CHAPTER-5

PLANT BIOMASS AND PRODUCTIVITY OF TREES

5.1 Introduction

The quantity of living plant material in a forest is called the biomass. Photosynthesis is the unique biochemical process by which carbohydrate from carbon dioxide is synthesized in green parts of the plant and stored in the form of organic matter which is termed as live plant biomass. Biomass is an important parameter to assess the assimilation of carbon by plants. Biomass and carbon storage in forest ecosystems play an important role in global carbon cycle (Goodale et al., 2002; Houghton, 2005; Li et al., 2011; Zhao et al., 2014) because forest ecosystems act as a major carbon sink and store more carbon per unit area than any other terrestrial ecosystem (Houghton, 2007). Tree biomass plays a key role in sustainable forest management by regulating different aspects of ecosystem structure and function. The plant biomass is mainly compartmentalized in aboveground biomass (AGB) and belowground biomass (BGB) in different types of forest ecosystems. Above-ground biomass consists of all living biomass above the soil including stem, stump, branches, bark, seeds and foliage. Above ground biomass (AGB) is a useful measure for assessing changes in forest structure (Brown et al., 1999) and an essential aspect of studies of carbon cycle (Cairns et al., 1997; 2001; Ketterings et al., 2001). Below-ground biomass consists of all living roots excluding fine roots (less than 2mm in diameter). Aboveground biomass is a key variable in the annual and long term changes in the global terrestrial carbon cycle and other earth system interactions. The quantification of forest biomass has a long history because of its importance for timber and fuel to many societies around the world. In the past decades, the forest biomass quantification has attracted renewed interests because forest standing biomass represents about 44 % of the world forest carbon pool (Pan et al., 2011), thereby having a key role in climate change mitigation.

The forests accumulate greatest plant biomass which has been reported to increase generally from temperate to tropical forest ecosystems. The perennial aerial structures in the forests account for nearly three-fourth of the total biomass, while the roots account for only about one-fourth. Above-ground biomass (AGB) estimates provide information on the location of sources and sinks of carbon and allow the
quantification of the amount of carbon lost from sinks through deforestation and
degradation (Ketterings et al., 2001; Houghton, 2005). Estimates of aboveground
biomass are critical for analyzing the carbon stocks and fluxes of forest communities
(Brown, 1997; Návar, 2009a, b); the amount of primary energy that can be obtained
from forests as an alternative to fossil fuels (Richardson et al., 2002) as well as
estimating the stocks and fluxes of other biogeochemical elements, such as nitrogen
(Hughes et al., 1999). Studies have indicated that biomass in mature tropical forest
generally increases along precipitation gradients. Recently, a review of 229 estimates
of aboveground biomass from 44 studies in seasonally dry tropical forest confirmed
the paramount importance of precipitation (Becknell et al., 2012). In this analysis,
above ground biomass (AGB) of mature forests ranged from 39 to 334 Mg ha\(^{-1}\) and
showed a positive relationship with mean annual precipitation which explained >50% of
the variation in AGB. The biomass in dry tropical forest is not uniformly
distributed across the forest but exhibits patchy distribution (Chaturvedi et al., 2011).
Tree diameter and height data from forest plots have been used to estimate carbon
stocks through the calculation of AGB (Kettering et al., 2001; Chave et al., 2005).
Estimating the amount of forest biomass gives an idea of carbon sequestration
potential in the forest ecosystems (see Gupta and Kumar, 2014).

Primary production of a community or any part thereof is defined as the total radiant
energy or CO\(_2\)-C fixed by photosynthetic activity of producer organisms, chiefly
the green plants; (Chapin III et al., 2006) per unit area in a given period of time. The
term net ecosystem production (NEP) was first introduced by Woodwell and
Whittaker (1968) to represent the difference between ecosystem level photosynthetic
gain of CO\(_2\)-C (i.e. GPP) and ecosystem level (plant, animal and microbial)
respiratory loss of CO\(_2\)-C (i.e. ecosystem respiration, ER). The tropical forest biome is
characterized by high productivity and tropical forests contribute approximately one-
third of the global terrestrial productivity (Beer et al., 2010). Improved measurements
of NPP have included annual litter fall, thereby resulting in high values of forest
biomass (Martínez-Yrízar et al., 1996; Bullock et al., 1995). Biomass distribution in
forest ecosystem is a function of vegetation type, its structure and site condition.
Dimension analysis involving measurement of the easily measurable parameters of
tree growth and weight of trees and tree components is the commonly used method
for estimating productivity in tree plantations and forest ecosystems (Kira et al., 1967; Whittaker and Woodwell, 1971).

Litter-fall is a major pathway for return of organic matter and nutrients from aerial parts of plant to the soil surface. It is another important component of organic matter dynamics and nutrient cycling in a forest and its input depends upon variety of factors such as species, age groups, canopy cover, weather conditions and biotic factors (Lodhiyal et al., 2002). A substantial amount of nutrients taken up by plants is returned to the soil as litter-fall followed by its decomposition in the soil. Standing crop of litter accumulated on the ground floor acts as an input–output system of nutrients, litter decomposition; regulate energy flow, primary productivity and nutrient cycling in forest ecosystems (Sundarpandian and Swamy, 1999; Pragasan and Parthasarathy, 2005). However, due to variations in canopy architecture and tree species, amounts and rates of litter-fall and decomposition show considerable spatial variation (Sundarpandian and Swamy, 1999; Pragasan and Parthasarathy, 2005). Tropical forest canopy productivity consists of the formation and growth of leaves, twigs, flowers, and fruits, and is typically estimated to be equal to the rate of litterfall (see Malhi, 2012). Indeed, litter fall is one of the most frequently measured components for estimating net primary productivity in forest ecosystems. Leaf litter fall is typically the largest fraction of total litter fall (Malhi, 2012).

This chapter deals with analysis of plant biomass and productivity of trees and its distribution among different primary producer compartments in different forest ecosystems.

