Spatial aspects of the influence of silver birch (*Betula pendula* L.) on growth and quality of young oaks (*Quercus* spp.) in central Germany

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Summary

This study was carried out to examine the influence of interference by silver birch (*Betula pendula* L.) on oaks (*Quercus* spp.) planted in clusters. On two sites in the north-eastern Hessian Mountains, Germany, transects starting with a birch were laid through oak clusters. Height, diameter at breast height (d.b.h.) and crown radii of the birch and the nearest three oaks on the transect were taken. The stem form and crown type of the oaks were noted and distances between birch and oaks were measured. Oaks on transects with birch interference were compared with oaks from birch-free transects. Results showed that, on the site where oaks were smaller, the birch did not consistently influence oak growth. On the other hand, the larger oaks on the second site were negatively influenced by the competing birch. Other measures than height or d.b.h. growth may be a more sensitive indicator of competition as all oaks shifted their crown centre away from the birch. Also, the proportion of trees with good stem form increased with the distance from the birch and the ratio of trees with bent stems decreased. Crown type was not affected by interference. To generalize, foresters should pay attention to the spatial aspects of birch, i.e. its location with reference to neighbouring oaks, and they may be able to use crown shift as an indicator of when to remove overtopping birch competitors before they influence growth of oak.

Introduction

Oak species are among the most important tree species for European forestry, especially in the European Union and its eastern neighbours. Although only about 5 per cent of commercial high forest area of the EU is covered by oak forests, large areas in coppice and coppice with standards (14.6 million ha in the EU in 1994; ONF, 1994) are dominated by oak species and

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many of these forests are being converted to high forest. In the future, the area of oak-dominated forest is expected to increase for two reasons. First, agricultural reforms within the EU have led to many old fields being planted with trees, often oak species. Secondly, oak is socially and environmentally preferred to non-native species particularly on sensitive sites, e.g. where Norway spruce (*Picea abies* (L.) Karst.) are prone to windfall.

To ensure the production of high quality wood, oak planting densities of 8000 seedlings per hectare or higher were common (e.g. Röhrig and Bartsch, 1992). Spacing experiments showed that growing space of young oaks should not exceed 1.5 m^2 per tree to ensure self-pruning, straight stems and thus high quality timber (Gaul and Stüber, 1996; Matic *et al*., 2000). Despite this, in recent years the pressure to lower the cost of stand establishment has led to reduced planting densities, i.e. the spacing between and within the planting rows has been increased. At wider spacings of planted oaks, retaining trees of other species that regenerate naturally may be needed to ensure the competitive pressure for self-pruning of the oak (Buresti *et al*., 1998). In this context, special concern is often directed to broadleaf species like silver birch (*Betula pendula* L.), willow (*Salix* spp.) and rowan (*Sorbus aucuparia* L.). They grow on a wide range of soils, often in species mixtures, and their early height growth is usually superior to oak species. Studies evaluating the effects of broadleaf species on young oaks have yielded contradictory results. On one hand, interspecific interactions can act as facilitation (Tonioli *et al*., 2001) and result in increased height growth (Leder, 1992) or better stem quality (von Lüpke, 1991; Leder, 1992, 1996; Ammer and Dingel, 1997). In other studies, species interactions acted mainly as competition and resulted in reduced height (Leder, 1992; Wagner and Röker, 2000), and diameter at breast height growth, and consequently in higher height : diameter ratios (von Lüpke, 1991; Leder, 1992; Wagner and Röker, 2000). One reason for these apparent contradictions may be the broad range of site and stand conditions used in these studies. For example, Ammer and Dingel (1997) and von Lüpke (1991) examined stands that originated from direct sowing of acorns, whereas Leder (1992) and Wagner and Röker (2000) studied oak plantings of different density. Also, different species regenerated naturally on-site, e.g. willow and aspen (*Populus tremula* L.) (Ammer and Dingel, 1997), birch (von Lüpke, 1991; Wagner and Röker, 2000) and birch and rowan (Leder, 1992). In addition, in most of these studies only cumulative effects of multiple trees and even multiple species were measured (Leder, 1992; Ammer and Dingel 1997).

Another opportunity to reduce costs of stand establishment is to plant oak seedlings in clusters (see Figure 1 which is taken from Gockel (1994), modified. The density within clusters is fairly high (individual growing space of an oak is about 1 m^2) to ensure high intraspecific competition in young stands. The number of trees within one cluster is determined by the genetic quality of the seedlings to ensure at least one high quality oak per cluster, i.e. seedlings from parent stands with genetically superior timber quality and excellent growth allow a lower number of oaks planted in a cluster. As the expectation is that at least one oak in any cluster has crop tree potential, the number of clusters per hectare is determined by the desired final crop tree density. Tending of young stands (e.g. weed control, thinning) is focused on clusters, thus reducing labour input and costs (Gockel *et al*., 2001). In addition, cluster-plantings allow for succession and natural regeneration to proceed in areas between the oak clusters, resulting in a more diverse plant community and a higher quality for wildlife habitat compared with traditional row planting (Rock *et al*., 2003).

