Production in wooded hay meadows

I. Austad¹, L. N. Hamre¹, K. Rydgren¹ & A. Norderhaug²

¹Faculty of Science, Sogn og Fjordane University College, Sogndal, Norway
²The Norwegian Crop Research Institute, Kvithamar, Stjørdal, Norway

Abstract

Production in the field layer of a wooded hay meadow in Sogn, Western Norway, was studied by comparing two sites, one in active use and the other abandoned since 1975. We also studied how production in the field layer varied with the composition of the vegetation and the influence of trees, and the extent to which production from the trees (foliage) contributed to total production in the hay meadow. Production in the field layer was significantly higher at the site in active use than at the abandoned site, despite the annual removal of hay from the former. Field layer production was lowest nearest the tree trunk and increased significantly with increasing distance from the trunk at both sites. Production was also significantly related to vegetation gradients (as revealed by ordination analyses). We estimated the average annual production in the field layer at the site in active use to be 582 g/m². This is high production compared with production in other meadow types, especially given that wooded hay meadows receive little or no manure/fertilizer. In a wooded hay meadow in active use, the deciduous trees also contribute to production, producing an average of 9.5 dry foliage/tree/year through pollarding. Thus, our production accounts for the wooded hay meadow indicate that this was and still can be a viable economic alternative for the farmer provided that he cut the trees regularly and used the foliage as fodder.
1 Introduction

The wooded hay meadow is a semi-natural vegetation type that has been widespread and common throughout history in many parts of the world [1,2]. A combination of pollarding (every 4-8 years), annual grazing (in spring and autumn) and hay-making (in summer) provided farmers with pasture, various types of winter fodder (grass, foliage and twigs), firewood and material for tools [3]. In earlier times, fodder from the tree layer was of crucial importance for farmers, especially in countries with a long winter season [3,4]. Nevertheless, hay was the most important yield from wooded hay meadows. A wooded hay meadow in active use has a characteristic small-scale pattern of open meadow and areas with scattered pollarded trees [1,5]. The wooded hay meadow is probably one of the few semi-natural vegetation types in the Nordic countries that has been possible to harvest intensively of hundreds of years without manuring [6]. In contrast, an open hay meadow that is harvested year after year will experience a gradual decrease in production unless it is not fertilized. To increase production in open hay meadows they can be set aside for some years before being used again [7,8]. In spite of the importance of wooded hay meadows as a production system, little is known about the level of production in the field and tree layers, and how production is influenced when a wooded hay meadow is abandoned. We also know little about how production in the field layer is related to the influence of trees and to variations in the vegetation.

The aim of this study is to evaluate production in both the field layer and the tree layer of a wooded hay meadow, and to answer the following questions: (1) How does the level of production in an abandoned wooded hay meadow compare with production in a wooded hay meadow in active use? (2) To what extent does field layer production in a wooded hay meadow vary with the composition of the vegetation and with the influence of trees? (3) To what extent do trees (through pollarding to harvest foliage) contribute to total production in a hay meadow?

2 Material and methods

2.1 Study area

The study area is located on the northern side of the Sognefjorden in Leikanger municipality, Western Norway (61°11'N, 6°45'E), and belongs to the southern boreal vegetation zone and to the slightly oceanic section [9]. The terrain in the area slopes 31° to 43° towards the east, and the meadows are situated at 100–125 m above sea level. The surficial deposits are glaciﬂuvial delta deposits, consisting of gravel and sand as well as silt and clay. The study area comprises a wooded hay meadow that has been continuously used at least since 1874 [5], and consists of the two sites 1 and 2 [5]. At site 1, traditional active use was resumed in 1992 after a 12–20 year period without any pollarding and mowing, while site 2 has been abandoned and only sporadically grazed since 1975 (see [5] for further details).
Traditionally, these hay meadows were lightly manured with sheep dung every third year, and grazed by sheep for 4-5 weeks in early spring (April-May) and 4-6 weeks from the middle of September. Because of the spring grazing, haymaking was delayed until the end of July or beginning of August. The hay was cut only once each summer, and dried on the ground or on hay racks. Pollarding was usually done in mid-August, but it could be continued throughout the autumn as long as the trees bore foliage. The trees were pollarded in 4- to 8-year cycles. Both sites have been left unfertilized since 1991.