5.2 Methods

5.2.1 Estimation of Litter fall

The litter fall was collected using 1x1m quadrats laid randomly on the ground lined with polyethylene sheet at monthly intervals from January 2012 to December 2012 in forest ecosystems of Gurgaon and from January 2013 to December 2013 in forests of Mahendergarh and Bhiwani districts. The amount of litter fall was determined at monthly intervals. The litter samples were brought to laboratory and separated into leaf litter and twig litter. The litter samples were oven-dried at 65°C and weighed and presented on dry weight basis.
5.2.2 Estimation of Forest Floor Litter

Standing crop of forest floor was determined seasonally using the quadrat method. The forest floor litter was collected at the first week of October, March and June by placing ten 1x1m quadrats during the study period. The litter samples were separated into leaf and twig components. The samples were freed from adhering soil particles and oven dried at 65°C for determining dry weight. Sub samples were washed with deionised water, oven dried at 45°C and stored for chemical analysis.

5.2.3 Estimation of Plant Biomass

Biomass of trees was estimated by dimension analysis of sampled trees using volume regression equations between circumferences at breast height (CBH) or diameter and using specific gravity. The circumference of trees was measured at 1.37m height from the ground.

Twelve experimental plots of 20×20m were demarcated within each forest site at Gurgaon, Bhiwani and Mahendergarh districts for recording the observations on growth parameters of trees. Trees were marked and their circumference measured at 1.37 m height above from the ground. Wood volume of individual trees was estimated using local species specific volumetric equations using either DBH (diameter at breast height) and/or height of the trees. The volume was multiplied by species specific gravity to obtain the aboveground biomass. For this the site and species-specific volumetric equations and specific gravity were published and compiled by Forest Survey of India (FSI, 1996) and ICFRE (1996–2002). The specific volumetric equations and species gravity of trees for 15 species were used following FSI (1996, 2011). For the remaining species general equations was used. The mean biomass of the various trees was added to find the biomass for each site. Volume equations and specific gravity values used for biomass estimation of trees species (FSI, 1996) are given in Appendix Table 3.

Below ground biomass was computed by using the regression equation of Cairns et al. (1997) for tropical trees for each forest type as follows: \( BGB = \exp \{ -1.0587 + 0.8836 \times \ln (AGB) \} \).

From tree density and the mean biomass of trees, total aboveground biomass (AGB) and belowground biomass (BGB) were computed. Field inventory for biomass
estimation of trees and shrubs in forest ecosystems of southern Haryana is given in plate 5.1.

5.2.4 Estimation of Net Primary Productivity

Aboveground net primary productivity (ANP) of trees was calculated as the sum of increment in biomass of non-photosynthetic parts over a time of one year and the annual litter production during the corresponding period (Olson, 1975). The belowground net primary productivity of trees was calculated as the sum of increment in belowground biomass over a time period of one year.

5.3 Results

5.3.1 Litter fall in different forest ecosystems

The litter fall from trees played an important role in organic matter addition and nutrient recycling in all tropical dry deciduous forests on all the sites. The litter fall deposition on ground floor was highest in winter and lowest in summer months in all studied tropical dry deciduous forests. Leaf litter was found to be almost two times higher than twig litter in all studied forests of three districts.

The litter accumulation on the ground floor in forest ecosystems of Gurgaon district was found to be higher in the mixed forest at Bhondsi (3.42Mg ha$^{-1}$) as compared to that of the AL-BA forest at Gawalpahari (1.63Mg ha$^{-1}$) and AP-AL forest Raisina (1.92Mg ha$^{-1}$). In the mixed forests at Bhondsi, leaf litter fall contributed 65.28%, whereas twig litter fall contributed 34.72% of total litter fall, where as leaf and twig litter contribution in AL-BA forest at Gawalpahari was observed to be 64.88% and 35.12% respectively. In AP-AL forest at Raisina, the annual litter fall was 1.93 Mg ha$^{-1}$, leaves contributed 63.08% and twig litter fall contributed 36.92% of total litter fall. Monthly variations in litterfall under forest ecosystems of Bhondsi, Gawalpahari and Raisina are shown in Fig.5.1.

Among the forest ecosystems of Mahendergarh district, litter accumulation on the ground floor was found to be higher in SO forest at Sisoth (2.74Mg ha$^{-1}$) as compared to that of the AP forest Buddin (2.39Mg ha$^{-1}$); mixed forest Duloth (2.39Mg ha$^{-1}$) and AT-PC Salimabad (1.92Mg ha$^{-1}$). In these forests, contribution of leaf litter ranged from 67.26% to 68.77%, whereas twig litter fall accounted for 31.23% to 32.74% of total litter fall. Monthly variations in litterfall under forest ecosystems of Mahendergarh district are shown in Figs.5.2 to 5.3.
In case of forest ecosystems of Bhiwani district, SO-AT forest at Jhumpa was found to accumulate slightly higher litter than AS-AT forest at Kairu; the value of litterfall being 2.87 Mg ha\(^{-1}\) and 2.08 Mg ha\(^{-1}\) respectively. Monthly variations in litterfall under forest ecosystems of Jhumpa and Kairu are shown in Fig. 5.4. In SO-AT forests at Jhumpa, leaf litter fall contributed 65.84\%, whereas twig litter fall contributed 34.16\% of total litter fall. The leaf and twig litter fall contribution in AS-AT forest at Kairu was observed to be 66.21\% and 33.79\% respectively. The data on litterfall in different forest ecosystems are given in Appendix Tables 4 to 6.

