Agroforest Syst (2008) 74:199–211
DOI 10.1007/s10457-008-9121-x

Sheep grazing in young oak *Quercus* spp. and ash *Fraxinus excelsior* plantations: vegetation control, seasonality and tree damage

P. M. McEvoy · J. H. McAdam

Received: 3 April 2007 / Accepted: 24 February 2008 / Published online: 21 March 2008

Abstract An experiment was carried out where sheep were grazed in temporary fenced paddocks at a stocking rate of 178 LSU ha^{-1} in a 5-year old broadleaf plantation of oak (*Quercus* spp.) and ash (*Fraxinus excelsior*) (1.5 m spacing) on fertile, former lowland pasture in Northern Ireland. The grazing regime was rotational and intensive, with two grazing periods of 5 days in February and October 2001. Results showed that a significant proportion of the rank herbage height was removed within the first 24 h of livestock introduction. Herbage biomass was reduced by approximately half after 5 days. Sward height in grazed plots remained significantly lower than control plots for over 6 months after cessation of grazing, whilst biomass remained significantly lower for over 4 months after cessation of grazing. No significant tree damage to either oak or ash was measured during the February grazing trial, however significant damage to the lateral branches of both oak and ash was observed in the October grazing trial. Leader damage did not occur on trees greater than 152 cm. Ash was more commonly browsed than oak. Annual height increment of both tree species was unaffected by grazing, but annual stem diameter increment was significantly reduced in both oak and ash in February grazed plots. Oak trees in both February and October grazed plots were found to have a significantly smaller annual increase in canopy diameter than those in control plots. Results are discussed with regard to practical implementation of controlled grazing in young broadleaf forestry plantations on fertile, lowland soils.

Keywords Silvopasture · Agroforestry · Tree damage · Vegetation control · Herbicide · Sheep · Grazing · Browsing

P. M. McEvoy (✉)
Agri-Environment Monitoring Unit, Department of Applied Plant Science, Queen's University Belfast, Belfast BT9 5PX, UK
e-mail: p.m.mcevoy@qub.ac.uk

J. H. McAdam
Applied Plant Science Division, Agri-Food and Biosciences Institute, Newforge Lane, Belfast BT9 5PX, UK

Introduction

Following the Second World War the need for a national timber resource in Britain was realised. Planting was forced onto infertile peatland because of the high prices paid for better land, with forestry policy tending towards fast-growing exotic species which were found to perform best on these poor soils. Such planting has caused considerable damage to key habitats and species (RSPB 2000). In recent years the Northern Ireland Forest Service has discouraged forest planting on raised and blanket bogs.

Current trends in tree planting favour slow-growing broadleaves which require fertile conditions. The introduction of grants and premia by the Government to the private sector in Britain i.e. the Woodland Grant Scheme (WGS) has vitalised interest in forestry among farmers and the choice of land available for tree planting has widened significantly. There is a considerable interest now in planting broadleaves on good quality lowland that was previously used for intensive pastoral agriculture. Future increases in forest cover are likely to come from such areas of converted farmland.

Forests established on intensively managed, species-poor grassland habitats can often increase site potential for wildlife as the variety of habitats increase. Forests in such areas also contribute to reductions in fertiliser and pesticide applications, as unlike modern agriculture, sustainable forests do not require large quantities of these chemicals on a continual basis. However herbicide applications are still required as ex-agricultural and improved grassland sites are normally much more fertile than the unimproved and marginal sites that have been the subject of forestry planting in the past and competition with established vegetation is a major establishment issue.

Competition by grasses and herbaceous weeds in young plantations can seriously reduce the survival and early growth of the trees and lead to an extended establishment period by competing for light, nutrients and water (Williamson and Lane 1989). Studies by Culleton and Bulfin (1992) found considerable amounts of apical bud death and dieback in young plantations with no weed control.

Herbicide treatments developed for use in conventional forestry situations may need to be repeatedly applied to control weeds in the establishment phase of plantations, and often need to be directed away from broad-leaved crop trees to prevent damage. High chemical and application costs, and perhaps more importantly, public concern about the environmental safety of pesticides and the advent of Sustainable Forest Management and the certification process (FSC) has substantially reduced the application of herbicides as a forest management tool (Sharrow et al. 1992; COFORD 2001). As a result, current research in forestry includes the need for socially acceptable alternatives to herbicides and an increased knowledge of vegetation management impacts on forest ecosystems (COFORD 2001). These alternatives must also be safe, environmentally sound; effective and economical (COFORD 2001).

One way of fulfilling all of the above requirements may be the use of livestock to graze the unwanted herbage as a form of biological control. Forest grazing has had a revival, following an initial interest in the 1970's (Adams 1975). This has most likely arisen from the research carried out on agroforestry systems since the early 1990's (Sibbald et al. 2001) in the UK.

Many silviculturalists are reluctant to support prescribed livestock grazing because of fears of browsing damage to young trees (Sharrow et al. 1992). However, this method of weed control in forest plantations has been successfully carried out in a number of countries including Greece (Papanastis et al. 1995), New Zealand (Breach 1986; Hansen 1986; Dale and Todd 1986; Brown 1986), the United States (Sharrow et al. 1992), Spain (Silva Pando and González-Hernández 1992; Silvo-Pando et al. 1998; Rigueiro-Rodríguez et al. 1997), Japan (Ide et al. 2001; Shibata 1970) and the Netherlands (Kuiters et al. 1996; Kuiters 1998). These systems differ from conventional agroforestry systems in which trees are incorporated into a livestock/pasture system, where the livestock forms the basis of the system. By contrast, in the forest grazing systems mentioned above, the livestock is used purely as a silvicultural tool, with the trees the principal component of the system. In order for such a system to be successful the benefits accrued from vegetation removal and associated effects must be greater than the negative effects inflicted on the tree crop. A summary of grazing effects is shown in Table 1.

Experimental aims

The aim of the experiment was to build on the findings of the literature, which has spanned over a wide geographical area and over a wide range of forest types, and attempt to apply these to a regime of grazing management in a young broadleaf plantation to ascertain if such management could be carried out commercially in a temperate system in Ireland. The investigation looked at the effects of grazing on sward height, biomass and botanical diversity, whilst measuring the effects on tree growth and damage. Other factors such as seasonality, stocking densities and grazing management were based on best practice suggested from previous findings.

