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Tree and livestock productivity in relation to tree planting configuration in a silvopastoral system in North Wales, UK

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Abstract

Silvopastoral systems in Europe offer the potential of introducing environmental benefits while at the same time increasing the diversity of farm outputs. The establishment of new silvopastoral systems by planting young trees into existing pasture was investigated at a site in North Wales, UK. Two tree species, sycamore (*Acer pseudoplatanus* L.) and red alder (*Alnus rubra* Bong.), were planted into pasture at a range of densities and planting arrangements. Growth of trees planted in farm woodland blocks (2500 stems ha^{-1}) was compared with the growth of trees planted at 400 stems ha^{-1} in clumps and dispersed throughout the plot and at 100 stems ha^{-1} (dispersed). Over the first six years after planting, alder trees were significantly taller and larger in diameter than sycamore. Sycamore trees planted at close spacing in farm woodland or clumped arrangements were significantly larger in diameter than widely spaced sycamore at 100 and 400 stems ha^{-1}. Livestock productivity was unaffected by the presence of trees during the six-year establishment phase of the system. The planting of trees in a clumped pattern appears to combine silvicultural benefits to tree growth with agricultural benefits of maintaining livestock production while trees are established.

Introduction

Although there is an ancient tradition of wood pasture systems in temperate Europe (Rackham 1980), trees and hedgerows have been progressively removed from farmlands for most of this century in a drive to increase the efficiency of agricultural production per unit of land and labour (Dupraz and Newman 1997). In the UK, this has been coupled with forest establishment occurring largely as conifer plantations in upland areas marginal for agriculture. Priorities are now changing in Europe, reflected in the reform of the Common Agricultural Policy leading to the removal of incentives to produce surplus agricultural products, the imposition of production quotas and the introduction of incentives to remove land from agricultural production altogether and to invest in farm woodland establishment. In the UK there has also been a shift from the traditional establishment of exotic conifers in the uplands towards the re-establishment of broad-leaved woodland in the lowlands using native species (Coates 1999). This has been accompanied by an interest in new woodlands for wildlife conservation, especially where they may mitigate fragmentation of existing tree cover (Kirby et al. 1999) and in the scenic and recreational value of trees. In Wales, response to shifts in European land use policy has led to the introduction of a national 'agrienvironment' scheme that attempts to reconcile productive and environmentally protective functions in the countryside (Griffiths 1999). Increasing tree cover on farms may, therefore, play a key role in sustaining and diversifying farm productivity (Sibbald 1999), the provision of wildlife habitat (Burgess 1999), and, because trees may root more deeply than agricultural plants (Sinclair 1999), the reduction of nitrate and phosphate pollution from farmland that may seriously upset the ecological balance of rivers and estuaries (Balls et al. 1995).

While silvopastoral systems still occur in northern Europe, for example in parklands and orchards where animals graze amongst widely spaced mature trees, establishing new systems by low density planting of broad-leaved trees into grazed pasture poses a number of challenges. Trees have to be protected against animal damage and managed so that quality timber is produced from a high proportion of the few trees that are planted. The cost of establishment is heavily dependent on planting density and arrangement and the form of individual trees may be influenced by their proximity to other trees. The presence of trees may have both positive impacts on the productivity of grazed pasture, through shelter effects (Sibbald et al. 1991), and negative impacts, through competition for light, water and nutrients (Sinclair et al. 2000). The balance amongst these interactions and their time course may be manipulated by choice of tree species and planting density and configuration. The research reported here investigates the impact of choice of tree species, planting density and planting arrangement on tree growth and the productivity of sheep grazing the understorey pasture during a six-year establishment phase of a silvopastoral system in lowland Britain.

