Northern Periphery and Arctic Programme

Northern Cereals – New Markets for a Changing Environment

RECENT WARMING AND THE THERMAL REQUIREMENT OF BARLEY IN THE FAROE ISLANDS

Report

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By

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1 Introduction

The Northern Cereals project was developed to encourage greater cultivation and use of local cereals, especially barley, within the Northern Periphery and Arctic Programme area. Partners in the project include organisations from Newfoundland, Iceland, northern Norway, the Faroes, and the Scottish archipelago of Orkney. One of the drivers for the project was a common perception amongst partners that climate change was resulting in warmer growing seasons, creating more suitable conditions for cereal cultivation. Nevertheless, none of the partners had carried out detailed research into this and so an analysis of forty years of temperature and rainfall data at 11 different sites across the project area, was carried out. The analysis was made relevant to barley by focusing on the months of the cropping season and by including research data from each partner on the thermal requirement of spring barley in their region. The overall results of the analysis were included in a scientific paper (Martin et al. 2017) and, in parallel with this, partner-specific summaries have been produced for each partner so that the information can be passed on to local stakeholders. This report summarises information for the Faroe Islands.

2 Context

The Faroes archipelago lies in the North Atlantic at approximately 62° N and 7° W and consist of 18 hilly islands. In spite of its high latitude, temperatures are milder than expected because of the influence of the Gulf Stream, but the climate is also very changeable, wet and windy as a result of frequent depressions which arrive from the south and west. Recent research indicates that barley was being grown in the Faroes possibly 300-500 years before the arrival of the Norse (Church et al. 2013). Following the Norse settlement, there is increasing evidence for cultivation of 6-row hulled barley (Church et al 2005), but the lack of other cereals like oats and rye suggests that growing conditions were challenging. Soil amendment with organic matter and tillage were important for increasing yields and resilience, to allow for poor growing seasons (Adderley and Simpson, 2005). The sub-optimal growing conditions resulted in the barley seldom ripened in the field and heads were dried indoors (Edwards and Borthwick, 2010). Barley was gradually replaced as a staple by potatoes which were first introduced at the end of the 18th century and growing of barley ceased around the middle of the 20th century (Edwards and Borthwick, 2010). With recent, warmer growing seasons and increasing interest from both growers and end-users there has been a re-awakening of interest in barley cultivation in the Faroes since about 2014 and this has included both research trials and commercial planting of the crop (Martin et al. 2016).

The constraints on barley cultivation which occur in the Faroes are also shared by other parts of the North Atlantic region. The main one is the short growing season, which is also often cool, resulting in a low number of effective growing days (Trnka et al. 2011). Most areas also have difficult harvesting conditions because of high rainfall (Chappell et al. 2017) while in areas with a more continental climate, late frosts and dry weather after sowing can result in poor establishment (Peltonen-Sainio 2012). Considering these challenges, it is likely that the main driver for barley cultivation in the past was the need of remote communities for self-sufficiency. In this respect, the versatility of barley was important as it was a source of grain for food and drink, animal feed, and straw for animal bedding and thatching. Recently, new methods of preserving high moisture grain and ensiling the crop have increased its use as an animal feed. With renewed interest in sustainability and a growing tourist market across the region for high provenance food and drink products, there has been a resurgence of interest in growing barley for these markets (Martin 2016).

Recent changes in climate have seen particularly high rates of warming in northern regions (Kovats et al. 2014) which are projected to result in expansion of cropping to new areas and higher yields, partly resulting from extended growing seasons (Bindi and Olesen 2011). While production in continental northern areas can be constrained by high summer temperatures and low rainfall (Peltonen-Sainio 2012), this does not normally affect maritime northern areas where high productivity is projected to continue with climate change (Kovats et al. 2014).

Against this background, the Northern Cereals Project provided an ideal opportunity to pool research resources across the region to investigate the temperature requirements of barley within the region and to determine how recent changes in temperature might have affected the viability of growing the crop.

3 Methods

3.1 Weather data

Average monthly temperature and total monthly rainfall data from 1975 to 2015 were obtained for the meteorological site at Tórshavn on the island of Streymoy in the Faroes (Table 1).

