DISCUSSION

On the basis of information now available, it appears logically sound to argue that the standing biomass in a forest or its tree species depends upon site quality, climatic conditions, age of trees, nature of species and rate of primary production, etc. Therefore, a comparison of standing biomass data of forest stands and species of different climatic regions has to be made with caution.

A study of standing aboveground biomass of four selected tree species, i.e., *T. grandis*, *T. tomentosa*, *A. latifolia* and *D. melanoxylon* has shown that the total aerial dry weights in these species at a lower CBH (< 75 cm.) are lesser than those of many other species like *Pinus sylvestris*, *Betula verrucosa* and *Shorea robusta* of about the same CBH (Table 55). For instance, a tree of *B. verrucosa* of 66 cm. CBH has been shown to possess 165.9 Kg. of dry organic matter while the aboveground biomass value for a tree of *T. grandis* of approximately the same CBH (72 cm.) was only 109.97 Kg.
A comparison of the four tree species of Sagar with an extensively investigated species of temperate regions of Europe, i.e., Pinus sylvestris shows that in lower CBH group, the aboveground biomass values of the former are appreciably low than the latter. On the other hand, at a CBH 79 cm. and above aboveground biomass of deciduous tree species of this region begins to exceed P. sylvestris and other conifers.

The lower biomass values at the smaller CBH and a higher biomass value at a bigger CBH of deciduous trees in comparison to temperate species may be due to an adverse condition of growth faced by deciduous trees at lower CBH stage. The scarcity of moisture and a poorly developed root system at a lower CBH stage, in trees of tropical deciduous forests, probably become limiting factors in the production and accumulation of organic matter. But, at a mature or higher CBH stage, the trees are able to make a strong hold of soil in deeper horizons for getting moisture and nutrients, hence are capable of synthesizing the organic matter more efficiently.

As far as the total number of leaves per tree is concerned, it is likely to be significantly higher in temperate species like conifers, than the broad leaved species of any region. A. latifolia, possessing the largest number of leaves per tree among the species of Sagar, show 13572 to 123726 leaves on the smallest and largest individuals respectively, whereas
Weetman and Harland (1964) found 1,00,000 to 2,000,000 needles per tree in *Picea marina* and Ovington (1965a) found 11,400 to 75,600 leaves/tree in *Betula verrucosa*.

It has already been described in Chapter V, that total leaf area per tree increased with an increase in tree CBH (i.e., age). All the four species studied have shown this phenomenon. In *T. grandis*, the values for photosynthetic area per tree ranged from 13.88 to 225.99 sq.m. from the lowest CBH (12.5 cm.) to maximum CBH (107 cm.) respectively. *A. latifolia* and *T. tomentosa* have also shown such a wide range of leaf area per tree (i.e., from 24.36 to 236.62 sq.m. and from 12.95 to 209.47 sq.m. respectively). But, *D. melanoxylon* has shown a very short range of leaf area per tree and the values ranged from only 0.97 to 98.7 sq.m. (Tables 18 and 19).

When these ranges in the values of photosynthetic area were compared with those of *Pinus sylvestris*, *Betula verrucosa*, *Shorea robusta*, *Erythrina suberosa* and many other tree species (Table 56) it was observed that these species showed comparatively shorter ranges of variation in total photosynthetic area per tree, and at the same time, the values were always lesser than those determined for *T. grandis*, *T. tomentosa* and *A. latifolia* in the present investigation.

In the present study, it has been found that on a percentage basis, trunk biomass ranged from 44.9% to 76.8% of
the total tree biomass while branch biomass ranged from 16.3% to 24.3% and the roots showed a range from 15% to 40.2% (Tables 9 to 12). Similar studies of other species like Picea abies and Fagus sylvatica (Nihlgard 1972), Betula verrucosa (Ovington and Madgwick 1959) and Shorea robusta (Misra 1970) also show such ranges (Table 58) of trunk, branch and root biomass values.

The percentage values of branch and root biomasses of trees of Sagar (CBH 55 and 72) were found to be higher than those of Picea abies, Fagus sylvatica and Shorea robusta, etc. This may be due to the fact that the branches of trees in dry deciduous forests are very much ramified (somewhat dichotomously) than those of the conifers where straight tapering bole and some thin branches are generally produced due to monopodial branching. Such a sparse branching results in a higher biomass value of trunk and a comparatively low value of branch biomass in conifers. On the other hand, usually the main bole gets bi- or trifurcated and two or three very huge branches are formed in trees of tropical deciduous zone. These branches in turn again form many small branches which divide profusely in several twigs, hence, a very broad canopy of the tree is formed. To support such a dense canopy, the roots have to prepare a very strong anchorage hence they travel to long distances forming an underground reticulum which binds a considerable amount of soil and fixes the tree strongly.
Naturally, the percentage fraction of such roots becomes quite high in the total tree dry weight. In conifers, such a profused branching of the roots is not seen and the biomass fraction of roots in them is lower (Table 58) than those of deciduous trees.