5.3.2 Forest floor litter in different forest ecosystems

The litter fall deposition on the ground floor was high in winter and summer. The annual forest floor litter in three forest ecosystems of Gurgaon varied from 2269 Kg ha\(^{-1}\) to 4669 Kg ha\(^{-1}\). In the case of mixed forest Bhondsi, standing crop of leaf litter varied 1461 Kg ha\(^{-1}\) to 4421 Kg ha\(^{-1}\) where as twig litter ranged from 1091 Kg ha\(^{-1}\) to 2223 Kg ha\(^{-1}\) across seasons (Table 5.1). The leaf litter accounted for 57 to 66\% of total litter deposition on the ground. Seasonal variations in standing crop of leaf and twig litter in AL-BA forest Gawalpahari was estimated from 785 Kg ha\(^{-1}\) to 2061 Kg ha\(^{-1}\) and 530 to 1213 Kg ha\(^{-1}\) respectively (Table 5.1). The leaf litter contributed 59 to 63\% of total litter deposition on the ground. Standing crop of leaf and twig litter was comparatively low in AP-AL forest Raisina, value being 718 Kg ha\(^{-1}\) to 2045 Kg ha\(^{-1}\) for leaf litter and 432 Kg ha\(^{-1}\) to 1084 Kg ha\(^{-1}\) for twig litter (Table 5.1). The forest floor litter exhibited significant differences between three seasons, the value for mixed forest Bhondsi being F= 848.42, d.f. =2, 12,14, P<0.05)The turnover rate of leaf litter in three forests of Gurgaon varied from 0.60 to 0.74, highest was recorded in the mixed forest Bhondsi (Table 5.4).

Seasonal variations and annual mean values of standing crop of litter under studied forest ecosystems of Mahendergarh are shown in Table 5.2. Highest standing crop of litter was estimated at SO forest Sisoth. Its values for leaf and twig litter ranged from 1585 Kg ha\(^{-1}\) to 4510 Kg ha\(^{-1}\) and 839 Kg ha\(^{-1}\) to 2263 Kg ha\(^{-1}\) respectively (Table 5.2). Lowest annual mean of standing crop (2969 Kg ha\(^{-1}\)) of ground floor litter was estimated under AT-PC forest Salimabad (Table 5.2). The leaf litter accounted for 65 to 69\% of total litter deposition on the ground. The forest floor litter exhibited significant differences between three seasons, the value for AT-PC forest Salimabad being F= 873.43, d.f. =2, 12,14, P<0.05. The turnover rates and turnover time of leaf
and twig litter varied from 0.65 to 0.68 and 0.60 to 0.65 respectively. The turnover rate and turn over time of total litter varied from 0.63 to 0.70 and 1.44 to 1.58 respectively (Table 5.4).

The annual forest floor litter in two forest ecosystems of Bhiwani district varied from 3356 Kg ha\(^{-1}\) to 4498 Kg ha\(^{-1}\). In the case of SO-AT forest at Jhumpa, leaf litter varied 1435 Kg ha\(^{-1}\) to 4353 Kg ha\(^{-1}\) where as twig litter ranged from 892 Kg ha\(^{-1}\) to 2226 Kg ha\(^{-1}\) across seasons (Table 5.7). Seasonal variations in standing crop of leaf and twig litter in AS-AT forest at Kairu was estimated from 887 Kg ha\(^{-1}\) to 3876 Kg ha\(^{-1}\) and 622 Kg ha\(^{-1}\) to 1837 Kg ha\(^{-1}\) respectively. The leaf litter accounted for 61 to 67% of total litter deposition on the ground. The forest floor litter exhibited significant differences between three seasons in both forest sites, the value for SO-AT forest Jhumpa being F= 554.03, d.f. =2, 12,14, P<0.05. The turnover rate and turn over time of various litter components and for total litter varied from 0.61 to 0.66 and 1.52 to 1.63 respectively the value for AT-PC forest Salimabad being (F= 873.43, d.f. =2, 12,14, P<0.05). The results of analysis of variance on standing crop of forest floor litter are given in Appendix Tables 7 to 9.

A close-up of forest floor litter and herbaceous plants on the forest floor is shown in plate 5.2.

### 5.3.3 Tree Biomass

The aboveground biomass of trees in the three forests sites at Bhondsi, Gawalpahari and Raisina of Gurgaon district was 37.93 to 63.73 Mg ha\(^{-1}\); the belowground biomass being 11.12 to 17.81 Mg ha\(^{-1}\) (Fig 5.4 and 5.5). Aboveground biomass accounted for 74.86 to 76.42% of total biomass, whereas belowground biomass contributed 23.58 to 25.14% of the total tree biomass in all the tree forests. Highest total tree biomass (63.73 Mg ha\(^{-1}\)) was observed in the mixed forest at Bhondsi followed that of the AP-AL forests at Raisina (42.50 Mg ha\(^{-1}\)) and AL-BA forest at Gawalpahari (37.93 Mg ha\(^{-1}\)) (Table 5.5). In the mixed forest at Bhondsi, three tree species which contributed highest above ground biomass are *Azadirachta indica* (13.20 Mg ha\(^{-1}\)), *Cassia fistula* (11.28 Mg ha\(^{-1}\)) and *Albigna lebbeck* (10.80 Mg ha\(^{-1}\)). Contribution of these species in below ground biomass was estimated to be 3.39 Mg ha\(^{-1}\), 2.95 Mg ha\(^{-1}\) and 2.84 Mg ha\(^{-1}\) (Fig.5.4). In AL-BA forest at Gawalpahari, *Azadirachta indica* contributed highest above ground biomass and below ground biomass value being 7.76 Mg ha\(^{-1}\) and 2.12
Mg ha⁻¹ respectively followed by *Prosopis cineraria* (5.13 Mg ha⁻¹ and 1.47 Mg ha⁻¹) and *Butea monosperma* 4.57 Mg ha⁻¹ and 2.12 Mg ha⁻¹) (Fig.5.5). In case of AP-AL forest at Raisina, *Anogeissus pendula* (16.01 Mg ha⁻¹) contributed 37.67% in aboveground biomass where as contribution of *Prosopis juliflora* (14.81 Mg ha⁻¹) was found to be 34.85%. Below ground biomass of these species was 4.02 Mg ha⁻¹ and 3.75 Mg ha⁻¹ respectively (Fig.5.5). Root-shoot ratio (R/S) for three forests of Gurgaon varied from 0.26 to 0.29.

