Effect of Browsing on Timber Production and Quality

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Abstract – Long term effect of seedling browsing as examined in the pole stage. According to our hypothesis browsing of seedlings and saplings by large herbivores causes long term negative changes in quantity and quality of forest stands, trees and timber. Data was collected in the Bükk mountains of North Hungary. Sample territory was marked out in sessile oak (*Quercus petraea,* Mattuschka – Lieblein) pole stand previously having been browsed the seedling stage by large herbivores. Similarly to the sample area a control territory was also marked out in an unbrowsed forest stand. The number of sample territories in each stand was 10, each of which measured 10×10m in size. We recorded the number of trees, measured the diameter at breast height (1.3 m) of the stems, the height of the trees and the malformations of the stems which occurred lower than 2m, such as tortuosity and fork growth. Data was evaluated by the *Student's t-test* and *Mann-Whitney U test.*

1. Browsing caused a slight but significant, 50 cm decrease in the height of trees and a high ratio of fork growth.
2. We concluded that despite heavy browsing activity which lasted several years timber quality at harvesting does not decrease.
3. At the same time a slight decrease in timber output occurs.
4. Browsing raises the costs of regeneration due to the expenses of increased weeding.

Keywords: red deer, roe deer, mouflon, pole stand, browsing by game, forest damage, sessile oak

Introduction

Browsing caused by large herbivors became the single biggest inhibiting factor of forest renewal efforts in many temperate countries (GILL 1992; PUTMAN 1996). Prolonged browsing of vegetation by ungulates reduces foliage cover and diversity of vegetation, changes the nutrient cycle of nitrogen and carbon, and influences energy flow (HOBBS

1996; Coté et al. 2004). In natural ecosystems ungulates' moderate browsing of vegetation stabilizes species composition of the forest by slowing of succession of various plant species; however, intensive browsing destabilizes this balance by accelerating the succession process (Hobbs 1996). Moderate feeding on deciduous species with higher N (protein) promotes shoot development and leaf mass which slows the successive dominance of coniferous species. Intensive browsing on the other hand reduces canopy cover and renewal which gives room for coniferous species to thrive. Browsing can also influence species composition of economically important forests. For example negative economic impact may be seen if oak is selectively consumed in turkey oak–sessile oak forests which then gives way to the expansion of turkey oak (Murányi 1988). Furthermore, those plant species that are preferentially selected by ungulates but represented in the species composition in a lower precentage become more intensively browsed upon as they become rarer. This however leads to the extinction from the community of such tree species as the sycamore maple, common ash and the rowanberries (Čermák et al. 2009).

Browsing can also promote the colonization of herbivorous insect species on plant seedlings (Hjältén – Price 1996, Olofsson – Strengbom 2000). In other cases herbivorous insect density may decrease as a result of reduced available habitat or colonization specific niches due to the extent of browsing damage; or as a result of a reduction in available food sources; or perhaps greater resistance of the plant against invaders which develops in response to the browsing damage (Hjältén 1999; Bergstrom et al. 2000). It appears that the ecological impact of browsing caused by ungulates may be many times greater depending on the affected species or ecosystem composition. At the same time any impact on the ecology can obviously negatively influence economic factors as well such as changes in plant community composition (Reimoser et al. 1999; Didion et al. 2009) or the synergistic effects of pests (Olofsson – Strengbom 2000).

The economic impact of ungulate-caused browsing becomes apparent in the increased costs associated with forest restocking and beating up, increased weeding costs and loss of growth potential or in the decrease of timber quality upon utilization (Reimoser et al. 1999; Náhlik et al. 2007). It is also a concern that plants which have been damaged by browsing are more exposed to further browsing by ungulates (Kinnaird 1974; Kullberg – Welander 2003; Pepin et al. 2006) and repeated browsing can result in development of several leading shoots (Kullberg – Welander 2003). Browsing by roe deer and red deer have proven negative effects on birch, beech and oak seedling mortality and growth (Van Hees et al. 1996).

In order to consider the extent of damage caused by browsing we also need to take into account the associated costs of forest protection, which on a national scale add up to be significantly higher than the actual loss due to browsing (Náhlik 2012). When we talk about ungulate-caused browsing damage we must not forget about the associated administrative costs such as forest protection penalties or inspection sanctions (Náhlik et al. 2007).

