ns}

d.f. for soil depth (4), plantation stand (4) and error (16) were same for all the chemical properties. ns = not significant.
Significant at: *$P < 0.05$, ** $P < 0.01$ and *** $P < 0.001$

Eucalyptus obliqua Eucalyptus dives and *Eucalyptus regnans* stands in Australia[3], 0–100 cm soil depth, 13.44 and 17.28 t ha^{-1} respectively; and 40 yr old *Alnus rubra* stand in Oregon, USA[4], 0–90 cm soil depth, 18.7 t ha^{-1}). *A. nepalensis* stand showed the highest soil total nitrogen value, nevertheless the *Pinus patula* and *Cryptomeria japonica* stands of the Eastern Himalayas also showed high values. Soil total nitrogen content of *A. rubra* stand[4] is half of the *A. nepalensis* stand when compared to 0–90 cm depths although both of them are efficient biological nitrogen fixing actinorhizals. Biological nitrogen fixation is not affected by the increasing fertility of the stands[15]. Total nitrogen content is increased in advancing age series stands irrespective of loss through surface runoff.

Soils with a very high C:N ratio have low net rate of mineralization. The ratios most favourable for mineralization lies between 10:1 and 20:1[11]. In all the horizons and plantation stands of *A. nepalensis,* C:N ratios are between 14:1 and 26:1 (Fig. 1c) indicating the most favourable ratios for mineralization. Faster mineralization of nitrogen is accorded with enhanced leaching[9].

Available phosphorus

Available phosphorus changed significantly between the soil depth ($P < 0.05$) and plantation stands ($P < 0.05$). Availability of phosphorus is highest at 40–60 cm horizon (Fig. 2a) and it increased in the stand soil-pool with plantation age (Fig. 3). Maximum value of 880.49 kg ha^{-1} is recorded in 46 yr old stand and is comparable to 855 kg ha^{-1} of *Eucalyptus obliqua* stand[3].

Exchangeable cations (Ca^{+2}, K^+ and Na^+)

Exchangeable calcium (Ca^{+2}) increased down the depth in all the plantation stands (Fig. 2b). There is no significant trend of variation from plantation to plantation stand, although the variation in quantity of exchangeable Ca^{+2} of the soil-pool is observed (Fig. 3). Exchangeable Ca^{+2} showed significant ($P < 0.01$) variation down the soil depth. Calcium availability decreases as acidity increases, thus the higher pH values down the depth resulted in presence of more exchangeable Ca^{+2}. The highest quantity (873.37 kg ha^{-1}) of exchangeable Ca^{+2} is found in the soil-pool of 56 yr old stand.

Exchangeable potassium (K^+) in 7 yr, 17 yr and 30 yr old stands decreased sharply form 0 to 60 cm depth, horizons of active nutrient absorption by roots, and then increased moderately down the depth. In contrast, exchangeable K^+ of the older stands (46 yr and 56 yr) decreased down the depth throughout (Fig. 2c). Variation of exchangeable K^+ is significant ($P < 0.01$) between the soil depths only (Table 1). Exchangeable K^+ is in higher concentrations (40.6 to 86.9 $\mu g\ g^{-1}$) in the upper two horizons of all the plantations. Highest value of 564.99 kg ha^{-1} is recorded in 46 yr old stand soil-pool (Fig. 3).

There is no variation of exchangeable sodium (Na^+) between the horizons and in plantation stands (Fig. 2d), although increase in soil-pool with the stand maturity is observed (Fig. 3). Na^+ being non-essential element does not show any significant trend.

Legumes symbiotically fix atmospheric nitrogen, they remove excess of cations over anions from the soil solution, and thus acidity increases at their root surface[1,7,8]. Similarly excess of cation uptake can be one of the causes of acidity in the actinorhizal *A. nepalensis* stands. Decrease of base content under red alder stand is reported[4].

Soil reaction

The pH of the soil has an effect upon its structure, weathering and humification processes and mainly on the mobilization of nutrients and exchange of ions. Soil reaction increased down the depth and lowest pH are recorded in the uppermost horizon of all the plantation stands (Fig. 1d). As in *A. nepalensis* stands soil pH down the depth is reported to increase in *A. rubra* stands whereas it decreased in conifer stands[4]. Soil pH of the pure *A. rubra* stand is 4–5 in 0–30 cm depth. *A. nepalensis* and *Cryptomeria japonica*[10] monoculture stands in the Eastern Himalayas showed 3.6–5.4 and 4.0–4.8 pH range in 0–40 cm depths respectively. Acidity is due to immobilization at the earlier stage of litter decomposition, accumulation of nitrates and higher cation uptake as compared to anions in nitrogen fixing species[5,13]. Increased soil acidity is coupled with reduced base content in soils[4].

