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Structure and function of oak forest ecosystem of north - eastern India
I. Biomass dynamics and net primary production

E.J. SINGH and P.S. YADAVA
Department of Life Sciences
Manipur University
Imphal-795003, India

Abstract. The paper elucides with biomass dynamics and net primary productivity in two sites of oak forests in north-eastern India. The allometric relationship of age and dbh (diameter breast height) in different important trees with respective biomass (i.e. bole, branch, twig and leaf) were computed and the r^2 values were highly significant. The total non-photosynthetic to photosynthetic biomass ratio decreased with the increase of age. The accumulation of biomass in the photosynthetic parts ranged from 1 to 3 times in age series of 12 tree species. Of the total aboveground forest biomass, tree acounted for 98.33%, shrub 1.09% and herb 0.58%. The mean and current annual production of tree species varied from 0.1 to 5.0 t ha^{-1} and 0.6 to 4.8 t ha^{-1} respectively. Production efficiency in terms of net production per unit weight of leaf or per unit area of leaf varied from 0.70 to 1.22 kg net production m^{-2} leaf area per year. The biomass accumulation ratio in tree layer ranged from 7.57 to 8.99. The total net production in both forests ranged from 27.84 t ha^{-1} yr^{-1} to 28.32 t ha^{-1} yr^{-1}.
Key words: Oak forests, biomass, non-photosynthetic to photosynthetic ratio, net primary production, north-east India

Introduction

Oak forest form the climax vegetation with one or more oak tree species at an elevation ranging from 800 m to 2750 m in eastern Himalaya (Champion and Seth, 1968). Most of the information on biomass dynamics and production in oak forests is available from the temperate regions of the world (Whittaker and Woodwell 1969; Rochow 1974a; Adams 1982; Monk and Day 1985), but few studies have been reported from India (Singh and Singh 1986; Rawat and Singh 1988; Yadava and Singh 1988; Singh and Yadava 1991). Oak forest in north-eastern India are under biotic pressure mainly owing to deforestation for timber, fuel wood, and shifting cultivation.

However there was no information on the vegetation, biomass and net primary productivity of oak forests from north eastern India including Manipur. Therefore the present investigation has been undertaken to elucide the structure and functioning of oak forest in north-eastern Himalayan region. This paper deals with vegetation, biomass dynamics and net primary productivity in the two secondary oak forests of Manipur; north eastern India, which falls under group 'II' (subgroup 11 BC_1) of Eastern Himalayan Wet temperate forest type (Champion and Seth 1968).

Study site and climate

The study site was located at 25°13'N latitude and 94°25'E longitude in Shiroy hills, 105 km east of Imphal in the State of Manipur at an altitude ranging from 1,800 to 1,900 m. The two sites were selected for study and the details of the sites were reported elsewhere (Yadava and Singh 1988). Forest vegetation is multilayered communities consisting of semievergreen to evergreen tree species dominated by *Quercus dealbata, Q. fenestrata, Q. griffithii, Alnus nepalensis* and *Rhododendron arboreum*. The climate of the area is monsoonic with warm moist summer and cool dry winter. The mean maximum temperature varied form 28.8°C (February) to 30.2°C (September) and mean minimum temperature from 3.6°C (January) to 15.2°C (September). The average annual rainfall was 1,617 mm. Geologicaly the study site is of volcanic origin. Soil is red loamy with fine silt and gravel. The soil is characterised by high organic matter (pH ranged from 5.40 to 6.90). The nitrogen content of the soil varied from 0.08 to 0.33%, available phosphorus varied from 0.0003 to 0.009% and exchangeable potassium ranged from 0.07 to 0.24%.

Material and methods

Vegetation analysis of the two forest sites was done in August at the paek of growing seasons. The density, frequency and basal area were studied through 10 x 10 m size of quadrat for tree, 5 x 5 m quadrat for shrubs and 1 x 1 m for herbs and 20 such quadrats were laid down randomly in the study sites. Importance value index (IVI) for all the species of trees, shrub and herb was calculated (Curtis 1959). Basal area of constituent tree species has been estimated by measuring circumference at breast high for each individual in each quadrat.

Biomass of constituent tree species was evaluated in the two forest sites by taking mean value of biomass harvested for two consecutive years in October-November 1983 and 1984. In forest site-I, 68 individuals of 8 dominant tree species of four different girth classes starting with 0-10cm cbh classes and ending with 40-50cm cbh each with minimum three individual tree i.e. *Quercus dealbata* HK.f., *Q. fenestrata* Roxb, *Q. griffithii* HK.f., *Cinnamomum camphor* Nees & Eberm, *Neolitsea zeylanicum*, *Styrax serrulatum* Roxb, *Gaultheria griffithiana* Wigh, *Pyrularia edulis* A.D.C. and in forest site II, 47 individuals of 4 dominant tree species with four to five different girth classes in three tree species starting with 20-30cm cbh classes and ending with 60-70cm cbh classes i.e. *Quercus griffithii* HK.f., *Rhododendron arboreum* Sm and *Alnus nepalensis* D. Doon, and four different girth classes starting with 20-30cm and ending with 50-60cm classes in one tree species of *Lyonia ovalifolia* (Wall) Drude were harvested. Thus, in all 115 trees with three individual trees belonging to each girth class of all the dominant species were felled for estimation of biomass and net primary productivity of various tree species.

The biomass estimates for standing crop of a given tree were computed using density values along different girth classes (Newbould 1967). For biomass estimation of shrubs and herbacious species 20 quadrats of 5x5m and 1x1m were laid down randomly in the forest sites respectively. These were sorted out into different species. Sub-samples of shrubs and herbs were brought to the laboratory for oven dry at 80°C to constant weight . The biomass for each shrub and herb species were estimated by multiplying the average biomass by its respective density (individuals ha^{-1}) in the stand. Net primary production was estimated by summing up the annual increment in the biomass components (i.e. bole, branch, twig, leaf and fruit) of constituent species in 1983 and 1984 and the corresponding, litterfall deposited on the forest floor.

Mean annual production has been estimated by dividing the stand biomass by its correspoding age and current annual production has been estimated by dividing the difference in biomass by the difference in age. For estimating biomass and net primary productivity, the method given by Newbould (1967) was followed. Age of the tree species has been calculated by counting annual rings from the base of the bole.

