European grasslands overview: Nordic region

Aslaug Helgadottir
The Agricultural University of Iceland

B. E. Frankow-Lindberg
Swedish University of Agricultural Sciences

Liv Østrem
NIBIO - Norwegian Institute of Bioeconomy

European grasslands overview: Nordic region

Helgadóttir Á.[1], Frankow-Lindberg B.E.[2], Seppänen M.M.[3], Søegaard K.[4] and Østrem L.[5]
[1]*Department of Land and Animal Resources, Agricultural University of Iceland, Árleyni 22, IS-112 Reykjavík, Iceland*
[2]*Department of Crop Production Ecology, Swedish University of Agricultural Sciences, P.O. Box 7043,SE-750 07 Uppsala, Sweden*
[3]*Department of Agricultural Sciences, P.O. Box 27, FI-00014 University of Helsinki, Finland*
[4]*Department of Agroecology, Aarhus University, P.O. Box 50, DK-8830 Tjele, Denmark*
[5]*Bioforsk - Norwegian Institute for Agricultural and Environmental Research, Fureneset, NO-6967 Hellevik i Fjaler, Norway*
Corresponding author: aslaug@lbhi.is

Abstract

The Nordic countries stretch over a large geographic area and, hence, conditions for plant growth vary considerably across the region. The western regions along the North Atlantic Ocean enjoy a mild maritime climate whereas continental climate prevails in the eastern part. Temperature variations have implications for the length of the growing season and Accumulated Day Degrees, thus influencing the timing and number of harvests in different areas across the region. Grasslands in the Nordic region are a diverse group and their relative importance differs greatly across countries. Thus, natural grasslands are extensive in Iceland and play an important role for livestock production, whereas they are much less significant in the other countries. Semi-natural grasslands are used for grazing but they are also important for maintaining biodiversity and landscape types. Forage for winter fodder and dairy in summer is obtained from cultivated grasslands of which short-term leys dominate in the southern regions. Milk and beef is the dominant produce, particularly in Denmark, whereas lamb and horse meat is a significant part of the production in Iceland. The expected climate change at northern latitudes will result in a longer growing season and higher temperatures during the growing season, both of which may lead to increased biomass production potential. However, new types of stresses may offset the potential gain. This will have various implications for adapting forage cultivars to the changing conditions both through breeding and different management schemes.

Keywords: agricultural production, climate, forage mixtures, local adaptation, soil

Geography and the natural environment

The Nordic region consists of the Nordic countries, the Faroe Islands, Greenland and Åland. The present paper will primarily focus on grasslands in the five Nordic countries: Denmark, Finland, Iceland, Norway and Sweden. These countries stretch over a large geographic area from 54° 58' N in the south of Denmark to 71° 08' N in Northern Norway, and from 24° 32' W in the west of Iceland to 31° 35' E on the eastern border of Finland with Russia (Figure 1). There are currently around 25 million inhabitants, making the region one of the most sparsely populated parts of the world. Iceland thus has around 3 inhabitants per km^{-2}, Sweden, Norway and Finland each have 16–23 inhabitants km^{-2} whereas Denmark has 130 inhabitants km^{-2}, a value close to the EU mean.

Climatic conditions

Conditions for plant growth vary considerably across the region, reflecting its wide geographic spread. The Gulf Stream brings warm sea from the Gulf of Mexico into the North Atlantic Ocean resulting in a milder climate than could otherwise be expected from the geographic location. However, various factors can affect the temperature as indicated for example by the

10 °C isotherm line in July, which falls below the Arctic Circle in Iceland but stretches well beyond in Northern Scandinavia (Figure 1). The difference in daily mean temperature during the warmest period in summer between the warmest (e.g. Helsinki, FI) and coldest agricultural areas (e.g. Akureyri, IS) is thus around 7 °C and temperature can vary up to 5 °C between coastal areas (Reykjavík, IS) and inland (Kajaani, FI) at the same latitude during summer (Figure 2). Temperature variations have implications for the length of the growing season and Accumulated Day Degrees, thus influencing the timing and number of harvests in different areas across the region. The growing season can be defined as the number of days from when the daily mean temperature exceeds 5 °C in spring and falls below 5 °C in autumn (SNP, 1992). The length of the growing season varies thus from around 230 days in the south west, to around 125 days in the northern-most and high altitude regions where agriculture is at its limit (Table 1). Similarly Accumulated Day Degrees (Tsum >5 °C) are currently only around 640 in Reykjavík (IS) compared to 1732 in Tranebjerg (DK), and 1020 – 1150 at Værnes (NO), Holmögadd (SE) and Kajaani (FI), which are at comparable latitudes to Reykjavík.

Figure 1. The Nordic region showing the Arctic Circle (broken line) and the 10 °C isotherm for July (solid line). Letters show geographic locations of sites listed in Table 1.

Temperature conditions during autumn and winter vary similarly across the region, both from north to south and from coast to inland at the same latitude (Figure 2). In the more maritime regions winters are often relatively mild with mean temperatures during the coldest month varying from around 2 °C in Sola (NO) and Tranebjerg (DK) to -3.5 °C in Tromsø (NO). Here, winters are characterised by unstable snow cover and frequent freeze-thaw cycles. In the more continental regions to the east of the Norwegian mountain range temperatures during winter are, on the other hand, much lower ranging e.g. from around -5 °C in Helsinki (FI) to -13 °C in Sodakylae (FI) resulting in much more stable winters. Such varying conditions during winter have different implications for winter damages of grasslands across the region.

