Appendix to:
Evaluation of the choice of biomass type, its quality (suitability), procurement and
cultivation, 24 month report to CRAFT Project No: CRAF-1999-70986:
Biochemicals and Energy from sustainable Utilization of herbaceous
Biomass (BESUB)

Feasibility study of green biomass procurement.

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Executive summary

This report studies the feasibility of using a variety of crops for large scale biomass production in Iceland. Extensive areas are available for such activities as only 8% of the 15,500 km² below 200 m suitable for cultivation is currently in agricultural production.

The Nootka lupine (Lupinus nootkatensis) is of primary interest as it can be cultivated on the extensive sandy and gravely plains in southern Iceland. It is able to carry out symbiotic fixation of atmospheric nitrogen, which eliminates the need for artificial nitrogen fertiliser. The report identifies areas suitable for lupine production in southern Iceland but a larger part of this is at some distance from a probable factory site where there is ample geothermal energy.

The Nootka lupine has, so far, not been used for continuous herbage production and experimental results on sustainable biomass production are limited. Harvestable yields can not be expected until after four years from establishment. The production potential varies depending on soil type, harvest date and repeated harvests over years. Small scale production could be restricted to favourable areas yielding about 5 t/ha DM over a period of four years or even more. On the extensive sandy areas, on the other hand, yields around 3 t/ha could be expected. Application of phosphorus and sulphur will improve yield and fertilisation with other nutrients would be required in the long run.

The cost of cultivation, cutting and wilting of the lupine crop was estimated for four scenarios of yield and longevity of the lupine in the field. The estimates range from 2.78 to 4.24 IKR/kg DM. The range of these estimates indicates the need to obtain more reliable results on lupine cultivation and harvest.

Barley cultivation is steadily increasing and experiments have shown that a barley field can give a total biomass in the range of 8-10 t/ha at moderate fertiliser rates, with a Harvest Index of 0.5. In the context of the present project both grain and straw biomass for fermentation is an option. The average cost for 8 t/ha of biomass would then be 7.70 IKR/kg DM. These figures include the cost of harvesting the seed and baling the straw.

Perennial grasses, such as reed canary grass (Phalaris arundinacea) and timothy (Phleum pratense), can give high sustainable DM yields if harvested in late summer and are thus an economic source of biomass. However, research specially designed for the production of biomass is needed. Set aside hayfields and left over hay bales could be a valuable addition to any other source of biomass.

Biomass can be used as a substrate for a variety of industrial processes that make use of different properties of the biomass. This will direct the choice of crop species and the feasibility of the biomass procurement. The quality factors that affect the value of green or wilted biomass are DM content at harvest and components making up the dry matter: ash, protein, fat, cell wall components and a remainder that is a measure of water soluble nitrogen free cell contents. Grasses contain more cell wall material for the production of fuels and industrial raw materials than the lupine, which, on the other hand can be a source of valuable alkaloids such as sparteins.

1. Introduction

1.1. Land resources

Iceland is located just below the Arctic Circle but the Gulf Stream secures mild maritime climate. The conditions for biomass production are thus characterised by a short and cool growing season and long and unstable winters. Agricultural land generally is restricted to areas below 200 m above sea level. Assuming a growing season of 130 days, from 7 May to 15 September, land suitable for cultivation can be
classified into three groups depending on the mean temperature during the growing season. This depends, among other things, on the height above sea level, distance from the sea and soil type. Zone 1 (mean temperature 10°C) covers land below 100 m in the south and west part of the country, and inland in the northeast and eastern part. Zone 2 (mean temperature 9°C) covers land between 100 and 200 m in the regions mentioned above and land below 100 m in other parts of the country, apart from areas closest to the sea along the north and east coast of the country. Zone 3 (mean temperature 8°C) is the remaining area classified as land suitable for cultivation (Hermannsson 2001).

This classification gives a good indication of where different crops can be grown. For example, cultivation of barley for maturity is limited to Zone 1 where as grass for hay production can be cultivated in all regions. Mapping of vegetation cover with the aid of satellite image classification can be used for further planning of crop production (Metússalemsson & Grétarsson 2003, http://www.nytjaland.is).

1.2. Crops for biomass production

The Nootka lupine (*Lupinus nootkatensis*, alaskalúpína) has been used successfully for land reclamation in Iceland for three to four decades. It has in many cases grown luxuriously on areas that previously had only very thin plant cover. Extensive areas of this kind still exist so that there is a potential for great increase of lupine cultivation. The lupine belongs to the leguminous family and is able to carry out symbiotic fixation of atmospheric nitrogen. This is an important economic feature since it eliminates the need of nitrogen fertilisation whereas the need for fertilisation with other nutrients is determined more by soil properties than the crop. The lupine is the prime choice for this project. There is, however, no experience of its use as a crop. Considerable effort was therefore put into studying its potential for this purpose and the results are reported in Section 2.

The potential of the Nootka lupine for sustainable biomass production has been studied in connection with the Icelandic Biomass Project (Björnsson & Dalmannsdóttir, 2004). New results are presented in Sections 2.3, 2.4 and 2.6. The lupine samples obtained in these experiments have been analysed for alkaloid content in another phase of this project (see Work Package 2).

Other crops considered for biomass production are grasses and annual crops, barley in particular. Section 3 is devoted to grassed and Section 4 to annual crops. Cost evaluations are reported in Section 5. Large scale production will lead to changes in technology and cost of production, mostly towards lower cost. It was not attempted to predict these changes.

1.3. Quality of biomass

The composition of biomass differs between species and varies depending on growing conditions and harvest dates. Biomass can be used as a substrate for a variety of industrial processes that make use of different properties of the biomass. This will direct the choice of crop species and the feasibility of the biomass procurement.

In the early stages of growth plants are rich in protein and other cell contents. They are rich in minerals and are well suited as animal feed. They may also be rich in special compounds such as alkaloids. As the plants grow older biomass is accumulated as cell wall material, mostly classified as crude fibre, or translocated to special storage organs, mostly as carbohydrates that are easily available for human
digestion and fermentation microbes. Old cell walls are usually lignified. The lignin is non-available for most organisms except some fungi and reduces the availability of other cell wall contents. At the termination of growth in late summer or autumn a substantial relocation of materials takes place. About 50-70% of the plant protein is the rubisco protein associated with the plant chlorophyll. The carbon dioxide assimilating cell tissues with the rubisco protein are partly or totally dissolved, the plant looses the green colour and senesces and the material is translocated to storage organs in the case of annual plants and the root system in the case of perennial plants. Minerals are also relocated to roots so that ash content is reduced.

