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Practice-Oriented Yield Table for White Poplar Stands Growing under Sandy Soil Conditions in Hungary

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Abstract

Background and purpose: *White poplar (*Populus alba *L.) and its most important natural hybrid, the grey poplar (*Populus x canescens *SM.) are native tree species in Hungary, covering 3.2% of the forested area. Thanks to their favourite silvicultural and growth characteristics as well as the wood utilization possibilities, their present area is increasing continuously. The most important task ahead of Hungarian poplar growers is to improve the quality and to increase the quantity of poplar stands for wood production. To determine their growth rate and yield as exactly as possible, a yield table has been constructed which is based on the currently applied silvicultural practice.*

Material and methods: *Chapman – Richards function with three parameters was successfully used as a growth function for constructing the height growth model. The white poplar yield table was constructed from data gathered on 50 permanent and 40 temporary plots (cca. 500-1000 m²). The age of the stands varied between 5 and 45 years. In the course of the stand surveys the key stand characteristics were measured, and then, on the basis of data collected, were calculated such major stand structure features as the average height, diameter (DBH), volume, basal area and stem number given separately for the main (remaining), secondary (removal) and total stands per hectare.*

Results and conclusion: *The numerical (tabulated) yield table of normative nature presents data given to six yield classes (base age: 25 years) including the most important stand structural and yield features expressing in terms of main stand, removing stand (which can be removed in tending operations) and the total stand. It is based on the Hungarian applied tending operations' practice. The published yield table has already been utilized in the field of the relevant forest inventory as well.*

*Keywords: white poplar (*Populus alba *L.), Chapman – Richards function, yield table, Hungary*

INTRODUCTION

White poplar (*Populus alba* L.) and the grey poplar (*Populus x canescens*) are native poplar species in Hungary. Their area was 65000 ha in 2006 (3.2% of the total forested land), with a standing volume of 9.8 million m^3 (163 m^3 ha^{-1}).

More than 70% of the white poplar stands can be found on calcareous sandy sites on the Danube-Tisza region. Native poplars have been regarded for several decades as weed tree species without any value for timber market. In spite of this fact about 35% of the new afforestation and artificial regeneration is carried out presently with white poplar in the mentioned region. White poplar has a rich gene pool on the sand dune region in the middle of the Great Hungarian Plain and on the bottomland of big rivers [1, 2]. In the near future, due to the establishment of national parks in these regions, considerable increases can be expected in the area of native poplars. At the same time their importance will be increasing in the large areas of marginal sites which are not suitable for hybrid poplars but can accommodate native ones.

In the Danube-Tisza region some very important ecological factors have become unfavourable for poplar growing in the last two decades. There is no sufficient precipitation during the growing season (appr. 200-300 mm), and the rivers' control and canalisation have caused a drastic lowering of the ground-water table in many places. In such spots the water supply for poplars depends on the moisture content of soils, accumulating waters on the surface and on the water-storing capacity of soils [3, 4].

It should also be emphasized that white poplar is a fast-growing species which in the seedling age rises quickly form the weed competition. In the first years of the forestations established by seedling it must perform the in-line and inter-row weeding, as well as the cutting back of injured plants. During of its tending operations it is important to take into consideration, that its populations consist of trees of varied genetic value (genotypic). From the point of view of its light-demand the fact deserves attention, that while it endeavours extremely strongly to the light, on the other hand it tolerates excellently the shade too.

The considerable white poplar afforestation of the last decades is indicated by the fact, that the 75% (according to the area), respectively the 60% (according to the growing stock) of white poplar stands can be found on calcareous sandy sites in the Danube-Tisza region [5]. The average growing stock is 161 m^3/ha; the average final cutting age is 32 years.

The white poplar yield table compiled *to the area of the sandy sites* as regards its nature is the first in the history of the national white poplar research. The course of the compilation, which can be programmed, makes possible enlarging the information content of the yield table and also changing its form and content.

MATERIAL AND METHODS

The white poplar yield table was constructed from data gathered on 50 permanent and 40 temporary plots (cca. 500-1000 m^2) located in stands in the sandy ridges between the rivers Danube and Tisza (Figure 1). The age of the pure stands owned by state varies between 5 and 45 years and they have been managed on base of growth and silvicultural model for white poplar stands [3].