Soil conditions

Most soil types in the Nordic countries are formed on glacial materials from the last ice age (European Commission, 2005). Large areas of Sweden and Finland are covered by a continuous layer of glacial till dominated by podzols but these tend to be weakly developed in the northernmost parts. In Norway, on the other hand, the glacial till is thin and discontinuous, exposing large areas of bare rock, and varying both in texture and nutrient value. Smaller areas of sandy glacio-fluvial deposits can be found in all three countries. In the low-lying coastal areas along the Gulf of Bothnia silty and clayey deposits are common, while marine and river deposits around fjords and in valley bottoms are most important parent materials for the agricultural soils in the middle and southern parts of Norway. Peat covers around 15% of the area in Finland and Sweden, while in Norway peat soils constitute a considerable part of agricultural land in the western and northern part, all of which is used for grassland. Peat soils are acidic, of low nutrient value and have to be drained. Land use in Sweden is dominated by forestry (56% of land) while agriculture covers approximately 7% of the area. The best soils are mainly used for growing cereals and oil crops, while grassland production most often occurs on the better soils in forested areas, or poorer soils in otherwise crop dominated areas. In Denmark Podzol forms a continuous block over nearly the whole western half of Jutland. The sandy Podzols in the far west are unfertile and limit agricultural activity unless heavily fertilized and limed. These regions were almost all covered by heath until the beginning of the 20th century. In the eastern part of the country Haplic Luvisols, the most productive soils, predominate. Dairy farms are primarily placed on loamy-sand or coarse sandy soil where the plant available water is around 90 and 60 mm, respectively. Therefore most of the intensive managed grasslands on sandy soils are irrigated at drought stress. Soils in Iceland originate from parent material of recent volcanic origin, which consists mostly of basaltic tephra, and are classified as Andosols (Arnalds, 2004). Such soils generally contain a range of pore sizes that can retain large amounts of water. They are high in organic C and N, and have a strong tendency to fix phosphorus. All these characteristics provide an excellent environment for root growth (Nanzyo *et al*., 1993).

The role of grasslands in agricultural production and environmental protection

Extent and importance of different types of grassland

Grasslands in the Nordic region are a diverse group that can be classified in various ways depending on their origin, vegetation type and/or current land use. In this paper we will primarily focus on grasslands that play a role in animal husbandry. We will follow the definition of grassland as a term that 'bridges pastureland and rangeland and may be either a natural or an imposed ecosystem. The vegetation of grassland in this context is broadly interpreted to include grasses, legumes and other forbs, and at times woody species may be present' (Allen *et al*., 2011). In our discussion we will further divide grassland into three major types with respect to origin (Hejcman *et al*., 2012): (i) natural grasslands dominated by indigenous grasses and other herbaceous species; (ii) semi-natural grasslands created by long-term human intervention and with a wide range of species richness and herbage productivity; and iii) improved grasslands established with domesticated forage species that receive intensive management (fertilization, weed control, renovation).

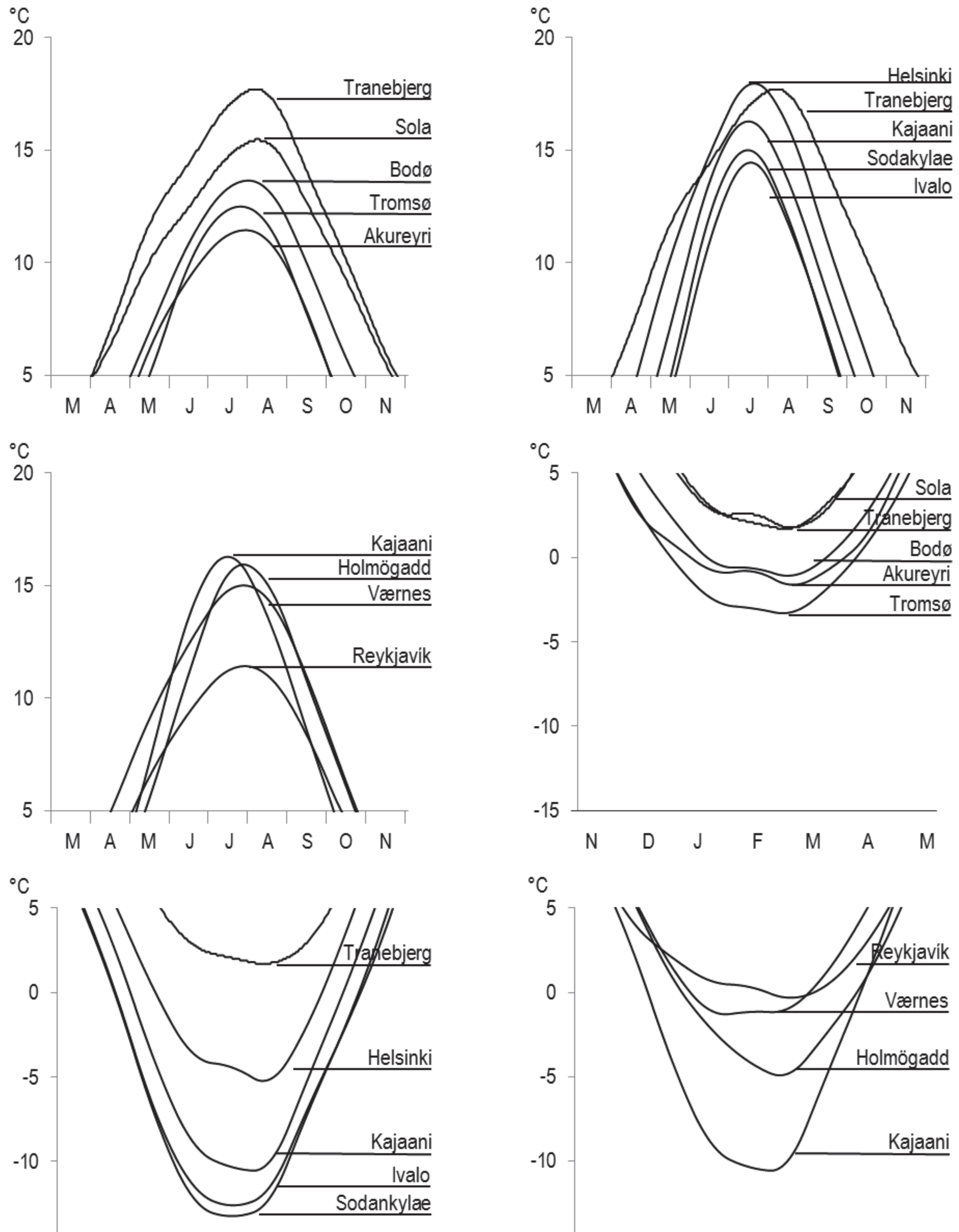

Figure 2. Estimates of mean temperature for each day of the year for the period 1986-2005 during summer (T>5 °C) and winter (T<5 °C) for selected sites in the Nordic countries, going from south to north in the maritime West (left) and continental East (centre), and from West to East at the same latitute of around 64°N (right) (for information of geographic location, see Table 1 and Figure 1) (estimates based on an improved method from Björnsson *et al*., 2007).