Table 1 List of positive and negative effects of prescribed livestock grazing in forests

Desired effects of forest grazing	Negative impacts of forest grazing
Reduction in sward height	Browsing of shoots
Reduction in sward biomass	Bark stripping
Input of organic fertilizer	Extra fencing
Improved access	Increased stock management
Reduction in fire risk	Root trampling/soil compaction
Extra income	Increased observation of tree damage
Potential increase in tree growth	Increased sapling mortality
Reduction in chemical inputs	

Materials and methods

Site description

A suitable broadleaf plantation was identified with the assistance of the Forest Service, Northern Ireland. The site was located in Grogey Forest, approximately 4 miles from Fivemiletown, Co. Tyrone (54°19.4′ N, 7°21.0′ W) at an altitude of 130 m. The forest is managed and owned by the Northern Ireland Forest Service.

The site consisted of an area of ex-pasture land on surface water gleys. acquired by the Forest Service and planted with oak (*Quercus* sp.), ash (*Fraxinus excelsior*) and Sitka spruce (*Picea sitchensis*) in 1996. Broadleaf saplings (oak and ash) were planted at 4,000 stems per hectare (1.5 m spacing). The growing season generally spans from late April to early October.

The site was deer-fenced but evidence of frequent deer trespass was observed. Ground flora consisted of rank grass swards with creeping bent (*Agrostis stolonifera*) and Yorkshire fog (*Holcus lanatus*) dominant. Broadleaf weeds typical of pasture were common throughout. The site consists of clearly demarcated field parcels, with overgrown hedgerows, mature trees and derelict buildings still characteristic of the site.

Initial measurements

Initial tree heights, stem girths and canopy diameters were measured in summer 2001 in order to assess the age and size structure of the trees on the site before any experimental plots were set up. Fenced experimental plots of 30 × 30 m were set up in February 2002 (Fig. 1), with two plots in ash plantations and two in oak plantations. Plots were fenced into four 15 m × 15 m paddocks using four strands of electric fencing wire. Wooden fence posts were used at 7.5 m intervals to reinforce the fencing. Plots were fitted with gates, water buckets and feeding troughs. Half the paddocks were mob grazed in winter (February) pre-bud break and half in late autumn (October) pre-leaf fall, but post-seasonal growth in order to limit

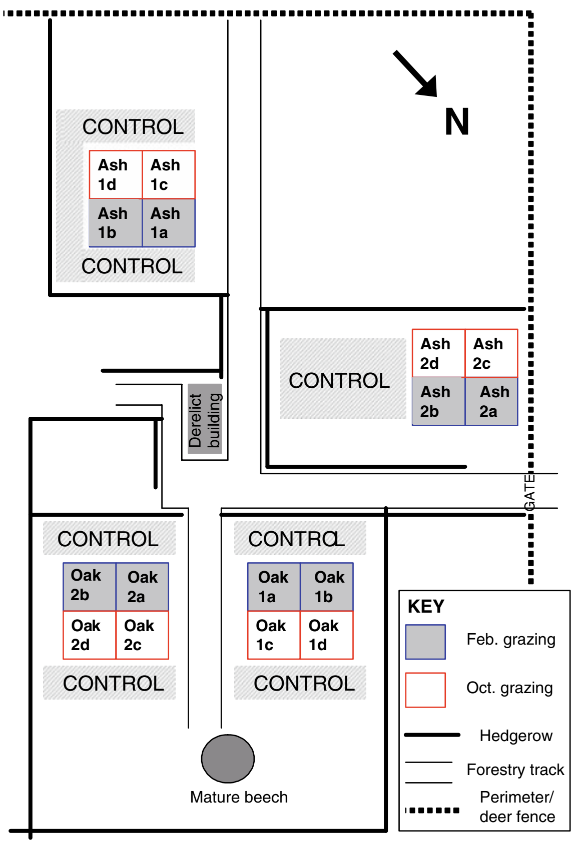


Fig. 1 Site map of grazing experiment detailing grazing plots, with subdivided paddocks, control plots and site features (Not to scale)

damage to saplings. A regular sample of 25 trees within each paddock were selected. Height, stem diameter, canopy diameter and a quantitative assessment of leader, lateral, bark and branch damage (scale of 0–5) were recorded. Trees were tagged to allow future measurements. Paired control plots were selected in areas adjacent to the paddocks and similar measurements carried out.

Livestock (Texel cross cull ewes) were provided from the Department of Agriculture farm at Loughgall, Co. Armagh. Four sheep were grazed for a period of five consecutive days in each paddock. This corresponded to a mob stocking density of 177.8 sheep ha^{-1}. Sheep were individually colour marked with marker paint so that behavioural observations could be attributed to individual sheep. Daily behavioural observations were made between 900 and 1,600 h at 15 min intervals, which included grazing, browsing, lying, ruminating, drinking and fraying (tree rubbing). Notes were made of any tree damage that had occurred. Water buckets were provided in each paddock. A small quantity of supplemental feed was given to the animals during the winter grazing experiment in accordance with their normal day to day management.

Daily sward height measurements (±0.5 cm) were taken at 40 random points in each paddock using an HFRO (Bartham 1986) sward height stick. Sward heights in control plots adjacent to the paddocks were taken at the start and finish of each grazing period. Repeat tree measurements were also taken at the end of each 5 day grazing period.

Biomass was assessed by clipping at the beginning and end of each grazing period. Two strips 1 m × 10 cm using Gardena Accu 6 battery clippers were cut in four random areas of each plot using a metal metre rule as a guide. Herbage samples were frozen and stored in the laboratory. Samples were weighed and a 150 g sub-sample sorted by species, weighed and dried at 80°C for 24 h until constant mass. Dry weight was then calculated for the full fresh weight and multiplied up to give a value of g DM m^{-2}.

Sward heights and clips were taken at intervals during the season following the experiment, in both paddocks and control areas in order to assess recovery of the sward height, biomass and species composition.

Tree measurements of the winter (February) grazed paddocks and controls were taken at the end of the following growing season (October) to assess the effects of removal of competitive vegetation and/or browsing on the tree height, stem, and canopy diameter growth. Similar measurements taken in October grazed plots were carried out in the following October. Crown diameter was taken as the mean of two measurements at the widest points on North–South and East–West crown axes.

Statistical analyses

Data were tested for normality using the Ryan-Joiner test and were log transformed (ln+1) for analysis. One-way ANOVA and Students t-test (Genstat 5; Lawes Agricultural Trust, 2000) were used to assess significance of effects of grazing on sward height, tree growth and damage. Results were compared between grazing season and tree species.

