Silvicultural methods of oak regeneration with special respect to shade tolerant mixed species

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Abstract

An overview is presented of the silviculture of pedunculate oak (Quercus robur L.) and sessile oak (Q. petraea Liebl.) in Germany. This presentation is confined to less dry to moist and stagnic gleysol sites, where the intention is to produce primary timbers in long rotation periods. Incorporation of a shade tolerant species as an admixture species is indispensable to the suppression of epicormic branches. The most frequent and recommended admixture species for this purpose is beech (Fagus sylvatica L.). Because beech is competitively stronger than the oaks on these sites, silvicultural measures must be taken to keep it in check. According to the classic silviculture which has taken shape in the Spessart and Pfälzer forests, the desired goal of a two-storeyed stand with oak in the overstorey and beech in the understorey is achieved by means of heavy seeding beneath an open and rapidly cleared canopy. Because this procedure resembles clear cutting and entails its recognized disadvantages, trials have recently been undertaken to regenerate oaks in a silviculture with permanent canopy cover. Trials with young oaks show that they still achieve satisfactory growth at 15–20% of full light. Accordingly, successful regeneration is possible in beech stands under an open canopy or in gaps, and under an approximately closed canopy cover in pine stands due to their more penetrable crowns. The problematic aspect of this, especially in beech stands, is that young beeches become competitively stronger than oaks as canopy cover increases. This requires great effort in restraining the beech during cleanings and thinnings. Furthermore, browsing by wild animals must be minimized as it exclusively affects oak. As a result, however, there will be significantly fewer oaks and more beeches in the dominant layer than when using classic methods. © 1998 Elsevier Science B.V.

Keywords: Quercus; Regeneration; Canopy density; Mixed species stand; Shade tolerance; Interspecific competition

1. Principles of the silviculture of oaks in Germany

The following overview looks at the regeneration process of the two species of oak, Quercus petraea Liebl. (sessile oak) and Q. robur L. (pedunculate oak), on the most commonly used sites for oak timber production in the sub-Atlantic climatic region of Germany. These are marked by the following characteristics: nutrient balance of the soil: low to fairly good nutrient supply, less acidic to acidic soils; water balance of the soil: moderately dry to moist, also intermittently moist and intermittently water-logged soil; and altitudinal zone: colline to submontane.

Sites which will not be treated here are surface or near-surface ground water sites, gleysols and dystric planosols, and regularly flooded sites on flood-plains. These do not comprise a broad area and are typically
designated as locations for a main tree species of pedunculate oak.

In all, the sites treated are characterized by the absence of extremes in water balance and nutrient balance. They concern areas dominated naturally by beech (Fagus sylvatica L.) where, as a result of human economic activity, oaks of both species have already been cultivated for centuries. Earlier, sessile oak was preferred for the moderately fresh, well-aerated and well-drained soils; on the other hand, pedunculate oak was preferred for more clayey, moist and more poorly drained soils usually made up of stagnic gleysols. Today, however, the silvicultural separation of the two species is becoming increasingly questionable. First, in accordance with the most up-to-date taxonomical botanical knowledge, we can still only speak of subspecies in any strict sense (Aas, 1994). The morphological, genetic and ecological differences in various provenances are greater within a so-called individual species than between species themselves (Müller-Starck et al., 1993). Furthermore, both species very often occur mixed together in old stands on the aforementioned sites without visible differences in growth or timber quality. Therefore, a silvicultural distinction is less commonly made today between species and much more commonly between provenances.

The economic goal of the cultivation of oak is to produce the greatest quantity of primary timber. Primary oak is mainly used for decorative veneers and commands the highest prices, thus, also making it one of the most profitable tree species (without taking into account interest payments). Primary oak must be free of knots and other defects, achieve large dimensions (at least 40 cm mid-diameter, preferably 50–60 cm) and possess a consistently light colour. Thanks to modern veneer technology, the maximum tolerable ring width today of approximately 4 mm is considerably greater than the previously acceptable limit of 2 mm (Peters and Becker, 1995). Two important consequences for silviculture result from this demanding quality-goal. First, the required breast-height diameter of 70–80 cm can only be achieved over a long production time-period of 160–240 years. Furthermore, a high stand density in the youth phase and continuous shading of stems by means of an assisting admixture species are necessary in order to ensure the absence of knots on the lower trunk and prevent the formation of epicormic branches. A sufficient level of primary timber production cannot be achieved by means of a pure oak stand.