In storage organs such as grain, fruits and potatoes, starch, sugars or plant oils are compounds that are of value for industrial processing. The quality factors affecting the value of green or wilted biomass (lignocellulosic) are dry matter content at harvest and the content in dry matter (DM) of ash, protein, fat, cell wall components (hemicellulose, cellulose and lignin) and a remainder that is a measure of water soluble nitrogen free cell contents. These include sugars and water soluble polymeric substances such as pectin and a variety of other substances. The cell wall components are determined analytically in a system developed by Van Soest (1967) as neutral detergent fiber (NDF), acid detergent fiber (ADF) and lignin. The other fractions were calculated as hemicellulose = NDF – ADF and cellulose = ADF – lignin. The cell wall components have different potential as substrate for industrial processes (Kamm and Kamm 2004). As a rule grasses are richer in cell wall material than leguminous plants such as lupine. Some crops contain substances of special value such as spartein in the Nootka lupine. Dry matter content is a quality factor since DM<85% causes in general extra cost for harvest, transport and/or storage.

2. The Nootka lupine

2.1. Availability of Nootka lupine in southern Iceland

The Soil Conservation Service in Iceland has, alone or in cooperation with others, established 9500 ha of lupine fields over the last twelve years (1991-2002), of which about 5900 ha are in southern Iceland (Soil Conservation Service 2003). To this can be added older lupine fields and areas planted by others (size unknown). If these fields were to be utilised for biomass procurement many of them would require some pre-treatment such as clearing of large stones. As most of these fields are on sandy soil they would be expected to last for a number of years if they will be harvested after 1 September.

The cost of cultivation has in most cases only been the production and sowing of lupine seed. No commercial use has so far been made of the biomass. The standing biomass increases with age in young lupine fields. In four well developed fields in southern Iceland (> 20 years old) the biomass was in the range 3-10 t DM/ha (Magnússon et al. 2001). Lupine standing biomass was measured in 1997 in a fertile field at Korpa Experimental Station and at three sites in southern Iceland where lupine could potentially be grown on large areas of sandy soils (Table 1). The harvest figures in Table 1 all represent fields where biomass has been allowed to accumulate over a

<table>
<thead>
<tr>
<th>Field</th>
<th>15-20 Oct.</th>
<th>20-21 Nov.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Korpa</td>
<td>7.5</td>
<td>7.4</td>
</tr>
<tr>
<td>Geitasandur</td>
<td>1.7</td>
<td>1.6</td>
</tr>
<tr>
<td>Markarfjötsaurar</td>
<td>3.8</td>
<td>1.8</td>
</tr>
<tr>
<td>Skógasandur</td>
<td>2.4</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Table 1. Lupine standing biomass DM t/ha in 1997 (Guðmundsson, unpublished report)
number of years without the intervention of harvest. The three sandy areas measured are most representative of those considered for biomass production. Biomass is less in October-November than in late summer or early autumn.

### 2.2. Potential lupine fields in southern Iceland

A rough estimate has shown that lupine fields could potentially be established on nearly 100,000 ha in southern Iceland, assuming that lupine can be cultivated on all glacial waste sands, gravel soil and the extensive sandy areas along the coast (Guðmundsson, unpublished report). However, only limited areas can be cultivated each year and it takes at least four years before a lupine field can be harvested. The planning of large scale planting of lupine is a complicated issue and involves a number of factors such as agreements with land owners and environmental assessment. It is therefore not attempted at this stage.

Another approach to estimate the potential areas for biomass production is to use the currently ongoing mapping of vegetation cover with the aid of satellite image classification (Metússalemssson & Grétarsson 2003, http://www.nytjaland.is). The vegetation classes are indicative of potential land use. Attention is limited to the western part of southern Iceland where the greatest lowland area is concentrated. Within this area there is access to plenty of geothermal energy. The area below 100 m, i.e. Zone 1, is of greatest interest since only minor areas 100-200 m above sea level are suited for cultivation. An outline of the areas is marked on the erosion map of Iceland on Fig. 1, and a slightly simplified vegetation map is shown on Fig. 2. The 100 m isoline is shown on both maps. The size of areas of the simplified classification is given in Table 2. The results are subdivided into 4 areas, Árnessýsla low areas (1 and 2), Árnessýsla upper areas (3), Rangárvallasýsla between Þjórsá and Ytri-Rangá (4) and Rangárvallasýsla between Ytri-Rangá and Markarfljót (5).

#### Table 2. Land areas in central South Iceland, km², with references to numbered areas on Fig. 1 and 2.

<table>
<thead>
<tr>
<th>In Icelandic on Fig. 2</th>
<th>Ölfus, Flói and Skeið (1, 2)</th>
<th>Uppsveitir Árnessýslu (3)</th>
<th>Rangárþ. vestra (4)</th>
<th>Rangárþ. eystra að Markarfljót (5)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultivated</td>
<td>Ræktað</td>
<td>66</td>
<td>43</td>
<td>54</td>
<td>50</td>
</tr>
<tr>
<td>Grassland</td>
<td>Graslendi</td>
<td>65</td>
<td>40</td>
<td>66</td>
<td>67</td>
</tr>
<tr>
<td>Rich heathland</td>
<td>Ríkt mólendi</td>
<td>103</td>
<td>99</td>
<td>80</td>
<td>51</td>
</tr>
<tr>
<td>Poor heathland</td>
<td>Rýrt mólendi</td>
<td>173</td>
<td>159</td>
<td>162</td>
<td>134</td>
</tr>
<tr>
<td>Brush and wood Mosses</td>
<td>Kjarr</td>
<td>31</td>
<td>41</td>
<td>18</td>
<td>38</td>
</tr>
<tr>
<td>Poorly drained and bog</td>
<td>Votlendi</td>
<td>34</td>
<td>15</td>
<td>18</td>
<td>10</td>
</tr>
<tr>
<td>Partly vegetated (&lt;50%)</td>
<td>Litt gróið</td>
<td>92</td>
<td>159</td>
<td>185</td>
<td>94</td>
</tr>
<tr>
<td>Total 0-100 m (Zone 1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>537</td>
</tr>
<tr>
<td>100-200 m (Zone 2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>47</td>
</tr>
</tbody>
</table>

1 Included with partly vegetated on the map
Fig. 1. Location of the areas tabulated in Table 2. The 100 m line is yellow.
Fig. 2. Mapping of vegetation classes and numbering of areas for results shown in Table 2. For English version of class names see Table 2. Blue is water and white is snow or clouds. The 100 m line, the upper limit of vegetation area measurements, is blue.
The sandy gravely areas that are the first choice for the Nootka lupine fall within the classes Partly vegetated, Poor heathland and Mosses, often in extensive continuous areas. The total area of these classes is 1081 km² and the greater part of this land would not be suited for this kind of cultivation. Of the 1000 km² in southern Iceland previously evaluated as potential lupine areas only about 10% fall within the areas tabulated. The greater part of the typical lupine areas is found further east along the south coast as can be inferred on Fig. 1, although at a greater distance from a probable factory site.