2.2 Sampling design

In order to investigate variations in productivity and vegetation in sites 1 and 2, each site was represented by 9 closed transects, each containing 14 sample plots (0.5 m x 0.5 m), giving a total of 18 transects and 252 sample plots. Six of the transects in each site ran from the trunk of a pollarded tree and 7 m out into open meadow (these are called tree-transects), to enable us to relate production to distance from the tree trunk, i.e. the influence of the tree. The other three transects (called open meadow transects) were marked out in open sections of the wooded hay meadows, in order to measure production in parts of the meadow not influenced by trees. The tree layer in the wooded hay meadows was formed by several species, and *Fraxinus excelsior*, *Ulmus glabra* and *Salix caprea* were all used in the tree transects. The transects were located where they would not be “influenced” by other tree crowns.

2.3 Production measurements and recording of vegetation

Hay production was measured in each of the 252 sample plots. The field layer was cut with shears (4-6 cm above ground), collected in bags, dried for 32 hours in a drying cupboard at 60°C, and then weighed. The production measurements were made at the end of July.

Three pollarded trees in site 1 (two *Ulmus glabra* and one *Fraxinus excelsior*) were used to measure production in the tree layer (from March 1993 to July 1998). Growth in the trunk and the underground biomass (roots) was not measured. All the branches were cut 5 cm above the last trace of pollarding and weighed. Foliage/bunches of twigs (approximately 1 m long), branches and wood were weighed separately.

The percentage cover of all vascular plant taxa and bare soil was estimated in each of the 252 sample plots.

Three small areas in site 1 were fenced in to prevent grazing so that we could estimate the biomass (in dry weight) consumed by sheep in spring and autumn. One of the areas was located below a tree crown and two were located in the open meadow. Hay production was measured in the same way as production in the sample plots (see above).
2.4 Statistical analysis

Ordination was performed by detrended correspondence analysis (DCA; [10]) using CANOCO, Version 4.0 [11]. Prior to ordination, the weight given to species whose frequency was below the median level was reduced by making their weight proportional to their frequency [12]. Two sample plots were omitted because they acted as outliers. DCA was used with detrending by segments and non-linear rescaling as recommended by Knox [13]. Weighting of each matrix element was performed by use of the power function [14]:

\[ y_{ij} = f(x_{ij}) = ax^{W_{ij}} \]

where \( x_{ij} \) is the abundance of the species \( i \) in sample \( j \), \( w \) is the weighting parameter, \( a \) is a ranging scalar, and \( y_{ij} \) the weighted abundance. Using a percentage cover scale (0-100) with 1 as the lowest value for occurrence, the range \( r \) of the scale (i.e. the ratio between the highest and lowest value) is [14]:

\[ r(w) = 100^w \]

We used \( w = 0.602 \) (\( r = 16 \)) in our ordinations.

The relationship between production and vegetation variation was analysed by calculating Kendall’s rank correlation coefficient (\( \tau \)).

To test for differences between the two sites in average field layer production, we performed a randomisation test where we re-sampled with replacement from the dataset of 126 production values within each site, and calculated new average production values. We then compared the new pairs of average production values pairs for the two sites, and calculated a \( p \) value as \( (s + 1)/(n + 1) \), where \( s \) is the number of simulations for which production of site 1 \( \leq \) site 2 and \( n \) (we used \( n = 999 \)) is the total number of simulations [15].

To test for any influence of trees on production in the field layer, we performed a linear regression analysis of sample plots from the tree transects with production as the dependent variable and distance from the tree trunk as the independent variable for each site separately. Because there was spatial autocorrelation [16] between sample plots in the same transect we used a randomisation test to find the significance level. We randomised the production values between sample plots within each site without replacement, and then calculated \( r \), which was used as the test statistics. A \( p \) value for the test was calculated as \( (s + 1)/(n + 1) \), where \( s \) is the number of simulations for which \( r_{\text{observed}} \leq r_{\text{simulated}} \) and \( n \) (we used \( n = 999 \)) is the total number of simulations [15].

2.5 Nomenclature

The nomenclature of vascular plants follows Lid and Lid [17]. *Geum*, *Galeopsis* and *Alchemilla* were only identified to genera.
3 Results

3.1 Production and vegetation variation

Production in the field layer in site 1 (268 g/m²) was significantly higher (P < 0.001) than production in site 2 (189 g/m²), the abandoned part of the wooded hay meadow. There were rather large differences in vegetation composition between the two sites as shown by the separation of sample plots along the main vegetation gradient, DCA axis 1 (fig. 1). Several species were confined to one of the sites, the commonest being *Holcus lanatus* (site 1) and *Geranium sylvaticum* (site 2) (table 1).