One to three trees for different girth classes of each species were taken into consideration for biomass estimation. The fresh weight of all boles, branches, twigs, leaves and fruits were determined in the fields and sub-samples of boles, branches, twigs, leaves and fruits were brought to the laboratory in the polyethylene bags. All the sub-samples were oven dried at 80°C to constant weight. Leaf samples of varying size (50 leaves) were also taken from each tree of a given tree species for determining leaf area. Leaf area were measured through leaf area meter. Allometric relationship have been established by taking two independent variables (Age and dbh) with different dependent variables (bole, branch, twig and leaf) of different constituent tree species.

Results and discussion

Vegetation analysis

In forest site-I *Quercus dealbata* and *Q. fenestrata*

Species	Forest site-I Basal cover*	IVI	Species	Forest site-II Basal cover*	IVI
Tree			Tree		
Quercus dealbata H.K.f. & Th.	905.0	70.1	*Quercus griffithii* Hook.f.& Thums	1856.4	130.2
Q. fenestrata Roxb.	803.8	64.2	*Rhododendron arboreum* Sm.	809.5	80.0
Q. griffithii Hook.f. & Thums	547.7	42.0	*Lyonia ovalifolia* (Will.) Rude	402.2	58.0
Cinnamomum camphor Nees & Eber.	270.1	19.0	*Alnus nepalensis* D. Doon	385.9	17.3
Neolitsae zeylanicum Merr.	182.4	17.5	Shrub		
Gaultheria griffithiana Weight	178.5	15.0	*Luculia pinciana* Hook.	48.1	157.9
Styrax serrulatum Roxb.	220.1	13.7	*Viburnum coriaceum* B. L.	20.2	79.8
Pyrularia edulis A.D.C.	182.5	10.7	*Polygala arellata* Ham.	18.6	62.2
Shrub			Herb		
Pilea scripta Wedd.	5.9	108.9	*Hedychium robrum*	32.7	61.3
Viburnum coriaceum B.L.	82.4	105.5	*Juncus khasiensis* Buchen.	5.7	44.4
Polygala arilata Ham.	14.9	49.2	*Cnicus involucratus*	13.3	29.3
Rubus racemosus	18.3	36.40	*Ainsliaca pteropoda* D.C.	5.3	24.9
Herb			*Asplenium* sps.	3.7	23.8
Ophiopogon wallichiana Hk.f.	4.9	67.9	*Eupatorium adenophorum* Spreng.	1.7	12.9
Hedychium robrum	10.3	42.6	*Impatiens arguta* Hook.f. & T.	1.1	11.4
Plectranthus hispidus Benth.	2.6	28.1	*Carex cruciata* Wahl.	4.0	10.5
Carex cruciata Wahl.	4.0	21.8	*Gynura hispida* Thw.	2.3	7.2
Curcuma sps.	1.2	21.8	*Plectranthus hispidus* Benth.	0.5	6.8
Paris hexaphylla Cham.	3.9	18.6	*Artemisia parviflora* Buch-Ham.	1.1	6.5
Impatiens arguta Hook.f. & Th.	0.8	18.3	*Plantago major* L.	1.2	5.2
Gynura hispida Thw.	4.6	17.4	*Astilbe rivularia* Ham.	0.5	4.9
Astilbe rivularia Ham.	2.9	14.9	*Anaphalis contorta* H.K.P.	0.4	4.3
Polygonum rude Meissn.	1.1	11.9	*Commelina benghalensis* Linn.	0.3	3.4
Eupatorium adenophorum Spreng.	0.8	10.5			

Table 1. Basal cover and Importance Value Index (IVI) of constituent species of forest site-I and site II
*Basal Cover: Tree $cm^2/100m^2$; Shrub $cm^2/25m^2$; Herb cm^2/m^2

FOREST SITE-I

Biomass (kg tree⁻¹)	Intercept (a)	Slope (b)	Syx	r^2	C.f.
Cinnamomum camphor					
Bole	4.143	1.056	1.428	0.941	1.062
Branch	1.453	0.451	0.950	0.884	0.208
Twig	0.908	0.354	0.672	0.903	0.052
Leaf	-0.678	0.391	0.997	0.828	0.252
Gaultheria griffithiana					
Bole	2.880	0.714	2.031	0.941	13.060
Branch	-1.430	0.189	0.678	0.947	0.038
Twig	-1.112	0.142	0.436	0.962	0.006
Leaf	-0.955	0.122	0.316	0.941	0.002
Neolitsea zeylanicum					
Bole	-0.438	0.580	0.742	0.981	0.067
Branch	0.206	0.383	0.820	0.941	0.101
Twig	0.517	0.322	0.406	0.980	0.006
Leaf	1.037	0.331	0.953	0.884	0.183
Pyrularia edulis					
Bole	-8.172	1.094	1.145	0.961	0.024
Branch	-7.957	1.008	0.825	0.980	0.103
Twig	-4.499	0.670	0.575	0.961	0.025
Leaf	-5.570	0.680	0.577	0.961	0.025
Quercus dealbata					
Bole	8.956	0.712	3.257	0.759	28.706
Branch	1.449	0.287	1.009	0.843	0.264
Twig	-1.170	0.369	0.981	0.901	0.236
Leaf	-2.253	0.380	1.338	0.842	0.817
Quercus fenestrata					
Bole	-5.145	0.915	1.750	0.962	0.678
Branch	-1.301	0.444	0.781	0.968	0.067
Twig	0.043	0.252	1.030	0.849	0.202
Leaf	-0.061	0.194	0.451	0.943	0.007
Quercus griffithii					
Bole	3.202	1.192	1.087	0.980	0.311
Branch	-6.705	0.750	1.084	0.960	0.307
Twig	-5.765	0.643	1.423	0.941	0.911
Leaf	-6.289	0.580	1.000	0.960	0.222
Styrax serrulatum					
Bole	-4.536	1.038	0.607	0.980	0.035
Branch	-2.905	0.788	0.573	0.980	0.027
Twig	-1.826	0.585	0.812	0.922	0.111
Leaf	-2.827	0.578	0.657	0.941	0.048

Note: Except for twig, branch and twig biomass of *Pyrularia edulis, Quercus dealbata* and *Quercus griffithii* all the equations are significant at P>0.05, 0.01 and 0.001.