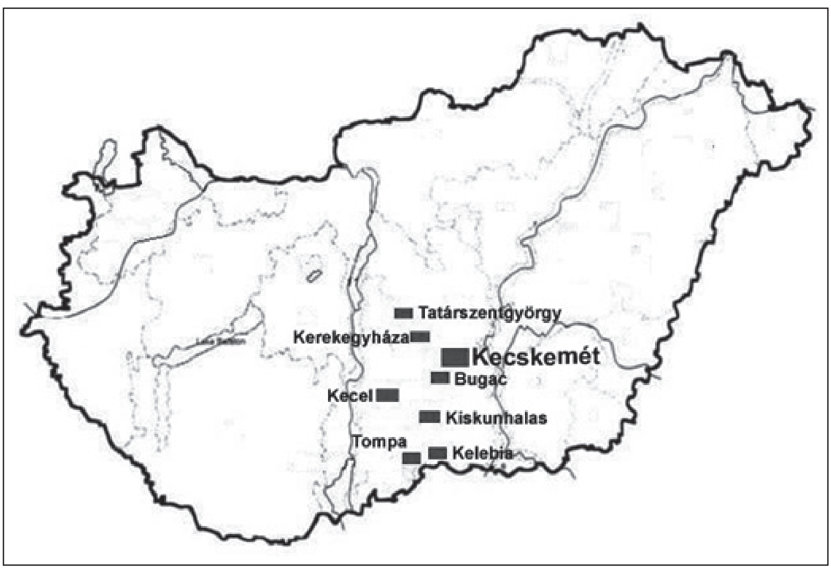
In the course of the stand surveys the key stand characteristics were measured, and then, on the basis of data collected, were calculated such major stand structure features as the average height, diameter (DBH), volume, basal area and stem number given separately for the main (remaining), secondary (removal) and total stands per hectare. Stem volume was estimated by the following volume function [6]:

$$v = 10^{-8} d^2 h^1 \left(h/[h-1.3]\right)^2 [-0.4236\,dh + 12.43\,d + 4.6\,h + 3298]$$

where v is stem volume (m^3), d is diameter at breast height (cm), and h is tree height (m).The regression analysis have been computed by the ANOVA statistical programme.

In the USA, South Africa and many other countries, the site index, site class or yield class of a stand is usually defined as the mean height of the dominants and codominants [7-10], at a reference age, which is closely

FIGURE 1
Locations of the sampling plots



linked with the rotation age. In Germany, the site index, which replaced the earlier site class concept, is defined as the regression height of the quadratic mean diameter of the 100 thickest trees per hectare at a reference age which is usually 100 years [11]. A much lower reference age is used for fast-growing stands and plantations, for example, 25 years for black locust (*Robinia pseudoacacia L.*) [12], and also 25 years were chosen for white poplar to construct the new yield table.

In Hungary the Chapman – Richards function [13] is the most frequently used function in the yield - (site -) dependent height growth model. It has three parameters a, b and c, which control the asymptote, slope, and the location of the function's inflection point. On base of this function a guide curve was fitted to the distribution of the average heights of main stands, plotted over age. This curve was used to generate a family of yield class curves on base of the reference age. The expected height values of the main stands at the reference age according to the yield classes are: 24.2 m, 21.6 m, 19.0 m, 16.4 m, 13.8 m and 11.2 m. According to the fitted guide curve and to the reference age (100%) a percentage value could be calculated at any ages and for any yield classes. The authors' yield table was constructed using the following formulas and coefficients (detailed dataset can be available at the authors):