Results

Behavioural observations

'Grazing' was the most common behaviour observed (64%) during the time sheep were observed on the plots. A large proportion of time was spent 'lying' (25%). Forty four percent of this time animals were observed to be actively ruminating. The most obvious interaction with the trees involved 'fraying' (5%). This is classified as times when sheep were observed to rub their heads against the stem and branches of the saplings. No obvious differences were observed in behavioural effects between plots. Due to the nature of the observations, no statistical significance could be attributed to the results.

Sward height

Prior to grazing, swards in ash plots were significantly taller ($P < 0.05$) than those in oak plots (Figs. 2 and 3). Initial sward heights prior to February grazing were 12.1 cm (ash) and 10.42 cm (oak). Initial sward heights prior to October grazing were 14.7 cm (ash) and 11.6 cm (oak). No obvious signs of grazing were observed prior to experimental grazing. There was no significant difference ($P > 0.05$) in final sward heights (day 5) for all plots in both seasons, which were between 2 and 2.5 cm.

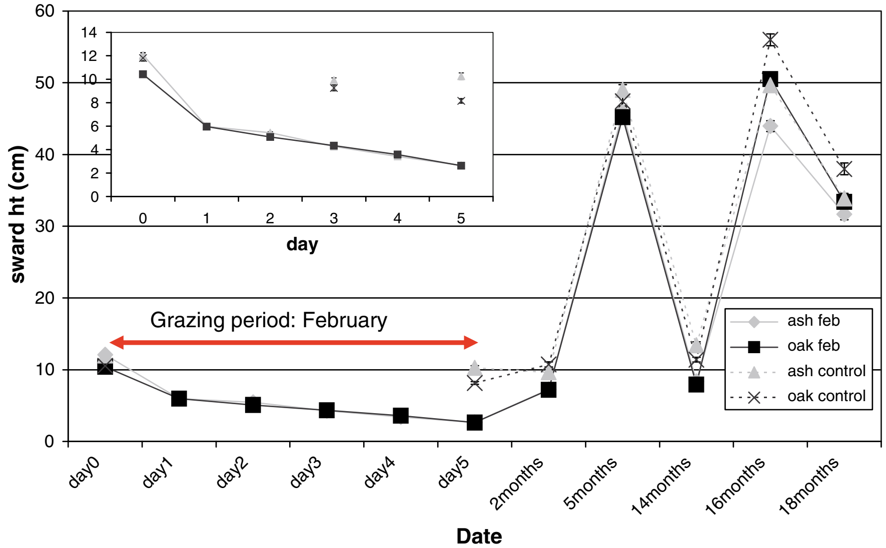


Fig. 2 Effects of grazing on sward height of 6 year old ash and oak plantations grazed for 5 days in February, with follow-up measurements on five occasions after grazing had ceased (±s.e.)

Swards experienced the greatest and most significant reduction in height during the first 24 h of grazing ($P < 0.01$), being approximately halved. A steady, linear, reduction in sward height was experienced for the remaining 4 days thereafter ($P < 0.01$).

Sward heights were found to remain significantly shorter in grazed plots compared to control areas for up to 6 months following grazing ($P < 0.01$) (Figs. 2 and 3). However the actual difference in height was less than 12%.

Sward biomass

Grazing significantly reduced sward biomass by over half (g DM m^{-2}) in grazed plots ($P < 0.01$) (Figs. 4 and 5). Initial sward biomass was similar in February and October grazed plots (>700 g DM m^{-2}). Sward biomass had almost fully recovered to that of the control plots 4 months after February grazing (oak $P > 0.05$; ash $P < 0.05$), whilst sward biomass had completely recovered 7 months after October grazing

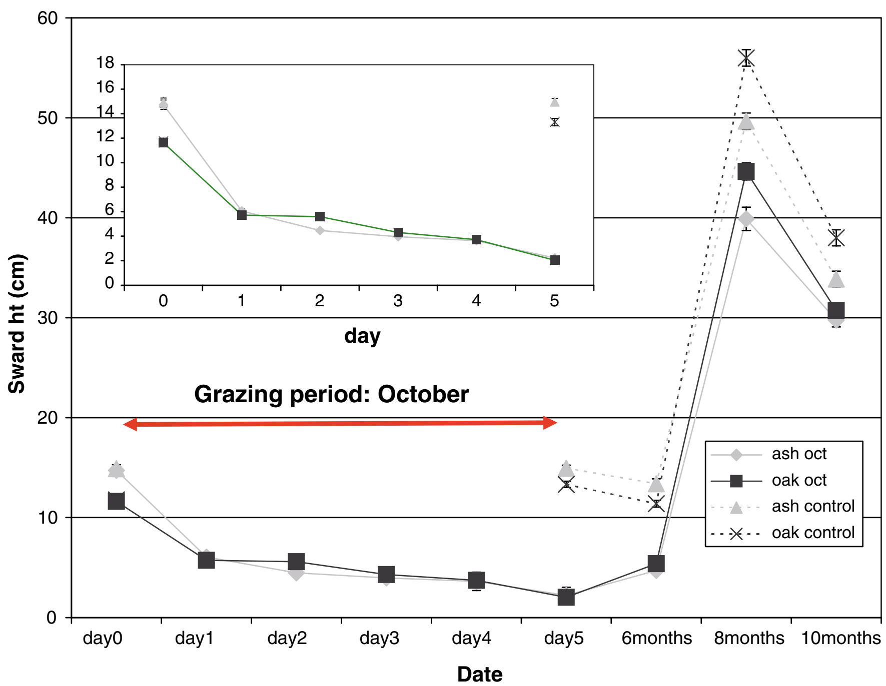


Fig. 3 Effects of grazing on sward height of 6 year-old ash and oak plantations grazed for 5 days in October, with follow-up measurements on three occasions after grazing had ceased (±s.e.)