In site 1, production was lowest in sample plots nearest the tree trunks (fig. 2a), and increased significantly (P = 0.001) with increasing distance from them. In the outermost sample plots production resembled that in open meadow (fig. 2a, b). Production also varied significantly (τ = -0.516, P < 0.001, n = 124) along the main vegetation gradient, DCA axis 1 (fig. 3a).

Production was highest in sample plots with a dense field layer (mostly open meadow sample plots). These plots usually had a high cover (≥ 20%) of one or several of the following species: *Agrostis capillaris, Anthriscus sylvestris, Filipendula ulmaria, Lathyrus pratensis* and *Trifolium medium*. Sample plots where production was low had a more open field layer and more open ground (sample plots nearest the tree trunk). *Dactylis glomerata* was usually among the species with highest cover in the low-productivity plots, although rarely exceeding ≥ 25%. Sometimes low-productivity plots had a high cover (≥ 20%) of species that occurred at low frequency in site 1 (cf. table 1), e.g. *Ulmus glabra* seedlings and *Urtica dioica*.

Figure 1: DCA plot of all sample plots in sites 1 and 2. Axes scaled in S.D. units.
Table 1: Constancy percentage and mean percentage cover (superscript) given for species occurring in >5% of the sample plots in at least one site.

<table>
<thead>
<tr>
<th>Species</th>
<th>Site 1</th>
<th>Site 2</th>
<th>Species</th>
<th>Site 1</th>
<th>Site 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achillea millefolium</td>
<td>7(^3)</td>
<td>6(^2)</td>
<td>Holcus lanatus</td>
<td>32(^2)</td>
<td>0</td>
</tr>
<tr>
<td>Agrostis capillaris</td>
<td>85(^{24})</td>
<td>100(^{24})</td>
<td>Hypericum maculatum</td>
<td>30(^3)</td>
<td>27(^{15})</td>
</tr>
<tr>
<td>Alchemilla spp.</td>
<td>13(^3)</td>
<td>4(^2)</td>
<td>Knautia arvensis</td>
<td>2(^3)</td>
<td>6(^7)</td>
</tr>
<tr>
<td>Angelica sylvestris</td>
<td>15(^6)</td>
<td>56(^8)</td>
<td>Lathyrus pratensis</td>
<td>40(^8)</td>
<td>10(^6)</td>
</tr>
<tr>
<td>Anthoxanthum odoratum</td>
<td>11(^7)</td>
<td>26(^7)</td>
<td>Myositis arvensis</td>
<td>21(^1)</td>
<td>3(^2)</td>
</tr>
<tr>
<td>Anthriscus sylvestris</td>
<td>98(^8)</td>
<td>84(^3)</td>
<td>Oxalis acetosella</td>
<td>25(^3)</td>
<td>80(^5)</td>
</tr>
<tr>
<td>Campanula rotundifolia</td>
<td>8(^1)</td>
<td>6(^3)</td>
<td>Phleum pratense</td>
<td>31(^8)</td>
<td>9(^4)</td>
</tr>
<tr>
<td>Cerastium fontanum</td>
<td>60(^2)</td>
<td>16(^2)</td>
<td>Poa pratensis</td>
<td>37(^3)</td>
<td>6(^3)</td>
</tr>
<tr>
<td>Dactylis glomerata</td>
<td>81(^{14})</td>
<td>97(^{23})</td>
<td>Poa trivialis</td>
<td>50(^4)</td>
<td>42(^3)</td>
</tr>
<tr>
<td>Deschampsia cespitosa</td>
<td>35(^{14})</td>
<td>42(^{17})</td>
<td>Potentilla erecta</td>
<td>7(^1)</td>
<td>7(^6)</td>
</tr>
<tr>
<td>Deschampsia flexuosa</td>
<td>0</td>
<td>7(^9)</td>
<td>Ranunculus acris</td>
<td>81(^1)</td>
<td>73(^2)</td>
</tr>
<tr>
<td>Epilobium montanum</td>
<td>6(^2)</td>
<td>10(^2)</td>
<td>Rumex acetosa</td>
<td>80(^3)</td>
<td>89(^2)</td>
</tr>
<tr>
<td>Festuca pratensis</td>
<td>17(^7)</td>
<td>34(^5)</td>
<td>Stellaria graminea</td>
<td>38(^3)</td>
<td>11(^3)</td>
</tr>
<tr>
<td>Festuca rubra</td>
<td>66(^4)</td>
<td>75(^{13})</td>
<td>Taraxacum vulgaris</td>
<td>21(^1)</td>
<td>2(^1)</td>
</tr>
<tr>
<td>Filipendula ulmaria</td>
<td>18(^{10})</td>
<td>28(^{13})</td>
<td>Trifolium medium</td>
<td>56(^{40})</td>
<td>21(^{10})</td>
</tr>
<tr>
<td>Fraxinus excelsior</td>
<td>5(^1)</td>
<td>52(^2)</td>
<td>Trifolium pratense</td>
<td>41(^1)</td>
<td>8(^2)</td>
</tr>
<tr>
<td>Galeopsis spp.</td>
<td>4(^2)</td>
<td>10(^2)</td>
<td>Trifolium repens</td>
<td>30(^3)</td>
<td>3(^3)</td>
</tr>
<tr>
<td>Galium aparine</td>
<td>17(^2)</td>
<td>23(^3)</td>
<td>Urtica dioica</td>
<td>7(^10)</td>
<td>6(^7)</td>
</tr>
<tr>
<td>Galium boreale</td>
<td>0</td>
<td>15(^2)</td>
<td>Valeriana sambucifolia</td>
<td>22(^3)</td>
<td>56(^5)</td>
</tr>
<tr>
<td>Galium spurium</td>
<td>0</td>
<td>13(^2)</td>
<td>Veronica chamaedrys</td>
<td>6(^2)</td>
<td>4(^2)</td>
</tr>
<tr>
<td>Galium uliginosum</td>
<td>1(^1)</td>
<td>8(^3)</td>
<td>Vicia cracca</td>
<td>37(^7)</td>
<td>50(^1)</td>
</tr>
<tr>
<td>Geranium sylvaticum</td>
<td>0</td>
<td>28(^3)</td>
<td>Vicia sepium</td>
<td>52(^3)</td>
<td>43(^3)</td>
</tr>
<tr>
<td>Geum spp.</td>
<td>16(^3)</td>
<td>8(^2)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2: Average production from sample plots in tree transects (n=6) and open meadow transects (n=3) in site 1 and 2 (dry weight in g/0.25 m\(^2\) ± se).
In site 1 we estimated average production consumed by sheep through spring and autumn grazing to be 314 g/m² (spring = 162 g/m², autumn = 152 g/m²) (n=3, see materials and methods).