3.2 Barley varieties

Barley data sourced for this study come from early maturing six-row (6-r) or two-row (2-r) spring barley varieties which have been grown successfully for several years in northern regions. Iskria (2-r; released in 2005) and Tiril (6-r; released in 2006), respectively, are Icelandic and Norwegian varieties. Bere (6-r) is an ancient Scottish landrace which is still grown in Scotland's Northern and Western Isles. Weal is a hooded 6-r barley developed in Alaska, while Galt (6-r) and Chapais (6-r) were developed in Canada and released in 1966 and 1988, respectively. Data on silage barley grown in Alberta, Canada and reported by Juskiw et al. (2001) came from three 6-r barley varieties (Brier, Duel and Tukwa) and two 2-r varieties (Manley and Seebe). These varieties are all Canadian and were released between 1989 and 1992.

3.3 Barley cropping season in the Faroes

The cropping season for spring barley is defined here as the period from sowing to harvesting. We recognise that this can vary considerably from year to year, but for the present analysis, we assume it starts on 15 April and ends on 30 September. In order to investigate the temperature sum over the cropping season, cropping season degree days (CSDD, ^{o}Cd) were calculated for Tórshavn meteorological site, from the sum of the degree days in each month of the cropping season, with the total for each month (M_{DD}) calculated from:

$$M_{DD} = (T_A - 5) \times N \qquad (1)$$

Where, T_A is a month's average temperature (^{o}C) and N is the number of days in that month. Equation 1 uses a base temperature of 5 ^{o}C which is commonly used for barley in northern areas (Peltonen-Sainio et al. 2009). When a month's average temperature was less than 5 ^{o}C, it was considered to have zero degree days.

In order to avoid confusion with CSDD, we use the term thermal requirement (TR) for the number of degree days between sowing and harvest for specific crops of barley. Day requirement (DR) is used for the number of days in this period.

Table 1. *Locational details of Tórshavn.weather station in the Faroes and summary temperature and rainfall data (1975 to 2015) affecting the barley cropping season*

Meteorological station	Latitude, longitude and elevation	Data source	Approximate barley cropping season	November to March average temperature (ºC)	November to March average rainfall (mm)	Average rainfall of month of sowing (mm)	June to August average temperature (ºC)	June to August average rainfall (mm)	Average cropping season degree days (ºCd)
Tórshavn, Streymoy	62º01' N 06º45' W 54 m	Danish Meteorological Institute	15 April to 30 September	4.2 (0.7)	646 (185)	69 (36)	10.2 (0.6)	222 (56)	690 (98)

Notes: Values in brackets are standard deviations

Table 2. *Summary site data for i) linear regression analyses of cropping season degree days (CSDD) on year and ii) analyses of the percentage of years when CSDD met the minimum thermal requirement (TR) for dry grain or silage*

	i Linear regression analyses of CSDD on year				ii Analysis of the percentage of years meeting the minimum TR for dry grain and silage					
Meteorological site	Period used to calculate CSDD	Equation for regression line, correlation coefficient (r) and p-values for the regression, and number of years of data (n)	Fitted CSDD value for 2015	Range of actual CSDD values (2010 to 2015)	Estimated minimum TR for dried grain and silage (ºCd)		Percent of years minimum TR met or exceeded, 1975-1994		Percent of years minimum TR met or exceeded, 1995-2015	
					Dry Grain	Silage	Dry Grain	Silage	Dry Grain	Silage
Tórshavn	15 April-30 September	$y = 3.828x – 6946$ ($r= 0.465$; $p<0.005$; $n=41$)	766	576-886	697	558	35	90	43	100

3.4 Crop data for producing dry grain

There are often major differences in DR and TR of a crop depending upon whether it is being grown for dry grain or animal feed, as crops for feed are usually harvested at an earlier stage of development. For dry grain, the crop is normally allowed to ripen in the field, harvested at a low moisture content (ideally ≤ 22%), and then dried to about 13% for safe storage. In some northern areas, like the Faroes, harvesting for dried grain may often be at a higher moisture content, however. Dried grain is required to supply higher value markets for seed, malting or milling.

Although this document deals with the Faroes, local data on DR and TR were limited, and so we have supplemented it with published data from other northern areas, multi-locational trials established by project partners in 2014 (Reykdal et al. 2016), fields of Bere grown in Orkney by supply chains managed by the Agronomy Institute and trial plots grown in Dundee by the James Hutton Institute.

