THE ESTABLISHMENT OF RED OAK AND PEDUNCULATE OAK SEEDLINGS IN THE EXPERIMENTAL FOREST OF AELMOESENEIE AT GONTRODE (BELGIUM)

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ABSTRACT

The natural regeneration of American oak and pedunculate oak under cover occurs regularly in the Aelmoeseneie forest. Nevertheless, these seedlings tend to establish very difficultly. They often die off after one year. In order to survive, the crown cover has to be strongly opened after the first year.
One year old seedlings of American oak, however, grow slightly better under cover than under partial freestand. The seedlings of pedunculate oak, on the other hand, hardly react on the different light conditions.
The American oak seeds are of good quality. A considerable amount is eaten by the birds. The seeds of pedunculate oak are of a minor quality; an important number is eaten by the worms.
The growth of the seedlings in the Aelmoeseneie forest does not always correspond to the growth on other sites.

1. Introduction and problems

In the experimental Aelmoeseneie forest, which can be considered mainly as a mixed 70 years old hardwood forest, seedlings of different tree species can be found regularly, especially of common maple (*Acer pseudoplatanus L.*), ash (*Fraxinus excelsior L.*) and American red oak (*Quercus rubra L.*). Most of these seedlings, however, die off in the course of their first or second life year. The causes of this phenomenon are obviously complex, even though it is evident that the soil characteristics and the light conditions play an important role.
Due to favourable climatological circumstances, good seed years are relatively frequent. In this way, 1986 was a good year too; especially for American red oak, ash and common maple. On this occasion, special attention was paid to the seedfall with American oak and pedunculate oak. The quality of the seed, as well as the losses, were determined accurately. At the same time, the existing one, two or three year old seedlings were analysed morphologically: the shoot, root and leaf features were characterised considering the light conditions and the age.
The aim of the researchers is to contribute to the explanation of the phenomenon of natural regeneration in the experimental forest. In other words: how is it possible to stimulate the establishment of the oak regeneration?
The experimental forest of Aelmoeseneie is located near Ghent in Belgium. The climate is characterised by :

- an average annual temperature of 9.6°C;
- an average annual precipitation of 752 mm;
- an average temperature of 2.4°C in the coldest month.

The soil consists mainly of sandy loamy soils with a relatively efficient water economy, even though it might get a bit too wet during winter.

2. General problems with the natural oak regeneration

A shortage in seed production is certainly not the cause of the difficult natural regeneration of the oak forests. Good seed years are frequent enough to contradict this theory (Poskin, 1934; Krahl-Urban, 1958; Rohmeder, 1972; Boudru, 1986). Nevertheless, there are a lot of other factors which can hamper the acorn development.

- Dengler (1982) refers to the factors which prevent the flowering: the maturity of the tree, the temperature, the light conditions and the food supply.

- The flowers themselves may be destroyed.
  Late frosts are very dangerous. Leibundgut (1983) found that all flowers can be destroyed in one night. Other weather conditions - such as hail, cold and humid weather - are also very harmful. Insect damage is not to be neglected either. According to Boudru (1986) it is mainly the caterpillars of *Tortrix viridana* which are harmful, whereas Malphettes in France refers above all to the caterpillars of *Operophtera brumata L., Erannis defoliara Cl.* and *Tortrix viridana* L.
- The pollination and the fertilization can also be hampered by a persistent and strong rainfall.

- The ripening of the acorns can be prevented by spring frosts, wet and cool summers, too much drought and by insect attacks (Vanselow, 1949; Krahl-Urban,1958; Rohmeder, 1972; Leibundgut,1983).

In this respect, Rohmeder (1972) refers to the results of Wachter (1953). This researcher found with pedunculate and sessile oaks 36 times a rich flowering within a period of 83 years. Only half of these led to a good seed year. The reasons were :

- 8 times spring frosts, which destroyed the flowers;
- 4 times insects and twice early frosts, which damaged the acorns;
- once rainfall which prevented the pollination;
- twice an unknown cause.

The acorn losses can be considerable. According to Tanton (1965) even more than 90% of the acorns can be lost before they fall. Shaw (1969) found in North-Wales a primary loss of 16%. According to him, the main predators of this phenomenon are the wood pigeon (*Columba palumbus L.*), the black crow (*Corvus corona L.*), the magpie (*Pica pica L.*), the jay (*Garrulus glandarius L.*)and the squirrel (*Sciurus vulgaris leucorus Kerr.*).

The main losses, however, normally occur when the acorns are lying down on the soil. The causes are numerous and various :
- The acorns are not viable. Boudru (1986) found an important share of unripe acorns with the American oak.

- Unfavourable soil conditions.

- Shaw (1969) underlined the predation of acorns. He found that 99 % of the losses occur between the falling and the germinating of the acorns.

Small mammalians are the main predators. Mouse species such as *Apodemus sylvaticus L.* and *Clethrionymus glareolus* (Schreber) turn out to be particularly harmful. They consumed 17 kg acorns/ha during a period of 8 months, i.e. 44% of the acorn losses. In this respect, it is important to notice that the acorns lying on the soil are first consumed; only afterwards do the animals start to excavate.
Vincent (1977) and Boudru (1986) also underline the considerable importance of rodents.
The wood pigeon too is very important. Shaw (1969) estimated the quantity consumed by each pigeon on 50 g D.W. per day. Jones (1959) even counted with 60 to 70 acorns (200 g fresh weight) in the crop, twice a day.
Mellanby (1969), on the other hand, remarks that just these animal species, which destroy the greatest number of acorns, are also the most important agents for the dispersion of the seeds (especially birds).