Very limited continuous areas suitable for biomass production such as lupine fields are found between 100 and 200 m. The cultivated and grassland areas are only 38 and 26 km² respectively within this zone.

2.3. Sustainability of production

Previous experiments have shown that the lupine plants badly tolerate harvesting at the time of flowering from May/June to mid August (Magnússon et al. 1995, Sigurðsson et al. 1995). Later studies have confirmed that survival of the lupine is poor if it is harvested before mid or late August. This is of particular relevance where the aim is to harvest valuable quality components such as sparteine. The lupine must not be harvested late, otherwise the sought after qualities may be lost. If harvested too early harvest of lupine the following year can not be expected. On fertile land other plants will take over and may give some yield in the years to follow. On infertile land a new cover of lupine may develop in a few years. This has though not been confirmed in experiments.

Sustainability of lupine production was studied in a series of experiments 1998-2004. In order to obtain rapid and even establishment pot-grown lupine plants were planted at 33 cm spacing in a fertile field at Korpa Experimental Station in spring 1998. The development of the lupine biomass was probably at least two years earlier than on a field established from lupine seed. In 1999 maximum biomass, 3.5 t DM/ha, was obtained on 1 September and a year later maximum biomass of previously intact lupines had reached 5.8 t DM/ha on 8 August. The standing biomass in early October had reduced to 1.5 and 3.3 t DM/ha in 1999 and 2000 respectively. In both years this was about 60% of the biomass on the plots on 15 August (Björnsson & Dalmannsdóttir 2004).

On the lupine field planted in 1998 a harvest experiment with three replicates was started in 2000 and harvested annually until 2004 when all plots were cut on the same date (Table 3). The experiment was designed with different harvest dates and combinations of harvest dates. The first two harvest dates were too early so that practically no lupine remained the following year. The field is fertile and other vegetation soon established in the plots. Its yield was measured in 2003 and 2004 or in 2004 only. When first cut the yield was higher than on lupine plots that had been cut annually. The following year the yield had declined however and this shows that fertilizer is needed when nitrogen fixing plants such as the lupine are missing from the sward. On plots cut late in 2003 the lupine recovered to some degree and made up nearly half of the yield in 2004.
Table 3. DM yield of lupine harvested annually at different dates 2000-2003, DM yield and herbage composition of the final harvest on 23 August 2004. Plots where lupine retreated after early date of harvest 2000 were also harvest 2003-2004.

<table>
<thead>
<tr>
<th>Harvest dates</th>
<th>Lupine yield, DM t/ha</th>
<th>Herbage composition 2004 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.7</td>
<td>4.2</td>
<td>2.8</td>
</tr>
<tr>
<td>2.8</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>4.9, 5.9, 3.9, 2.9</td>
<td>5.5</td>
<td>3.5</td>
</tr>
<tr>
<td>4.10, 15.10, 15.10</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>4.10, 16.8, 15.10, 21.8</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Not cut</td>
<td>16.8</td>
<td>16.8</td>
</tr>
<tr>
<td>Plots where lupine retreated after 2000, harv. again 2004</td>
<td>21.8</td>
<td>5.2</td>
</tr>
<tr>
<td>Cut 2004 only</td>
<td>15.10</td>
<td>4.3</td>
</tr>
</tbody>
</table>

SED: 0.34 0.49 0.50 0.81 0.94 15 15 5

It seems that cutting lupine annually in early September gives the best result. Lupine still made up the largest part of the herbage although the yield declined at the rate of 0.4 t DM/ha per year. The four different harvest schemes for lupine resulted in similar yield (not significantly different) when harvested on the same date in 2004 although the lupine made up only about one half of the herbage on plots that were harvested in mid August two or three times.

Plots harvested on 4-15 October 2000-2003 showed yield decline from early September except in 2003. Throughout summer the DM content in fresh lupine was ≤25% and often <20%. Plots with <70% lupine had >25% DM at harvest in 2004 on the other hand because other plants have higher DM content than lupine late in the season.

The main advantage of delaying the harvest from August to October is to increase dry matter in the fresh biomass in order to reduce the requirement for field drying before baling. DM in October was 55% and 44% in 2000 and 2002 respectively but only about 30% in 2001 and 2003. Lupine litter quickly disintegrates and under wet and warm conditions the loss in DM yield may be appreciable if harvest is delayed for several weeks in return for only limited gain in DM content. There is no experience of field drying of the lupine. Appreciable losses can be expected, especially mechanical loss of leaves, and in wet weather easily degradable substances will be lost.

2.4. Nutrient requirements

The experimental results summarized in 2.3 were obtained on a fertile field at Korpa Experimental Station without any application of fertilisers. Plant nutrients are removed from the field with the harvest, especially if harvested before wilting, and repeated harvest will, sooner or later, deplete the soil unless replenished with some kind of fertiliser. It is assumed that a large scale lupine cultivation would be concentrated on unfertile, light sandy soils (2.1, 2.2), which are likely to become depleted of nutrients fairly quickly.

A fertiliser experiment has thus been initiated on a very poor site at Geitasandur in southern Iceland in order to gain some insight into the fertiliser requirements of the lupine under such conditions. Four soil samples were taken from the top 10 cm in previously nonfertilized plots, two samples in each of two out of four experimental
replicates. In each replicate one sample was taken half way between lupine plants and the other close to the plants. The mean results for all samples appear in Table 4. Results for elements such as Ca and Mg show similarity to Icelandic andosols whereas organic matter (C and N) content is very low compared to such soils. This is because the topsoil, rich in organic matter, has eroded away. In the samples taken close to the plant C and N were on average 0.35 and 0.035 respectively. Comparison with the overall mean does not indicate accumulation of soil organic matter near the lupine over the five experimental years.