Fig. 4 Effects of grazing on sward biomass (g DM m^{-2}) in oak and ash plots before and after a 5-day mob-stocking grazing trial in February (±s.e.). Two follow-up measurements are also displayed

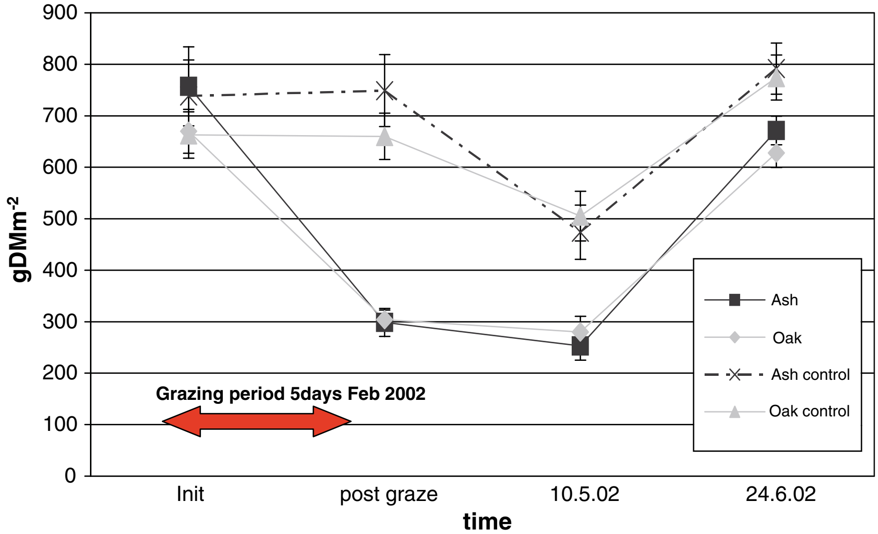
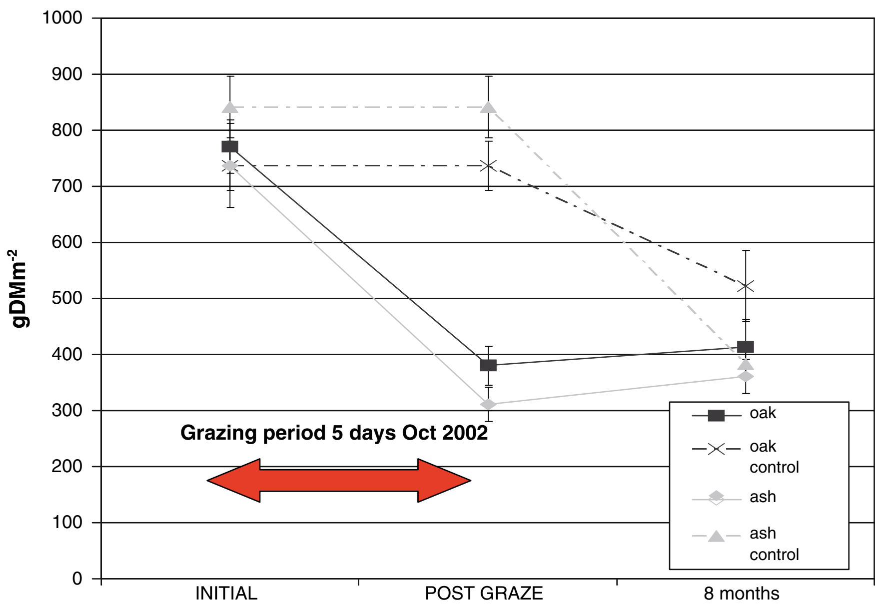


Fig. 5 Effects of grazing on sward biomass (g DM m^{-2}) in oak and ash plots before and after a 5-day mob-stocking grazing trial in October (±s.e.). One follow-up measurement is also displayed



($P > 0.05$). No data were collected between these measurements, so the actual time-scale of vegetation recovery is not known following October grazing.

Tree damage

No significant damage was observed to any of the four key areas (terminal leader, lateral leader, bark, branch) of either oak or ash in the February grazed plots ($P > 0.05$) (Figs. 6–9). Significant damage was observed to the branches of both oak and ash in the October grazed plots ($P < 0.01$) (Fig. 10a and b). Branch damage was the most common form of sapling damage for both oak and ash. Terminal leader damage only occurred on saplings less than 152 cm in height (Fig. 10c).

Tree growth

Tree growth was divided into three parameters; terminal leader height, stem diameter and average crown diameter. Grazing had no significant effect on

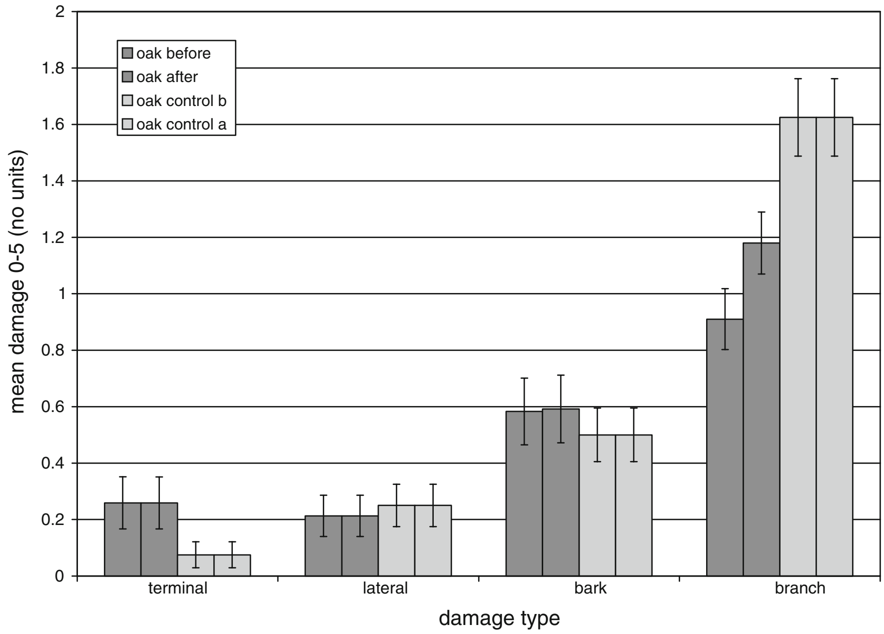


Fig. 6 Effect of sheep browsing damage to oak saplings before (deer damage) and after February sheep grazing (±s.e.)

annual height increase for either species, nor in either grazing season (Figs. 10 and 11) ($P > 0.05$) after one complete growing season.

Grazing was found to significantly reduce annual stem diameter increase (Fig. 10) in both ash and oak sapling in the February grazed plots ($P < 0.05$). No significant difference was observed between oak or ash stem diameter and control plots in the October (Fig. 11) grazed plots ($P > 0.05$).

Grazing was found to significantly reduce oak sapling canopy diameter in both the February and October grazed plots when compared to control plots ($P < 0.01$) (Figs. 10 and 11). Grazing had no effect on ash sapling canopy diameter ($P > 0.05$).

Discussion

Animal behaviour

Animals were not observed to spend a significant amount of time interacting with or browsing saplings. Fraying (the act of rubbing against the saplings, particularly with the head) is an activity that did not appear to have any observable effects on the saplings, but could damage twigs and smaller branches. Previous studies on animal/tree interactions in agroforestry systems have shown animals to spend significantly more time closer to trees than at the maximum distance from them (Sibbald et al. 1997). The high density of trees in the experimental plots (1.5 m spacing) meant that animals were always in close proximity to the trees. This made it difficult to ascertain animal preference towards the trees. However this close spacing is likely to provide good shelter.