FOREST SITE-II

Biomass (kg tree⁻¹)	Intercept (a)	Slope (b)	Syx	r^2	C.f.
Alnus nepalensis					
Bole	-8.762	0.209	2.379	0.943	0.015
Branch	-4.396	0.711	0.673	0.987	0.058
Twig	-5.059	0.684	0.874	0.976	0.164
Leaf	-4.955	0.626	0.868	0.967	0.160
Lyonia ovalifolia					
Bole	-1.138	0.565	0.854	0.985	0.118
Branch	-2.090	0.485	0.502	0.985	0.014
Twig	-2.546	0.472	0.235	0.980	0.001
Leaf	-3.413	0.486	0.265	0.997	0.001
Quercus griffithii					
Bole	-9.103	1.913	3.158	0.980	5.378
Branch	-0.463	0.482	3.025	0.775	21.367
Twig	-2.791	0.534	0.819	0.980	0.115
Leaf	-2.773	0.485	0.344	0.980	0.004
Rhododendron arboreum					
Bole	-5.689	1.084	2.513	0.947	10.176
Branch	-3.780	0.752	1.226	0.974	0.577
Twig	-4.388	0.601	1.022	0.972	0.278
Leaf	-2.850	0.397	0.645	0.971	0.044

Note: Except for twig and leaf biomass of *Alnus nepalensis* all the equations are significant at P>0.05, 0.01 and 0.001.

Table 2. Allometric relationship between the biomass of tree components (Y.kg tree⁻¹) and age (X. year). (lny=a+b lnx).

were the dominant species whereas on site-II *Quercus griffithii* and *Rhododendron arboreum* were dominant tree species (Table 1). Among shrubs, *Pilia scripta* and *Luculia pinciana* were dominant species in forest site-I and site-II. *Ophiopogon wallichianus* and *Luculia pinciana* were dominant herbs in site-I and II respectively. The number of tree and shrub species was more in site-I than that of site-II. However the number of herbaceous species was higher in site-II than that in site-I which may be owing to large canopy gaps in the latter site. Both the forest sites are poorly represented by the shrub species indicating their extinction in future.

Biomàss

Allometric relationships between indepedent variables (age and dbh) with different dependable variables (bole, branch, twig and leaf) in various tree species were given in Table 2 and 3. The level of P ranged from 0.025 to 0.001 in both forest sites. The aboveground biomass of the different components i.e. bole, branch, twig and leaf in all the tree species increase with the increase of age and dbh in both forest sites. In both forest sites the age and dbh of tree species ranged from 7 to 33 years old, and 4 to 23 cm respectively. The r^2 values from the allometric relationship of age and dbh with biomass components were satisfactory. The total non-photosynthetic to photosynthetic biomass ratio was decreased consistantly from 18 year to 26 year in all the tree

Biomass (kg tree^{-1})	Intercept (a)	Slope (b)	Syx	r^2	C.f.
FOREST SITE-I					
Cinnamomum camphor					
Bole	1.378	1.750	1.013	0.980	0.269
Branch	0.322	0.734	1.001	0.865	0.256
Twig	-0.174	0.601	0.313	0.980	0.002
Leaf	-1.871	0.654	0.569	0.941	0.027
Gaultheria griffithiana					
Bole	-5.176	1.827	1.026	0.980	0.200
Branch	-1.982	0.477	0.563	0.922	0.180
Twig	-1.573	0.364	0.224	0.980	4E-4
Leaf	-1.330	0.310	0.153	0.980	1E-4
Neolitsea zeylanicum					
Bole	0.869	1.069	1.349	0.922	0.736
Branch	0.053	0.694	1.222	0.846	0.495
Twig	0.203	0.600	0.622	0.941	0.033
Leaf	-1.221	0.605	1.191	0.191	0.447
Pyrularia edulis					
Bole	-10.356	1.850	2.859	0.960	14.851
Branch	-10.554	1.760	2.185	0.185	5.067
Twig	-6.071	1.156	1.565	0.828	1.334
Leaf	-7.136	1.169	1.606	0.828	1.479
Quercus dealbata					
Bole	12.465	0.712	1.331	0.962	0.801
Branch	-1.714	0.711	0.925	0.869	0.187
Twig	-4.828	0.899	1.560	0.787	1.511
Leaf					
Quercus fenestrata					
Bole	-1.631	1.818	3.300	0.867	21.347
Branch	-2.577	0.910	1.178	0.828	0.346
Twig	-0.514	0.502	1.277	0.769	0.478
Leaf	-1.069	0.386	0.716	0.860	0.047
Quercus griffithii					
Bole	-2.655	2.574	3.842	0.846	48.413
Branch	-9.592	1.568	3.010	0.792	18.231
Twig	-8.341	1.334	2.918	0.757	16.122
Leaf	-8.517	1.999	2.491	0.792	8.549
Styrax serrulatum					
Bole	-10.953	1.836	1.289	0.941	0.706
Branch	-7.325	1.351	1.453	0.884	1.133
Twig	-5.453	1.035	1.095	0.884	0.367
Leaf	-6.148	0.995	1.139	0.865	0.430

Note: Except for twig biomass of *Pyrularia edulis*, bole and branch of *Quercus dealbata* and twig biomass of *Styrax serrulatum* all the equations are significant at P>0.05, 0.01 and 0.001.

Biomass (kg tree^{-1})	Intercept (a)	Slope (b)	Syx	r^2	C.f.
FOREST SITE-II					
Alnus nepalensis					
Bole	-13.776	2.117	1.660	0.974	2.137
Branch	-6.941	1.214	1.098	0.965	0.408
Twig	-5.191	1.175	0.956	0.972	0.235
Leaf	-6.165	1.085	0.775	0.978	0.101
Lyonia ovalifolia					
Bole	-4.607	1.204	1.031	0.956	0.251
Branch	-5.166	1.054	0.972	0.970	1.198
Twig	-5.191	0.986	0.929	0.986	0.929
Leaf	-6.165	1.017	0.966	0.946	0.193
Quercus griffithii					
Bole	-23.603	3.877	7.944	0.875	10.160
Branch	-6.383	1.132	1.714	0.928	1.199
Twig	-7.160	1.104	1.841	0.913	2.932
Leaf	-6.459	0.984	1.869	0.891	3.114
Rhododendron arboreum					
Bole	-21.265	2.495	2.721	0.938	13.992
Branch	-13.226	1.687	2.916	5.853	5.853
Twig	-11.522	1.319	2.105	0.876	5.006
Leaf	-7.860	0.892	2.140	0.892	0.431

Note: Except for bole biomass of *Rhododendrom arboreum* all the equations are significant at P>0.05, 0.01 & 0.001.