Average production under the tree crowns in site 1, within a radius of 3.5 m around the trunk of each of the 6 trees, was 184.8 g/m², while average production in the outer sample plots and sample plots from the open meadow was 356.8 g/m² (fig. 4). Thus the reduction in production under the tree crowns was 172 g/m², which gave a reduction of 6.6 kg/year for each tree in the meadow.

In site 2, there was also a significant (P = 0.001) increase in production with increasing distance from the tree trunk (fig. 2c). Moreover, production varied significantly (τ = -0.491, P < 0.001, n = 126) along the second most important vegetation gradient, DCA axis 2 (fig. 3b), but not along DCA axis 1. Production was highest in sample plots with a dense field layer. *Anthriscus sylvestris* and *Trifolium medium* were usually among the species with highest cover in these plots (>25%). Sample plots with low production had a more open field layer and more open ground. In many of these plots *Deschampsia flexuosa* was the species with highest cover, but it rarely exceeded >20% cover.

### 3.2 Production in the tree layer

In site 1, total production from the three pollarded trees was 403 kg (*Ulmus glabra I*), 200 kg (*Ulmus glabra II*) and 104 kg (*Fraxinus excelsior*) over the five-years period (table 2). The amount of dry fodder from the three trees utilized by the animals was calculated to be 83.8 kg, 35.4 kg and 23.3 kg (table 2). Over a 5-year cycle, this gave an average of 9.5 kg foliage/tree/year (table 2), which in site 1 with 10 trees per 0.1 ha corresponded to production of 950 kg foliage/ha/year.
Figure 4: Average production in the field layer under and outside the tree crown.

Table 2: Production from the pollarded trees 1993-1998. In order to estimate utilized dry fodder/tree/year we assumed 39\% loss in weight from fresh to dry foliage [3], and that 74\% of dry foliage (average of *Ulmus glabra* and *Fraxinus excelsior*) was utilized by the animals [3].