2. Beech as the appropriate admixture species in oak stands (disadvantages of other species)

Beech is by far the most widespread assisting admixture species because it occurs naturally on the aforementioned sites, grows vigorously in the shade of an oak stand and casts dense shade. It can therefore effectively suppress the development of epicormic branches and still contribute to overall timber production when the oaks mature and thin out naturally. Nevertheless, the beech tree’s competitive strength is so superior that it must be constantly restrained by forestry measures. This will be elaborated on in Section 3.

Hornbeam (Carpinus betulus L.) has been preferred by forestry operations for some time now as a means of avoiding these problems with beech. This species provides the clear advantage of not growing into the crowns of oak with age, while providing a favourable litter as well. However, hornbeam also presents a number of grave disadvantages (list in the paper of Fricke, 1986).

It places higher demands on the nutrient supply than oak or beech and is therefore only worth cultivating on the better sites dealt with here.

Its average lifespan of 150 years is much shorter than that of beech. It therefore appears uncertain whether, given a rotation period for oak of 200 years, it can fulfil an assisting function over the necessary time period.

Extreme difficulties often arise in the youth phase. Following planting, which represents the usual means of establishing the stand, it suffers from a considerable amount of damage from mice which can lead to a 100% mortality. When it does survive, it quickly outgrows the oak and must be cut back even in early cleanings. For these reasons, the planting of oak–hornbeam stands is not common. Rather, it represents an exception. Only hornbeam from natural regeneration gains unequivocal acceptance.

In some cases, the lime tree (Tilia cordata Mill.) is used as an assisting admixture species in oak
stands as a means of getting around these difficulties presented by hornbeam. However, the lime tree places even more demands on the nutrient supply than hornbeam and, thus, only remains an option for an extremely small portion of sites designated for oak (Jahn, 1987). On these sites, it very quickly demonstrates that even in early youth it begins to outgrow oaks. This continues into the mature phase. Thus, the lime tree cannot be seen as a suitable assisting species of tree in mixtures of the same age.

3. The superior competitive strength of beech as a problem

Generally speaking, young oaks grow initially faster in clear cut areas than beech of the same age and achieve an advantage of 1–2 m within 30 years. However, beech then steadily catches up and after about 60 years becomes increasingly dominant. In old stands, it ultimately surpasses oak in the dominant layer by 2–5 m. This has already been described by Wiedemann (1951).

There is no ideal admixture tree species. In most cases, the beech still represents the best compromise. In recent times, we can increasingly hear a view again advocating the subsequent underplanting of beech in what were established as pure stands of oak. In my view, this can only be an aid to correct an unplanned and unsatisfactory situation which has already arisen. This situation could occur, for instance, if the initially intended simultaneous introduction of beech has been unsuccessful due to insufficient natural regeneration or high mortality in youth. A later underplanting, however, should not be planned from the outset as it always increases overall costs and entails the risk of subsequently not being carried out.

Added to this are the known silvicultural disadvantages which, first, come about because underplanting can only serve its function—namely, the repression of epicormic branches—after a period of 15–30 years. Until that time, however, the oak stands must be more intensively thinned to enable swift growth for the underplanted beeches, directly promoting the formation of epicormic branches. Second, on most sites, it is not a means by which beech trees can be prevented from growing into the oak crowns in the long term. The point of time when this occurs is merely delayed several decades. This will be demonstrated by means of a 180-year old sessile oak stand in the Göttingen area, which was underplanted with beech in the age of 70 years—i.e., according to current notions, at the latest possible point of time. The beeches in this stand have already beset the oaks for approximately 30 years and must be regularly removed from the dominant layer during thinnings. Despite continuous restraint, the dominant layer still presently consists of up to 6% beech trees which, at an average height of 33 m, are exactly the same height as the oaks. Thus, it is not possible to produce primary oak in the site—regions treated here without a constant struggle against the more competitively strong beeches.