Table 3. Allometric relationship between biomass of tree components (Y.Kg tree^{-1}) and dbh (X.cm) (lny=a+blnx)

species and fluctuated thereafter in the forest site-I whereas in the forest site-II the ratio decreased untill 30 to 34 years (Fig. 1&2). In the forest site-I the accumulation of biomass ranged from 1 to 3 times more in non-photosynthetic parts in age series of *Cinnamomum camphor, Gaultheria griffithiana, Neolitsea zeylanicum, Pyrularia edulis, Quercus dealbata, Q. fenestrata, Q. griffithii* and *Styrax serrulatum*. The accumulation of biomass in forest site-II ranged from 1.25 to 2.25 times more in non-photosynthetic parts in age series of *Alnus nepalensis, Lyonia ovalifolia, Rhododendron arboreum* and *Quercus griffithii*.

Tree biomass was recorded to be 183.3 t ha^{-1} in the forest site-I of which about 65% was contributed by the three oaks, *Quercus dealbata, Q. fenestrata, Q. griffithii* (Table 4).

To the total biomass the bole contributed 51%, branch 20%, twig 15%, leaf 11% and fruit 2.4% (Table 4). The total forest aboveground biomass in this site was 186.96 t ha^{-1} (Table 5).

The tree biomass of forest site-II was recorded to be 211.5 t ha^{-1}, of which 44.5% was due to *Quercus griffithii*, 23.83% to *Alnus nepalensis*, 21.65% to *Rhododendron arboreum* and 9.98% to *Lyonia ovalifolia* (Table 6). The component-wise distribution was similar to that described for the site-I (Table 6). The total forest aboveground biomass in forest site-II was 215.08 t ha^{-1}.

The present biomass values are similar to that re-

Compon-nents	A	B	C	D	F	F	G	H	Total
Bole	8.33	5.00	4.93	4.20	36.34	16.39	14.57	4.18	93.94 (51.25)
Branch	3.43	1.04	3.61	3.68	10.11	6.66	4.67	3.44	36.64 (19.99)
Twig	2.56	0.75	3.09	2.79	7.08	4.62	4.05	2.79	27.73 (15.13)
Leaf	2.03	0.63	2.51	2.38	8.04	2.74	3.13	2.14	20.60 (11.24)
Fruit	-	-	-	-	2.53	1.26	0.59	-	4.38 (2.39)
Total Biomass	16.35 (8.92)	7.41 (4.04)	14.14 (7.71)	13.05 (7.12)	61.10 (33.34)	31.67 (17.28)	27.01 (14.74)	12.55 (6.85)	183.29

Table 4. Tree biomass (t ha^{-1}) and the value in the parentheses are relative percentage of the total biomass of the total biomass in forest site-I. A-*Cinnamomum camphor*, B-*Gaultheria griffithiana*, C-*Neolitsea zeylanicum*, D-*Pyrularia edulis*, E-*Quercus dealbata*, F-*Quercus fenestrata*, G-*Quercus griffithii*, H-*Styrax serrulatum*

Different layer	Biomass (t ha^{-1})	
	Forest site-I	Forest site-II
Tree	183.29 (98.04%)	211.49 (98.33%)
Shrub	3.33 (1.78%)	2.35 (1.09%)
Herbaceous	0.34 (0.18%)	1.24 (0.58%)
Total	186.96	215.08

Table 5. Biomass contribution by tree, shrub and herbaceous layer in forest site-I and site-II (the value in the parenthesis are the relative percentage of the total biomass).

Compo-nents	A	B	C	D	Total
Bole	18.31	6.85	51.83	18.39	95.38 (45.10)
Branch	11.84	5.31	15.87	12.79	45.81 (21.66)
Twig	10.45	4.67	13.91	8.45	37.48 (17.72)
Leaf	9.17	4.23	12.38	5.71	31.49 (14.89)
Fruit	0.64	0.06	0.18	0.45	1.33 (0.63)
Total biomass	50.41 (23.83)	21.12 (9.98)	94.17 (44.54)	45.79 (21.65)	211.49

Table 6. Tree biomass (t ha-1) and the value in the parentheses are the relative percentage of the total biomass in forest site-II. A-*Alnus nepalensis*, B-*Lyonia ovalifolia*, C-*Quercus griffithii*, D-*Rhododendron arboreum*

FOREST SITE-I

Components	A	B	C	D	E	F	G	H	Total
Bole	0.53 (29.11)	0.48	0.52	0.57	2.51	1.12	0.77	0.55	7.05
Branch	0.27 (15.52)	0.23	0.25	0.29	1.37	0.58	0.44	0.33	3.76
Twig	0.24 (13.34)	0.18	0.22	0.25	1.23	0.51	0.36	0.24	3.23
Leaf	1.21 (40.17)	0.44	0.62	0.96	2.28	1.47	1.64	1.11	9.73
Fruit	- (1.86)	-	-	-	0.29	0.10	0.06	-	0.45
Total	2.25 (9.29)	1.33 (5.49)	1.61 (6.65)	2.07 (8.55)	7.68 (31.71)	3.78 (15.61)	3.27 (13.50)	2.23 (9.20)	24.22

FOREST SITE-II

Components	A	B	C	D	Total
Bole	1.54	0.66	3.10	1.90	7.20(30.26)
Branch	1.05	0.46	1.59	1.13	4.23(17.78)
Twig	0.97	0.29	1.43	0.98	3.67(15.43)
Leaf	1.93	1.08	2.94	2.16	8.11(34.09)
Fruit	0.11	0.05	0.25	0.17	0.58(2.44)
Total	5.60 (23.54)	2.54 (10.68)	9.31 (39.13)	6.34 (26.65)	23.79

Table 7. Aboveground net production in tree layer (t $ha^{-1}yr^{-1}$) in Oak forests. (Values in parentheses are the percentage of the total net production). Tree species:
Forest site-I A-*Cinnamomum camphor*, B-*Gaultheria griffithiana*, C-*Neolitsea zeylanicum*, D-*Pyrularia edulis*, E-*Quercus dealbata*, F-*Quercus fenestrata*, G-*Quercus griffithii*, H- *Styrax serrulatum*
Forest site-II A-*Alnus nepalensis*, B-*Lyonia ovalifolia*, C-*Quercus griffithii*, D-*Rhododendron arboreum*

Parameter	Site-I	Site-II
Production Efficiency		
On the basis of foliage weight*	1.17	0.76
On the basis of foliage area**	0.38	0.54

Table 8. Production efficiency of tree leaves in Forest Site-I and Site-II. * Kg net production kg^{-1} leaf biomass per year ** Kg net production m^{-2} leaf area per year

ported for *Quercus robus* of Sweden, 201 ha^{-1} (Anderson 1971) and *Quercus perfreae* forest of Belgium (261 t ha^{-1} Duvigneaud, Kestemont and Ambraces 1971). However, higher values have been reported for some oak forest from former USSR (Sonn 1960; Rodin and Bazilevich 1967) and Central Himalaya.