There have been numerous studies, mostly simulated experiments, which examined the short term effects of browsing on seedling growth. In many cases a one-off browsing incident does not have any impact on height or biomass of the plant (Eiberle 1975; Hoogester – Karlsson 1992), in other cases however we see a compensation effect where the slightly browsed plant grows taller than its undamaged counterparts (Pollanschütz 1988; Náhlik – Walter-Illés 1998; Kullberg – Welander 2003). It is also known that in areas where the soil is of poor nutritional quality the damaged seedlings are less able to compensate with increased growth rate in the following year or years (Danell et al. 1991). Repeated or intensive browsing damage of seedlings can result in significant retardation in growth or mortality of the plant (Eiberle 1975; Pollanschütz 1988; Siegel 1988; Náhlik – Walter-Illés 1998).

While there is sufficient data available on the short term effects of browsing on seedlings there is only limited data available on the long term effects of ungulate-caused browsing damage on a forest scale. In the present research we examined the long term effects of ungulate-caused browsing in sessile oak forest compartments where we compared one affected area with an unaffected area 16 years after reforestation took place. We examined whether there were any differences in either output or morphology of trees in areas affected by browsing versus unaffected forest compartments.

Materials and Methods

We selected our study sites in two compartments of a sessile oak pole stand on the Egererdő ZRt. Szilvásváradi Erdészet's property where both compartments showed similarities in all aspects except for the browsing caused by ungulates.

The two selected study compartments were the Szilvásvárad 11I and 11F. Both compartments had brown soil type with a growing layer of medium-deep loam, free from excess water infiltration, situated 400m above sea level, facing to the west, sloping at 15°. The future study plan includes turkey oak – sessile oak forests. The total area of the *Szilvásvárad 11I forest compartment* is 5.5 ha from which 1.5 ha of encroaching black locust was clear-cut in 1995; in the same year reforestation began and 2-year-old oak seedlings germinated from acorn were replanted in 100% of the area. In 1996 protective measures against damage by cockchafer (*Melolontha spp.*), and protection with Cervacol against browsing damage by ungulates were initiated on four separate occasions at a cost of 300,000 HUF. Despite these measures there was considerable damage caused by deer, mouflon and roe deer in each year which accounted for 44% in 1996, 45% in 1997, 75% in 1998, 75% in 1999, 50% in 2000, 80% in 2001 and 20% in 2002 qualitative oak stand damage. Complete regeneration was achieved in 2002, 7 years post-commencement of reforestation. In response to sparse foliage cover, beating up was done on 4 separate occasions (2003, 2004, 2005, 2006) at a total cost of 94,000 HUF/hectare. The total area of *Szilvásvárad 11F forest compartment (control)* is 7.3 ha from which 7.0 ha of encroaching turkey-sessile oak-black locust was clear-cut in 1995; in the same year reforestation began and 2-year-old sessile oak seedlings germinated from acorn were replanted in 100% of the area. There were no reports of damage due to wild game feeding in the area. In 1996 there were protection measures taken against cockchafer (*Melolontha spp.*); also in 1996 protective fencing was installed around the clear-cut area to keep ungulates away, which was removed in 2003. Reforestation measures were ended in 2000, the new forested site was released at the age of 5 years. In response to sparse foliage cover, beating up was done on 3 separate occasions (2003, 2004, 2005) for a total cost of 40,428 HUF/hectare.

Estimation of damage was done in the usual manner at the end of summer by the forest inspector via visual estimation. Therefore, the above-mentioned extent of damages is somewhat inaccurate; however, the exact numbers are irrelevant as those figures are only informative in nature. They do, however, clearly show that there was considerable damage done by ungulates in the study site whereas no damage occurred in the protected control site.

In terms of growth factors no differences were detected between the two study sites. The expected growth ability of the two areas is categorized as "medium" (Sali 1975; Béky 1989).

In both of our study sites we systematically selected 10 sample quadrants, each of which measured 10×10m; the trees were observed in these sample areas. We measured the diameter of each tree at breast height. We estimated tree height by individual height curves (Fekete 1951; Veperdi 2002). We recorded any malformations of the tree trunk (tortuosity and forking) as well as the number of stems. In terms of "tortuosity" and "forking" only those seen below 2m were recorded as those would most likely be the result of early damage of end buds due to browsing by ungulates; this would be apparent if there were marked differences in this regard between our study site and the control site.

