EXTENSIVE SHEEP GRAZING IN OCEANIC CIRCUMPOLAR CONDITIONS

Olafur Gudmundsson

Feed, Seed and Fertilizer Inspectorate, RALA building, Keldnaholt, IS-112 Reykjavik, Iceland

INTRODUCTION

The common identifier for sheep production in circumpolar regions is that sheep have to be fed by farmers for long periods of the year, as the season of vegetative growth is short and extensive grazing on native pastures is common. In general, the production period can be divided in two parts, indoor feeding and grazing. These can be further divided into the periods shown in Figure 1. Winter grazing is not shown. It was common for centuries, but it has now been virtually abandoned, sheep being feed mostly indoors during the winter.

The main emphases in this paper will be spring, summer and autumn grazing. It will discuss extensive grazing in general and with regard to the utilization of large areas of land for grazing with minimal outlay and labor. In the circumpolar areas, there are significant differences in geology, botany, and topography both within and between countries. The climate is variable, ranging from oceanic, humid, and rather cool in Iceland and West Norway, to the inland climate of central Scandinavia, mainland Russia and Canada. In some of these areas, land degradation and subsequent erosion are a major environmental concern, and grazing can be a major problem (Arnalds et al. 1997), whereas in others, lack of grazing results in regrowth of shrub and woodland followed by changes in the cultural landscape and reduction in species diversity (Garmo et al. 1993). In the latter areas, livestock grazing can be an important instrument for preserving an open landscape.

This paper’s arguments will be based mainly on research done in Iceland, although some studies from other countries also have been included. The main emphasis has therefore been placed on existing systems of sheep grazing under oceanic rather than inland circumpolar conditions.

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GRAZING SYSTEM

Sheep are grazed from lambing in early spring, usually May to June, on both cultivated and natural pastures surrounding the farms. It is now common practice to keep sheep indoors during lambing. However, in spite of the greater quantity and higher quality of winter feed in recent years, most farmers still like to turn the sheep out as soon as possible and are therefore highly dependent on spring herbage for their sheep. Grazing has been considered profitable compared to indoor feeding in spring, especially for ewes suckling twins (Thorsteinsson and Palsson, 1975). Early grass growth is therefore very important, but sometimes farmers supplement grazing by feeding hay or concentrate at the pasture. During this time, grazing is generally intensive, but ewes’ milk production and lambs’ weight gains are usually good (Gudmundsson and Dyrmundsson, 1989). It is most often the quantity rather than the quality of herbage that is the limiting factor, as both protein and energy content are high in the pastures (Thorsteinsson and Olafsson, 1965 & 1969; Olafsson, 1973). Defoliation at this time is considerably more detrimental than defoliation later in the season, and it can eventually decrease the production of the pasture by reducing the number of desirable forage species, as undesirable plants gain a competitive advantage (Archer and Arnalds, 1982).

In early spring it is common to graze ewes with their lambs on parts of the cultivated fields surrounding the farms. This is done shortly after lambing, but before the uncultivated fields are ready for grazing. The lambs grow faster in the spring when grazing on cultivated rather than uncultivated pastures. This, however, can decrease hay production later in the summer (Palmason, Olafsson and Arnason, 1976).

Some sheep are grazed on the lowlands throughout the summer, but the majority of sheep are grazed without herding on extensive common mountain or
highland ranges from late June or early July until September. Both lowland and highland grazing have developed over the centuries. The variability of both lowlands and highlands is great, with different plant communities intermixed. The lowland areas are often composed of mires that are poorly utilized for grazing, whereas in the highlands, large areas are often eroded or in great danger of erosion. In some countries these areas are covered with forests, whereas lowland areas have either cultivated or improved pastures, the only extensive natural areas being open pastures in the mountains or highlands above the tree line.

Although common grazing areas exist in the lowlands, most farms have their own lowland pastures or ranges where the sheep from that particular farm are grazed, if they are not taken to the highland commons. These lowlands may be open to areas belonging to other farms within a particular farming district or they may be fenced off for a particular farm or even divided into several pastures. In these areas, horses and young cattle being raised for meat and replacement purposes are often grazed along with the sheep, whereas dairy cows are grazed mostly on cultivated pastures. In Iceland however, the highlands are divided into extensive grazing commons by fences and natural barriers such as rivers, glaciers and steep mountains. Sheep from farms in a particular lowland district utilize each common. In these areas, horses used to be grazed together with the sheep, but for some years, horse grazing has been banned on many of these highland ranges.