Sward response

Swards in ash plots were significantly taller than those in oak plots. This was probably related to the reduction in irradiance experienced in the oak plots due to the greater canopy diameters.

Sward heights showed the most significant reduction during the initial 24 h grazing period, followed by a steady decline thereafter. This is likely to be related to the initial period of trampling of the sward, thereafter followed by a linear decline through reduction by grazing. Whilst sward heights in grazed plots were found to be significantly shorter than associated control plots for up to 6 months after grazing, relative differences in height were small with little appreciable reduction in competition between grasses and saplings likely. Sward heights appear to peak around June, which is linked with the period of

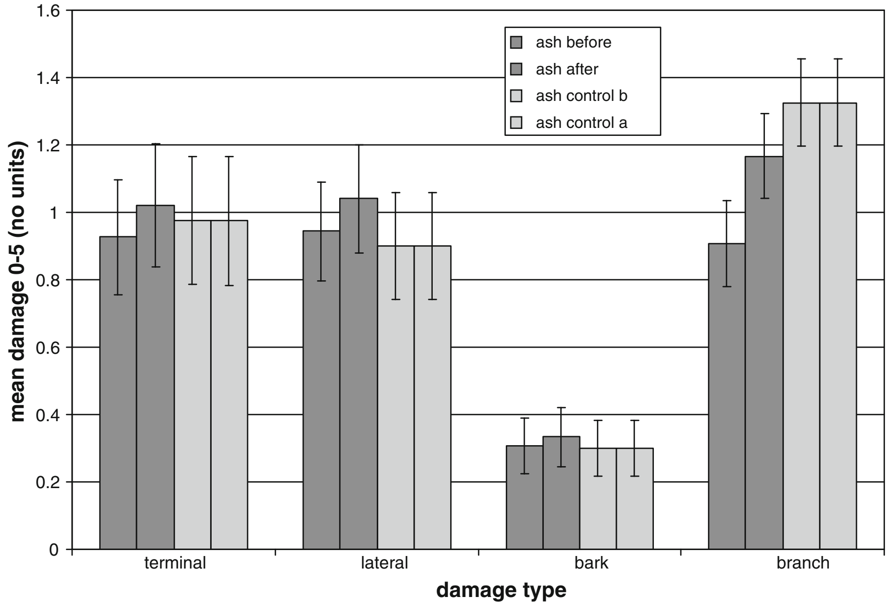


Fig. 7 Effect of sheep browsing damage to ash saplings before (deer damage) and after February sheep grazing experiment, (±s.e.)

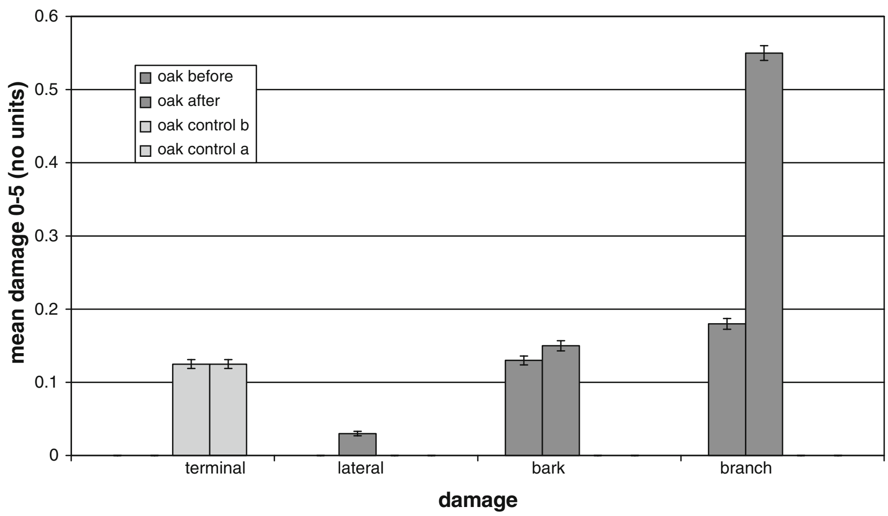


Fig. 8 Effect of sheep browsing damage to oak saplings before (deer damage) and after October sheep grazing (±s.e.)

inflorescence and maximum grass growth for many grass species. Grazing at this time, or shortly before may have the most significant impact in reducing competition between the sward and saplings. Further investigation would be required to validate this hypothesis, particularly as severity of sapling damage at this time of year in particular, is not known.

Despite sward height being reduced by over 70%, sward biomass was only reduced by approximately half. The resultant vegetation following grazing consisted mainly of unpalatable stems of Agrostis stolonifera. The combined effects of trampling and the creeping nature of this grass species would account for half the biomass being present in the first 2 cm of vegetation above ground level. This would also suggest that a shorter time spent grazing would prove to be more beneficial as the main effects of trampling occur in the first 24 h. Frequent mob stocking events of 24 h or thereabouts may provide the desired results whilst potentially reducing damage incurred to saplings, as damage may increase as the availability of preferred forage decreases (Hester et al. 1996).

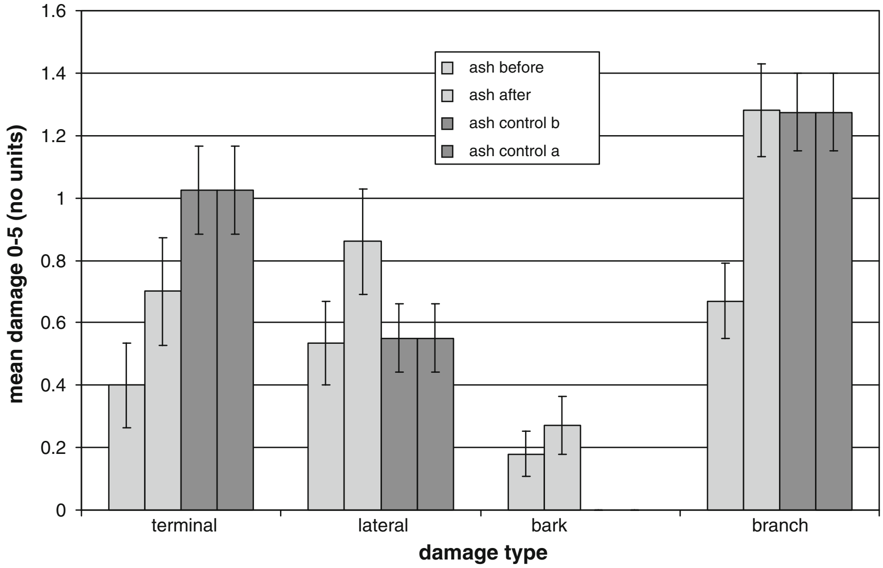


Fig. 9 Effect of sheep browsing damage to ash saplings before (deer damage) and after October sheep grazing trial (±s.e.)