Materials and methods

Experimental site

The experimental site is one of a national network of six sites established across the country investigating the potential of silvopastoral agroforestry on UK farms (Sibbald and Sinclair 1990). It was established in 1992 on 14 ha of agricultural land at the University of Wales, Bangor farm (Henfaes), which is located in Abergwyngregyn, Gwynedd, 12 km east of the city of Bangor. The climate is Hyperoceanic, with an annual rainfall of about 1000 mm. Data on climatic variables is collected on site with a Campbell Automatic Weather Station (Campbell Scientific Ltd, Shepshed, UK). The soil is a fine loamy brown earth over gravel (Rheidol series) classified as a Dystric Cambisol in the FAO system. The parent material consists of postglacial alluvial deposits from the Aber river, comprising Snowdonian rhyolitic tuffs and lavas, microdiorites and dolerite in the stone fractions and Lower Paleozoic shale in the finer fractions (Teklehaimanot and Sinclair 1993). Topography consists of a shallow slope on a deltaic fan of approximately 1–2° and the aspect is northwesterly, at an altitude of 4–14 m above sea level. The depth of the water table ranges between 1 and 6 m (Teklehaimanot and Sinclair 1993). The entire site was sown to a mixture of perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) in April 1992 at a seed rate of 12.5 kg ha^{-1} of *L. perenne* var. Talbot, 12.5 kg ha^{-1} of *L. perenne* var. Condessa, 2 kg ha^{-1} of *T. repens* var. Gwenda and 2 kg ha^{-1} of *T. repens* var. S184.

The network sites have a common set of core treatments described by Sibbald and Sinclair (1990). These comprise sycamore (*Acer pseudoplatanus* L.) planted at 100 and 400 stems ha^{-1} into grazed pasture and at 2500 stems ha^{-1} without grazing as a farm woodland control, and pasture without trees as an agricultural control (Sibbald et al. 2001). Farm woodland plots were managed according to normal forestry practice for farm woodlands in the UK (Hibberd 1988) and are therefore equivalent to farming system controls *sensu* Dupraz (1999), in as much as normal recommended practice for farmers was applied but implemented on a research site owned and managed by the University of Wales rather than by a farmer. The size of the farm woodland control plots (0.1 ha) is the smallest area of trees defined as small woods in the UK Forestry Commission National Inventory of Woodland and Trees (Wright 1998). There are three additional treatments at the Henfaes site: red alder (*Alnus rubra* Bong.) planted at 400 stems ha^{-1} into grazed pasture and at 2500 stems ha^{-1} without grazing as a farm woodland control, and, sycamore planted at an overall density of 400 stems ha^{-1} but in clumps (described below) rather than as individual trees (Figure 1). Treatments are replicated three times in a complete randomised block design. Water table varies across the site and blocks were identified so that plots in each block had similar water table depth. Blocks were defined and mapped and allocation of treatments within blocks was done by ordering the treatments in a random sequence and then working from the south-eastern corner of each block demarcating the treatment plots on a field plan. Orientations of individual plots were adjusted to fit with field boundaries and to avoid a gas pipeline running under the site. All grazed plots, except those planted with alder (see below), receive standard fertilization for productive pasture at 160 kg N ha^{-1} a^{-1}. All grazed plots are managed according to the network protocol (Sibbald et al. 2001) and are grazed from spring until autumn by a core group of Welsh Mountain ewes with