In the case of forest ecosystems of Mahendergarh district, aboveground biomass of trees was found to range from 41.97 to 131.90 Mg ha⁻¹; the belowground biomass being 10.42 to 26.49 Mg ha⁻¹ (Table 5.6). Highest above ground and below ground tree biomass was observed in *Salvadora oleoides* forest ecosystem at Sisoth, the value being 131.90 Mg ha⁻¹ and 26.49 Mg ha⁻¹ respectively. Lowest aboveground (41.39 Mg ha⁻¹) and belowground (11.23 Mg ha⁻¹) tree biomass was estimated at AT-PC forest Salimabad. In AT-PC forest at Salimabad aboveground biomass of dominant tree species was in the order: *Acacia tortilis* (20.45 Mg ha⁻¹) and *Prosopis cineraria* (17.97 Mg ha⁻¹). Belowground biomass of these species was 4.99 Mg ha⁻¹ and 4.46 Mg ha⁻¹ respectively (Fig.5.6). *Salvadora oleoides* contributed 96.97% in aboveground biomass and 95.32% in belowground biomass in SSO dominated forest at Sisoth (Fig.5.6). Its values for aboveground and belowground biomass were 127.91 Mg ha⁻¹ and 25.24 Mg ha⁻¹ respectively. In the mixed forest at Duloth, *Acacia tortilis* contributed highest above ground biomass and below ground biomass value being 30.42 Mg ha⁻¹ and 7.09 Mg ha⁻¹ respectively followed by *Acacia nilotica* (11.08 Mg ha⁻¹ and 2.91 Mg ha⁻¹ and *Prosopis cineraria* 5.25 Mg ha⁻¹ and 1.50 Mg ha⁻¹) (Fig.5.7). In the AP forest at Buddin, tree species which contributed highest above ground biomass are *Anogeissus pendula* (34.16 Mg ha⁻¹) and *Prosopis juliflora* (28.55 Mg ha⁻¹). Contribution of these species in below ground biomass was estimated to be 7.86 Mg ha⁻¹, and 6.71 Mg ha⁻¹ (Fig.5.7). Root-shoot ratio (R/S) for the forest sites of Mahendergarh varied from 0.20 to 0.22.

The aboveground biomass, belowground biomass and total plant biomass in dry deciduous forests at Jhumpa and Kairu are shown in Table 5.8. The aboveground biomass of trees at SSO-AT forest Jhumpa (70.32 Mg ha⁻¹) was more than double as compared to aboveground biomass at AS-AT forest Kairu (28.58 Mg ha⁻¹). Below ground biomass was also observed to be higher at Jhumpa (17.29 Mg ha⁻¹) than that
at Kairu (7.87 Mg ha\(^{-1}\)) (Table 5.8). In the SO-AT forest at Jhumpa, *Salvadora oleoides* (AGB=35.72 Mg ha\(^{-1}\), BGB=8.17 Mg ha\(^{-1}\)) contributed 50% of above ground biomass and 47.25% of belowground biomass. *Acacia tortilis* have second highest contribution in aboveground and belowground biomass. Its values for aboveground and belowground biomass were 20.51 Mg ha\(^{-1}\) and 5.01 Mg ha\(^{-1}\) (Fig. 5.3). *Prosopis juliflora*, *Acacia senegal* and *Acacia tortilis* were top contributing species in aboveground and belowground biomass in AS-AT forest at Kairu. Aboveground biomass of these species ranged from 10.19 to 5.86 Mg ha\(^{-1}\) whereas their belowground biomass ranged from 2.70 to 1.66 Mg ha\(^{-1}\) (Fig. 5.7). Root-shoot ratio (R/S) was 0.25 for SO-AT forest Jhumpa and 0.275 for AS-AT forest Kairu.

### 5.3.4 Net Primary Productivity of Trees

The productivity of different tree components of forests at Bhondsi, Gawalpahari and Raisina are shown in Table 5.5. The average rate of accumulation of dry matter in the trees was higher for mixed forest at Bhondsi (12.06 Mg ha\(^{-1}\)yr\(^{-1}\)) than in the AL-BA forests at Gawalpahari (6.57 Mg ha\(^{-1}\)yr\(^{-1}\)) and AP-AL forest at Raisina (6.17 Mg ha\(^{-1}\)yr\(^{-1}\)). Total aboveground net production was 3.58 to 6.90 Mg ha\(^{-1}\)yr\(^{-1}\) whereas belowground net production ranged from 0.83 to 1.74 Mg ha\(^{-1}\)yr\(^{-1}\) in three forests of Gurgaon district (Table 5.5). Foliage production in the three forests accounted for 24.73 to 28.52% of the total productivity in the three forest ecosystems.

In the case of the forest ecosystems of Mahendergarh district, total net productivity of trees was found in the range of 4.51 to 7.50 Mg ha\(^{-1}\)yr\(^{-1}\) (Table 5.7). Total aboveground net productivity was 3.68 Mg ha\(^{-1}\)yr\(^{-1}\) in AT-PC forest at Salimabad, 4.43 Mg ha\(^{-1}\)yr\(^{-1}\) in mixed forest at Duloth, 4.79 Mg ha\(^{-1}\)yr\(^{-1}\) in AP forest at Buddin and 6.37 Mg ha\(^{-1}\)yr\(^{-1}\) in SO forest at Sisoth. The belowground net production was 0.82 Mg ha\(^{-1}\)yr\(^{-1}\), 1.02 Mg ha\(^{-1}\)yr\(^{-1}\), 1.06 Mg ha\(^{-1}\)yr\(^{-1}\) and 1.01 Mg ha\(^{-1}\)yr\(^{-1}\) respectively in the forests at Salimabad, Duloth, Buddin and Sisoth, respectively.