Tree response

Damage to saplings by sheep was generally no more observable than the 'background' damage caused by deer. The most common form of damage was the removal of small branches. It is not thought that this would have any impact on tree growth or subsequent tree form or timber quality. The differences between sapling damage between plots at the beginning of the experiment highlights the unevenness of deer browsing across the site. No deer browsing damage was observed in the control plots during the experiment, suggesting that the presence of sheep and humans on the site discouraged deer from feeding in the area.

Sheep-inflicted damage was more severe in October grazed plots than February grazed plots, therefore suggesting that early spring is a better time of year to carry out forest grazing management.

The cut-off height at which terminal leader browsing ceases is an important factor in managing woodland grazing systems, as this is perhaps the most critical form of damage that would impact on sapling growth, form and timber quality (Rindt 1965). If grazing were to be used for weed control it would be desirable to initiate grazing at the earliest opportunity in the rotation. It would not be practical to exclude stock until saplings were above 152 cm, as the need for control of competing vegetation is required long before this.

However, this knowledge could be used in the management of semi-natural woodlands where some livestock grazing is desirable, but saplings are at risk from browsing.

Results would suggest that grazing in February (pre-growing season) has more of a negative effect on the saplings than grazing in October (post growing-season) due to the reduction in stem diameter increase observed for both oak and ash saplings. Sharrow et al. (1992) also found radial growth to be more sensitive to browsing than tree height in Douglas fir. This would also appear to be the case for both oak and ash. Crown diameters of oak were also significantly reduced in both the February and October grazing trials. Ash was not significantly affected despite being browsed more frequently than oak. This is most likely due to the growth pattern of both species. Ash tends to have strong apical dominance with few branches, whilst oak has a broad canopy consisting of many minor branches. At the time of experiment the oak saplings were approaching canopy closure therefore sheep were more likely to push past branches, potentially causing more damage. Such reduction in branch growth is unlikely to have any negative impact on tree growth, form or timber quality. Removal of branches could improve the timber quality as a form of pruning. More research could be carried out to assess the effectiveness of browsing on improving tree form.

Sapling height and stem diameter are the most important growth parameters as these will affect timber volume. A grazing regime following the end of the growing season appears to have little effect on

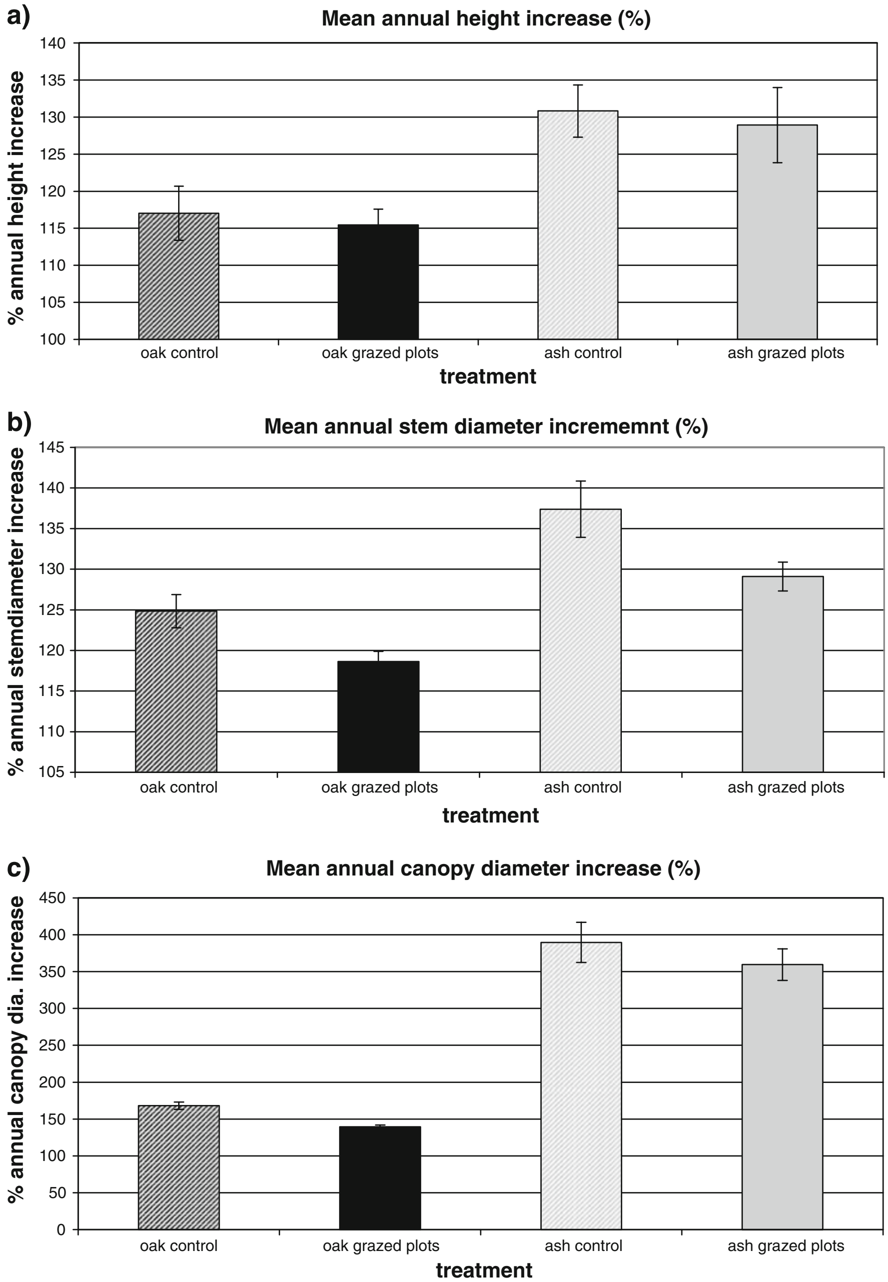


Fig. 10 Effect of grazing on (**a**) mean annual height (**b**) stem and (**c**) canopy diameter increase of saplings in the growing season following February grazing (±s.e.)

tree growth, despite more damage occurring to trees at this time. Grazing pre bud-break would appear to have more of a negative impact on annual stem diameter increase in late season growth.

