Studies on the Heavy Minerals of Some Soils Under *Casuarina equisetifolia* Plantations in India

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Casuarina equisctifolia is an important economic forest species of multifarious uses and has, therefore, evinced considerable interest during the past three decades. Owing to its fast growth and great utility, particularly as a fuel source, large tracts of both inland and coastal areas in India have been put under *Casuarina* plantations. Several studies have been conducted to evaluate the performance of *Casuarina* plantations under varied site conditions and to determine the soil factors which are responsible for good and poor growth of these plantations. Contributions to such studies could be referred to the various workers (GUPTA [2], KHAN and YADAV [4], YADAV et al. [8]). While considerable information on the physical and chemical characteristics of the soils under these man-made forests is available, practically no systematic data on the mineralogical make-up of the soils have been collected, although the nature of the minerals greatly influence the properties and hence the soils' potential fertility status, which has an important bearing on the successful continued growth of the plantations. It was, therefore, desirable to know the mineralogical composition of certain coastal soils bearing *Casuarina equisctifolia* plantations in the States of Andhra Pradesh, Orissa, Karnataka and Tamil Nadu.

Experimental

For the above purpose, field studies were undertaken in some typical areas of the Forest Divisions of Guntur and South Nellore (Andhra Pradesh), Kujang and Konark Forest Ranges (Orissa), Karwar and Honawar Forest Ranges of W. D. Forest Division (Karnataka) and Soolere Kudu village (Tamil Nadu). In all, 14 soil profiles — 7 in Andhra Pradesh, 4 in Orissa, 2 in Karnataka and 1 in Tamil Nadu were examined and soil samples were collected from the profiles for mineralogical studies in the laboratory. The soils are coastal alluvium or sand deposits on almost flat land with a gradual slope towards the sea, modified by the flocculating, sieving and sifting action of the oceanic waters. These soils are dry, structureless and single grained with mottled and gleyed layers at lower depths due to high water table caused by proximity of the sea. The climate of these localities remains warm and humid during most part of the year. In general, the external drainage is slow, but the internal drainage is rapid unless in-

Table 1

Site characteristics and growth status of *Casuarina equisetifolia* plantations in Andhra Prades, Orissa, Karnataka and Tamil Nadu

Locality	Profile No.	Geological formation	Ground water depth, cm	Altitude, m	Year of plantation; growth status
Andhra Prades					
Ponna Series, Sriharikota Range, South Nellore Forest Division	I	Coastal alluvium	Below 30 cm; high in rains	—	1953; very good growth
Kotacheru Series, Sriharikota Range, South Nellore Forest Division	II and III	Coastal sand	Below 1 meter; 30 cm in rains	3.5	1952; mortality high
Sundala Doruvu, Sriharikota Range, South Nellore Forest Division	IV	Coastal sand	Below 2 meters; 90 cm in rains	5.0	1952; good growth
Sundala Doruvu, Sriharikota Range, South Nellore Forest Division	V	Coastal sand	Below 2 meters; 90 cm in rains	5.0	1953; good growth
Muthayapalam Block, Guntur Forest Division	VI	Coastal alluvium	Below 2.9 m; 1 m in rains	5.0	1947; poor growth
Golapalam Block, Guntur Forest Division	VII	Coastal alluvium	Below 1.5 m; 0.5 m in rains	2.5	1954; good growth
Orissa					
Dhankia Block, Kujang Range, Afforestation Division	I	Coastal alluvium	Deep; not encountered in profile; high in rains	High mound	1958; good growth
Dhankia Block, Kujang Range, Afforestation Division	II	Coastal sand	Below 1 meter; high in rains	3.0	1958; very good growth
Konark Block, Konark Range, Afforestation Division	III	Coastal sand	Below 1.5 m; high in rains	1.5	1956; excellent growth
Konark Block, Konark Range, Afforestation Division	IV	Coastal sand	Below 1.5 m; high in rains	2.0	1957; very poor growth
Karnataka					
Karwar Range, W. D. Kanara Forest Division	I	Coastal alluvium	Below 1.5 m; high in rains	2.5	1954; poor growth
Karwar Range, W. D. Kanara Forest Division	II	Coastal alluvium	Below 2 m; high in rains	2.5	1949; very good growth
Tamil Nadu					
Sooleru Kadu Village, Tamil Nadu	I	Coastal alluvium	Below 6 m; 2 m in rains	3.0	1957; good growth

hibited by high water table. The data on site characteristics and growth status of *Casuarina* plantations in different States are summarized in Table 1.