Net primary productivity in various components of trees in the forest ecosystems at Jhumpa and Kairu is shown in Table 5.8. The total net productivity of trees was higher for SO-AT forests at Jhumpa (7.71 Mg ha\(^{-1}\)yr\(^{-1}\)) than in AS-AT forest at Kairu (5.64 Mg ha\(^{-1}\)yr\(^{-1}\)) Table 5.8. Total aboveground net production was 5.46 Mg ha\(^{-1}\)yr\(^{-1}\) in SO-AT forest at Jhumpa and 4.83 Mg ha\(^{-1}\)yr\(^{-1}\) in AS-AT forest at Kairu. The belowground net production was 1.25 Mg ha\(^{-1}\)yr\(^{-1}\) in SO-AT forest at Jhumpa and 1.08 Mg ha\(^{-1}\)yr\(^{-1}\) in
AS-AT forest at Kairu. Foliage production accounted for 37.22 to 38.30% of total productivity in two forests.

5.4 Discussion

Tree biomass in forest ecosystems vary with forest type, species composition, stand age, size class of trees, site conditions, rainfall pattern, edaphic factors and altitude (Peichl and Arain, 2006; Gairola et al., 2011; Cao et al., 2012; Zhao et al., 2014). Knowledge of biomass allocation to roots lags behind that of its aboveground counterpart. In this study biomass of trees was estimated by dimension analysis of sampled trees using volume regression equations between circumferences at breast height (CBH) or diameter and using specific gravity.

Plant biomass in the tree layer of different forest ecosystems in this study ranged from 38.61 Mg ha\(^{-1}\) to 160.64 Mg ha\(^{-1}\), which was found to be related to forest type, species composition, stand age, size class of trees, soil conditions. The biomass of trees was found to be greatest in the case of dry deciduous forest ecosystems of Gurgaon district as compared to that of Mahendergarh and Bhiwani district. It may be stated that soil conditions, tree species composition and variations in girth classes of trees were the main factors causing such a large variations in plant biomass as the rainfall was not much variable across the forest sites. This range of biomass was lower than that observed by Singh (1975) in case of tropical dry forest, Varanasi, India. Tree biomass range was comparable with the results of sub-tropical dry forest of India (130.0 Mg ha\(^{-1}\)) as reported by IPCC (2006). Ramachandran et al. (2007) observed total plant biomass of 57.50 Mg ha\(^{-1}\) in case of scrub forests of Eastern Ghats in India. The biomass values are lower than the results of this study.

The contribution of above and belowground biomass of trees to the total biomass in the present study was 74.0 to 82.1% and 17.9 to 25.9 %, respectively. Total aboveground and belowground biomass in Indian forests has been found to be 79% and 21 %, respectively (Chhabra et al., 2002). Gairola et al. (2011) have also reported the relative contribution of AGB and BGB in total biomass was 80.8 % and 19.2 %, respectively for Garhwal Himalaya, India. The tree trunks accounted for 25 to 46% of the ANP but their contribution in biomass was from 43% to 77%.

Several workers have concluded that mature tropical forests with high AGB contain a large proportion of their aboveground biomass in large trees (Brown et al., 1995;
Brown and Lugo, 1992; Clark and Clark, 1996). The results of this study also found similar observations as high girth class *Salvadora oleoides* dominated forest at Sisoth were characterized by have highest tree biomass. Tree growth rates have been linked to plant functional traits (Poorter et al., 2008).

In this study net primary productivity of the tree layer varied from 6.17-12.06 Mg ha\(^{-1}\) yr\(^{-1}\). Singh (1979) found that net primary productivity for dry deciduous forest ecosystems of India varied from 14.6-15.7 t ha\(^{-1}\) yr\(^{-1}\). The average rate of accumulation of dry matter in the trees was higher for the mixed forest at Bhondsi. For a variety of dry forests and wet tropical forests NPP ranged from 8-28 t ha\(^{-1}\) yr\(^{-1}\) (Murphy and Lugo, 1986b). Foliage production accounted for 23.05 to 29.95% of the total productivity in the studied forest ecosystems. The contribution of foliage, branches and trunk in the aboveground biomass and net above ground primary production (ANP) in some forest ecosystems of India has been reported by several workers (Singh and Singh 1991, 1993; Singh and Singh, 1989; Chaturvedi and Singh, 1987; Rawat and Singh, 1988). These studies have shown that leaves accounted for 37% to 41% of the tree layer ANP although they comprise only 3.4% to 4.6% of the above ground tree biomass. Thus, most of the ANP used in the development of foliage would find its way to detritus each year through litter fall. The dry deciduous forest and the evergreen oak forest allocate 38 to 33% of the ANP to branches while the pine and the old-growth Sal forests allocate only 14 to 26% ANP to branches (see Singh et al., 2014).

Root shoot ratios (R/S) have been used to partition plant biomass into aboveground and belowground plant components (Klepper, 1991). Recent studies indicate that R/S varies with stand/age (Gerhardt and Fredrickson, 1995), or is the function of tree species and differs between gymnosperms and angiosperms (Cuevas et al., 1991). Several abiotic factors like soil moisture, texture and nutrient availability are thought to influence biomass allocation to roots (Chapin, 1980; Murphy and Lugo, 1986; Nadelhoffer et al., 1985). Cannel, (1982) reported R/S of 0.26, 0.25 and 0.31 for coniferous, deciduous and tropical forests, respectively. In this study, the R/S ratio of 0.20 to 0.29 for studied tropical dry deciduous forest ecosystems is comparable to the reported values.

Litter constitutes an important component of the soil in all forest ecosystems which plays an important role in organic matter and nutrient return to the soil. Litterfall is an
important indicator of primary production and recycling processes. The earlier studies on tree plantations and natural forest have shown that the addition of organic matter in the form of litterfall from the tree plays an important role to improve soil organic matter of degraded sodic soil (Tripathi and Singh, 2005). In the present study litterfall in different dry deciduous forest ecosystems ranged from 1.62-3.42 Mg ha\(^{-1}\) yr\(^{-1}\) across the sites. Quantity of litterfall as reported by Dantas and Philipson (1989) ranged from 8.1 Mg ha\(^{-1}\) yr\(^{-1}\) for primary forest and 5.1 Mg ha\(^{-1}\) yr\(^{-1}\) for a secondary forest of Amazonian terra firma. Proctor et al (1983) reported litterfall in the range of 3-10 Mg ha\(^{-1}\) yr\(^{-1}\) for a variety of tropical forests. Richards (1981) reported a higher litterfall of 8.8 and 5.8 Mg ha\(^{-1}\) yr\(^{-1}\) for tropical low lands and mixed rain forests respectively. For the forest ecosystems of India, Singh et al. (1992) have reported litterfall of 7.9 t ha\(^{-1}\) yr\(^{-1}\) in Sal forest. Litter production has been found to vary according to the tree species, its age and local environmental condition (Hawkins et al., 1990; Szott and Kass, 1993).

