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NUTRIENT AND CARBON STORAGE IN SOILS OF DECIDUOUS FORESTS IN INDIA

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RESUME

Engendrés sous un climat de type mousson à saison sèche prolongée et sous une végétation dont la physionomie varie de la savane discontinue au peuplement à couvert pratiquement fermé, les sols des forêts décidues présentent des profils qui se développent sur des profondeurs variables (de 30 cm à 100 cm). Dérivant de roches gréseuses sous-jacentes, ces sols sont rouge vif lorsqu'ils se développent en place et tendent vers le gris clair lorsqu'ils proviennent de dépôts alluvionnaires. Du point de vue de leur texture ces sols appartiennent principalement à la classe sablo-argileuse; ils sont neutres à légèrement acides.

La présente note étudie la teneur en éléments majeurs et en carbone des sols à cinq profondeurs différentes pour cinq types de forêts, à savoir forêts à Terminalia tomentosa et Shorea robusta, à Tectonia grandis, à Diospyros melanoxylon et Anogeissus latifolia, à Shorea robusta et Buchanania lanzan et à Butea monosperma. Les éléments majeurs étudiés sont N, Ca, Mg, K et P. Tous les peuplements montrent une accumulation maximale de ces éléments dans l'horizon de surface, et leur teneur diminue rapidement avec la profondeur. Les différences observées entre les sols des divers types de forêt et à diverses profondeurs sont significatives. Elles traduisent en partie les différences de quantité et de composition chimique de l'apport de matière organique à la litière par les divers peuplements forestiers. Les estimations de la quantité totale (exprimée en Kg/ha) accumulée dans les sols pour ces diverses forêts montrent que la partie principale de l'apport en éléments minéraux et en carbone est fournie par l'édaphotope pour les écosystèmes forêts caducifoliées.

ABSTRACT

Formed under a monsoonic climate having prolonged dry period, and the vegetation physiognomy varying from open savannah like to almost closed canopied stands, the soils of

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deciduous forests show profile development to different depths (30 cm to 100 cm). Arising from underlying sandstone rocks, these soils are bright red when developed in situ and tend towards light grey when formed by alluvial deposits. Texturally these soils mainly belong to the sandy loam class, and are neutral to slightly acidic in reaction. The present communication concerns with the storage of major nutrients and carbon throughout the soil profile (five in each stand) under five forest stands dominated by : Terminalia tomentosa-Shorea robusta, Tectona grandis, Diospyros melanoxylon - Anogeissus latifolia, Shorea robusta - Buchanania lanzan, and Butea monosperma. The major nutrients investigated include nitrogen, calcium, magnesium, potassium and phosphorus. All the stands exhibit maximum accumulation of these elements in the soil surface layer, and their amounts rapidly decrease at lower depths, possibly due to limited leaching of the litter decomposition products from the surface. The differences amongst forest stands in their nutrient and carbon concentrations at comparable depths are largely statistically significant. These differences are to some extent the reflections of the differing quantity and chemical quality of the annual litterfall in respective stands. Estimations of total accumulations (kg/ha basis) in soils under these stands reveal that the bulk of nutrient and carbon supply in deciduous forest ecosystems is stored in the soil component.

INTRODUCTION

The tropical deciduous forests, grading from moist to dry deciduous depending mainly on rainfall, constitute the bulk of the Indian forests (about 70%), and have been subjected to intense population pressure through the millenia, resulting in extensive structural changes from the original closed canopy high density physiognomy to different degrees of progressively open forests and ultimately to large grassy areas. Scattered pockets of relatively less disturbed forests still exist to serve as the reference. Despite their economic significance the structure and functioning of deciduous forests has been much less studied. The Varanasi Forest Division (24°42' to 25°50' N lat. and 83°22' to 83°40' E long.) encompasses essentially the dry deciduous forests, whose structure and successional trends have been studied in a limited area in the vicinity of rivers Karmanasa and Chandraprabha by RAO (1967). As a part of the International Biological Programme, to study the functional aspects of these forests, five stands, identified by varying physiognomy and associated dominant tree species, were investigated especially from the point of view of litter production and nutrient cycling. Some of the information gathered pertaining to the extent of annual litter production, its detailed chemical composition, and rate of decomposition, and nutrient release has been published elsewhere (SINGH, 1969b). The present communication focusses attention on the storage pattern of carbon and five important nutrients (total nitrogen, exchangeable calcium, magnesium and potassium, and available phosphorus) in the soils of the same five forest stands.

MATERIALS AND METHODS

Vegetation

The forests belong to the northern tropical dry deciduous type of CHAMPION and SETH (1936). Physiognomically they range from open *Butea* stand to almost closed canopy *Terminalia-Shorea* stand. Differentiation in to storeys is less distinct and the canopy is formed entirely of deciduous trees. Usually a thin shrubby undergrowth including some xerophytic evergreen species is present. The characteristic feature of the forest is the contrast between the summer aspect, when it is almost entirely leafless (for various duration in different stands), and the soil becomes significantly exposed, and the monsoon aspect when it is covered with dense growth of tree foliage and herbaceous ground layer. The phytosociological analysis has been summarised in SINGH (1968).