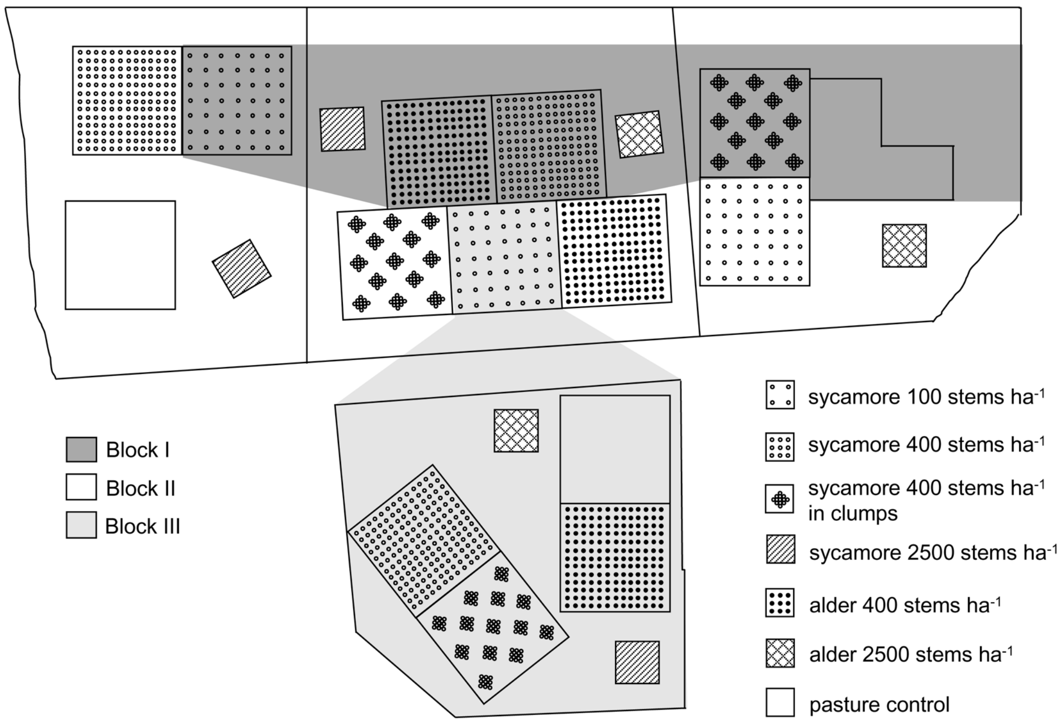

Figure 1. Diagram showing layout of silvopastoral experiment at Henfaes farm, North Wales, UK. Plot size is 0.42 ha except woodland control plots, which are 0.10 ha.

single lambs (12 ewes ha^{-1}) with additional stock from a buffer flock added or removed to maintain a threshold sward height of 5 cm.

The clump treatment was introduced at Henfaes to investigate an alternative planting pattern to widely spaced individuals dispersed throughout fields. Clumps have several potential advantages in terms of production and environmental impact over individual tree planting. The cost of tree protection may be lower for clumps than for individually protected trees. Within clumps it is possible to select high quality trees, as is done in conventional forestry, by progressive thinning to leave a small number of final crop trees in each clump. Furthermore, shading amongst trees within the clump may have silvicultural benefits of enhancing tree height growth and self pruning and in exposed conditions the outer trees may shelter inner trees. From an environmental perspective, a micro-woodland habitat may be created in the clump with a richer wildlife value than that associated with single trees in fields. From a landscape perspective, clumps resemble copses, which are a traditional feature in the UK countryside. Copses were historically dense groups of coppiced trees or bushes, many of which have subsequently grown into larger groups of trees in fields after coppicing ceased.

Each clump comprised 13 trees and there were 31 clumps ha^{-1} with approximately 20 m between clump centres. The term clump refers to a group of trees and has been variously applied in forestry. What are termed clumps at Henfaes fall within the definition of groups of trees in the UK Forestry Commission National Inventory of Woodland and Trees (Wright 1998), distinguishable from individual trees on the one hand and small woods on the other.

The widely spaced trees were protected against sheep browsing using 4 m of stock-proof fence around each individual tree whereas clumps only required 24 m of fence surrounding the entire clump, equivalent to 1.8 m $tree^{-1}$, less than half of what was required for individual tree protection. Trees within clumps were planted in a diamond pattern, 1.5 m apart, with the fence a further 1.5 m from the outer trees.

Red alder was also introduced at Henfaes to investigate the use of biological nitrogen fixation as an alternative to chemical fertilizer. This could have on-farm economic advantages by reducing fertilizer costs and, if part of an organic production system, by attracting price premiums, as well as environmental benefits brought about by reduction in the amount of N leached. Red alder was chosen because it grows rapidly when young, can tolerate wet sites and produces a wide range of quality wood products (McIver 1991). Alder was managed at the site on a low input basis (no inorganic N was applied), to encourage biological nitrogen fixation associated with the alder and with clover in the pasture.