3.5 Crop data for producing animal feed

Grain can be harvested for animal feed at about 25-35% moisture and treated with preservatives. Alternatively, the whole crop can be cut earlier, when the grain is between the milky and soft dough stage (Juskiw et al. 2001), to make silage.

The TR of silage barley is important because it represents the threshold for using barley on farms. Since we had little data on this from Iceland, we have used data from trials in Alberta, Canada over 12 location-years (Juskiw et al. 2001) and from Orkney (Martin et al. 2017). These indicated that the TR for silage barley is 0.8 that for dry grain.

4 Results

4.1 Day and thermal requirements of barley in northern regions

Using a range of sources (Table 3), we found large differences in DR and TR (at 5^{o}C base temperature) of spring barley in northern regions when grown for dry grain. Much of this is associated with the latitude at which the crop is grown because of its link with important factors like temperature, day length and radiation intensity. Temperature and day length, in particular, have a strong positive effect on the rates at which crops pass through different development stages and these tend to be shorter at high latitudes, resulting in shorter cropping seasons. An extreme example of this in Table 3 is the difference between Bere grown in Orkney (142 days and 938 ^{o}Cd to harvest) and Weal in Alaska (85 days and 791 ^{o}Cd to harvest). The trend for decreasing thermal requirement of barley with increasing latitude can be seen in Fig. 1 (solid circles) for early varieties reported in Table 3. The fitted line indicates a decrease in requirement of about 16.0 ^{o}Cd per 1^o increase in latitude. For the latitude of Tórshavn, Fig. 1 indicates a thermal requirement for producing dry grain of 849 ^{o}Cd. It should be noted, however, that the line indicates the average value and considerable variation around the values predicted by the line can occur with individual crops for reasons discussed below.

Table 3. *Day and thermal requirements (5 °C base temperature) of spring barley grown in northern regions*

Variety (early or late maturing)	Latitude, location and data source	Data collection period	Day requirement (d)	Thermal requirement (°Cd)
Bere, Iskria, Tiril (early)	68°N, Vestvågøy, Norway (Reykdal et al. 2016)	2014	97	761
Weal (early)	64°N, Fairbanks, Alaska (Sharratt et al. 2003)	1972-89 n=15	Mean: 85	Mean: 791
Galt (medium)	64°N, Fairbanks, Alaska (Sharratt et al. 2003)	1972-89 n=15	Mean: 90	Mean: 837
Spring barley (early)	60-65°N, Finland (Peltonen-Sainio et al. 2013)	1985-2009 (MTT Variety trials)	83-91	784-866
Spring barley (late)	60-65°N, Finland (Peltonen-Sainio et al. 2013)	1985-2009 (MTT Variety trials)	96-102	913-961
Iskria, Tiril (early)	60°N, Shetland, Scotland (Reykdal et al. 2016)	2014	121	859
Bere (early)	59°N, Orkney, Scotland (Agronomy Institute trials)	2003-16 (n=58)	Mean: 142 Range: 104-168 SD: 12.6	Mean: 938 Range: 802-1069 SD: 68.5
Tartan (medium)	59°N, Orkney, Scotland (Agronomy Institute trials)	2009-16 (n=35)	Mean: 156 Range: 135-169 SD: 9.0	Mean: 1008 Range: 847-1104 SD: 59.1
Bere (early)	56°N, Dundee, Scotland (James Hutton Institute trials)	2011-16 n=5	NA	Mean: 924 Range: 733-1105 SD: 110.5
Bere, Iskria, Tiril (early)	49°'N, Newfoundland, Canada (Reykdal et al. 2016)	2014	117	1171
Chapais (early)	49°N Pasadena, Newfoundland (Spaner et al. 2000)	1996-98 n=8	NA	Mean: 1052 Range: 860-1119 SD: 89.5
Chapais (early)	48°N, St John's, Newfoundland (Spaner et al. 2000)	1996-98 n=12	NA	Mean: 1032 Range: 903-1165 SD: 84.4

Notes: Crop thermal requirement for Weal and Galt were calculated from the average cropping season temperature and days to maturity provided in the reference. SD, standard deviation