In the autumn, it is quality rather than quantity that is usually the limiting factor in grazing. Depending on the weather, the nutritive value drops considerably in late summer, and by late August, nutritive value has reached undesirably low levels (Thorsteinsson and Olafsson, 1965 & 1969). A corresponding decline in lamb weight gain has been observed at this time, with positive interaction with the stocking rate (Gudmundsson and Bement, 1986). This is caused to a large extent by the low protein content in herbage at this time, but also by increased fiber content and lower digestibility (Gudmundsson and Dyrmundsson, 1989). Later in the autumn and early winter, the ewes start losing weight. Weight loss can be prevented by feeding a small amount of protein supplement (Gunnarsson, 1953; Jonsson, 1955), which is important with respect to the future fertility and production of the ewes.

The heavier lambs are usually slaughtered directly from the natural ranges, but the poorer lambs may be weaned and put on improved pastures, usually hayfield aftermath or spring sown crops for approximately 3-5 weeks, to be slaughtered in late October. In general, it has been found that lambs do not gain as fast on hayfield aftermath as on green annual forage crops (Palsson and Sveinsson, 1952; Palsson and Gunnarsson, 1961). This improved autumn grazing considerably increases carcass weight, but does not reduce the quality of the meat, as the lambs accumulate protein and fat in similar proportions (Gudmundsson and Dyrmundsson, 1983).

GRAZING RESEARCH

The negative relationship between grazing pressure and animal performance has been recognized for centuries. An Icelandic law that is over a thousand years old, states that “…no more animals should be allowed to graze on a range than a group where the remaining animals would not get fatter, even if one of them were removed…” (Grágás, early 12th century) (Gudmundsson and Thorhallsdottir 1999).

A very comprehensive experimental grazing project was initiated in Iceland in 1975, covering both extensive and intensive grazing (Gudmundsson and Arnalds, 1976 - 1980). Although this research started twenty-five years ago, no other research of the same caliber and scope has been done under these conditions. Stocking rate
experiments with sheep were carried out at 10 different locations on dry lowland, lowland mire, forested land, hills, re-vegetated highland, and natural highland and mountains, and lasted for three to eight years each. At most locations, both unfertilized and fertilized native pastures were studied, and finishing lambs on cultivated pastures in the autumn was compared to finishing lambs on unimproved pastures. Furthermore, there was also a comparison of mixed grazing (sheep and cattle or sheep and horses) versus single grazing, on both unfertilized and fertilized lowland mires.

**Intermittent grazing**

Continuous stocking is the only extensive grazing system for sheep that has been advocated for the Arctic and subarctic regions. Although defined as continuous, it can be intermittent to some extent, as in many cases, sheep are grazed in spring and autumn on the same land.

The period of grass growth on unimproved grasslands is short, extending beyond 120 days per annum only in exceptional cases. Under more southern conditions, in a temperate climate where grass growth extends over a longer period, intermittent grazing systems that involve rotational grazing have rarely shown advances over continuous grazing on relatively intensive pastures where the stocking rate has been low or intermediate (Rattray, 1987; Maxwell, Grant and Wright, 1988).

In a recent experiment, (Thorhallsdottir, Olafsson and Sigurdarson 2001) sheep and horses were rotated on lowland mire using the horses as leaders and having the sheep graze on the aftermath. The results did not show any additional live weight lamb gain over lambs grazing on common highland range.

It is therefore apparent that rotational grazing systems are not the solution for improving individual carcass weight on extensive pastures for sheep, especially on the low-valued extensive pastures in the Arctic or subarctic regions, if the additional labor and cost are taken into account.