- Generally speaking, insect attacks do not have a great effect (Jones, 1959; Malphettes, 1978), especially in the case of American oak. Most of the times, the share of wormeaten acorns is small, viz. between 0 and 5 % (Lanier et al., 1980; Boudru, 1978). The acorns of European oak are attacked more often. Jones mentions the larvae of *Curculio venosus* and *C.glandium* as the most serious attackers, whereas Malphettes in France indicates mainly the larvae of *Balaninus alandium* Marsch and *Lospeuresia splendana Hbn*.
- Attacks from fungi occur in warm and humid weather conditions (Burschel et al., 1964). According to Jones, however, they are mainly found when the acorns have already suffered from frost or dehydratation.

- The weather conditions are very important too. Jones and Lamond et al. (1980) point out that only few acorns survive when they lose more than 30 to 35 % of their fresh weight. For that reason it is very useful that the acorns are covered with a litter layer. Ovington & Macrae (1960) found that less than 1 % of sessile oak acorns, which are lying unprotected on the soil, germinate due to the dehydration of the radicle. On the other hand, it is mainly sessile oak acorns which are particularly sensitive to an exaggerated humidity. European oak acorns are able to survive, at least if they are not lying in stagnant water (Jones).
  Frost kills many acorns too. Jones found that all acorns were dead at a temperature of - 6° C and after a period of eight hours.

When the acorns eventually do survive, it is still possible that the germinating and/ or establishing circumstances are unfavourable. As was mentioned already, the covering of the acorns is very important. A litter layer of 2.5 to 4 cm is very useful (Shaw; Fowells, 1965). A sufficiently high soil humidity is one of the most important factors for the survival of American oak seedlings (Larson, 1974; Naidenova et al, 1975). It is obvious that the litter layer is of a good quality. Vanselow (1949) already considered the humus condition as the most important silvicultural factor in the regeneration process.
The establishment of the seedlings is also determined by

several biotic factors. In this respect Viney (1970) considered mildew (*Microsphaera alphitoides* Griffon & Maublanc) as the main reason for the lack of natural regeneration of European oak in France and Belgium. Fanta (1982) found that the regeneration of oak under a *Pteridium* cover of 50 to 60 % is practically not possible anymore. On the other hand, oak seedlings are able to establish themselves to some extent in a *Deschampsia* vegetation. A *Vaccinium* vegetation even creates a good germinating bed for oak. Moreover, during the first years it offers a good protection against browsing by game.

3. Methodology

The research on the seed production and its conservation with American and European oak has been carried out in 10 mixed stands in the experimental forest of Aelmoeseneie. (Table 1).

Table 1. Composition of the stands (basal area/ha)

Stand:	1	2	3	4	5	6	7	8	9	10
Pedunc. oak	4.9	8.2	4.0	8.8	12.5	11.6	16.7	11.6	11.6	13.2
red oak	17.4	0.4	0.3	6.6	7.1	4.4	5.4	9.1	3.0	6.4
other sp.	11.0	12.6	19.1	15.8	11.5	10.6	6.6	7.7	8.0	11.1
total	33.3	21.5	23.4	31.2	31.1	26.6	28.7	28.4	22.6	30.7
% oak	67.0	40.0	18.4	49.4	63.0	60.1	77.0	72.9	64.6	63.8

On average, the oaks take up some 55 %. The European oak is well represented in almost every stand. The American oak, on the other hand, is mainly found in stand 1.
The research on the seed production was concentrated in two stands.

- In stand 1 a total of 15 recipients was placed. Most attention is given to American oak, which includes 52 % of the basal area.

- In stand 9 19 recipients were set up. Here most attention was given to European oak, which includes more than 50 % of the basal area. (This stand is also less accessible than stand 7).

The recipients have a diameter of 37.5 cm. The acorns were sorted in two classes, viz. the aborted ones and the fully-grown ones. The latter group was split into seemingly healthy acorns and worm-eaten ones.

In addition, at the end of December five sample plots with an area of 0.5 m^2 were laid out in each of the then stands. In each plot the acorns or their rests were collected. The sorting occured according to the scheme :

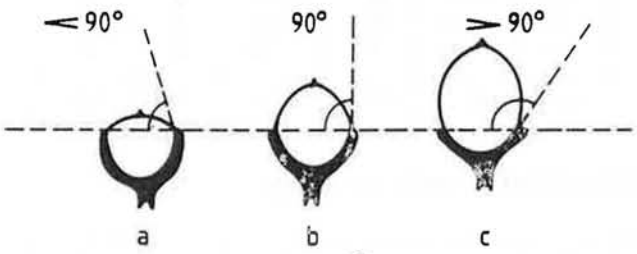
total = number of fruit walls + cups + aborted + fully-grown

The fully-grown acorns were split up into :

- bad : - rotten;
  - worm-eaten;
- seemingly healthy : - normal;

- germinating;
- with radicle.

As a criterion for the separation of aborted acorns on the one hand and fully-grown ones on the other hand, the norm of Shaw was used (Fig.1).



a) aborted acorn.
b and c) potentially viable acorns.

Fig.1. Criteria for the separation of acorns.

The aim of the second part of the research was to investigate into the influences of the light conditions on the growth of the seedlings. For this reason, two sites were selected.
- site A : under cover;
- site B : at the stand border, in partial freestand.

In both places, twenty seedlings of European oak and American oak were excavated and analysed morphologically.
Finally, an analysis of surviving two and three year old oak seedlings was carried out and the results were compared to the ones of the one year old seedlings. To this end, 50 one year old seedlings, 20 two year old ones and 20 three year old ones - which were dispersed all over the forest - were excavated and analysed.