1. Age of stand (A)

2. H_m = average height of main (remaining) stand (height of dominant and co-dominant trees) in m:

$$H_m = 1.21592 \times (1 - e^{-0.09236A})^{1.6554}$$

3. D_m= average DBH of main (remaining) stand in cm:

$$D_m = 1.58356 + 0.73502 \times H_m + 0.01571 \times H_m^2$$

with R^2=0.886

4. V_m= volume of main (remaining) stand in *m³ ha⁻¹:*

$$V_m = BA_m \times H \times F$$

where $H \times F$ = form-height quotient

$$H \times F = 1.96791 + 0.40778 \times H_m$$

with R^2=0.923

5. BA_m= basal area of main (remaining) stand in m^2h^{-1}:

$$BA_m = \frac{D_m^2 \times \Pi}{4 \times 10000} \times N_m$$

6. N_m= stem number of main (remaining) stand in ha^{-1}:

$$N_m = e^{8.75483 - 0.83879 \ln D_m}$$

with R^2=0.826

7. H_r= average height of removal stand in m:

$$H_r = 0.7 \times H_m$$

8. D_r= average DBH of removal stand in cm:

$$D_r = 0.7 \times D_m$$

9. V_r= volume of removal stand in $m^3\ ha^{-1}$:

$$V_r = BA_r \times H \times F_m$$

10. BA_r = basal area of removal stand in m^2h^{-1}:

$$BA_r = \frac{D_r^2 \times \Pi}{4 \times 10000} \times N_r$$

11. N_r= stem number of removal stand computing from reduction of stem number of main crop in five year intervals in ha^{-1}

12. H_t= average height of total stand in m:

$$H_t = 1.14174 + 1.02809 \times H_m$$

with R^2=0.917

13. D_t= average DBH of total stand in cm:

$$BA_m = \frac{D_m^2 \times \Pi}{4 \times 10000} \times N_m$$

14. BA_t= basal area of total stand in $m^2 \times ha^{-1}$:

$$BA_t = BA_m + BA_r$$

15. V_t= volume of total stand in $m^3 \times ha^{-1}$:

$$V_t = V_m + V_r$$

16. N_t= stem number of total stand in ha^{-1} :

$$N_t = N_m + N_r$$

17. Cumulative volume of intermediate cuttings $= \Sigma$ total volume of removing stands in $m^3\ ha^{-1}$.

18. Cumulative total volume (ΣV_c)= volume of total

stand in age A + volume of removing stand in age *A – 5* in $m^3\ ha^{-1}$.

19. Mean annual increment of cumulative total volume $= (\Sigma V_c) \times A^{-1}$ in $m^3ha^{-1}yr^{-1}$. Due to the yield table construction followed by the authors, the culmination of the mean annual volume increment in each yield class can be found at the reference age.

20. Current increment of cumulative total volume = one year increment of (ΣV_c) in five year intervals in $m^3ha^{-1}yr^{-1}$.

RESULTS

The numerical (tabulated) yield table of normative nature presents data given to six yield classes (base age: 25 years) including the most important stand structural and yield features expressing in terms of main stand, removing stand (which can be removed in tending operations) and the total stand. It is based on the currently applied silvicultural practice [3]. The data are given form 5 to years 45 (Table 1). Figure 2.a to 2.f show the height, DBH, volume and stem number indices for main stand as well as the total volume and the mean annual increment of total volume indices in function of age and yield class.

When using the yield table for determining the actual volume per ha (V_{act}) of a stand, a basal area ratio is to be recommended:

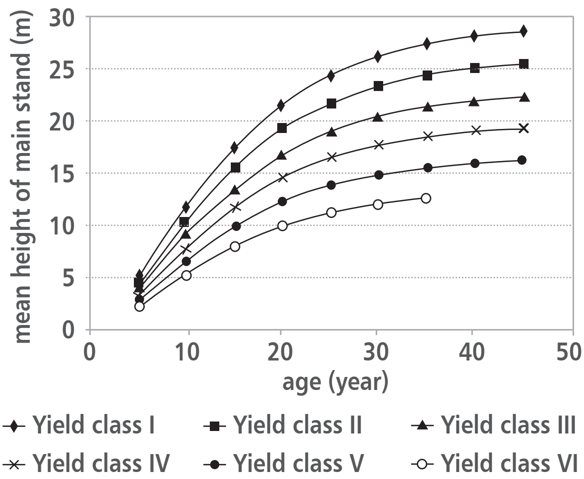
$$V_{act} = V_{tab} \times BA_{act} BA_{tab}^{-1}$$

where:

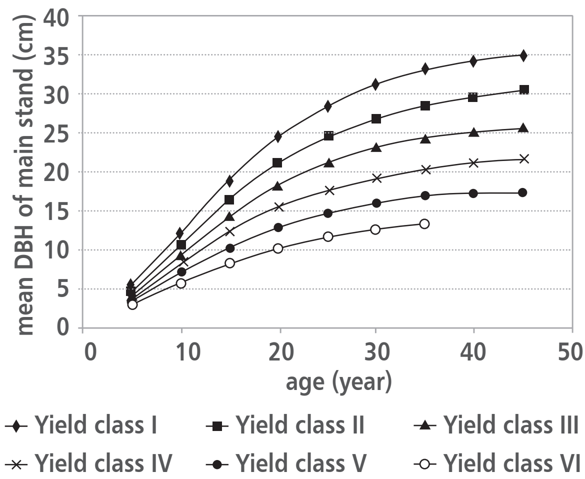
V_{tab} = volume of the stand by yield table according to the age and yield class,