Regardless of the planting regime, a limited presence of trees naturally regenerated on-site may be generally desirable. First, as competitors they may improve the stem form of oak by providing side competition and limiting forking and/or the diameter growth of branches. Secondly, they may provide an alternative crop. Thirdly, they have value for biodiversity and wildlife habitat. On the other hand, excessive competitive pressure may lead to sub-optimal growth, reduced tree stability, timber quality problems, and mortality of oak seedlings. The balance between these aspects is driven predominantly by density, size, and spatial location of neighbouring plants (Moore and Allen, 1999). We utilized an opportunity to examine these factors by comparing performance of oak cluster plantings with and without naturally regenerated

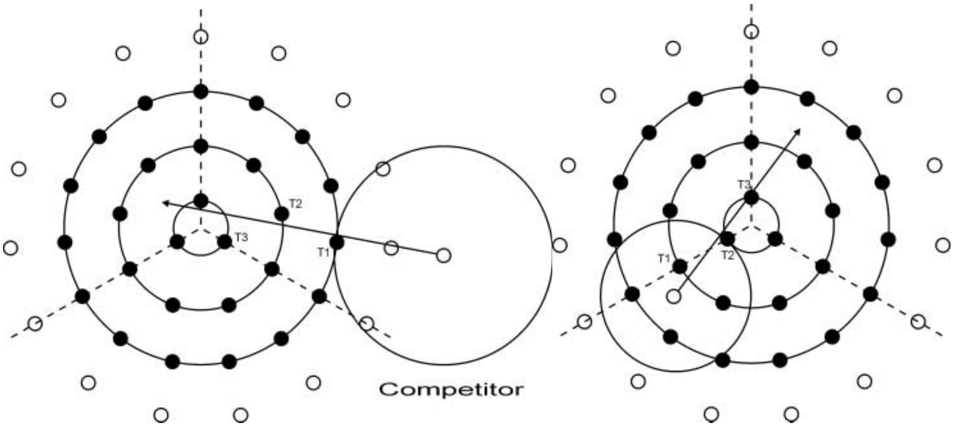

Figure 1. Example of transects for assessing interference by a broadleaf pioneer tree: birch is located outside (left) or inside (right) the cluster (large circle = crown radius of broadleaf pioneer; T1–T3 = oaks 1–3 on transect). Filled circles = oaks; open circles = secondary tree species. Note that the distance between two rings of oaks is 1 m and that the distance between two oaks on the same ring is also ~1 m.

silver birch. Specifically, we wanted to test the following hypotheses: (1) the presence of overtopping birch reduces growth and stem form and crown quality of neighbouring oaks; and (2) these influences vary with position on a transect, i.e. distance from the competing birch.

Materials and methods

Study species

The most economically important oak species in the EU are common oak (*Quercus robur* L.) and sessile oak (*Quercus petraea* (Mattuschka) Liebl.). Both can tolerate some shade during early seedling stages (Hauskeller-Bullerjahn, 1997), but become more light demanding after a few years. This can prevent them from invading understoreys and makes them vulnerable to competition from faster-growing species. In central Europe, adult sessile oaks require more light than common oaks and are less tolerant of extreme site conditions (Jahn, 1991; Ellenberg, 1996). Common oaks are more tolerant of soil water deficits and also waterlogging of soils compared with sessile oak (Jahn, 1991). The elevation range for both species is very similar, ranging from plains and foothills to colline or low submountaine conditions (Jahn, 1991). Management objectives for both species are also very similar being mostly oriented toward production of high quality veneer and sawlogs. Consequently, a major focus of management activities is ensuring straight, clear boles throughout fairly long rotations. This has traditionally been accomplished by maintaining oak densities high enough to encourage natural pruning and/or artificial pruning.

Study sites

The study sites included two oak cluster plantings that were established in the Federal Forest District of Schwarzenborn, Hesse, Germany (50° 40′ N, 9° 30′ E) in the north-eastern Hessian Mountains. This area has a mean annual air temperature of 6.0–7.0°C and a mean summer (May–September) temperature of 12.5–14°C. Annual precipitation is generally in the range 700–850 mm, with a summer (May–September) precipitation of 330–390 mm (AK Standortskartierung, 1985). The climate is subcontinental. The average number of days with air temperature >10°C is 120–150 days, but late and early frosts are common, especially on plateaux. Both study sites cover ~1 ha. The previous stands of ~80-year-old Norway spruce were windthrown in 1990. Both sites were cluster planted with 27 oaks and 15 European beech (*Fagus* *sylvatica* L.) as secondary tree species in each cluster (Figure 1) and 100 clusters ha^{-1}. Up to 2001, the performance of the beech was very poor and they were not incorporated in the analysis. The first stand, Kamphuette, covers the middle and upper parts of a south to south-east facing slope at 460–480 m a.s.l. Dominant soil material is weathered sandstone, resulting in dystric cambisols and podsols. The nutrient supply and water availability are medium (forest soil inventory according to AK Standortskartierung, 1996; Scheffer and Schachtschabel, 1992). Cluster planting was conducted in spring 1993 with sessile oak and European beech. Natural regeneration of Norway spruce, Scots pine (*Pinus sylvestris* L.), silver birch and rowan (*Sorbus aucuparia* L.) is abundant.