4. Results and evaluation

First, due attention was paid to seed production and seed fall, then to the conservation and the quality of the seed and finally to the characteristics of the seedlings in function of light conditions and age.

4.1. Seed production and seed fall

It is known that the acorn fall, both of the American oak and of the European oak, normally takes place shortly after the ripening of the fruits during the month of October. However, according to Jones, empty and worm-eaten acorns may already fall down at the end of September. The biggest part of the healthy acorns are falling in the second and third weeks of October, whereas the last fall down in the second week of November.
In the Aelmoeseneie forest the fall of the American oak acorns begin very early, viz. at the end of August (Tables 2 and 3)

Table 2. The fall of the red oak acorns

Date	number of aborted acorns		total number of fully grown acorns		number of seemingly sound acorns		number of worm-eaten acorns	
	absol.	per m^2	absol.	per m^2	absol.	per m^2	absol.	per m^2
29/8	6	3.6	31	18.7	29	17.5	2	1.2
22/9	13	7.9	7	4.2	7	4.2	0	0
29/9	3	1.8	19	10.9	19	10.9	0	0
8/10	9	5.4	68	41.1	68	41.1	0	0
17/11	1	0.6	12	7.2	12	7.2	0	0
24/11	0	0	0	0	0	0	0	0
total	42	19.3	137	82.1	135	80.9	2	1.2

Tab. 3. The fall of pedunculate oak acorns

Date	number of aborted acorns		total number of fully grown acorns		number of seemingly sound acorns		number of worm-eaten acorns	
	absol.	per m2	absol.	per m^2	absol.	per m^2	absol.	per m^2
28/8	0	0	4	1.9	0	0	4	1.5
18/9	10	4.8	10	4.8	2	1	8	3.8
8/10	5	2.4	11	5.2	6	2.9	5	2.4
5/11	5	2.4	7	3.3	4	1.9	3	1.4
24/11	0	0	0	0	0	0	0	0
total	20	9.6	32	15.2	12	5.8	20	9.5

This happened during the first autumn gale. For that matter, the remaining acorns also fell down later on mostly during stormy weather or periods with strong wind. It is remarkable that a great number (23 %) of fully-grown acorns - which are furthermore still very healthy - fall down very early. Nearly all (98%) American oak acorns fell down before October 8th. The aborted acorns fell mainly during the month of September, unlike the fully-grown acorns which fell some two weeks later, at the beginning of October. After the first important fall at the end of August, there is a relative stagnation in September.

The seedfall of European oak differs to some extent :

- It does not start so early. The seedfall in August is limited.
- The seedfall is spread more regularly over the months of September and October.

The 1986 season was, at last in accordance with the standards of Cemagref (1982), a good seed year for the American oak. The number of fully-grown seeds reached 82/m^2 and the number of aborted ones 19/m^2. Almost a quarter of the American oak acorns were aborted.

For the European oak, on the other hand, it was just a moderate seed year, with 15 fully-grown acorns and 10 aborted ones per m^2. The ratio of aborted acorns is relatively very high (38%).

In addition, the number of worm-eaten acorns is very high with the European oak (62%); logically, the number of seemingly healthy and fully-grown acorns is low (6/m^2). With the American oak, on the other hand, the number of worm-eaten acorns is negligible. Almost all fully-grown acorns are seemingly healthy.

It is also obvious that the worm-eaten acorns are the first to fall down. They fall practically as early as the aborted ones.

4.2. Characteristics of the seeds

The weight, the height and the diameter of fully-grown seeds of both species have been determined in function of the seedfall. With the American oak, the variability was investigated too. (Tables 4 and 5; Fig.2). The results can be compared with the general data of Boudru and Poskin.

Table 4.Weight, height, diameter and H/D of seemingly healthy acorns of red oak.

Datum	n	weight (g)			height H(mm)			diameter D(mm)			H/D
		aver	min	max	aver	min	max	aver	min	max	
29/8	29	4.27	1.12	7.24	23.1	13.1	28.1	19.5	15	28.7	1.18
22/9	7	3.28	1.71	6.03	21.2	16.0	26.1	17.7	14.8	21.8	1.21
29/9	19	4.02	1.63	6.75	23.2	17.9	28.3	18.8	7.5	27.8	1.31
8/10	68	3.25	1.76	5.15	22.6	17.9	28	17.9	15.5	21.1	1.26
17/11	12	3.93	2.83	6.11	22.5	18.1	28.8	17.7	15.8	20	1.27
sum aver.	135	3.64			22.7			18.3			1.23
BOUDRU 1978		3.01			18.7			17.5			1.07

Table 5. Weight, height, diameter and H/D of seemingly healthy acorns of pedunculate oak. -

Datum	n	weight (g)			height H(mm)			diameter D(mm)			H/D
		aver	min	max	aver	min	max	aver	min	max	
18/9	2	2.77	1.29	4.25	27.0	22.7	31.4	14.0	10.6	17.5	1.96
8/10	6	6.65	1.14	5.10	23.1	17.8	31	14.7	12.7	16.3	1.54
5/11	4	1.31	0.59	2.21	18.2	13.1	23.1	11.8	9.3	13.5	1.53
sum aver.	12	2.22			22.1			13.6			1.61
POSKIN (1934)		3.01			18.7			17.5			1.07