The proportion of foliage to the aboveground biomass 12.6-17.4% in the study oak forest is higher than those reported of ranges (4.5-9.3%) for mature Central Himalayan Oak forests (Negi, Rawat and Singh 1983; Rawat 1988).

Net primary production

The total aboveground net production was 24.22 t ha^{-1} yr^{-1}. Of the total aboveground net production in trees, *Quercus dealbata* accounted for 31.71%, *Quercus fenestrata* 15.61%, *Quercus griffithii* 13.50%, *Cinnamomum camphor* 9.29%, *Styrax serrulatum* 9.20%, *Pyrularia edulis* 8.55%, *Neolitsea zeylanicum* 6.65% and *Gaultheria griffithiana* 5.49% (Table 7).

In the forest site-I the aboveground net production was in the order: leaf (40.17%) > bole (29.11%) > branch (15.52%) > twig (13.34%) > fruit (1.86%). The total aboveground net production in forest site-II was 23.79 t ha^{-1}. The component-wise distribution in oak forest site-II was similar to that in site-I (Table 7). Assuming the ratio root production to shoot production is 0.17 (Singh and Singh 1986), the belowground would be 4.12 t ha^{-1} yr^{-1} and 4.04 t

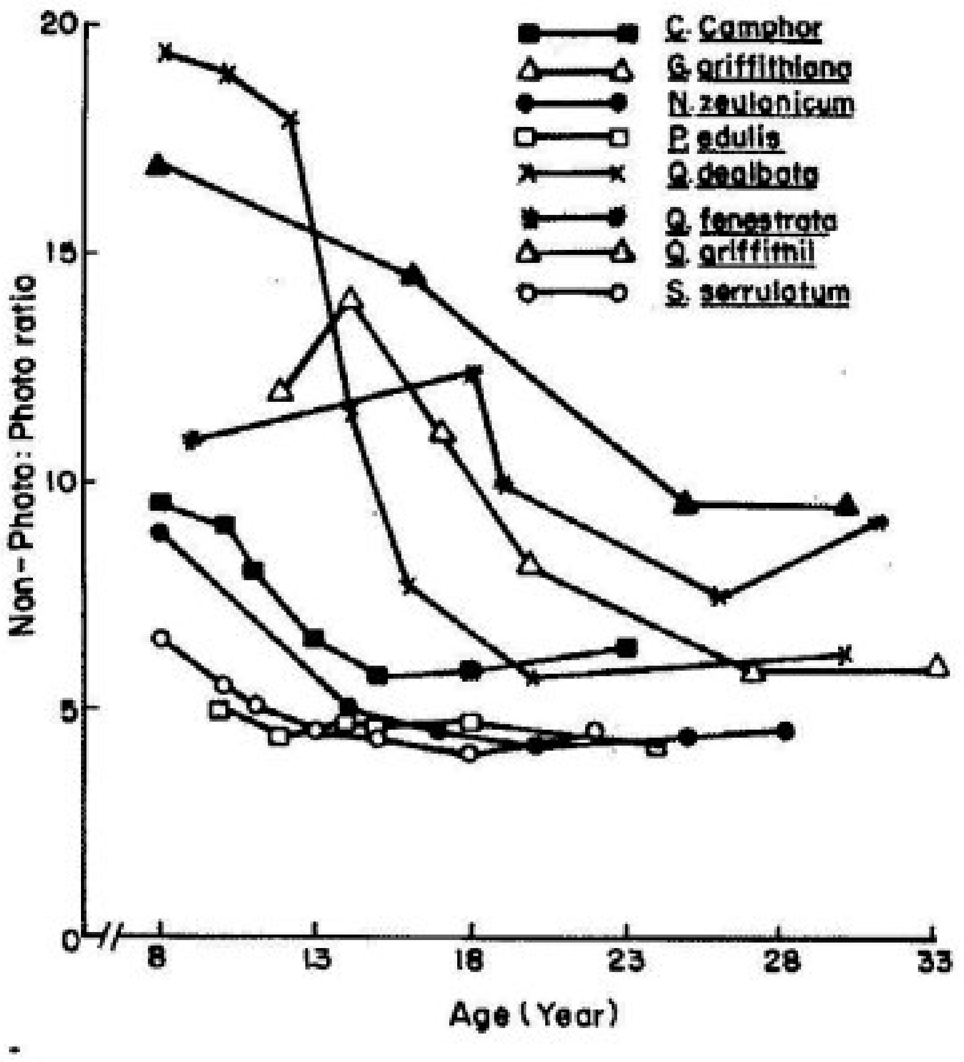

Fig. 1. The non-photosynthetic to photosynthetic ratio in oak forest site-I.

ha^{-1} yr^{-1} in site I and II respectively.