Table 1. Geographic location, length of the growing season (T>5 °C) and Accumulated Day Degrees (° D; Tsum>5 °C) for selected sites in theNordic countries, based on estimates of mean temperature for each day of the year for the period 1986-2005 (Björnsson *et al*., 2007).

	Site	Latitude	Longitude	Growing season		
				Period	No. of days	°D
A	Akureyri (IS)	65.7° N	18.1° W	9 May – 1 Oct.	146	669
B	Bodø (NO)	67.3° N	14.4° E	2 May – 19 Oct.	171	900
C	Helsinki (FI)	60.3° N	25.0° E	21 April – 18 Oct.	181	1379
D	Holmögadd (SE)	63.6° N	28.8° E	13 May – 20 Oct.	161	1028
E	Ivalo (FI)	68.4° N	27.3° E	21 May – 22 Sept.	125	718
F	Kajaani (FI)	64.3° N	27.7° E	6 May – 3 Oct.	150	1020
G	Reykjavík (IS)	64.1° N	21.9° W	4 May – 9 Oct.	159	642
H	Sodankylae (FI)	67.4° N	26.7° E	17 May – 21 Sept.	128	785
I	Sola (NO)	58.5° N	05.3° E	3 April – 17 Nov.	229	1391
J	Tranebjerg (DK)	55.9° N	10.6° E	2 April – 21 Nov.	234	1732
K	Tromsø (NO)	69.7° N	18.9° E	16 May – 1 Oct.	139	659
L	Værnes (NO)	63.5° N	12.9° E	17 April – 21 Oct.	188	1145

Natural grasslands

Virtually all of Icelandic grasslands are either rangeland or pastureland and therefore important for livestock production. There are discrepancies as to how grassland in Iceland has been defined. In connection with the land-use related GHG emission reported to the UN-Framework Convention on Climate Change, the Icelandic land-use category Grassland is defined as all land with > 20% coverage of vascular plants, and not included under categories Forest land, Cropland, Wetland or Settlement, and estimated to be 53,000 km^2 or 51% of the country (Gudmundsson *et al*., 2013). On the other hand, according to results obtained from the Icelandic Farmland Database, which classifies the surface of the country into twelve different classes based on satellite images and field research (Arnalds and Barkarson, 2003), only around 43,000 km^2 or 42% of the country is vegetated (Arnalds, 2011). In the present context two of these classes could be truly classified as natural grassland; 'grassland' being 2,375 km^2 or 2.3% of the country and 'rich heath' 6,843 km^2 or 6.6% or a total of 9,218 km^2 (Table 2).

Table 2. The extent of different types of grasslands (in thousand hectares) in the Nordic region.

	UAA[1]	Cultivated grasslands	Semi-natural grasslands	Natural grasslands
Denmark	2,645	332	200	0
Finland	2,285	650	40	0
Iceland	130	120	42	922
Norway	990	470	177	?
Sweden	3,030	1,100	440	0

[1] Utilizable Agricultural Area

These areas are characterized by low-growing vegetation of grasses, sedges, forbs and woody perennials. They are the most valuable part of the rangelands and used for extensive summer grazing of sheep and horses from the end of June to early September when the animals are rounded up. Around 40% of these natural grasslands are found above 200 m and each local community has grazing rights in the common grazing areas of the highlands. Roughly half of the required feed for sheep and a large part of feed for horses is obtained from summer grazing on the natural grassland.

The grazing resources of outlying fields in Norway are significant and these are currently being surveyed. Preliminary data for a grazing period of 100 days year^{-1} show that about 760,000 FEm (milk feeding units) may be utilized (Rekdal, 2013). Natural grassland rarely occurs in Sweden, Finland and Denmark.

Semi-natural grasslands

The Icelandic Farmland Database defines 'cultivated land' as being 1,723 km^2 or 1.7% of the country (Arnalds, 2011). Of this it is estimated that around 42,000 ha are 'abandoned crop land' (Gudmundsson *et al*., 2013). Most if not all of this consists of old hayfields that have been taken out of use, mostly because of structural changes in agricultural production over the last few decades. In the present context these old grass fields can be defined as semi-natural grasslands in Iceland (Table 2). Some of these have been used for hay making over centuries but mostly they originate from the cultivation era that started around 100 years ago (Helgadóttir *et al*., 2013). Even though most of the fields were originally sown with improved grass cultivars they are now dominated by indigenous species. Such ecotypes may become valuable for future breeding (Rognli *et al*., 2013a).

In Norway grasslands are defined as areas covered with grass that may be mechanically harvested or grazed but never ploughed and that may be cultivated by fertilization, harvested mechanically and improved by selected species (CPA, 2013). Grazing lands are assigned to areas with at least 50% grass cover and annual grazing. Trees, stumps, and rocks may be present but grazing is considered the most important land use form either as surface-cultivated grass leys or unimproved grazing land (NFLI, 2011). Statistics Norway (2014) further defines the two types of grassland management: (1) surface-cultivated pastures have shallow topsoil layers, often with surface rocks, and can be mechanically harvested but are not ploughed, and (2) unimproved grazing land is never mechanically harvested (or ploughed) but only grazed and can be considered semi-natural landscapes. For the second class at least half of the area should be covered by grasses or palatable herbs and enclosed by a fence or a natural barrier. It must also be grazed or harvested at least once a year to be eligible for subsidy support (Kynding Borgen and Hylen, 2013). Such areas will also include active summer farms that still can be found in specific regions. In 2012 semi-natural grasslands amounted to 177,000 ha of which 20,000 ha were surface-cultivated pastures and 156,000 ha were unimproved grazing land (Statistics Norway, 2014) (Table 2).

In the past, Sweden had large areas of semi-natural grasslands, culminating at around 1.6 million ha at the end of the 18^{th} century (Statistics Sweden, 2013), that were mainly used to provide winter fodder. Summer grazing took place in the forests. Today, only some 440,000 ha of these semi-natural grasslands remain, almost all of which are now used for grazing (Table 2). They play an extremely important role for the protection of biodiversity in the Swedish landscape, and farmers can receive subsidies if they are managed according to a set of rules aimed at the preservation of biodiversity (no fertilization, specified grazing regimes). The output in terms of animal produce is low but the marketing of beef to a premium price from cattle that have grazed in these areas is increasing.