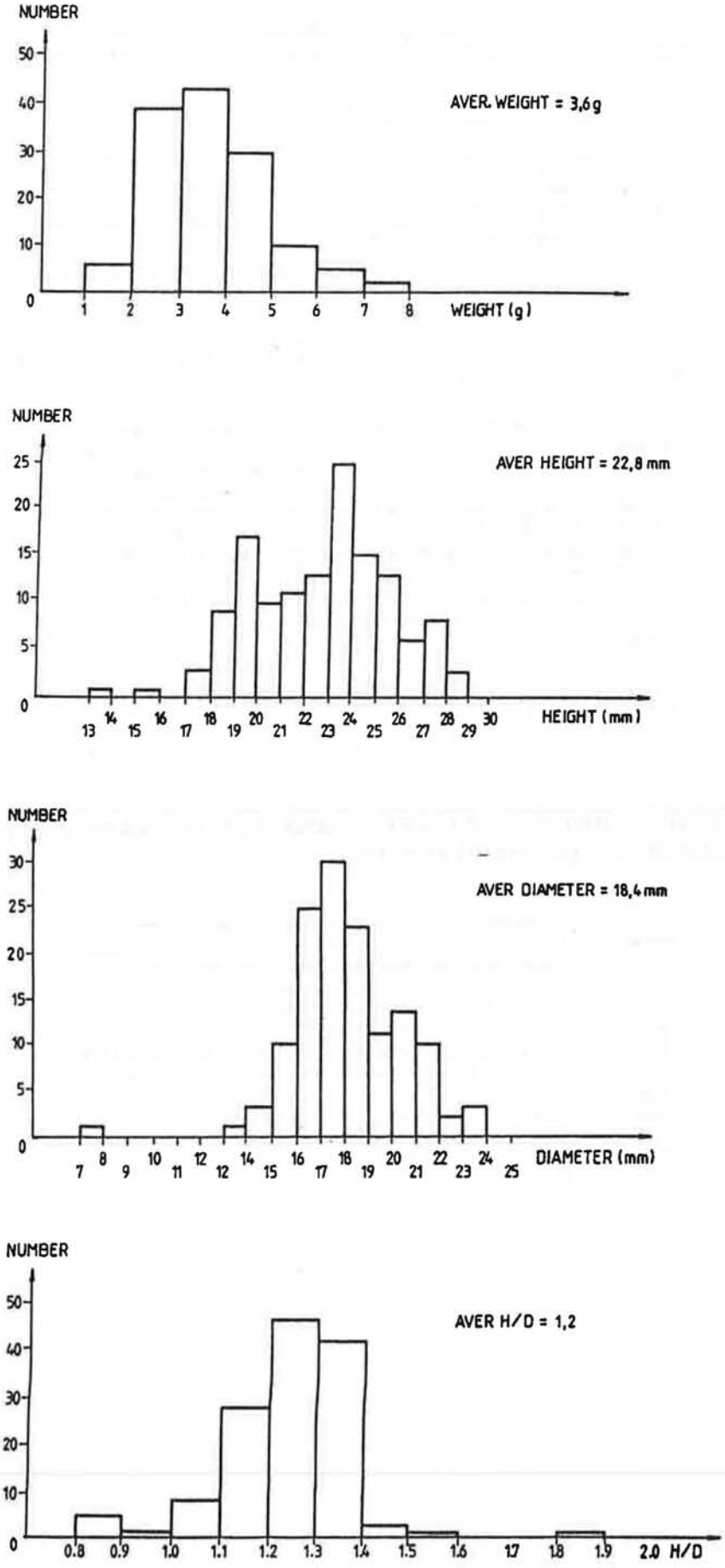


Fig.2 Characteristics of American oak acorns.

The American oak acorns have great dimensions: they are on average 21% heavier, 21% taller and 5% thicker than the average values of Boudru. Consequently, the H/D value is 5% higher, which is a guarantee for good quality.
Differences as to the time of seed fall are not significant. Nevertheless, the acorns which fall down first tend to be a bit heavier than the other ones.
With the native oak, the results are not so analogous and even a bit less reliable : their weight is clearly lower than with the ones of Poskin. They are also remarkably thinner (22%) even though they are 18% taller. Their quality is undoubtedly less good. In all, it is not a good seed year for the native oak (few seeds, many worm-eaten seeds, low weight).

The variabililty of the seeds is in all respects very great. There is a broad range between the minimum and the maximum values. It is especially the height variation which is very high.

4.3. The conservation and the quality of the seeds

At the end of December the acorns on the soil were collected in some ten stands, each time divided up in five sample plots, and thoroughly sorted (Tables 6 and 7).

Table 6. Quality of the oak acorns at the end of December (n/m^2)

	American oak									
stand	healthy	normal	germinating	with rad.	bad	rotten	worm-eaten	fruit-wall	cupules	aborted
1	62.4	34.4	28	-	82.4	51.2	-	31.2	173.6	161.6
2	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-
4	2.4	2.4	-	-	8	4.8	-	3.2	9.2	5.2
5	3.2	3.2	-	-	-	-	-	-	9.6	7.2
6	15.6	10.4	5.2	-	3.2	1.6	0.4	1.2	25.2	102.4
7	17.2	7.2	8	2	11.2	6.4	2.4	2.4	26.8	22
8	28.4	21.6	6.4	0.4	12	9.6	-	2.4	34.4	15.2
9	23.6	6.4	15.2	2	4	4	-	-	35.2	16.8
10	0.8	0.4	-	0.4	-	-	-	-	0.8	1.2
aver.	15.4	8.6	6.3	0.5	12.1	7.8	0.3	4	31.5	33.2

Table 7. Quality of the acorns of pedunculate oak at the end of December (n/m^2).