4. Solving this problem within the classic silviculture of oak

The silviculture of oaks which has taken shape in the known oak cultivation regions of Spessart and Pfälzer Wald in the course of the past 150 years can be termed a classic case in particular. It has been described in more recent times by Fleder (Fleder, 1981, 1988) and represents the model for many other areas of cultivation in Germany. In the context of this paper, it should mainly be pointed out that the aim was to incorporate beeches as young growth from the very beginning, though only in the understorey. In doing so, the competitive strength of the oaks should be enhanced by the following measures.

The beeches (either from natural regeneration or planting) are as a rule several years younger than the oaks.

In most cases, the regeneration areas are fenced off so as to avoid browsing by wild animals, which selectively affects oak. Both measures enable the oaks to safely outgrow the beeches from the start.

A very high plant count of oaks is achieved by the standard means of extensive direct seeding. The young growth closes up rapidly and very densely over the beeches, which trail behind.

Regeneration takes place fundamentally under canopy cover. But this canopy cover is usually very
open and quickly removed for the promotion of growth in height for the oaks (4–8 years following sowing).

Extremely careful release cutting and thinning measures maintain a closed overstorey during the first decades, beneath which the beeches grow clearly more slowly. Individual beeches which penetrate into the dominant layer, however, are promptly removed.

This produces the development of stands with two clearly distinct storeys: oak dominates the overstorey and beech the intermediate and understoreys. With the increase in age, beech forces its way more and more into the dominant layer and has to be chopped out. The mixed portion must be relatively dense and differentiated in itself in order to facilitate the constant regrowth of beech from below. A model stand contains approximately 2000–5000 beeches per hectare at an age of 40–60 years (Fricke, 1982).

With the (when possible) optimum regulation of competition in favour of oak, quality-goals for oak are reached to the highest degree. The large number of dominant oaks prevents the development of wolf trees, leads to a broader selection range during thinnings and to a consistent annual ring growth with an average width of 1.5–2 mm.

Some forestry operations today strive for even greater diameter increments in order to shorten their production time-frames. To achieve this, more severe thinning measures in youth are required in order to provide space for the selected crop trees to form a large crown (Mosandl et al., 1991). It is likely that not only the selected oaks but also the suppressed beeches are promoted by this procedure. The fear is that problems brought about by beech’s superior competitive strength are aggravated again.

5. Solving this problem within the new silviculture of oak with permanent canopy cover

5.1. Objectives

Despite the unquestionable successes of the classic silviculture of oaks in the past 100 years, recent years have brought about an increase in the number of critical voices (e.g., Lang, 1988). They are based primarily upon three arguments.

The rapid removal of the canopy in effect leads to clear-cuttings and their well-known consequences for the nutrient balance.

Regeneration on inevitably large areas (in order to optimally exploit mast years, which occur at irregular intervals) in a process similar to clear-cutting does not allow the use of selection cutting according to individual diameter limits of each tree. The sessile oak in particular tolerates more shade in youth as was previously accepted. It can successfully compete with beech even under permanent canopy cover.

These critics therefore demand long-term regeneration beneath a canopy cover even for oak. For this, however, several conditions must be fulfilled:

First, old stands which are to be regenerated must be so stable that they can tolerate an opening up of the canopy. As a rule, this is the case for pine, beech and oak; for spruce, on the other hand, it is usually insufficiently so. Spruce stands which are to be transformed into oak stands often occur on stagnic gleysols and are so unstable that regeneration by means of clear-cutting becomes unavoidable.

Second, the oak must show the capability to grow satisfactorily under these conditions. This raises the question of how much shade can be tolerated by this species, which is normally categorized as a light demander (Krahl-Urban, 1959).

5.2. Silvicultural research by the institute

Several investigations have been conducted recently into this matter by our institute.