**Lowland and highland grazing**

As indicated earlier, several stocking rate experiments were done in Iceland. The results of four of them are presented in order to compare highland and lowland grazing (Gudmundsson and Arnalds, 1976 - 1980). One experiment was on dry lowland grassland in the most southern part of Iceland at approximately 20 m above sea level (a.s.l.). The vegetation consisted mostly of *Festuca* spp., *Thymus arcticus*, and mosses. The second experiment took place on lowland mire, also in the south of the country, at approximately 20 m a.s.l. It was drained by open ditches. The dominant plant species were *Agrostis* spp., *Festuca* spp., *Carex nigra*, *Eriophorum angustifolium*, and *Equisetum palustre*. The third experiment was on dry scrubland in the highlands of north central Iceland at approximately 500 m a.s.l. The most frequent plant species were *Festuca* spp., *Polygonum viviparum*, *Thalictrum alpinum*, *Betula nana*, *Salix* spp., lichens, and mosses. The fourth experiment was in the mountains of eastern Iceland on a mixture of dry and wetlands at approximately 600 m a.s.l. The plant composition consisted mostly of *Equisetum* spp., *Poa* spp., *Festuca* spp., *Carex* spp., *Empetrum nigrum*, *Thalictrum alpinum*, *Kobresia myosuroides*, lichens, and mosses. It should be pointed out that experiments with a variable stocking rate allowing for constant grazing pressure and based on repeated measurement of standing herbage such as herbage height, do not apply under variable extensive conditions, although they can be valuable on more uniform intensive pastures.
Figure 2. Average daily gain of twin lambs grazing with their dams on different pastures and range-lands on lowlands and highlands

The sheep used in these experiments were of the Icelandic landrace, belonging to the North European short-tailed group of sheep. They were from particular farming districts having grazing rights on the lowland or highland grazing commons where each particular experiment was located. These grazing methods (grazing on highland and lowland, and wet and dry areas) can be compared by looking at the average daily gain of the lambs as a function of time (Figure 2). Considerable variation was found in the growth rates of lambs, and it is apparent that in general, lambs grow better in the highlands and mountains than on the lowlands. This was especially noticeable during the peak growing season, but in late summer and autumn, the average daily gain dropped very quickly in the highland experiments, whereas there was a more gradual decrease during the summer in the lowlands. In late August, the growth of lambs in the highlands and mountains was no better than on the lowlands and became even lower in early September (Gudmundsson and Dyrmundsson, 1989). This difference in lamb gain between the highlands and lowlands was first shown experimentally in the fifties (Palsson, 1957), and is supported by the longstanding experience of many farmers.
Figure 3. Effect of stocking rate on carcass weight of twin lambs on different pastures and rangelands on lowlands and highlands.

Figure 4. Effect of stocking rate on average daily gain of ewes suckling twin lambs on different pastures and rangelands on lowlands and highlands.
Table 1. Stocking rate, average daily gain per lamb (ADG) and carcass weight per hectare for production of lambs of 12 kg carcass weight for five different extensive grazing methods in Iceland (Gudmundsson, 1989).

<table>
<thead>
<tr>
<th>Grazing methods</th>
<th>Stocking rate Ewes/ha</th>
<th>ADG g/lamb/day</th>
<th>Carcass weight kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry lowland</td>
<td>0.36</td>
<td>196</td>
<td>8.6</td>
</tr>
<tr>
<td>Lowland mire</td>
<td>0.69</td>
<td>223</td>
<td>16.6</td>
</tr>
<tr>
<td>Highland</td>
<td>0.50</td>
<td>246</td>
<td>12.0</td>
</tr>
<tr>
<td>Mountain</td>
<td>1.14</td>
<td>254</td>
<td>27.4</td>
</tr>
</tbody>
</table>

Table 2. In vitro dry matter digestibility (IVDMD), crude protein (CP) and mineral content of standing herbage (Gudmundsson, unpublished data).