The fine sand samples were first made free from carbonates (PIPER [7]), organic matter (HUTTON [3]) and sesquioxide (MEHRA and JACKSON [5]) and were then separated into heavy and light mineral fractions by using bromoform. The heavy fractions so obtained, were mounted in Canada balsom. The sand

grains were identified under the microscope and the distribution of opaque free heavy mineral species was determined. The results were expressed by allocating each mineral species a frequency number according to the method outlined by EVANS et al. [1].

Results and discussion

The relevant data on mineralogical composition of the soils are presented in Table 2. From Table 2 it is seen that in A. P. the epidote group of minerals occurs as the most abundant grains in the heavy mineral residues of the soil samples. The hornblende is found in abundant to fairly abundant quantities. Garnet is variable, being abundant to scarce mineral grains. Tourmaline is fairly abundant to scarce, while zircon is of common to rare occurrence.

From among the metamorphic minerals, garnet, andalusite, sillimanite and kyanite occur in almost all the profiles. Andalusite does not occur in Gola Pallem private Casuarina Plantation, North Nellore Forest Division.

Of these minerals, kyanite and andalusite are of common to rare occurrence followed by sillimanite which is fairly common to rare or absent in some of the soil horizons. Staurolite has been found in all the layers of Ponna series, Sriharikota Range, South Nellore Forest Division. In the rest of the profiles, its occurrence like zoisite is confined to only some of the horizons. The opaque minerals flood the Ponna series. This profile shows the occurrence of chlorite in fairly common to scarce amounts. Rutile is found in Gola Pallem private Casuarina Plantation and in the last soil layer of Muthaya Palan Block, Guntur Forest Division. Based on the preponderant occurrence of minerals, Andhra Pradesh soils are characterized by epidote-hornblende mineral association and epidote-garnet mineral assemblage.

The soil profiles of Orissa (Table 2) indicate pyroxenes as the most abundant mineral group and garnet as fairly abundant to very common mineral grains. The hornblende, tourmaline and epidote occur as fairly common to scarce minerals. The occurrence of minerals like staurolite, zircon, kyanite and rutile is noticed only in some of the layers and as such, is not of much significance. These profiles are characterized by pyroxene-garnet mineral associations.

The data on the Karnataka soil profiles (Table 2) indicate the occurrence of opaques in the top soil layers of Karwar Range (Profile II), in which no other heavy minerals were found. The other soil profile (Profile I) from the same Forest Range indicates flooding of opaques in the heavy minerals. These include epidote, tourmaline, andalusite and hornblende as minerals of major occurrence followed by subordinate amounts of staurolite, kyanite and zoisite. Garnet and pyroxenes are found in these two profiles separately. On the whole, the mineral associations can be designated as epidote-garnet and epidote-hornblende.

In the soil profile examined from Tamil Nadu (Table 2), garnet occurs in abundance, epidote as fairly abundant mineral group and andalusite as common to fairly common mineral grains. Tourmaline, zircon, chlorite, kyanite and rutile follow suit as preponderant mineral grains in the descending order. The soil profile is characterized by garnet-epidote mineral association.

The soils derived from the detrital materials usually contain a large variety of mineral grains. Distribution of minerals in such deposits is governed by

Table 2

Relative frequencies of the heavy minerals in fine sands of the soils under *Casuarina equisetifolia* plantations