The net primary productivity of forest site-I (28.34 t ha^{-1} yr^{-1}) is slightly higher than the forest site-II (27.83 t ha^{-1} yr^{-1}). The present oak forests were more productive than that of post-black-Jack oak forest of USA (Johnson and Risser 1974), *Quercus alba* forest of USA (Rochow 1974a,b 1975), *Quercus* forest of Belgium (Duvigneaud and Denaeyer-Desmet 1970) and oak forest of Coweeta (Monk and Day 1985). The present estimates of net primary production are higher than the average data for the oak forests of Central Himalaya with exception of Tilonk oak *(Q. floribundea)* forest and the later exhibited more or less similar production potential. The high rate of primary production in this oak may be due to humid climatic condition with high rainfall coupled with many evergreen species found in north eastern India. Production efficiency in term of net production per unit weight of leaf or per unit area of leaf has been calculated for the present forest (Johnson and Risser 1974). The efficiency of leaf varied from 0.76 to 1.17 kg net production kg^{-1} leaf biomass per year and 0.38 to 0.54 kg net production m^{-2} leaf area per year in these forest sites (Table 8). Chaturvedi and Singh (1987) has also reported higher values of efficiency on the basis of foliage weight (1.33-2.30) and lower values on the foliage area basis (0.17-0.28) in pine forests in Central Himalaya of India. Of the total biomass in the tree layer the net production ranged from 11.25% to 13.21% in the present oak forests. The present values are more than the data reported by Monk and Day (1985) for different oak forest of the world.

The mean and current annual production of tree species in the forest site-I (Fig.3) and forest site-II have been estimated (Fig.4).

In forest site-I, the mean production of all components attained the peak value at the age of 15, 30, 20, 24, 19 and 27 years old trees in *Cinnamomum camphor, Gaultheria griffithiana, Neolitsea zeylanicum, Pyrularia edulis, Quercus dealbata, Q. fenestrata,* and *Q. griffithii* and in forest site-II the eak value was at the age of 34, 30 and 30 years ld trees in *Quercus griffithii, Rhododendron rboreum, Alnus nepalensis* and *Lyonia ovalifolia.*

The highest value of current annual production in tree species in forest site-I was in between 15 and 8 years old trees. In forest site-II *Alnus nepalensis* nd *Rhododendron arboreum* was found to increase f age upto 30 years old trees whereas in *Quercus riffithii* and *Lyonia ovalifolia* the peak values were at ie age of 32 and 27 years old trees. In both forest site- and site-II the mean and current annual production icreased with upto certain age and declined there- fter. Chaturvedi and Singh (1982) reported similar end for bole, branch and roots in *Pinus roxburghii* t the age of 39 years old tree.

The biomass accumulation ratio (biomass/net pro- uction) has been taken into consideration for deter- iining the production condition in forest communi- es and it depend upon size, rate of increment, age f species in the different sites. In the present forests ie biomass accumulation ratio in the tree ranged om 7.7 to 8.9. The ratio of biomass accumulation in the present study are lower than the ranges reported for intermediate and mature forests (Whittaker 1966) and oak forest of Central Himalaya (Singh and Singh 1986) and oak and swamp forests (Reiners 1972). However, the present ratios are more or less similar to the ratio reported for oak-pine forest at Brookhaven (Whittaker and Woodwell 1969). In the present study the low biomass accumulation ratios show that for a given amount of the primary production the system support a lesser total biomass. The present oak forest exhibited relatively a high rate of net accumulation, being a young secondary forest.

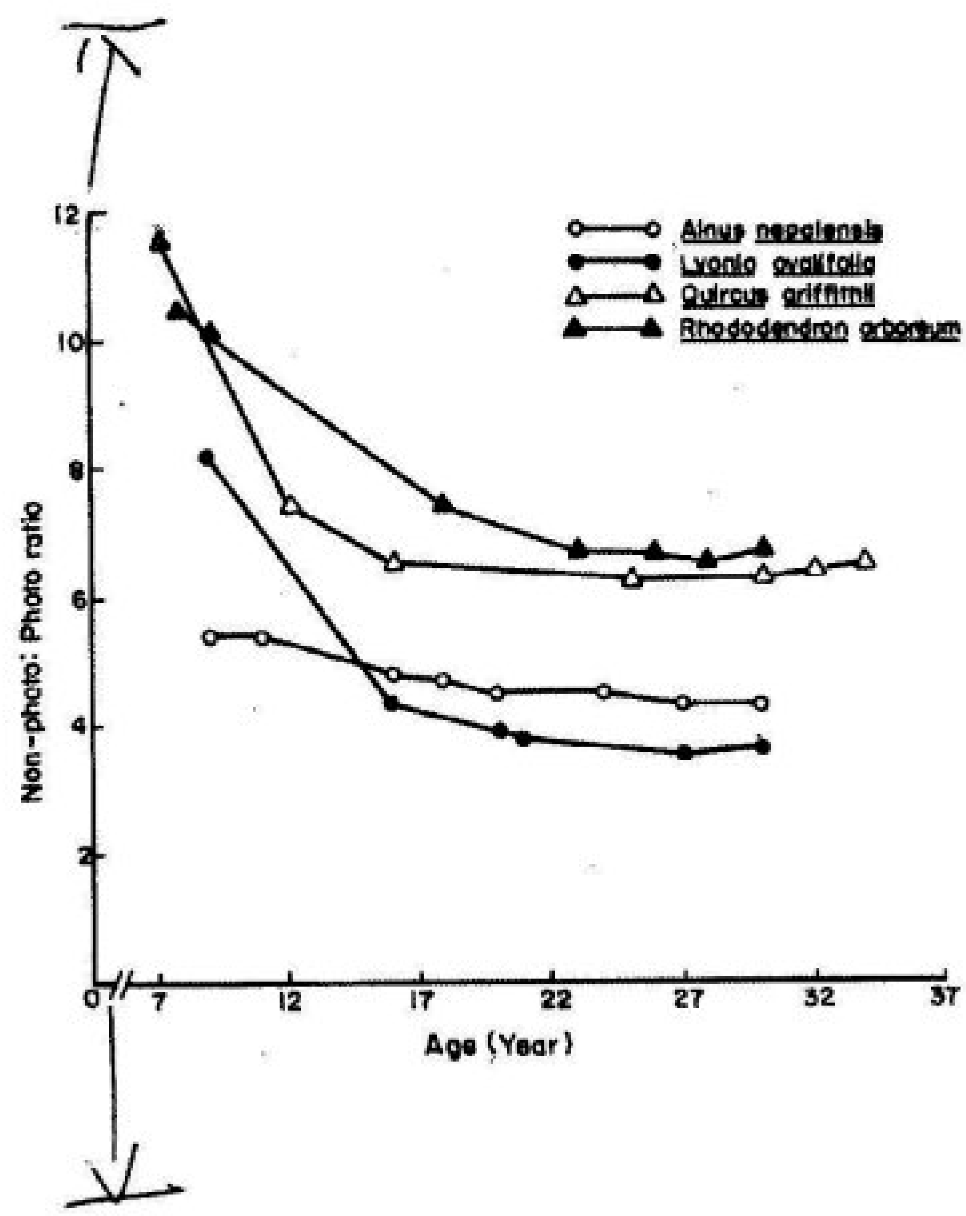

Fig. 2. The non-photosynthetic to photosynthetic ratio in oak forest site-II.