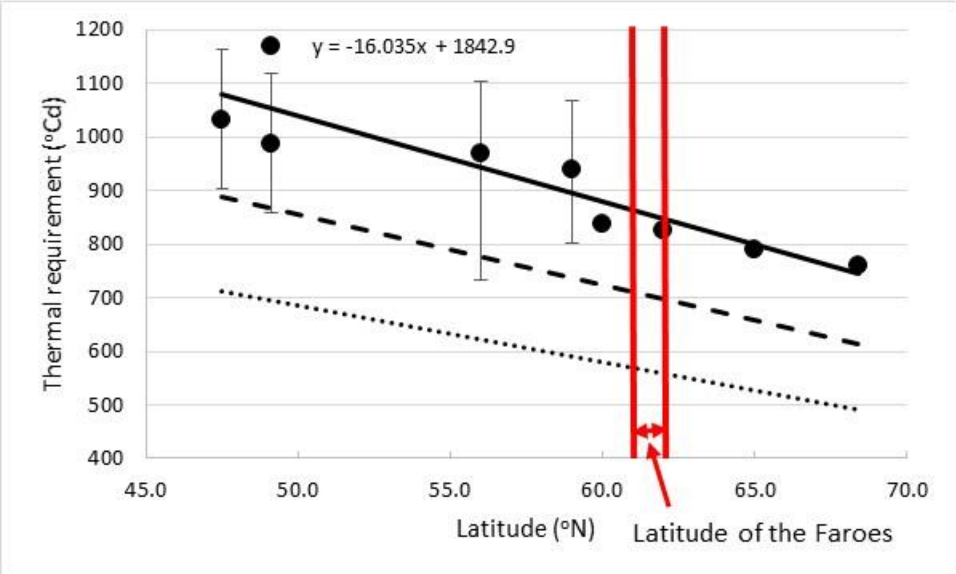

Fig. 1. *Thermal requirement (5 °C base temperature) of early maturing spring barley varieties at different latitudes (solid circles), based on data in Table 3. Bars indicate the range of values where these are available. The correlation coefficient (r) is 0.905 (p<0.001) and the equation and solid line is the line of best fit through the data points. The heavy dashed and dotted lines, respectively, are the estimated minimum thermal requirements for producing dry grain and silage. The vertical red lines show the approximate latitudinal range of the Faroes*

Even at the same location, there are differences between the DR and TR of varieties depending upon several factors. For example, early-maturing varieties have shorter requirements than late-maturing ones and late sowing can also result in a shorter requirement. In Orkney, for example, a 10-day delay in sowing Bere was associated with a 6-day shorter DR. Other important sources of variation in both DR and TR in Table 3 are the harvest date, which may be delayed by wet weather, and the grain moisture content which is considered acceptable at harvest.

Although varieties can be harvested successfully for dry grain in northern areas over a range of TR values (Table 3), Spaner et al. (2000) found the greatest yields at the highest values of TR and a positive correlation between TR and yield. This was also the case for Tartan grown in Orkney between 2010 and 2016 and yield increased by 1.1 t per 100 °Cd (Martin et al. 2017).

Given the large variation which occurs in barley TR from year to year at a site, it is useful to identify a minimum requirement as an indicator of the threshold for producing a successful crop. Based on the variation which occurred in TR within the data sets used in Fig. 1, the minimum requirement (the dashed line in Fig. 1) was estimated as two standard deviations below the mean. We then estimated the minimum TR for making silage (the dotted line in Fig. 1) as 0.8 of the minimum value for dry grain. These results are used in Section 4.3.

