monazite ranging from 14.29 to 15.40% while in profile 4, its values vary from 6.25 to 9.38%. The amount of monazite present in the heavy minerals of Gyaspur is comparable to its values in Travancore[1]. Moreover, its values for Barpalia are slightly higher. The values of monazite would have, however, been much lower, if computed for the bulk of sand and soil mass, since their heavy mineral fractions constitute only 13–32% of the fine sand in the soils of both the profiles (Table 1).

These soils are derived from alluvium in the Indo-Gangetic plain of Bihar and the deposit of alluvium is affected by Ghaghra and Chhoti Gandak rivers (Figure 1) emanating from the Himalayas. The chief rock types of the Himalayan series include quartzitic sandstone, slate, limestone, schist, conglomerate, granite and gneiss. The light minerals in the fine sand include quartz, feldspar and muscovite in abundance[4]. Monazite may occur in granitic pegmatite[5] and gneissic metamorphic rocks[1] in association particularly with feldspar and with zircon and apatite[5].

It is concluded that monazite present in the fine fraction of some alluvial soils in north Bihar is considerable not only from the pedological point of view, but its occurrence in such quantities should be of interest to geologists, radiologists as well as health physicists. As such, further investigation is desirable.

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Nitrogen dynamics of actinorhizal *Casuarina* forest stands and its comparison with *Alnus* and *Leucaena* forests

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***Casuarina equisetifolia* (Forst. & Forst.) plantation forests of 5 yr and 8 yr age in dry tropics of Shaktinagar, Sonebhadra in Vindhyan plateau were studied for N cycling through vegetation, litter and soil pool and compared with similar work on subtropical actinorhizal *Alnus nepalensis* and tropical rhizobial *Leucaena leucocephala*. Interannual variation in nitrogenase activity was observed with a maximum in July–August while peak N-accretion was in September–October. N input through foliage litter accounted for 85–95% of total litter N, of which 90% was released through decomposition in one year, whereas in *Alnus* only 60% of the litter N was annually released. The contribution of biological N_2 fixation to total N uptake was maximum in *Casuarina* (37%) followed by *Alnus* (33%) and *Leucaena* (16%). It has been concluded that *Casuarina* successfully covers the thin soil profile of freshly degraded Vindhyan hills and restores the soil N fertility.**

RAPID deforestation has accelerated savannization and desertification. Afforestation by fast-growing, preferably N-fixing tree species has been attempted at several places in the tropics and subtropics. In tropics, such species are mostly *Rhizobium*-nodulated leguminous trees[1] while in the temperate region, *Frankia*-nodulated non-leguminous actinorhizals[2] are of importance. However, *Casuarina*, which is an actinorhizal species bearing *Frankia* as N-fixing symbiont in its root nodules[3], is predominantly tropical and capable of growing on nutrient poor[4] and coastal sandy saline soils[4].

Nitrogen plays a key role in soil fertility and plant productivity and often poor productivity is due to its deficiency in soil[5]. Root nodules not only fix and transfer nitrogen to plants, but also enrich soil fertility on its decomposition. Nodules are short-lived and have a rapid cycle of formation, growth, death and decay[6]. Litter decomposition rate is usually faster in tropical, warm and moist condition than in subtropical, less warm and moist condition[7,8]. Therefore, it is of interest to compare an actinorhizal tropical species *Casuarina equisetifolia*, which we have presently studied, with the earlier studies of Sharma and Ambasht on subtropical actinorhizal *Alnus nepalensis* trees[9–11]. These actinorhizal trees are also compared with a tropical rhizobial tree *Leucaena leucocephala*, introduced in India on large scale, studied by Sandhu and coworkers[12,13]. Such a comparison would help in policy decision for afforestation and restoration strategies and rehabilitation of deforested landscape.