The second stand, Lerchenfeld, is situated on the lower part of a gently sloping north–north-east facing plain at 540–550 m a.s.l. It is surrounded by meadows, fallow lands and fields. Remnants of the previous Norway spruce stand are still standing on the western, southern and eastern borders. The soil is mostly a stagnic gleysol/cambisol originating from basalt loam. The nutrient supply is good and water supply is medium to very good (forest soil inventory according to AK Standortskartierung, 1996; Scheffer and Schachtschabel, 1992). Parts of the area show periodic surface water. The planting took place in autumn 1992 using the same layout as described for Kamphuette but with common oak as the main species. Natural regeneration of rowan, silver birch, willow and aspen is abundant.

Transect selection

To avoid measuring impacts of more than one competitor, we selected only clusters that had a single naturally regenerated silver birch in or near the cluster. In the autumn of 2001, we established transects through oak clusters so that the centre line of the transect touched the inner circle (Figure 1). The orientation of transects and slope were recorded (with a hand-held compass) to allow for assessing effects of orientation. Starting with the birch, the next three oaks on transects proceeding to the middle of the cluster were marked and labelled as first, second and third oaks.

To quantify conditions influenced only by intraspecific interactions we duplicated the sampling scheme (described above) in oak clusters without competing broadleaves. For this part we used data from a related study which used the same sites (Gockel *et al*., 2001). To avoid confounding effects of sampling layout we ensured that the orientation of transects in the oak-only clusters matched the orientation of transects in clusters with competitors, i.e. the proportions of transects in the four cardinal directions were similar. In addition, in the oak-only clusters we started transects without competitors at within-cluster locations that matched starting locations in oak–birch clusters. Due to these restrictions, we could not establish an equal number of transects with and without birch. Within this constraint, both sets of clusters were randomly distributed over the entire study sites.

Measurements

We measured total height and diameter at breast height (d.b.h.) for all trees and calculated height : d.b.h. ratios (*h*/*d* ratios) as an indicator of tree stability. For the 18 oaks at Kamphuette that had not reached breast height, d.b.h. was set as a missing value. In addition, for trees on birch transects, crown radius was measured in four directions, the axis along and perpendicular to the transect and defined as the distance between the tip of the branch extending furthest along the axis of interest and the stem of the tree. If no branch grew in that 45° sector along a given axis, or if the angle between branch and axis was greater than ~22.5°, we interpolated the radius as distance between stem and the line connecting the two branches next to, but at different sides of, the axis. Based on these measurements, we calculated average crown radius (as the mean of the four radii measured). In addition, as an indicator of crown eccentricity, the horizontal distance between the base of a tree and the midpoint of it's crown was calculated by adding up the four radii (taken as vectors), using the stem base as origin of an orthogonal Carthesian coordinate system. The length of the resulting vector was 'crown shift' (Figure 2).

We also characterized crown types and stem forms (Figure 3) of all oaks (on transects with and without birch competitors) using a slightly

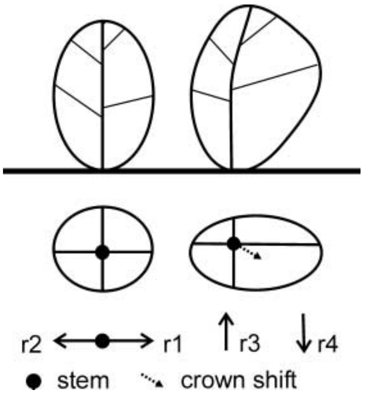

Figure 2. Example of two oaks indicating how crown shift was measured. The arrows r1–r4 indicate the crown radii taken. The left oak has a crown shift of zero, the amount of crown shift for the right oak is indicated by the dashed arrow.