Table 4. Measurements on soil samples. Chemical analyses were done on fine soil (<2mm). pH was measured in water, readily soluble P and cations were extracted in AL-solution (Egner et al. 1960), C and N were measured in samples burnt at 900°C in pure oxygen.

<table>
<thead>
<tr>
<th>Gravel %, mg/100g</th>
<th>meq/100g</th>
<th>% of DM</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 2mm</td>
<td>pH</td>
<td>P</td>
</tr>
<tr>
<td>21</td>
<td>6.6</td>
<td>0.78</td>
</tr>
</tbody>
</table>

The experiment was established in spring 1999 by planting lupine plants and it was first harvested in autumn 2003. The results are summarized in Fig. 3. This is, by nature, a long term experiment but results obtained so far have already shown significant effects of phosphorus (P) and, in particular, sulphur (S).

At harvest on Sept. 2 2003 plants receiving S in the spring were green and lush while other plants were yellow and wilting. Survival was good on the S-plots although the yield was much less in 2004 than in 2003. S-fertilization in 2004 only did not help much (column to the far right, grey colour). P was applied to a treatment yearly from the planting of the experiment. These plants showed some advantage from the beginning but some undervegetation developed also. Survival of lupine plants receiving P and no S was poor.

These results are not unexpected since sulphur is an essential element for protein synthesis. Values of the ratio N/S <20 indicate adequate sulphur supply. Sulphur deficiency has previously been found on light soils in all parts of Iceland (Helgadóttir et al. 1977). Yield samples from the experiment were analysed and the results showed increase in both N- and S-content and a slight decrease in the N/S ratio to values <20.

The results of the experiment show the need for S-fertilisation from the beginning and that fertilisation with phosphorus is also useful for good establishment of the lupine and for increasing the yield. Sulphur is essential for the survival of lupine following harvest. The experiment has only been harvested twice and no effect of the depletion of plant nutrients has been found. The soil is however poor in potassium and the need for potassium fertilisation would probably appear after few years of harvest. Yield declined more rapidly following harvest than on the more fertile field in the experiment at Korpa reported in Section 2.3, even on the plots receiving both P and S. The biomass was still at a low level in 2003 although the plants were established in the greenhouse before planting and had developed in the field since 1999. Fertilisation with sulphur from the beginning might give a better stand. Early
fertilisation with P may encourage the development of other vegetation, especially
grasses, which competes with the lupine thus accelerating the retreat of the lupine
following harvest. A harvesting scheme with harvest every other year should be
considered.

2.5. Techniques for cultivation and harvesting

The Soil Conservation Service has ample experience with establishing lupine fields
all around the country. In later years fields have been established using slot seeders
without prior cultivation, generally with adequate results. Only rarely, fields are either
ploughed and harrowed or harrowed only prior to sowing. At sowing the seed must
be inoculated and scarified to increase germination. Sowing must be carried out as
early as possible in spring to ensure good establishment of the lupine sward. In order
to enhance establishment a cover crop is sometimes used, such as Italian ryegrass,
giving short term cover and it is often fertilised in the year of sowing. The new results
presented in the previous section suggest that on poor soils some fertilization is
needed.

So far lupine fields have only been harvested for seed production. The lupine is then
cut fairly high with a combine harvester leaving a good deal of standing biomass.
With this practice the fields can in most cases be harvested for many years.
Harvesting of biomass for industrial purposes will have to be carried out in the same
manner as for hay production and it will make use of comparable equipment. This
type of harvesting is harder on the lupine than harvesting for seed production. Firstly,
cutting height is much lower, leaving less standing biomass for plant recovery.
Secondly, cutting, turning, gathering and baling of the biomass involves heavy traffic
of machinery of the lupine field. This has not been tested but it is likely that the lupine
plant would be vulnerable to such treatment. It is therefore unrealistic to assume that
fields that are harvested in early September would be harvested for many
consecutive years. It is important to obtain experimental evidence on the persistence
of lupine to repeated harvest and the use of heavy machinery.

The best known technique for harvest and conservation of biomass is to use round
bales. The fresh biomass must be wilted in the field to a minimum of 35-40% DM.
Better results are obtained if it can be wilted to 50-60% DM. This also reduces the
cost of baling and transport since each bale will contain more dry matter and less
water is thus transported. The results presented in 2.3 indicate that delaying harvest
until October is not reliable to get lupine biomass ready for baling without field drying.

2.6. Quality factors

The Nootka lupine is potentially valuable as a lignocellulosic substrate for the
production of fuels or industrial raw material and as a source of valuable alkaloids.
The content of alkaloids is generally expected to decline with time during the summer
although this is not always the case. Alkaloids have been analysed in series of
(Wink 2004, WP2, Final scientific report from UH). Methods of analysis and the
alkaloids determined vary between investigations. The sampling in 1999 and 2000
was very intensive. The results from 2000 show a decline in spartein content from
June to September as expected whereas in 1999 there was a maximum in August. A
further summary of the results is not attempted here.

Cell wall components, protein, ash and in some cases fat were analysed in lupine
samples from 1987, 1988 (Magnússon & Sigurðsson 1995), 1990 (Þórsson &
Guðmundsson 1993), 2000 and 2001. In 1988 the lupine was fractioned into leaves, stem and inflorescence and the fractions analysed separately. Stems are the most important fraction, increasing after June 20 from 56 to 64% (Magnússon et al. 1995) and the other fractions are more prone to mechanical losses in harvest. The results from 1988 cited here are for stems only. Samples from 2000 and 2001 are from the experiment reported in 2.3 and the results are original to this investigation (Table 5). The results are averages of two samples, except fat was determined in only one sample. NDF in samples from 1987, 1988, 2000 and 2001 is shown on Fig. 4. The results from 1987 and 1988 are readings off the published diagrams. The results 1990 were not available for this presentation.

Table 5. Chemical analysis of lupine, % of DM.

