BULL. BOT. SURV. INDIA
Vol. 8, No. 2: pp. 108-116, 1966

STUDIES IN THE FOLIAR ANALYSIS OF SAL (*SHOREA ROBUSTA* GAERTN. F.) AND THE PHYSICO-CHEMICAL STATUS OF THE UNDERLYING SOILS IN MADHYA PRADESH*

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ABSTRACT

The paper describes the foliar analysis of sal (*Shorea robusta* Gaertn. f.) and the physico-chemical status of soils under the respective sal forests of Madhya Pradesh.

The soils are fresh, immature to leached down ones. The best growth of sal, as determined by *Relative Growth Index* (RGI—a new concept) is base poor, leached-down sandy loams. Coarse, fresh and thin soils under sal climate have poor growth of the species; and medium growth is registered in comparatively base richer soils.

The soils are discussed to have been derived so by the process of 'laterisation' under the forest floor and the existing climate.

Further, foliar analysis confirms the chemical status of the soils and reveals that sal is not a heavy demander of soil bases.

Sal (*Shorea robusta* Gaertn. f.), belonging to the family Dipterocarpaceae, is a semi-evergreen timber tree of India. In the country it occurs in two belts; one in north (sub-Himalayan) and the other in Madhya Pradesh. Good amount of work has been done on some important aspects of ecology of the sub-Himalayan sal. Special mention may be made of the investigations by Puri (1955, 60), Bhatnagar (1957), Seth and Bhatnagar (1959, 60), Khan (1961) and Seth *et al.* (1963). However, no systematic ecological studies have been done so far on sal in Madhya Pradesh. Puri (1953, 57) discussed some problems in the ecology of the species in the state and suggested detail studies on nutrition of the tree.

To better understand the physico-chemical relationships between plants and underlying soils, Lundegårdh (1935, 38) suggested "Triple analysis" method based on the analysis of plants, soil and subsoil. According to Gilbert (1950) the proportion of an element in the ash is not an absolute indication of its relative value to the plant but it usually indicates the bases available to the plant from the soil. However, if quantity of exchangeable bases from soil and their respective proportion in parts of overlying plants are analysed, it may reveal to some extent the chemical requirements of plants. Fruitful studies on these lines, conducted in the forests of Madhya Pradesh, pertain to *Tectona grandis* Linn. (Bhatia, 1954), *Boswellia serrata* Roxb. (Sharma, 1955) and *Anogeissus latifolia* Wall. (Joshi, 1960).

In view of this an attempt has been made to study the physico-chemical status of soils under sal and proportion of the same elements in foliar ash of the corresponding sal trees. The studies have been confined to Madhya Pradesh (formerly called as Central Provinces), India. The different sal forest communities of the state have already been described elsewhere (Jain, 1958). Likewise, the climate of the area too has been given by the authors (1960).

In Madhya Pradesh, sal occurs in the eastern parts interrupted by Chhattisgarh plains. An outlier is also found at Pachmari in Hoshangabad division.

METHODS OF STUDY

At least five pits (one m deep × 1.5 m × 0.75 m) were dug in each sal forest community of Madhya Pradesh. Soil samples were collected from 5, 15, 45 and 90 cm depth. In addition to this about 20 soil samples were also collected from every community from a depth of 5 cm after removing litter and undecomposed matter.

Mature leaves of sal were sampled (at least 10 from each community) from the respective forests within a period of one month.

Soil samples were analysed for pH, total nitrogen, organic carbon and exchangeable elements like calcium, magnesium, phosphorous and iron. Leaves were analysed for ash, silica, total nitrogen,

* The work was conducted at Government Science College, Jabalpur.

calcium, magnesium and phosphorous contents. Methods of soil and leaf analysis were those of Loomis and Shull (1937), Piper (1947), Robinson, McLean and Williams (1929) and Yoe (1928).

Soil texture was determined by mechanical separation; and pH was estimated in 1:5 solution by Beckman's pH meter using hydrogen electrode.

PRESENTATION OF DATA AND INTERPRETATION OF RESULTS

I. Geology of Madhya Pradesh and Sal Growth: In Madhya Pradesh sal has been observed on all lithology from the oldest Archeans to Recent deposits with the exception of Vindhyan sandstones (Himalayan Puranas). Table I gives the different rock types under sal forests of the state. The table dissuades to seek any correlation between rock type and sal distribution. This is in confirmation with the views expressed by Champion (1933), Hewetson (1953) and Khan (1953).

II. Soils: In general soils under sal forests are sandy in texture and red to dark brown in colour. Physical and chemical analysis of the top soils and those of pit profiles (soil-tessera) are presented in the appendices 1 to 4 and summarised in Figs. 1 to 3.