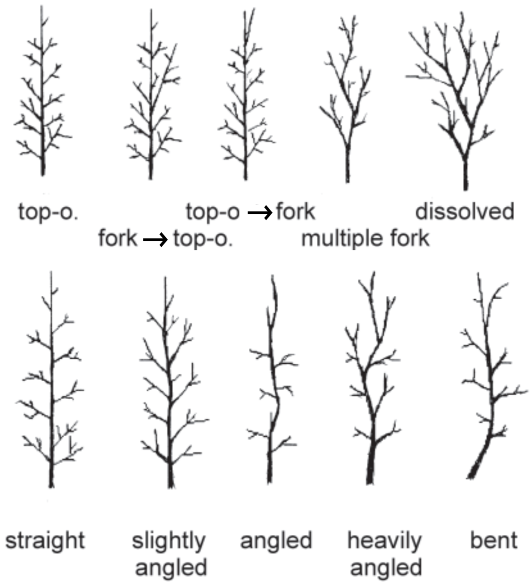

Figure 3. Crown types (top) and stem forms (bottom) used for characterization of young oaks. Crown types, from left to right: top-o. = top-oriented; fork → top-o. = fork with tendency to top-oriented growth; top-o. → fork = top-oriented with tendency to fork; multiple fork; dissolved = dissolved crown. (Modified from Gockel, 1994).

modified version of the scheme developed by Gockel (1994). This allowed for objective assessment of crown and stem quality (Gockel, 1994; Ammer and Dingel, 1997; Fischer, 1998; Gockel *et al*., 2001). The crown type is believed to be genetically fixed and does not change in reaction to intraspecific competition (with very few exceptions; Gockel, 1994). The stem form is influenced by crown type (e.g. a tree with the tendency to fork will in most cases show an angled stem) and external factors such as frost killing leaders, browsing, and shading by overtopping trees. Therefore, stem form may change over time and minor defects may improve with age or can be influenced by silviculture. The determination of stem form can be done on the last 3–4-year shoots (and branches). If a tree was forked above ground in two shoots with almost identical dimensions, it was labelled a ‘fork’. Due to the limited sample size, for the data analysis, ‘forked’ trees were combined with the ‘multiple fork’ category. Trees with straight boles that leaned in one direction were classified as ‘bent’.

Statistical analysis

Kolmogorov-Smirnov tests were used to test for normal distribution of data. Each site was analysed separately as a completely randomized design using analysis of variance (Littell *et al*., 1996) with birch (presence or absence) as a main effect; position on the transect and position × birch interaction were treated as a repeated measure within the main effect. Thus, to account for non-independence of oaks within a transect, transects were considered replicate experimental units and each oak on the transect was analysed as a repeated measured unit within a transect.

Stem quality and crown type parameters were compared using χ^2 analysis. Due to the small frequencies of some combinations of stem form/position of oak and crown type/position classes, data were combined in the following ways to assure feasibility of χ^2 analysis. First, the number of bent stems was compared with the number of all non-bent (straight and angled) stems. Secondly, desirable (straight and slightly angled) stem forms were pooled and compared with all other forms. Thirdly, crown types were assigned to three classes: top-oriented growth, transition types (top-oriented with tendency to fork and forks with tendency to top-oriented growth) and undesirable types (forks, multiple forks and dissolved crown). All statistical tests were done using SPSS version 10.0 or SAS version 8.0.

Results

Growth

On both sites the birch were much bigger than the oak, being twice as tall and three to four times the diameter. The size of the oaks differed between the two sites (Table 1) and the results of the analysis of variance (Table 2) were not consistent for the two sites. At Lerchenfeld, where the birch and oak trees were larger than those at Kamphuette, the presence of birch showed no significant influence on the height of oak, but d.b.h. was significantly larger in transects without birch. An important factor in this effect was the relative diameters of oak trees in position 1; when birch was present, oak in position 1 were only half the diameter of oak in the same position on transects without birch. The interaction of presence of birch and position of oak along the transect was significant for both height and diameter. For both height and diameter, the main factor causing the interaction was that when birch was present the oak in position 1 was smaller than in positions 2 or 3. However, when birch was absent, the oaks in position 1 were the largest. Pairwise comparisons showed that oaks in position 1 were smaller than second ($P = 0.02$ and 0.03 for height and d.b.h., respectively) and third oaks ($P = 0.001$ and 0.016 for height and d.b.h., respectively), indicating a significantly negative impact of competing birch.

At Kamphuette, where the birch and oak trees are smaller than at Lerchenfeld, oaks on transects with birch competitors were significantly taller and had a larger diameter than oaks on transects without birch. The position of the oak trees on the transect had no significant impact on height but it was significant on diameter. However, in both cases the interaction of presence of birch and position of oak was also significant. The main factors contributing to this interaction were, for height, oak in position 2 with birch were tallest but when birch was absent they were the shortest. For diameter, oak in position 2 with birch were the largest but when birch was absent they were ranked only second. On transects without birch, there were no significant differences between oak in different positions for both height and diameter. When birch was present, oak in position 1 had smaller heights and diameters than the other oaks on transects ($P < 0.017$ and 0.004 for height and d.b.h., respectively).