The trees were planted in November 1992 in pits 30 cm in diameter by 30 cm deep, with 1 m^2 of black polythene mulch laid around each tree to control weeds and a spiral guard added for rabbit protection. Seedlings of both species were obtained from the Forestry Commission nursery at the Northern Research Station, Bush Estate, Roslin, Midlothian, UK. The alder was a North Pacific USA provenance and was inoculated with *Frankia* spp. at the nursery. The sycamore was of UK origin. Any dead trees were replaced on an annual basis for the first three years after planting.

Data collection and analysis

Tree height and diameter (at 20 cm stem height) were measured on a core group of 25 trees in the centre of each plot at the time of planting and at the end of each growing season thereafter for six years. For trees in clumps, two trees from the central five were sampled from each of the 13 clumps in a plot.

Each year the ewes and lambs were moved to the experimental plots in spring (March/April); the lambs were subsequently removed in July (at weaning) while the ewes continued to graze until autumn (September/October). The exact timing of commencement and termination of grazing was decided each year in relation to climatic factors and pasture availability. The ewes and lambs were weighed every month. These data were then used to calculate the annual livestock carrying capacity in tonne-days ha^{-1} a^{-1} that reflects the overall productivity of the grazed pasture and the average liveweight gain in g day^{-1} ha^{-1} for the core lambs, a measure of livestock performance. Animal and tree growth data were analysed using a repeated measures approach with split plot in time ANOVA, where treatment is considered the main plot factor and year the subplot factor. Mean plot values were used in the analyses of tree data. Within plot coefficients of variation ranged from 11–40% for diameter, and 9–38% for height. Comparisons between treatment means were made using planned contrasts and differences were generally considered significant at $P < 0.05$, unless otherwise indicated. All analyses were carried out using Genstat (1996). Tree height and diameter were $\log_{10}$ transformed before analysis because of non-normal distribution.

Results

Overall tree survival to the end of the 1998 growing season was very high (91.8%), with no significant differences amongst treatments. Over the six-year measurement period as a whole, alder trees at both spacings were significantly larger in height and diameter than sycamore ($P < 0.001$; Figure 2). For sycamore, trees planted at farm woodland density (2500 stems ha^{-1}) and at close spacing within clumps were significantly larger in diameter than the more widely spaced agroforestry trees (400 and 100 stems ha^{-1}; $P = 0.018$). In alder, trees planted at woodland density were not significantly larger in diameter than agroforestry trees at $P < 0.05$ but were at $P < 0.1$ (actual P value 0.073).

Treatment differences in increment in tree height and diameter followed similar trends (Figure 3). Alder trees at both spacings had larger mean height ($P = 0.003$) and diameter ($P < 0.001$) increments over the measurement period than sycamore trees. Alder trees planted at farm woodland density had higher height increment than alder trees growing at agroforestry spacing ($P = 0.014$). There was a significant decline in diameter increment in alder trees at 2500 stems ha^{-1} in 1997–1998 (Figure 3b)), which was not evident in trees in any of the other treatments, but is commensurate with the onset of canopy closure in this treatment. Trees in all treatments except sycamore 100 and 400 stems ha^{-1} showed a significantly lower height increment in 1997–1998 than in 1996–1997 (Figure 3a).

There was no significant difference between treatments in either livestock carrying capacity or individual lamb growth rate (Figure 4). There were, however, significant differences between years. The highest carrying capacity was achieved in 1993 and the lowest in 1995, which had a very dry summer (total April–August rainfall in 1995 was 152 mm, compared with the 1993–1998 mean of 309 mm). The highest rate of lamb growth was also achieved in 1993, consistent with the high carrying capacity. The high lamb growth rate in 1995 is not directly comparable to the other years because lambs were weaned