Plantation of *C. equisetifolia* (Forst. & Forst.) has been done by the forest department at Shaktinagar in Sonebhadra district of Vindhyan plateau (24°–24°–12' N, 82° 40'–82° 44' E), central India. Two age class stands available there were of 5-years and 8-years (December 1988 census) with the tree densities of 3500 and 666 trees/ha in the respective age classes. Both these stands were selected for our studies. The trees had an average height of 8.6 m and 16.0 m with maximum

Table 1. Range of nitrogen concentration (mg g^{-1}) in components of harvested sample trees of *Casuarina*, *Alnus* and *Leucaena*

Component	Species		
	Casuarina	*Alnus*	*Leucaena*
Bole	7.2–12.7	2.4–7.1	8.5–10.8
Branch	8.0–10.3	7.8–15.0	10.0–12.5
Leaf	15.8–21.2	33.3–36.7	30.0–38.2
Root	7.0–11.2	9.0–16.7	6.5–10.0

stem diameter (DBH) of 12.5 cm and 23.0 cm in the respective stands. The results of these are compared with the *Alnus nepalensis* (D. Don)[6,7,10,14] forest stands of 7, 17, 30, 46 and 56-yr age in Darjeeling Himalaya (27°7' N, 88°35' E) with respective tree densities of 715, 545, 505, 470 and 435 trees/ha and 3-yr old *Leucaena leucocephala* (Lam) de Wit plantation stand at Varanasi (25°17' N, 83°1' E) with a density of 8000 trees/ha[13]. These *Casuarina* and *Leucaena* forest stands are in warm dry tropics and experience hot and dry summer, warm and wet monsoon (1100 mm rainfall) and cool dry and wet winter seasons of almost equal duration in a year. *Alnus* forest is in subtropical belt with very wet condition (2260 mm).

Measurements have been made for standing state and uptake of N in different tree components, N return through litterfall and release through decomposition of litter, N retention in the system and N accretion through biological nitrogen fixation. Nitrogen concentration in the bole, branch, leaf and root components of harvested sample trees of *Casuarina* was predicted[15] and compared with that of *Alnus*[14] and *Leucaena*[13] (Table 1). The nitrogen content in different components was obtained by multiplying the respective component biomass of harvested trees and N concentration. Regression equations have been developed from component biomass (predictor variable) and component nitrogen content (dependent variable) to obtain the standing state of nitrogen in *Casuarina*[16], *Alnus*[14] and *Leucaena*[13] plantation stands. The difference between the nitrogen standing state values of two successive years (component-wise and total) gave the nitrogen uptake values[9]. The N returned through litterfall was quantified by multiplying the litterfall mass and nitrogen concentration. N release was measured by litter decomposition through litter bag technique[8,10,12]. Retention is the difference between uptake and return. Nitrogen fixation and accretion were studied by estimating nitrogenase activity of excised root nodules (soil core method) by acetylene reduction assay[17].

In *Casuarina*, among the components bole accounted for 50–67% of the standing state N whereas in *Leucaena* it was 42%. In young *Alnus* plantation of 7-yr the roots accounted for the maximum N storage but as the tree age advances, bole components overtake the root and peak bole storage reaches to 30% in 56-yr plantation[14].