This study showed that leaf litter was 63.08 to 68.77%, which is comparable to several other reports of forest ecosystems (Singh, 1984; Sanchez and Sanchez, 1995; Pedersen and Hansen, 1999; Sundarpandian and Swamy, 1999; Zhou et al., 2007). Leaf fall was confined to autumn and winter seasons while decomposition was most rapid during wet period (Singh et al., 1992). This study also showed that litter fall deposition on ground floor was highest in winter and lowest in summer months.
Fig. 5.1 Monthly variations in litterfall under forest ecosystems at (A) Bhondsi, (B) Gawalpahari and (C) Raisina in Gurgaon District
Fig. 5.2 Monthly variations in litterfall under forest ecosystems at (A) Salimabad, (B) Sisoth in Mahendergarh District
Fig. 5.3 Monthly variations in litterfall under forest ecosystems at (A) Duloth, (B) Buddin in Mahendergarh District.
Fig. 5.4 Monthly variations in litterfall under forest ecosystems at (A) Jhumpa, (B) Kairu in Bhiwani District.
Fig. 5.5 Aboveground and belowground biomass of different tree species in the mixed forest at Bhondsi in Gurgaon district.

AL = Acacia leucophloea; AS = Acacia senegal; AE = Ailanthus excelsa; AL = Albizia lebbeck; AP = Anogeissus pendula; AI = Azadirachta indica; BM = Butea monosperma; CF = Cassia fistula; DS = Dalbergia sissoo; DI = Derris indica; DC = Diospyros cordifolia; KP = Kigelia pinnata; LL = Leucaena leucocephala; NA = Nyctanthes arbor-tristis; SC = Syzygium cumini; TA = Tamarix articulata
Fig. 5.6 Above ground and belowground biomass of different tree species in forest ecosystems at (A) Gawalpahari and (B) Raisina, Gurgaon District. AL = Acacia leucophloea; AS = Acacia senegal; AP = Anogeissus pendula; AZI = Azadirachta indica; BA = Balanites aegyptiaca; BM = Butea monosperma; CD = Cordia dichotoma; DS = Dalbergia sissoo; DC = Diospyros cordifolia; PC = Prosopis cineraria; PJ = Prosopis juliflora; ZM = Ziziphus mauritiana.
Fig. 5.7 Above ground and belowground biomass of different tree species in forest ecosystems at (A) Salimabad and (B) Sisoth in Mahendergarh District
Fig. 5.8 Above ground and belowground biomass of different tree species in forest ecosystems at (A) Duloth and (B) Buddin in Mahendergarh District
**Fig. 5.9** Above ground and belowground biomass of different tree species in forest ecosystems at (A) Jhumpa and (B) Kairu in Bhiwani District
Table 5.1
Standing crop of forest floor litter (kg ha\(^{-1}\)) under forest ecosystems at Bhondsi, Gawalpahari and Raisina, Gurgaon during March, 2011 to February, 2012

<table>
<thead>
<tr>
<th>Sites/Litter components</th>
<th>Summer season</th>
<th>Rainy season</th>
<th>Winter season</th>
<th>Annual mean</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bhondsi</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaf litter</td>
<td>3193(^{b})±44.98</td>
<td>1461(^{c})±42.84</td>
<td>4421(^{a})±51.68</td>
<td>3025</td>
</tr>
<tr>
<td>Twig litter</td>
<td>1618(^{b})±28.69</td>
<td>1091(^{c})±23.06</td>
<td>2223(^{a})±33.28</td>
<td>1644</td>
</tr>
<tr>
<td>Total</td>
<td>4811</td>
<td>2552</td>
<td>6644</td>
<td>4669</td>
</tr>
<tr>
<td><strong>Gawalpahari</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaf litter</td>
<td>1573(^{b})±42.79</td>
<td>785(^{c})±32.57</td>
<td>2061(^{a})±45.81</td>
<td>1473</td>
</tr>
<tr>
<td>Twig litter</td>
<td>906(^{b})±20.49</td>
<td>530(^{c})±13.79</td>
<td>1213(^{a})±26.05</td>
<td>883</td>
</tr>
<tr>
<td>Total</td>
<td>2479</td>
<td>1315</td>
<td>3274</td>
<td>2356</td>
</tr>
<tr>
<td><strong>Raisina</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaf litter</td>
<td>1665(^{b})±44.54</td>
<td>718(^{c})±29.53</td>
<td>2045(^{a})±42.21</td>
<td>1476</td>
</tr>
<tr>
<td>Twig litter</td>
<td>863(^{b})±17.79</td>
<td>432(^{c})±15.81</td>
<td>1084(^{a})±18.58</td>
<td>793</td>
</tr>
<tr>
<td>Total</td>
<td>2528</td>
<td>1150</td>
<td>3129</td>
<td>2269</td>
</tr>
</tbody>
</table>
Table 5.2
Standing crop of forest floor litter (kg ha\(^{-1}\)) under forest ecosystems at Salimabad, Sisoth, Duloth and Buddin, Mahendergarh during March, 2012 to February, 2013