Three of the experimental sites are located near Göttingen (Reinhausen Forest District, approx. altitude 300 m) in 140–160 years old mature beech stands on cambisol consisting of sandy-clay weathered material of red sandstone and some loess. One experimental site was located north of Braunschweig (Forest District Sprakensehl, approx. altitude 50 m) on level ground with pleistocene sand and clay in a 95-year old pine stand. The stands had various levels of opening up, ranging from closed canopies to a clear cutting over an area of about 1 ha. Two-year old sessile oak, pedunculate oak and beech were planted or sown in separate groups on 30–40 plots for each experimental site, covering the entire range of canopy and radiation conditions. Mortality and growth height were recorded annually for oak and
beech. The minimum observation period is 3 years; the maximum period is currently 8 years. On another experimental site with the same conditions as the first three (Forest District Bramwald, approx. altitude 300 m) density and height increment were measured for a naturally regenerated sessile oak–beech young forest under a broken canopy of mature beech and oak. Observations took place over two consecutive years on plots with various canopy conditions. Because radiation readings were not technically possible above the crown canopy of the young forest, canopy cover was characterized by its proximity to a mature tree.

On the other experimental sites, radiation conditions at the top of young oak and beech trees were measured using hemispheric photographs according to methods developed by Wagner (1994). At the same time, PAR sensors with integrators or registering data loggers were used (manufactured by Lambda Instruments, Lincoln, USA). In each case, radiation was recorded as total radiation for the whole growth period and expressed as a percentage occurring above the crowns of the mature stands (relative radiation).

5.3. Results

Our most important results are reproduced in Fig. 1. This gives the yearly height increment—in this context, certainly the most important growth parameter—dependent upon relative light intensity beneath the canopy of an old beech stand with various degrees of opening. According to this, a reduction in height increment took place in up to 10-year old oaks only below 40% light. The increment decreased considerably again below 10% light. No increase in mortality was recognizable descending to a level of 8–10%. Below this level many oaks died. A clear difference for pedunculate and sessile oak did not appear (Lüpke, 1995).

That applies to old beech stands. On an experimental site in the Sprakensehl Forest District, we were unable to ascertain a drop in the height growth of oaks beneath the canopy of an old stand of pines (Pinus sylvestris L.)—on a soil suitable for oak—as the canopy cover increased. The reason for this is the high light values allowed through by the pine crowns. They ranged from 30% under a closed canopy up to 50% beneath a broken canopy cover. Furthermore, we found a clearly lower density of fine roots among the pines as compared to the beech stand, which we interpret as an indication of less root competition.

The discovery that oak is capable of growing in conditions of moderate to heavy shade is not sufficient to form judgments on the possibility of a silviculture of oak with a permanent canopy cover. Because a combination with an assisting tree species is indispensable for the production of primary oak (as elucidated above), it must still be examined whether the oak can also hold its own against beech under these conditions.

It was shown on an experimental site near Göttingen that the oaks were considerably superior to simultaneously planted beeches up to an age of 10
years in clear-cut areas and gaps with 44% light (Lüpke, 1987b, see Fig. 2).

This superiority was most pronounced on the clear-cut area. The beeches there showed less growth than in the gap due to late-frost damage at the beginning of the 5th year. The oaks, however, were not affected by the frost. Only under the relatively dense canopy of the old stand of beeches with 11% light did the height growth of the oaks fall away much more sharply than was the case for the beeches, reversing the relationship. The conclusion can be drawn here that the canopy covers, which allow between 40% and 10% of full light to penetrate, transfer the competitive relationship more and more away from the oaks in favour of the beeches. Unfortunately, however, what we do not yet know in this field—and this would have great importance for silvicultural practices—is the exact course of the competitive relationship between the two tree species.

The analysis of an 11-year old thicket of naturally regenerated oaks and beeches with an open canopy in a single-tree mixture (Bramwald/Göttingen Forest District) resulted in the composition presented in Fig. 3.

According to this, the majority of the predominant and dominant crown class is comprised of oak, but beeches represent a considerable portion at 27% and 41%, respectively. In both classes, oaks and beeches achieve approximately the same average heights.

5.4. Discussion

If we apply the classification suggested by Grime (Grime, 1979, 1981), then oak is a ‘shade avoiding’ species which employs the strategy in shady habitats of maintaining as much height growth as possible or even of increasing it in order to grow out of a shade zone. On the other hand, ‘shade tolerant’ species reduce their growth under these conditions primarily in order to ensure long-term survival.