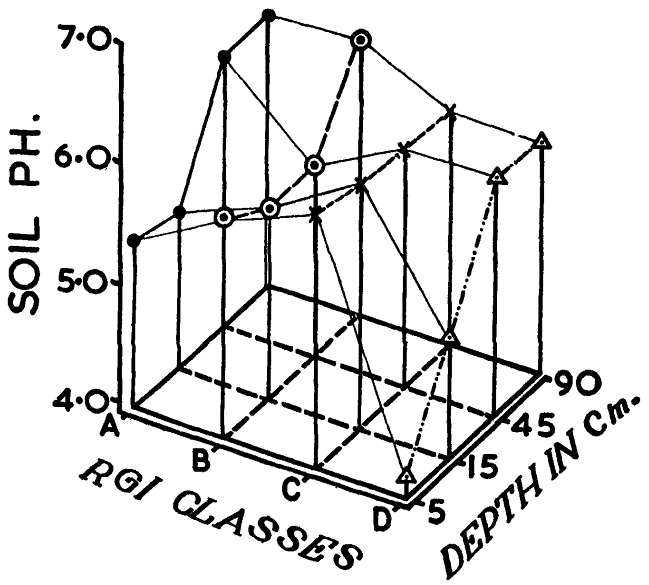


Fig. 1. Variations in soil pH with depth in the profiles under the four RGI class sal (*Shorea robusta* Gaertn. f.) forests of Madhya Pradesh.

Relative Growth Index (RGI): Although characters like number (abundance), coverage and frequency are distinct attributes of community structure yet a number of different methods have been suggested in which these and other characters may

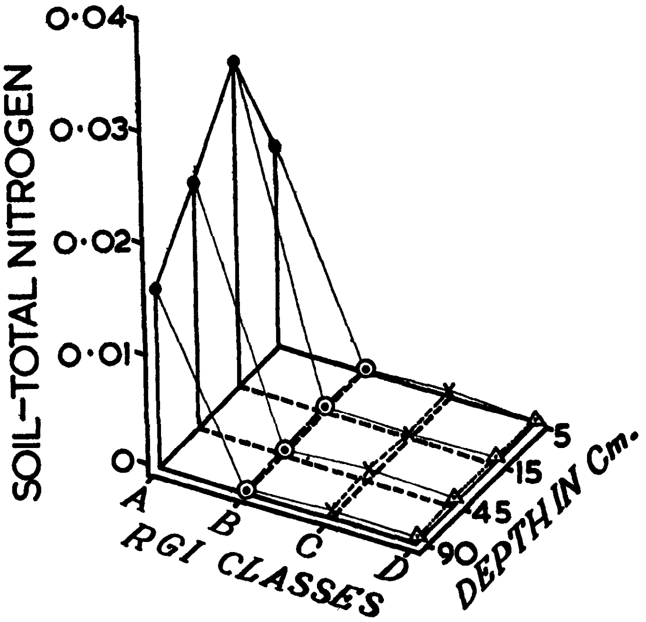


Fig. 2. Variations in total nitrogen with depth in the soil profiles under the four RGI class sal forests.

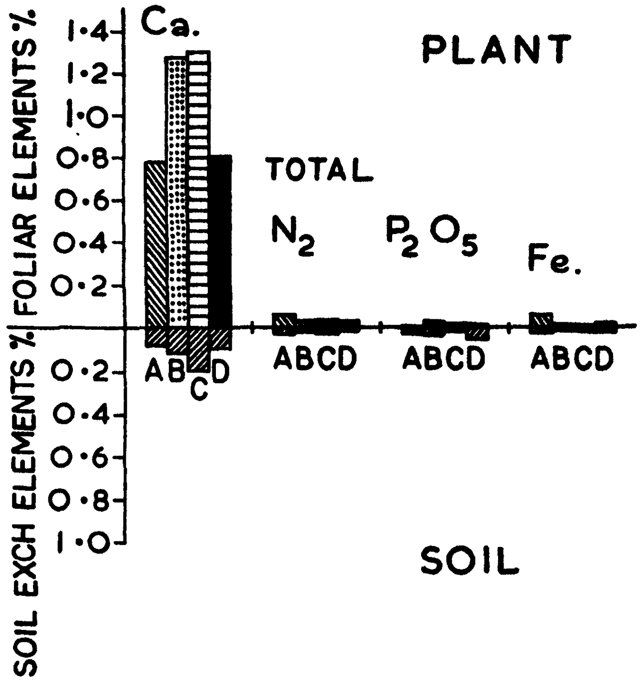


Fig. 3. Interrelations between total nitrogen and exchangeable bases of soils under the four RGI classes of *Shorea robusta* and the corresponding foliar elements in the tree.

be combined to facilitate or enhance description (*cf.* Braun Blanquet, 1932; Dansereau, 1946; Curtis, 1947; Curtis and McIntosh, 1951; Cottam, 1949; and Cain and Castro, 1959). In all these studies

TABLE I

Sal forest communities, growth qualities (after Maitland, 1924) and observed RGI classes in different localities of Madhya Pradesh with respect to lithology.