In Denmark semi-natural grasslands cover 200,000 ha and are either not ploughed at all or only rarely. Some of these are on wet organic or sandy soils along rivers, near the coastline or on old hilly grasslands. This is therefore a very heterogeneous group with respect to yield, species composition and use. The aim of the authorities is to preserve these permanent grasslands in order to enhance a landscape of light and open (non-forest) river valleys and to maintain biodiversity. Strict rules apply to the management of these grasslands.

Semi-natural grasslands are of minor significance in Finland and most of these can be found in coastal areas where the aim is to keep the landscape open to encourage bird life and natural meadows (Table 2).

Cultivated grasslands

The total area of cultivated land in Iceland in current use is around 130,000 ha (Table 2), of which approximately 45% is on drained wetland (Hallsdóttir *et al*., 2012). Around 90% of this area is used for permanent grass fields, most of which are older than five years and the remainder is under annual crops of which 5,000 ha are currently used for barley. Grassland or cropland constitutes about 3.0% of total land area in Norway, and in 2012 total agricultural land amounted to 990,000 ha of which cultivated leys constituted 470,000 ha or 73% of the total grassland area. Grass leys in rotation with other crops are classified as cropland so the grassland area is actually higher than shown by Statistics Norway (2014) (Kynding Borgen and Hylen, 2013). In 2008, 60% of the grassland was owned and 40% rented land (STM2011-2012). In Sweden, short-term leys on arable land dominate the production of forage for winter feeding and grazing. Today they cover approximately 1.1 million ha, or 45% of the arable land area (Statistics Sweden, 2013). Cultivation of forage maize occurs on approximately 20,000 ha and is increasing. In Finland cultivated grasslands cover 650,000 ha or 28% of the utilizable agricultural area. Cultivated grasslands are around 330,000 ha or 13% of the utilizable agricultural area in Denmark and include grass and clover in grass-arable rotation. Other main forage crops are maize and cereal and pea whole-crop, which constitute 184,000 and 54,000 ha, respectively (Statistics Denmark, 2012).

Management of cultivated grasslands and their production potential

The livestock

The number of farm animals varies considerably across countries both in absolute terms and relative to population size (Table 3).

Table 3. Number of farm animals (total no. in thousands and per thousand inhabitants) and main agricultural produce from grassland in the Nordic countries in 2012.

Country	Dairy cows		Sheep		Horses		Goats	
	Total ×1000	Per 1000 inhabitants	Total ×1000	Per 1000 inhabitants	Total ×1000	Per 1000 inhabitants	Total ×1000	Per 1000 inhabitants
Denmark	568	101	160	29	60	11	?	?
Finland	284	52	130	24	31	6	5	<1
Iceland	25	77	476	1480	77	240	1	3
Norway	233	46	906	144	36	7	35	7
Sweden	348	37	610	64	363	39	5	<1

Country	Milk		Lamb meat, t		Beef, t		Horse meat, t	
	Total, ML	L per inhabitant	Total	Per 1000 inhabitants	Total ×1000	Per 1000 inhabitants	Total	Per 1000 inhabitants
Denmark	4909[1]	877	2000	<1	142	25	1000	<1
Finland	2188	404	950	<1	81	15	487	<1
Iceland	127	396	9920	31	4	13	1510	5
Norway	1531	305	17500	3	78	16	140	<1
Sweden	2861	300	5030	<1	121	13	1160	<1

[1] Of this 9% is organically produced

The numbers of both sheep and horses per inhabitant are highest in Iceland whereas dairy cows are of greatest importance in Denmark. In Iceland dairy cows are usually housed from early September to late May and are grazed on cultivated grass fields during summer. With the advent of automatic milking it is though getting more common to keep milking cows inside for the whole year, with access to grazing. Most sheep farmers house their flocks from November to May. Riding horses are similarly housed from November to May but otherwise the Icelandic horse is, by tradition, kept outdoors all year around. Dairy cows are mainly fed indoors all year in Norway. The -razing period for stabled dairy cows is 8 weeks, whereas in loose-housing dairy cows should, from 2014, have the possibility to 'exercise and move around' outdoors for at least 8 weeks during the summer period. In some regions, where the main calving time is during autumn, dry cows may be grazed during summer. The housing of sheep varies much across the country depending on the duration of winter. Sheep will normally be kept indoors for one to three weeks after lambing (mid-April–mid-May), followed by some weeks of on-farm grazing before being taken to the areas of summer grazing. The sheep return to the farm in early/mid-September. The Old Norse sheep breed (*Ovis aries*) (3% of total sheep number) is being grazed all-year round, however, with strict regulations for animal welfare to secure feeding possibilities during harsh winters. Dairy cows are the main consumers of forage in Sweden and Finland. Grazing is compulsory by law for dairy cows and provides forage from May/June until the end of August/September, depending on latitude. However, supplementary feeding of dairy cows during summer is very common. In Denmark conventional dairy cows (+heifers and calves) are mostly kept in the stable the whole year, whereas the organic dairy cows are grazed at least 150 days for a minimum of 6 hours a day, in accordance with the rules.

Harvest management

Most of the fodder produced for winter feeding is ensiled either with or without additives in round bales or bunker silos in all countries. Dairy farmers in Iceland aim to take the first cut around the heading of timothy, which may occur as early as the middle of June in the more favourable regions. A second cut is usually taken on these fields around the middle of August. On sheep farms the first harvest is commonly delayed until early July and the fields are used for grazing in early spring and again in autumn for fattening the lambs prior to slaughter, rather than taking a second cut. Where two cuts are taken from hay fields about two-thirds of the fertilizer is applied in spring and one-third after first cut. Otherwise all fertilizer is applied in spring. Nitrogen inputs vary around 100 – 140 kg ha^{-1}. In addition most farmers use animal manure to its fullest potential. In Norway fields are cut three times in the more favourable regions, in early June, late July and mid-September, whereas only two cuts are taken in the middle of June and again in the middle of August where the growing season is shorter. In Sweden and Finland winter feed is produced on intensively managed short-term leys with inputs of 150 – 250 kg N ha^{-1} and two to four cuts per season, depending on latitude. The aim is to cut the first harvest at the beginning of heading, or at >80% IVOMD (*in vitro* organic matter digestibility). In addition most farmers use animal manure to its fullest potential. This is also the case in Denmark. There dairy farmers aim to take the first cut at a certain IVOMD or NEL (net energy lactation) concentration, and they decide the cutting time from a herbage sample and an on-line prognosis which calculates the decrease in feeding value due to growth and the effect of weather on the decrease rate. The targeted nutritive value depends on the feeding ration on the farm, but is typically 80% IVOMD. The recommended cuts are five and four for red and white clover mixtures respectively. For beef cattle, sheep and goats there is less focus on nutritive value. The maximum N-application in intensive managed grasslands is around 240 and 360kg ha^{-1} in grass-clover and pure grass, respectively. In permanent grasslands, N varies from 0 – 130 kg ha^{-1}, depending of production level, use and nature value. Most of the applied N comes from slurry, all of which must be injected. The only other possibility is acidification and using trailing hoses.