<table>
<thead>
<tr>
<th>Grazing methods</th>
<th>Dry lowland</th>
<th>Lowland mire</th>
<th>Highland</th>
<th>Mountains</th>
<th>P&lt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>26</td>
<td>94</td>
<td>66</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>IVDMD, %</td>
<td>57.5</td>
<td>51.9</td>
<td>49.1</td>
<td>49.5</td>
<td>0.001</td>
</tr>
<tr>
<td>CP, %</td>
<td>10.7</td>
<td>12.5</td>
<td>13.0</td>
<td>12.1</td>
<td>0.01</td>
</tr>
<tr>
<td>P, %</td>
<td>0.21</td>
<td>0.12</td>
<td>0.17</td>
<td>0.18</td>
<td>0.001</td>
</tr>
<tr>
<td>Ca, %</td>
<td>0.47</td>
<td>0.30</td>
<td>0.56</td>
<td>0.81</td>
<td>0.001</td>
</tr>
<tr>
<td>Ca:P</td>
<td>2.3</td>
<td>2.7</td>
<td>3.7</td>
<td>3.6</td>
<td>0.001</td>
</tr>
<tr>
<td>Mg, %</td>
<td>0.22</td>
<td>9.17</td>
<td>0.25</td>
<td>0.22</td>
<td>0.001</td>
</tr>
<tr>
<td>Number</td>
<td>15</td>
<td>58</td>
<td>27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu, ppm</td>
<td>7.7</td>
<td>7.7</td>
<td>10.2</td>
<td>-</td>
<td>0.001</td>
</tr>
<tr>
<td>Mn, ppm</td>
<td>86</td>
<td>341</td>
<td>121</td>
<td>-</td>
<td>0.001</td>
</tr>
<tr>
<td>Fe, ppm</td>
<td>1534</td>
<td>695</td>
<td>757</td>
<td>-</td>
<td>0.001</td>
</tr>
<tr>
<td>Zn, ppm</td>
<td>55</td>
<td>27</td>
<td>106</td>
<td>-</td>
<td>0.001</td>
</tr>
</tbody>
</table>

The final outcome from the comparison of these grazing methods is shown in Figures 3 and 4. The lambs on dry highland range (pooled data for five years and all stocking rates) had, on average, a significantly (P<0.001) higher carcass weight than lambs in the mountains, which also gave a higher (P<0.001) carcass weight than the lambs in the dry and wet lowlands. This difference is chiefly noticed in the carcass weight, as the dressing out percentage of the lambs is usually significantly lower (P<0.001) on the lowland mires than in the highlands. It is therefore impossible to use live weight as a parameter to determine this difference. However, the dams of these lambs were not slaughtered at the end of the experiments, and they were, on average, heavier (P<0.001) at the end of grazing in the autumn in the wet (lowland mire) and semi-wet (mountain) areas than on the dry grazing lands, both lowland and highland. The effect of stocking rate on carcass weight was much greater on the dry land than in the wet area, regardless of altitude (Figure 3). The effect of stocking rate on the live weight gain of the ewes was greatest in the dry highlands and least on the lowland mire with the dry lowland and mountain areas being very similar (Figure 4). It is interesting that in no instance did the carcass weight of the lambs or the gain of the ewes reach a point where it started to level off at a low stocking rate.

The steeper the slope of the relationship between stocking rate and gain or carcass weight, the more vulnerable the area is to damage by grazing. It is apparent that the dry highland and lowland areas are more vulnerable to grazing than the mixed mire and dry land area in the mountains, and much more vulnerable than the lowland mire.
Where land is limited, it is common to try to maximize the live weight gain per area of land. This was adequately described some time ago for production functions for more southern parts of the world (Jones and Sandland, 1974; Hodgson, 1976). This does not necessarily apply to subarctic and Arctic conditions, where the rate of lamb growth has to be very high to reach slaughter weight during the short summer. This is especially true of fragile highlands where there may be little leeway between maximum gain per area and no gain or actual losses (Arnalds, 1985). Therefore, when maximizing the production per unit area using quadratic functions, sometimes defined as “optimum” production, substantial extrapolation beyond the range of reality would be needed, as the stocking rate at “optimum” production could not exist within the production system in the lowlands or in the highlands. Therefore, maximum production per unit area at minimum acceptable individual carcass weight is a more realistic approach when comparing the different grazing methods (Gudmundsson, 1989). The maximum average daily gain and carcass weight per unit area at a 12 kg carcass weight per lamb is shown in Table 1. Production is lowest in dry lowlands and highest in the mountain area. However, farmers would prefer carcasses over 14 kg, which is a difficult weight to obtain for twin lambs on the lowland mires except at extremely low stocking rates. Furthermore, the use of uncultivated pastures and rangelands is relatively cheap, making production per unit area less important. A factor of much greater importance is the durability of grazing, because in Iceland, for example, there are serious erosion problems in the mountains and highlands, putting more pressure on farmers to considerably reduce or even totally abolish grazing in the central highlands. This puts more pressure on utilization of the lowlands for grazing and calls for a solution to the poor lamb performance.