Data was recorded, sorted and analysed by *Microsoft Excel* software. We calculated the average diameter of tree trunks at breast height, the average height of trees, and we also counted the number of those trees that showed forking below 2 m and those that had tortuosity below 2 m as a result of bud damage. We examined our data from different aspects and we discussed these results in detail.

First we compared our data between the study compartment affected by ungulate browsing damage versus the control site. In the next step we categorized the study compartments into crop categories based on our data and crop tables (Sopp 1974), then we compared our results with crop data from old growth forests of this area, and with other research works (Sali 1975; Béky 1989) detailing parameters of this study site. In terms of discussion on the two forest compartments we used stem data from old growth forests of the area; we used actual data from our crop categories for breast height diameter. The reason for this was that we could compare and relate our observations to the highest possible number of stems and greatest possible trunk diameter.

We used *Past* software to statistically analyse our data. Normality of the distribution was analysed with the Kolmogorov-Szmirnov test. When normal distribution was detected we used t-test, in all other cases we used the Mann-Whitney U-test to compare means.

Results

In the forest compartment where significant browsing damage had been reported in the past, we could clearly observe the long term effects on the current state of the area.

In the affected forest compartment we counted 3570±330 seedlings whereas in the control area we counted 4660±542. There was significant difference detected ($p=0.000$; $df=18$). Since we do not know the original number of seedlings, it would be ill-advised to draw any major conclusions based on this; however, it was interesting to see that at present there were isolated patches where distance between stems appeared larger, which may point to ungulate caused browsing damage.

In terms of trunk diameter measured at breast height, our results showed somewhat lower average values in browsing-affected woodlots; however, statistically this proved to be insignificant ($p>0.05$). On the other hand, we measured significantly shorter trees in the affected study site versus the control site ($p<0.01$). Since there were no differences in habitat characteristics and site quality between the two study sites, and no differences were noted in applied forest management techniques; differences could only be explained as browsing damage caused by ungulates (Table 1).

TABLE 1. Comparison of growth characteristics of sessile oak stands (* p<0.05; ** p<0.01; *** p<0.001; NS not significant)

	Trunk diameter 1.3 (cm)	Height (m)	Forked (%)	Tortuosity (%)
Browsed by ungulates	5.7	6.5	27.23	39.79
SD	2.33	1.1456	5.6202	12.6941
Total measured tree	357	357	357	357
Control	5.9	7	8.1	37.33
SD	2.4117	1.4185	4.0057	8.9233
Total measured tree	466	466	466	466
df	821	821	18	18
p	0.0996 NS	0.0001***	0.0001***	0.6171 NS

We could show that the incidence of trees with some degree of damage, that is greater measurable tortuosity and fork growth below 2m, was more significant ($p<0.01$) in areas affected by browsing damage caused by ungulates. Forked trunk development was observable since pruning to a single branch form did not take place. In the affected study site the average height of forked trunks was 6.0±1.35; whereas, non-forked trunks averaged 6.6±1.0.

However, no notable differences ($p>0.05$) could be detected between the browsing-affected area versus the control site in respect of the percentage of trunk forking under 2m which occurred as a result of early seedling damage.

Discussion

There are several difficulties associated with objectively analysing the browsing damage caused by ungulates (Gill 1992; Reimoser et al. 1997). The effects of browsing are greatly influenced by the tree species in question, the quality of the habitat, the time when the damage occurs and its intensity (Canham et al. 1994; Náhlik – Walter-Illés 1998), the age of the seedling and its maturity, as well as whether the damage has affected a leading shoot or not (Náhlik – Walter-Illés 1998; Hammer 2001; Jones et al., 2009). Although the quality of the habitats and the reforestation techniques were not totally identical we can still draw careful conclusions based on our data.