Geology and Soil

The geologic formation of the area is Vindhyan system, which is composed of two facies of deposits, marine and calcareous in the lower system and estuarine in the upper system. Red coloured and fine textured sandstone is the most important rock of this area. Sandstone is generally underlain by shale and limestone. Soils developing from these rocks are bright red and brown grey in colour, sandy to sandy loam in texture with shallow profile development, and are frequently underlain by red "moorum" fragments followed by parent rocks. Soil depth usually varies between 0.5 - 1.5 m. All the forest stands studied are confined to upland soil type with almost level topography.

Soil Sampling

In April soil samples were collected from five pits located at random in each stand. Every pit was sampled at following depths : 0-5, 5-10, 10-20, 20-30, 30-40 and 40-50 cm. For sake of brevity each soil layer has been designated by its mean depth; e.g., 0-5 cm layer has been recorded as 2.5, the 5-10 cm layer as 7.5 and so on. Under *Butea* stand sampling was done upto 30 cm only due to shallowness of the soil. Estimation of bulk density was made from additional pits in each stand.

Physico-Chemical Analysis

The physico-chemical properties of soil samples were determined as follows : (I) Mechanical analysis was performed by pipette method as described by PIPER (1944); (II) Bulk density and pore space were estimated according to the procedure described by DAUBENMIRE (1947); (III) Soil reaction was measured in 1 : 5 soil-water suspension by a pH meter having glass electrodes; (IV) Organic carbon was estimated by Walkley and Black method described by JACKSON (1962); (V) Total nitrogen was determined by Kjeldahl method as outlined by JACKSON (1962); (VI) Cation exchange capacity was determined by versene titration method described by JACKSON (1962); (VII) Exchangeable cations were extracted from the soil by ammonium acetate leaching (JACKSON 1962). The soil extract was analysed for calcium by oxalate precipitation method, for magnesium by pyrophosphate gravimetric method, and for potassium by cobalt nitrite titrimetric method; (VIII) available phosphorus was leached from the soil by 0.002 N sulphuric acid and estimated by chlorostannous-reduced molybdophosphoric blue colour (in sulphuric acid system) method described by JACKSON (1962).

Statistical Analysis

Data of all the five pits in each stand were pooled to determine the mean and the standard deviation for different parameters for individual depths. Differences between means, of each parameter at corresponding soil depths of different stands, were tested for statistical significance by $\underline{t}$ test. Minimum level of probability for significance was chosen to be 0.05.

Total Nutrient Storage

Using an average soil bulk density of 1.4 g/ml and concentration values (%) of carbon and nutrients, their amounts stored in each soil layer were calculated in different stands. These were summated to obtain total storage in the profile upto 50 cm depth (30 cm for *Butea* stand). Based on above value of bulk density, per hectare the soil profile weighs approximately seven million kg (four million kg in *Butea* stand).