Different plants have also been studied for summer pasture production, for example Nootka lupine (Lupinus nootkatensis) (Gudmundsson & Thorsson 1994), which originated in Alaska. Nootka lupine is hardy and high-yielding (Magnusson et al., 1995), but it contains bitter alkaloids and as such is unfit for grazing or feed production (Gudmundsson et al. 1994). It has therefore been suggested that this lupine be sweetened through breeding to make it available for grazing and feed production.

Similarly poor performance of lambs grazing pastures where conditions should be adequate for good growth is well documented in different parts of the world (Roberts, 1933; Clarke and Filmer, 1958; Brewer, Calder, McIntyre and Taylor, 1971).
Figure 5. Herbage intake of ewes and lambs grazing lowland mire and dry highland range

Figure 6. Chemical composition of extrusa from grazing sheep on lowland mire and dry highland range

**Diet selection, intake and nutritive value**
A large majority of the research projects on diet selection, intake, utilization and growth of grazing sheep have been done on cultivated or natural grasslands under temperate conditions. Relatively little is known about these parameters on low producing pasture and rangelands in the circumpolar regions.

Studies on diet selection of sheep have been done in Iceland. The main foraging plants consist of fewer than ten species, i.e. Festuca sp, Poa sp, Agrostis sp, Calamagrostis neglecta, Carex sp, Salix sp, Polygonum viviparum, Galium sp, and Equisetum sp. independent of lowland and highland grazing (Thorsteinsson 1980; Thorhallsdottir and Thorsteinsson 1993). The proportion of these plants in the diet, however, has been shown to vary according to amount available, time of day, and time of year (Thorhallsdottir 1981). Thus, free roaming sheep in Iceland have been shown to select mires during the daytime and dryer areas at night (Thorhallsdottir and Thorsteinsson 1993) and to prefer and select some species like Equisetum sp and Salix sp early in the growing season but not later on (Thorhallsdottir 1981; Thorhallsdottir and Thorsteinsson 1993). Diet selection studies from Norway and Denmark (Garmo et. al. 1990, Fisker 1991) indicate a similar pattern by sheep in these countries.

In a study by Thorhallsdottir (1981), plant preference was estimated by comparing demand and supply. Results from early July and late August showed high preferences for certain plant species on a mountain range in the early season, with less selective grazing in the late season. On a mountain range in Iceland in late August, after the first frost, all plants are senescent, and their nutritional value is down. For grazing sheep, therefore, selective grazing is not as great a gain as in early July, when the differences between good and bad bites are much larger (Gudmundsson and Thorhallsdottir 1999).

Research has been done on intake, digestibility and growth, to study the effect of stocking rate, location, soil, and vegetation type on foraging activity, plant production and livestock performance (Gudmundsson and Thorsson 1998; Gudmundsson, Jonsdottir and Thorsson 1998). Intake and digestibility, in association with weight changes, were studied on both lowland mires and dry highland ranges using esophageally fistulated ewes to collect herbage samples and fecal bags to collect the feces. Internal plant markers were used to determine digestibility.

The main results were that even though there was better lamb gain on highland ranges than lowland, digestibility is usually similar or higher in the herbage consumed on the lowland mire than on the dry highland (Gudmundsson 1993; Gudmundsson, Jonsdottir and Thorsson 1998), but forage intake is higher on the highland range (Gudmundsson and Thorsson 1998). Figure 5 shows these results, the relationship between intake and seasonal grazing time being similar to that between average daily gain and time (Figure 2). In the highlands and mountains, the intake is much higher during the peak growing season than in the lowlands. Also, in late summer and early autumn, intake on the highland ranges decreases very rapidly, whereas the drop was minimal on the lowland pastures (Gudmundsson 1998).