Soil organic carbon, total nitrogen, available phosphorus, exchangeable Ca^{+2}, K^+ and Na^+ increased with stand age. Acidity is higher in 7 yr, 17 yr and 30 yr stands as compared to 46 yr and 56 yr stands.

These alder stands show higher values of soil total nitrogen and organic carbon with the increase in plantation stand age indicating increased fertility status of the soil. Thus, *A. nepalensis* plantations not only make significant contribution to the nitrogen economy but also improve soil quality and protect the vulnerable slopes against erosion with luxuriant undergrowth in the Himalayan region. But the effect of (i) acidity on base status of the stands and (ii) slope on nutrient loss through surface runoff and leaching, are to be answered by further investigations.

Acknowledgements The authors (ES and MPS) are thankful to CSIR and UGC for financial support in the form of research fellowships. Thanks are also due to the special and General Division Kalimpong of West Bengal Forest Development Corporation for facilities.

References

1 Beusichem M L van 1982 Nutrient absorption by pea plants during dinitrogen fixation 2. Effects of ambient acidity and temperature. Neth. J. Agric. Sci. 30, 85–97.
2 Black C A, Evans D D, Ensminger L E, White J L and Clark F E 1965 Methods of Soil Analysis. Agronomy No. 9, 1572.
3 Feller M C 1980 Biomass and nutrient distribution in two eucalypt forest ecosystems. Aust. J. Ecol. 5, 309–33.
4 Franklin Jerry F, Dyrness C T, Moore Duane G and Tarrant Robert T 1968 Chemical soil properties under coastal oregon stands of alder and conifers. *In* Biology of Alder. Eds. J M Trappe *et al.* pp 157–172. USDA Portland, Oregon.
5 Israel D W and Jackson W A 1978 The influence of nitrogen nutrition on ion uptake and translocation by leguminous plants. *In* Mineral Nutrition of Legumes in Tropical and Sub-tropical Soils. Eds. C S Andrew and E J Kamparth pp 113–129. CSIRO, Melbourne.
6 Jackson M L 1967 Soil Chemical analysis. Prentice-Hall, New Delhi.
7 Jarvis S C and Robon A D 1983 The effects of nitrogen nutrition on the development of acidity in Western Australian soils. I Effects with subterranean clover growth under leaching conditions. Aust. J. Agric. Res. 34, 341–353.
8 Jarvis S C and Robon A D 1983 The effects of nitrogen nutrition on the development of acidity in Western Australian soils. II Effects of differences in cation/anion balance between plant species grown under non-leaching conditions. Aust. J. Agric. Res. 34, 355–365.
9 Keeney Dennis R 1980 Prediction of Soil Nitrogen Availability in Forest Ecosystems: A Literature Review. Forest Science 26(1), 159–171.
10 Lal I P 1981 Ecology of *Cryptomeria japonica* in Darjeeling Himalaya. Ph.D. Thesis, Banaras Hindu University, India.
11 Larcher W 1975 Physiological Plant Ecology. Springer-Verlag Berlin-Heidelberg pp 252.
12 Newbould P J 1967 Methods for estimating the Primary Production of Forests. Blackwell Scientific Publication, Oxford.
13 Nyatsanga T and Pierre W H 1973 Effects of nitrogen fixation by legumes on soil acidity. Agron. J. 65, 936–940.
14 Piper C S 1950 Soil and Plant Analysis. Inter Science Publishers, New York.
15 Sharma Eklabya and Ambasht R S 1984 Seasonal variation in nitrogen fixation by different ages of root nodules of *Alnus nepalensis* plantations, in the Eastern Himalayas. J. Appl. Ecol. 21, 265–270.

16 Silvester W B 1977 Dinitrogen fixation by plant associations excluding legumes. *In* A Treatise on Dinitrogen Fixation IV Agronomy and Ecology, Ed R W F Hardy and A H Gibson, John Wiley and Sons, New York, pp 141–190.
17 Singh B 1979 Ecology of *Pinus patula* planted in Darjeeling Himalaya. Ph.D. Thesis. Banaras Hindu University, India.
18 Tarrant R F 1961 Stand development and soil fertility in Douglas-fir-red alder plantations. For. Science 7, 238–246.
19 Tarrant R F and Miller R E 1963 Accumulation of organic matter and soil nitrogen beneath a plantation of red alder and Douglas-fir. Soil Sci. Soc. Am. Proc. 27, 231–234.