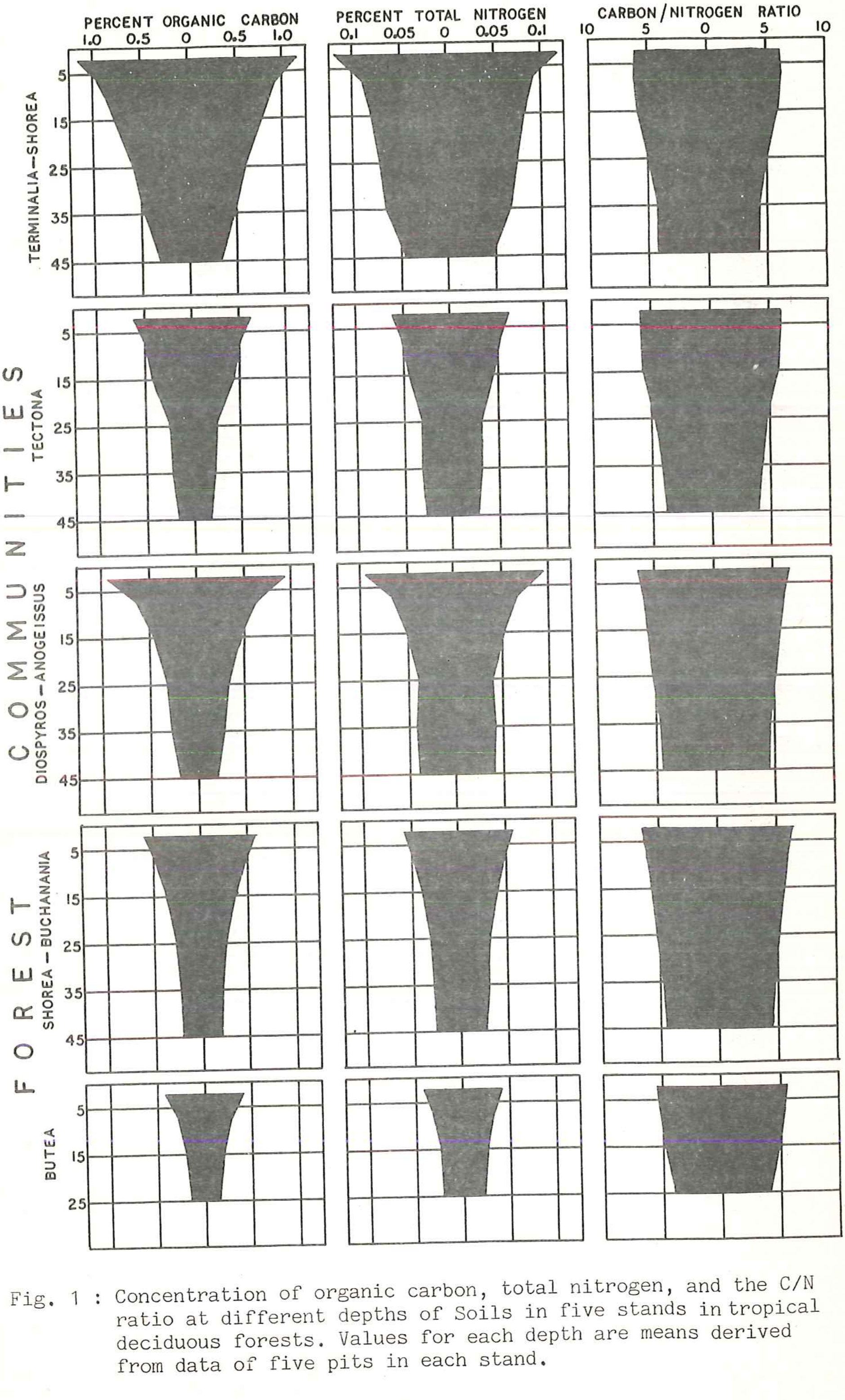

Fig. 1 : Concentration of organic carbon, total nitrogen, and the C/N ratio at different depths of Soils in five stands in tropical deciduous forests. Values for each depth are means derived from data of five pits in each stand.

RESULTS

Mechanical Analysis

The pattern of distribution of soil particle size is essentially similar in all stands, and the soils belong to the sandy loam class. Generally the particles of fine sand dimension (0.02 - 0.2 mm diameter) constitute about 50-58% of the soil, while silt (0.02 - 0.002 mm) and clay (< 0.002 mm) together make up 30-35%. Coarse sand fraction (0.2 - 2.0 mm) varies between 3 - 15%. With increasing depth the sand fractions tend to decrease, whereas the finer fractions, especially clay, show distinct increase. The details of the mechanical analysis data are omitted here.

Bulk Density and Pore Space

Soil bulk density and pore space in 0-5 cm layer varies between 1.25 - 1.56 g/ml and 40.9 - 52.8 % respectively (Tabl. I). The differences amongst stands are mostly insignificant; therefore an average value of 1.4 g/ml has been used for calculating the nutrient storage pattern.

Stands	Bulk density (g/ml)	Pore space (%)
Terminalia-Shorea	1.25 ± 0.070	52.8 ± 2.6
Tectona	1.47 ± 0.045	44.3 ± 1.5
Diospyros-Anogeissus	1.35 ± 0.071	48.6 ± 2.3
Shorea-Buchanania	1.42 ± 0.030	46.3 ± 1.1
Butea	1.56 ± 0.041	40.9 ± 1.5

Tabl. I : The bulk density and percentage pore space in 0-5 cm layer of soil under different forest stands. Values represent mean ± standard deviation.

Soil Reaction

Terminalia-Shorea, *Tectona* and *Diospyros-Anogeissus* stands exhibit neutral soil reaction (6.9 - 7.1), but *Shorea-Buchanania* and *Butea* stands are slightly acidic (6.4 - 6.5). In all the stands soil pH tends to decrease with depth (Tabl. II).

Soil depth (cm)	Forest Stands				
	Terminalia-Shorea	*Tectona*	*Diospyros-Anogeissus*	*Shorea-Buchanania*	*Butea*
2.5	6.9 ± 0.27	7.1 ± 0.19	7.1 ± 0.18	6.4 ± 0.35	6.5 ± 0.26
7.5	6.8 ± 0.24	7.0 ± 0.25	7.2 ± 0.18	6.3 ± 0.33	6.3 ± 0.38
15	6.8 ± 0.45	7.0 ± 0.19	7.1 ± 0.21	6.4 ± 0.20	6.3 ± 0.29
25	6.7 ± 0.37	7.0 ± 0.14	7.0 ± 0.27	6.2 ± 0.27	6.1 ± 0.25
35	6.6 ± 0.24	6.9 ± 0.13	6.8 ± 0.18	6.2 ± 0.21	...
45	6.6 ± 0.36	6.8 ± 0.15	6.8 ± 0.14	6.0 ± 0.14	...

Tabl. II : The pH of the soils under different forest stands. Values represent mean ± standard deviation.