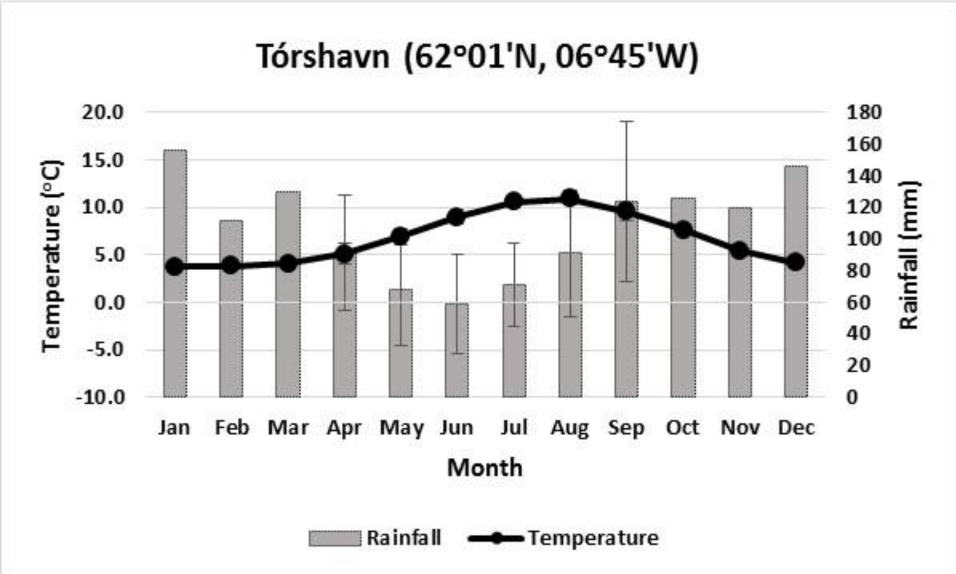

Fig. 2. *Average monthly temperature and rainfall (1975 to 2015) at Tórshavn. Bars indicate one standard deviation above and below the mean for monthly values from April to September*

4.2 Temperature and rainfall patterns at Tórshavn and effects on barley cultivation

The main weather factors influencing the cultivation of barley in the Faroes are the very high rainfall and the cropping season's cool temperature (Fig. 2 and Table 1). The high winter rainfall results in soil waterlogging, and cultivations in the spring can only start after some soil drying has occurred. This situation is aggravated by the majority of the land available for cropping having peaty, rather than sandy, soils. Consequently, sowing of cereals cannot normally occur until after mid-April. After sowing, crop production is predominantly influenced by the number of degree days over the cropping season (Table 1) which is determined by its length and the summer (June to August) temperature (Table 1). Compared with other North Atlantic locations, this is low (10.2 ^{o}C) and the high rainfall over the summer (222 mm) and frequent fog diminish the sunshine hours crops are exposed to. This can be expected to result in delayed ripening. Suitable fields for barley cultivation are mostly at low altitudes and therefore are not appreciably affected by the reduced temperature and much higher rainfall which occurs at higher altitudes in the interior of the islands. June is the month with the lowest rainfall, but monthly rainfall then increases and is around 100 mm and 120 mm in August and September, respectively. This makes harvesting of grain difficult, particularly if dry grain is required for milling, malting or seed. Wet soil conditions at harvest will require light harvesting machinery to avoid trafficking problems.

4.3 Trends in temperature and degree days at Tórshavn from 1975 to 2015

Linear regression of average monthly temperatures between April and September on year (Table 4) showed a significant warming trend in April, August and September, with the largest warming trend in September. The warming trend over the entire growing season (May to September) was very significant.

Linear regression of CSDD on year showed very significant positive relationship (Table 2 and Fig. 3), with a rate of increase of 38.3 ^{o}Cd per decade. The fitted value of CSDD for 2015 (Table 2) was substantially larger than the average for 1975 to 2015 (Table 1), but the range of recent actual values has been large and some were considerably lower than the fitted values (e.g. 2012, Fig. 3).

Estimated minimum thermal requirements for producing dry grain and silage were calculated for Tórshavn (Table 2) using the methods outlined in Section 4.1 and were then compared with the actual site values of CSDD for the periods 1974-1994 and 1995-2015. Differences between the two periods in the percentage of years with CSDD values greater than the minimum thermal requirements indicate how the trend for warmer temperatures has affected the potential for growing barley (Table 2). The data indicate a slight increase in the proportion of years in which dry grain and silage can be produced and that the TR for silage now appears to be met in most years. Recent warming can therefore be considered to have increased the potential for growing barley successfully in the Faroes, especially for silage. The success of growing, however, will be influenced by other factors, like rainfall, which will be discussed later.