A surprising height growth for 9-year old oak was also found by Preuhsler et al. (1994) beneath the canopy of an old pine stand in the Nürnberg Forest District. However, pine of the same age, which is a typical light demander, showed a significantly reduced height growth under these conditions. It was surpassed considerably by the oaks. The sum crown projection area as percentage of total surface area was 55% on average for the experimental area, with substantial differences within micro-areas. A closer analysis of the height growth of the oaks showed that it was significantly greater for a canopy cover of less than 35% than for a canopy cover of more than 80%. Unfortunately, light values were not measured.

A similar picture emerged from the initial evaluations of long-term experimental sites in the Bavarian forest districts of Ebrach/Steigerwald (Utschig et al., 1994) and Gräfendorf/Spessart (Pretzsch, 1993). In all, with crown projection areas of 10–50%, the influence of density of canopy cover of old stands on the height increment of oaks and beeches was very small for the 15- to 18-year old trees in Ebrach/Steigerwald and 3- to 5-year old young growth in Gräfendorf. With an open canopy cover, the height growth of both species was almost unrestrained. As canopy cover increased, the height growth of the oaks decreased more sharply than that of the beeches. In some areas during the (in part)
ten-year observation period, the oaks were pushed back into the understorey by the beeches; in some, they remained equally dominant; and in others even became predominant, in each case without possible explanation by differential canopy relations. Unfortunately, no light values were taken, thus, limiting the possibility of comparison with our own observations. However, in all areas, beech is represented to a noteworthy degree in the overstorey.

Initial height has proved to be very important to the height increment within a particular period: plants which were initially larger had a greater increment. These plants were generally beeches of preexisting advanced growth which was already present prior to the opening and planned regeneration of the stands. These were able to persist due to their high shade tolerance and low risk of browsing by wild animals, whereas the young oaks perished.

5.5. Conclusions

The following conclusions can be drawn from these results for practical application. Both species of oak regenerate successfully when the light level does not fall below 15–20%. In the short term (i.e., 4–6 years), survival with minimal growth at a light level of 10% is also still possible. The translation of the specified percentage light values into degree of canopy cover, as is standard practice, follows from Table 1 (Lüpke, 1995). Oak regeneration is thus possible in small gaps of at least 17–20 m diameter or beneath a broken to open canopy.

In summary, current knowledge leads to the following consequences for the silviculture of oaks with permanent canopy cover.

The oaks should have as great an age advantage as possible over the beeches; beeches should never originate from advanced growth.

The oaks must be similarly ensured an advantage from the start through the most far-reaching measures possible to prevent browsing by wild animals, which have an exclusive preference for oak.

Extremely dense canopy covers are tolerated for the first one or two years of regeneration (direct seeding, planting or natural regeneration), but must later be radically opened up to a 30–40% crown projection area (corresponding to 60–30% of full light).

This average crown projection area allows an almost unrestrained height growth. Exploitation of the old stand can therefore concentrate solely on how quickly each tree reaches its desired individual diameter limit.

In most cases, we can expect to find dominant and predominant beeches present in the overstorey of the stands from the very beginning. This represents a fundamental difference from the classic silviculture of oaks.

The regulation of inter-specific competition during cleanings and thinnings often necessitates great effort to maintain such a high number of oaks required in the overstorey to justify our speaking of it in terms of the silviculture of oaks and not of the silviculture of beeches with individual oaks mixed in (Lüpke, 1987a).

<table>
<thead>
<tr>
<th>Type of stand</th>
<th>Degree of canopy opening</th>
<th>Relative light intensity %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beech (height 30–36 m)</td>
<td>Closed</td>
<td>2–5</td>
</tr>
<tr>
<td></td>
<td>Broken</td>
<td>10–12</td>
</tr>
<tr>
<td></td>
<td>Open</td>
<td>40–50</td>
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<tr>
<td></td>
<td>Gap of 125 m² (13 m diameter)</td>
<td>8–11</td>
</tr>
<tr>
<td></td>
<td>Gap of 250 m² (17 m diameter)</td>
<td>12–15</td>
</tr>
<tr>
<td></td>
<td>Gap of 500 m² (25 m diameter)</td>
<td>18–20</td>
</tr>
<tr>
<td></td>
<td>Gap of 2000 m² (50 m diameter)</td>
<td>45–60</td>
</tr>
<tr>
<td>Pine (height 25–32 m)</td>
<td>Closed</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Broken</td>
<td>50</td>
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</tbody>
</table>

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References