Production capacity

According to the Icelandic Agricultural Statistics (Statistics Iceland, 2013) the mean fodder yield obtained in 2011 was 4,012 and 2,720 FEm ha^{-1} for dairy and sheep farms, respectively (Statistics Iceland, 2013). The total fodder produced on-farm in the whole country was worth a total of around 54 million Euros in 2011, which was around 55% of the total fodder costs for the whole agricultural sector that year (Statistics Iceland, 2013). Most of this was roughage obtained from hayfields. Barley produced locally has been sufficient to supply around 40% of the concentrate use in the dairy sector.

In Norway the mean fodder yield is estimated to be around 4,000 and 3,500 FEm ha^{-1} on dairy farms and sheep farms, respectively (Bakken and Johansen, 2014; A.K. Bakken, personal communication). There is no exact on-farm dry matter yield (DMY) registration, but estimated DMY and the amount of milk and meat being produced indicates a reduction in grass yield over the last few years. Important reasons are poor soil cultivation, need for drainage and use of heavier agricultural machinery. Increased conservation in round bales also may have caused increased loss due to wilting (Lunnan, 2012). Organic grassland (ley and grazed area) constituted <10 % of total area in 2012 (DEBIO, 2012). Imported feed constitutes 32% of the total feed and especially the protein fraction is increasing (SLF). If imported soya used for feed is included the imported feed is 38%. A higher degree of food self-sufficiency in Norway will require considerable changes of the diet from animal-based food to fish and plants grown in Norway (Bakken and Johansen, 2014).

In Sweden the intensively managed short-term leys yield 7 – 12 tons dry matter ha^{-1}, with a digestibility of >80% and a crude protein of around 15%. In Finland the yield is 5 – 10 tons dry matter ha^{-1}. This fodder is primarily used for dairy and beef cattle. Forage for horses and suckler cows is less intensively cultivated, and is generally harvested at a later phenological stage.

In Denmark the potential production is around 12,000 FE (90,000 MJ net energy), but due to different losses in the feed processing the net energy yield (energy consumed by the cows) was 8,410 and 2,560 FEm ha^{-1} on intensive grasslands (in crop rotation) and permanent grasslands, respectively (Statistics Denmark, 2012). For the whole country, home-grown fodder accounted for 79% and imported for 21% of the total requirements. For forage crops 97% was produced locally and 3% was imported.

The main agricultural produce obtained from this fodder in the different countries can be seen in Table 3.

Procurement of suitable plant material

Breeding for local adaptation

In a European context the main limiting factors for forage crops in the Nordic environment are a short and cool growing season and various winter stresses such as frost, ice encasement, low temperature fungi, prolonged snow cover, water-logging and low light intensity (Figure 2). Temperature and photoperiod are probably the two most important factors that control phenological development and play a decisive role for the adaptation of perennial fodder crops. This is of special importance for growth cessation of perennial crops in the autumn and obviously complicates the transfer of forage crops within the region. The photoperiod is directly related to latitude and can thus vary within the Nordic region from 14 to 24 hours and from 9 to 12 hours at the beginning and the end of the growing season, respectively. Temperature, on the other hand, can vary considerably at the same latitude, as discussed earlier, making transfer of material even more complicated. One way of dealing with such genotype-environment interactions is to calculate agroclimatic indices. These are commonly based on Accumulated Day Degrees, which are related to plant growth and development, and have been applied successfully, together with indicies reflecting the risk of winter damage, for assessing overwintering of perennial crops in Eastern-Canada (Bélanger *et al*., 2002) and Norway (Thorsen and Höglind, 2010).

When dealing with the whole Nordic region it is sensible to define agroclimatic areas that differ in climatic conditions for plant production (SNP, 1992). One attempt has been made to construct such agroclimatic zones based on results from variety trials with timothy across the whole Nordic region (Björnsson, 1993). The outcome was five internordic zones based on similarity of results and geographic considerations. Interestingly though, in a recent study of molecular variation (SSR markers) of local Nordic timothy populations and cultivars, only 6% of the variation was between populations, and no variation was found between cultivars and local populations (Rognli *et al*., 2013a). The results for timothy are in stark contrast to meadow fescue where local Nordic populations show clear geographic structuring based on molecular variation (Fjellheim and Rognli, 2005; Fjellheim *et al*., 2009). Similarly, Finne *et al*. (2000) found highly significant genotypic variation between local populations of white clover collected from a wide range of latitudes and altitudes in Norway.

Breeding of grassland species for Denmark and different areas of Norway, Sweden and Finland has been carried out for over a 100 years. In the early days, natural selection in local material was the main method to extend the area in which a population performed well. Natural selection was likewise used to increase the resistance to various pests and diseases. Poly-crossing and progeny testing of individual plants selected for good performance followed by mass selection is nowadays the most common method. The original plant material may then be of indigenous or foreign origin, depending on the species in question. Icelandic agriculture has to a large extent depended on the import of forage cultivars. Not unexpectedly, the most suitable material has originated from the northern areas of Norway and Sweden. Northerly adapted plant material is generally characterized by low yields, slow regrowth potential after first cut and reasonable tolerance to frost and ice encasement. Timothy (*Phleum pratense*) is the only forage species for which cultivars have been bred specifically for Icelandic conditions.