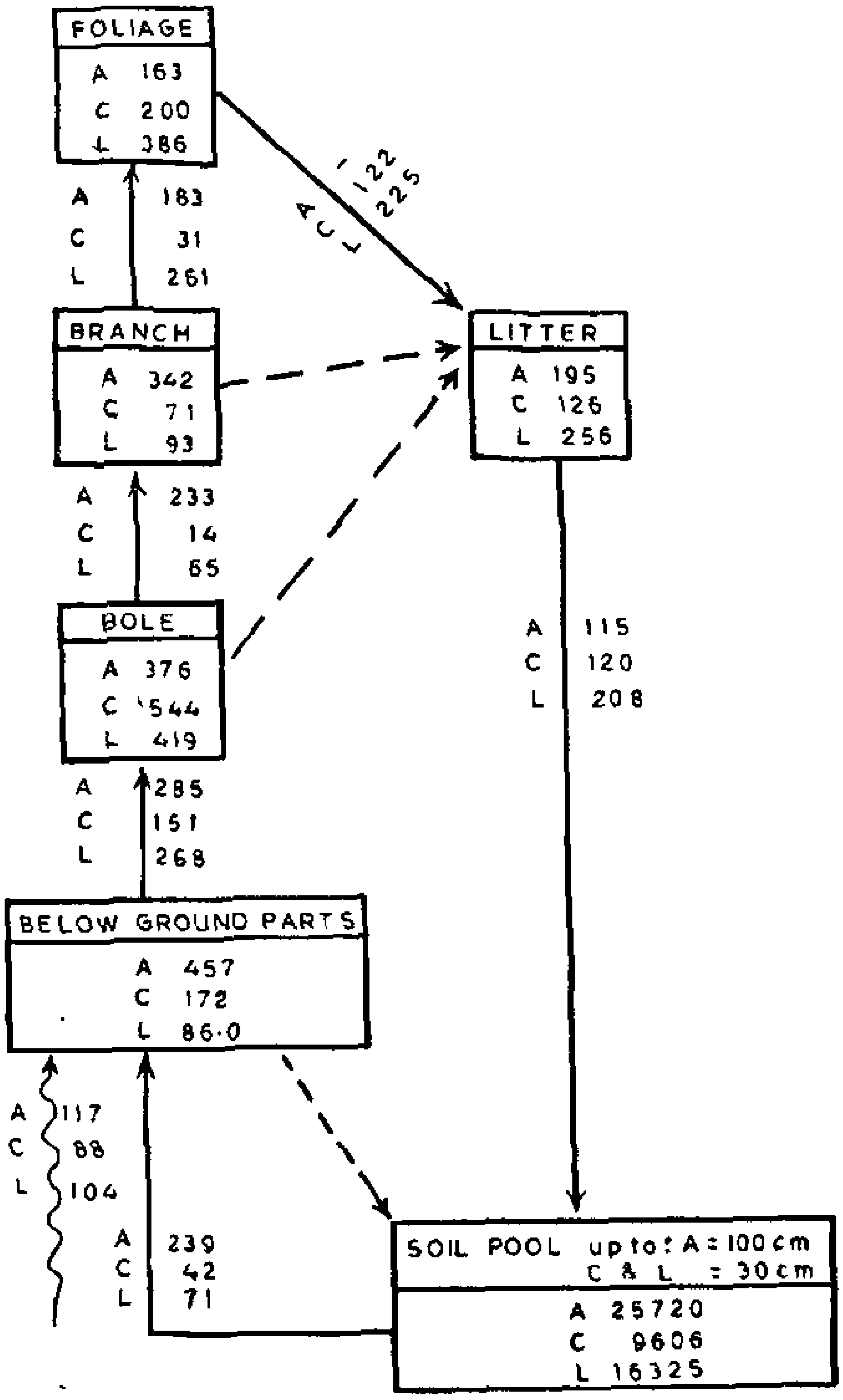

Figure 1. Compartment model depicting standing state (in boxes, kg ha^{-1}) and flow rates (on arrows, kg ha^{-1} yr^{-1}) of nitrogen, through major components of vegetation and soil pool A = *Alnus nepalensis*, 7-year age C = *Casuarina equisetifolia*, 5-year age. L = *Leucaena leucocephala*, 3-year age Zig-zag line is for biological nitrogen fixation Dashed lines indicate 'not determined'.

Branch had almost equal share to the bole N storage. The range of N standing state of 500 to 1000 kg ha^{-1} in *Casuarina* and 1370 kg ha^{-1} in *Alnus* is comparable to reports for post oak black jack oak forest in USA. (1071 kg ha^{-1})[18] and *Quercus fraxinus* forest in Belgium (1260 kg ha^{-1})[19]. In *Leucaena* higher standing state of nitrogen has been recorded. In fast growing plantations normally short cycle for quick harvest of fuelwood is practised, hence here we have preferred to make a comparison of N-dynamics of young age plantations and their impact on soil N fertility. The data for the youngest available plantation was for 7-yr in *Alnus*, 5-yr in *Casuarina* and 3-yr in *Leucaena*. The nitrogen distribution and flow rates in the components of these species are shown in Figure 1.

Nitrogen uptake in *Casuarina* was maximum in bole, followed by root > foliage > branch. Total annual nitrogen uptake was 240 kg ha^{-1}. In *Alnus*, N uptake by branch was more than the leaf component. However, in *Leucaena*, the bole and leaf contribute approximately equally to total N uptake of 665 kg ha^{-1}. These N uptake estimates, except in *Leucaena* are well within the reported range of 136–430 kg ha^{-1} yr^{-1} N uptake for humid forests[20–22]. The higher uptake values in *Leucaena* is attributed to the very young and dense nature of the studied stand. In general, the N uptake decreased with increase in stand age[9, 16].