	pedunculate oak									
stand	healthy	normal	germinating	with rad.	bad	rotten	worm-eaten	fruit-wall	cupules	aborted
1	-	-	-	-	4.8	2.4	-	2.4	-	-
2	4.4	1.2	-	3.2	21.2	5.2	14.4	1.6	55.6	37.6
3	-	-	-	-	-	-	-	-	-	2.3
4	1.2	0.4	-	0.8	6.4	5.6	0.8	-	9.6	14.8
5	0.8	-	-	0.8	1.6	0.8	0.8	-	4.8	2
6	1.6	1.2	-	0.4	10.4	2.4	5.2	2.8	24.8	15.6
7	1.2	-	-	1.2	2.4	1.6	0.8	-	5.2	6.8
8	4.4	2	-	2.4	21.2	13.2	4.8	3.2	23.6	15.2
9	0.8	0.4	-	0.4	2.8	1.6	0.4	0.8	10.8	12.4
10	0.8	-	-	0.8	17.2	5.6	5.2	6.4	33.2	26.4
aver.	1.5	0.5	-	1.0	8.8	3.8	3.2	1.7	16.8	13.3

The average number of American oak acorns is not so high :

- fully-grown : - healthy : 15.4/m^2
  - bad : 12.1/m^2
- aborted : 33.2/m^2

It is obvious that the differences between the stands are very great, as the proportion of the species is variable (see table 1). The seed production, however, is not always proportional to the share of American oak. The very low production in stand 10, for example, is quite remarkable since the basal area amounts here still to 6.4 m^2/ha. About the same phenomenon takes place in stands 4 and 5. The occupation in stand 9, on the contrary, is not so high, even though there is a fair seed production. The causes for this are not really clear. Obviously they are independent of the density and the structure of the stands. The variability seems to be a normal phenomenon.

With the native oak the average seed production is still much lower, regardless of the important share of this species in most of the stands. Anyway, it is clear that a seed year of American oak does not necessarily coincide with one of the European oak. In stand 7, which has the highest proportion of nature oak (16.7 m^2/ha), the seed production is very low.

With both species, the number of aborted acorns is relatively very high. In both cases it is higher than the number of fully-grown ones (per m^2) :

	aborted	fully-grown	ratio
- average American oak	33.2	27.5	1.21
- average European oak	13.3	10.3	1.29

Relatively speaking, the number of aborted acorns is not much higher with European oak. This could mean that the abortion of acorns is not linked with the quality of the seed years. In good seed years, the number of aborted acorns is very high too.
This number is also very variable and unpredictable. With the American oak it is very high in stand 6. The ratio here amounts up to 5.4. In other stands, however, this ratio is lower than 1.

At the end of December, there are clearly more healthy American oak acorns than bad ones. This is not the case with the native oak; quite on the contrary. As a matter of fact, the phenomenon was already visible at the moment of the seed fall (see Table 3). But the situation has even deteriorated (per m^2).

	number healthy	number bad	ratio
- average Am. oak	15.4	12.1	1.27
- average Eur. oak	1.5	8.8	0.17

The healthy American oak acorns can already be split up into three groups at the end of December :
- normal : 56%
- germinating : 41%
- with radicle : 3%

As a conclusion, we see that the germination of American oak is already well advanced, partly due to the relative warm, humid weather in December.
In some stands, all seeds have already germinated. With the native oak, the germination seems to go on fast too.

The bad acorns can also be divided up into three groups :

	American oak	European oak
- rotten	64%	43%
- worm-eaten	3%	36%
- fruit walls	33%	19%

Both species differ fundamentally from each other :

- more rotten acorns and more fruit walls are found with the American oak;

- with the European oak, the share of worm-eaten acorns is relatively high, unlike with the American oak.

The number of cups can be useful for the estimation of the overall acorn production. From the ratio acorns/cups we can derive how many acorns disappeared due to the predators :

- American oak : 87 %
- European oak : 61 %

On average, it amounts to 13% with the American oak - with a maximum of 67% in stand 5 - whereas with the European oak the average is about 39% (with a maximum of 67% in stand 9). Therefore, predation is an element which is not to be neglected.If it proceeds at the same rate, the ultimate losses will be considerable.

4.4. Light influence on the seedlings

The objective of this part of the research is to examine the effect of light on the growth of one year old seedlings of American and European oak under the general circumstances of the Aelmoeseneie forest.
Several authors have already treated this subject, albeit under different conditions. A lot of their results are, however, contradictory.
Bourdeau (1954) considers the seedlings of American oak as shade tolerant and insufficiently resistent to drought. Lyr et al.(1964) found a limit of shade tolerance with a relative light intensity of 5%, provided good nutrition and humidity circumstances are present, barring root competition. Generally

speaking, the biomass is found to decrease with an increasing cover. This effect is particularly important on the root growth (Lyr; Phares, 1971; Farmer, 1975; Mcgee, 1976).
The light requirements of the pedunculate oak are more important. It is generally known that in Western Europe the light is in most stands the limiting factor for the natural regeneration. Karpinosova underlines that sufficient light is more important and affects more drastically the growth and the development of pedunculate oak seedlings than soil fertility does.

4.4.1. Morphological characteristics of the seedlings

It is remarkable that several characteristics of one year old seedlings, grown up under different light conditions, do not differ essentially from each other (Table 8).