In the present study, it has been observed in all the four species that total plant biomass of a tree increases, with an increase in different growth parameters like CBH or height of the tree. Tree CBH has shown a positive correlation with total plant dry weight although after a certain limit, the biomass of a tree does not increase and becomes almost constant while the CBH increases continuously and the trunk becomes hollow. The regression equations and coefficients of correlation obtained for different species are as follows:

<table>
<thead>
<tr>
<th>Species</th>
<th>CBH (cm.)</th>
<th>Coefficient of correlation (r)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T. grandis</td>
<td>50.71 ± 0.1 y</td>
<td>0.90</td>
</tr>
<tr>
<td>T. tomentosa</td>
<td>38.27 ± 0.09 y</td>
<td>0.82</td>
</tr>
<tr>
<td>A. latifolia</td>
<td>27.37 ± 0.09 y</td>
<td>0.94</td>
</tr>
<tr>
<td>D. melanoxylon</td>
<td>26.70 ± 0.2 y</td>
<td>0.98</td>
</tr>
</tbody>
</table>
Similar observations have also been made by Pandeya et al. (1971a, b, c, 1973) for *Mitragyna parviflora*, *Butea monosperma*, *Adina cordifolia* and *Erythrina suberosa*, etc. in India and by Rutter (1955) for *Pinus sylvestris* and *Picea sitchensis* in England. Nomoto (1964) has also cited such correlations in *Fagus crenata*, *F. japonica* and *Querus crispula*.

Since the CBH of a tree was found to show a direct relationship with the total aboveground dry weight of the tree, rate of organic matter production was determined in relation to tree CBH. It was observed that the rate of trunk dry matter production was very high in the deciduous species than those of many other species like *Pinus sylvestris*, *Betula verrucosa* (Table 59). Results, similar to those of present study have been recorded in *Shorea robusta* by Misra et al. (1967). In case of *S. robusta*, at the lower CBH stage the rate of dry matter production in trunk is considerably higher than those of the four species, viz. *I. grandis*, *I. tomentosa*, *A. latifolia* and *D. melanoxylon*. But, at a higher CBH or adult stage the rate appears to be equal.

Except *D. melanoxylon*, each species showed a straight rise in the rate of trunk dry matter production as has also been encountered by Misra et al. (1967) in *Shorea robusta*, and Ovington (1957) in *Pinus sylvestris*. On an average basis, more or less similar rates of organic matter production in *S.*
robusta and other species of Sagar may be due to similar climatic conditions prevailing in these regions.

Rate of organic matter production for the total non-photosynthetic parts of these trees appeared to follow the trend of dry matter production by trunk. The value was very high (22.22 Kg./tree) in A. latifolia while it was found very low in Mitragyna parviflora (8.85 Kg./tree), Butea monosperma (5.50 Kg./tree), Erythrina suberosa (6.34 Kg./tree) and many other species (Table 60).

Rate of trunk dry matter production in different species per sq.m. of leaf area has shown an irregular trend in values. In L. grandis, the production rate was seen increasing straight way with an increase in tree CBH (0.37 to 8.31 Kg./sq.m. leaf area/tree) while in L. tomentosa, A. latifolia and D. melanoxylon, the rates declined a little after reaching the maximum values at the adult or mature stage of life.

Similar studies, conducted by Ovington (1957) and Ovington and Madgwick (1959) for trunk dry matter production in Pinus sylvestris and Betula verrucosa respectively have also shown such a decline in the production rates. But, in Shorea robusta, Misra et al. (1967) did not find such a decline and the values showed a straight rise (from 0.14 to 0.47 Kg./sq.m. leaf area/tree).

The values for trunk dry matter production per sq.m. of
photosynthetic area were found to be very high in all the species taken into consideration in the present study.

A study of aboveground standing plant biomass in the five forest sites of Sagar has shown that on an average these forests possess $115 \times 10^3$ Kg. of dry organic matter per hectare. This value when compared with those of other forests of the world (Table 62) was seen to be quite low. In temperate (Picea abies, Sweden; Pseudosuga taxifolia, Washington; Fagus sylvatica, Sweden and Betula verrucosa, Moscow) as well as in tropical deciduous forests (Shorea robusta, India and forest of Ghana) the total aboveground dry weight per hectare was seen to be very high in comparison to that of the tropical deciduous forests of Sagar.