<table>
<thead>
<tr>
<th>Tree</th>
<th>Total prod. (kg)</th>
<th>Dead biomass</th>
<th>Fresh biomass</th>
<th>Dry fodder</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dry twigs (kg)</td>
<td>Wood (kg)</td>
<td>Foliage (kg)</td>
<td>Dry fodder for the animals</td>
</tr>
<tr>
<td><em>Ulmus glabra I</em></td>
<td>403</td>
<td>14.1</td>
<td>203.5</td>
<td>185.4</td>
</tr>
<tr>
<td><em>Ulmus glabra II</em></td>
<td>199</td>
<td>8.2</td>
<td>113.4</td>
<td>78.4</td>
</tr>
<tr>
<td><em>Fraxinus excelsior</em></td>
<td>104</td>
<td>2.7</td>
<td>49.6</td>
<td>51.7</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4 Discussion

4.1 Variations in production in the field layer

Production in the field layer in the abandoned wooded hay meadow (site 2) is lower than in site 1 (on average 29%), which is surprising given that biomass (hay) is removed from site 1 each year. One explanation of this pattern may be that the changes in microclimate (radiation, temperature, humidity) that occur during overgrowing [5] lead to changes in species composition. Shade-tolerant woodland species, e.g. Oxalis acetosella, increase at the expense of meadow species such as, Trifolium pratense and Phleum pratense. The decrease in radiation also means that many plants develop distinct shade forms with large thin leaves, resulting in lower production [18]. Moreover, the vegetation in site 2 is more patchy and there is more bare soil than in site 1.

At both sites, production increases with increasing distance from the tree trunks. This trend is most marked in site 1 (cf. fig. 2), where the increase is steeper due to the recent pollarding of the trees, and more gradual in the abandoned site (site 2). Thus, the importance of the influence of trees on production is clear at both sites. Field layer production is hampered below trees, because these areas receive less radiation and are in general (although depending on the climate in the region) dryer than areas between trees [19]. Production in both sites is significantly related to variations in vegetation, as shown by the significant correlations with DCA axes. Production is related to the main vegetation gradient (DCA axis 1) in site 1, whereas it is related to the second most important vegetation gradient in site 2. This is because the main vegetation gradient in site 2 is related to some other unmeasured environmental factor, or most likely to a succession gradient.

Average hay production in the field layer in the wooded hay meadow in active use (site 1) is 268 g/m², while the grazing effect (spring and autumn grazing) is estimated to be 314 g/m². Thus total production in the field layer might be as high as 582 g/m² on average. In comparison, the average production from fertilized meadows in Norway is 578 g/m² [20]. Thus production in the wooded hay meadow is therefore very high given that it has not been manured or fertilized since 1991. One explanation of the high level of production may be that a sort of “pioneer clearing fertilization” occurs after the trees are pollarded [18,21,22]. The die-back of rootlets following the reduction of the canopy, reduces competition between the roots of grasses, herbs and trees, especially in the topsoil layer, with an accompanying increase of production in the field layer.

Although care should be taken in drawing conclusions on the basis of one study, our results indicate that field layer production in the wooded hay meadow is very high even without use of fertilizers. This helps to explain the important position they had for hundreds of years in the Nordic countries.

4.2 Production accounts

Our figures show an average reduction in production under the tree crowns of 6.6 kg/year (hay) for each tree in the meadow. However, this figure is based on
the fifth year in a five-year pollarding cycle. In the other four years, the tree crowns will be smaller after pollarding, and production in the field layer beneath the trees is likely to be higher.

The foliage, harvested from one tree every fifth year corresponds to an average production of 9.5 kg/year. Foliage is a more reliable source of fodder than hay and less dependent on weather conditions. In addition foliage is tasty and rich in important minerals for the animals, and several deciduous tree species (e.g. *Ulmus glabra*, *Fraxinus excelsior* and *Sorbus aucuparia*) have a nutrient value at least as high as that of hay [23,24]. However, there are clear differences between tree species, and *U. glabra* foliage has the highest fodder values throughout the growing season [24]. In conclusion, our estimates of production indicate that it was and still can be a viable alternative for the farmer to retain trees in a meadow, and given that the pollarded trees could reach a great age (200-300 years) and were a reliable source of fodder, it is likely that it was economically viable to maintain foliage trees that could be harvested regularly in the meadow. However, to determine how generally profitable the system is, more studies are needed from other localities to cover a range of topographical features and variations in other environmental factors.

References


[10] Hill, M.O. *DECORANA – A FORTRAN program for detrended correspondence analysis and reciprocal averaging*. Cornell University, Itacha, New York, 1979