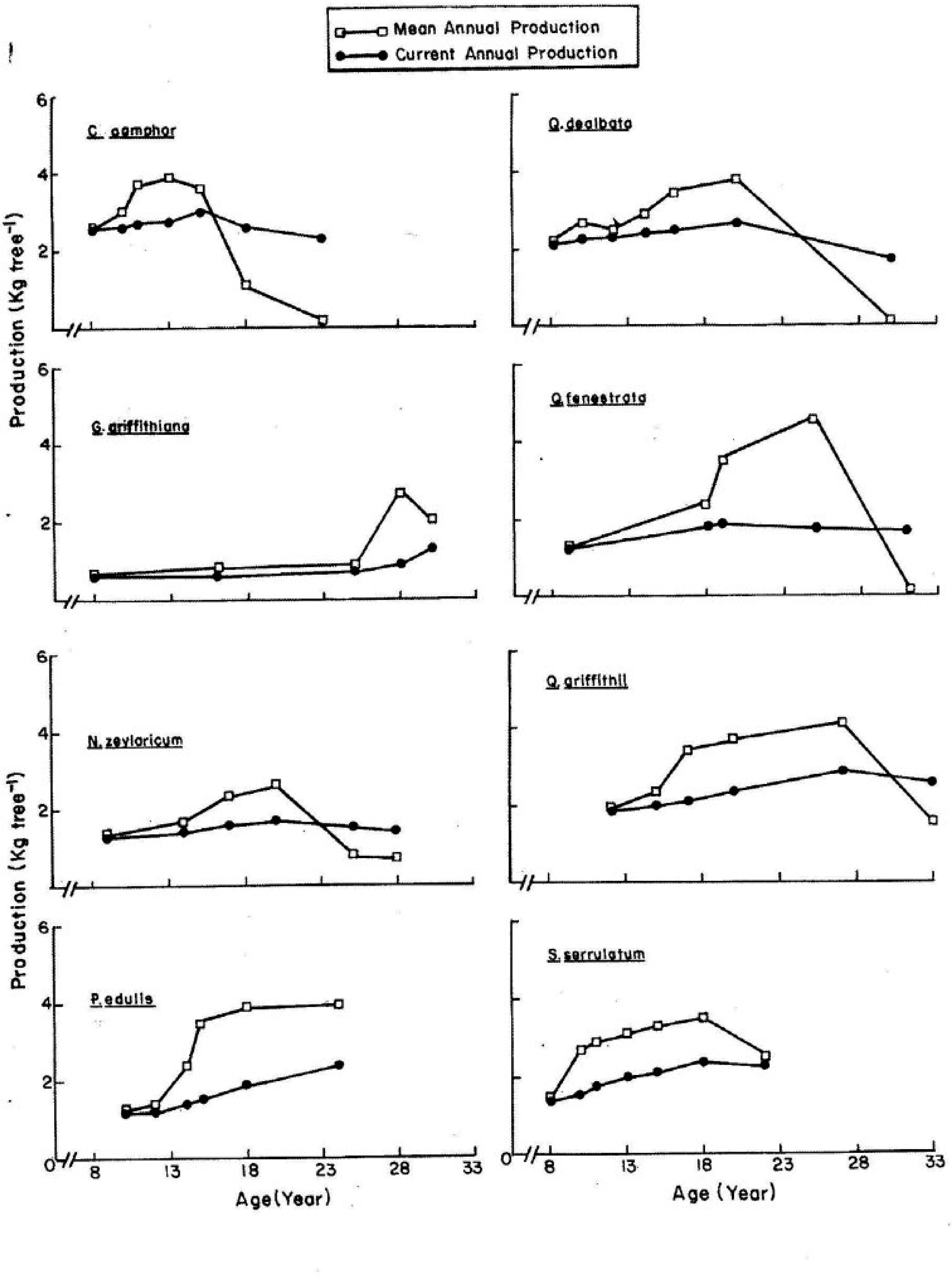

Fig. 3. The mean and current annual production at different ages of tree species in oak forest site-I.

