CHAPTER VI

BIOMASS STUDIES
INTRODUCTION AND REVIEW OF LITERATURE:

The significance of exchange of organic and inorganic material between living organisms and soil has long been recognized yet only scanty information is available, especially in tropics, about the quantitative aspect and mechanisms concerned in the diverse processes involved. For example, there are abundant data on the productivities of different wood lands in terms of volume of marketable stem but relatively few data on the weights of bole, branch, leaf and root material produced, and the total amounts of nutrients and energy which they contain (Ovington, 1960).

Forest ecosystem is a vast reserve of energy and minerals. A major part of this energy is stored in trunks, branches, leaves and roots of the trees in the form of various organic substances and the minerals remain in continuous circulation between the plants and soil. In measuring rate of production of energy and minerals, organic matter has been of vital importance to biologists.

Storage of organic matter in plant tissues, in excess of respiratory utilization is the basis of primary productivity.
of an ecosystem (Odum, 1971). Leith (1971) was of the view that ecological production processes cannot be dealt with exclusively as single chemical reactions because the potential level of primary production is not often achieved due to certain limiting factors like light, water and nutrients.

In spite of a greater interest of ecologists in the production of organic matter in different ecosystems, work of this nature on the forests of tropical region is scanty mainly owing to a great biological richness and diversity of species. Unpatterned nature of the crop stand and relatively a few species showing prominent annual growth rings frequently posed problems in assessing the productivity. In the absence of knowledge of tree age, Newbould (1967) has suggested that other parameters of trees like g.b.h., d.b.h. or height can also be used with a reasonable accuracy in estimating biomass and forests productivity in temperate region.

In the tropical dry deciduous forests where majority of the tree species possess the power of regeneration by coppice growth, measurements of productivity depending upon g.b.h., d.b.h. or height increment cannot be a reliable parameter. The g.b.h. of a tree in the early 25-30 years of coppice growth is supposed to be significantly higher in comparison to a normal tree derived from a seed. The g.b.h. of a coppiced tree is also dependent upon the age of the stump. Therefore, in these regions there appears a complete lack of attempt to
correlate biomass and productivity with any of the tree parameters or age of the stand. Application of methods or generalization of temperate regions as recommended by Ovington (1956, 57) cannot be applied with the same success in the tropics. The methods of Newbould (1967) and others have yet to be tested with caution and modifications suiting the vegetation of tropical zone.

Attention of ecologists on dry matter production was focussed after the pioneer work of Boysen-Jenssen (1932), who emphasized the harvest method in relation to forests, for measuring the organic matter production. Kittredge (1944) estimated foliage production in some trees. Weetman and Harland (1964) determined foliage and wood production in Picea marina, and prepared diameter tables for estimating total dry weights of needles per tree. They concluded that dominant species in the forests are less efficient producers of organic matter per unit weight of needles than the suppressed trees.

Study of forest productivity was given an impetus by the works of Ovington (1956). He found out a relationship between form of a tree and dry matter content and described the efficiency of trees to utilize site conditions. Several studies have been carried out in different countries after the 'International Biological Programme' was launched. Concentrated efforts for measuring biomass production by trees and their
various components and other minor strata of forests were made by Fearsall (1959) and Ovington and Maddick (1959). Other publications on the subject are that of Ando et al. (1959), Ogino et al. (1964); Tadaki et al. (1965); Ogawa et al. (1965); Baskerville (1965); Sattoo (1966) and Kira et al. (1967). Ovington (1962) has reviewed the world literature on forest biomass data and related studies in an ecosystem context.

Rutter (1955) found out the relation between dry weight of the tree and linear measures of growth in two young conifers - *P. sylvestris* and *P. silicbensis*. He concluded that while the mean diameter was inversely related to density, mean tree height remained constant. Peterson (1966) observed that a tree having low trunk biomass supports an exceptionally heavy canopy. Newbould (1967) estimated the primary productivity in very minor components of the trees like bud scales, flowers and fruits. According to him, stem production was the major part and needed special attention. He suggested that the principle of such estimations should be the complete enumeration and measurements of stem followed by a correlation between tree diameter and its dry weight.

Kira et al. (1967) in a monsoon, savanna and rain forests determined the gross and net production of organic matter per annum and revealed the dynamic equilibrium in a climax forests in terms of the balance between input and output of the matter.
to and from the standing biomass.

Loomis et al. (1966) found out the relationship between crown weight and stem diameter in *Pinus echinata* and concluded that stand density had apparently no effect on such relationship and bole diameter at the base of crown was the best single measure for foliage and branch weight.

Holland (1969) estimated the aerial biomass and its annual increment in two forests of mallee vegetation which differed in species between composition and age.

Gabaev (1969) compared the phytomass in 10 years old Scots pine plantations with (i) sparse population (3,330 plants/ha) and (ii) a dense population (8,800 plants/ha), both growing on rich leached chernozems on an old terrace. In first case the herbaceous vegetation formed 49.1% of the total phytomass of 31.48 tons/ha, whereas in second case it formed only 21.9% of a total phytomass of 38.43 tons/ha.

Boyer (1968) summarized the relations between wood volume increment and foliage weight for various conifer species. Zukhova (1969) made a detailed study of sample tree from stands aged 25, 35, 55 and 75 years and worked out the mean annual phytomass increment.

Post (1970) estimated the biomass of standing crop in *Acer spicatum* which ranged from 0.74 ton/ha at one year to 40.45 tons/ha at 26 years of age. In 25 years old *Abies*
The standing crop was 58.55 tons/ha. Annual increments in organic matter were 0.31 ton/ha/year in stem wood, 0.51 ton/ha/year in branches, 0.17 ton/ha/year in stem bark. The annual weight increment was found to be constant from 8 years to 26 years age in A. spicatum while in A. balsamea it was initially very low but increased at 25 years of age.

Nihlgord (1972) estimated the plant biomass primary productivity and distribution of organic matter in various plant parts in a beech and a planted spruce forests. The standing crop was 1069 kg in a 78 years old beech tree while it was 423 kg in a 55 years old spruce tree.

In India, the studies on forest productivity have been confined mainly to three centres, viz. Varanasi (U.P.), Saugar (M.P.) and Udaipur (Rajasthan). Though ample data are available on volume tables of some important timber tree species like T. grandis, T. tomentosa and A. latifolia (Laurie and Sant Ram, 1940; Griffith, 1947; Dabral and Lala, 1964), the productivity of the forest stand as a whole with biological bias was not attempted till recently when some works on tropical dry deciduous forests started appearing in last few years. Bandhu (1970) presented the results of investigations on productive structure of forests with an emphasis on Shorea robusta. Vyas et al. (1971 a, b, c; 1972; 1973) estimated the plant biomass and productive relations in T. grandis and five other species. Pandey et al. (1967,
1970, 1972) determined the net primary productivity in five important tree species of the forests of Gujrat. Misra (1969, 1970) reviewed the Indian literature on the subject. Recently Bandhu (1972) presented the total available Indian data on primary productivity of forests. This has provided a sound foundation to the understanding of tropical deciduous forest ecosystem.

More recently, Kandya (1974) carried out investigations on organic matter production in above and underground parts of four selected tree species, viz. I. grandis, I. tomentosa, D. melanoxylon and A. latifolia of Sagar forests. The study was confined to standing biomass on these four tree species. Sodhia (1974) correlated the foliage structure and composition with the photosynthesis and organic matter production by aboveground parts. In these studies the productivity was confined to individual tree species and no attempt was made to correlate it with crop density. Litter productivity was not taken into account while measuring the total productivity.

The present investigation, therefore, aims at correlating the productivity of teak forests of Gourjhamar forests with various plant parameters and age which has not been done in these forests. The present work envisages to explore the absolute (wt/ha) and relative productions of different species in teak forests.
6.1 STANDING BIOMASS OF VARIOUS PLANT PARTS IN SELECTED TREE SPECIES:

Data on distribution of biomass in various plant parts of *I. grandis*, *I. tomentosa*, *D. melanoxylon* and *A. latifolia* are presented in Tables 21 to 24 respectively. Table 21 summarizes the results of biomass distribution in various plant parts at different g.b.h. In all eleven girths varying from 7.5 to 133.0 cm with corresponding age of 7 years to 120 years, respectively were analysed in *I. grandis*. Table 22 contains the biomass data of *I. tomentosa* of various g.b.h. (10.0 to 145.0 cm) with corresponding age of 25 to 150 years. In Table 23, the biomass data of *D. melanoxylon* are summarized at different growth stages, viz. 8.5 to 135.0 cm g.b.h. with corresponding age of 15 to 120 years, respectively. Table 24 contains biomass data of plants placed in 5 g.b.h. groups varying from 7.5 (15 years age) to 100.0 cm g.b.h. (110 years).