Higher aboveground biomass values in the temperate and evergreen forests (Table 62) may be due to greater age of stand, larger amount of nutrients as available in temperate soils and better moisture condition in the forests. In temperate regions, a large amount of organic matter accumulates on the soil surface and maintains a constant supply of nutrients and moisture to the tree roots. Similarly, in the humid regions of tropical zones, the conditions for growth of plants are always optimum, and maximum production of organic matter can take place.

But, in the forests of Sagar and similar regions supporting
deciduous vegetation, there is a strong periodicity in growth conditions. An absence of leaves from the tree canopy for more than a couple of months and a scarcity of soil moisture, limit the plant growth and hence a low value of standing aboveground biomass per hectare is seen.

The value of average photosynthetic area per hectare for the forests of Sagar was found to be $44.55 \times 10^3$ sq.m./ha, showing a range of variation between $29.29 \times 10^3$ sq.m. to $65.52 \times 10^3$ sq.m. per hectare (Table 63). Westman and Harland (1964) estimated a Leaf-Area-Index (LAI) of 9.8 ha./ha. in a forest of *Picea marina* of Canada, while Nihlgard (1972) observed values of LAI as high as 11.5 ha./ha. in a stand of *Picea abies* and as low as 2.9 ha./ha. in a stand of *Fagus sylvatica* in Sweden. On the other hand, in a forest of *Shorea robusta* at Gorakhpur, Foruqui (1972) found a range of LAI from only 2.1 to 13.4 ha./ha. and in a *Tectona grandis* forest, from 8.6 to 17.4 ha./ha. LAI was observed by him.

When the contribution of various plant parts towards the total aboveground biomass per hectare was observed in different forests, it was marked that usually the trunk fraction ranged from 67.92% to 91.75%. The branch dry weight per hectare showed a range from 8.74% to 31.79% while leaves were found to contribute 1.0% to 8.38% of the total aboveground plant biomass per hectare. In the present study, the results are obtained similar to those of Ovington (2957), Misra (1970) and Nihlgard
In Table 64 it can be seen that the highest bole biomass (262 tons/ha.) was recorded in a stand of *Picea abies* in Sweden. In comparison to this, in the forests of Sagar, the value of bole biomass comes to only 100.8 tons/ha. This value is lower than those of many other forests of the world (Table 64).

The contribution of branch biomass was 103 tons/ha. in a forest of *Fagus sylvatica* in Sweden, while in a forest of *Pinus nigra*, the value was as low as 11.2 tons/ha. In the forests of Sagar, the average branch biomass values were 28.5 tons/ha.

Percentage proportions of bole and branch biomasses indicate that in *Betula verrucosa* trunk formed a very high fraction. On the other hand, in *Cuercus borealis*, the branch fraction was very high indicating the fact that branching in this species is probably very much profuse. In the present study also, a range from 16% to 34.6% has been observed in different forest sites for the branch fraction (Table 29) per hectare. Though, the mode of branching and thickness of branches may undoubtedly be an inherent characteristic feature of each species but in xeric habitats receiving a higher insolation, the same species may have spreading umbrella-like canopy. This may result in a higher branch biomass.

A maximum of leaf dry weight per hectare was observed in an evergreen gallery of Thailand (19 tons/ha.) while lowest
value was noted for a forest of *Northofauxa truncata* in New Zealand (2.7 tons/ha.). In the local forests, the values for total leaf dry weight per hectare did not show much fluctuations (3.2 to 5.7 tons/ha.) as is seen in Table 29.

In the present study, an inverse relationship has been observed between the girth of trunk or root and the percentage weight of bark in the trunk or root at that girth. As the circumference of trunk or root increases, the thickness of overlying bark does not increase proportionately hence its proportion in the trunk for root biomass decreases (Tables 18 and 19). It has already been mentioned earlier (Chapter V) that percentage dry weight of bark in the trunk ranged from 62.2% to 14.1% in *T. grandis*. Approximately, similar ranges were marked in other species also.

Attwill (1962) also found out such a relationship in *Eucalyptus obliqua* although the values for percentage dry weight of bark in the trunk showed a range from 33% to 18.3% only. This range of variation in bark biomass fraction of the trunk is smaller as compared to the results as found in the tree species of Sagar. Attwill suggested that such a relationship can be used to predict and to estimate directly the weight of wood and bark at each girth of the trunk or root, whatever it may be.

The total quantity of bark produced by a tree may infact
be considerably large and even more than the wood biomass since the superficial dead layers periodically scale off from the trunk and branches and gets incorporated into soil hence remain unnoticed. In case of deciduous trees around the trunk, a heap of soil is seen formed which is mainly due to accumulation of trunk bark which peals off and continuously falls. In the tropical deciduous forests, dead retangular pieces of bark remain coated with soil and do not decompose quickly hence form an appreciable fraction of soil organic matter.