Organic Carbon

Organic carbon accumulation is maximum in the 0-5 cm layer (Fig. 1), and the mean values range between 0.78 - 2.33 % in different stands. In all the stands the carbon accumulation decreases with soil depth; the decrease being conspicuous upto 45 cm depth in *Terminalia-Shorea* stand, 25 cm depth in *Tectona, Diospyros-Anogeissus* and *Shorea Buchanania* stands, and 15 cm depth in *Butea* stand.

The soil of *Terminalia-Shorea* stand contains significantly higher amount of carbon than all other communities throughout the profile (Tabl. III). The lowest carbon status occurs in the soil profile of *Butea* stand.

Total Nitrogen

The amount of total nitrogen ranges between 0.067 ± 0.014 to 0.190 ± 0.024 % in the surface layer of different stands (Fig. 1). The distribution pattern of nitrogen in the soil profiles is similar to that of organic carbon; but the decrease in nitrogen content with depth is relatively more gradual than the carbon content.

The nitrogen content of soil profile under *Terminalia-Shorea* stand, which is significantly highest amongst all stands, is approximately three times more than that of the poorest *Butea* stand. The nitrogen content of soil of *Diospyros-Anogeissus* stand is significantly higher than *Tectona* and *Shorea Buchanania* stands; while the latter two have comparable values (Tabl. III).

Depth (cm)	Stand	Organic Carbon				Total Nitrogen				C/N Ratio				C.E.C.			
		II	III	IV	V	II	III	IV	V	II	III	IV	V	II	III	IV	V
2.5	I	***	**	***	***	***	*	***	***	NS	NS	NS	*	**	*	**	***
	II		***	NS	**		***	NS	***		NS	NS	*		NS	NS	***
	III			***	***			***	***			NS	*			*	***
	IV				*				***				**				***
7.5	I	***	***	***	***	***	***	***	***	NS	NS	NS	**	**	**	**	***
	II		*	NS	***		**	NS	**		NS	NS	**		NS	NS	***
	III			NS	***			**	***			NS	*			NS	***
	IV				**				**				*				***
15	I	***	***	***	***	***	***	***	***	NS	NS	NS	***	***	**	***	***
	II		NS	*	***		*	NS	***		NS	NS	***		NS	NS	***
	III			NS	***			NS	***			NS	**			NS	***
	IV				***				***				**				**
25	I	***	***	***	***	***	***	***	***	NS	NS	NS	**	**	**	*	***
	II		NS	NS	***		*	NS	***		NS	NS	**		NS	NS	**
	III			NS	***			*	***			NS	**			NS	**
	IV				***				***				**				***
35	I	***	***	***	***	***	***	***		NS	NS	NS		*	NS	NS	
	II		**	NS			***	*			NS	**			*	NS	
	III			**				***				*				NS	
45	I	***	**	***		***	***	***		**	*	*		**	NS	*	
	II		***	*			***	NS			NS	***			*	NS	
	III			*				***				**				NS	

Legend for forest stands : I. *Terminalia-Shorea*, II. *Tectona*, III. *Diospyros-Anogeissus*, IV. *Shorea-Buchanania*, V. *Butea*.
Level of significance : * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS Not significant.

Tabl. III : Summary of statistical significance (by t test) of differences between mean values of Organic Carbon, Total Nitrogen, C/N Ratio and cation exchange capacity (C.E.C.) of corresponding soil depths under five stands of tropical deciduous forests at Varanasi.