The explanation for more herbage intake and better gain in the mountains should be related to the nutrition of the animal or the nutritive value of the herbage as shown in Figure 6, where the content of soluble carbohydrate and lignin is higher and cellulose and hemicellulose lower in pastures consumed on the highland. The composition of the herbage consumed on the dry highland range is therefore closer to legumes than to grasses, causing higher intake in the highlands and explaining the difference in growth between highlands and lowlands. Table 2 shows the in vitro digestibility and chemical composition of standing herbage pooled over five years and various times of the grazing season (Gudmundsson and Arnalds 1975-
In general, digestibility was higher (P<0.001) and Ca:P ratio lower (P<0.001) in the lowlands than in the highlands. However, under these conditions *in vitro* digestibility does not necessarily represent the *in vivo* digestibility (Gudmundsson and Thorsson 1998). The protein content was lower (P<0.001) on the dry lowland range than in the other areas. Fiber content, analyzed according to Goering and Van Soest (1970), is usually higher in the lowland mire than the dry highland, as shown in Figure 6, and could cause reduced intake and utilization, although this is not reflected in the *in vitro* digestibility. It is apparent that the nutritive value often becomes the limiting factor in the growth of grazing sheep. However, nutritive value changes with time, being highest in the spring and lowest in the autumn. The same is true for phosphorus and potassium, whereas the opposite is true for calcium and magnesium, and by late August, the nutritive value of the range plants has reached quite low levels (Thorsteinsson and Olafsson, 1965 and 1969). Several trace elements are also shown in Table 2 (Gudmundsson and Arnalds, 1975-1980). In spite of great differences in trace mineral content, these differences do not explain the differences in lamb growth between the grazing methods.

**Internal parasites and microorganisms**

In the spring, grazing is generally intensive, which can cause problems such as coccidiosis. It is therefore recommended that the same pastures not be used for spring grazing for two years in a row. During extensive mountain or highland grazing, gastro-intestinal parasites in sheep are rarely a problem. The same is true for the natural lowland ranges if they are properly managed and not overstocked. Helminthes burdens can be prevented by the use of anthelmintics (Thorhallsdottir, Olafsson and Sigurdsson 2001) but in general, they are not used for sheep during extensive grazing. However, it is common to treat ewes and rams during housing in the winter. Aside from spring grazing, Coccidiosis can cause problems during intensive summer and autumn grazing (Gudmundsson et al. 1983), but not during more extensive grazing, such as that in summer in the highlands and mountains. It can be prevented during intensive grazing in the lowlands by carefully planning the grazing, frequently moving the sheep to cleaner pastures or using coccidiostats, but the latter cannot increase the gain significantly enough to justify this type of summer grazing (Gudmundsson, unpublished data).

Experimental results have indicated that a penicillin-like compound produced by a soil fungi *Paecilomyces carneus* that is present in the lowland mires but not found in the dry highland soils (Eyjolfsdottir, Olafsson and Brewer, 1988) can depress the *in vitro* digestibility of grasses and change the end products of the fermentation process (Eiriksson et al., 1989). This is clearly shown in Figure 7 where *in vitro* digestibility is significantly (P<0.001) reduced by *Paecilomyces carneus* extract, but not when Penicillinase is added. If this is also true *in vivo* this could explain the difference in growth on the lowland and the highland areas.
For centuries, mixed grazing has been a common practice in temperate climates. It has been the subject of many experiments in different countries (Nolan and Connolly, 1977), and the benefit of grazing sheep with other animal species is relatively well established (Wright and Connolly 1995). In the circumpolar regions it has been common practice to graze sheep with both horses and cattle, as well as in areas also grazed by wild animals such as reideer/cariboo and moose.

Sheep grazing with cattle and horses has been studied in Iceland, where the emphasis has been on doing experiments on the lowland mires, where mixed grazing of sheep and horses, and sheep and cattle, have been compared with single grazing (Gudmundsson and Helgadottir, 1980; Gudmundsson 1985; Gudmundsson, 1987). Pooled data from these experiments for sheep production is shown in Figure 8. This data is from various stocking rates, and ratios of sheep to cattle or horses, without adjustments for these factors. However, analysis according to Connolly and Nolan (1976) did not change the general results significantly. Sheep benefit from grazing with both cattle and horses, this benefit increasing as the number of sheep in the mixture decreases. However, the growth rates of lambs do not reach the level accomplished in the highlands. The horses also benefit from grazing with sheep (Gudmundsson, 1985), but there is negligible benefit to growing cattle (Gudmundsson, 1987). These results are more or less in agreement with results from other countries (Nolan and Connolly 1977) and in general, the advantage of mixed grazing has been shown to be greatest where the diversity of vegetation, site and terrain are highest (Valentine 1990).