Selection of appropriate species

Not surprisingly the choice of appropriate species varies depending on the geographic location. Timothy has been the major grass species in the Nordic region north of 60° N. Timothy is thus by far the most important fodder species in Iceland. It has a clear quality advantage over other grass species that are currently available for forage production in Iceland, both with respect to mean dry matter digestibility (DMD) and daily voluntary DM intake (see Helgadóttir *et al*., 2013). Similarly in Norway and Sweden and Finland, timothy is the only grass species that can be grown successfully almost anywhere because of its superior persistence (Larsen and Marum, 2006; Østrem *et al*., 2013). Where it is the main species in seed mixtures, the harvesting dates are mostly determined by the developmental stage of timothy. An increased regrowth capacity will, however, be required in a prolonged growing season. Meadow fescue (*Festuca pratensis*) is a well-adapted grass species and is frequently used in timothy-based mixtures in these countries, and in mixtures for combined cutting and grazing, smooth meadow-grass (*Poa pratensis*) is a winter-hardy species. Perennial ryegrass (*Lolium perenne*) has played a role in the more maritime regions south of 60° N. It has for many years been the most important grass species in Denmark because of high nutritive value (Søegaard *et al*., 2010) and it is also grown successfully in the southern parts of Sweden but here always in mixtures with other grasses as it is still too unreliable to be grown in monoculture. With its high biomass yield and regrowth capacity, and superior feed quality perennial ryegrass will undoubtedly become a promising option at higher latitudes with prolonged growing season and milder winters. The same is true for ×*Festulolium* hybrids (Østrem and Larsen, 2010). *Festulolium* holds a vast genetic variation (Ghesquière *et al*., 2010) and several *Festulolium* hybrids have been introduced in the last 10 years to Sweden, Denmark and Norway. Compared to perennial ryegrass it has an earlier spring growth and a lower nutritive value at the same date. Farmers therefore harvest mixtures with *Festulolium* in spring about one week earlier than mixtures with perennial ryegrass only. Targeted breeding goal for *Festulolium* is to understand the mechanisms behind the growth cessation to secure cold hardening and winter survival. For high latitudes the allotetraploid approach, including the full genome of both parental species, seems to be the most useful approach for exploiting the genetic variation, among others for winter survival, in the combination of *L. perenne* and *F. pratensis* (Østrem *et al*., 2013). The more deep-rooted tall fescue (*Festuca arundinacea*) might become a more important species also at high latitudes, due to possible drought incidences in spring/early summer in a changing climate (IPCC, 2013). When tall fescue is one of the parents, cultivars of *Festulolium* have proved a winter hardy alternative in the Nordic-Baltic region (Gutmane and Adamovics, 2008; Halling, 2012; Østrem *et al*., 2013).

Red clover (*Trifolium pratense*) and white clover (*T. repens*) are the most important legume species in the Nordic countries (Marum, 2010). In Sweden red clover dominates followed by white clover and lucerne, which is an important species in the drier eastern parts of the country. In Finland red clover is the most important forage legume. In Denmark white clover was successfully reintroduced in the 1990s after the high-N period during 1960-1990. Red clover was reintroduced a few years later. The main reason for using clover in Denmark, Finland and Sweden is the well-known higher intake of clover mixtures, demand for reduced N-application and a general perception of better quality. Today the goal for nearly all intensively managed grasslands in Denmark is to have a high content of clover, which means at least 50% in the summer period. In organic farming clover has a significant impact on the whole crop rotation system. However, white clover fatigue has been a big challenge due to a high proportion of clover in the grazing area for the cows close to the stables (Søegaard and Møller, 2005).

The importance of forage mixtures

Species mixtures are the norm in all countries. Mixtures provide yield stability over time, as well as an extended period over which a good feeding quality can be maintained. A typical mixture for large areas where grassland farming is important would contain timothy, meadow fescue, perennial ryegrass, red and white clover in different proportions depending on location, soil condition, planned sward duration and the use of the herbage. In Sweden all-grass mixtures (timothy, meadow fescue and perennial ryegrass) are grown for the production of forage for horses. Recent pan-European experiments have shown that grass-legume mixtures are more productive and show greater yield stability over time than their individual components in monoculture irrespective of fertilizer treatment (Finn *et al*., 2013) and in the northern regions higher yields were not at the cost of poorer nutritive value (Sturludóttir *et al*., 2014).

Future challenges

Climate change

Over the next 100 years the global temperature is expected to increase in the range 0.3–4.8 °C in the world, depending on climatic models, with the Arctic region warming more rapidly than the global mean (IPCC, 2013). In the Nordic countries this temperature increase is likely to be larger in northern areas than in the south, and most probably temperature will increase more during winter than summer with more of the precipitation falling as rain (Björnsson *et al*., 2008; Hanssen-Bauer *et al*., 2009). This will have various implications for adapting forage cultivars to the changing conditions both through breeding and different management schemes.

The expected changes in climate at northern latitudes will result in a longer growing season, because of earlier spring and later autumn, and higher temperatures during the growing season, both of which may lead to increased biomass production potential. However, new types of

stresses may offset the potential gain, such as insufficient hardening conditions during autumn to prepare the plants for altered winter conditions. Higher temperature in the autumn at the same light intensity will mean that the forage species are cold hardened at later stages during autumn, calling for new breeding strategies. Also during the winter deacclimation and reacclimation are important challenges due to experienced and expected temperature increase during winter (January-April) which will pose stress on plants if warm spells occur during mid-winter. In adapting forage plants to new conditions in the north, new variation in exotic material has to be looked for and the most promising material subsequently introgressed into present cultivars. As grassland agriculture in the region is a low value enterprise it would be desirable to breed material with as wide adaptation as possible so material could be used across larger areas within specific agroclimatic zones rather than focus on narrow adaptation to certain geographic regions. Such an approach would require considerable pre-breeding efforts in line with the already initiated Nordic Public Private Partnership for pre-breeding in perennial ryegrass (Rognli *et al*., 2013b).
Climate change may also increase disease pressure in forage plants. This has already occurred for leaf spots in meadow fescue, whereas e.g. crown rust is expected to become a problem on perennial ryegrass. Breeding material of vulnerable species should therefore be tested under more southern growing conditions.