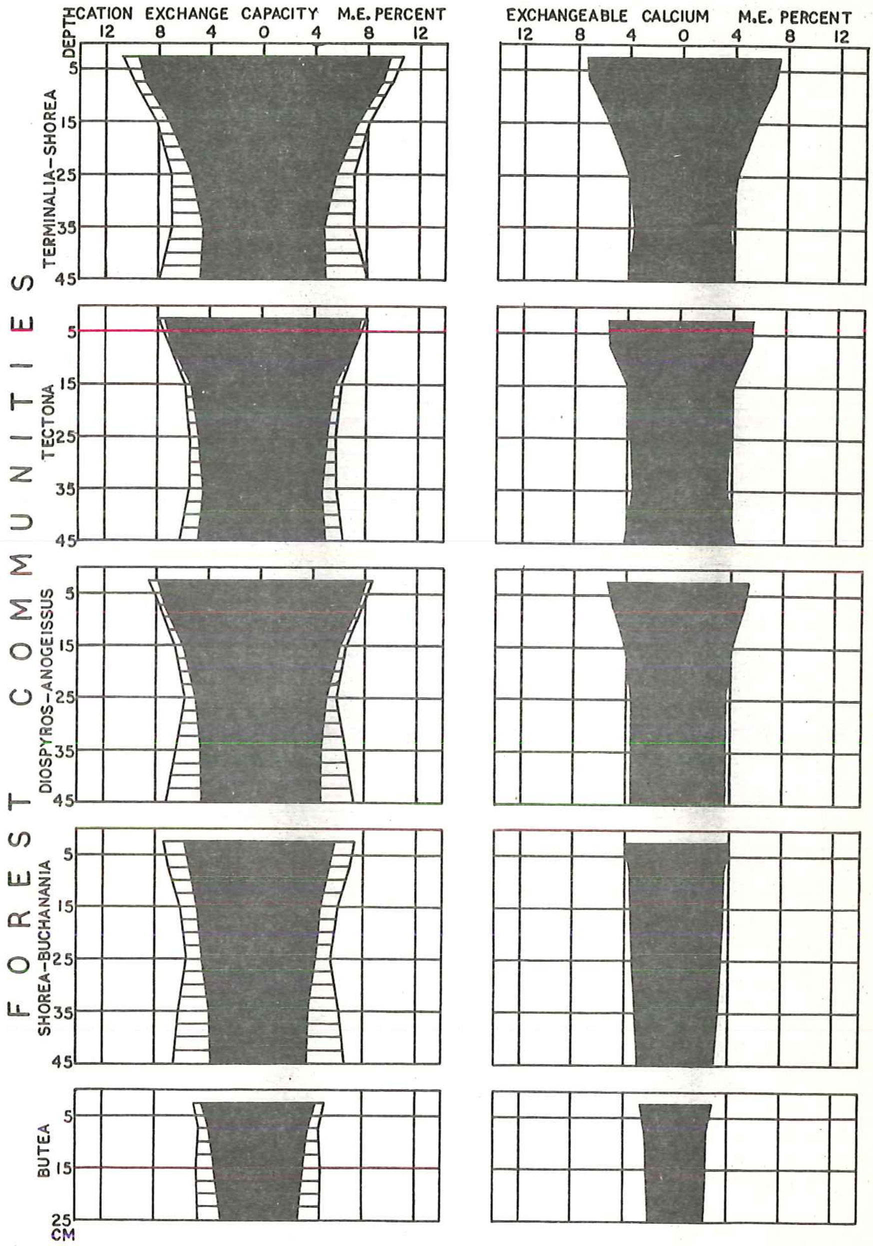

Fig. 2 : Cation exchange capacity and exchangeable calcium content at different depths in soils of five stands of tropical deciduous forests. In case of cation exchange capacity only the dark shown fraction is base saturated, while the hatched fraction represents value of base unsaturation. Values for each depth are means derived from data of five pits in each stand.

Carbon / Nitrogen Ratio

All the stands have low C/N ratio, which varies between 11.1 $\pm$ 0.79 to 12.8 $\pm$ 0.64 in the surface layer of the soil (Fig. 1). This indicates that the organic matter of these soils is in highly decomposed state. With increasing depth the C/N ratio tends to decrease in all stands, presumably due to relatively rapid decrease of carbon than nitrogen, and becomes as low as 7-8 at 45 cm depth under some of the stands. The C/N ratio of the soil of *Butea* stand is significantly lower than all other stands; but the differences amongst others are not significant (Tabl. III).

Cation Exchange Capacity and Base Saturation

In all stands highest cation exchange capacity is obtained in the surface layer of soil (9.9 $\pm$ 0.88 to 21.6 $\pm$ 3.3. m.e. %), and it decreases gradually with depth, and finally tends to increase at 35 or 45 cm depth (Fig. 2). But the increased cation exchange capacity at deeper layers is always less than that of the surface layer. More than 90% of the cation exchange complex of *Terminalia-Shorea*, *Tectona* and *Diospyros-Anogeissus* stands is base saturated in the top 15 cm soil layer, while in the *Shorea-Buchanania* and *Butea* stands the values range between 70 - 90%. At greater depths the saturation percentage decreases in all the stands, reaching as low as 56% in *Shorea-Buchanania* stand at 45 cm depth. The soil profile under *Tectona* stand is comparatively more base saturated than all other stands.

Terminalia-Shorea stand possess significantly higher cation exchange capacity than other stands in the upper 25 cm layer of the soil, but at greater depth the differences are often obliterated (Tabl. III). Except at the surface where *Diospyros-Anogeissus* stand has slightly higher value than *Shorea-Buchanania* stand, almost throughout the profile differences at corresponding depths are insignificant amongst *Diospyros-Anogeissus*, *Tectona* and *Shorea-Buchanania* stands. The cation exchange capacity of *Butea* stand is significantly lower than all other stands.

Exchangeable Calcium

Calcium, the predominant component of the exchange complex, varies between 5.4 $\pm$ 0.5 to 14.7 $\pm$ 1.9 m.e.% in the surface layers of soils (Fig. 2). The soil of *Shorea-Buchanania* stand also contains relatively less amount of exchangeable calcium. In all the stands the amount of exchangeable calcium declines with depth.