Table 8. Dimensions of 1 year old seedlings grown up under different light conditions :
A = seedlings under cover
B = seedlings under partial freestand
(P = level of significance)

lenght shoot	Red oak			Pedunculate oak		
	A	B	P	A	B	P
length shoot (cm)	16.7	15.9	-	22.3	17.3	0.2
length terminal bud (mm)	2.9	3.1	-	2.4	2.8	0.4
length root (cm)	17.5	16.9	-	13.4	16	0.3
depth root (cm)	12.5	11.6	-	12.2	14.8	0.3
number branches of roots	3	3		1.1	1.6	0.3
length acorn (cm)	2	2.1	0.4	2.6	2.8	-
width acorn (cm)	2	1.9	0.4	1.4	1.3	-
diameter shoot (mm)						
at ground level	2.1	2.4	0.05*	2.2	2.4	0.3
5 cm above ground level	1.4	1.6	0.5	1.6	1.9	0.1
leaf area / plant (cm2)	125.8	91.9	0.05*	42.3	47.2	0.5
number leaves/plant	4.4	4.5	-	44	4.5	-
area/leaf (cm2)	28.9	20.8	0.01**	10.5	11	-

- With the pedunculate oak there are no significant differences, as well for the shoot as for the root, the leaves and the terminal bud. This is, however, partly due to the considerable variation among the seedlings.

- With the American oak some differences are apparent :
  - The diameter of the shoot is slightly greater with the seedlings that have grown up under a partial isolation (9%);
  - The overall leaf area per plant is significantly greater with the seedlings under cover (37%). This is not due to a greater number of leaves, but to a greater area of the leaves : the leaves of the American oak seedlings under cover are much greater than the ones with more light (39%). On the other hand, there are no differences with the native oak.
  - There are no differences in the length of the shoot and the root.

Some tendencies can be observed with the pedunculate oak. It is also obvious that these tendencies indicate a different behaviour from the one of the American oak :

- the shoot length is greater under cover;
- the root length is slightly greater with more light;
- the overall leaf area is a bit greater with more light; here the differences with the American oak are the biggest.

A more general comparison between the seedlings of European and American oak show that :

- the overall leaf area is much greater with the American oak (almost 200% under cover and 95% with partial isolation);
- the number of leaves of the seedlings is almost the same;
- the separate leaves from the American oak are much greater (175% under cover and 89% with partial freestand);
- the shoot length is greater with the pedunculate oak (34% under the cover and 9% with partial freestand);
- the shoot diameter is the same at ground level, even though it thickens a bit at 5 cm above the ground (14% and 19%);
- the root depth is almost the same, though it should be noted that the roots are not yet deeply developed : 12 to 14 cm.

4.4.2. Biomass of the seedlings

There are no significant differences as to the biomass of the seedlings grown up under different light conditions (Tables 9 and 10).

Table 9. Biomass of 1 year old seedlings (mg dry weight per plant) grown up under different light conditions.

above ground part underground	red oak			pedunculate oak		
	A	B	P	A	B	P
root (mg)	475	403	0.2	403	391	-
shoot (mg)	295	278	-	264	268	-
above ground part (mg)	211	202	-	187	195	-
underground part (mg)	84	76		77	92	-
leaves (mg)	429	339	0.1	136	163	0.2
total (mg)	1200	1021	0.2	803	822	-

The variability is too great and the selected number of seedlings is not so high. Nevertheless, it is interesting to look at the tendencies and to compare the American oaks with the European ones:

- The average dry weight of a 1 year old American oak is remarkably higher : some 35%.
  These differences are mainly due to the leaf biomass.The ratios between American and European oak are on average the following :
  - leaves : 2.57
  - roots : 1.11
  - shoot : 1.08

  The superiority in leaf biomass of the American oak is much greater than the one in total biomass. The much greater leaf biomass, however, did not result in a much greater net (remaining) production (sum of roots and shoots). It means that the efficiency of the photosynthesis of the pedunculate oak is much higher. This is even more apparent from the ratio between root and shoot mass on the one hand and the leaf weight on the other hand :
  - pedunculate oak : 4.43
  - American oak : 1.88

  It means that 1 mg of leaves of the pedunculate oak seedlings produces 2.35 times more root and shoot mass than the American oak.

- With the American oak seedlings, there is a clear tendency that the overall biomass under cover is greater than the one under partial isolation (17.5%). These results seem to contradict the data of several other authors (Phares; Farmer; Mcgee).
  The differences amount to 27% with the leaves and to 18% with the roots. The expected inferiority of the root development under cover is not found here.
  Again, the situation is different with the native oak. Obviously, the light conditions have no influence on the root and shoot mass. On the contrary, with the leaves there is a clear tendency (but not a significant difference) towards a higher production under more favourable light circumstances. On the other hand, the production of light demanding leaves is not so high as the one of more shade tolerant leaves. This can be concluded from the ratio leaf weight/ root and shoot mass:
  - under cover : 4.91
  - partial freestand: 4.04

  The differences in productivity are of the order of 20%.

- The light conditions have an opposite influence on the leaf mass of both tree species :
  - with the American oak the shade tolerant leaves under the cover have the greatest mass (+ 27%);
  - with the native oak the light demanding leaves take up the greatest mass (+ 20%).

  These results clearly underline the differences in light requirements of both tree species.

The tree species differ obviously as to the distribution of the biomass of the seedlings (Table 10) :

Table 10. Biomass distribution of the seedlings.

	red oak		pedunculate	
	A	B	A	B
root	39.6%	39.5%	50.1%	47.5%
shoot	24.6%	27.3%	32.8%	32.6%
leaves	35.8%	33.2%	17.1%	19.9%
total	100.0%	100.0%	100.0%	100.0%

- the share of the leaves is very limited with the pedunculate oak (17 to 20%); the biomass is concentrated in the roots; it amounts to some 50%;
- with the American oak the share of the leaves is much greater (about 1/3); consequently, the share of the roots and of the shoots is not so great.