In regards to stem numbers we were unable to locate specific data about the starting number of the colonies but since replantation was artificially done, however, we can assume that the starting number of seedlings was close to 10 000 individuals in both locations. It is a fact that we found significant differences in the number of stems between the two sites with the affected site having lower values which also coincides with other previous observations (Van Hees et al. 1996). Seedling mortality in the browsed study site may be inferred based on an earlier experiment where simulated damage to sessile oak seedlings was studied over four years. The leading shoots were not necessarily affected but depending on the degree of pruning, mortality of seedlings was 30-60% (Náhlik –Walter-Illés 1998). In the affected study site heavy browsing damage had been recorded in the past 6 years and a further 1 year of moderate browsing damage. If we consider that damaged seedlings are more prone to further browsing damage in the following years (Kinnaird 1974; Kullberg – Welander 2003; Pepin et al. 2006) then we can safely assume that the observed difference in seedling numbers between the affected study site and the control area is the result of browsing damage by ungulates.

It is evident that in both sessile oak forest sites the actual stem number is less than the optimal expected number; and this difference is significantly larger in the browsing damaged study site (Béky 1981). In the affected oak forest site the actual stem number was 3570 pcs/ha instead of the desired 7000; whereas in the control area the actual stem number was 4660 versus the optimal which would be 6000.

In terms of trunk diameter measured at breast height we could not show any significant negative effect in the case of browsing affected oak trees. Based on the 2005 census of the replanted trees in the browsed oak forest and the old growth forest the area is classified as crop class III. However, based on our current data we suggest that the replanted area should be classified as crop class I if we consider Béky's (1981) nomogram which describes the age and average height of the trees. Our study site had a higher diameter reading (5.7 cm) than the nomogram-suggested value of 4.8 cm.

In the case of the control oak site we also have a similar situation where the forest compartment was classified as crop class IV in 2003 just as the other old growth trees had been before based on the forestry database. Based on our measurements and Béky's (1981) nomogram we classified the forest site as crop class I. In this case as well we had a higher breast height trunk diameter (5.9 cm) than the nomogram-suggested 5 cm. It can safely be suggested that browsing damage by ungulates does not influence breast height trunk diameter of oak in any significant manner either in actual numbers or statistically speaking.

We did however find moderately significant differences in the height of sessile oak in response to browsing-caused damages. Our earlier simulated experiments showed that seedlings were able to compensate for 2 years' repeated damages by increased growth rate; however, from the third year on the sessile oak is sensitive to pruning of the leading shoots which results in retarded growth and height of the affected trees (Náhlik – Walter-Illés 1998).

Similar observations were made in other experiments as well which studied the effects in the longer term, over 12-13 years of browsing of different tree species. In the case of extreme browsing seedlings cannot even surpass the 20-30 cm height (Gill – Beardall 2001; Horsley et al. 2003; Kumar et al. 2006). In our case we did not find such extreme browsing pressure in our study area; however, the height of seedlings in the affected study site was lower compared to the seedlings of the control site.

There was no significant difference found in the proportion of tortuous trunks between the browsing damaged study site and the unaffected control site. In terms of forking growth of the trunk, there was significant difference seen between the two study sites. It is known and also supported by our observations that browsing changes the morphological characteristics of plants which not only influences plant growth but may also cause mortality as it reduces the plant's competitive edge (Peinetti – Menezes 2001). The question is whether a relatively intensive browsing that may occur repeatedly over several years can cause any significant economic loss at the time of logging either due to the changes in morphology or quality of the timber or due to the overall decrease of available wood mass.

In the case of the affected oak the expected maturity for logging is 80 years (Sali 1975; Béky 1989). According to the forest maturation classification scheme (III) at this age the optimal stem number is 459 pcs/ha. If we subtract all tortuous and fork shaped trees from the 3570 pcs/ha of stems counted by us then we get 1177 pcs/ha which is more than double the desired stem number at age 80.

Even though there was statistically significant difference seen in the height of sessile oak, the degree of this difference doesn't appear to be high. Nevertheless, the smaller number of stems, which is significantly less than the desired number as described by Béky (1981), resulted in the prolonged recovery period that lasted 2 years longer than that of the control site. Fewer stems and shorter height of trees may increase the number of weedings which can result in increased cultivation costs.

In addition, costs are also increased by the expenses of protection measures against browsing damage which in case of the cheaper chemical treatment, depending on seedling height and number of stems, for every single treatment (over 4 years, annually 1-1 treatment) amounts to 3,500-7,000 HUF per hectare. In such a case the forest manager would need to consider whether this expanse is returned with the earlier closing time which in turn reduces costs that would be associated with a longer cultivation period. In this study we found that the later closing time due to browsing by ungulates results in an increased number of weedings and higher cultivation costs.