<table>
<thead>
<tr>
<th>Date of cut</th>
<th>2000</th>
<th>2001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samples from 2000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17.07</td>
<td>17.5</td>
<td>5.3</td>
</tr>
<tr>
<td>2.08</td>
<td>14.9</td>
<td>7.2</td>
</tr>
<tr>
<td>4.09</td>
<td>12.0</td>
<td>24.1</td>
</tr>
<tr>
<td>4.10</td>
<td>10.4</td>
<td>34.2</td>
</tr>
<tr>
<td>Samples from 2001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not cut</td>
<td>16.08</td>
<td>8.9</td>
</tr>
<tr>
<td>4.09</td>
<td>5.09</td>
<td>5.9</td>
</tr>
<tr>
<td>4.10</td>
<td>9.9</td>
<td>7.3</td>
</tr>
<tr>
<td>SED</td>
<td>0.7</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Ash content was similar to the results from 1987-88 except for the low value in October 2000 that indicates transport of mineral nutrients from leaves and stems to roots. Leaves are however richer in minerals than shoots (Magnússon & Sigurðsson 1995) and loss of leaves in autumn would lead to lower ash content. This difference is small and stems are expected to be >60% so that the loss of leaves is probably not sufficient to explain the decline in ash content.

The content of cell wall material (NDF) increases as the plant matures and it differs between years (Fig. 4). In 1988 the results presented are for stems only and this explains the high values that year. In 2001 the results show decline of NDF from August to September. The August samples are from plots that were not cut in 2000 and the yield was higher than on plots cut in September 2000 (Table 5). This result is typical of the complexity that may occur when dealing with biological material. The increase from September to October is probably enrichment due to loss of easily degradable material rather than formation of new cell wall material. Cellulose was near 49% of NDF in 2000 and 2001 and changed little with time whereas hemicellulose decreased and lignin increased. Lignin was similar in 1987-88 as in 2000-2001, but hemicellulose was less and cellulose higher relative to NDF.

Fig. 4. NDF % of dry matter. SED = 1.1 in 2000 and 2001

2 The values measured were 7.5 and 14.6. The ratio of lignin to cellulose is fairly stable. It was concluded that the value 14.6 was a factor of two off and it was therefore replaced with 7.3.
Lupine has lower content of cell wall material (NDF) than grass or barley as reported in later sections and, consequently, it has greater content of water soluble materials. A further consequence is that the water content remains high (<25% DM) towards the end of the growing season while e.g. grasses develop much higher DM content as the cell walls become more dominant in the biomass. The high content of soluble materials is probably also the reason why the lupine litter reduces so quickly.

2.7. Scenarios for lupine biomass

The current knowledge on the production potential of the Nootka lupine was summarised in previous sections. The results indicate high variability and only limited information is available on the effect of repeated harvests. Small scale production could be restricted to favourable areas yielding about 5 t/ha of DM over a period of four years or even more. On the extensive sandy areas that have been proposed as lupine fields in the future, however, the measurements done so far indicate yields below 3 t/ha DM. Modest use of fertilisers will most likely improve the yield potential so that 3 t/ha DM, average over fields and four years of harvest, is considered the most realistic figure for use in cost evaluations. Higher yield, 4 t/ha DM, is though also considered as a scenario. This could be achieved either by choosing land for cultivation more selectively or by improving cultivation. The latter option would, though, involve some extra costs.

As we lack both practical and experimental evidence on the response of the lupine to repeated harvests over time we consider here two scenarios, either four years or eight years. Yield of lupine fields is expected to decline with time and this should be taken into account when comparing the two scenarios. The decline is taken to be 25% from the first four to the last four years, i.e. to 2.25 and 3 t/ha DM for the scenarios 3 and 4 t/ha DM respectively.

3. Perennial grasses

Perennial grass is the main crop plant in Iceland and covers 90% of the agricultural land currently under cultivation. Grasses are thus probably the best crop for production of biomass when no special qualities are sought.

3.1. Reed canary grass

Grass as a source of biomass has been extensively studied in Sweden and it has been concluded that reed canary grass (Phalaris arundinacea, strandreyr) is the best species for this purpose (Tuveson 1977, Landström 2000). Preliminary results indicate that the same is also the case in Iceland. In Sweden and Finland the recommendations are to let the grass stand until late winter. Although this is at the cost of some loss in biomass there are several advantages. In these countries there is usually a short period in late winter when the standing grass can be harvested with low moisture content so that there is no need for drying. The translocation of minerals to the roots has twofold advantage; (i) there will be less ash remaining after burning the material, this would probably also be an advantage in some other uses of the biomass, and (ii) lower amounts of minerals and nitrogen are removed with the herbage and the need for fertilisation is much reduced.

At Korpa Experimental Station in South-Iceland yield was measured on a ten year old reed canary grass field in 1986 and 1987. The field had only been cut once before and had not been fertilised but the standing biomass was burnt each year in late
winter or early spring. In the two harvest years the field was fertilised in spring with the equivalent of 120 kg N/ha. The mean yield in late August over the two years was 10.8 t DM/ha. A field with *Bromus inermis* (*fóurfax*) and similar history gave 8.7 t DM/ha (RALA Report 124, p. 64-65). In Iceland reed canary grass has been used for making compost in mushroom production with good results (Ragnar Kristjánsson personal communication). The present area is about 150 ha and it is fertilised as a hay field. It is usually harvested in October and dried on the field before baling. It will break if it stands too long.

3.2. Timothy

Timothy (*Phleum pratense, vallarfoxgras*) is the most valuable fodder grass in Iceland. The yield is commonly about 8 t DM/ha when harvested in early August.

In 1979 and 1980 timothy was sampled weekly throughout the summer at Korpa Experimental Station. In 1979, which was a particularly cold and short summer, maximum yield of 9.2 t DM/ha was obtained on 28 August and in 1980, an early and warm summer, maximum yield of 10.6 t DM/ha was obtained on 12 August. These values can be regarded as an estimate of the potential maximum yield. Immediately following the maximum, yield started to decline at approximately the same rate as the previous growth rate, and the loss of protein was even more rapid. The growth rate was about 140 kg DM/ha/day over more than 50 days and this compares well with growth rates of high yielding plants in other countries, although the growing seasons may be longer (Björnsson 1987). Even higher potential yield can be obtained for perennial ryegrass (*Lolium perenne, vallarrýgresi*) but its cultivation is less reliable.

Limited information is available on the sustainability of production of grasses when cut in late season every year. Thus, as a part of the current project an old timothy field, slightly mixed with other grass species and broad leaved weeds, was harvested five times at unconventional harvest dates from 18 August 2003 to 24 May 2004 (Table 5). The fertilisation in spring 2003 was 120 kg N/ha. Fertilisation on 24 May 2004 was 80 kg N/ha and all plots, including plots not harvested before, were harvested on 25 June 2004. The plots were arranged in a randomized block experiment with 4 replicates.