Anyway, it is remarkable that the share of the remaining organs is greater underground than above ground. In this respect, the seedlings produce in the first place roots.

Other ratios between the different components of the seedlings can be reproduced by all kind of indices (Table 11). From this can be concluded :

Table 11. Ratios between the different components of the seedlings

	Red oak			Pedunculate		
	A	B	P	A	B	P
LAI(cm2/g)	104	91	-	59.7	57.4	-
LWI	0.3	0.33	0.3	0.17	0.20	-
SLA (cm2/g)	288	275	0,4	311	286	0.3
RS	1.6	1.54	-	1.5	1.5	-
A/U	1.17	1.17	-	0.81	0.81	-

$$\text{LAI} = \text{leaf area index} = \frac{\text{leaf area (cm2)}}{\text{total biomass (g) (excl. acorn).}}$$

$$\text{LWI} = \text{leaf weight index} = \frac{\text{leaf biomass (g)}}{\text{total biomass (g) excl. acorn}}$$

$$\text{SLA} = \text{specific leaf area} = \frac{\text{leaf area (cm2)}}{\text{leaf biomass (g)}}$$

$$\text{R/S} = \text{root/shoot ratio} = \frac{\text{root biomass (g)}}{\text{shoot biomass}}$$

$$A/U = \frac{\text{above ground biomass}}{\text{underground biomass}} = \frac{\text{above ground shoot + leaves}}{\text{underground shoot + roots}}$$

- the leaf area index is much greater with the American oak;
- the leaf weight index is much greater with the American oak;
- the specific leaf area of both species has approximately the same value;
- the R/S ratio has the same values too and is clearly positive;
- the A/U values are different : the above ground-share is the greatest with the American oak, whereas the underground share is the greatest with the pedunculate oak.

The results of the seedling characteristics do not always correspond clearly to the ones of the other authors, such as Lyr et al.

4.3.3. Interpretation

It is clear from this research that a one year old seedling of American oak grows slightly better under a cover than under partial freestand.
The tree species reacts on the cover by forming a greater leaf area. The efficiency of the leaves,however, is greater with more sun leaves. To a certain extent, the cover also favours the root growth, allowing more water to be taken up, and the cover is also very useful and desired to resist the drought sensitivity of the seedlings.
In all, the one year old seedlings of the pedunculate oak are only very little influenced by the light conditions. The leaf biomass, however, is the greatest under more favourable light conditions, which shows the greater light requirements of these tree species.

From the sylvicultural point of view, it is fair to conclude that the American oak can be regenerated best under a cover. But the question still stands, how long and how dense this cover should be.
The pedunculate oak can be regenerated under a light cover too. In this way, the competition of hindering vegetation can be limited.

4.5. Comparison of 1 year, 2 year and 3 year old seedlings

It is generally known that in the Aelmoeseneie forest the seedlings of both pedunculate and American oak die off in great numbers after 1 year (at least under the normal cover circumstances). Only a very restricted number survives. The morphological features of the surviving seedlings have been compared with the ones of normal growing, 1 year old seedlings (Tables 12,13 and 14).

4.5.1. The shoot

It is very remarkable that the growth of both the American and the European oak is very limited during the second and third years. The average values of the three year shoots equal :

	American oak	European oak
1st year shoot	15.5	15.8
2nd year shoot	3.4	6.4
3rd year shoot	2.1	3.5

The height growth of the American oak decreases most, although this species is generally speaking more shade tolerant and the one year old seedlings have also more characteristics of shade tolerant leaves. During the second year, the year shoot of American oak drops to 22%, whereas the one of pedunculate oak still reaches 40%. The growth diminishes further during the third year.
As long as the seedlings can profit from the food reserves of the seed, they can survive and grow moderately. Afterwards - at least under the circumstances of the Aelmoeseneie forest - they need a new energy source. To this end, the crown cover has to be opened in an appropriate way.

The pedunculate oak also has the greatest shoot diameter (5 cm above ground level). The third year increase is here also relatively high (37%). The height growth is more limited than the diameter growth.
Especially the American oaks form each year a fairly long terminal bud. Its length even increases, especially with the pedunculate oak. The reserve of stored nutrients is, however, very small.

4.5.2. The acorn

At the end of the first season the acorns are still present with all seedlings. Afterwards they disappear :
- relatively slowly with the American oak; in most cases they are completely decomposed during the third growing season;
- in a first phase relatively fast, but more regularly and dispersed over a longer period with the pedunculate oak; after three growing seasons up to 17% of the acorns are still found back.

The prolonged conservation of the acorns can be an element to determine the survival and the growth in the second and the third growing seasons.

Several researchers have stressed the importance of the acorn weight and the acorn size (Ingrain, 1978; Rohmeder). Seedlings from greater seeds have an advantage, which can last 3 to 8 years.
The dimensions of the acorn rests of the two years old pedunculate oaks are greater than the ones of one year old plants. This could be an indication that the seedlings, originating from greater acorns, are more likely to survive.

4.5.3. The root

The length and the depth of the roots do not increase very much either during the second and the third growing seasons. After three growing seasons the tap root does not go deeper than 20 cm.
Very interesting is the study of the multiple tap roots. In 1934 Poskin already found that :

- early germinated acorns often form a multiple root system, especially when the radicle dies off;
- 75 to 82 % of the one year old seedlings of pedunculate oak have a simple root;
- seedlings with a multiple root system have a greater weight, a greater diameter and height, yet a smaller root length;
- these differences are still noticeable - or even accentuated - with 3 or 4 year old seedlings.