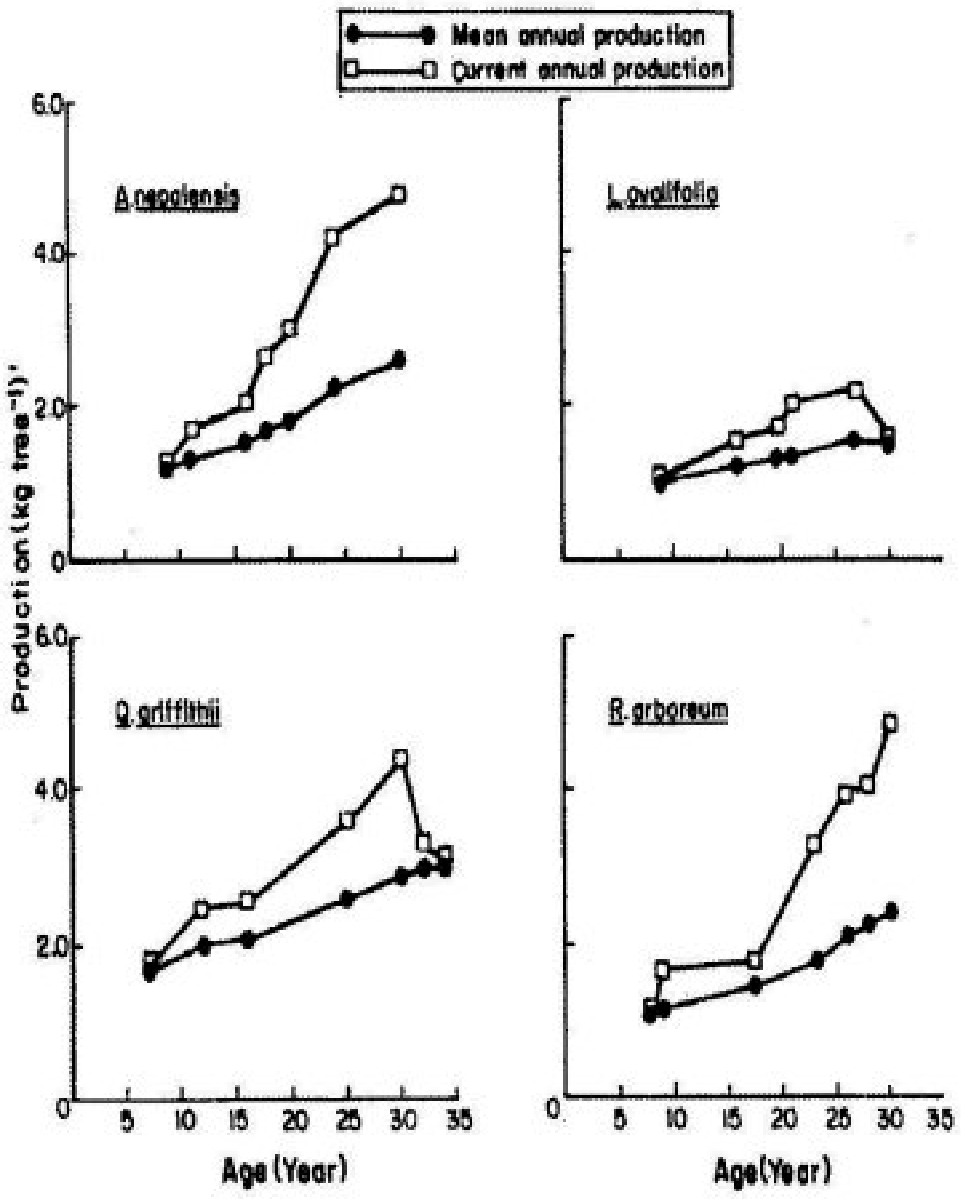

Fig. 4. The mean and current annual production at different ages of tree species in oak forest site-II.

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References

Adams, P.W. 1982: Estimating biomass in northern lower Michigan Forest stands. *Forest Ecology and Management*, **4**: 275-286.

Anderson, F. 1971: Methods and preliminary results of estimation in South Swedish mixed deciduous woodland. In *Proceedings of Brussels Symposium on Productivity of forest ecosystems* (ed. Duvigneaut), pp. 281-288, UNESCO, Paris.

Champion, H.G. and Seth, S.K. 1968: A revised survey of the forest types of India. *Government of India Publ.* **404**, Delhi.

Chaturvedi, O.P. and Singh, J.S. 1982: Total biomass and biomass production of *Pinus roxburghii* trees growing in all aged natural forest. *Canadian Journal of Forest Research*, **11**: 632-640.

Chaturvedi, O.P. and Singh, J.S. 1987: The structure and function of Pine forest in Central Himalaya. I Dry Matter dynamics. *Annals of Botany*, **60**: 237-252.

Curtis, J.T. 1959: The vegetation of Wisconsin. An ordination of plant communities. Wisconsin Press, Madison.

Duvigneaud, P. and Denaeyer-De Smet, S. 1970: Biological cycling of minerals in temperate deciduous forests. In *An analysis of temperate forest ecosystem* (ed. Reichle D.E.), pp. 199-225, New York.

Duvigneaud, P., Kestemont, P. and Ambraces, P. 1971: Productivite primarie des ferets temperees desseree foilles conducifoliees on Europe accidentale. In *Productivity of forest ecosystems* (ed. P. Duvigneaud), pp. 259-270, UNESCO, Paris.

Johnson, F.L. and Risser, P.G. 1974: Biomass, annual net primary production and dynamics of six mineral elements in a post Oak-black Jack Oak forest. *Ecology*, **55**: 1246-1258.

Monk, C.D. and Day JR.F.P. 1985: Vegetation analysis, primary production and selected nutrient budgets for a southern appalachian oak forest: a synthesis of IBP studies at Coweeta. *Forest Ecology and Management*, **10**: 87-113.

Negi, K.S., Rawat, Y.S. and Singh, J.S. 1983: Estimation of biomass and nutrient storage in a Himalayan moist temperate forest. *Canadian Journal of Forest Research*, **13**: 1185-1196.

Newbould, P.J. 1967: Methods of estimating the primary production of forests. IBP Handbook, No. 2. Oxford.

Rawat, Y.S. 1988: Plant biomass, net primary production and nutrient cycling in oak forest. Ph.D. Thesis, Kumaun University, Nainital.

Rawat, Y.S. and Singh, J.S. 1988: Structure and function of oak, forest in Central Himalaya I. Dry matter dynamics. *Annals of Botany*, **62**: 397-411.

Reiners, W.A. 1972: Structure and energetics of three Minnesota forest. *Ecological Monograph*, **42**: 71-94.

Rochow, J.J. 1974a: Estimates of aboveground biomass and primary productivity in a Missouri forest. *Journal of Ecology*, **62**: 567-577.

Rochow, J.J. 1974b: Litterfall relation in a Missouri forest. *Oikos*, **25**: 80-85.

Rochow, J.J. 1975: Mineral nutrient pool and cycling in a Missouri forest. *Journal of Ecology*, **63**: 985-994.

Rodin, I.E. and Bazilevich, N.I. 1967: The biological productivity of the main vegetation types in the northern hemisphere of the old world. *Forest Abstract Leading Article*, Ser. **38**.

Singh, E.J. and Yadava, P.S. 1991: Aboveground biomass and net production in two oak species growing in the natural forest of Manipur, India. *Tropical Ecology*, **32**: 117-126.

Singh, J.S. and Singh, S.P. 1986: Structure and function of Central Himalayan oak forest.*Proceedings of Indian Academic Science*, **96**: 159-189.

Sonn, S.W. 1960: Der Einfluß des Waldes und Boden. VEB Gustav Fischer Verlag, Jena.

Whittaker, R.H. 1966: Forest dimension and production in the Great Smoky Mountains. *Ecology*, **47**: 105-121.

Whittaker, R. H. and Woodwell, G. M. 1969: Structure, production and diversity of the oak-pine forest at Brookhaven. *Journal of Ecology*, **57**: 155-174.

Yadava, P.S. and Singh, E.J. 1988: Some aspects of ecology of oak forests in Shiroy hills, Manipur (North eastern India). *International Journal of Ecology and Environmental Sciences*, **14**: 103-113.

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