| Sites/Litter components | Standing crop of litter (kg ha\(^{-1}\)) |  
|-------------------------|-----------------------------------------|---|---|---|---|
|                         | Summer season | Rainy season | Winter season | Annual mean |  
| Salimabad               |              |              |               |             |  
| Leaf litter             | 1945\(^b\)±41.32 | 942\(^c\)±38.34 | 3143\(^a\)±57.71 | 2010 |  
| Twig litter             | 1018\(^b\)±15.35 | 523\(^c\)±19.81 | 1336\(^a\)±28.54 | 959 |  
| Total                   | 2963          | 1465          | 4479           | 2969 |  
| Sisoth                  |              |              |               |             |  
| Leaf litter             | 3173\(^b\)±45.52 | 1585\(^c\)±39.61 | 4510\(^a\)±42.85 | 3091 |  
| Twig litter             | 1752\(^b\)±42.22 | 839\(^c\)±34.48 | 2383\(^a\)±35.64 | 1618 |  
| Total                   | 4930          | 2429          | 6773           | 4709 |  
| Duloth                  |              |              |               |             |  
| Leaf litter             | 2725\(^b\)±42.26 | 1358\(^c\)±38.06 | 3576\(^a\)±45.29 | 2553 |  
| Twig litter             | 1102\(^b\)±26.81 | 595\(^c\)±20.59 | 1684\(^a\)±36.03 | 1127 |  
| Total                   | 3827          | 1953          | 5260           | 3680 |  
| Buddin                  |              |              |               |             |  
| Leaf litter             | 2390\(^b\)±39.94 | 1227\(^c\)±30.85 | 3496\(^a\)±36.48 | 2376 |  
| Twig litter             | 1350\(^b\)±30.89 | 773\(^c\)±21.33 | 1684\(^a\)±29.78 | 1269 |  
| Total                   | 3740          | 2000          | 5180           | 3640 |  
Table 5.3
Standing crop of forest floor litter (kg ha\(^{-1}\)) under forest ecosystems at Jhumpa and Kairu, Bhiwani during March, 2013 to February, 2014

<table>
<thead>
<tr>
<th>Sites/Litter components</th>
<th>Standing crop of litter (kg ha(^{-1}))</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Summer season</td>
<td>Rainy season</td>
<td>Winter season</td>
<td>Annual mean</td>
</tr>
<tr>
<td><strong>Jhumpa</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaf litter</td>
<td>2978(^{b})±43.06</td>
<td>1435(^{c})±32.93</td>
<td>4353(^{a})±45.67</td>
<td>2962</td>
</tr>
<tr>
<td>Twig litter</td>
<td>1610(^{b})±26.89</td>
<td>892(^{c})±34.04</td>
<td>2266(^{a})±41.50</td>
<td>1576</td>
</tr>
<tr>
<td>Total</td>
<td>4588</td>
<td>2327</td>
<td>6579</td>
<td>4498</td>
</tr>
<tr>
<td><strong>Kairu</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaf litter</td>
<td>1795(^{b})±39.86</td>
<td>887(^{c})±40.67</td>
<td>3876(^{a})±42.12</td>
<td>2186</td>
</tr>
<tr>
<td>Twig litter</td>
<td>1051(^{b})±26.24</td>
<td>622(^{c})±27.45</td>
<td>1837(^{a})±32.08</td>
<td>1170</td>
</tr>
<tr>
<td>Total</td>
<td>2846</td>
<td>1509</td>
<td>5713</td>
<td>3356</td>
</tr>
</tbody>
</table>
Table 5.4

Turnover rate (k) and turnover time (yr) of the forest floor litter in studied forest ecosystems during March to February of corresponding study years

<table>
<thead>
<tr>
<th>Forest sites</th>
<th>Turnover rate (k)</th>
<th></th>
<th></th>
<th>Turnover time (yr)</th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Leaf litter</td>
<td>Twig litter</td>
<td>Total litter</td>
<td>Leaf litter</td>
<td>Twig litter</td>
<td>Total litter</td>
</tr>
<tr>
<td>Mixed forest Bhondsi</td>
<td>0.74</td>
<td>0.72</td>
<td>0.73</td>
<td>1.35</td>
<td>1.39</td>
<td>1.37</td>
</tr>
<tr>
<td>AL-BA forest Gawalpahari</td>
<td>0.72</td>
<td>0.65</td>
<td>0.69</td>
<td>1.39</td>
<td>1.54</td>
<td>1.45</td>
</tr>
<tr>
<td>AP-AL forest Raisina</td>
<td>0.60</td>
<td>0.58</td>
<td>0.59</td>
<td>1.66</td>
<td>1.72</td>
<td>1.68</td>
</tr>
<tr>
<td>AT-PC forest Salimabad</td>
<td>0.65</td>
<td>0.63</td>
<td>0.64</td>
<td>1.53</td>
<td>1.58</td>
<td>1.54</td>
</tr>
<tr>
<td>SO forest Sisoth</td>
<td>0.67</td>
<td>0.65</td>
<td>0.66</td>
<td>1.49</td>
<td>1.53</td>
<td>1.50</td>
</tr>
<tr>
<td>Mixed forest Duloth</td>
<td>0.70</td>
<td>0.64</td>
<td>0.68</td>
<td>1.44</td>
<td>1.57</td>
<td>1.48</td>
</tr>
<tr>
<td>AP forest Buddin</td>
<td>0.68</td>
<td>0.60</td>
<td>0.65</td>
<td>1.46</td>
<td>1.65</td>
<td>1.52</td>
</tr>
<tr>
<td>SO-AL forest Jhumpa</td>
<td>0.64</td>
<td>0.61</td>
<td>0.63</td>
<td>1.54</td>
<td>1.63</td>
<td>1.57</td>
</tr>
<tr>
<td>AS-AL forest Kairu</td>
<td>0.66</td>
<td>0.61</td>
<td>0.64</td>
<td>1.52</td>
<td>1.62</td>
<td>1.55</td>
</tr>
</tbody>
</table>

*AL-BA=Acacia leucophloea- Balanites aegyptiaca
AP-AL= Anogeissus pendula- Acacia leucophloea
SO= Salvadora oleoides
AP= Anogeissus pendula
SO-AL= Salvadora oleoides- Acacia leucophloea
AS-AL= Acacia Senegal- Acacia leucophloea*
Table 5.5
Biomass (Mg ha\(^{-1}\)) and net primary productivity (NPP) in various plant components of trees in the tropical dry deciduous forest ecosystems of Bhondsi, Gawalpahari and Raisina in Gurgaon district during March 2011 and March 2014; values in bold stand for biomass of trees during March 2012