The causality of the benefits of mixed grazing compared to single grazing has not been studied under northern conditions, but in this context, it is appropriate to

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**Figure 7. Effect of Paecilomyces carneus extract on in vitro digestibility of Phleum pratense**
refer to papers on the complementarity of grazing activity (Dudzinski and Arnold, 1973) and the distribution of dung and its effect in mixed grazing, which have received some attention (De Rancourt, Nolan and Connolly, 1981; Bjarnason, 1984; Forbes and Hodgson, 1985). It is probably due to the differences in plant preference and thus diet selection of different animal species, but it could also be associated with other factors such as reduced gastrointestinal burden (Nolan and Connolly 1977; Valentine 1990).

Figure 7. Comparison of carcass weight of lambs grazed alone or with cattle or horses

Use of fertilizer and semi-extensive grazing

It is apparent that the natural pastures and rangelands in the subarctic regions and the Arctic are not productive compared to more southern countries. In addition they are often vulnerable to erosion when overgrazed. It is therefore often critical to increase the carrying capacity and productivity of the land. Fertilizer application has been studied as one alternative for this purpose. You can argue that fertilizer use changes an extensive grazing system into a semi-extensive one, although the carrying capacity is still similar or lower than under conditions that are considered extensive in most southern countries. Furthermore, only parts of the total summer grazing areas can in practice be fertilized.

The use of fertilizer to increase plant production on natural pastures under these conditions has been studied in several experiments (e.g. Thorsteinsson and Sigurbjornsson, 1961; Arnalds, 1974; Arnalds et al, 1980). These studies have shown a manifold increase in forage production and a shift in plant composition toward a dominance by grasses. A limited number of grazing experiments have also been conducted on fertilized natural pastures, under both lowland and highland systems of grazing (Gudmundsson and Arnalds 1976-1980). Only a single application of 78-104
kg N ha\(^{-1}\) and 18-25 kg P ha\(^{-1}\) was used each year. The relationship between stocking rate and carcass weight on the fertilized dry lowland, lowland mire, and the dry highland range are shown in Figure 9. It

![Figure 9. Effect of stocking rate on carcass weight of twin lambs on different pastures and rangelands on lowlands and highlends](image)

**Table 3.** Comparison of carcass weight of lambs on extensive, intensive and semi-intensive grazing (Dyrmundsson et al. 1979; Dyrmundsson, Unpublished data).

<table>
<thead>
<tr>
<th>Grazing treatments</th>
<th>Number of lambs each year</th>
<th>Average carcass weight, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Cultivated lowland pastures for 15 weeks</td>
<td>28</td>
<td>14.6</td>
</tr>
<tr>
<td>B Cultivated lowland pastures for 9 weeks followed by spring-sown forage for 6 weeks (weaned lambs)</td>
<td>28</td>
<td>14.9</td>
</tr>
<tr>
<td>C Cultivated lowland pasture for 5 weeks followed by highland range for 10 weeks</td>
<td>28</td>
<td>15.0</td>
</tr>
<tr>
<td>D Unimproved lowland range for 5 weeks followed by highland range for 10 weeks (traditional system)</td>
<td>28</td>
<td>13.9</td>
</tr>
</tbody>
</table>