(i) *I. grandis*:

Perusal of data given in Table 21 shows that the mature trees with 133.0 cm g.b.h. and with corresponding age of about 120 years, showed the biggest crown formation and maximum trunk and root biomass. The minimum value of crown, trunk and root biomass was observed at 7 years of age (7.5 cm g.b.h.).
### Table 21: Average Dry Weight (kg/tree) and Percentage Biomass (in brackets) of Different Plant Parts in T. grandis

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Plant Parts/ Dry Weight (kg/tree)</th>
<th>G.B.H. (cms)</th>
<th>7.5</th>
<th>8.5</th>
<th>15.0</th>
<th>25.0</th>
<th>44.0</th>
<th>53.5</th>
<th>72.0</th>
<th>76.0</th>
<th>95.0</th>
<th>112.0</th>
<th>133.0</th>
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<tr>
<td></td>
<td>AGE (yrs)</td>
<td></td>
<td>7</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>30</td>
<td>40</td>
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<td>65</td>
<td>75</td>
<td>85</td>
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<td>1.</td>
<td>Crown (Leaves + Twigs)</td>
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<td>2.</td>
<td>Trunk (With Bark)</td>
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<td>Total Aboveground Biomass (Kg/Tree)</td>
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<td>3.</td>
<td>Root Biomass (Underground)</td>
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<td>TOTAL PLANT BIOMASS (Kg/Tree)</td>
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<tr>
<td>UNDERS</td>
<td>GROUND-ABOVEGROUND BIOMASS RATIO</td>
<td>0.40</td>
<td>0.30</td>
<td>0.13</td>
<td>0.17</td>
<td>0.33</td>
<td>0.38</td>
<td>0.38</td>
<td>0.32</td>
<td>0.28</td>
<td>0.27</td>
<td>0.26</td>
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</table>

### Table 22: Average Dry Weight (kg/tree) and Percentage Biomass (in brackets) of Different Plant Parts in T. tomentosa

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Plant Parts/ Dry Weight (kg/tree)</th>
<th>G.B.H. (cms)</th>
<th>10.0</th>
<th>35.0</th>
<th>50.0</th>
<th>68.0</th>
<th>98.0</th>
<th>145.0</th>
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<tbody>
<tr>
<td></td>
<td>AGE (yrs)</td>
<td></td>
<td>25</td>
<td>40</td>
<td>60</td>
<td>70</td>
<td>90</td>
<td>150</td>
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<tr>
<td>1.</td>
<td>Crown (Leaves + Twigs)</td>
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<td>2.</td>
<td>Trunk (With Bark)</td>
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<td>3.</td>
<td>Root Biomass (Underground)</td>
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<td></td>
<td>TOTAL PLANT BIOMASS</td>
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<td></td>
<td>UNDERGROUND-ABOVEGROUND BIOMASS RATIO</td>
<td>1.70</td>
<td>0.38</td>
<td>0.22</td>
<td>0.22</td>
<td>0.23</td>
<td>0.20</td>
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</table>
Mature teak tree of 120 cm g.b.h. produced 1305.40 kg/tree aerial biomass and 336.60 kg/tree root biomass.

Underground/aboveground biomass ratio was observed to be 0.40 at 7.5 cm g.b.h. and 0.26 at 133.0 cm g.b.h. A critical examination of the data reveals that the biomass ratio of 0.40 at 7 years age decreased to 0.17 at 20 years of age and then further increased to 0.38 at 50 years age (72.0 cm g.b.h.) beyond which it started falling off, though very gradually (Fig. 26).

A comparative study of the percentage weights of all the above and underground plant parts reveals that trunk dry weight varied from 23.0 to 55.7 per cent while crown dry weight ranged from 23.7 to 48.0 per cent. Contribution of roots to the total plant biomass ranged from 12.0 per cent at 15 years of age (15.0 cm g.b.h.) to 29.8 per cent at 40 years of age (53.5 cm g.b.h.). Crown dry weight was found to be maximum (47-48%) between 20-40 years of age (25.0 - 53.5 cm g.b.h.). This can be taken as the age of maximum crown development in the life of a teak tree. Maximum value of crown dry weight as observed in mature trees cannot be taken as the age of maximum crown growth because this weight was not only due to the leaves and twigs but mostly due to thick woody branches. The trunk biomass first, tended to increase between 10-15 years of age and then gradually reduced up to 40 years of age and then again increased rapidly between 50 to 120 years of age. The
maximum trunk biomass of 55.7 per cent was recorded at 120 years of age and 54.2 per cent at 75 years of age. The root biomass also showed two growth peaks (Fig. 26), the maximum production was observed between 40 to 50 years of age.

The phenomenon of two growth peaks in trunk and root biomass can be partly explained by the process of dying back. As discussed earlier, the dying back ceased between 5-10 years of age. Beyond this stage the normal growth in roots and aboveground parts was observed as exhibited by a root/shoot ratio of 0.98 (Table 20A). As can be seen in Table 16, the growth pattern in *T. grandis* indicated that the height growth is maximum between 10-50 years of age beyond which height growth rate starts falling off. Beyond this stage, the silvicultural operations like thinning if carried out, the radial increment in main trunk takes place taller faster. This is in conformity with the findings of Autter (1955) who postulated that within a fairly wide limits of thinning intensity the mean height of a stand remained constant while the mean diameter was inversely related to density.

(ii) *T. tomentosa*:

Perusal of data in Table 22 shows that the crown biomass tended to increase with g.b.h. and age. The minimum crown biomass of 0.40 kg/tree at 10 cm g.b.h. and maximum crown biomass of 360.50 kg/tree at g.b.h. 145 cm was observed. A
similar trend was observed in trunk and root biomass. The maximum trunk and root biomass of 852.00 kg and 246.40 kg/tree, respectively was observed at 145 cm g.b.h.

A comparative study of the percentage dry weight of all the plant parts showed that crown weight varied from 20 to 40 per cent, trunk weight from 20.0 to 51.5 per cent and root dry weight from 17.6 to 60.0 per cent.

At the g.b.h. between 35-65 cm (40-70 years of estimated age) the percentage of crown weight was maximum (34-40%). Therefore this period may be termed as the age of branch (crown) growth. Similarly, 50-145 cm g.b.h. (60-150 years of age) might be considered as the period of maximum radial increment (42.4-51.5%). Root biomass was observed to be maximum (60%) at 10 cm g.b.h. Beyond this stage the per cent dry root weight contributed to the total plant biomass did not show any marked change. Initially, very high percentage of root weight contributed to the plant biomass is probably due to the aftermath of dying back.

Underground/aboveground biomass ratio was exceptionally high (1.7) at 10 cm g.b.h. probably due to dying back effect as explained above. After this stage the ratio tended to decrease to 0.22 at 50 cm g.b.h. which ultimately remained almost constant (0.22 - 0.22) indicating a normal plant growth.
### Table 23: Average Dry Weight (kg/tree) and Percentage Biomass (in brackets) of Different Plant Parts in *D. melanoxylon*

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Plant Parts/ Dry Weight (kg/tree)</th>
<th>G.B.H. (cms)</th>
<th>AGE (yrs)</th>
<th>8.5</th>
<th>35.0</th>
<th>52.0</th>
<th>62.0</th>
<th>115.0</th>
<th>135.0</th>
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<tr>
<td>1.</td>
<td>Crown (Leaves + Twigs)</td>
<td>0.20</td>
<td>15</td>
<td>11.75</td>
<td>26.30</td>
<td>28.50</td>
<td>84.75</td>
<td>300.50</td>
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<td></td>
<td></td>
<td>(20.5)</td>
<td>25</td>
<td>(25.2)</td>
<td>(33.4)</td>
<td>(20.0)</td>
<td>(18.1)</td>
<td>(24.1)</td>
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<td>2.</td>
<td>Trunk (With Bark)</td>
<td>0.25</td>
<td>35</td>
<td>23.55</td>
<td>30.75</td>
<td>89.66</td>
<td>306.42</td>
<td>652.75</td>
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<td></td>
<td></td>
<td>(25.8)</td>
<td>50</td>
<td>(50.0)</td>
<td>(39.0)</td>
<td>(62.7)</td>
<td>(65.5)</td>
<td>(52.4)</td>
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<tr>
<td></td>
<td>Total Aboveground Biomass</td>
<td>0.45</td>
<td>50</td>
<td>35.30</td>
<td>57.05</td>
<td>118.16</td>
<td>391.17</td>
<td>953.25</td>
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<td>(47.4)</td>
<td>100</td>
<td>(75.2)</td>
<td>(72.4)</td>
<td>(82.7)</td>
<td>(83.6)</td>
<td>(76.5)</td>
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<tr>
<td>3.</td>
<td>Root Biomass (Underground)</td>
<td>0.52</td>
<td>120</td>
<td>11.20</td>
<td>21.60</td>
<td>24.75</td>
<td>76.60</td>
<td>292.00</td>
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<td></td>
<td></td>
<td>(53.6)</td>
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<td>(24.8)</td>
<td>(27.6)</td>
<td>(17.3)</td>
<td>(16.4)</td>
<td>(23.5)</td>
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<td>TOTAL PLANT BIOMASS</td>
<td>0.97</td>
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<td>46.50</td>
<td>78.65</td>
<td>142.91</td>
<td>467.77</td>
<td>1245.25</td>
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<td>UNDERGROUND-ABOVEGROUND BIOMASS RATIO</td>
<td>1.10</td>
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<td>0.38</td>
<td>0.20</td>
<td>0.19</td>
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### Table 24: Average Dry Weight (kg/tree) and Percentage Biomass (in brackets) of Different Plant Parts in *A. latifolia*