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References

Béky, A. (1981): Mag eredetű kocsánytalantölgyesek fatermése. [Tree crops of seed germinated turkey oak – sessile oak forests.] Erdészeti Kutatások, 74: 309-320. (in Hungarian)

Béky, A. (ed.) (1989): A tölgy termesztése és hasznosítása. [Growing and utilization of oak.] Mezőgazdasági Kiadó, Budapest (in Hungarian)

Bergstrom, R. – Skarpe, C. – Danell, K. (2000): Plant responses and herbivory following simulated browsing and stem cutting of *Combretum apiculatum*. Journal of Vegetation Science, 11: 409-414.

Canham, C. D. – McAninch, J. B. – Wood, D. W. (1994): Effects of the frequency, timing, and intensity of simulated browsing on growth and mortality of the tree seedlings. Canadian Journal of Forest Research. 24(4): 817-825.

Čermák, P. – Horsák, P. – Špirík, M. – Mrkva, R. (2009): Relationship between browsing damage and woody species dominance. Journal of Forest Science, 55(1): 23-31.

Coté, S. D. – Rooney, T. P. – Tremblay, J. P. – Dussault, C. – Waller, D. M. (2004): Ecological impacts of deer overabundance. Annual Review of Ecology, Evolution, and Systematics, 35: 113-147.

Danell, K. – Niemel, Ä. P. – Varvikko, T. – Vuorisalo, T. (1991): Moose browsing on scots pine along a gradient of plant productivity. Ecology, 72(5): 1624-1633.

Didion, M. – Kupferschmid, A. D. – Bugmann, H. (2009): Long-term effects of ungulate browsing on forest composition and structure. Forest Ecology and Management, 2585: 544-555.

Eiberle, K. (1975): Ergebnisse einer Simulation des Wildverbisses durch den Triebschnitt. Schweiz. Z. Forstwesen, 126(11): 821-839.

Fekete, Z. (1951): Erdőbecsléstan a faállományszerkezettan és a faterméstan vázlatával. [The science of forest estimation by the aid of forest stand structure and forest crop draft.]. Akadémiai Kiadó, Budapest (in Hungarian)

Gill, R. M. A. (1992): A review of damage by mammals in North Temperate forests: 3. Impact on trees and forests. Forestry, 74(3): 209-218.

Gill, R. M. A. – Beardall, V. (2001): The impact of deer on woodlands: the effects of browsing and seed dispersal on vegetation structure and composition. Forestry, 74: 209-218.

Hammer, R. (2001): The effect of plant competition and simulated summer browsing by deer on tree regeneration. Journal of Applied Ecology. 38: 1094-1103.

Hjältén, J. (1999): Willow response onto pruning: the effect of plant growth, survival and susceptibility to leaf gallers. Ecoscience, 6: 62-67.

Hjältén, J. – Price, P. V. (1996): The effect of pruning on willow growth and sawfly population densities. Oikos, 77: 549-555.

Hobbs, N. T. (1996): Modifications of ecosystems by ungulates. Journal of Wildlife Management, 60(4): 695-713.

Hoogester, J. – Karlsson, P. S. (1992): Effects of defoliation on radial stem growth and photosynthesis in the mountain birch (*Betula pubescens ssp. Tortuosa*). Functional Ecology, 6: 317-323.

Horsley, S. B. – Stout, S. L. – deCalesta, D. S. (2003): White-tailed deer impact on the vegetation dynamics of a northern hardwood forest. Journal of Applied Ecology, 13: 98-118.

Jones, B. E. – Lile, D. F. – Tate, K. W. (2009): Effect of simulated browsing on aspen regeneration: implications for restoration. Rangeland Ecology and Management. 62: 557-563

Kinnaird, J. W. (1974): Effect of site conditions on the regeneration of birch (*Betula pendula* Roth and *B. pubescens* Ehrh.). Journal of Ecology. 62: 467-472.

Kullberg, Y. – Welander, N. T. (2003): Effects of simulated winter browsing and drought on growth of *Quercus robur* L. seedlings during establishment. Forest Ecology and Management. 173: 125-133.

Kumar, S. – Takeda, A. – Shibata, E. (2006): Effects of 13-year fencing on browsing by sika deer on seedlings on Mt. Ohdaigahara, central Japan. Journal of Forest Research, 11: 337-342.