A study of biomass of various plant parts in average mature individuals of six selected tree species in present work has shown that about 64% of the total tree dry weight which is stored in the form of trunks and thick straight branches of economic value, is utilized for timber purposes, i.e. in making the buildings and huts, etc. About 12% part which is represented by comparatively thinner and curved branches, is utilized for fuel and coal making, but it is also useful in short-length purposes of timber, i.e. in furniture making, etc. Only 4% part of the total tree dry weight contributed by twigs and leaves comes to the forest floor when such a tree is cut (Table 36). About 20% of the biomass which is contributed by the roots of harvested trees may be incorporated in soil if the root-system becomes dead. Otherwise, it may give rise to some coppices and ultimately tree to live for some more years.
Such balance or budget-sheets indicating the dynamics of different components of the plant body have also been prepared by Ovington (1965b) for many tree species of temperate zone. Ovington (1965b) calculated that in a plantation of *Pinus sylvestris*, the total aboveground biomass per hectare was 1,16,200 Kg., out of which about 96,700 Kg., contained in boles is meant for timber purpose while 12,300 Kg. of dry weight, represented as branch and twig fraction can be utilized for fuel, coal and short-length purposes of timber, 7,200 Kg. of dry weight contained in needles is always added to the forest soil in the form of litter. Corresponding values in the forests of Sagar are found a little higher. Still higher values are reported in other species like *Fagus sylvatica*, *Picea abies*, *Northofagus truncata* and many others (Table 64).

In the present study, data on individual tree basis have shown that at the time of silvicultural falling, after all deductions, maximum addition of organic matter to the forest eco-system is by *A. latifolia* (203.53 Kg./tree) while the lowest amount is by *D. melanoxyylon* (132.61 Kg./tree).

In a study of morphological appearance of the root systems (Figs. 16-20) it was observed that roots were profusely branched in all directions in each of the six tree species, i.e. *T. grandis*, *T. tomentosa*, *A. latifolia*, *D. melanoxyylon*
B. monosperma and L. coromandelica. Such highly spreaded roots provide a strong anchorage to the aerial parts of the tree by finding a considerable amount of soil within the underground reticulum. Very thin, minute rootlets were seen arising frequently from any part of the primary, secondary and tertiary roots of all species, except B. monosperma. Similar rootlets of straw-diameter, arising randomly and only 3 to 8 cm. long were also noted by Danial (1962) in Pinus contorta.

In all the species presently studied, most of the stouter and thicker roots were found in upper 50 cm. of soil as has also been noted by Nihlgard (1972) in Fagus sylvatica and Picea abies. Danial (1962) reported that a zone up to the depth of only one foot (30 cm.) from the top of soil was occupied by largest amount of roots in Pinus contorta. He found that occasionally vertical offshoots arose from the roots of this species for vegetative propagation. Such a phenomenon is very common in D. melanoxylon in this area.

A detailed account of root diameters at different intervals showed that beyond two meters from the tree's centre, the tapering of lateral roots slowed down. A radius of 3 meters from the tree's centre has been reported by Danial (1962) for the lowering of tapering rate of the lateral roots.

In a study of energy content contained in the aboveground
vegetation, it has been seen in the present study that on an average about 334.2 x 10^6 Kg.cal./ha. of energy is accumulated in trees only, while Ovington (1965b) in a 26 yrs. old plantation of *Pinus sylvestris* found that 339 x 10^5 Kg.cal./ha. of energy content was contained in the tree vegetation. This value is a little lesser probably due to the lesser age of the plantation in comparison to that of the dry deciduous forests of Sagar (Table 53). According to Ovington (1965b), the higher values observed in the plants of tropical forests are due to the fact that plants in these forests receive larger amount of solar energy (about 600 x 10^{10} cal./ha.) in comparison to those of the temperate forests (100 x 10^{10} cal./ha.), although the energy held within the plant biomass represents only a tiny (1 to 3%) part of the total solar radiation captured by photosynthesis.

Ovington (1965b) calculated that the energy content contained in the shrub layer was only 6 x 10^5 Kg.cal./ha. in *Pinus sylvestris* plantation while in the present investigation a quite higher value (9.8 x 10^6 Kg.cal./ha.) has been observed for shrub layer (Table 53).

On individual tree basis, it has been estimated that, after all subtractions, an average mature tree of *B. monosperma* (>100 cm. CBH) can add maximum energy content to the forest floor (to an extent of 635 x 10^3 Kg.cal.) at the time of its harvest. This energy becomes available to various soil
organisms when the litter of different plant parts (twigs and leaves, etc.) left unnoticed in the forest at the time of silvicultural cutting, gets decomposed. Some 4-5 times more energy is exported from the forest ecosystem in the form of trunk and branches of cut trees (Table 54).