Table 4. *Values for the warming trend (WT; ^{o}C per decade), correlation coefficient (r) and the significance (p), of linear regressions of average monthly temperature on year (1975 to 2015) for Tórshavn*

Site		April	May	June	July	August	September	May to September
Tórshavn	WT	0.36	0.09	0.10	0.15	0.18	0.50	0.20
	r	0.37	0.13	0.15	0.26	0.31	0.64	0.44
	p	**0.016**	0.421	0.336	0.096	**0.045**	**<0.001**	**0.004**

Notes: Significant p-values are highlighted in bold

Table 5. *Values for the rainfall trend (RT; mm per decade), correlation coefficient (r) and the significance (p) of linear regressions of average monthly rainfall on year (1975 to 2015) for Tórshavn*

Site		April	May	June	July	August	September	May to September
Tórshavn	RT	11.6	5.5	5.0	2.7	8.2	1.2	18.2
	r	0.37	0.18	0.19	0.12	0.24	0.03	0.23
	p	**0.018**	0.263	0.234	0.444	0.124	0.865	0.146

Notes: Significant p-values are highlighted in bold

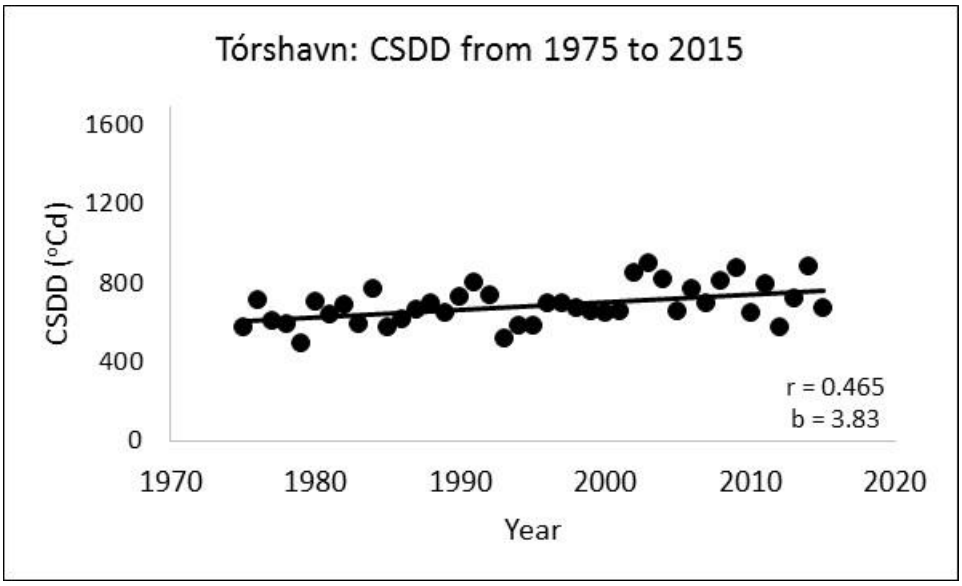

Fig. 3. *Trend in CSDD from 1975 to 2015 for Tórshavn; r and b, respectively, are the correlation coefficient and the slope of the fitted regression line.*

4.4 Trends in monthly rainfall at Tórshavn from 1975 to 2015

Since climate change is generally expected to affect rainfall and temperature, trends in monthly rainfall were also investigated (Table 5). Although all months showed a trend for increasing rainfall, this was only significant for April. Over the cropping season (May to September), the total rainfall showed a trend to increase of 18.2 mm per decade, but this was not significant. The possible trend for increasing rainfall in August (8.2 mm per decade), while not significant, is of concern as it can be expected to make harvesting more difficult. It should be noted, though, that monthly rainfall is extremely variable as indicated by the large standard deviations in Fig. 2 and this makes it difficult to identify significant trends.

5 Discussion

This report has combined an analysis of recent trends in warming and rainfall at Tórshavn with an investigation into the TR of early maturing spring barley varieties in the Faroes to allow an initial assessment of the effects of recent warming on the potential for spring barley cultivation in the islands. Our investigation of TR indicated a minimum requirement of about 697 ^{o}Cd for dry grain and 558 ^{o}Cd for silage. While results from other partner regions show that TR varies with latitude, the latitudinal range within the Faroes is not wide enough for the latitude of growing to have a significant effect on this.