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Plant Parts/ Dry Weight (kg/tree)</th>
<th>G.B.H. (cms)</th>
<th>AGE (yrs)</th>
<th>7.5</th>
<th>42.0</th>
<th>55.0</th>
<th>85.0</th>
<th>100.0</th>
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<tr>
<td>1.</td>
<td>Crown (Leaves + Twigs)</td>
<td>0.25</td>
<td>15</td>
<td>98.50</td>
<td>180.50</td>
<td>268.00</td>
<td>268.00</td>
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<td>(40.7)</td>
<td>(37.7)</td>
<td>(31.5)</td>
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<td>2.</td>
<td>Trunk (With Bark)</td>
<td>0.40</td>
<td>55</td>
<td>52.00</td>
<td>65.50</td>
<td>152.30</td>
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<td></td>
<td></td>
<td>(42.1)</td>
<td>90</td>
<td>(20.3)</td>
<td>(15.0)</td>
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<td>(30.0)</td>
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<td></td>
<td>Total Aboveground Biomass</td>
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<td>245.50</td>
<td>420.30</td>
<td>527.70</td>
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<td></td>
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<td>(68.4)</td>
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<td>(54.8)</td>
<td>(55.7)</td>
<td>(59.1)</td>
<td>(61.5)</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Root Biomass (Underground)</td>
<td>0.30</td>
<td></td>
<td>106.00</td>
<td>198.00</td>
<td>290.50</td>
<td>340.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(31.6)</td>
<td></td>
<td>(46.2)</td>
<td>(44.3)</td>
<td>(40.9)</td>
<td>(38.5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TOTAL PLANT BIOMASS</td>
<td>0.95</td>
<td></td>
<td>256.50</td>
<td>443.50</td>
<td>710.80</td>
<td>867.70</td>
<td></td>
</tr>
<tr>
<td></td>
<td>UNDERGROUND-ABOVEGROUND BIOMASS RATIO</td>
<td>0.50</td>
<td></td>
<td>0.70</td>
<td>0.80</td>
<td>0.70</td>
<td>0.67</td>
<td></td>
</tr>
</tbody>
</table>
(iii) *D. melanoxyylon*:

Review of data given in Table 23 indicates that both aerial and underground biomass increased with g.b.h. and age. At g.b.h. 135 cm, crown, trunk and root biomass (total biomass) per tree was maximum (1245.25 kg/tree).

Comparative study of the contribution of various plant parts to the total biomass expressed on percentage basis shows that maximum crown development (25.2 - 33.4%) was observed between g.b.h. 35 to 52 cm. In case of trunk biomass it was maximum (65.5%) at g.b.h. 115 cm. However, the difference between 62 and 115 cm g.b.h. was not appreciable (62.7 and 65.5% respectively). Root biomass ranged from 17.3 per cent at 62 cm g.b.h. to 27.6 per cent at 52 cm g.b.h. Exceptionally high percentage of 53.6% was observed at g.b.h. 8.5 cm, probably due to the initial set-back to shoot growth due to dying back stress. This was manifested by very high underground/aboveground biomass ratio of 1.10 at g.b.h. 8.5 cm. This ratio at later stages ranged between 0.19 to 0.33 at g.b.h. 52 to 115 cm respectively.

(iv) *A. latifolia*:

An examination of data in Table 24 shows that maximum biomass was produced at g.b.h. 100 cm though the difference between g.b.h. 85 to 100 cm was not very marked. At 85 cm g.b.h. the total biomass was 710.80 kg as compared to
867.70 kg/tree at 100 cm g.b.h.

Comparison of the percentage weights of all the aerial and underground parts shows that crown weight ranged from 26.3 per cent at 7.5 cm g.b.h. to 40.7 per cent at 55.0 cm g.b.h. Trunk weight on the other hand ranged from 15.0 per cent at 55 cm g.b.h. to 30.0 per cent at g.b.h. 100 cm. Exceptionally, high growth rate was manifested (42.1%) at g.b.h. 7.5 cm, corresponding to 15 years of age. This was an abnormal shoot growth immediately after the period of dying back which was observed to last up to 10-20 years of age (Chapter V).

Underground/aboveground biomass ratio was initially 0.50 at g.b.h. 7.5 cm which subsequently increased to 0.70 at g.b.h. 42 cm, and thereafter remained almost constant.

From the above observations it can be concluded that the process of dying back was reflected by exceptional root development in the initial growth stages (especially during the period of dying back) and phenomenal shoot growth after the culminination of dying back.

**GROWTH PHASES IN PLANTS:**

On the basis of biomass studies of four important tree species in Sagar forests, Kandya (1974) had identified the following g.b.h. classes corresponding to various phases of
plant growth.

(i) Seedling or coppice phase : 0-20 cm g.b.h.
(ii) Juvenile phase : 21-50 cm "
(iii) Adult phase : 51-90 cm "
(iv) Senile phase : over 90 cm "

In the first growth phase the trees of a species having approximately same age may be different in g.b.h. because the growth in coppice is faster in the early stages than the seedlings. This phase is theoretically, a very short and temporary phase in which the plant g.b.h. possesses a long range of variation. The plants are short lived due to lopping and competition among themselves in this phase.

In the juvenile phase, trees become well-established. This phase is sufficiently long and mostly the crown develops in this stage.

The adult phase is the longest in duration and usually the synthesized organic matter is stored in the trunk, hence it increases considerably in radial measurement and also in biomass. This is the most active growth phase. In the senile phase of life the trees generally become hollow at the base.

This classification is based on normal plant growth under optimum habitat conditions. But in these forests seedlings of almost all plant species appear to suffer from dying back stress, lasting for different periods in different species
depending upon their capability to develop extensive root system in shortest period. The trees develop from seedling coppice rather than from seedlings. Therefore, regeneration in this region may be termed as 'seedling coppice' regeneration. Immediately after the dying back phenomenon is over, the plants may not show any significant radial growth, they show a marked growth in shoot length. Thus there appears to be need for identifying the initial growth phase by plant height with basal girth rather than by g.b.h. alone which is manifestation of normal growth condition. Therefore, the growing phase one can be subdivided into seedling and seedling coppice stage. Similarly, the juvenile growth phase can be reckoned from 31 cm to 60 cm g.b.h. which is the period of maximum height growth in teak (Table 16) and its associate species. After the culmination of height growth the synthesized food material is mostly available for radial development of the tree trunk. This growth phase in teak lasts up to 90 years of age corresponding to a g.b.h. of 105 cm (Table 16). The maturity appears to take place at 120 years of age corresponding to about 120 cm g.b.h. Beyond this stage trees develop hollowness and thus show the sign of overmature stem. Thus the growth phases suggested by Kandya (1974) need to be modified to suit these forest stands as follows:

(1) Seedling phase -- Plant height up to 1.0 m and up to 7.5 cm g.b.h.
HORIZONTAL DISTRIBUTION OF ROOTS
(2) Sapling phase  
7.5 - 15 cm g.b.h.

(3) Seedling coppice phase  
16 - 30 cm

(4) (A) Juvenile phase I  
31 - 60 cm
(Maximum height growth)

(B) Juvenile phase II  
61 - 105 cm
(Maximum diameter growth)

(5) Adult phase  
106 - 120 cm

(6) Senile phase  
Over 120 cm

6.2 PRODUCTIVITY IN RELATION TO RADIAL INCREMENT OF MAIN TRUNK:

For measuring the productivity of a tree, the difference in g.b.h. attained at various ages have been used by Sodhia (1974) and Kandya (1974). In the present study, however, in addition to g.b.h., age has also been used to determine the productivity of four tree species under investigation.

Data on productivity of four tree species at various g.b.h. intervals and age are summarized in Tables 25 to 28. Besides, total biomass production for every cm increase in radial measurement, mean annual and current annual biomass increment (WAI & CAI) of various plant parts have also been computed and compared at various ages.

General perusal of the data shows that with increasing age and g.b.h. the productivity of a tree tended to increase up to a certain stage beyond which it declined. The minimum
values were observed in trees of lower girth class in all tree species under investigations. However, the g.b.h. limit for maximum production was found to vary from species to species. While in *T. grandis* maximum production was observed at g.b.h. 72-76 cm; in *T. tomentosa* it was found at g.b.h. 68-98 cm; in *D. melanoxylon* at g.b.h. 115-135 cm; and in *A. latifolia* it was at g.b.h. 42-55 cm.