To provide an indication of the impact of competing birch on potential tree stability and as an indication of crop tree potential, Table 1 also includes information about *h*/*d* ratios. We did not test for statistically significant differences, because it was not possible to achieve distributions with equal variances, even with transformation of the data. However, *h*/*d* ratios of 120 (Wagner and Röker, 2000) to 150 (von Lüpke, 1991) are considered critical values for the stability of a young oak stand, especially in areas with wet snow accumulation during wintertime. In this study, 150 is used as critical limit. On Kamphuette, this threshold is reached or exceeded by oaks on all three positions in transects without birch and by first oaks in transects with birch. On Lerchenfeld only first oaks on transects with competitors show mean *h*/*d* ratios above 150.

Stem form and crown quality

On both sites, all crowns shifted significantly away from competing birches (Tables 1 and 2). The average crown shift of oak in position 1 at Lerchenfeld was significantly larger than the shift of oak in the second and third positions ($P = 0.002$ and $P < 0.001$, respectively). Oak at Kamphuette showed the same trend but it was not as pronounced. Here, only the difference between oak in the first and third positions was significant ($P = 0.021$).

Oaks on both sites differed in terms of crown and stem quality. On Lerchenfeld oaks with better crowns, i.e. top-oriented growth and intermediate crown types (top-oriented with tendency to fork and forks with tendency to top-oriented growth), were found more commonly in oak-only clusters (Figure 4). The data suggest that the influence of birch resulted in a higher proportion of crowns prone to fork or grow into a dissolved crown; however, this was not fully confirmed in

Table 1: Mean and standard deviation (in parenthesis) of tree measurements on transects with and without birch competitors

	Kamphuette				Lerchenfeld			
	Birch	Oak 1	Oak 2	Oak 3	Birch	Oak 1	Oak 2	Oak 3
With birch								
Height (m)	6.98 (1.34)	2.50 (0.88)	2.96 (0.75)	2.68 (0.75)	7.97 (1.54)	3.09 (1.01)	3.81 (0.90)	4.05 (0.83)
d.b.h. (cm)	8.9 (3.3)	1.6 (0.9)	2.3 (0.9)	2.2 (1.3)	10.8 (3.4)	2.1 (1.4)	3.1 (1.3)	3.8 (1.1)
h/*d* ratio (cm cm^{-1})	85 (21.3)	176 (61.9)	137 (43.2)	134 (46.1)	78 (17.5)	193 (95.9)	137 (36.2)	112 (24.3)
Crown radius (m)	1.64 (0.47)	0.53 (0.28)	0.63 (0.23)	0.62 (0.27)	2.00 (0.40)	0.60 (0.32)	0.83 (0.21)	0.94 (0.24)
Crown shift (m)	NA	0.71 (0.64)	0.42 (0.46)	0.31 (0.38)	NA	0.90 (0.55)	0.50 (0.40)	0.34 (0.21)
Distance to birch (stem basis) (m)	NA	0.78 (0.53)	1.76 (0.58)	2.71 (0.67)	NA	0.71 (0.52)	1.73 (0.59)	2.63 (0.64)
Without birch								
Height (m)	NA	2.27 (0.59)	2.14 (0.68)	2.34 (0.76)	NA	3.80 (0.65)	3.62 (0.63)	3.69 (0.68)
d.b.h. (cm)	NA	1.6 (0.9)	1.5 (0.9)	1.8 (1.1)	NA	3.9 (1.2)	3.1 (1.1)	3.6 (1.2)
h/*d* ratio (cm cm^{-1})	NA	178 (100.6)	166 (63.5)	148 (53.9)	NA	102 (19.3)	125 (29.3)	113 (35.8)

Number of observations is 50 and 27 for Kamphuette and 15 and 23 for Lerchenfeld with and without birch, respectively.
Note that 18 oaks on Kamphuette had not reached d.b.h.

Table 2: Results of analysis of variance for the influence of the presence/absence of birch, position of oaks along transects, and birch × position interaction

		Height		d.b.h.		Crown radius		Crown shift	
Site	Effect	d.f.	*P*	d.f.	*P*	d.f.	*P*	d.f.	*P*
Kamphuette	Birch	1;75	<0.001	1;75	0.004				
	Position	2;150	0.343	2;132	0.020	2;98	0.067	2;98	<0.001
	Birch × position	2;150	0.040	2;132	0.041				
Lerchenfeld	Birch	1;36	0.748	1;36	0.029				
	Positon	2;72	0.048	2;72	0.003	2;28	0.012	2;28	0.002
	Birch × position	2;72	0.018	2;72	0.030				

Degrees of freedom (d.f.) are for the numerator; denominator of the *F*-distribution.

the analysis as the effect was only significant at $P = 0.065$. At Kamphuette, the influence of birch was not detectable in the frequency of crown types (all P values > 0.415).