Lithology	Locality and forest division	C. P. sal quality after Maitland (1924)	RGI Classes	Observed Plant Community
IGNEOUS:				
1. Granite	(a) Banjar Range, Mandla	II	B	Sal—*Terminalia-Diospyros*
	(b) Mangli, Motinala, Mandla	IV	D	Sal—*Ougeinia*
2. Basalt (Deccan trap)	(a) Aamer, Mandla	IV	D	Sal—*Anogeissus*
	(b) Bikrampur, Mandla	IV	D	Sal—*Diospyros*
	(c) Motinala, Mandla	IV	D	Sal—*Ougeinia*
	(d) Sarai, Dindori, Mandla	II	A	Sal—*Terminalia*
SEDIMENTARY:				
1. Sandstone	(a) Sitapur, Rewa	III	D	Sal—*Ougeinia*
	(b) Baikuntpur, N. Bilaspur	IV	C	Sal—*Buchanania*
2. Conglomerate	Pachmari, Hoshangabad	III	D	Sal—*Buchanania-Anogeissus*
3. Limestone and shaly limestones (Metamorphic mixed)	(a) Tigri Pagar, E. Bastar	I	B	Sal—*Syzygium*
	(b) Machkot, E. Jagdalpur, Bastar	I	B	Sal—*Anogeissus*
	(c) Dhanpungi, E. Bastar	II	C	Sal—*Madhuca*
METAMORPHIC:				
1. Quartzite & Slate	Kharka (Nagri), S. Raipur	I	A	Sal—*Tectona-Cassia*
2. Banded Gneissic complex	(a) Dongatola, S. Raipur	I	A	Sal—*Carthamus*
	(b) Karka, Risgaon, S. Raipur	I	A	Sal—*Syzygium*
	(c) Kanha Kisli, Mandla	II	B	Sal—*Terminalia*
	(d) Risainath, S. Raipur	III	D	Sal—*Terminalia*
3. Mica-Schist	Muki, Balaghat	II	C	Sal—*Terminalia*
RECENT:				
Alluvium & Clay Schist	Lormi, Bilaspur	III	B	Sal—*Diospyros-Terminalia*

abundance (or density), coverage, frequency or their relative values have been employed. In the present studies it was found desirable to include also the average height of the trees, because of timber value. The relative growth index (RGI) so obtained has been formulated as follows:

$$RGI = \frac{C}{D} \times \frac{Ht}{100} \times \frac{F}{100}$$

where,

C—Average canopy cover % all plants of a species per quadrat

D—Average Density per species per quadrat

Ht—Average height in metres

F. — % frequency

By this formula, the RGI of sal trees only were calculated in all the sal forest communities of the state occurring in 15 forest ranges. (*cf.* table II). The RGI values were then grouped in four classes:

RGI :	1 to 3 — class	D
	3 to 6 — „	C
	6 to 9 — „	B
	Above 9 — „	A

For details of phyto-sociological characters of the communities reference may be made to Jain (1958).

A. "Soil Profiles" (or SOIL-TESSERA) STUDIES:

Comparing the soil-tessera under the four RGI classes the following tendencies are noted:

(*a*) *pH Value*: Invariably in the soil-tessera examined the pH has been found to increase slightly with depth. Only in class D soil-tessera at Baikuntpur it remains somewhat constant. Although there is no detail information regarding the behaviour of Indian forest soils yet it appears that since class A forests are under heavier rainfall with closed canopy there may be more of leaching than in class D forests. Furthermore, since class D forests do not have much closed shades (which is responsible for maintaining greater humidity on forest floor) the extensive process of evaporation of soil moisture may bring about back capillary action and thus increase the base status as well as pH of the upper layers.

(*b*) *Organic Carbon*: It decreases with depth in all the soil-tesseras studied. Organic carbon is more in top layers in class A but suddenly decreases with depth; again demonstrating fast decomposition and leaching in the soils.

(*c*) *Total Nitrogen*: Like organic carbon it also decreases with depth. The highest values have been recorded in class A soil-tesseras.

Jenny (1929) has shown that climatic factors like mean annual temperature has correlation with average total nitrogen content of soils. This may account for the high total nitrogen content in class A 'profiles' where well developed canopy of sal

TABLE II

Calculations for Relative Growth Index of sal (Shorea robusta Gaertn. f.) *examined in different localities of Madhya Pradesh*

Size of quadrat: 6.1 m. square Dates: February to June, 1957

Locality (for forest community refer table I)	Average Abundance (D)	Average % Cover (C)	Average Height in m. (Ht)	C/D	$\frac{C}{D} \times \frac{Ht}{100}$ =(x)	$\frac{(x)\times(F)}{100}$	RGI classes
1. Kharka, S. Raipur	1.0	88.3	31.57	88.30	27.88	27.88	A
2. Karka, S. Raipur	1.2	90.0	35.36	75.00	26.52	26.52	A
3. Dongatola, S. Raipur	2.6	88.3	28.95	33.20	9.61	9.61	A
4. Kanha Kisli, Mandla	1.2	44.0	24.08	36.60	8.78	8.78	B
5. Machkot, E. Bastar	3.0	90.0	25.91	30.00	7.77	7.77	B
6. Lormi, Bilaspur	2.0	68.7	21.33	34.35	7.33	7.33	B
7. Tigri Pagar, E. Bastar	4.0	92.5	28.95	23.12	6.69	6.69	B
8. Muki, Balaghat	6.1	85.5	21.82	14.02	4.36	4.36	C
9. Dhanpunji, E. Bastar	3.5	70.0	20.57	20.00	4.11	4.11	C
10. Baikuntpur, N. Bilaspur	1.6	43.3	14.20	27.06	3.83	3.83	C
11. Aamer, Mandla	3.3	60.6	14.20	18.40	2.61	2.61	D
12. Pachmari, Hoshangabad	6.2	72.0	17.68	11.60	2.04	2.04	D
13. Risainath, S. Raipur	7.0	70.0	18.29	10.00	1.83	1.83	D
14. Bikrampur, Mandla	4.0	60.0	10.67	15.00	1.60	1.60	D

(F)—% frequency of occurrence

causes deep shade and local temperature is lesser than the forests of open canopy.