Conclusion

Results from this trial indicate that grazing of sheep in young broadleaf plantations can fulfil the requirements of rank grass control without causing a significant amount of damage to the trees. A number of practical considerations must be noted if such a forest management system is to become successful and widely adopted in Ireland.

1. Trees should have the leader out of range of browse height (>150 cm for the sheep used in this trial). This can be a problem as the most need for weed control is in the early years. A

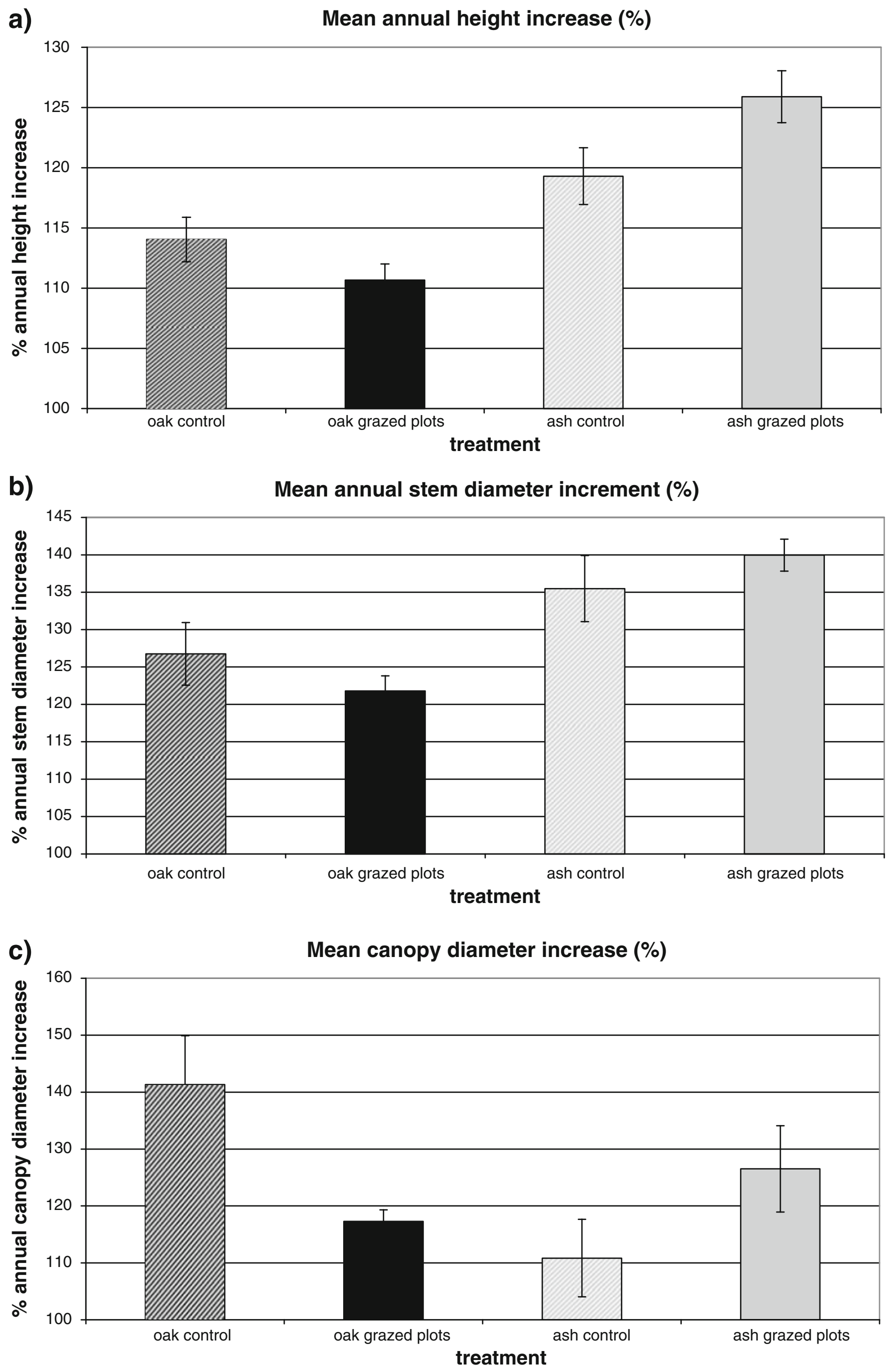


Fig. 11 Effect of grazing on (**a**) mean annual height (**b**) stem and (**c**) canopy diameter increase of saplings in the growing season following October grazing (±s.e.)

further trial using newly planted saplings at a range of sapling heights should be instigated to assess the relationship between severity of browsing and sapling height. Alternately larger saplings could be planted if financially viable. The balance between the extra establishment expense and the benefits accrued from weed control could be further researched.

2. Despite the fact that ash is more prone to browsing damage than oak, reduced growth was

not observed compared to oak. This may be due to compensatory growth (Hester et al. 1996; Mitchell 1991).