Depth (cm)	Stand	Calcium II	III	IV	V	Magnesium II	III	IV	V	Potassium II	III	IV	V	Phosphorus II	III	IV	V
2.5	I	**	**	***	***	NS	NS	*	*	NS	NS	NS	*	*	**	NS	***
	II		NS	***	***		*	NS	NS		**	NS	NS		NS	NS	***
	III			**	***			***	**			**	**			NS	*
	IV				***				NS				NS				**
7.5	I	*	**	***	***	NS	NS	NS	NS	*	NS	*	**	*	*	NS	***
	II		NS	***	***		NS	NS	NS		*	NS	NS		NS	NS	***
	III			**	***			***	***			*	*			NS	**
	IV				**				*				NS				***
15	I	***	**	***	***	NS	NS	**	**	NS	**	*	***	*	**	NS	***
	II		NS	NS	***		*	***	**		***	NS	**		NS	NS	***
	III			NS	***			***	***			***	***			NS	**
	IV				**				NS				**				**
25	I	NS	NS	**	***	NS	NS	***	***	NS	NS	***	***	*	**	NS	***
	II		NS	NS	***		NS	**	**		NS	*	**		NS	NS	***
	III			NS	***			***	***			***	***			NS	***
	IV				**				NS				*				***
35	I	NS	NS	NS		*	NS	***		NS	NS	*		NS	**	**	
	II		NS	NS			NS	***			*	NS			*	NS	
	III			NS				NS				**				NS	
45	I	NS	NS	NS		NS	NS	*		*	NS	**		NS	NS	*	
	II		*	**			*	**			**	NS			NS	NS	
	III			*				***				**				NS	

Legend for forest stands : I. *Terminalia-Shorea*, II. *Tectona*, III. *Diospyros-Anogeissus*, IV. *Shorea-Buchanania*, V. *Butea*.
Level of significance : * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS Not significant.

Tabl. IV : Summary of statistical significance (by t test) of difference between mean values of exchange cations (Calcium, Magnesium and Potassium) and available Phosphorus of corresponding soil depths under five stands of tropical deciduous forests at Varanasi.

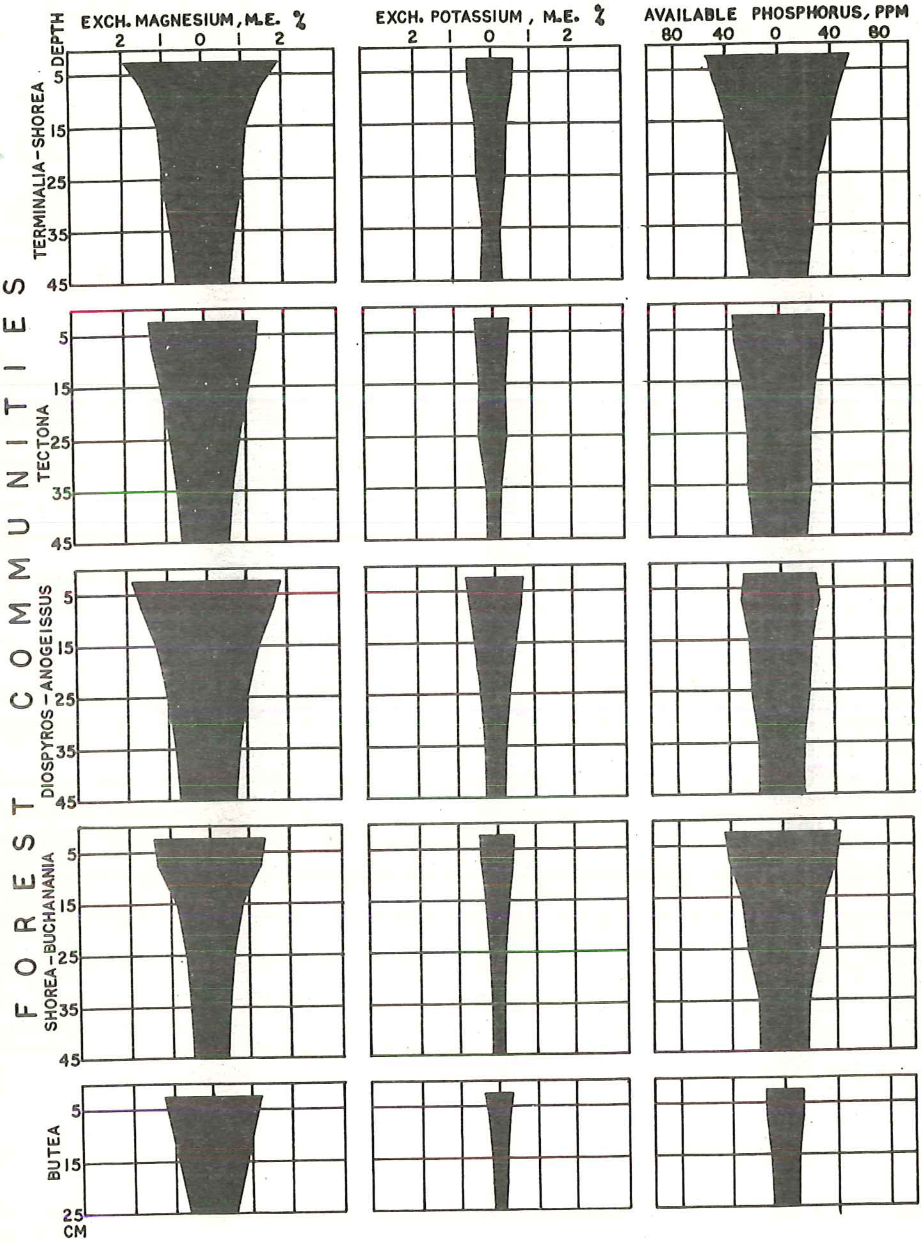

Fig. 3 : Exchangeable magnesium and potassium, and available phosphorus contents at different depths in soils under five stands of tropical deciduous forests. Values for each depth are means derived from data of five pits in each stand.