(*d*) *Exchangeable calcium*: It increases in the first 15 cm followed by a decrease and again increases at 90 cm depth. This tendency is found in almost all soil-tesseras.

Lutz and Chandler (1955) have noted that in temperate climate calcium usually increases in lower horizon. Taylor *et al* (1935), Chandler (1937) and Coile (1939) adduced that deep rooted plants frequently build up the concentration of lime in the surface soil as a result of contribution made by leaf fall annually. In our studies the increase of calcium in first 15 cm may be due to decomposition of litter; the subsequent decrease may be due to leaching; and final increase may be due to concentration of the element.

(*e*) *Iron*: The proportion of soluble iron is more in class A soil-tesseras. It decreases with depth. This fact further illustrates the mode of translocation of solutes in the soil.

B. Top Soils: The physical and chemical characters of the top 5 cm soils under different RGI classes are given in appendices 2 & 3.

Edaphology: An attempt has been made here to correlate the chemical and physical characters of the top soils with the corresponding RGI values of sal. The soils under different classes can be characterised as follows:

(*i*) *pH*: It decreases from class A to D possibly due to annual return of bases in class A by leaf fall and its rapid decomposition.

(*ii*) *Organic Carbon*: Organic carbon increases slightly from class A to C followed by a decrease in class D.

(*iii*) *Total nitrogen*: It behaves similar to organic carbon.

(*iv*) *Exchangeable calcium*: It increases from class A to C followed by a decrease in class D. This decrease may be due to fresh and coarse nature of soils under this class.

(*v*) *Exchangeable iron*: Exchangeable iron decreases sharply from class A to C followed by a very slight increase in class D. It may be pointed out here that much emphasis can not be put on iron content since in the sal tract of the state a number of iron ores are present which may hamper the true characters of the immature soils.

(*vi*) *Exchangeable magnesium* and P_2O_5 follows a trend similar to calcium.

From the above description it may be concluded that class A soils are generally poorer in bases and are more leached than those of other classes. They are sandy loams.

Class D soils are fresh and sandy (sand above 70%), poorer in bases and lower in pH.

Soils under classes B and C are richer in bases and appear to be immature.

III. Foliar Analysis: Leaf analysis of the four RGI classes is presented in appendix 4.

A comparison of soil and leaf analysis (Fig. 3) reveals that there is a direct correlation between soil pH and exchangeable calcium with the foliar ash and foliar calcium (*see also* Jain, 1960).

Similarly soil nitrogen and foliar nitrogen are directly correlated. Direct correlations have also been noted between soil exchangeable iron, magnesium and P_2O_5 and the corresponding foliar contents.

From the above findings it could be argued that sal is not a very heavy demander of soil bases.

DISCUSSION

The foregoing description of the soils under sal in Madhya Pradesh clearly suggests that they are leached down soils to a certain extent and that leaching is more under class A forests. Interest, therefore, arises as to the mode of soil development under sal forests.

Podsolisation does not occur in tropical countries like India, as observed by Misra and Puri (1954). Only weakly podsolised soils with high base status on the surface have been found in the Himalayas under oak and conifers (*cf.* Puri, 1960). The process of calcification occurs under grassland communities and hence will not occur under sal. As given by Oosting (1956), laterisation generally occurs under humid and hot climate and where the surface is not covered by tall vegetation. Lateritic soil has been, however, recorded by Puri (1953) under sal in Madhya Pradesh at Supkhar (Balaghat) and at a few other places. He has considered these laterites as the forest soils of late glacial period.

What laterisation means?

Initially laterisation brings about rapid liberation of bases such as calcium, sodium, potassium, etc.; consequently the upper soil is nearly neutral. This neutral solution favours leaching of even silica, and iron and aluminium are left behind. Fox (1936) has noted the process of desilicification to occur under laterisation even in quartz. As a result of progressive leaching the base content is sharply reduced in the upper soils and when the hydrolysis of primary minerals is complete the acid condition develops. This is termed as 'laterite'.

Mode of soil development under sal:

Barshad (1956) has observed that to evaluate the development of a soil profile it is necessary to define and evaluate the initial state of the soil material at each horizon and to compare it with the initial state of the parent material. According to him once a initial state is established, the degree of development can readily be determined in terms of minerological, chemical and physical changes that occur in the transformation of the parent material to soil material. In view of this concept soil-tesseras under sal may be compared with the characters of the parent rocks. The soils of Pachmari and Baikuntpur divisions are situated on sedimentary rocks and those of Kharka (Nagri) in S. Raipur division on quartzites of metamorphic origin. Of the two rocks, pH has been observed by Puri (1953) to vary between 7.3 to 7.7 and 8.8, respectively. Thus the two rocks are not acidic. However, the soils derived from these rocks under sal are slightly acidic. Puri (1960) opines that soils develop different composition depending upon the conditions for the process of decomposition. The plants usually develop, under humid conditions, slightly acidic soils like the present case; but under teak (*Tectona grandis* Linn.) pH is somewhat higher (*cf.* Bhatia, 1954). This one example regarding pH value of parent rocks and soils under sal may indicate clearly that upon development soil hardly retains the characters of the parent rock and that factors of vegetation and climate are paramount in soil maturation under similar relief (*cf.* Pandeya, 1959, 63).