Improved land- and nutrient-use efficiency

The Nordic countries must rise to the pressing challenge of sustainable intensification of their agricultural production (The Royal Society, 2009). For grassland-based agriculture this may involve improving the quality of the herbage either through breeding or optimizing D-values through more precise management strategies, thus obtaining more feeding units per land unit, as higher temperatures during summer will, without changing the management, reduce quality because of increased lignification of cell walls and lower digestibility of organic matter (Buxton, 1996). One approach would also be to increase the use of perennial ryegrass as discussed earlier and benefit from its superior feed quality and productivity. It is also important to reduce the reliance on artificial fertilizers. An obvious way is to make better use of N-fixing species and it is therefore especially important to improve their adaptation in the more marginal regions. Forage mixtures have also been shown to enhance yields compared to their individual components in pure stand (Finn *et al*., 2013) but the mixtures have to be carefully designed in order to realize their full potential in order to improve resource complementarity and increase yield.

References

Allen V.G., Batello C., Berretta E.J., Hodgson J., Kothmann M., Li X., Mcivor J., Milne J., Morris C., Peeters A. and Sanderson M. (2011) An international terminology for grazing lands and grazing animals. *Grass and Forage Science* 66, 2-28.

Arnalds Ó. (2004) Volcanic soils of Iceland. *Catena* 56, 3-20.

Arnalds, Ó. 2011. Náttúrufar [Physiography]. In: Aradóttir Á.L. and Halldórsson G. (eds) Vistheimt á Íslandi [Ecological restoration in Iceland], Agricultural University of Iceland and Soil Conservation Service of Iceland, Reykjavík, Iceland, pp. 14-18. [In Icelandic].

Arnalds O. and Barkarson B.H. (2003) Soil erosion and land use policy in Iceland in relation to sheep grazing and government subsidies. *Environmental Science and Policy* 6, 105-113.

Bakken A.K. and Johansen A. (2014) Matproduksjon på norske arealressursar med og utan import av fôrråvarer [Food production on Norwegian land with and without the import of raw feed stuffs]. *Bioforsk FOKUS* 9(2), 82.

Bélanger G., Rochette P., Gastonguay Y., Bootsma A., Mongrain D. and Ryan D. (2002) Climate change and winter survival of perennial forage crops in Eastern Canada. *Agronomy Journal* 94, 1120-1130.

Björnsson H. (1993) Zones for performance testing of timothy (*Phleum pratense* L.) in the Nordic countries. *Acta Agriculturae Scandinavica, Section B, Soil and Plant Science* 43, 97-113.

Bjornsson H., Olason E.O., Jonsson T. and Henkirksen, S. (2007) Analysis of a smooth seasonal cycle with daily resolution and degree day maps for Iceland. *Meteorologische Zeitschrift* 16, 57-69.

Björnsson H., Sveinbjörnsdóttir Á.E., Daníelsdóttir A.K., Snorrason Á., Sigurðsson B.D., Sveinbjörnsson E., Viggósson G., Sigurjónsson J., Baldursson S., Þorvaldsdóttir S. and Jónsson T. (2008) *Hnattrænar loftslagsbreytingar og áhrif þeirra á Íslandi – Skýrsla vísindanefndar um loftslagsbreytingar* [Global climate change and their effects in Iceland – Report of the scientific committee on climate change], Ministry for the Environment and Natural Resources, Reykjavík, Iceland, 118 pp. [In Icelandic].
Buxton, D.R. (1996) Quality–related characteristics of forages as influenced by environment and agronomic factors. *Animal Feed Science Technology* 59, 37-49.
CPA (2013) *National Inventory Report 2013 Norway*. Climate and Pollution Agency, Oslo.
Danmarks Statistik (2012) *Statistisk Årbog 2012*, 524 pp.
DEBIO (2010). *Statistikkhefte* [Statistics Booklet]. http://www.debio.no
European Commission (2005) *Soil Atlas of Europe*, European Soil Bureau Network. Office for Official Publication of the European Communities, Luxembourg, 128 pp.
Finn J. *et al*. (2013) Ecosystem function enhanced by combining four functional types of plant species in intensively-managed grassland mixtures: a three-year continental-scale field experiment. *Journal of Applied Ecology* 50, 365-375.
Finne M.A., Rognli O.A. and Schjelderup I. (2000) Genetic variation in a Norwegian germplasm collection of white clover (*Trifolium repens* L.). 1. Population differences in agronomic characteristics. *Euphytica* 112, 33-44.
Fjellheim S., Pasakinskiene I., Grønnerød S., Paplauskiene V. and Rognli O.A. (2009) Genetic structure of local populations and cultivars of meadow fescue from the Nordic and Baltic regions. *Crop Science* 49, 200-210.
Fjellheim S. and Rognli O.A. (2005) Genetic diversity within and among Nordic meadow fescue (*Festuca pratensis* Huds.) cultivars determined on the basis of AFLP markers. *Crop Science* 45, 2081-2086.
Ghesquière M., Humphreys M.W. and Zwierzykovski Z. (2010) *Festulolium*. In: Boller B., Posselt U.K. and Veronesi F. (eds) *Fodder Crops and Amenity Grasses*, Handbook of Plant Breeding 5. Springer Science+Business Media, LLC 2010, pp 293-316.
Gudmundsson J., Brink S.H. and Gísladóttir F. Ó. (2013) Preparation of a LULUCF land-use map for Iceland: Development of the Grassland layer and subcategories. *Grassland Science in Europe* 18, 102-104.
Gutmane I., and Adamovics A. (2008) Analysis of *Festulolium* and hybrid ryegrass (*Lolium x boucheanum*) dry matter stability. *Grassland Science in Europe*, 13, 248-250.
Halling M. (2012) Yield stability of *Festulolium* and perennial ryegrass in southern and central Sweden. *Grassland Science in Europe* 17, 118-120.
Hallsdóttir B.S., Wöll C., Guðmundsson J., Snorrason A. and Thórsson J. (2012) *Emissions of greenhouse gases in Iceland from 1990 to 2010. National Inventory Report 2012*. Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol, Environmental Agency of Iceland, UST: 330, 293 pp.
Hanssen-Bauer I., Drange H., Førland E.J., Roald L.A., Børsheim K.Y., Hisdal H., Lawrence D., Nesje A., Sandven S., Sorteberg A., Sundby S., Vasskog K. and Ådlandsvik B. (2009) *Klima I Norge 2100. Bakgrunnsmateriale til NOU Klimatilplassing* [Climate in Norway 2100. Background material to NOU Climate Adaptation], Norsk klimasenter, September 2009, Oslo, 148 pp. [In Norwegian]. Available online at: http://www.regjeringen.no/upload/MD/Kampanje/klimatilpasning/Bilder/NOU/Klima-Norge-2100 lavoppl 2opplag okt2009.pdf.
Helgadóttir Á., Eythórsdóttir E. and Jóhannesson T. (2013) Agriculture in Iceland. *Grassland Science in Europe* 18, 30-43.
Hejcman M., Hejcmanová P., Pavlů V. and Beneš J. (2012) Origin, history, management and plant species composition of grasslands in Central Europe – a review. *Grassland Science in Europe* 17 554-567.
Kynding Borgen S. and Hylen G. (2013) Emissions and methodologies for cropland and grassland used in the Norwegian national greenhouse gas inventory. *Report from the Climate Center Norwegian Forest and Landscape Institute*, 38 pp.
Larsen A. and Marum P. (2006) Breeding goals and possibilities in future timothy breeding. *In:* Sveinsson, T. (ed) *Timothy productivity and forage quality – possibilities and limitations*. Proceedings from NJF Seminar 384, Akureyri, Iceland, 10–12 August 2006, AUI Report No. 10, pp. 31-39. ISSN 1670-5785.
Lunnan T. (2012) Avlingsutvikling i engdyrkinga [Yield developements in cultivated grasslands]. *Bioforsk FOKUS* 7(2) 141-142.
Marum P. (2010) Legume breeding and adaptation to changing environments. In: Rasmussen J., Schacht M. and Helgadóttir Á. (eds) *The potential of forage legumes to sustain a high agricultural productivity – a Nordic perspective*. Proceedings from NJF Seminar 432, Hvanneyri, Iceland, 20–22 June 2010, NJF Report, Vol. 6, No. 3, pp. 13-16. http://www.njf.nu/filebank/files/20100803$084935$fil$93yaFekFtVspuHW8KAcG.pdf
Nanzyo M., Dahlgren R. and Shoji S. (1993) Chemical characteristics of volcanic ash soils. In: Shoji S., Nanzyo M. and Dahlgren R. (eds) *Volcanic Ash Soils: Genesis, Properties and Utilization*, Elsevier, Amsterdam, The Netherlands, pp. 145-187.
NFLI (2011) *Landskogstakseringens Feltinstruks 2011* [National forest inventory field guide]. Norwegian Forest and Landscape Institute. [In Norwegian].