<table>
<thead>
<tr>
<th>Date of harvest 2003-4</th>
<th>DM % 2003-4</th>
<th>DM t/ha 2003-4</th>
<th>DM t/ha 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.08.</td>
<td>25</td>
<td>7.3</td>
<td>4.3</td>
</tr>
<tr>
<td>05.09.</td>
<td>17</td>
<td>7.4</td>
<td>4.2</td>
</tr>
<tr>
<td>15.10.</td>
<td>21</td>
<td>5.8</td>
<td>4.5</td>
</tr>
<tr>
<td>22.03.</td>
<td>84</td>
<td>4.1</td>
<td>4.7</td>
</tr>
<tr>
<td>24.05.</td>
<td>47</td>
<td>4.3</td>
<td>3.0</td>
</tr>
<tr>
<td>Not harvested 2003-4</td>
<td></td>
<td></td>
<td>6.3</td>
</tr>
</tbody>
</table>

**Table 5.** Yield and DM % of timothy cut from late summer to spring and yield the following summer.

Residual effect on yield of different harvest was measured by equal fertilization and harvesting all plots on the same date in 2004. Yield was highest on plots that were harvested in late fall or winter. Although not statistically significant these results suggest that more plant nutrients were available due to recycling of nutrients when the biomass is allowed to wilt prior to harvest as suggested in the previous section. The harvest date in March was chosen following a period of dry weather and the biomass was sufficiently dry to be stored without further drying. The standard error of

Spring growth had started when plots were harvested on 24 May 2004 and the yield was composed of 3.4 t/ha litter and 0.9 t/ha fresh grass. On plots not cut 2003-4 one third of the yield was litter or 2.1 t/ha and 4.2 t/ha green grass. The results demonstrate that wilting had begun on 15 October although the biomass was still wet due to wet weather conditions and lodging of the grass.
difference (SED) for DM % is valid only for comparison of the three earliest harvest dates.

Table 6. Cell and cell wall contents of timothy in late summer and winter 2003-2004 % of DM.

<table>
<thead>
<tr>
<th>Date</th>
<th>Protein</th>
<th>Fat</th>
<th>Ash</th>
<th>Cellulose</th>
<th>Hemicellulose</th>
<th>Lignin</th>
<th>Water soluble</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.08.</td>
<td>6.6</td>
<td>2.2</td>
<td>6.9</td>
<td>29.1</td>
<td>27.2</td>
<td>3.5</td>
<td>24.5</td>
</tr>
<tr>
<td>05.09.</td>
<td>6.6</td>
<td>2.3</td>
<td>7.1</td>
<td>29.9</td>
<td>27.6</td>
<td>3.5</td>
<td>23.1</td>
</tr>
<tr>
<td>15.10.</td>
<td>6.2</td>
<td>2.0</td>
<td>6.2</td>
<td>34.6</td>
<td>39.7</td>
<td>4.9</td>
<td>16.5</td>
</tr>
<tr>
<td>22.03.</td>
<td>4.9</td>
<td>1.6</td>
<td>6.1</td>
<td>38.1</td>
<td>33.5</td>
<td>5.5</td>
<td>10.4</td>
</tr>
<tr>
<td>SED</td>
<td>0.9</td>
<td>0.6</td>
<td>1.0</td>
<td>0.6</td>
<td>0.5</td>
<td>1.3</td>
<td></td>
</tr>
</tbody>
</table>

Cell and cell wall contents were determined in samples from 2 replicates except for fat (one replicate only) (Table 6). No significant changes in forage composition were detected from 20.8. to 5.9. In autumn and winter water soluble cell materials decreased and the cell wall material (NDF) increased from 61 to 77% of the DM. There was also a minor decline in hemicellulose relative to NDF. Timothy contains more cell wall material, although less lignified, than the Nootka lupine. The total cellulose mass decreased from 2.2 t/ha in early September to 1.6 t/ha in March. For uses when cell wall materials are of greatest value the gain by getting sufficiently dry yield, without need for any further drying, may very well outweigh the loss in biomass.

3.3. Other grass species

Some other species like tufted hair grass (Deschampsia caespitosa, snarrótpuntur), Bering hair grass (D. beringensis, beringspunktur) and meadow foxtail (Alopecurus pratensis, hálíðagras) commonly give yields comparable to timothy. Among these, tufted hair grass grows particularly well under sub optimal conditions, such as in infertile sandy soils and where severe winter conditions prevail. It is known, however, to accumulate much silicon and the ash content is high. Some other common species can also be of interest and some of them may yield equally well when cut once and twice.

3.4. Set aside hayfields

The traditional farming sector in Iceland has changed considerably in recent years. Number of dairy cows and sheep has reduced by 22 and 43% respectively from 1980 to 2001. Number of horses has increased on the other hand by 41% in the same period. This has meant that fodder requirements have dropped significantly. At the same time yield from each hectare has increased as a result of changes in hay making techniques and fodder conservation as well as increasing temperature. Fodder is now predominantly preserved in silage bales and this has lead to both higher yield and quality of the fodder. All these changes mean that less cultivated land is required for the conservation of winter forage and thousands of hectares of grass fields will be set aside in the foreseeable future. It is important to find use for these fields for two reasons. Firstly, large investments are at stake that may get lost if the fields are allowed to degrade. Secondly, it is important to find ways to maintain the quality of the cultivation for future needs for fodder and food that may arise unexpectedly in the future.

Set aside hayfields can provide cheap raw material for biomass production. Firstly, their utilisation doesn’t involve any establishment costs. Secondly, in contrast to fodder production species composition of the sward is of little significance as secondary species can give high DM yields if harvested late in the season. There is,
therefore, no need for sward renovation. Thirdly, it is probably possible to get away with less fertiliser than for the production of high quality fodder. Fourthly, biomass production will provide extra income (or become an additional activity) for farmers that are otherwise engaged in the production of meat or milk. All this means that prices for each kg DM produced in this way should be considerably less than for hay primarily intended as high quality fodder (see 5.2).