BA_{act} = actual basal area of the stand per ha,

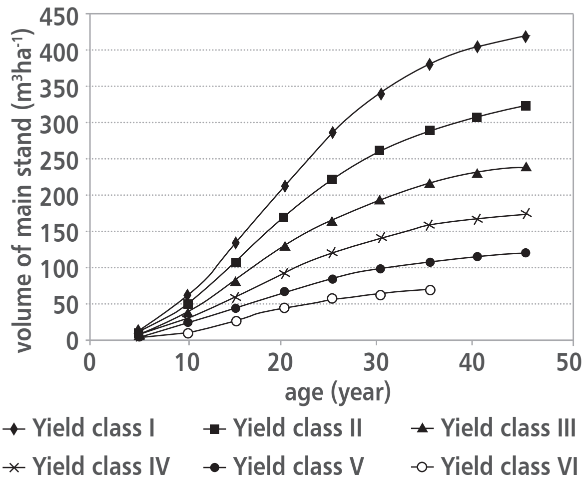
BA_{tab} = basal area by yield table according to the age and yield class of the stand.



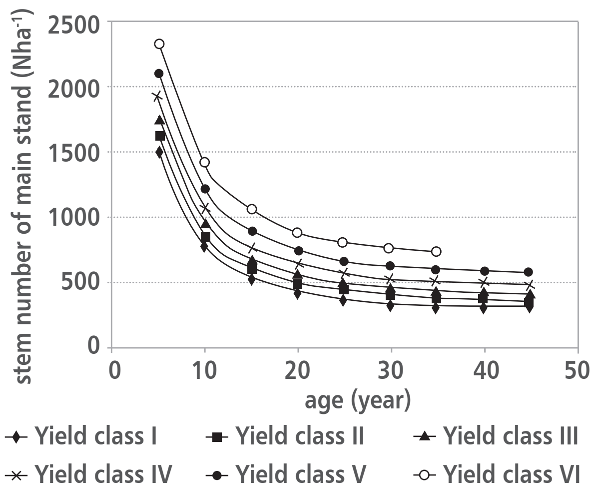
a) Mean height yield class indices for main stand



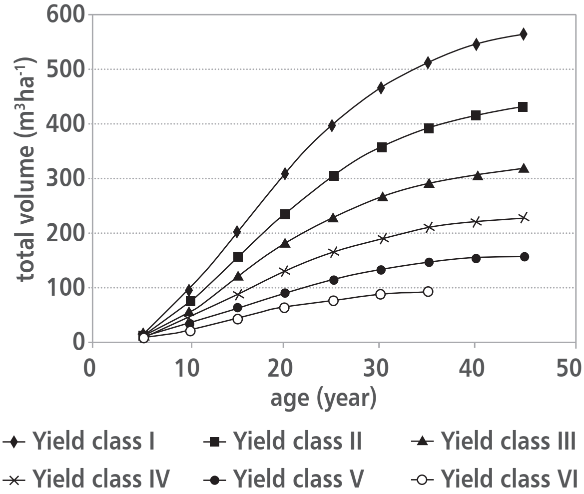
b) Mean DBH yield class indices for main stand



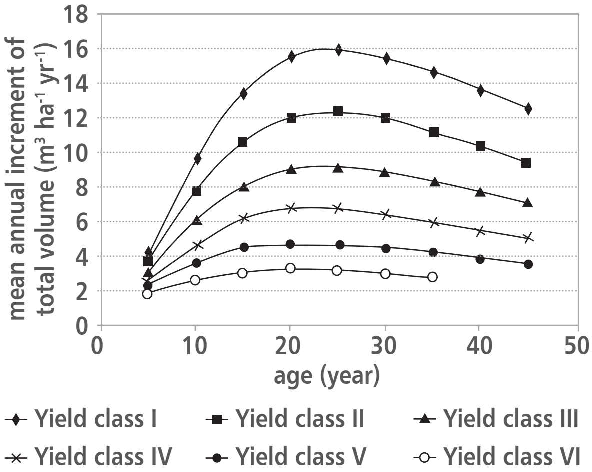
c) Volume yield class indices for main stand