Göhre and Wagenknecht (1955) found 94% simple tap roots in seedlings of American oak.
The differences in the number of multiple tap roots between both species is explained by the earlier germination of the pedunculate oak. In warm and humid circumstances the latter can start germinating shortly after the fall. In this way, the radicle is exposed to numerous dangers, such as dehydratation, frost nad mouse damage. After the first radicle has died off, the acorn often forms a new one, which then creates a multiple tap root. The American oak, on the other hand, first has to go through a rest period before the germination can start, so that the risks for destruction of the radicle are smaller and, consequently, the chances on the formation of a multiple root system.

In the Aelmoeseneie forest the number of 1 year old seedlings with multiple tap roots amounts to 12% with the American oak and to 18% with the pedunculate oak. This share is increased with three year old seedlings to 40%. It is mainly the seedlings with a multiple tap root which survive. This is, however, not exactly the case with the pedunculate oak. There is a difference between the 1 year old seedlings with simple or multiple root system of both species (Table 15).

Table 15. Characteristics of 1 year old seedlings with simple and with multiple tap roots.

	Red oak				pedunculate oak			
	simple		multiple		simple		multiple	
length shoot (cm)	17		17.4		16.4		18	
length terminal bud (mm)	2.9		2.7		1.6		1.2	
length root (cm)	12.1		17.2		13.5		13.5	
depth root (cm)	10.9		13.8		10.2		8.5	
total biomass (g)	1.02		1.18		0.80	100%	0.63	100%
biomass shoot (g)	0.31	31%	0.37	31%	0.25	31%	0.26	41%
biomass root (g)	0.40	39%	0.43	36%	0.40	49%		
biomass leaves (g)	0.30	30%	0.38	33%	0.15	20%	0.11	18%

With the American oak, the seedlings with a multiple tap root are superior :

- the length and the depth of the roots are greater;
- the biomass of the shoot, the root and the leaves is greater;their overall biomass is 16% greater.

The differences are not so numerous with the pedunculate oak. They are, however, more important and even contradictory. The biomass of the roots with a simple tap root is 54% greater than the ones with a multiple root.

The results allow us to conclude that the seedlings with a multiple root system have better chances to survive with the American oaks, whereas they are less strong with the European oaks.

4.5.4. The leaves

The growth crisis, which the seedlings undergo, reveals itself in the leaf formation, especially with the American oak. The number of leaves hardly increases, just like the individual leaf area and the total leaf area per plant. With the pedunculate oak the growth crisis seems less serious. Both the individual leaf area as well as the total leaf area per plant double. However, this does not affect the height growth.

4.5.5.The biomass

The total biomass is the result of the shoot and root growth and of the leaf formation. This leads once again to the conclusion that the growth crisis is the greatest with the American oak :

- with the pedunculate oak the total biomass increases four times between the end of the first and the third year. The increase is limited in the second growing season; during the third year, on the other hand, it is relatively great.

- With the American oak the increase of biomass is very small.
  It does not even double. Especially the increase of the shoot and the leaf mass is limited, whereas the root mass still increases slightly during the third year.

With the pedunculate oak the greatest increment occurs during the third growing season. There is a relatively dramatic increase of the root mass, viz. more than the quadruple. Consequently, the increment is mainly concentrated in the roots. This is also reflected in the ratio between the several components of the seedlings. With both species, the share of the roots increases, mainly at the expense of the leaves. With the pedunculate oak there is already a decrease of the root-shoot ratio, which is not yet the case with the American oak.

4.5.6. Conclusions

It is obvious that the seedlings of both species go through a very serious growth crisis after the first growing season.
Their growth is very limited. The crisis is less apparent with the pedunculate oak than with the American oak. The latter maintains itself partly due to the existence of multiple tap roots.
The growth of the seedlings is mainly concentrated in the roots. Therefore it is desirable or necessary to create favourable growth circumstances. This explains the importance of mixed stands with some tree species forming a good mull-humus.

5. Summary and general conclusions

Despite the favourable growth conditions in the Aelmoeseneie forest, the establishment of the seedlings of pedunculate and American oaks is a very difficult process. Even though numerous seedlings can be found, most of them die off after one year. The seeds of the American oak are characterised by their great size and their good quality. The seedfall, however, starts early and is induced by strong winds. About 25% of the seeds are aborted. At the end of December there are obviously more healthy acorns than bad ones. The latter are mainly rotten or have been eaten by birds.
The seeds of the pedunculate oak are of a less good quality. The share of worm-eaten acorns is very great (62%). Almost 40% of the acorns are also aborted. The predation of small mammalians is not so important.
The variability of the seeds, however, is in every respect very great.
One year old seedlings of American oak grow slightly better under cover than under partial freestand. They react on the cover by forming a greater leaf area. The efficiency, however, is greater with the bigger amount of sun leaves. To some extent, the cover favours root growth too.
The one year old seedlings of pedunculate oak are only slightly affected by the light conditions. The leaf biomass, however, is the greatest under favourable light conditions.
The seedlings react in the Aelmoeseneie forest relatively specifically. The results are often in contradiction with the findings of other authors.

It is obvious that both species go through a very serious growth crisis after the first growing season. This crisis is less apparent with the pedunculate oak than with the American oak, which takes profit of its multiple tap root.
The growth of the seedlings is concentrated in the roots.

The natural regeneration of the American oak in the experimental forest occurs possibly best under a cover. It is necessary, however, for the survival of the seedlings that the crown cover is already strongly opened after one year.
The natural regeneration of pedunculate oak can occur practically in the same way, even when this species is more light demanding.

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