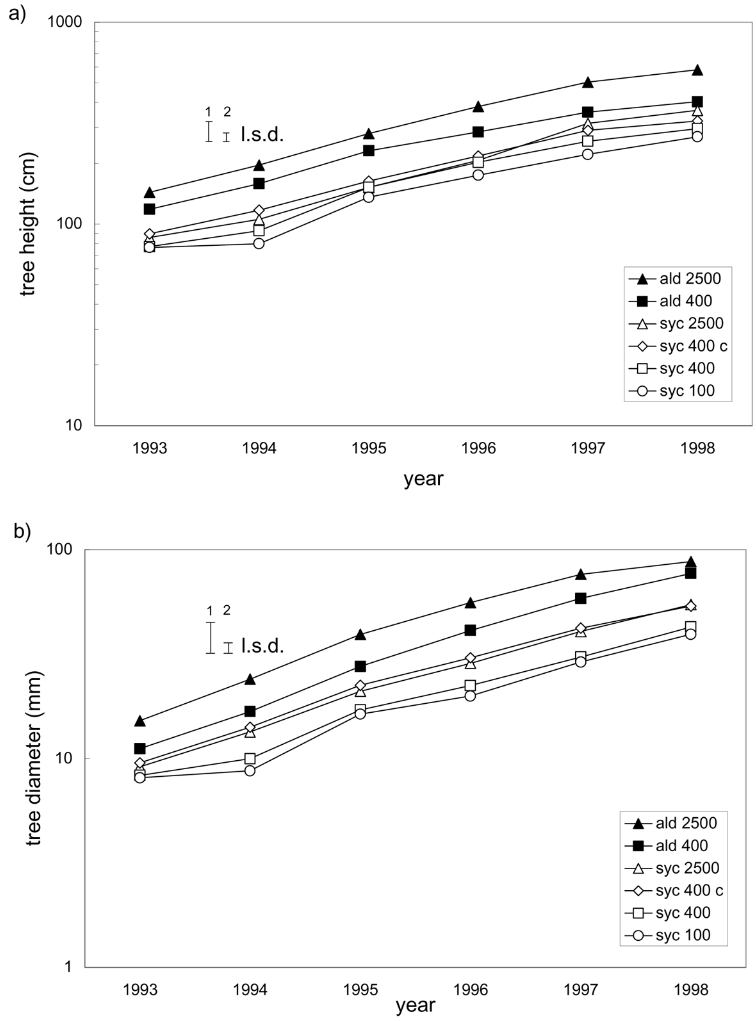

Figure 2. Mean tree height (a) and diameter (b) from 1993 to 1998 in a silvopastoral experiment in North Wales. L.s.d. = [1]least significant difference between means of any treatment × year combination at $P < 0.05$; [2]least significant difference between yearly means of same treatment at $P < 0.05$; ald 2500 = alder planted at 2500 stems ha^{-1}; ald 400 = alder planted at 400 stems ha^{-1}; syc 2500 = sycamore planted at 2500 stems ha^{-1}; syc 400 c = sycamore planted in clumps to give an overall spacing of 400 stems ha^{-1}; syc 400 = sycamore planted at 400 stems ha^{-1}; syc 100 = sycamore planted at 100 stems ha^{-1}.

early (in June) because dry weather had severely reduced pasture availability and stock had, therefore, to be removed from plots.

Discussion

It is clear from the high tree survival and reasonable growth rates in all treatments that trees can be established in grazed pasture in lowland Britain without affecting livestock production for at least the first six years. This has important implications because it means, on the one hand, that farmers do not lose annual agricultural income from the land under agroforestry during the establishment period, but on the other, that this type of agroforestry may not necessarily contribute to short-term reductions in surplus agricultural production in Europe as had once been thought (Sheldrick and Auclair 2000). It is also clear that the choice of tree species and planting pattern affect the initial growth of the trees but not the productivity of livestock grazing on the understorey pasture.

Growth of individual trees at wide spacing was generally slower than in woodland control plots for both tree species, which could have been caused by greater exposure of widely spaced trees (Green et al.