is apparent that the use of fertilizer greatly increased stocking rate and therefore total production per area of land, and it reduced the effect of stocking rate on lamb production (Gudmundsson and Bement, 1986). The results of these experiments also showed a five- to eleven-fold increase in stocking rate and carcass weight per area of land, at 12 kg carcass weight per lamb. The increase was highest on the least productive land, i.e. the dry lowland, and lowest on the lowland mire (Gudmundsson, 1989). It is interesting to note that there was a greater increase in the highlands and mountains than on the lowland mire. Nevertheless, the increase in individual carcass weight was very limited (Gudmundsson and Bement, 1986).
Economic studies of these grazing systems indicate that fertilizer application to improve production during the summer, regardless of the grazing system used, is not profitable (Stefansson, 1984a,b; Arnalds, 1985; Arnalds and Rittenhouse, 1986). Fertilizer, however, can be applied as a management tool to reduce the grazing pressure on poor grazing lands or areas vulnerable to erosion and to improve the distribution of grazing animals on the grazing lands (Gudmundsson and Dyrmundsson, 1989). Fertilizer application can also be valuable in supplying enough nutritious herbage when sheep are turned out after lambing and again in the autumn for finishing off lambs for slaughter, as well as for ewes and replacement lambs.

**Intensive and semi-intensive grazing**

Intensive grazing on cultivated land is used to some extent in sheep production in some of the subarctic areas. It can be used in conjunction with the extensive grazing system, making the system semi-intensive and can therefore not be entirely disregarded in this paper. As indicated before, cultivated pastures that are used later in the summer for haymaking are often used in the early spring for the ewes and their lambs just after parturition. In the middle of the summer, cultivated pastures give much higher production of sheep per area of land than both the native and fertilized native grasslands (Gudmundsson and Arnalds, 1976-1980), but variable results have been observed concerning the gain per head (Adalsteinsson and Jonsson, 1973; Gudmundsson, 1980). Most experiments, however have shown that lambs grazed with their dams on cultivated pastures during the summer have similar or lower growth rates than comparable lambs on unimproved ranges (Gudmundsson and Arnalds, 1976 - 1980).

There are experiments that show relatively good results from intensive and semi-intensive grazing compared to traditional grazing. In one of these experiments, sheep were rotated with cattle between cultivated pastures on a yearly basis as shown in table 3 (Dyrmundsson, Jonmundsson and Richter, 1979; Dyrmundsson, Jonmundsson and Richter 1996). The sheep therefore never grazed the same cultivated pastures two years in row. The lambs on intensive (A-B) and semi-intensive (C) grazing produced a higher average carcass weight over a two-year period than the lambs on traditional extensive grazing (D). Still, intensive grazing of sheep during the summer is probably not an economically feasible choice, as in addition to fertilizer cost, which has not proven economical on uncultivated pastures (Stefansson, 1984a,b; Arnalds, 1985), there is the additional cost of fencing, anthelmintics, and the growing of forage crops (Dyrmundsson et al., 1979).

As indicated above, cultivated pastures can be important in the autumn when finishing lambs that are not ready for slaughter directly from the native grassland are put on re-fertilized hayfield aftermath or green annual forage crops such as kale (Thorgerísson, Thorsteinsson and Thorkelsson, 1987). Lupine, such as *Lupinus angustifolius*, may also be used (Gudmundsson & Runolfsson 1988) depending on its growth potential under harsh weather conditions. In general, it has been found that lambs do not gain as fast on hayfield aftermath as on green annual forage crops (Palsson & Gunnarsson 1961). This improved autumn grazing increases the carcass weight considerably but does not reduce the quality of the meat, as the lambs accumulate protein and fat in similar proportions (Gudmundsson & Dyrmundsson 1989).

**CONCLUSIONS**
Extensive grazing research with sheep has been done in order to study feed intake, utilization, and production in relation to various soil, vegetation and environmental parameters. This research has shown that extensive highland or mountain ranges produce more lamb meat per ewe, but less per unit of land than extensive lowland grazing, which in many cases does not produce acceptable lamb carcasses in spite of relatively high forage densities of high quality. This result has not been fully explained by the quality of the vegetation consumed but is most likely due to higher intake on highland ranges occurring in mid summer during peak plant growth. Mixed grazing of sheep with growing calves or horses on lowland mires has shown some advantages, but not enough to support acceptable lamb gain on the lowlands. Use of fertilizer on summer pastures is not profitable but can be used successfully on improved pastures in the autumn.

On the basis of experience and accumulated research results in Iceland, sustainable sheep grazing is seen as an efficient way of utilizing the huge resources of natural vegetation in the circumpolar areas, and in that way boost the quality and standard of living of residents.

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