d) Stem number yield class indices for main stand



e) Total volume yield class indices



f) Mean annual increment of total volume yield class indices

FIGURE 2
White poplar stand structure factors in function of age and yield class

DISCUSSION AND CONCLUSIONS

Growth is a biological process, which is defined and measured as the change in volume and other size parameters as a function of age. Yield quantifies the volume (or weight) of the whole stand or of a single tree, which is potentially available at the time of harvesting. In order to obtain a biologically meaningful estimate for growth, the volume should reflect the total, rather than merchantable stand volume, although the latter is required for management inventories.

The published empirical yield table is the first one for white poplar stands in the international literature based on Chapman – Richards function used for yield – dependent height growth model. This type of yield tables supposedly applies to "average" rather than full stocking. In other words, an empirical yield table applies only to the average density levels found on the sample plots used.

Empirical yield tables provide few advantages over full stocking yield tables; the principal idea behind their construction was that the resultant tables should more closely approximate realizable yields under operational forest management than would the values from full stocking yield tables [8]. In spite of this fact the modern growth and yield modelling techniques do not rely on either "average" or full stocking density concepts, but, rather, include density as a dynamic part of the stand-projection system. Such growth and yield models are commonly termed variable-density tables (or equations).

In the last decades, growth models focussed on stand level data have gradually been replaced by stand growth models that predict stem number frequencies and individual-tree growth models [11]. In spite of this fact yield tables will remain very useful tools for forest management and forest inventory in the future.

The published yield table can be widely utilized in the following fields of the Hungarian white poplar management and the relevant forest inventory:

- appraisal of statistical nature of the white poplar stands,
- harvest scheduling of white poplar stands, implementing the volume estimations,
- elaborating or further developing silvicultural (tending operation) models for white poplar stands,
- elaborating and explaining the guidelines of the local tree species policy, and
- national analysis related to the growing of white poplar stands.

To improve the yield models for white poplar stands is to be considered as a continuous task in the future, too.

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TABLE 1
Yield table for white poplar stands