At the same g.b.h. the production of dry matter in *A. latifolia* was maximum followed by *T. tomentosa*, *T. grandis* and *D. melanoxylon*. At g.b.h. 50-55 cm the total production was found to be 443.50 kg/tree in *A. latifolia*, 184.18 kg/tree in *T. tomentosa*; 157.39 kg/tree in *T. grandis* and 78.65 kg/tree in *D. melanoxylon*.

Critical perusal of data in Table 25 reveals that the mean annual and current annual increments of crown dry weight in *T. grandis* showed two growth peaks: (i) between 30-40 years of age corresponding to g.b.h. 25.0-53.5 cm and (ii) beyond 75 years of age with corresponding g.b.h. 76-133 cm. At first instance, the age of 30-40 years can be termed as period of maximum crown growth while at subsequent stage it might have been due to secondary growth in branch wood instead of more foliage production.

Perusal of data in Table 26 pertaining to *T. tomentosa* indicates two growth peak, the first between 10-35 cm g.b.h. for crown and root dry weight and 35-50 cm g.b.h. for trunk
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Crown Biomass</td>
<td>(a) Total Production: 0.01 1.39 0.31 0.43 2.53 2.23 0.61 1.50 2.40 5.65 2.60</td>
<td>(b) MAI: 0.02 0.15 0.23 0.40 1.90 1.93 1.77 1.45 1.87 2.77 7.25</td>
</tr>
<tr>
<td></td>
<td>(kg/tree)</td>
<td>(c) CAI: 0.46 0.40 0.87 4.82 2.11 1.13 0.40 4.55 9.61 4.41</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Trunk Biomass</td>
<td>(a) Total Production: 0.01 2.10 0.32 0.21 1.36 0.50 4.46 35.15 6.63 8.23 23.30</td>
<td>(b) MAI: 0.01 0.21 0.28 0.31 1.07 0.91 2.80 2.46 3.80 5.00 7.62</td>
</tr>
<tr>
<td></td>
<td>(kg/tree)</td>
<td>(c) CAI: 0.70 0.42 0.42 2.59 0.42 8.26 2.70 12.60 14.00 14.00</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Root Biomass</td>
<td>(a) Total Production: 0.01 0.86 0.02 0.14 1.47 2.00 1.90 2.37 0.60 5.54 7.00</td>
<td>(b) MAI: 0.01 0.09 0.70 0.12 0.96 1.12 1.57 1.35 1.34 2.28 2.80</td>
</tr>
<tr>
<td></td>
<td>(kg/tree)</td>
<td>(c) CAI: 0.29 0.02 0.27 2.66 1.53 3.42 0.63 1.20 9.41 4.10</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Total Plant</td>
<td>(a) Total Production: 0.03 4.35 0.65 0.78 5.36 4.73 6.97 39.02 9.63 19.42 32.90</td>
<td>(b) MAI: 0.04 0.45 1.21 0.33 3.93 3.96 6.14 5.26 7.01 15.05 17.67</td>
</tr>
<tr>
<td></td>
<td>Biomass (kg/tree)</td>
<td>(c) CAI: 1.45 0.84 1.56 10.07 4.06 12.81 3.73 18.35 33.02 22.51</td>
<td></td>
</tr>
<tr>
<td>S. No.</td>
<td>Plant Parts</td>
<td>G.B.H. (cms):</td>
<td>0 - 10.00</td>
</tr>
<tr>
<td>--------</td>
<td>----------------------</td>
<td>---------------</td>
<td>-----------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AGE (years):</td>
<td>25</td>
</tr>
<tr>
<td>1.</td>
<td>Crown Biomass (kg/tree)</td>
<td>(a) Total Production</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) MAI</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(c) CAI</td>
<td>2.56</td>
</tr>
<tr>
<td>2.</td>
<td>Trunk Biomass (kg/tree)</td>
<td>(a) Total Production</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) MAI</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(c) CAI</td>
<td>2.03</td>
</tr>
<tr>
<td>3.</td>
<td>Root Biomass (kg/tree)</td>
<td>(a) Total Production</td>
<td>0.013</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) MAI</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(c) CAI</td>
<td>1.76</td>
</tr>
<tr>
<td>4.</td>
<td>Total Plant Biomass (kg/tree)</td>
<td>(a) Total Production</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) MAI</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(c) CAI</td>
<td>6.35</td>
</tr>
</tbody>
</table>
dry weight. The second growth peak was observed in mature tree with g.b.h. 98-145 cm. Trend of mean and current annual biomass increment worked on the basis of estimated age appeared to be very irregular. This irregular growth trend indicated the futility of estimated age based on volume and stand tables which are prepared from relatively fast grown plantation crops in moist localities. Such irregular growth trend was also exhibited by D. melanoxylon and A. latifolia.

From the above observations it can be concluded that while age gives an accurate result of net annual productivity of a tree, its g.b.h. provides an equally reliable results because the radial increment in the main trunk reflects the added amount of organic matter in various plant parts in a fixed time (Newbould, 1967). Moreover, while it is easier to determine the age of teak trees accurately, for other hardwood species like T. tomentosa, D. melanoxylon and A. latifolia, the determination of age is neither easy nor accurate in view of non-prominent annual rings. The results of correlation between growth rate and age based on trees of moist deciduous forests cannot be applied in dry deciduous forest owing to marked variations in climate, soil and biotic interferences in two regions.

6.3 AVERAGE DENSITY, BASAL AREA AND TOTAL STANDING BIOMASS:

Data on average density expressed as number of trees/ha;
### Table 27: Productivity in Relation to each cm Radial Increment of Main Trunk; Mean Annual and Current Annual Biomass Increment (MAI & CAI) in Various Plant Plants of D. melanoxylon

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Plant Parts</th>
<th>G.B.H. (cms)</th>
<th>0-8.5</th>
<th>8.5-35.0</th>
<th>35.0-52.0</th>
<th>52.0-62.0</th>
<th>62.0-115.0</th>
<th>115.0-135.0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>AGE (yrs)</td>
<td>15</td>
<td>25</td>
<td>50</td>
<td>100</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Crown Biomass (kg/tree)</td>
<td>Total Production</td>
<td>0.02</td>
<td>0.44</td>
<td>0.85</td>
<td>0.22</td>
<td>1.06</td>
<td>43.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(a) MAI</td>
<td>0.01</td>
<td>0.47</td>
<td>0.75</td>
<td>0.57</td>
<td>0.84</td>
<td>2.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(c) CAI</td>
<td>1.15</td>
<td>1.45</td>
<td>0.15</td>
<td>1.13</td>
<td>1.08</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Trunk Biomass (kg/tree)</td>
<td>Total Production</td>
<td>0.03</td>
<td>0.90</td>
<td>0.42</td>
<td>5.89</td>
<td>4.09</td>
<td>69.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) MAI</td>
<td>0.02</td>
<td>0.94</td>
<td>0.90</td>
<td>1.80</td>
<td>3.06</td>
<td>5.44</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(c) CAI</td>
<td>2.33</td>
<td>0.72</td>
<td>3.93</td>
<td>4.33</td>
<td>17.30</td>
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</tr>
<tr>
<td>3.</td>
<td>Root Biomass (kg/tree)</td>
<td>Total Production</td>
<td>0.06</td>
<td>0.40</td>
<td>0.61</td>
<td>0.31</td>
<td>5.15</td>
<td>43.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) MAI</td>
<td>0.03</td>
<td>0.45</td>
<td>0.62</td>
<td>0.50</td>
<td>0.77</td>
<td>2.44</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(c) CAI</td>
<td>1.07</td>
<td>1.04</td>
<td>0.21</td>
<td>5.46</td>
<td>10.80</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Total Plant Biomass (kg/tree)</td>
<td>Total Production</td>
<td>0.11</td>
<td>1.74</td>
<td>1.88</td>
<td>6.42</td>
<td>10.30</td>
<td>155.48</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) MAI</td>
<td>0.06</td>
<td>1.86</td>
<td>2.27</td>
<td>2.87</td>
<td>4.67</td>
<td>10.38</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(c) CAI</td>
<td>4.55</td>
<td>3.21</td>
<td>4.29</td>
<td>10.92</td>
<td>29.18</td>
<td></td>
</tr>
</tbody>
</table>

### Table 28: Productivity in Relation to each cm Radial Increment of Main Trunk; Mean Annual and Current Annual Biomass Increment (MAI & CAI) in Various Plant Plants of A. latifolia