Returning to characters of the soil-tesseras with reference to those under class A sal forests it would appear that the soils are perhaps 'laterite type'. This concept is as followed by Pendleton (1936 and 1940) and more liberally adopted by Lutz and Chandler (1955). According to latter authors term 'laterite' has been applied to soils having top horizon with the incorporated organic matter and below this is reddish leached soil which rests on very highly weathered parent material. Such laterite soils (lateritic and laterite soils have been distinguished on the basis of silico-alumino ratio) have been further classified into six zonal types in the forested warm temperate and tropical regions.

From the foregoing discussion the soils under sal may be tentatively called as 'laterite soils'. These soils are doubtless not of glaciation age for the same never occurred at least in eastern and south-eastern Madhya Pradesh where sal exists.

If we presume the above concept of the mode of soil development under sal then the status of its soils can be understood to some extent. It may be concluded that sal develops its own soil, gradually, under the process of laterisation and that finally the soil is base poor and leached out laterite one in which best growth of sal occurs. Further since some soils under sal have attained partial to full maturation it will not be inappropriate to call the soil-tesseras here as Soil Profiles.

ACKNOWLEDGEMENTS

We are grateful to Prof. R. Misra, F.N.I., Head of the Department of Botany, Banaras Hindu University, Varanasi, for constant encouragement and kind suggestions during the course of the present study and to Dr. G. S. Puri, F.N.A.Sc., Ghana, for helpful criticisms and going through the manuscript.

LITERATURE CITED

BARSHAD, F. E. *Chemistry of the soil.* ACS mono. 126. Reinhold Publishing Corp., New York, 1955.

BHATIA, K. K. *Factors in the distribution of teak (Tectona grandis Linn.) and a study of teak forests in Madhya Pradesh.* Doctoral thesis, Saugar Univ., 1954.

BHATNAGAR, H. P. Mineral constituents of foliage of sal (*Shorea robusta*) of different quality classes. *Indian For.* 83 (11) : 647-650, 1957.

BRAUN BLANQUET, J. *Plant Sociology—The Study of Plant Communities.* Translated by Fuller, George D. and Henry S. Conard. MacGraw-Hill Book Co., Inc., New York and London, 1932.

CAIN, S. A. AND G. M. DE OLIVETRA CASTRO. *Manual of Vegetational Analysis*. Harper & Bros., Publishers, New York, 1959.

CHAMPION, H. G. Regeneration and Management of sal (*Shorea robusta*). *Indian For. Mem.* 19 : 16, 1933.

CHANDLER, R. F. JR. Certain relationships between the calcium and oxalate contents of foliage of certain forest tree. *J. agric. Res.* 55 : 393-396, 1937.

COILE, T. S. Forest soil fertility : Influence of stand composition on nitrogen transformation in the surface soil. *Proc. Soil Sci. Soc. Amer.* 3 : 225-229, 1939.

COTTAM, G. The phytosociology of an oak woods in South-Western Wisconsin. *Ecology* 30 : 271-287, 1949.

CURTIS, J. T. The palo verde forest type near Gonivavas, Haiti and its relation to the surrounding vegetation. *Caribbean For.* 8 : 1-26, 1947.

—— AND R. P. MCINTOSH. An upland forest continuum in the prairie-forest border region of Wisconsin. *Ecology* 32 : 476-496, 1951.

DANSEREAU, P. Os planos da Biogeografia. *Rev. Brazil Geogr.* 8 : 189-211, 1946.

FOX, C. Buchanan's laterite of Malabar and Kanara. *Rec. geol. Surv. India* 69 : 389-422, 1936.

GILBERT, F. A. *Mineral nutrition of plants and animals.* Univ. Oklahoma Press, Norman, 1950.

HEWETSON, C. F. A discussion on the ecological position of sal in Central India. *Indian For.* 79 : 310-320, 1953.

JAIN, N. K. Composition of some sal (*Shorea robusta* Gaertn. f.) forests of Madhya Pradesh. *Proc. nat. Acad. Sci. India* 28 (B-II) : 130-154, 1958.

—— Calcium relations of sal. *J. Indian bot. Soc.* 39 : 357-372, 1960.

JENNY, H. Relation of temperature to the amount of nitrogen in soils. *Soil Sci.* 27 : 169-188, 1929.

—— AND S. P. RAYCHOUDHURY. *Effect of climate and cultivation on nitrogen and organic matter reserves in India.* Coun. Sci. Indust. Res., New Delhi, 1960.

JOSHI, S. R. *Autecology of Anogeissus latifolia* Wall. Doctoral thesis, Jabalpur Univ., 1960.

KHAN, M. A. W. Effects of geological formations on the distribution of sal. *Indian For.* 79 : 462-474, 1953.

——*et al.* Ecology of sal. *Proc. 10th Silvic. Conf.* : 120-131, 1961.