In the first 15 cm layer of soil the exchangeable calcium content of *Terminalia-Shorea* stand is significantly higher, but at greater depths its amount drops to the level of other stands (Tabl. IV). The difference between exchangeable calcium content of soils of *Tectona* and *Diospyros-Anogeissus* stand is insignificant, but both show distinctly higher content than *Shorea-Buchanania* stand in the upper 7.5 cm layer. The calcium content of *Butea* stand soil is evidently much less than all other stands.

Exchangeable Magnesium

The amount of exchangeable magnesium, which is next to calcium in proportion, ranges between 2.48 $\pm$ 0.71 to 3.85 $\pm$ 0.99 m.e. % in surface layer (Fig. 3). At deeper layers its amount decreases upto one half to one third of that in the surface layer.

Comparatively higher exchangeable magnesium content occurs in the soil of *Terminalia-Shorea* and *Diospyros-Anogeissus* stands (Tabl. IV). In the case of *Tectona* stand although the mean content is much less, due to large variations within each stand, almost throughout the profile it is not significantly different from *Terminalia-Shorea* and *Diospyros-Anogeissus* stands. The amount of exchangeable magnesium in the surface layers of *Shorea-Buchanania* and *Butea* stands is only slightly less than the other three stands, but at greater depths the difference is significantly increased. However, the magnesium status of soils is comparable under *Shorea-Buchanania* and *Butea* stands.

Exchangeable Potassium

The exchangeable potassium in surface soils varies between 0.73 $\pm$ 0.15 to 1.47 $\pm$ 0.32 m.e. % (Fig. 3). The soil profiles of all the stands show a decrease in exchangeable potassium with depth, but in contrast with calcium and magnesium the increase is more gradual.

The mean exchangeable potassium contents of soil of *Diospyros-Anogeissus* stand is higher than the *Terminalia-Shorea* stand throughout the profile, but the differences between means are statistically insignificant due to wide profile-to-profile variations (Tabl. IV). *Diospyros-Anogeissus* stand is significantly richer in soil potassium than *Tectona*, *Shorea-Buchanania* and *Butea* stands at all depths. Potassium status of soil of *Terminalia-Shorea* stand, although indistinguishable from *Tectona* and *Diospyros-Anogeissus* stands, is distinctly higher than that of *Shorea-Buchanania* and *Butea* stands. *Tectona* and

Shorea-Buchanania stands do not differ significantly in this regard. Although upper 7.5 cm layer of soil of *Butea* stand contains almost the same amount of potassium as the *Tectona* and *Shorea-Buchanania* stands, at greater depths its amount decreases considerably to become statistically significant.

Available Phosphorus

The available phosphorus content of the surface soil varies between 29 ± 8 to 109 ± 27 ppm (Fig. 3). Like most of the other nutrients studied, the amount of phosphorus also decreases with depth to about half of the amount at the surface.

In the upper 25 cm layer of the soil the amount of available phosphorus in *Terminalia-Shorea* stand is significantly higher than *Tectona* and *Diospyros-Anogeissus* stands (Tabl. IV). However, the difference between means of *Terminalia-Shorea* and *Shorea-Buchanania* stands is not significant, although the mean phosphorus content of the former is higher at all depths. At greater depths (35 - 45 cm) the differences amongst mean phosphorus contents of *Terminalia-Shorea*, *Tectona* and *Diospyros-Anogeissus* stands become insignificant; but that between *Terminalia-Shorea* and *Shorea-Buchanania* stands become significant due to a sharp decrease in the phosphorus content of the latter. Amongst *Shorea-Buchanania*, *Tectona* and *Diospyros-Anogeissus* stands, the mean phosphorus content in the 2.5 - 25 cm layer of the soil is in decreasing order; however, the differences between means are statistically insignificant. The soil of *Butea* stand contains significantly lower amount of phosphorus than all other stands.

DISCUSSION

Physico-Chemical Properties of Soils

Soils under all the stands (studied presently) belong to sandy loam textural class. This is to be expected, since they have been derived mainly from sandstone rocks, which are known to produce rather coarse texture soils (LUTZ and CHANDLER, 1946). Small variations in soil organic matter tend to have profound effects on the physico-chemical properties of coarse textured soils; and this is obviously reflected in the general inverse relationship between organic matter content and bulk density, and the positive relationship between organic matter content and cation exchange capacity, especially in the upper soil layers under these stands. On the basis of data from all the twenty-five profiles from different stands, the statistical analysis yields significant ($P < 0.001$) positive correlation ($\underline{r}$ values from 0.833 to 0.976) between organic matter and cation exchange capacity for soil layers with mean depth varying from 2.5 - 25.0 cm; but the relationship becomes insignificant at deeper layers, probably due to modifying effect of greater accumulation of silt and clay fractions in contrast to relatively decreased amount of organic matter. Higher accumulation of organic carbon in the upper soil layer is also paralleled by distribution pattern of nutrients. This seems to be due to the fact that considerable input of nutrients and carbon to the soil occurs through litter fall (SINGH, 1968) at the surface, which rapidly decomposes during rainy season; however, the humified organic matter and released nutrients are mostly held in the upper soil layers due to limited leaching. Due to differential rates of decomposition of litter of component species (SINGH, 1969b) of the stands, the nutrients are released gradually and are less liable to loss through run off or percolation. The nutrients may also be brought towards surface during subsequent eight months dry period.