Birch interference resulted in a higher proportion of bent stems on first oaks on both sites (Figure 5) ($P = 0.001$ for Kamphuette and for Lerchenfeld), while straight and slightly angled stems were more common on transects without birch interference ($P = 0.034$ and 0.039 for Kamphuette and Lerchenfeld, respectively). A similar effect was also present for oak in position 2 at Kamphuette, which were more likely to have bent stems ($P = 0.028$), but there was also a suggestion ($P = 0.071$) that they could also have more straight stems in transects with birch. Oak in position 3 showed no difference in frequency of stem forms ($P = 0.465$ and $P = 0.905$ for bent and straight stems, respectively). At Lerchenfeld there were only a few oak in the second and third positions with a bent stem, hence differences in stem form were not significant ($P = 0.463$ and $P = 0.944$ for second and third oaks, respectively).

Discussion

Most studies investigating the influence of competing hardwoods on oaks have focused on the impacts of multiple neighbours on oaks (e.g. von Lüpke, 1991; Leder, 1992; Ammer and Dingel, 1997; Wagner and Röker, 2000) and assess the net results of the combined impacts on single trees. However, especially in stands with multiple interacting species, such studies cannot separate the variety of negative and positive effects that are in operation (e.g. Bronstein 1994; Tonioli *et al*., 2001); neither can these be separated by species or individuals. We chose a different approach and focused on the influence of single competitors on a number of oaks over a spatial gradient. This approach is based on the assumption that intraspecific interference within the oaks is fairly constant and the influence of overtopping broadleaf species is more important (*sensu* Welden and Slauson, 1986) and thus can be quantified. The validity of this assumption is supported by several studies in young oak stands (e.g. von Lüpke, 1991; Leder, 1992, 1996; Ammer and Dingel, 1997; Wagner and Röker, 2000). The smaller variation of measurements in the oak-only clusters compared with the findings from the transects with competing birch also underlines the validity of this assumption. Our two study stands are on different sites, the stands were the same biological age but planting date varied, and they were planted with different oak species. Thus, it is not possible to separate exactly which specific differences between the two stands can be attributed to species and which ones are likely due to site conditions.

As seedlings and saplings, common and sessile oak do not differ notably in their light (Hauskeller-Bullerjahn, 1997) and nutrient requirements (Ellenberg, 1996). The reactions of both species to limited light or nutrient availability should therefore be fairly similar at this age. Given the annual rainfall and its distribution

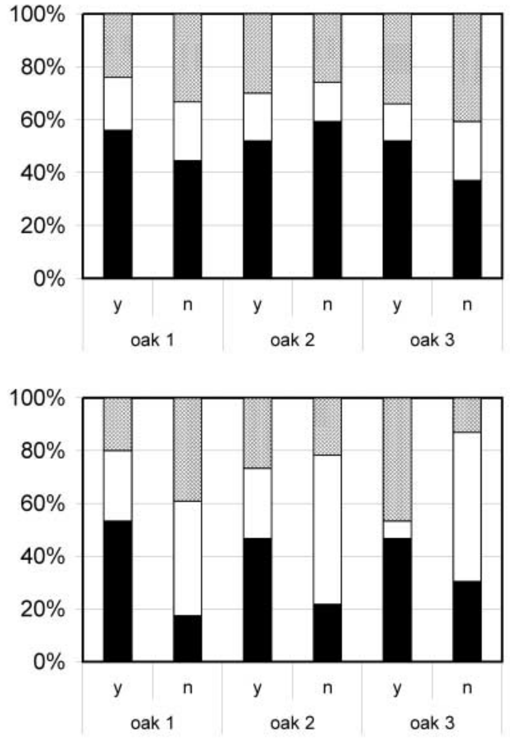

Figure 4. Crown types of oaks on Kamphuette (top) and Lerchenfeld (bottom). For analysis, the types 'top-oriented with tendency to fork' and 'fork with tendency to top-oriented' are combined as 'intermediate' types and 'multiple forks' and 'dissolved crown' as 'forked' (see Figure 3). y = Oaks from transects with birch competitor; n = oaks from transects without birch; shaded column = top-orientated type; open column = intermediate type; filled column = forked type.