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Plant Parts</th>
<th>G.B.H. (cms)</th>
<th>0-7.5</th>
<th>7.5-42.0</th>
<th>42.0-55.0</th>
<th>55.0-85.0</th>
<th>85.0-100.0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>AGE (years)</td>
<td>15</td>
<td>40</td>
<td>55</td>
<td>90</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Crown Biomass (kg/tree)</td>
<td>Total Production</td>
<td>0.03</td>
<td>2.85</td>
<td>6.31</td>
<td>2.92</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) MAI</td>
<td>0.02</td>
<td>2.46</td>
<td>3.30</td>
<td>3.00</td>
<td>2.48</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(c) CAI</td>
<td>3.93</td>
<td>5.46</td>
<td>5.46</td>
<td>2.50</td>
<td>0.28</td>
</tr>
<tr>
<td>2.</td>
<td>Trunk Biomass (kg/tree)</td>
<td>Total Production</td>
<td>0.05</td>
<td>1.50</td>
<td>1.04</td>
<td>2.89</td>
<td>6.80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) MAI</td>
<td>0.03</td>
<td>1.30</td>
<td>1.20</td>
<td>1.70</td>
<td>2.30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(c) CAI</td>
<td>2.06</td>
<td>0.90</td>
<td>2.50</td>
<td>5.10</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Root Biomass (kg/tree)</td>
<td>Total Production</td>
<td>0.04</td>
<td>3.07</td>
<td>7.08</td>
<td>3.08</td>
<td>2.70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) MAI</td>
<td>0.02</td>
<td>2.65</td>
<td>3.60</td>
<td>3.22</td>
<td>3.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(c) CAI</td>
<td>4.23</td>
<td>6.13</td>
<td>2.70</td>
<td>2.02</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Total Plant Biomass (kg/tree)</td>
<td>Total Production</td>
<td>0.12</td>
<td>7.42</td>
<td>14.43</td>
<td>8.89</td>
<td>9.86</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) MAI</td>
<td>0.07</td>
<td>6.41</td>
<td>8.10</td>
<td>7.92</td>
<td>7.88</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(c) CAI</td>
<td>10.22</td>
<td>12.49</td>
<td>7.70</td>
<td>7.40</td>
<td></td>
</tr>
</tbody>
</table>
basal area as sq metre/ha; and aboveground and root biomass expressed as tons/ha are presented in Table 29.

In the forest stand, with teak as prominent tree species in top canopy, the tree density of 1387.39 and basal area of 10.10 sq metre per hectare was observed. The main associates of teak in top canopy, viz. *I. tomentosa*, *D. melanoxxylon* and *A. latifolia* accounted for about 70 per cent of the total crop density and 73 per cent of basal area. Teak, though constituted about 21 per cent of the crop density, it accounted for about 55 per cent of the total basal area per hectare.

The total estimated standing biomass was observed to be 70.60 tons/ha of which aboveground biomass accounted for 47.77 tons per hectare (70%) and root constituted about 30 per cent (20.83 tons/ha) of the total plant biomass. Four important tree species, viz. *I. grandis*, *I. tomentosa*, *D. melanoxxylon* and *A. latifolia* taken together contributed 65 per cent (37.97 tons/ha) to the aboveground biomass and 35 per cent (11.74 tons/ha) to the total root biomass. These four species constituted about 75 per cent (15.66 tons/ha) of the total crown biomass (20.41 tons/ha) and 30 per cent (22.31 tons/ha) of the total trunk biomass.

Basal area appeared to be directly related to the production of organic matter as exhibited by very high and
<table>
<thead>
<tr>
<th>S.No.</th>
<th>Species</th>
<th>Density Trees/ha</th>
<th>Basal Area sq.m/ha</th>
<th>Aboveground Biomass</th>
<th>Underground Biomass (Roots)</th>
<th>Total Plant Biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Crown</td>
<td>Trunk</td>
<td>Total</td>
</tr>
<tr>
<td>1.</td>
<td><em>T. grandis</em></td>
<td>292.27</td>
<td>5.50</td>
<td>13.51</td>
<td>19.17</td>
<td>32.68</td>
</tr>
<tr>
<td>2.</td>
<td><em>T. tomentosa</em></td>
<td>47.43</td>
<td>0.46</td>
<td>1.05</td>
<td>1.76</td>
<td>2.81</td>
</tr>
<tr>
<td>3.</td>
<td><em>D. melanoxylon</em></td>
<td>232.94</td>
<td>0.64</td>
<td>0.33</td>
<td>0.71</td>
<td>1.04</td>
</tr>
<tr>
<td>4.</td>
<td><em>A. latifolia</em></td>
<td>381.19</td>
<td>0.74</td>
<td>0.77</td>
<td>0.67</td>
<td>1.44</td>
</tr>
<tr>
<td></td>
<td><strong>TOTAL</strong></td>
<td><strong>953.83</strong></td>
<td><strong>7.34</strong></td>
<td><strong>15.66</strong></td>
<td><strong>22.31</strong></td>
<td><strong>37.97</strong></td>
</tr>
<tr>
<td>5.</td>
<td><em>P. marsupium</em></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td><em>D. dalbergioides</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>M. parvifolia</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>L. parviflora</em></td>
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</tr>
<tr>
<td>6.</td>
<td><em>A. catechu</em></td>
<td>364.05</td>
<td>2.31</td>
<td>3.46</td>
<td>5.10</td>
<td>8.56</td>
</tr>
<tr>
<td></td>
<td>Other species</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>GRAND TOTAL</strong></td>
<td><strong>1387.39</strong></td>
<td><strong>10.10</strong></td>
<td><strong>20.41</strong></td>
<td><strong>29.36</strong></td>
<td><strong>49.77</strong></td>
</tr>
</tbody>
</table>

* $\bar{x}$ 1.68 3.40 4.89 8.29 3.70 11.99
  $r$ - 0.99 0.98 - 0.89 -
  $t$ - 14.14** 9.80** - 3.95*

* Sig. at 5% level of significance.
** Sig. at 5% and 1% level of significance.
positive correlation co-efficient \((r)\) between basal area and plant biomass. Correlation co-efficient between basal area and crown dry weight \((0.99)\) and trunk biomass \((0.98)\) was significant at 5\% and 1\% levels of significance while the correlation co-efficient between basal area and root biomass was significant at 5\% level only.

*Anogeissus latifolia* though showed the maximum plant density of 381.19 trees/ha \((27\% \text{ of the total density})\) its basal area per hectare was only 0.74 sq metre \((\text{about} \ 7.5\%)\). Its contribution to the total biomass was only 3.3 per cent \((2.33 \text{ tons/ha})\). This low production was mainly due to the fact that of the total density of 381.19 plants/ha about 99 per cent belonged to seedling and sapling stage \((\text{up to} \ 30 \ \text{cm g.b.h.})\) and only one per cent \((1.93 \text{ plants/ha})\) belonged to mature class \((\text{Table 9})\). Similarly, though the plant density of *D. melanoxylon* and *I. grandis* were almost similar their contribution to the total plant biomass was significantly different. While *I. grandis* contributed 42.45 tons/ha it was only 1.39 tons/ha biomass contributed by *D. melanoxylon* indicating the immaturity of latter species. In *D. melanoxylon*, 93 per cent of the plants belonged to younger age classes \((\text{seedlings and saplings})\). Similarly, in case of *I. tomentosa* also the plant density of 47.43 trees/ha was very unevenly distributed. Teak, on the other hand, showed normal age distribution. Due to relatively better distribution of trees
in higher age classes in *T. grandis*, it was able to contribute maximum plant biomass. There was a general deficiency of mature trees of other species.

6.4 LITTER PRODUCTION:

Though, few records are available about the total litter production of various forest stands (Upadhyay, 1955; Singh, 1962; Singh and Mali, 1963; Singh, 1967) but the species were never examined separately for their individual contribution within the stands. Bhatnagar (1960) carried out extensive work on various aspects of litter production. He also examined the mineral contents of leaf litter samples of different species in the forest stands of Katharia hills of Sagar.

The present study was undertaken in Saurjhamar teak forests where other studies such as structure, composition, growth rate and production of organic matter were also taken up. Data on litter production by various constituent species of the forests are presented in Table 30. Perusal of data reveals that *T. grandis* alone produced more than one-third of the total litter production of the stand. The other species which dominated the leaf litter production in this stand were *T. tomentosa*, *C. malanoxylon*, *Butea monosperma* and *Miliusa tomentosa*. Leaf fragments of other minor species accounted for about one-
<table>
<thead>
<tr>
<th>S. No.</th>
<th>Name of Species</th>
<th>Parameters of Vegetation</th>
<th>Parameters of Production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Density Trees/ha</td>
<td>Relative Density</td>
</tr>
<tr>
<td>1.</td>
<td>Tectona grandis</td>
<td>292.27</td>
<td>21.20</td>
</tr>
<tr>
<td>2.</td>
<td>Terminalia tomentosa</td>
<td>47.43</td>
<td>3.42</td>
</tr>
<tr>
<td>3.</td>
<td>Ficus microcarpa</td>
<td>29.28</td>
<td>2.12</td>
</tr>
<tr>
<td>4.</td>
<td>Ouginia dalbergioides</td>
<td>7.33</td>
<td>5.28</td>
</tr>
<tr>
<td>5.</td>
<td>Mitragyna parvifolia</td>
<td>0.59</td>
<td>0.05</td>
</tr>
<tr>
<td>6.</td>
<td>Anogeissus latifolia</td>
<td>38.19</td>
<td>27.53</td>
</tr>
<tr>
<td>7.</td>
<td>Lagerstroemia parviflora</td>
<td>32.31</td>
<td>2.34</td>
</tr>
<tr>
<td>8.</td>
<td>D. melanoxylon</td>
<td>232.94</td>
<td>17.50</td>
</tr>
<tr>
<td>9.</td>
<td>Butea monosperma</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>Buchanania lanzan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Milicia tomentosa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>Bridelia retusa</td>
<td>332.56</td>
<td>24.00</td>
</tr>
<tr>
<td>13.</td>
<td>Cassia fistula</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14.</td>
<td>Madhuca indica</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15.</td>
<td>Garuga pinnata</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16.</td>
<td>Fragments (Mixed Broken Pieces)</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL** | 572.7                  | -                           | 4,959                     | -                       | -                       |
third of the total production. Tree species like *A. latifolia* and *L. parviflora* contributed only a fraction of the total litter production.