<table>
<thead>
<tr>
<th>Plant components</th>
<th>Biomass (Mg ha(^{-1}))</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bhondsi</td>
<td>Gawalpahari</td>
<td>Raisina</td>
</tr>
<tr>
<td>Leaf+Twig*</td>
<td>3.42</td>
<td>1.62</td>
<td>1.93</td>
</tr>
<tr>
<td>Aboveground (Stem+branches)</td>
<td>63.73</td>
<td>37.93</td>
<td>42.50</td>
</tr>
<tr>
<td></td>
<td><strong>70.63</strong></td>
<td><strong>41.90</strong></td>
<td><strong>46.08</strong></td>
</tr>
<tr>
<td>Belowground</td>
<td>17.81</td>
<td>11.12</td>
<td>11.18</td>
</tr>
<tr>
<td></td>
<td><strong>19.55</strong></td>
<td><strong>11.88</strong></td>
<td><strong>12.01</strong></td>
</tr>
<tr>
<td>Total</td>
<td>84.96</td>
<td>50.67</td>
<td>55.61</td>
</tr>
<tr>
<td></td>
<td><strong>93.60</strong></td>
<td><strong>55.40</strong></td>
<td><strong>59.09</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Plant components</th>
<th>NPP (Mg ha(^{-1}) yr(^{-1}))</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Foliage*</td>
<td>3.42</td>
<td>1.62</td>
</tr>
<tr>
<td>Aboveground (Stem+branches)</td>
<td>6.90</td>
<td>3.97</td>
</tr>
<tr>
<td>Belowground</td>
<td>1.74</td>
<td>0.96</td>
</tr>
<tr>
<td>Total</td>
<td>12.06</td>
<td>6.55</td>
</tr>
</tbody>
</table>

*From litterfall data
Table 5.6

Biomass (Mg ha\(^{-1}\)) in various plant components of trees in the tropical dry deciduous forest ecosystems of Mahendergarh district during March 2012 and March 2013; values in bold stand for biomass of trees during March 2014.

<table>
<thead>
<tr>
<th>Plant components</th>
<th>Biomass (Mg ha(^{-1}))</th>
<th>Salimabad</th>
<th>Sisoth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf+Twig*</td>
<td></td>
<td>1.92</td>
<td>2.25</td>
</tr>
<tr>
<td>Aboveground (Stem+branches)</td>
<td></td>
<td>41.39</td>
<td>131.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>45.08</strong></td>
<td><strong>138.27</strong></td>
</tr>
<tr>
<td>Belowground</td>
<td></td>
<td>10.41</td>
<td>26.49</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>11.23</strong></td>
<td><strong>27.63</strong></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>53.72</td>
<td>160.64</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>58.23</strong></td>
<td><strong>168.15</strong></td>
</tr>
<tr>
<td>Duloth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaf+Twig*</td>
<td></td>
<td>2.29</td>
<td>2.38</td>
</tr>
<tr>
<td>Aboveground (Stem+branches)</td>
<td></td>
<td>49.97</td>
<td>67.72</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>54.41</strong></td>
<td><strong>72.51</strong></td>
</tr>
<tr>
<td>Belowground</td>
<td></td>
<td>12.54</td>
<td>16.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>13.56</strong></td>
<td><strong>17.15</strong></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>64.80</td>
<td>86.24</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>70.26</strong></td>
<td><strong>92.04</strong></td>
</tr>
</tbody>
</table>

*From litterfall data
Table 5.7
Net primary productivity (NPP) (Mg ha\(^{-1}\)yr\(^{-1}\)) in various components of trees in the tropical dry deciduous forests of Mahendergarh district during March 2012 and March 2013

<table>
<thead>
<tr>
<th>Plant components</th>
<th>NPP (Mg ha(^{-1})yr(^{-1}))</th>
<th>Salimabad</th>
<th>Sisoth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf+Twig*</td>
<td>1.92</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>Aboveground (Stem+branches)</td>
<td>3.69</td>
<td>6.37</td>
<td></td>
</tr>
<tr>
<td>Belowground</td>
<td>0.82</td>
<td>1.14</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>7.43</td>
<td>9.76</td>
<td></td>
</tr>
<tr>
<td><strong>Duloth</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaf+Twig*</td>
<td>2.29</td>
<td>2.39</td>
<td></td>
</tr>
<tr>
<td>Aboveground (Stem+branches)</td>
<td>4.44</td>
<td>4.79</td>
<td></td>
</tr>
<tr>
<td>Belowground</td>
<td>1.02</td>
<td>1.01</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>7.75</td>
<td>8.19</td>
<td></td>
</tr>
</tbody>
</table>

*From litterfall data*
Table 5.8
Biomass (Mg ha\(^{-1}\)) and net primary productivity (NPP) in various plant components of trees in the tropical dry deciduous forest ecosystems at Jhumpa and Kairu in Bhiwani district during March, 2013 and March, 2014; values in bold stand for biomass of trees during March 2014

<table>
<thead>
<tr>
<th>Plant components</th>
<th>Biomass (Mg ha(^{-1}))</th>
<th>Jhumpa</th>
<th>Kairu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf+Twig*</td>
<td></td>
<td>2.87</td>
<td>2.16</td>
</tr>
<tr>
<td>Aboveground</td>
<td></td>
<td>70.32</td>
<td>28.58</td>
</tr>
<tr>
<td>(Stem+branches)</td>
<td></td>
<td>75.78</td>
<td>33.14</td>
</tr>
<tr>
<td>Belowground</td>
<td></td>
<td>17.29</td>
<td>07.87</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>18.54</strong></td>
<td><strong>08.95</strong></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>90.48</td>
<td>38.61</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NPP (Mg ha(^{-1}) yr(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf+Twig*</td>
</tr>
<tr>
<td>Aboveground (Bole+branches)</td>
</tr>
<tr>
<td>Belowground</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

*From litterfall data