LOOMIS, W. E. AND C. A. SHULL. *Methods in Plant Physiology.* MacGraw-Hill Book Co., New York, 1937.

Lundegârdh, H. Leaf analysis as a guide to soil fertility. *Nature* 151 : 310-311, 1934.

——The triple analysis method of testing soil fertility and probable crop reaction to fertilisation. *Soil Sci.* 45 : 447-454, 1938.

LUTZ, H. C. AND R. F. CHANDLER. *Forest Soils.* John Wiley & Sons., New York, 1955.

MAITLAND, V. K. Volume tables for teak (*Tectona grandis*) and sal (*Shorea robusta*) forests for Central Provinces. *Indian For. Rec.* 11 : 215-222. 1924.

MISRA, R. AND G. S. PURI. *Indian Manual of Plant Ecology.* The English Book Depot, Poona, 1954.

OOSTING, H. J. *The Study of Plant Communities.* W. H. Freeman & Co., San Francisco, 1956.

PANDEYA, S. C. The Concept of Maturation in Indian Soils. *Proc. nat. Acad. Sci. India* 29 (B-V) : 262-271, 1959.

——Soil-vegetation relationships in Central India. *Proc. nat. Acad. Sci. India* 33 (B-I) : 63-66.

——AND N. K. JAIN. Edaphic and climatic factors in determining distribution patterns of plants in Madhya Pradesh forests with special reference to sal (*Shorea robusta* Gaertn. f.) *Mem. Indian bot. Soc.* 3 : 35-42, 1960.

PENDLETON, R. L. On the use of term laterite. *Bull. Amer. Soil Surv. Ass.* 17 : 102-108, 1936.

——Further notes on laterite. *Proc. 6th Pacific Sci. Cong.* 4 : 975-981, 1940.

PIPER, C. S. *Soil and Plant Analysis.* Univ. Adelaide Press, Adelaide, 1947.

PURI, G. S. Problems in the ecology of sal (*Shorea robusta*) in Madhya Pradesh. *Bull. bot. Soc. Univ. Saugar* 5 : 24-31, 1953.

——The foliar ash content in some *Shorea robusta* trees of different quality classes and its relation with soil calcium in some forests of India. *Indian For.* 81 (2) : 98-102, 1955.

——The ecology of sal (*Shorea robusta*) in Madhya Pradesh. *J. Indian bot. Soc.* 36 : 591, 1957.

——*Indian Forest Ecology.* 2 vols. Oxford Press, New Delhi, 1960.

ROBINSON, G. W., W. MACLEANS AND RICE WILLIAMS. *The determination of Organic carbon in Soils.* University of North Wales, Bangor.

SHARMA, V. B. *Autecology of Boswellia serrata* Roxb. Doctoral thesis, Saugar Univ., 1955.

SETH, S. K. AND H. P. BHATNAGAR. Soil suitability index for sal (*Shorea robusta*) regeneration. *Indian For.* 85(11) : 631-640, 1959.

——AND——Interrelations between mineral constituents of foliage, soil properties, site quality and regeneration status in some *Shorea robusta* Forests. *Indian For.* 86 (10): 590-601, 1960.

——, O. N. Kaul AND A. C. GUPTA. Some observations on nutrition cycle and return of nutrients in plantations at New Forest. *Indian For.* 89 (2) : 90-97, 1963.

TAYLOR, E. M., I. D. MAHENDRU, M. L. MEHTA AND R. C. HOON. A study of the soils in the hill areas of the Kullu forest division, Punjab. Pt. I. An investigation of soil profiles under deodar, spruce, blue pine and chir. *Indian For. Rec. (N. S.) Silvic.* 1 : 289-346, 1935.

YOE, J. H. *Photometric Chemical Analysis.* John Wiley & Sons., Inc., New York, 1928.

APPENDIX I

Chemical characters of soil-tesseras under the four RGI classes of sal in Madhya Pradesh (Average values; in percentage of dry weight)

Locality	RGI class	Depth in cm	pH value	Organic carbon	Total nitrogen	Exch. calcium	Exch. iron
SOUTH RAIPUR:		5	5.40	2.12	0.018	0.090	0.0072
Karka,	A	15	5.30	0.17	0.029	0.090	0.0263
Risgaon Range		45	6.25	0.27	0.022	0.079	0.0198
		90	6.25	0.27	0.017	0.090	0.0032
EAST BASTAR:		5	5.65	1.68	0.002	0.065	0.0016
Machkot,	B	15	5.60	0.57	0.005	0.090	P
East Jagdalpur		45	5.60	0.10	0.003	0.036	0.0272
		90	6.30	0.21	0.002	0.060	P
BILASPUR:		5	6.20	2.86	0.006	0.060	P
Baikuntpur,	C	15	6.06	1.10	0.003	0.075	P
Koria		45	6.00	1.77	0.005	0.054	0.0069
		90	5.95	0.36	0.006	0.035	P
HOSHANGABAD:		5	4.20	1.34	0.003	0.027	0.0085
Pachmari	D	15	5.00	2.19	0.005	0.054	0.0317
		45	6.00	2.03	0.006	0.030	0.0246
		90	5.95	1.36	0.005	0.024	0.0080

P—Values in less than four decimal places.