Teak which showed a normal distribution of tree density contributed the maximum to litter production partly due to greater density in higher g.b.h. classes and partly due to large leaf size. Kitteredge (1948) and Bray and Gorhan (1964) have discussed the influence of age of tree and stands over the litter production. While Kitteredge (1948) considers the possibility of decline in litter production with increasing age after a certain limit, Bray and Gorham (1964) found no distinct correlation between higher and lower leaf fall with the increase in age, once the canopy becomes closed. However, Bhatnagar (1968) comparing the leaf litter output of 'teak' and 'non-teak stands' of Pithoragarh hills of Sagar observed that 'teak stands' which were younger in age and denser were more productive than more mature and rather sparse 'non-teak stands'.

6.4 Correlation Between Various Analytical Attributes of Stands and Litter Production:

Three types of analytical measures, absolute, relative and integrated have been employed in the course of present investigations.
FIG. 25 POLYGRAPHS SHOWING PRODUCTION AND VEGETATION MEASURES OF SOME IMPORTANT TREE SPECIES

- T. GRANDIS
- T. TOMENTOSA
- D. MELANOXYLON
- A. LATIFOLIA
- P. MARSUPIUM
- L. PARVIFLORA
6.42 **Correlation Between Absolute Attributes:**

(a) **Litter Frequency and Tree Density:** (Fig. 25; Table 30). Perusal of data in Table 30 shows that generally species showing higher density values of trees, showed higher frequency values of their leaf litter. Apart from absolute density other significant factors which are likely to influence directly the leaf litter frequency may be (1) weight, (2) size, (3) shape and curvature type of the leaf litter, and (4) maturity of plants. On this analogy, though *A. latifolia* showed highest density value, did not show higher frequency value of their leaf litter. In this case, the leaf size is smaller and weighs less than the leaves of *T. grandis*, *T. tomentosa*, *C. melanoxylon*, *L. parviflora*. Species like *T. tomentosa* with 47.43 plants/hectare showed 93 per cent leaf litter frequency as compared to only 20 per cent in *A. latifolia* which had maximum density value (381.19 plants/ha). Similarly, *L. parviflora* with a low density value of 32.31 plants/ha, showed one of the maximum frequency values of leaf litter (47%). Though, the leaves of *A. latifolia* being lighter in weight are provided with more mobility, its leaf frequency was one of the lowest because of immature plants (seedlings and saplings).

(b) **Tree Density and the Leaf Litter Output:** Tree density appeared to be directly related with leaf litter output. The only exception to appear was that of *A. latifolia* which
in spite of high density did not produce enough leaf litter. This was probably because of the fact that the younger age plants, viz. seedlings and saplings constituted the major portion of the total plant density of this species.

(c) **Basal Area and Leaf Litter:** Litter production appears to be directly proportional to the basal area in most of the species of this stand. However, the exception in case of *A. latifolia* was observed. This can be explained on the basis of plant distribution in different age (g.b.h.) classes as explained in the foregoing para.

Critical examination of data in Table 30 reveals that while species of top canopy layer with an average basal area of about 184 sq cm/tree gave the highest production values; in the same stand species of middle storey with lower average basal area (70 sq cm/tree) registered lower values of litter production.

Most species living as understorey lived in a quite suppressed state and as such produced lesser leaf litter against the lesser basal area figures. However, Bhatnagar (1968) observed that the species of shrub layer and ground flora, although exhibited the least basal area produced considerable quantities of leaf litter. It can be explained on the basis of the fact that in case of these plant forms, loss of plant height is compensated by the lateral spread of branches which run horizontally, or else in case of suckers
**Fig. 26** Biomass Distribution in Different Plant Parts at Various Stages of Growth
Table 31: Organic Matter Dynamics at the Time of Silvicultural Exploitation

<table>
<thead>
<tr>
<th></th>
<th>Tons/Ha</th>
<th>% Total Biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Standing Biomass</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Trunk</td>
<td>29.36</td>
<td>41.5</td>
</tr>
<tr>
<td>(2) Crown (Branches + Leaves)</td>
<td>20.41</td>
<td>29.0</td>
</tr>
<tr>
<td>(3) Roots</td>
<td>20.83</td>
<td>29.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>70.60</td>
<td>100.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Tons/Ha</th>
<th>% Total Biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>B. Removed During Exploitation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Trunk</td>
<td>29.36</td>
<td>41.5</td>
</tr>
<tr>
<td>(2) Branchwood</td>
<td>15.31</td>
<td>21.8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>44.67</td>
<td>63.3</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Tons/Ha</th>
<th>% Total Biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C. Organic Matter Added to the Soil</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Branches + Leaves</td>
<td>5.10</td>
<td>7.2</td>
</tr>
<tr>
<td>(2) Roots</td>
<td>20.83</td>
<td>29.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>25.93</td>
<td>36.7</td>
</tr>
</tbody>
</table>
FIG. 27 CONTRIBUTION OF ORGANIC MATTER (TONS/HA) BY DIFFERENT TREE SPECIES
of the plant the organic output of single plant is compensated by the output of litter from sucker system. The density figures also go high particularly in those cases where tree species survive in the shrub layer by means of suckers.

Ground flora and other lianas, stragglers and shrub also compensate the loss of tree density as most of these plants come up in gaps where light can penetrate through the canopy.

6.5 **EFFECT OF BIOTIC EXPLOITATION AND SILVICULTURAL OPERATIONS ON THE ORGANIC MATTER DYNAMICS IN THE ECOSYSTEM:**

Almost all important species belonging to different stands are exploited for human needs. Exploitation varies from 30-80 per cent of the total biomass depending upon the utility of a particular species. Roots, leaves and flowers of *Butea monosperma* are extensively taken out for making the ropes and brushes for the whitewash, indigenous trays (*Kattal*) and colour, respectively. Leaves of *D. melanoxyylon* are utilized for making common Indian smoke 'bidi'.

At the time of silvicultural fellings, a greater part of aboveground plant biomass is removed from the ecosystem as merchantable timber, fuel and charcoal. The trunk and straight thick branches of large dimensions of important species such as *I. grandis, I. tomentosa, F. marsupium, D. dalbergioides*
etc., are utilized as plywood and sawing logs. Straight and long branches of these species are called poles (ballies) and are utilized in building construction. Small straight branches of *I. grandis* are called 'dengri' and are utilized as fencing posts. Branches which are neither straight nor very thick are called lop-tops and are mostly used as fuel or for the manufacture of charcoal. Species like *A. latifolia* and *D. melanoxylon* are highly favoured for making the charcoal. Various parts of other species are also utilized as food, fodder and fuel.

On an average about 63.3 per cent (44.67 tons/ha) of the total organic matter (70.60 tons/ha) is removed away from the forest at the time of silvicultural exploitation. The only remaining 25.93 tons/ha of the organic matter (\(\overline{C} 36.7\%\)) in the form of roots, leaves and twigs remains in the forest ecosystem. Amongst these, only the small twigs, leaves, flowers and fruits get decomposed subsequently while the thick roots may continue to live and give rise to one or many coppice shoots. Only dead roots, microorganisms and insects which are buried in the soil year after year account for the underground biomass.

In brief, the following points emerge from the above discussion on stand productivity:
(1) Though in Gourjhamar teak forest, a mature tree of *A. latifolia* produced maximum organic matter than trees of same dimension of *I. grandis*, *I. tomentosa* and *D. melanoxylon* (Tables 21-24), its total contribution in the stand biomass was only about 3.3 per cent. As against this, *I. grandis* contributed to the extent of about sixty per cent to the total production of the stand (Table 29) because of a large basal area and normal distribution of age classes. Low total litter production of associate species in general and *A. latifolia* in particular, was due to the immaturity of stand and consequent low basal area.

(2) The leaf biomass which annually becomes a part of the litter layer, though appears to be very insignificant in comparison to total biomass, but on a long term basis it contributes significantly to the stand productivity. In the teak forests of Gourjhamar, leaf litter alone contributed to the extent of 4.96 tons/ha.