Litterfall is a major pathway of nutrient transfer from vegetation to soil pool. Total nitrogen returned through litterfall in *Casuarina* was 126 kg ha^{-1} yr^{-1}, of which 85–95% was contributed by foliage litter (phylloclades). The annual nitrogen return in *Alnus* and *Leucaena* was 195 and 256 kg ha^{-1} respectively, of which leaf litter accounted for 60–70% and 88% respectively[7, 12]. Nitrogen return values in tropical *Casuarina* and *Leucaena* are comparable to the reports for the over 50 tropical stands, which have a wide range of 64–162 kg ha^{-1} yr^{-1} (ref. 23). A range of 43–156 kg ha^{-1} yr^{-1} of nitrogen return in tropical forests has been reported[24, 25]. N return in subtropical *Alnus* is similar to Beech forest in Great Britain[26]. The nutrient return through litterfall is affected by tree density and age of the forest which actually determine the quantity of litterfall and hence the nitrogen return. Nitrogen retention was maximum in 3-yr young *Leucaena* (409 kg ha^{-1}) in comparison to *Alnus* (231 kg ha^{-1}) and *Casuarina* (114 kg ha^{-1}). The higher nitrogen retention showed that N tended to get locked up in the biomass during the growth of the trees.

Research in biological N_2 fixation has received an impetus in recent years. In *Casuarina*, nitrogenase activity increased with increase in plantation age[16] and highest activity was recorded in months of July–August and minimum in May–June. However, nitrogen accretion to soil was reduced in older plantations and the peak was also shifted to the months of September–October, the period of peak nodule biomass[6]. The annual nitrogen accretion ranged from 88 kg ha^{-1} (5-yr) to 60 kg ha^{-1} (8-yr) in *Casuarina* plantations[27]. The highest activity in July–August is consistent with the view that young nodules have higher activity[10]. In these studies, nitrogenase activity was affected by the soil moisture and temperature[27]. Similar behaviour of nodulation and activity has also been reported for *Myrica gale*[28]. The annual N accretion in *Leucaena* was 104 kg ha^{-1} (ref. 13) and in *Alnus*, it ranged from 117 kg ha^{-1} to 29 kg ha^{-1} for 7-yr to 56-yr old stands[10]. These N accretion values are in the range of 40–60 kg ha^{-1} N in *C. equisetifolia*[29], 10–106 kg ha^{-1} in *A. sinuata*, *A. crispa* and *A. rubra*[30] and 110 kg ha^{-1} in *Leucaena*[31]. However, these nitrogen accretion values are lower than the 243 kg ha^{-1} yr^{-1} of N accretion in tropical Varzea forest in Brazil[32]. The contribution of biological N_2 fixation in total N uptake was maximum in *Casuarina* (37%), followed by *Alnus* (33%) and *Leucaena* (16%).

Microbial decomposition of litter is the dominant pathway of nitrogen release in forested ecosystems. In *Casuarina*, 120 kg ha^{-1} of N (90% of litter) is released during the one year period of decomposition[16]. Similar pattern of decomposition was found for *Leucaena*, with 208 kg ha^{-1} of N release (81% of litter) in a year[12]. But in *Alnus*, only 115 kg ha^{-1} of N (60% of litter) was released during the one-year period of decomposition[7]. Thus, there was litter mass accumulation on the ground surface in sub-tropical *Alnus* forest stand, due to slower litter disappearance rate than the tropical *Casuarina* and *Leucaena* forests. The wide difference in litter disappearance is attributed to resource quality, range of decomposer organisms present and the environmental regimes under which decomposition occurs[8, 33]. Temperature and moisture are correlated to a very great extent with decomposition rate. Also, the N-rich litter decomposed slowly[34]. Nitrogen release of 123–170 kg ha^{-1} yr^{-1} for *Terminalia* plantations, 169 kg ha^{-1} yr^{-1} for mature rainforest sere and 156 kg ha^{-1} yr^{-1} for mixed deciduous forest of central America has been reported[35, 36].

It may be concluded that *Casuarina* trees contribute greatly to the nitrogen nutrition and productivity of degraded Vindhyan plateau. Nitrogen fixation is highest, when the demand is maximum, during rapid plant growth phase. However, the lower contribution of biological N_2-fixation to N uptake in young *Leucaena* (16% only) revealed the need for an initial fertilizer treatment during seedling establishment[13]. *Alnus* can serve to nitrogen economy of denuded habitats and erosion-prone Himalayan slopes[10, 11]. *Casuarina* is quite suitable for plantation and restoration of vegetal cover on freshly degraded Vindhyan hills as it rapidly and successfully covers the thin soil profile and enriches the soil nitrogen status. The soil nitrogen content of the *C. equisetifolia* plantation stand is enriched to the level of 9606 kg ha^{-1} (up to 30 cm profile) in comparison to 1903 kg ha^{-1} in abandoned (not under plantation) site soil[37].

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