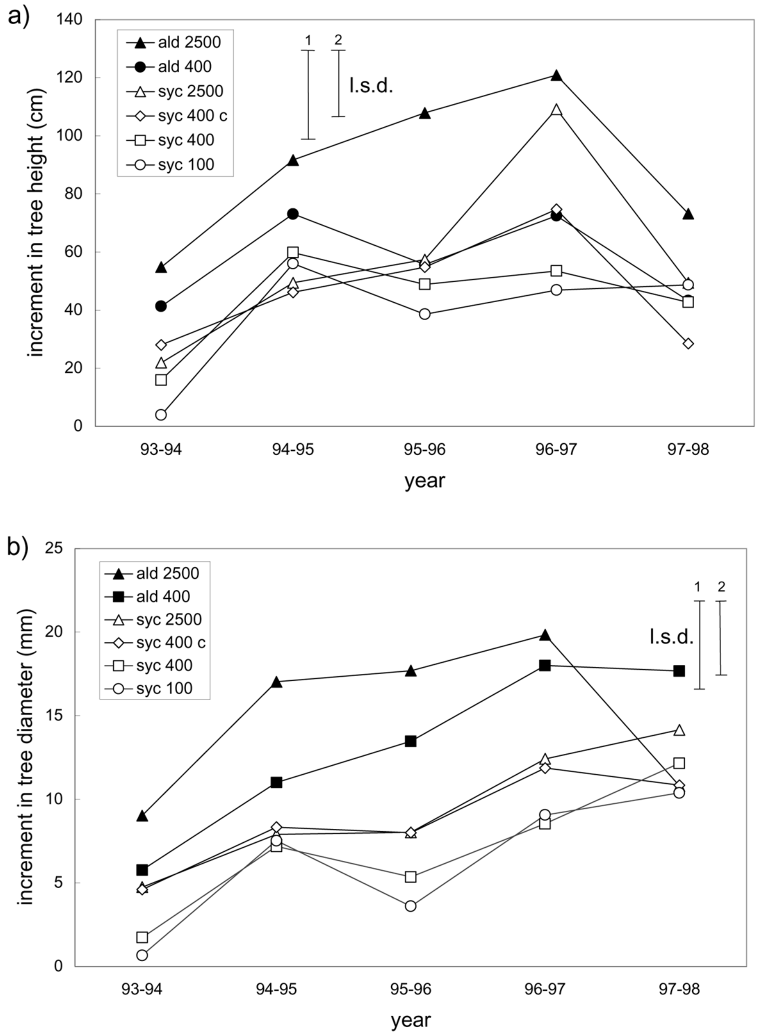

Figure 3. Mean annual increment in tree height (a) and diameter (b) from 1993 to 1998 in a silvopastoral experiment in North Wales. L.s.d. = [1]least significant difference between means of any treatment × year combination at $P < 0.05$; [2]least significant difference between yearly means of same treatment at $P < 0.05$; ald 2500 = alder planted at 2500 stems ha^{-1}; ald 400 = alder planted at 400 stems ha^{-1}; syc 2500 = sycamore planted at 2500 stems ha^{-1}; syc 400 c = sycamore planted in clumps to give an overall spacing of 400 stems ha^{-1}; syc 400 = sycamore planted at 400 stems ha^{-1}; syc 100 = sycamore planted at 100 stems ha^{-1}.

1995), competition from the sward for water and nutrients (Campbell et al. 1994), or the effects of animals, either through browsing or soil compaction (Bezkorowajnyj et al. 1993). It should be noted that only central trees in the farm woodland controls were measured, representative of sheltered trees in woodland blocks. The ratio of sheltered to edge trees in woods on farms will vary depending upon the size and shape of woodlands, affecting the magnitude of the difference in tree performance for woods over individual trees. While the polythene mulch would have reduced sward competition in the beginning, the tree roots would be expected to extend beyond the mulched area (50 cm from the tree base) within the first growing season and pasture roots may ingress. Animals, especially small lambs that were able to put their heads through the wire netting, caused some browsing damage, leading to reinforcement of the fencing around individual trees with smaller gauge mesh after the second growing season. Similar reductions in initial tree growth at higher animal:tree ratios have been reported from other UK sites (Sibbald et al. 2001). However, the lower growth of trees at wide spacing than in woodland controls observed here con-