(3) While a large part of aboveground plant biomass (C 63.3%) is removed during human exploitation, about 36.7 per cent of the plant biomass still remains to subsequently become as part of forest floor. Annual leaf litter also adds significantly on a long term basis. Similarly, in the last but not the least, ground flora directly and indirectly also enriches the forest floor with organic matter.
6.6 **ROOT SYSTEM OF IMPORTANT TREE SPECIES:**

Laifakari (1927) studied the root development of *F. sylvestris*. After him Gail and Long (1935) did such work on *F. contorta*. Horton (1958) again investigated the rooting habits of *F. contorta* in Canada. Berndt and Gibbons (1958) studied the root distribution of some native trees and understorey plants growing on three sites within *P. ponderosa* watershed in Colorado. Danial (1962) in his studies of rooting habits of *F. contorta*, described a plant-soil adaptation and indicated the zone of greater root development and soil moisture use by repeated and extensive examinations. Leith (1968) suggested methods for determining the productivity of these underground organs.

Saurina and Kamenkaja (1969) carried out root studies on a 32-year pure pine stand, carrying 4,430 living and 950 dead pines per ha. They found out that the total weight of roots was about 26 tons (oven dry) per ha of which 57 per cent represented the 'skeleton' root and 16 per cent the conducting roots. Results were found close to those obtained by Ovington (1962) for pine plantations of about the same age.

Hermann and Petersen (1969) studied the root development and height increment of Ponderosa Pines. A significant increase in the rate of stem elongation, observed when the roots grew from the surface soil into the subsoil, was
attributed to an improvement in moisture relations and possibly, availability of nutrients in the subsoil.

Jørgensen (1968) investigated into root growth of direct seeded Southern Pine seedlings. Root length was longest in loam and slightly shorter in clay soils but only ½ this length in sand. Freezailah and Sandrasegaram (1969) studied the root systems of Pinus caribaea grown in Malaya. The horizontal roots were observed within the top 60 cm of soil.

While the root studies on conifers in temperate zone have been extensive, very little is known about the root system of tree species in tropical dry deciduous forests. An attempt in this direction was made by Kandya (1974) who investigated the horizontal root distribution of some tree species of Sagar forests. This study was carried out purely from biomass production point of view and no attempt was made to study the correlation between various plant organs with root development. However, this study provided a basis for further research in this, hitherto, unknown field.

In the present study, root system of T. grandis, T. tomentosa, D. melanoxylon and A. latifolia of various g.b.h. were investigated and its correlation with various plant parts and their ultimate productivity was analysed.

Data on root system of the tree species investigated are presented in Tables 32-33 and diagrammatically illustrated by figs. 20-24.
<table>
<thead>
<tr>
<th>S.No.</th>
<th>Girth at Breast Height (CMS)</th>
<th>Approximate Age In Years</th>
<th>Length of Taproot (M)</th>
<th>Development of Lateral Roots</th>
<th>Total Root Length (Relative) (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stump Girth (CMS)</td>
<td></td>
<td></td>
<td>Lateral Root Spread (M)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Average No. of Primary Lateral</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Girth of Lateral Roots at Stump Point</td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>12.5</td>
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<td>0.55</td>
<td>1.60</td>
<td>4.0</td>
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<tr>
<td>2.</td>
<td>15.0</td>
<td>10</td>
<td>0.93</td>
<td>1.70</td>
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<tr>
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<tr>
<td>5.</td>
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<td>30</td>
<td>1.20</td>
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</tr>
<tr>
<td>6.</td>
<td>71.0</td>
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<td>1.42</td>
<td>3.68</td>
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<tr>
<td>7.</td>
<td>115.0</td>
<td>50</td>
<td>1.85</td>
<td>6.55</td>
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<td>8.</td>
<td>84.0</td>
<td>65</td>
<td>1.95</td>
<td>6.65</td>
<td>11.0</td>
</tr>
<tr>
<td>9.</td>
<td>130.0</td>
<td>75</td>
<td>1.96</td>
<td>6.50</td>
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</tr>
<tr>
<td>10.</td>
<td>143.0</td>
<td>85</td>
<td>2.01</td>
<td>10.06</td>
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<tr>
<td>11.</td>
<td>165.0</td>
<td>120</td>
<td>2.08</td>
<td>13.20</td>
<td>13.0</td>
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</tbody>
</table>

**Tectona grandis**

**Terminalia tomentosa**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Girth at Breast Height (CMS)</th>
<th>Approximate Age In Years</th>
<th>Length of Taproot (M)</th>
<th>Development of Lateral Roots</th>
<th>Total Root Length (Relative) (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stump Girth (CMS)</td>
<td></td>
<td></td>
<td>Lateral Root Spread (M)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Average No. of Primary Lateral</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Girth of Lateral Roots at Stump Point</td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>14.0</td>
<td>25</td>
<td>1.20</td>
<td>0.56</td>
<td>4.0</td>
</tr>
<tr>
<td>2.</td>
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<td>40</td>
<td>1.60</td>
<td>2.75</td>
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<tr>
<td>4.</td>
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<td>8.05</td>
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<tr>
<td>6.</td>
<td>171.0</td>
<td>150</td>
<td>3.60</td>
<td>15.60</td>
<td>11.0</td>
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</tbody>
</table>

**D. melanoxylon**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Girth at Breast Height (CMS)</th>
<th>Approximate Age In Years</th>
<th>Length of Taproot (M)</th>
<th>Development of Lateral Roots</th>
<th>Total Root Length (Relative) (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stump Girth (CMS)</td>
<td></td>
<td></td>
<td>Lateral Root Spread (M)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Average No. of Primary Lateral</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Girth of Lateral Roots at Stump Point</td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>10.0</td>
<td>15</td>
<td>0.90</td>
<td>1.06</td>
<td>3.0</td>
</tr>
<tr>
<td>2.</td>
<td>41.0</td>
<td>25</td>
<td>1.10</td>
<td>5.90</td>
<td>3.5</td>
</tr>
<tr>
<td>3.</td>
<td>65.0</td>
<td>35</td>
<td>0.98</td>
<td>7.20</td>
<td>4.0</td>
</tr>
<tr>
<td>4.</td>
<td>72.0</td>
<td>50</td>
<td>0.80</td>
<td>7.80</td>
<td>4.8</td>
</tr>
<tr>
<td>5.</td>
<td>135.0</td>
<td>100</td>
<td>1.06</td>
<td>10.65</td>
<td>4.0</td>
</tr>
<tr>
<td>6.</td>
<td>148.5</td>
<td>120</td>
<td>1.05</td>
<td>11.70</td>
<td>5.0</td>
</tr>
</tbody>
</table>

**A. latifolia**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Girth at Breast Height (CMS)</th>
<th>Approximate Age In Years</th>
<th>Length of Taproot (M)</th>
<th>Development of Lateral Roots</th>
<th>Total Root Length (Relative) (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stump Girth (CMS)</td>
<td></td>
<td></td>
<td>Lateral Root Spread (M)</td>
<td></td>
</tr>
<tr>
<td></td>
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<td>Average No. of Primary Lateral</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Girth of Lateral Roots at Stump Point</td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>10.0</td>
<td>15</td>
<td>1.02</td>
<td>1.06</td>
<td>4.5</td>
</tr>
<tr>
<td>2.</td>
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<td>40</td>
<td>1.20</td>
<td>8.50</td>
<td>6.0</td>
</tr>
<tr>
<td>3.</td>
<td>72.0</td>
<td>55</td>
<td>1.15</td>
<td>11.90</td>
<td>6.0</td>
</tr>
<tr>
<td>4.</td>
<td>105.0</td>
<td>90</td>
<td>0.90</td>
<td>14.60</td>
<td>7.0</td>
</tr>
<tr>
<td>5.</td>
<td>120.0</td>
<td>110</td>
<td>1.25</td>
<td>15.40</td>
<td>7.0</td>
</tr>
</tbody>
</table>
A perusal of data in Table 32 reveals that while the vertical root penetration ranged from 0.55 to 3.60 m the horizontal root spread was found to vary from 0.56 to 15.60 m. In *T. grandis*, the horizontal root spread ranged from 1.60 m in plants of 7.5 cm g.b.h. to 13.20 m in trees with 133 cm g.b.h. While in young plants of *T. tomentosa* (10 cm g.b.h.) the root was 0.56 m, in mature tree of g.b.h. 145 cm the lateral spread of 15.60 m was recorded. In young *D. melanoxylon* (g.b.h. 7.5 cm) and *A. latifolia* (8.5 cm g.b.h.) the lateral spread was found to be 1.06 m. In mature trees of these species (135 and 100 cm g.b.h., respectively) the root spread was found to be 11.70 and 15.40 m, respectively. When these species of identical g.b.h. were compared for their lateral spread, *A. latifolia* showed greater lateral spread followed by *T. tomentosa*, *T. grandis* and *D. melanoxylon*. While a stout and deep taproot was observed in *T. grandis* and *T. tomentosa*, it was poorly developed in *A. latifolia* and *D. melanoxylon*. In the latter species it was sometimes very difficult to identify the taproot from lateral roots. In *T. grandis* and *T. tomentosa* the secondary and tertiary roots were prominent coming out rather sparsely (Figs. 21-23). In *A. latifolia*, small rootlets in brush-like cluster were observed coming out mostly from the base of main trunk (Fig. 20). This formation was found more pronounced in middle and mature-aged trees rather than in young plants. The cluster of wiry roots, probably provide maximum absorption, enabling this species to
survive and develop on difficult and xeric sites also. Development of secondary and tertiary roots in *D. melanoxylon* were very poor, only few prominent lateral roots coming out from the base of trunk (Fig. 24).