APPENDIX II

Analysis of the texture of top soils from different sal forests of Madhya Pradesh. (Average values; in percentage of dry weight)

Locality	RGI class	Sand %	Silt %	Clay %	Sand/Silt ratio
SOUTH RAIPUR: Nagri and Risgaon ranges (Kharka & karka)	A	60.52	29.47	7.93	2.05
BILASPUR: Lormi range	B	63.50	29.87	6.10	2.12
EAST BASTAR: E. Jagdalpur range (Machkot)	B	56.09	18.37	23.76	3.04
NORTH BILASPUR: Baikuntpur range	C	54.79	30.28	13.79	1.81
BALAGHAT: Muki range	C	75.55	17.50	6.45	4.31
HOSHANGABAD: Pachmari range	D	74.20	20.45	4.97	3.62
MANDLA: Aamer and Bikrampur	D	86.03	11.00	3.23	7.82

APPENDIX III

Chemical characters of top soils under different sal forests of Madhya Pradesh. (Values, expressed in percentage of dry wt. of soil, are averages of each stand examined)

Locality	RGI class	pH	Organic carbon	Total nitrogen	Exch. calcium	Exch. iron	Exch. magnesium	Exch. P_2O_5
S. RAIPUR:								
Dongatola	A	6.00	0.490	0.0293	0.084	0.0180	0.0057	0.0270
		5.65	2.050	0.0308	0.060	P	—	—
		6.50	1.080	0.0231	0.126	0.0129	0.0057	0.0270
Kharka	A	6.25	0.220	0.0231	0.066	0.0229	0.0140	0.0300
		5.85	1.170	0.0231	0.060	0.0047	0.0052	0.0207
Karka	A	5.40	2.120	0.0185	0.090	0.0072	0.0115	0.0234
		5.75	0.830	0.0178	0.084	P	—	—
		5.45	1.150	0.0262	0.084	P	0.1934	0.0197
		6.05	0.030	0.0246	0.085	0.0482	0.0841	0.0324
E. JAGDALPUR. E. BASTAR:								
Tigripagar	B	5.00	0.580	0.0046	0.060	P	0.0455	0.0088
		5.05	1.630	0.0553	0.055	0.0054	0.0344	0.2225
Machkot	B	5.40	3.340	0.0039	0.084	P	0.0027	0.0178
MANDLA:								
Kanha Kisli	B	6.20	3.090	0.0108	0.238	0.0003	0.0002	P
		6.85	0.189	0.0062	0.129	0.0025	P	P
		5.60	1.545	0.0123	0.109	0.0038	P	P
		6.05	1.544	0.0077	0.139	0.0022	0.0025	P
		6.15	3.213	0.0103	0.159	0.0009	P	P
		6.00	3.770	0.0077	0.075	P	0.0042	0.0120
BILASPUR:								
Lormi, Karisongri	B	5.85	2.010	0.0070	0.120	P	0.0043	0.0606
		6.10	1.310	0.0077	0.132	P	0.0050	0.0347
		6.00	2.290	0.0062	0.132	P	0.0047	0.1113
		5.55	6.760	0.0336	0.048	P	0.0047	0.0013
BALAGHAT:								
Muki	C	5.55	3.440	0.0506	0.056	0.0002	0.0056	0.0017
		6.50	4.080	0.0098	0.084	0.0009	0.0052	0.0016
		5.60	4.440	0.0276	0.086	0.0001	0.0047	0.0013
		5.85	0.930	0.0462	0.050	P	0.0043	0.0013
		5.20	1.680	0.0210	0.162	0.0009	0.1177	0.0013
		5.65	1.770	0.0140	1.484	0.0013	0.0146	0.0013
N. BILASPUR:								
Baikuntpur	C	5.75	0.320	0.0062	0.114	P	0.0004	0.0487
		6.40	4.200	0.0093	0.030	P	0.0005	0.0066
		5.90	3.590	0.0046	0.120	P	0.0045	0.0488
EAST BASTAR:								
E. Jagdalpur, Dhanpunji	C	6.00	0.930	0.0062	0.096	P	0.0059	0.0128
		6.00	1.020	0.0185	0.072	P	0.0037	0.0112
S. RAIPUR:								
Risainath	D	4.70	1.160	0.0200	0.072	P	0.0133	0.0327
		5.70	0.830	0.0208	0.030	P	—	—
		5.65	0.430	0.0308	0.096	0.0008	0.0224	—
MANDLA:								
Aamer	D	5.65	1.480	0.0293	0.180	P	0.0224	0.0411
		5.60	2.920	0.0262	0.192	0.0005	0.1891	0.0787
		5.35	1.330	0.0185	0.156	0.0036	0.0003	0.0017
Bikrampur	D	5.40	1.340	0.0032	0.114	P	0.0037	0.0032
		6.20	3.390	0.0064	0.168	0.0005	0.0027	0.0005
		5.50	1.590	0.0064	0.192	0.0009	0.0013	0.0004
HOSHANGABAD:								
Pachmari Big Fall	D	6.15	2.530	—	0.078	0.0099	0.0011	0.0400
		6.05	2.460	0.0057	0.057	0.0086	0.0011	0.0610
Chhota Mahadeva	D	6.20	1.360	0.0112	0.075	0.0143	0.0024	0.3013
		5.10	1.140	0.0028	0.054	0.0052	0.2095	0.0098
		6.05	2.130	0.0014	0.129	0.0035	0.0016	0.0180
		4.90	0.870	0.0056	0.048	0.0475	0.0037	0.1800
		6.05	2.460	0.0057	0.057	0.0086	0.0011	0.0610