3.5. Left-over hay bales

In a normal year farmers produce more hay than is required for the winter feeding of the animals. This is essential in order to meet poor hay making years or late advent of spring. Hay is most commonly stored as silage with 50-60% dry matter content in bales covered with several layers of plastic film. It is not practiced to store hay bales for more than one winter so in a normal year farmers have to get rid of some old bales. Under favourable conditions for grass growth, such as in summer 2003, farmers do not even make hay from all the grass that grows on their fields.

For example, the surplus in southern Iceland alone from summer 2002 was approximately 100,000 m³ or 20,000 t DM (The Farmers Association in South Iceland, personal communication). This is unusually much and exceeds the winter feed required of around 20%. The willingness of farmers to sell some of their reserves to a biomass factory would depend on how much the factory would pay in excess of the baling costs. This cost is presently around 2.50 to 4 IKR/kg DM (Agricultural Economics Institute 2003b).

4. Annual crops

4.1. Barley grain and straw

The cultivation of barley is steadily increasing in Iceland and is approaching 3000 ha at present, about half of which is in southern Iceland. A large increase in grain production is forecast in the foreseeable future (Helgadóttir and Hermannsson 2003). The benefits of this development are not only the value of the grain as such. The cultivation of barley introduces crop rotation as a normal farming practice. This is beneficial to other crops and would be of particular value e.g. in the potato growing districts if the farmers could find a market for the grain produced. Experiments at Korpa Experimental Station have shown that a barley field can give a total biomass in the range of 8-10 t DM/ha at 60 kg N/ha. The Harvest Index (HI), i.e. grain in proportion to the total standing biomass, was around 0.5 (RALA Report 208, pp. 50-52). In the context of the present project both the grain and straw biomass as fermentation material might also be an option.

Typically the dry matter in barley grain is composed of 60% starch and 20% NDF and the remainder is mainly protein, fat and ash (Björnsson et al. 2002). The NDF is mostly composed of hemicellulose and about one quarter (5% of DM) is cellulose. Four samples of straw from an experiment with different harvest dates of barley (Björnsson et al. 2002) were analysed for the present study. NDF (cell wall components) increased from 68 to 77% when harvest was delayed for four weeks from 30 August to 27 September and cellulose content increased from 32 to 37%. The fat content was 1.5% of DM. The experimental field was not homogeneous and nitrogen mineralization differed significantly within the experiment. On plots with high N-mineralization the straw continued growing and remained green into autumn, indicating higher protein content. The straw was also less lignified with only 5.1%
lignin compared to 10.5% on plots where the straw stopped growing when the grain matured. Cutting dates did not have effect on lignin content in this small study.

The production of barley grain has to compete with subsidised imports from the EU. If the straw can be given a market value the economy would change. Presently the growers are striving for a high HI. Barley is mostly grown on light soils where the HI is around 0.5 and the protein content in straw is normally \( \leq 4\% \) of DM. On soils that release sufficient nitrogen throughout the growing season, i.e. organic soils and other soils rich in organic matter, the HI will be lower and the maturity of the grain crop is sometimes delayed. The straw becomes less lignified and if it remains green until harvest the protein content may be as high as 6-7%. The total yield of biomass is often greater than on lighter soils and, if the straw has a value, the production may become more profitable.

4.2. Other annual crops

Other annual crops, apart from barley, are efficient in producing biomass since they utilize the growing season better than perennial crops that prepare early for the winter. This includes annual ryegrass, cereals like oats and ryewheat that can not be grown for maturity, root crops like swedes and turnips, and potatoes. These might be considered if qualities other than those found in wilting lupine, grass or barley can be given value.

5. Cost analyses

Three models will be considered in the cost analyses:
1. Lupine harvested in early September for maximum biomass production
2. Grass cut in early September for maximum biomass production
3. Barley grain and straw

Calculations are based on information from the Soil Conservation Service, the Agricultural Economics Institute, the Agricultural Association and through personal communication. All estimates are based on 2003 prices.

5.1. Lupine

A number of assumptions are made in the following simple cost estimates. It is clear that were the assumptions changed the cost estimates would change accordingly. It would be desirable to set up a model involving the different cost parameters to be able to study the effects of changing the assumptions for the various parameters upon the total costs. However, this requires far more information than is currently available.

✔ The costs of field establishment for barley (see below) include ploughing, harrowing, rolling, sowing and fertilising. For the lupine cultivation we assume, on the other hand, that light sandy soils would be selected in the early phases where lupine could be seeded directly into the soil with no prior cultivation. This will reduce costs of field establishment considerably. Experience from fields established by the Soil Conservation Service has shown that germination is often very poor and extensive winter kill occurs, especially where frost heaving is a problem. To improve establishment in certain areas either seed rates could be increased or a cover crop, such as annual grasses, could be used together with N-fertilisation (Magnús Jóhannsson, personal
communication). The results presented in 2.4 indicate that some fields may require fertilisation with phosphorus and/or sulphur for good establishment and development. This would though increase the establishment costs considerably but give better cover and, hence, higher yields in these areas.

The Soil Conservation Service is presently the only producer of lupine seed in the country. Their current price is 3200 IKR/kg. We believe though that it should be possible to produce lupine seed at considerably lower cost, especially if seed production would become a part of the biomass production and therefore we use 1000 IKR/kg in our calculations. We assume the sowing rate of 5 kg/ha without the use of cover crop and N-fertiliser.

✓ Four yield scenarios are used, established as combinations of two factors at two levels each (Section 2.7). Yield t/ha DM is shown in the following table:

<table>
<thead>
<tr>
<th>Yield level</th>
<th>Harvested 4 years</th>
<th>Harvested 8 years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>year 1-4</td>
<td>year 5-8</td>
</tr>
<tr>
<td>Normal (3 t/ha)</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>High (4 t/ha)</td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>

✓ We assume that fields will be fertilised with Superphosphate at the rate of 16 P and 24 S kg/ha at the time of sowing and then every second year throughout the period of utilisation. This equals an annual application of 8 kg P and 12 kg S/ha. More research is required into the use of fertilisers.

✓ The dry matter content of the lupine mass in September is expected to be ≤25%, at least in the early half of the month. This must be wilted on the field to 35-40% DM or more. The currently best known method of collecting the material is baling. The cost of this operation is not evaluated in this report.