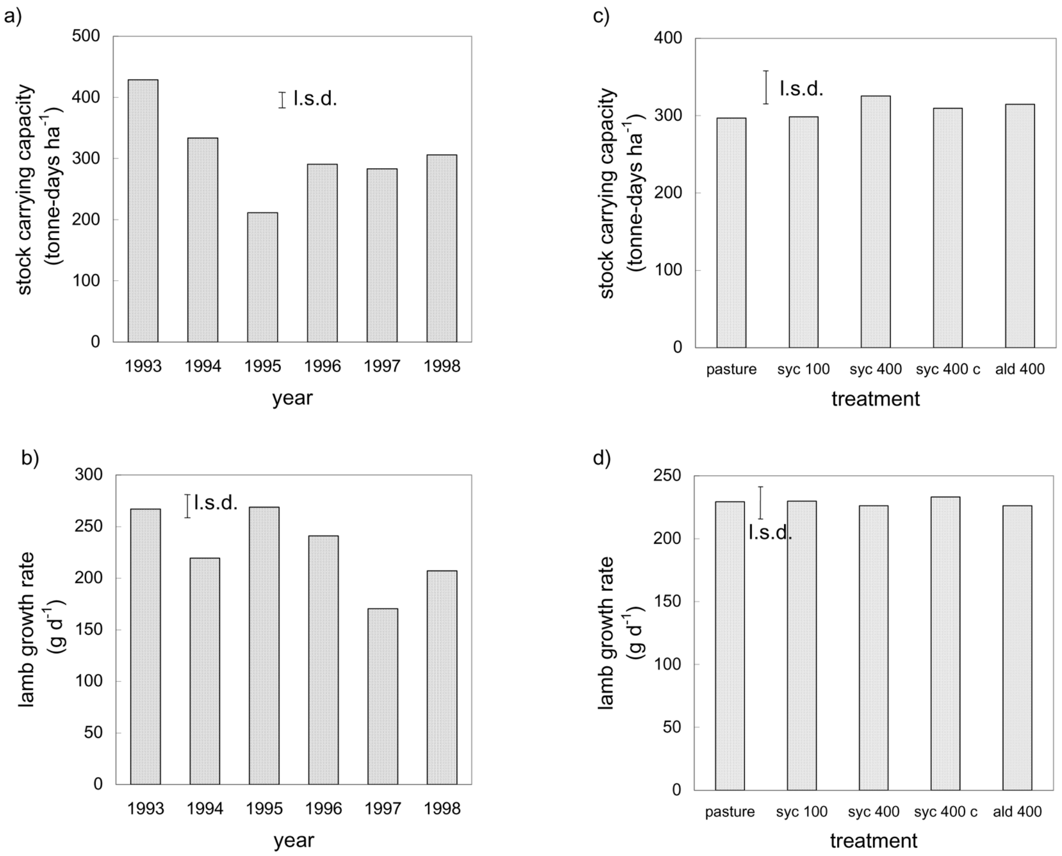

Figure 4. (a) mean stock carrying capacity of sheep and (b) lamb growth rate from 1993 to 1998 in a silvopastoral experiment in North Wales. (c) and (d) show treatment means of stock carrying capacity and lamb growth rate respectively, averaged over the six years. L.s.d. = least significant difference between means at $P < 0.05$.

trasts with other European research (Balandier and Dupraz 1999; Sibbald et al. 2001) where agroforestry trees were protected by tree shelters and compared with forestry control trees which were not. This suggests that the enhanced height growth in agroforestry measured at other UK sites (Sibbald et al. 2001) is caused by the tree shelters promoting height growth (Tuley 1982; Dupraz 1997), rather than being a result of biotic interactions (Anderson and Sinclair 1993).