Nutrient Storage in Soil

Amongst all the stands, the *Terminalia-Shorea* stand shows maximum organic carbon, nitrogen, calcium, magnesium and phosphorus contents, and cation exchange capacity. The lower extreme is represented by *Butea* stand, while other stands generally occupy intermediate positions. The *Terminalia-Shorea* and *Butea* stands produce maximum and minimum amounts of leaf litter respectively (SINGH, 1968). Soils of *Diospyros-Anogeissus* stand have comparatively high potassium status probably due to the high return of potassium in the leaf litter of *Diospyros melanoxylon* (SINGH, 1969a). The low calcium and high phosphorus contents of leaf litter of *Shorea robusta* is evidently reflected in the status of corresponding nutrients in the *Shorea-Buchanania* stand soil.

Table V shows the estimated amounts of organic carbon and nutrients contained in the soils (upto 30 cm depth in *Butea* stand and 50 cm in others) under different stands. Obviously the maximum accumulation of carbon and nutrients occurs in the soils of *Terminalia-Shorea* stand, and the minimum in *Butea* stand. Generally the order of preponderance of nutrients is as follows :

$$Ca > N > K > Mg > P$$

Forest stands	Organic carbon	Nitrogen	Calcium	Magnesium	Potassium	Phosphorus
TROPICAL DECIDUOUS FORESTS AT VARANASI						
Terminalia-Shorea	89600	8330	13734	1701	2030	476
Tectona	45920	3440	11816	1540	1582	364
Diospyros-Anogeissus	59220	5670	11200	1881	2289	308
Shorea-Buchanania	44800	4060	9660	1232	1365	385
Butea	18240	1800	6608	849	700	96
FOREST ECOSYSTEMS IN OTHER PARTS OF THE WORLD						
Conifers[1]		1639-7781	293-6240	227-328	87-359	5-319
Hardwoods[1]		1300-7476	269-8260	156-301	119-329	4-463
Mixed tropical forest (Africa)[2]		4587	2573	369	649	13
Tropical forest (South America)[3]			551	537	50	169

1. OVINGTON (1962); Soil sampling depth 60 - 70 cm.
2. GREENLAND and KOWAL (1960); Soil sampling depth 30 cm.
3. ODUM and PIGEON (1970); Soil sampling depth 50 cm.

Tabl. V : Estimated organic carbon and nutrient storage (kg/ha) in soils of different forest ecosystems.

For comparison the table V also includes values of corresponding nutrients in soils of temperate forests in Europe (OVINGTON, 1962) and wet tropical forests in Africa (GREENLAND and KOWAL, 1960) and South America (ODUM and PIGEON, 1970). The range of storage of nitrogen and phosphorus is comparable in the tropical and the temperate (mineral portion only) forest soils. However, the accumulation of exchangeable bases appears to be greater in the tropical deciduous forest soils than the forests of temperate as well as wet tropical forests.

Nutrient Storage in Ecosystem

The *Shorea-Buchanania* stand typically represent the tropical deciduous forest ecosystem on comparatively deeper soils with plain topography. Several such stands have been studied at nearby locations in Varanasi Forest Division by SHARMA (1971) and SINGH (1974). Using their

Compartment	Nitrogen	Phosphorus	Calcium
1. Storage in Tree biomass (Bole + Branch + Leaf + Root)	383	29	915
2. Storage in litter layer (Summer maximum)	21	13	32
3. Storage in soil (50 cm depth)	4060	385	9660
Total	4464	427	10607

1. Storage in Trees : N and P values from SINGH (1974); Ca estimated using 1.7 % concentration in tree parts (DESH BANDHU, 1971) and biomass figures of SINGH (1974).

2. Storage in litter from SINGH (1968).

Tabl. VI : Nutrient storage (kg/ha) in tropical deciduous forest ecosystem typified by *Shorea-Buchanania* stands in Varanasi Forest Division.

figures for nutrients in tree biomass, the storage pattern of few nutrients in different compartments of the ecosystem has been shown in table VI. Soil compartment is evidently the main reservoir of nutrients, accounting for more than 90 % of the total nutrient storage in the ecosystem. This situation is in sharp contrast with that occurring in a tropical rain forest (ODUM and PIGEON, 1970), where the major portion of the nutrient capital is locked up in the tree biomass. In a tropical deciduous forest ecosystem, if an adequate plant cover exists, the primary productivity is mainly limited by relative scarcity of water, rather than the nutrients which seem to be plentiful in the soil.

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