- Costs, IKR/ha

<table>
<thead>
<tr>
<th>Establishment</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Field establishment</td>
<td>10,000</td>
</tr>
<tr>
<td>Seed costs</td>
<td>5,000</td>
</tr>
<tr>
<td>Fertiliser at sowing</td>
<td>3,500</td>
</tr>
<tr>
<td>Fertiliser two years from sowing</td>
<td>5,500</td>
</tr>
<tr>
<td>(materials and application)</td>
<td></td>
</tr>
<tr>
<td><strong>Total costs of establishment</strong></td>
<td>24,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Costs in years of production</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertiliser</td>
<td>2,750</td>
</tr>
<tr>
<td>(materials and application)</td>
<td></td>
</tr>
<tr>
<td>Cutting and field drying</td>
<td>4,000</td>
</tr>
<tr>
<td><strong>Yearly costs/ha</strong></td>
<td>6,750</td>
</tr>
</tbody>
</table>

- Cost, IKR/ kg DM

<table>
<thead>
<tr>
<th>Yield level</th>
<th>Harvested 4 years</th>
<th>Harvested 8 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal (3 t/ha)</td>
<td>4.25</td>
<td>3.71</td>
</tr>
<tr>
<td>High (4 t/ha)</td>
<td>3.19</td>
<td>2.78</td>
</tr>
</tbody>
</table>

The results show the importance of developing cultivation and harvesting techniques such that good yields can be obtained over an extended period of years.
Other costs not accounted for:

- **Capital costs**
- **Fencing**
  
  Cost of electric fencing is at present around 140,000 IKR/ha (Handbók bænda 2001). For example, fencing off an area of 1000 ha (25m × 40m) would cost around 2000 kr/ha.
- **Lease of land, including land maintenance, property tax and insurance.**

5.2. Grass

Average cost of hay per kg DM has been estimated by the Agricultural Economics Institute of Iceland (2003a). The calculations include all cost elements, including baling. Factors such as depreciation of investments may be overestimated. The costs refer to high quality hay as forage and utilisable yield is assumed to be 3.85 t DM/ha. Much higher DM yields can be expected from fields where the aim is to produce biomass when no special qualities are sought. The cost has been recalculated for 7 t DM/ha for hay bales and wrapped silage bales as 11.47 and 12.40 IKR/kg DM respectively (Jónas Bjarnason personal comm.). Grass cut late in the season has relatively high dry matter percentage and this would reduce some elements of the cost. The baling cost would probably also be lower than in conventional farming since the equipment is used more efficiently. If the herbage is intended for biomass production it would be possible to economise on the use of fertiliser. This would, however, require some experimentation.

The production of grass as biomass would differ from farming operations in several respects so that the whole cost model would have to be revised. Cultivation of species especially suited for biomass production, such as canary reed grass, is also likely to increase the efficiency. Left-over hay-bales are a source of biomass of special interest and so is herbage from set aside hayfields that would be available at a much lower cost than presented above.

5.3. Barley

The Agricultural Economics Institute (1998) calculated the cost of barley production in Iceland. The costs presented here have been adjusted to present day values and current prices offered by contractors in the field. It is assumed that both the grain and straw are of value for biomass production. Costs at two different yield levels are considered, 6 or 8 t/ha of total biomass.

<table>
<thead>
<tr>
<th>Grain</th>
<th>3 t/ha</th>
<th>4 t/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil cultivation and sowing, IKR/ha</td>
<td>18,000</td>
<td>18,000</td>
</tr>
<tr>
<td>Seed, IKR/ha</td>
<td>10,000</td>
<td>10,000</td>
</tr>
<tr>
<td>Fertiliser IKR/ha</td>
<td>12,000</td>
<td>12,000</td>
</tr>
<tr>
<td>Harvest, IKR/ha</td>
<td>10,000</td>
<td>10,000</td>
</tr>
</tbody>
</table>

**Total costs for barley grain, IKR/ha**

- 50,000
- 50,000

**Price, IKR/kg DM**

- 16.67
- 12.50

**Baling of straw, IKR/ha**

- 8,700
- 11,600

**Total costs, IKR/ha**

- 58,700
- 61,600

**Price, IKR/kg DM**

- 9.78
- 7.70
These figures do not include costs of fungicides and herbicides. This is a growing problem as barley cultivation becomes more extensive in the country and can involve considerable costs, especially where cultivation is carried out for a long time in the same fields. We don’t assume that the grain will be delivered dry from the farmer. Wet grain is commonly stored in large bales at some additional cost.

Currently, the grain has to carry all these costs except for the baling of straw. Small amounts of the straw have a market value of 5-7 IKR/kg DM, based on the quality of the product. If all the biomass from the barley cultivation, i.e. both the grain and the straw, can be utilised in the fermentation process the average costs for 6 and 8 t/ha of biomass would then be 9.78 and 7.70 IKR/kg DM respectively.

5.4. Summary of cost analyses

The three analyses of cost of biomass from lupine, grass and barley are carried out on different grounds so that the results can not be compared directly. The analysis is most complete for barley with straw. In order to make the cost of lupine comparable the cost of collecting the biomass, baling or otherwise, must be added. The cost of having to wait four years for the first harvest must also be taken into account. The cost of grass production is again analysed in a different way. If intended for biomass production it will, in most cases, cost less than barley with straw, especially if available from set aside fields or as left over bales.

6. Conclusions

The analyses carried out in this study show that there are several options available for procurement of biomass in Iceland. Most attention is, in this report, given to the Nootka lupine, grass and barley. Estimates of their feasibility depend to a large extent on the assumptions that can be made. The most important factor is the DM yields that can be obtained from each hectare of land.

The Nootka lupine has, so far, not been used for continuous production of any kind except seed harvest and experimental results of sustainable biomass production are very limited. It is particularly well suited for sandy areas that are presently non-productive and the cultivation could in some cases be included in a program of land reclamation. Fertilisation with phosphorus and sulphur is in some cases required and, in a longer perspective, fertilisation with other nutrients would also be required. The cost of cultivation, cutting and wilting of the crop was estimated for four scenarios of yield and longevity of the lupine in the field. The estimates range from 2.78 to 4.25 IKR/kg DM. The range of these estimates is an indication of the need to obtain more reliable results on lupine cultivation and harvest.

Fairly good experience and experimental evidence is available on the yield that can be expected from grass and barley fields, indicating that grass in particular could probably be an economic source of biomass. Research, specially designed for the production of biomass, is though needed. Late cut grass contains more cell wall material, although less lignified, than the lupine. Set aside hay fields and left over bales are an economic but limited source of biomass that would be a valuable addition to any other source of biomass.
7. References