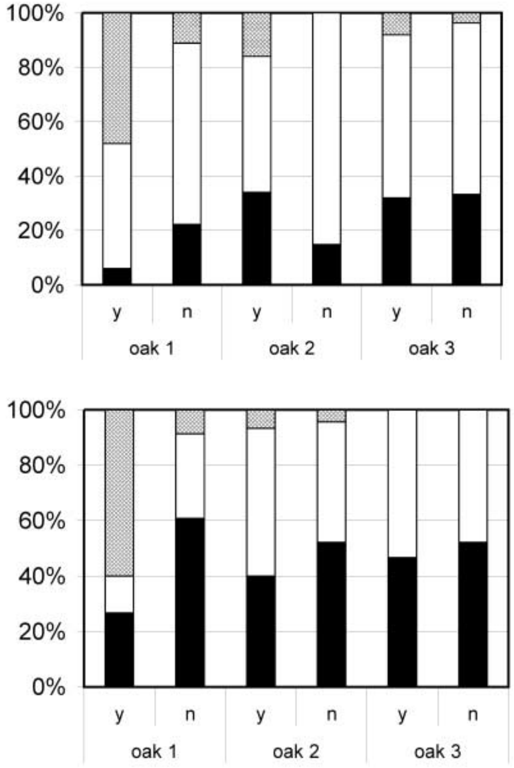

Figure 5. Oak stem forms on Kamphuette (top) and Lerchenfeld (bottom). Angled and heavily angled stems are combined to facilitate analysis (for reference see Figure 3). y = Oaks from transects with birch competitor; n = oaks from transects without birch; shaded column = bent stem; open column = angled stem; filled column = straight/slightly angled stem.

throughout the year, water supply should be sufficient to ensure unhindered growth of both oak species (Röhrig and Bartsch, 1992; Ellenberg, 1996). The distribution of transects over the entire stand area and the similarities in their orientation should ensure equal light conditions. Differences in size or shape are therefore not likely due to biomass partitioning caused by different reaction to the overall growing conditions (Kolb and Steiner, 1990). Given this and the lack of other distinguishing factors, such as differences in damage to the boles or shoots, it seems evident that the difference in tree size may be the major factor determining the difference in results on both sites (Puettmann and Reich, 1995). Apparently, the interactions between oaks and birch competitors were not as intense and important (*sensu* Welden and Slauson, 1986) in the stand with smaller trees (Kamphuette) as in the other stand at Lerchenfeld. We hypothesize that this will change in the next few years as birch and oak increase in size.

Tree growth

Earlier studies suggested that oaks under interference from taller broadleaves show little or no reduction in height growth, have smaller d.b.h., and thus higher *h*/*d* ratios than trees growing only under intraspecific interference (Kramer, 1988; Leder, 1992; Wagner and Röker, 2000). Our study showed apparently contradicting results at the Kamphuette site with smaller trees, while the oaks at Lerchenfeld conformed to the predicted trend. In general, the oaks on transects with birch competitors on Kamphuette showed no negative reaction in height or diameter growth to interference, instead they showed a slight tendency to be facilitated by the broadleaves. This type of nurse crop effect was more strongly expressed in oaks in the second position. These results support the findings from Leder (1992, 1996), who showed that oaks under mild interference pressure by other broadleaf species benefited from this competition (Leder, 1992; McLeod *et al.*, 2001; Tonioli *et al.*, 2001). Nurse crop effects can result from several reasons: protection from the elements (i.e. changes in microclimate), better interaction in the rhizosphere (Prescott *et al.*, 1996), through alterations of the red–far red light as influenced by overtopping foliage (Ballaré *et al.*, 1990), and/or the pressure to put resources into height growth to assure access to light (Leder, 1992; Röhrig and Bartsch, 1992). However, within the transects with competitors the oaks in position 1 exhibited reduced growth compared with oaks in positions 2 and 3. At Lerchenfeld, oaks next to birch trees were apparently subject to more intense competition. They showed larger reductions in height and diameter. Similar findings for height and diameter have been shown by Miller (1990), von Lüpke (1991), Ammer and Dingel (1997), Wagner and Röker (2000), and have been associated with differences in number and size of growth flushes (Collet and Frochot, 1996).

A more detailed investigation of interference patterns indicated that spatial aspects are related to the tree sizes and thus their effects cannot clearly be separated when comparing the differences on both sites. On both sites first oaks were generally located within the crowns of the birch competitor. On Kamphuette, birches were smaller and second oaks were mostly located slightly outside of the birch crowns, while at Lerchenfeld birch crowns had expanded to encompass second oaks. It is thus possible that, on Kamphuette, the second oaks profit most from the nurse crop effect because they are subject to a lesser degree of competition pressure from the birch than first oaks on the same transect, while, at the same time, they receive more beneficial influence from the birch than third oaks.

Tree stability

The *h*/*d* ratio is of special interest as it is an indicator of tree and stand stability, e.g. in respect to potential breakage caused by heavy loads of snow. On our study sites, the results were not consistent. On Lerchenfeld, most oaks only influenced by intraspecific interference, i.e. without birch, had *h*/*d* ratios below the critical threshold of 150 given by von Lüpke (1991). On Kamphuette, only second and third oaks on transects with birch clearly showed *h*/*d* ratios below 150, but on both sites in transects with birch first oaks had the highest values for *h*/*d* ratios. The first, contradictory result can be explained by influences on growth, i.e. nurse crop effects. As diameter growth has been shown to be more sensitive to competitive pressure than height growth (e.g. Puettmann and Reich, 1995; Saunders and Puettmann, 1999) it seems as if birch interference leads to a shift in carbon allocation patterns of oaks. The extremely high *h*/*d* ratios of first oaks are an indication of more unstable trees. When neighbouring birch are removed, these oaks have a higher probability to bend down and/or break under snow or even heavy rain, thus opening up the stand canopy. Studies with other species indicated that early trends in *h*/*d* ratios are not likely reversed in later stages (Wilson and Oliver, 2000). Thus, even at this early stage, oaks may have been influenced by the interference pressure from the birch to the extent that they should not be considered likely crop trees. The high *h*/*d* ratios of oaks on birch-free transects on Kamphuette cannot be explained by intraspecific competition as the oak crowns have just started to close in to each other in large parts of the clusters. It seems likely that the *h*/*d* ratio values are due to the comparatively high number of oaks that just grew past d.b.h., resulting in high *h*/*d* ratios. We hypothesise that further growth will lead to lower *h*/*d* ratios.