Profile No. and depth, cm	Garnet	Tourmaline	Epidote	Zoisite	Staurolite	Zircon	Kyanite	Chlorite	Sillimanite	Andalusite	Hornblende	Pyroxene	Sphene	Rutile	Opaques
Andhra Pradesh															
I (Pale yellow to brownish yellow)															
0—92	6	6⁻	7	0	3	1	3	2	2	4	3	0	0	0	Flooding
92—160	7	3	7⁻	3	3	3	4	2	0	5	2	0	0	0	Flooding
160—210	6	5	7+	3	1	0	3	3	0	4	0	0	0	0	Flooding
II (Greyish yellow to light brownish yellow)															
0—22	5	5	7⁻	0	0	5	2	0	2	4	7	0	0	0	Poor
22—60	5	5	7⁻	0	0	5	2	0	2	4	7	0	0	0	Poor
60—90	5	4	7	0	0	2	2	0	1	3	7⁻	0	0	0	Poor
III (Greyish yellow to light brownish yellow)															
0—22	5	5	7	1	0	2	3	0	0	5	7⁻	0	0	0	Poor
22—60	5	5	7	1	0	2	3	0	0	5	7⁻	0	0	0	Poor
60—90	5	4	7	0	0	4	4	0	2	4	7⁻	0	0	0	Poor
IV (Greyish yellow to brownish yellow)															
0—13	6⁻	4	7	0	2	4	0	0	3	5	6	0	0	0	Poor
13—60	6⁻	4	7	0	2	4	0	0	3	5	6	0	0	0	Poor
60—108	4	3	7	0	0	0	2	0	1	4	7	0	0	0	Poor
V (Greyish yellow to brownish yellow)															
0—12	5	5	7	1	2	2	3	0	2	4	7	0	0	0	Poor
12—60	5	5	7	1	2	2	3	0	2	4	7⁻	0	0	0	Poor
60—102	5	5	7⁻	0	0	0	2	0	1	5	7⁻	0	0	0	Poor
VI (Dark brown to pale brown)															
0—23	2	2	7+	3	0	1	2	0	3	1	7⁻	0	0	0	Poor
23—60	2	2	7+	3	0	1	2	0	3	1	7⁻	0	0	0	Poor
60—98	5	2	7+	1	1	1	3	0	1	0	7⁻	0	0	2	Poor
VII (Greyish brown to brown)															
0—5	5	3	8⁻	2	0	4	3	0	0	0	6⁻	0	0	2	Poor
5—23	5	3	8⁻	2	0	4	3	0	0	0	6⁻	0	0	2	Poor
23—50	5	3	8	2	0	4	3	0	0	0	6⁻	0	0	2	Poor
50—70	5	3	8	2	1	0	1	0	1	0	6+	0	0	1	Poor
Orissa															
I (Dark grey to dark grey brown)															
0—20	6⁻	3	1	0	0	1	1	0	1	0	2	8⁻	0	0	Poor
20—40	6⁻	3	1	0	0	1	1	0	1	0	2	8⁻	0	0	Poor
40—110	6⁻	0	3	0	0	1	0	0	0	0	1	8	0	1	Poor
II (Pale grey to black grey)															
0—20	5	3	2	0	0	0	0	0	0	0	2	8⁻	0	3	Poor
20—63	6	3	2	0	0	0	0	0	0	0	2	8⁻	0	3	Poor
63—105	5	3	3	0	0	0	0	0	0	0	4	8	0	3	Poor
III (Pale brown to reddish brown)															
0—18	3	2	2	0	1	1	0	0	0	0	3	8	0	0	Poor
18—70	5	2	2	0	0	1	0	0	0	0	2	8	0	1	Poor
IV (Pale brown to rusty reddish brown)															
0—25	3	0	1	0	1	0	1	0	0	0	1	8	0	1	Poor
25—70	5	0	1	0	1	0	1	0	0	0	1	8	0	1	Poor
70—135	5	1	1	0	0	1	0	0	0	0	1	8+	0	0	Poor

Table 2 (cont.)