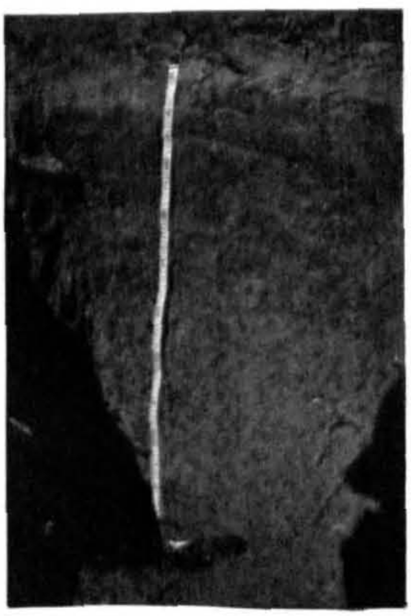
P—Values in less than four decimal places

APPENDIX IV

Sal foliar analysis from different sal forest communities of Madhya Pradesh. (Values, expressed as percentage of dry wt., are averages of each stand)

Locality	RGI class	Ash	SiO_2	Calcium	Nitrogen	Magnesium	P_2O_5	Iron
S. RAIPUR:								
Kharka	A	4.00	1.217	1.334	0.0544	0.0014	0.0020	0.1450
		5.65	0.671	0.119	0.0544	0.0003	0.0016	0.0737
		2.90	0.621	0.633	0.0585	—	—	—
Karka	A	2.60	1.471	0.973	0.0617	0.0006	0.0005	0.0570
		4.40	2.571	0.896	0.0585	0.0008	0.0040	0.0259
		2.70	0.421	0.896	0.0568	0.0008	0.0012	0.0190
		5.75	1.611	0.597	0.0674	—	—	—
E. BASTAR:								
Machkot	B	7.85	1.471	0.836	0.0600	0.0078	0.0024	0.0116
		4.68	0.321	1.134	0.0577	0.0033	0.1023	0.0240
		2.55	0.421	0.075	0.0568	0.0033	0.1023	0.0135
MANDLA:								
Kanha Kisli	B	7.64	1.820	2.208	0.0644	0.0005	0.0065	0.0272
		2.90	0.760	0.716	0.0021	0.0066	0.0078	0.0206
		4.30	1.400	1.194	0.0280	0.0066	0.0055	0.0090
		3.15	0.670	0.897	0.0126	0.0108	0.0027	0.0286
BILASPUR:								
Lormi	B	2.91	0.800	1.104	0.0058	0.0118	0.0261	0.0070
		3.98	0.271	1.104	0.0090	0.0139	0.0245	0.0081
		7.20	0.521	1.522	0.0090	—	—	0.0040
BALAGHAT:								
Muki	C	7.68	1.460	1.624	0.0039	0.0158	0.0217	0.0003
EAST BASTAR:								
Dhanpunji	C	5.12	0.571	0.848	0.0552	—	—	0.0265
		6.50	0.231	1.134	0.0479	—	—	0.0110
BILASPUR:								
Baikuntpur	C	7.16	0.471	2.029	0.0130	0.0117	0.0270	0.0089
		5.76	0.800	1.536	0.0025	0.0097	0.0313	0.0059
S. RAIPUR:								
Risainath	D	3.84	2.021	1.045	0.0544	0.0003	0.0018	0.0475
		4.85	1.521	0.418	0.0958	—	—	—
HOSHANGABAD:								
Pachmari	D	3.36	0.257	0.840	0.0042	0.0015	0.0245	0.0072
Big Fall		3.28	1.977	0.920	0.0028	0.0116	0.0058	0.0011
Chhota Mahadeva	D	3.80	2.377	0.960	0.0045	0.0103	0.0250	0.0032
		2.20	0.577	0.880	0.0056	—	—	—
		3.12	0.576	0.680	0.0038	0.0085	0.0217	0.0321
		3.28	1.977	0.920	0.0028	0.0116	0.0058	0.0011
MANDLA:								
Aamer	D	2.15	0.671	1.075	—	0.0039	0.0015	0.0175
		2.35	0.671	0.460	0.0934	0.0062	0.0100	0.0115
Bikrampur	D	4.75	0.071	0.776	0.0909	0.0041	0.0135	0.0378
		1.56	0.573	0.925	0.0926	0.0016	0.0019	0.0880
		4.20	0.279	0.895	0.0909	0.0017	0.0095	0.1200

A typical soil profile in RGI—A class *Shorea robusta* forests of Madhya Pradesh. Note a thick humus zone merging into dark red extraction zone demonstrating ample leaching of bases leaving behind mostly the hydroxides of iron and aluminium. (S.C.P.)



Soil profile in RGI—C class sal forest of Madhya Pradesh. Note a narrow humus layer and not too deep red coloured extraction zone. (S.C.P.)