Stem form and crown quality

Measures other than tree growth were more sensitive and thus may be potentially an earlier indicator of interference pressure. Our results support findings that indicate that crown sizes and centricity of oak crowns is a consistent indicator of competitive conditions (Miller, 1990; Umeki, 1995; Guerard *et al*., 2001; Paulo *et al*., 2002). For example, crowns of all oaks, regardless of position, were shifted in the direction away from the birches. This information may be useful in stands with multiple broadleaf competitors, as the direction of crown shift may indicate which of the broadleaves surrounding an oak is the strongest competitor (see also Umeki, 1995). Oaks directly next to a competing birch show a crown shift that is equivalent to about 20 per cent of the tree's height, indicating that branch length on both sides of the oaks differs greatly. Since there is a positive correlation between length and diameter of branches (Nutto, 1999; Struck, 1999), these conditions lead to concerns of larger stubs and knots after branch dieback. Especially for high value hardwoods, like oaks, knot size is one of the most critical factors determining log values (Röhrig and Gussone, 1990; Nutto, 1999). Thus, the crown shift may result in reduced timber values, especially for oaks located within the perimeter of competing broadleaves.

Another factor influencing timber quality is stem form. The most desirable stem form is a straight upright bole. Deviations from this form include lack of straightness, e.g. angles caused by genetic factors (crown type; Gockel, 1994) or frost-killed leaders (Leder, 1992), or bent stems. Ammer and Dingel (1997) found fewer low-quality stem forms in areas with higher interference, but in their study the oaks were mostly located in between surrounding oaks and competitor trees. On the other hand, von Lüpke (1991) did not find this trend. In contrast to these findings, our study showed a negative impact of birch interference on the form of oak stems. Oaks on both sites consistently tried to evade the birch crowns by growing bent stems and longer branches in the direction away from the competitor. Jones and Harper (1987a, b) had similar results with silver birch. In their study, numbers of buds were lower on shoots under competitive pressure, and shorter shoots developed from these buds. The apparent contradiction between the results of the various studies on oaks and this study may be explained by the spatial set-up of the study conditions. All studies cited above assessed interference by several neighbours on a single oak. If competitors were located all around a single oak and their competitive pressure is similar, the shade-intolerant oaks may have had no other choice than to grow upright. On the other hand, oaks seem to react to one-sided pressure by altering crown and stem forms to less desirable conditions, thus potentially greatly impacting timber quality. Studies that evaluated various competition indices often indicated that including distance to competitor in the competition index did not improve growth predictions significantly (for reviews, see Biging and Dobbertin, 1992; Ammer and Dingel, 1997). Also, Lindquist *et al*. (1994) and Wagner and Radosevich (1998) found that angular dispersion of competitors did not influence growth responses in their respective study systems. Our analysis suggests that responses other than growth, such as crown shift or other indicators of stem quality may be more sensitive to spatial aspects and distance between competitors. Apparently, in our study the results may not be a function of distance or angle *per se*, but whether the interference pressure was one sided.

The lack of competitive influence on crown type was expected as crown type is more determined by genetic factors than by external influences (Gockel, 1994). The competitive pressure in our study sites may not have been high enough to override the genetic influence.

In summary, a comprehensive assessment of the influence of birch on young oaks must include the combination of all factors, i.e. growth parameters and quality measures. Under certain conditions (e.g. when trees are still small and/or further apart), competition may not be severe. Under other conditions, when trees get larger or when competitors are closer, faster growing species will suppress oaks beyond their direct neighbours. The directional response of crown shift may be an early indicator of when competition is becoming severe and influencing growth of the oaks. It may be a useful indicator of when to remove competing trees.

Acknowledgements

Part of this work was funded by the Ministry of Environment and Nature Conservation, Agriculture and Consumer Protection, Northrhine-Westphalia. The authors thank Ch. Goebel and his team at the Federal Forest District Office in Schwarzenborn/Hesse for assistance during data collection. We also highly appreciate M. Huso's help with the statistical analysis and the comments P.M. Elzö and G. Kerr made to previous versions of this manuscript.

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Received 18 November 2002