Profile No. and depth, cm	Garnet	Tourmaline	Epidote	Zoisite	Staurolite	Zircon	Kyanite	Chlorite	Sillimanite	Andalusite	Hornblende	Pyroxene	Sphene	Rutile	Opaques
Karnataka															
I (Pale grey brown to black grey)															
0— 8	All opaques														
8—23	All opaques														
23—53	6⁻	3	7+	1	2	0	3	0	0	4	5	0	0	0	Poor
53—80	6⁻	3	7+	1	2	0	3	0	0	4	5	0	0	0	Poor
II (Pale grey brown to black grey)															
85—150	0	4	7+	2	5	0	2	2	0	4	6	2	0	0	Flooding
150—210	0	5	8⁻	0	3	0	3	0	1	4	3	4	0	0	Flooding
Tamil Nadu															
I (Reddish brown to grey brown)															
0—7	7	2	6+	0	1	2	1	1	0	4	2	0	0	1	Poor
7—35	7	2	6+	0	1	2	1	1	0	4	2	0	0	1	Poor
35—90	7	4	7	1	0	0	0	1	0	3	6⁻	0	0	0	Poor

Mineral percentages have been shown by symbols as follows

Most abundant	Abundant	Fairly abundant	Very common	Common	Fairly common	Scarce	Rare	Absent
8+=90—100	7+=48—59	6+=23—27	5=7—13	4=4—6	3=2—3	2=1—2	1=1/2—1	0
8 =75— 89	7 =35—47	6 =18—22						
8⁻=60— 74	7⁻=28—34	6⁻=14—17						

three factors — (i) the nature of source (provenance), (ii) mode of transportation, and (iii) the nature of depositional environment. Different geological regions release materials of different mineralogical make-up. For example, a high grade metamorphic region will be characterized by a particular set of minerals as distinguished from a low grade metamorphic region. Similarly, igneous or sedimentary regions would contribute differently. The agency of transport plays an important role in shaping the mineral grains. During this process, the soft and friable minerals generally get destroyed owing to physical and chemical weathering. In the last stage when the sediments get settled or deposited, geochemical processes play their lasting role in modifying the mineralogical composition both qualitatively and quantitatively. In the coastal areas, the marine waters rework these sediments which acquire a totally different provenance as compared with the original sediments and are enriched in their mineral composition based on the specific gravity.

Owing to the above reasons a wide variety of heavy minerals occur in these coastal soils. Therefore, based on the preponderant occurrence of mineral grains, different mineral associations characterize them. Heavy minerals like garnet, staurolite, kyanite, sillimanite, andalusite and zoisite are indicative of high grade metamorphic rock sources of these soil materials. These minerals further reveal the basement complex source of the soils.

As compared with these resistant and hard minerals, the occurrence of soft and more easily weatherable minerals like hornblende and pyroxenes can be reckoned as derived from the local sources.

Since soil formation is conditioned largely by the weathering of minerals forming new material with possible losses of constituents from the profile, the stability of minerals and the formation of weathering products are all of considerable importance. PETTIJOHN [6] examined the frequency of the occurrence of a number of mineral species in sedimentary rocks of increasing geological age and proposed a sequence which is a measure of their relative persistence known as mineral stability table. According to this the weathering intensity of these soil profiles is as follows:

Tamil Nadu > Andhra Pradesh & Karnataka > Orissa

The heavy minerals are a major source of plant nutrients, apart from indicating the progress of soil development. They release a great variety of nutrient elements which are essential for the growth of the plants. In the soils under the *Casuarina* plantations reported here, mineral assemblage of hornblende, pyroxene and tourmaline can be considered as important sources of plant food. Epidote and chlorite are also of some significance in this respect. In conclusion, these soils are expected to be rich particularly in alkaline earths, iron, iron oxides and boron and are able to support satisfactory growth of *Casuarina* plantations unless other adverse factors like excessive soil salinity, prolonged waterlogging and disease incidence operate seriously in an area. In such cases, appropriate soil and water management practices suited to a particular locality are required to be adopted to prevent mortality of the *Casuarina* plantations.

Summary

The results of the investigation reveal that the soils under the *Casuarina equisetifolia* plantations in the States of Andhra Pradesh, Orissa, Karnataka and Tamil Nadu in India, mostly belong to the coastal alluvium of finer texture or sandy deposits and show wide variations in their mineralogical composition. On the whole, these soils are characterized by epidote-hornblende, epidote-garnet, pyroxene-garnet and garnet-epidote mineral associations with subordinate amounts of other heavy minerals. The mineralogical study further suggests that the parent materials are derived from the metamorphic rock formations, and indicate a good reserve of plant nutrients in these soils.

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