Age of stand	Main (remaining) stand					Removal stand					Total stand					Cumulative volume of intermediate cuttings	Share of intermediate cuttings	Cumulative total volume		
	average height	average diameter	volume	basal area	stem number	average height	average diameter	volume	basal area	stem number	average height	average diameter	volume	basal area	stem number			volume	mean annual increment	current increment
	H_m	Dm	V_m	BA_m	N_m	H_m	Dm	V_m	BA_m	N_m	H_m	Dm	V_m	BA_m	N_m					
yr	m	cm	m^3ha^{-1}	m^2ha^{-1}	ha^{-1}	m	cm	m^3ha^{-1}	m^2ha^{-1}	ha^{-1}	m	cm	m^3ha^{-1}	m^2ha^{-1}	ha^{-1}	m^3ha^{-1}	%	m^3ha^{-1}	$m^3ha^{-1}yr^{-1}$	$m^3ha^{-1}yr^{-1}$
Yield Class I																				
5	4.7	5.4	14	3.5	1539	3.3	3.8	7	1.8	1587	3.7	4.7	21	5.3	3126	7	33.6	21	4.1	0.0
10	11.6	12.2	61	9.1	778	8.1	8.5	29	4.4	761	10.8	10.5	90	13.4	1539	36	37.3	97	9.7	15.2
15	17.3	19.0	136	15.1	537	12.1	13.3	30	3.3	241	16.6	17.4	166	18.5	778	66	32.6	203	13.5	21.1
20	21.4	24.5	217	20.4	433	15.0	17.1	26	2.4	104	20.8	23.2	243	22.7	537	92	29.7	309	15.5	21.3
25	24.2	28.5	288	24.3	381	16.9	20.0	19	1.6	52	23.8	27.6	307	25.9	433	111	27.8	398	15.9	17.9
30	26.0	31.3	341	27.1	352	18.2	21.9	14	1.1	29	25.6	30.7	354	28.2	381	125	26.8	465	15.5	13.4
35	27.2	33.2	379	29.0	336	19.0	23.2	9	0.7	16	26.8	32.8	388	29.7	352	134	26.0	513	14.7	9.5
40	28.0	34.3	405	30.3	326	19.6	24.1	6	0.5	10	27.6	34.1	411	30.7	336	140	25.6	545	13.6	6.4
45	28.4	35.2	421	31.0	319	19.9	24.6	5	0.3	7	28.1	35.0	425	31.3	326	144	25.5	565	12.6	4.1
Yield Class II																				
5	4.2	5.0	12	3.2	1654	3.0	3.5	6	1.7	1802	3.2	4.3	18	4.9	3456	6	34.8	18	3.6	0.0
10	10.3	10.9	49	7.9	858	7.2	7.6	22	3.6	796	9.5	9.4	71	11.5	1654	29	36.8	78	7.8	11.9
15	15.4	16.6	107	13.0	599	10.8	11.6	23	2.8	259	14.7	15.3	130	15.8	858	51	32.3	159	10.6	16.2
20	19.1	21.3	169	17.4	487	13.3	14.9	19	2.0	112	18.5	20.3	188	19.3	599	70	29.4	240	12.0	16.2
25	21.6	24.7	222	20.7	430	15.1	17.3	14	1.3	57	21.0	24.0	237	22.0	487	85	27.6	307	12.3	13.5
30	23.2	27.1	262	22.9	398	16.2	19.0	10	0.9	32	22.7	26.6	272	23.8	430	95	26.6	357	11.9	10.0
35	24.3	28.7	290	24.4	379	17.0	20.1	7	0.6	19	23.8	28.3	297	25.0	398	102	26.1	392	11.2	7.0
40	24.9	29.7	309	25.5	368	17.5	20.8	8	0.4	11	24.5	29.5	314	25.8	379	107	25.7	416	10.4	4.7
45	25.4	30.4	322	26.2	362	17.8	21.2	3	0.2	6	24.9	30.2	325	26.4	368	109	25.3	432	9.5	3.2
Yield Class III																				
5	3.7	4.5	10	2.9	1787	2.6	3.2	6	1.6	2070	2.7	3.9	16	4.5	3857	6	26.2	16	3.1	0.0
10	9.1	9.6	39	6.8	954	6.4	6.7	17	2.9	833	8.2	8.3	55	9.8	1787	22	36.5	61	6.1	9.1
15	13.5	14.4	83	11.0	675	9.5	10.1	17	2.2	279	12.8	13.3	99	13.3	954	39	32.1	122	8.1	12.1
20	16.8	18.3	128	14.6	552	11.7	12.8	14	1.6	123	16.1	17.5	142	16.1	675	53	29.3	181	9.1	11.9
25	19.0	21.2	167	17.2	490	13.3	14.8	10	1.1	62	18.3	20.6	177	18.3	552	63	27.5	230	9.2	9.9
30	20.4	23.1	196	19.1	455	14.3	16.2	7	0.7	35	19.8	22.7	204	19.8	490	71	26.5	267	8.9	7.3
35	21.3	24.4	217	20.3	434	14.9	17.1	5	0.5	21	20.8	24.1	222	20.8	455	76	25.9	293	8.4	5.1
40	21.9	25.3	231	21.1	422	15.4	17.3	3	0.3	12	21.4	25.1	234	21.4	434	79	25.5	310	7.7	3.4
45	22.3	25.8	240	21.6	414	15.6	18.1	2	0.2	8	21.8	25.7	242	21.8	422	81	25.4	321	7.1	2.2