IPCC (2013) Summary for Policymakers. In: Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
Olsen O.B. (ed) (1993) *Forskning for landbruk og samfunn i forandring* [Agricultural Research for Society in Transition]. Statens forskingsstasjoner i landbruk, 64 pp. ISBN 82-991161-4-7. [In Norwegian].
Rekdal Y (2013) Beite i utmark – kvalitet og kapasitet [Grazing in extensive grasslands – quality and quantity]. *Bioforsk FOKUS* 8(2), 135-137.
Rognli O.A., Fjellheim S., Pecetti L. and Boller B. (2013a) Semi-natural grasslands as a source of genetic diversity. *Grassland Science in Europe* 18, 303-313.
Rognli O.A., Larsen A.S., Nielsen N.C., Helgadóttir Á., Aavola A., Persson C., Isolahti M., Asp T. and Marum P. (2013) The Nordic Public-Private Partnership (PPP) for pre-breeding in perennial ryegrass (*Lolium perenne* L.). *Book of Abstracts of the 17th Symposium of the European Grassland Federation, Akrueyri, Iceland, 23-26 June 2013*, p. 84.
Søegaard K., Jensen S.K. and Sehested J. (2010) Vitaminer, mineraler og foderværdi af græsmarksarter [Vitamins, minerals and feed value of forage species]. *Intern Rapport Husdyrbrug* nr. 27, 15-20. [In Danish].
Søegaard K. and Møller K. (2005) White clover soil fatigue: an establishment problem on large and intensive farms. In: Murphy J.J. (ed) *Utilisation of grazed grass in temperate animal systems*. Proceedings of satellite workshop of the XXth International Grassland Congress, Cork, Ireland. Wageningen: Wageningen Academic Publishers (ISBN 9076998760), p. 231.
SNP (1992). *Agroklimatisk kartlegging av Norden* [Agroclimatic mapping of the Nordic countries], Samnordisk planteforedling, Skrifter och rapporter nr 5. [In Norwegian].
Statistics Denmark (2012) http://www.dst.dk/pukora/epub/Nyt/2013/NR397.pdf
Statistics Iceland (2013). (http://www.statice.is) and (http://hag.is/pdf/2011/kaflar2011.pdf). Retrieved from www.statice.is on 30 December 2013.
Statistics Norway (2014) (http://www.ssb.no/) Retrieved from www.ssb.no on 10 February 2014.
Statistics Sweden (2013) https://www.jordbruksverket.se/download/18.765a35dc13f7d0bf7c4639/1372238974961/Kapitel+1+Historisk+jordbruksstatistik.pdf and https://www.jordbruksverket.se/download/18.765a35dc13f7d0bf7c463b/1372238975402/Kapitel+3+%C3%85kerarealens+anv%C3%A4ndning.pdf
Sturludottir E., Brophy C., Bélanger G., Gustavsson A.-M., Jørgensen M., Lunnan T. and Helgadottir A. (2014) Benefits of mixing grasses and legumes for herbage yield and nutritive value in Northern Europe and Canada. *Grass and Forage Science*, 69, 229-240.
The Royal Society (2009) *Reaping the benefits: science and the sustainable intensification of global agriculture*, The Royal Society, London, United Kingdom, 73 pp.
Thorsen S.M. and Höglind M. (2010) Assessing winter survival of forage grasses in Norway under future climate scenarios by simulating potential frost tolerance in combination with simple agroclimatic indices. *Agricultural and Forest Meteorology* 150, 1272-1282.
Østrem L. and Larsen A. (2010) Fiber content and plant development in *Festulolium*. In: Huyghe C. (ed) *Sustainable Use of Genetic Diversity in Forage and Turf Breeding*. Springer, Netherlands, pp. 563-568.
Østrem L., Volden B. and Larsen A. (2013). Morphology, dry matter yield and phenological characters at different maturity stages of ×*Festulolium* compared with other grass species. *Acta Agriculturae Scandinavica, Section B, Soil and Plant Science* 63, 531-542.