A mature tree of *T. tomentosa* having a g.b.h. of 145 cm possessed 11 primary lateral roots. The circumference of these primary lateral roots ranged from 31-68 cm at their points of origin and 3-4 cm at the end (Fig. 23). In a mature teak tree (133 cm g.b.h.) there were 13 primary lateral roots with an average circumference of 46 cm (Figs. 21-22). Though, the lateral roots were more profusely branched in *T. grandis* than *T. tomentosa*, in the latter species, the lateral roots extended to a greater distance from the trunk and penetrated deeper than *T. grandis*. An extensive lateral and deep taproot system of *T. tomentosa* thus, probably provide a better anchorage to this species and thus the trees are generally not uprooted by winds.

The root system of *D. melanoxylon* appeared to be very much different from other trees. The regeneration of this species by root suckers was extremely prevalent. In any area a group of plants of various sizes can be seen which on excavation may be found to be connected together by horizontally running (20-30 cm deep) root suckers. All these sucker plants may ultimately be found connected with a long extending root of immature tree at some remote distance.
Occasionally, the horizontal root suckers may produce lateral roots which may coil while growing vertically. The root system of trees of six different g.b.h. which were studied showed poor development of taproot.

In Acacia latifolia, at the base the tree trunk acquired an appearance of frying buttresses due to upward extension of lateral roots.

Comparative study of total estimated root length* (relative root length) showed that Acacia latifolia showed the maximum root length because it possessed cluster of small fibrous roots at the base of trunk. Trees of T. grandis and T. tomentosa showed almost similar root length, it was poorest in D. melanoxylon because of poor branching primary lateral roots (Fig. 24).

6.7 CORRELATION BETWEEN ROOT SPREAD, CROWN SPREAD AND OTHER PLANT PARAMETERS:

Two types of correlation, bimorphological and correlation of growth have been suggested in the plants by Kolesnikov (1971). In the second type of correlation he postulated that a tree with vigorous root system has a vigorous aboveground system and vice-versa. On this analogy, the root spread was

---

* Roots up to 2 cm in thickness were traced and accounted for computing total length.
Table 33: Relationship Between Root Spread and Crown Spread in Important Tree Species

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Average Girth at Breast Height (CM)</th>
<th>Estimated Age (Years)</th>
<th>Root Spread (M)</th>
<th>Crown Spread (M)</th>
<th>Root Spread / Crown Spread Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>7.5</td>
<td>7</td>
<td>1.60</td>
<td>1.10</td>
<td>1.50</td>
</tr>
<tr>
<td>2.</td>
<td>8.5</td>
<td>10</td>
<td>1.70</td>
<td>1.20</td>
<td>1.41</td>
</tr>
<tr>
<td>3.</td>
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<td>15</td>
<td>2.20</td>
<td>1.95</td>
<td>1.12</td>
</tr>
<tr>
<td>4.</td>
<td>25.0</td>
<td>20</td>
<td>2.40</td>
<td>2.02</td>
<td>1.17</td>
</tr>
<tr>
<td>5.</td>
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<td>30</td>
<td>3.08</td>
<td>2.70</td>
<td>1.14</td>
</tr>
<tr>
<td>6.</td>
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<td>40</td>
<td>3.68</td>
<td>5.43</td>
<td>0.66</td>
</tr>
<tr>
<td>7.</td>
<td>72.0</td>
<td>50</td>
<td>6.55</td>
<td>6.20</td>
<td>1.05</td>
</tr>
<tr>
<td>8.</td>
<td>76.0</td>
<td>65</td>
<td>6.65</td>
<td>6.30</td>
<td>1.05</td>
</tr>
<tr>
<td>9.</td>
<td>95.0</td>
<td>75</td>
<td>6.50</td>
<td>6.05</td>
<td>1.08</td>
</tr>
<tr>
<td>10.</td>
<td>112.0</td>
<td>85</td>
<td>10.06</td>
<td>7.55</td>
<td>1.33</td>
</tr>
<tr>
<td>11.</td>
<td>133.0</td>
<td>120</td>
<td>13.20</td>
<td>10.60</td>
<td>1.22</td>
</tr>
</tbody>
</table>

Tectona grandis

|       |                                     |                       |                 |                 |                               |
| 1.    | 10.0                                | 25                    | 0.56            | 0.25            | 2.2                           |
| 2.    | 35.0                                | 40                    | 2.75            | 2.40            | 1.2                           |
| 3.    | 50.0                                | 60                    | 6.05            | 3.50            | 2.4                           |
| 4.    | 68.0                                | 70                    | 4.20            | 3.90            | 2.1                           |
| 5.    | 96.0                                | 90                    | 11.20           | 5.40            | 2.0                           |
| 6.    | 145.0                               | 150                   | 15.60           | 9.00            | 1.7                           |

Terminalia tomentosa

|       |                                     |                       |                 |                 |                               |
| 1.    | 8.5                                 | 15                    | 1.06            | 0.55            | 2.0                           |
| 2.    | 35.0                                | 25                    | 5.90            | 4.00            | 1.5                           |
| 3.    | 52.0                                | 35                    | 7.20            | 5.20            | 1.4                           |
| 4.    | 62.0                                | 50                    | 7.80            | 6.00            | 1.3                           |
| 5.    | 115.0                               | 100                   | 10.65           | 9.50            | 1.1                           |
| 6.    | 135.0                               | 120                   | 11.70           | 10.00           | 1.1                           |

D. melanoxylon

|       |                                     |                       |                 |                 |                               |
| 1.    | 7.5                                 | 15                    | 1.06            | 0.62            | 1.7                           |
| 2.    | 42.0                                | 40                    | 8.50            | 5.00            | 1.7                           |
| 3.    | 55.0                                | 55                    | 11.90           | 6.00            | 2.0                           |
| 4.    | 85.0                                | 90                    | 14.60           | 7.50            | 2.0                           |
| 5.    | 100.0                               | 110                   | 15.40           | 10.00           | 1.5                           |

A. latifolia
correlated with the crown spread and other growth parameters. The result of this correlation are summarized in Table 33.

In the present investigation, in almost all the cases horizontal root spread was found to extend far beyond the crown spread, being less pronounced in younger plants and more conspicuous in mature trees. On an average the root spread was 1.16 times of crown spread in teak and two times in *I. tomentosa*. Other two species occupied the intermediate position. From these observations, it can be concluded that frequent uprooting in teak may be due to relatively bigger crown than in other species. The other possible reason for frequent uprooting in teak may be its leaf size which appears to offer resistance to winds.

In *I. tomentosa*, root/crown spread ratio was superior to other species and thus this species is able to withstand the impact of high wind velocity.

Relationship between root spread \((x)\), crown spread \((y)\) in metres and total aboveground biomass \((z)\) computed for *I. grandis* can be expressed in the form of regression equation as follows:

\[ Z = 63.09 \times + 52.30 \times Y \]

where,
- \(Z\) = aboveground biomass kg/tree,
- \(X\) = root spread (m),
- \(Y\) = crown spread (m).
Thus, by knowing the root and crown spread, it is possible to determine the aboveground plant biomass. Similarly, other two parameters can be computed by aboveground plant biomass.

In the light of above observations, it can be postulated that competition sets in between the root systems of adjacent plants before the branches meet, particularly those of the same species with similar requirements. Reduction of the number of competing crowns carries with a reduction in the number of competing root systems, and it is difficult to differentiate the effects of the two factors. Experiments on Shorea robusta show that the growth of an overwood is significantly reduced by the root competition of an underwood of coppice shoots (Champion and Griffith, 1948). It has also been amply demonstrated that the competition of the root system of an overwood has a markedly detrimental effect on the development of seedling regeneration (Bhatnagar, 1959). The roots of adjoining forest stand may similarly check the growth of plantation along their line of junction. Moisture supply is believed to be the usual limiting factor, and weak development commonly ascribed to inadequate light is often really due in the first place to excessive root competition for water; this competition of course generally sets in during the dry season and is unlikely to come into play under monsoon conditions which usually prevail during the first few months.
of a seedling's life (Seth and Khan, 1960). Root competition is, therefore, of the greatest importance in 'Dry Deciduous Teak' forests.