Age of stand	Main (remaining) stand					Removal stand					Total stand					Cumulative volume of intermediate cuttings	Share of intermediate cuttings	Cumulative total volume		
	average height	average diameter	volume	basal area	stem number	average height	average diameter	volume	basal area	stem number	average height	average diameter	volume	basal area	stem number			volume	mean annual increment	current increment
	H_m	Dm	V_m	BA_m	N_m	H_m	Dm	V_m	BA_m	N_m	H_m	Dm	V_m	BA_m	N_m					
yr	m	cm	m^3ha^{-1}	m^2ha^{-1}	ha^{-1}	m	cm	m^3ha^{-1}	m^2ha^{-1}	ha^{-1}	m	cm	m^3ha^{-1}	m^2ha^{-1}	ha^{-1}	m^3ha^{-1}	%	m^3ha^{-1}	$m^3ha^{-1}yr^{-1}$	$m^3ha^{-1}yr^{-1}$
Yield Class IV																				
5	3.2	4.1	8	2.6	1943	2.2	2.9	5	1.6	2453	2.1	3.5	14	4.1	4396	5	38.2	14	2.7	0.0
10	7.8	8.3	30	5.8	1073	5.5	5.8	12	2.3	870	6.9	7.3	42	8.1	1943	17	36.3	47	4.7	6.7
15	11.7	12.3	62	9.2	771	8.2	8.6	12	1.8	302	10.9	11.4	74	11.0	1073	29	31.9	91	6.1	8.7
20	14.5	15.5	94	12.0	636	10.1	10.9	10	1.2	135	13.7	14.8	104	13.3	771	39	29.1	133	6.7	8.5
25	16.4	17.8	122	14.1	566	11.4	12.5	7	0.9	70	15.7	17.3	129	14.9	636	46	27.5	168	6.7	6.9
30	17.6	19.4	142	15.6	527	12.3	13.6	5	0.6	39	17.0	19.0	147	16.1	566	51	26.5	194	6.5	5.1
35	18.4	20.4	157	16.5	504	12.9	14.3	4	0.4	23	17.8	20.2	160	16.9	527	55	25.9	211	6.0	3.6
40	18.9	21.1	166	17.2	491	13.2	14.8	2	0.2	13	18.3	21.0	169	17.4	504	57	25.5	223	5.6	2.4
45	19.3	21.6	173	17.6	482	13.5	15.1	2	0.2	9	18.6	21.5	174	17.7	491	59	25.3	231	5.1	1.5
Yield Class V																				
5	2.7	3.7	7	2.3	2128	1.9	2.6	5	1.5	2964	1.6	3.1	12	3.8	5092	5	40.6	12	2.3	0.0
10	6.6	7.1	23	4.9	1223	4.6	5.0	8	1.8	905	5.6	6.3	31	6.6	2128	13	36.4	36	3.6	4.8
15	9.8	10.3	45	7.5	894	6.9	7.2	8	1.3	329	9.0	9.6	53	8.8	1223	21	31.9	66	4.4	6.0
20	12.2	12.9	67	9.6	744	8.5	9.0	7	1.0	150	11.4	12.3	73	10.6	894	28	29.2	94	4.7	5.7
25	13.8	14.7	85	11.2	666	9.6	10.3	5	0.6	78	13.0	14.3	90	11.9	744	32	27.6	118	4.7	4.7
30	14.8	15.9	99	12.4	622	10.4	11.1	3	0.4	44	14.1	15.6	102	12.8	666	36	26.6	135	4.5	3.4
35	15.5	16.7	109	13.1	597	10.8	11.7	2	0.3	25	14.8	16.6	111	13.4	622	38	26.0	147	4.2	2.4
40	15.9	17.3	115	13.6	581	11.1	12.1	2	0.2	16	15.2	17.1	116	13.8	597	40	25.7	155	3.9	1.6
45	16.2	17.6	119	13.9	572	11.3	12.3	1	0.1	9	15.5	17.5	120	14.0	581	41	25.4	160	3.6	1.0
Yield Class VI																				
5	2.2	3.3	6	2.0	2352	1.5	2.3	4	1.5	3742	1.1	2.7	10	3.5	8094	4	43.8	10	2.0	0.0
10	5.3	6.0	10	4.0	1418	8.7	4.2	5	1.3	934	4.4	5.3	22	5.2	2352	10	37.1	26	2.6	3.2
15	8.0	8.4	31	5.9	1059	5.6	5.9	5	1.0	359	7.1	7.9	36	6.9	1418	15	32.4	46	3.0	3.9
20	9.9	10.4	45	7.5	892	6.9	7.3	4	0.7	167	9.0	9.9	49	8.2	1059	19	29.6	64	3.2	3.7
25	11.2	11.7	57	8.7	803	7.8	8.2	3	0.5	89	10.3	11.4	60	9.2	892	22	28.0	79	3.1	2.9
30	12.0	12.7	65	9.5	753	8.4	8.9	2	0.3	50	11.2	12.5	67	9.8	803	24	27.0	89	3.0	2.1
35	12.5	13.3	71	10.0	724	8.8	9.3	1	0.2	29	11.8	13.2	72	10.2	753	26	26.4	97	2.8	1.5

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