Planting sycamore trees in small clumps rather than as individuals resulted in silvicultural advantages due to the proximity of other trees within the clump at the same time as agroforestry advantages of permitting grazing between the clumps. The clumps required less than half the cost of tree protection of individual trees but initial tree growth was not significantly different from the woodland control and livestock productivity was not significantly different from the agricultural control. In this experiment we used elaborate protection of individual trees, whereas tree shelters have been used elsewhere in the UK (Sibbald et al. 2001). While use of individual shelters would remove the difference in cost between dispersed trees and clumps, shelters have not proved effective long-term protection. They have resulted in inappropriate stem development in conifers and have deteriorated rapidly under stock pressure and so have had to be replaced after two to three years with plastic netting at high labour and material cost (Beaton and Hislop 2000). It is intended that four final crop trees will remain per clump as a result of progressive thinning, giving a final density of 124 trees ha^{-1}, which is lower than the 400 trees ha^{-1} in the 5 m × 5 m dispersed tree planting, although this could also be progressively thinned. The timing of thinning will depend upon the future growth of the trees which is difficult to predict in agricultural conditions which are much more fertile than woodland sites for which growth data already exist. Together with other potential environmental and aesthetic advantages of planting trees in small clumps, and the possibility of selection of final crop trees, this planting pattern, which is not replicated at other UK network sites, merits further attention.

The two tree species performed differently. Initial growth of alder was much higher than sycamore. Sycamore grew faster at close spacing than as individual trees and there was some evidence ($P = 0.073$) that alder also grew faster in the woodland control than as individual trees in grazed pasture. The higher growth rates of alder than sycamore are particularly significant given that no nitrogen fertilizer was applied to the alder plots and the pasture was as productive on these unfertilized plots as those receiving 160 kg of N ha^{-1} a^{-1}. This could either be because soil N is not limiting plant productivity on the site or that biological nitrogen fixation is substituting for applied inorganic N fertilizer. The alder at the site is nodulated, and both alder and clover at the site have been demonstrated to be actively fixing N (Teklehaimanot and Martin 1998) although the amount of N they fix at a field scale has not been quantified. The height of sycamore was at the low end of the range of observations of sycamore growing at a number of sites in France (Balandier and Dupraz 1999), but taller than the mean of sycamore growing at the other UK sites in the silvopastoral national network experiment (Sibbald et al. 2001). However, height values were similar to those at Loughgall, the other lowland site in the silvopastoral national network experiment.

The lack of significant difference in lamb growth rate and livestock carrying capacity between treatments indicates that either the trees are not yet large enough to compete significantly with the pasture for light, water and nutrients or that negative effects of competition are mitigated by positive effects of shelter. The lack of significant differences is particularly indicative of some positive interaction since carrying capacity is related to the total area of the plot but addition of trees results in some area of pasture being eliminated (1% for trees at 100 stems ha^{-1}; 4% for trees at 400 stems ha^{-1} and 11% for clumps). Conifers at wide spacing in the UK uplands have been shown to reduce wind speeds (Green et al. 1995), providing significant shelter to livestock (McArthur 1991) and to buffer spring and autumn temperatures extending the growing season of pasture (Sibbald et al. 1991). While the broad-leaved trees used in the present research shed their leaves in winter, the site is exposed and experiences high winds throughout the year, and the trees are in leaf for much of the grazing season. The much higher carrying capacity and lamb growth rate during the first year (1993) was possibly because of the residual effects of the high level of fertilization applied to the site for crop production prior to the establishment of the present experiment. The remaining differences from year to year are explainable by different weather conditions. The very low level of carrying capacity during the third year was caused by an unusually dry period in the summer of 1995, as a result of which animals had to be removed from plots as there was not enough grass. The anomalous high rate of lamb growth in this year occurs because lambs achieve their maximum growth rate early in the growing season (April–June) and then their liveweight gain starts to decline and they are usually weaned by the end of July. However, in 1995 they were weaned early in June so that only their early growth occurred on the experimental plots.

Conclusion

Broad-leaved trees were established in grazed pasture in lowland Britain without reducing livestock productivity in the first six years of tree growth, for tree planting densities up to 400 trees ha^{-1} regardless of the planting pattern and species. The growth of widely-spaced individual sycamore trees was lower than in conventional farm woodland plantings but planting sycamore trees in small clumps reduced tree protection costs and combined the benefits for tree growth of a woodland habitat within the clump with the agroforestry benefits of being able to graze, and so obtain agricultural income, between the clumps of trees.

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