3. Sapling damage was more severe in October than February grazed plots. The trees may have higher N content at this time of year. Further chemical work should be carried out to assess the comparative differences in palatability of ash and oak throughout the year. This should be referenced against the palatability of the associated grasses growing in the sward as variations in forage quality are also likely to occur throughout the year.
4. Despite the increased damage in late season grazing, lower growth rates were observed in trees that had been part of February grazing trials. No obvious explanation of this exists at present, but the most likely cause is soil compaction and trampling damage around the roots.
5. Sward heights were observed to be reduced significantly in the first 24 h, with a steady (linear) decline each day afterwards. This is most likely attributed to the effects of trampling. The mechanical effects of trampling may be just as effective as grazing in reducing the height and vigour of competing vegetation. If this is the case then regular mob-stocking for 24 h or less may provide the desired results, in addition to adding fertilizer via dung and urine. There will also be less risk of tree damage if livestock is removed from the plantation before quality forage becomes limited.
6. If reduction in vegetation bulk is required then mob stocking for a short period of time (i.e. 5–10 days) would seem to be the best management practice, as both sward height and biomass are reduced quickly and animals have little time to get acquainted with the presence of trees. Sward height stays significantly lower than control plots for many months following grazing, however sward heights do increase rapidly following removal of grazers. Frequent mob-stocking throughout the year, even if for short periods of time may elicit an increase in sapling growth as cumulative effects of sward removal will reduce competition much more than one episode such as that used in the experiment. Longer periods of grazing would encourage poaching and patches of bare ground which could improve colonisation of new species and tree seedling establishment.
7. The reduction in oak canopy diameters caused by browsing does not significantly affect tree growth. However, the effects on form may have an positive impact on the final quality of the tree by increasing the pruning of lateral branches and increasing apical dominance. It may also have the effect of reducing the shading from canopy closure, thus increasing the period of time that weeds, particularly light-requiring vigorous grasses are able to compete with the trees.
8. If deer are present in the area and inflicting damage to the saplings, the presence of sheep and reduction in vegetation through grazing may discourage the deer from frequenting the area by removing palatable forage and creating regular disturbance. This may reduce the overall damage to saplings in the plantation assuming that deer are responsible for a significant proportion of the damage. Further investigation is required to assess the degree of facilitation between herbivore species.
9. In order for such grazing management to be practical, a number of points must be considered. Mob stocking for a short period of time is likely to give best results as sheep may 'learn' to browse if allowed extensive access. Semi-natural features, such as native woodland, streams, ponds etc. should be fenced to prevent overgrazing. Daily observation is required to ensure stock welfare, inspect tree damage and check sward height/quality. Supplementary feed and water should be provided. Such factors would prevent grazing management on some sites, due to their vastness, secludedness and lack of intensive day-to-day management. Acquiring stock, either to loan or to buy is likely to be deemed too complicated by state forestry enterprises. This type of management however, will suit farm woodland plantations, particularly those which were planted in field parcels and are already stockproof (grants are paid for fencing of new woodlands in agri-environment schemes) and have ready access to livestock.
10. Many new broad-leaved plantations are planted on land which was previously used as pasture, and in many cases whole farms have been bought up and planted. Forestry practice is less intensive than agriculture and as a result wildlife can flourish in the many features that are retained on the site, such as hedgerows, mature trees, streams

and other semi-natural habitats. There is also the danger that over time these features will become overgrown by scrub, or out-shaded by the trees in the plantation. These areas should remain unplanted and grazing could be used to restore species-rich grassland and other habitats that require some form of management.

Acknowledgements The authors would like to thank the following: Forest Service (DARDNI) for their assistance in finding a suitable experimental site and permitting the grazing of livestock on their lands. Ian Dodds, Farm Manager of DARDNI Manor Farm (NIHPBS, Loughgall) for provision, transportation and welfare of livestock. Staff in Ecology and Land Use, Applied Plant Science Division for assistance with fieldwork.

References

Adams SN (1975) Sheep and cattle in forests: a review. J Appl Ecol 12:143–152
Barthram GT (1986) Experimental techniques: the HFRO sward stick. Hill Farming Research Organisation, Biennial Report 1984–1985, pp 29–30
Breach T (1986) Bracken fern control with livestock: Te Wera Forest. Agroforestry Symposium Proceedings, FRI Bulletin No. 139, pp 76–84
Brown PC (1986) Grazing in Kaingaroa forest: the Goudies project. Agroforestry Symposium Proceedings, FRI Bulletin No. 139, pp 104–111
COFORD (2001) Annual report. University College, Dublin
Culleton N, Bulfin M (1992) Effects of weed and grass control on the establishment of *Fraxinus excelsior* L. Irish Forest 49:55–60
Dale RW, Todd AC (1986) Using cattle to control Pampas grass in Maramarua and Waiuku forests. Agroforestry Symposium Proceedings, FRI Research Bulletin No. 139, pp 95–103
Hansen JA (1986) Experience in the use of livestock to control gorse in Ashley forest. Agroforestry Symposium Proceedings, FRI Bulletin No. 139, pp 85–94
Hester AJ, Mitchell FJG, Kirby K (1996) Effects of season and intensity of sheep grazing on tree regeneration in a British upland woodland. For Ecol Manage 88:99–106
Ide Y, Miyashige T, Sato S, Shijimaya K (2001) Grazing in secondary forest developed on abandoned field in southwestern Japan 1. Characteristics of cattle tracks formed in secondary forest. Grassl Sci 47:134–138
Kuiters L (1998) Ungulates and forest management in the Netherlands. In: Humphrey J, Gill R, Claridge J (eds) Grazing as a management tool in European Forest Ecosystems. Forestry Commission, Edinburgh, pp 11–19
Kuiters AT, Mohren GMJ, Van Wieren SE (1996) Ungulates in temperate forest ecosystems. For Ecol Manage 88:1–5
Mitchell FJG (1991) Grazing in upland woodlands. NCC/MLURI Contract No. HF3-03-319. English Nature, Peterborough
Papanastis V, Koukora Z, Alifragus D, Makedos I (1995) Effects of thinning, fertilisation and sheep grazing on the understorey vegetation of Pinus pinaster plantations. For Ecol Manage 77:181–189
Rigueiro-Rodríguez A, Silva-Pando FJ, Rodríguez-Soalleiro R, Castillón-Palomeque PA, Álvarez-Álvarez P, Mosquera-Losada R, Romero-Franco R, González-Fernández MP (1997) Manual de sistemas silvopastorales ADAPT. Santiago de Compostela
Rindt CA (1965) A silviculturalist look at grass and grazing effects on Ponderosa pine. Proc Soc Am Foresters 1964:69–70
RSPB (2000) Irelands forested future: a plan for forestry and the environment. RSPB, Sandy Bedfordshire
Sharrow SH, Leininger WC, Osman KA (1992) Sheep grazing effects on coastal Douglas fir forest growth: a ten-year perspective. For Ecol Manage 50:75–84
Shibata Y (1970) The effect of grazing cows on young birch afforestation. Annu Rep For Exp Stn Hokkaido 1969: 108–121
Sibbald AR, Dick J, Jason G (1997) Grazing behaviour of sheep under larch saplings planted at wide spacings. In: Trees for Shelter. Forestry Commission Technical Paper 21, Edinburgh
Sibbald AR, Eason WR, McAdam JH, Hislop AM (2001) The establishment phase of a silvopastoral national network experiment in the UK. Agroforest Syst 53:39–53
Silva-Pando FJ, González-Hernández MP (1992) Agroforestry helps prevent forest fires. Agroforest Today 4:7–8
Silva-Pando FJ, Gonzalez-Hernanadez MP, Rigueiro-Rodríguez A, Rozados-Lorenzo MJ, Prunell A (1998) Grazing livestock under pinewood and eucalyptus forests in northwest Spain. Agroforest Forum 9:36–43
Williamson DR, Lane PB (1989) The use of herbicides in the forest Forestry Commission. Edinburgh