Murányi, J. (1988): Az erdőművelés és az eredményszámítás néhány kapcsolata. [Relationships between silviculture and result calculations.] Erdészeti Lapok. 37(123)1: 3-8. (in Hungarian)

Náhlik, A. (2012): Nagyvadgazdálkodásunk helyzete és gondjai napjainkban. [State of our big game management and its difficulties today.] In: Faragó, S. – Fáczányi, Ö. (eds.): Régi dicsőségünk – a Magyar Tudományos Akadémia Erdészeti Bizottságának és az Országos Magyar Vadászkamara Kulturális Bizottságának tudományos konferenciája a Vadászati Világkiállítás 40. évfordulóján. Past Glory - Forestry Committee of the Hungarian Academy of Sciences and the Hungarian National Chamber of Hunters Cultural Committee's Scientific Conference of the World's Fair on the 40th anniversary.] Országos Magyar Vadászkamara, Budapest. p. 59-74. (in Hungarian)

Náhlik, A. – Tari, T. – Sándor, Gy. (2007): Az erdei vadkár keletkezésének okai és következményei. [Causes and consequences of wildlife caused forest damages.] A vadgazdálkodás időszerű kérdései VII. Vadkár: 12-39, Országos Magyar Vadászkamara, Budapest (in Hungarian)

Náhlik, A. – Walter-Illés, W. (1998): Die Einwirkung des Wildverbisses auf die Mortalität und das Höhenwachstum der Pflanzen verschiedener Baumarten – ein simuliertes Experiment. Beiträge zur Jagd- und Wildforschung, Halle/Saale, Deutschland, 23: 95-105

Olofsson, J. – Strengbom, J. (2000): Responses of galling invertebrates on *Salix lanata* to reindeer herbivory. Oikos, 91: 493-498.

Peinetti, H. R. – Menezes, R. S. C. (2001): Changes induced by elk browsing in the aboveground biomass production and distribution of willow (Salix monticola Bebb.): Their relationships with plant water, carbon, and nitrogen dynamics. Oecologia 127: 334-342.

Pepin, D. – Renaud, P. C. – Boscardin, Y. – Goulard, M. – Mallet, C. – Anglard, F. – Ballon, P. (2006): Relative impact of browsing by red deer on mixed coniferous and broad-leaved seedlings – An enclosure-based experiment. Forest Ecology and Management. 222: 302-313.

Pollanschütz, J. (1988): Ergebnisse aus Untersuchungen über die Auswirkungen simulierten Verbisses an Fichte. Zeitschrift des Tiroler Jagdverband, 40: 13-17.

Putman, R. J. (1996): Ungulates in temperate forest ecosystems: perspectives and recommendations for future research. Forest Ecology and management, 88(1-2): 205-214.

Reimoser, F. – Odermatt, O. – Roth, R. – Suchant, R. (1997): Die Beurteilung von Wildverbiß durch SOLL-IST-Vergleich. Allgemeine Forst- und Jagdzeitung. 168(11-12): 214-227.

Reimoser, F. – Armstrong, A. – Suchant, R. (1999): Measuring forest damage of ungulates: what should be considered. Forest Ecology and management. 120: 47-58.

Sali, E. (ed.) (1975: Az egyes termőhelytípusokon alkalmazható célállományok és azok várható növekedése. [Target species that may be utilized in various habitats and their prospective growth. Manuscript] Kézirat. Mezőgazdasági és Élelmezésügyi Minisztérium Erdőrendezési Főosztály, Budapest (in Hungarian)

Siegel, G. (1988): Auswirkungen von Triebrückschnitten auf das Wachstum junger Fichtenpflanzen. Österreischische Forstzeitung, 4: 59-61

Sopp, L. (1974): Fatömegszámítási táblázatok – fatermési táblázatokkal. [Wood weight calculation tables - with wood crop tables.] Mezőgazdasági Kiadó, Budapest (in Hungarian)

Van Hees, F. M. – Kuiters, L. A. T. – Slim, P. A. (1996): Growth and development of silver birch, pedunculate oak and beech as affected by deer browsing. Forest Ecology and Management, 88: 55-63.

Veperdi, G. (2002): Fatermékstan. [Tree crop studies.] Oktatási segédanyag, Sopron (in Hungarian)