The study identified significant warming (0.20 ^{o}C per decade) over the barley cropping season (May to September), with warming being greatest and very significant in September. But, it was also significant in April and August. Higher temperatures at the start and the end of the growing season are especially valuable in northern growing areas as they can help to extend the length of the cropping season. This can make cropping more viable or secure, or allow the use of later, higher yielding varieties (Olesen et al. 2011). Earlier planting is also often associated with higher yields (Martin et al. 2010). Other factors, however, like high or low rainfall, the risk of frosts, or the need to wait for some soil drying (Peltonen-Sainio and Jauhiainen 2014; Uleberg et al. 2014) may limit the ability of farmers to take advantage of warmer spring temperatures and it was notable that there was a significant trend for increased rainfall in April at Tórshavn.

In Finland, it has been argued that 15 September is the latest appropriate harvesting date (Peltonen-Sainio et al. 2009) as this represents the end of the physiologically effective growing season. Although higher September temperatures may extend this, in more maritime northern areas the ability of growers to exploit this may be limited by high rainfall in this month. With an average September rainfall at Tórshavn of around 120 mm, this would be especially likely in the Faroes. Opportunities for earlier sowing or later harvesting are likely to come as narrow windows and farmers will be most able to take advantage of this if they have ready access to appropriate machinery. In the Faroes, such machinery would need to be suitable for small fields and capable of dealing with wet ground conditions which result from the islands' high rainfall. If farmers aim to produce dry grain, it is likely that it will often be harvested at a high moisture content so that it will need to be dried quickly if it is not to spoil. This will require access to grain drying equipment of an appropriate capacity.

There was a significant trend for CSDD to increase between 1975 and 2015 and our analysis (Table 3) indicated that this has probably resulted in a small improvement in the potential for growing spring barley. Although the TR for silage is now met in most years, the TR for dry grain has only been met in about 43% of the past twenty years, however, suggesting that dry grain production is still difficult under Faroese conditions. This is made even more difficult by the high rainfall that usually occurs around harvest time. This, of course, is not new and the Faroese grain gravest often relied upon harvesting immature grain which was subsequently dried inside (Edwards and Borthwick, 2010). It is, however, worth noting that, although May to September temperatures have risen (0.20 ^{o}C per decade) over the past 40 years in the Faroes, leading to increased CSDD, the warming trend is much less than at several other neighbouring locations (for example, decadal increases of 0.47 ^{o}C at Reykjavik, 0.39 ^{o}C at Kirkwall and 0.34 ^{o}C at Stavanger).

Since CSDD are still insufficient for dry grain in many years, and because rainfall is very high in September, it is especially important in the Faroes to use very early maturing barley varieties. These have a lower TR than later maturing varieties and it should be possible to harvest them earlier, probably under better weather and soil conditions than would be possible with later varieties. They would also be expected to have a lower grain moisture at harvest which would make drying easier and cheaper. Furthermore, it seems that, initially at least, growing barley for silage may be a safer strategy than growing it for dry grain, although it is important that research on the latter should also continue.

Generally, increases in CSDD are expected to result in higher yields (Bindi and Olesen 2011), but this will depend upon the importance of other constraints. In Finland, only a small increase in yield was found from higher CSDD (about 0.1 t ha^{-1} per 100 ^{o}Cd), possibly because farmers applied insufficient inputs (Peltonen-Sainio et al. 2009) or as a result of dry weather and high temperatures (Trnka et al. 2011). In Scotland, national barley yields showed no correlation with temperature, but appeared to be limited by high rainfall in July and overcast conditions from April to July (Brown 2013). Modelling has also indicated that saturated soil conditions resulting from future changes in climate may reduce yields in parts of Scotland in some years (Yawson et al. 2016). In contrast, in Alaska, low precipitation was considered to be the most important climatic limitation (Sharratt et al. 2003). While trials in Newfoundland (Spaner et al. 2000) and data from Orkney (Martin et al. 2017) indicated increases in yield with CSDD of 0.9-1.1 t ha^{-1} per 100 ^{o}Cd, it is clear that variable yield responses to increases in CSDD can be expected. In the Faroes, barley revival is at such an early stage that the most important effect of the increase in CSDD will probably be to increase the viability of growing barley rather than to increase its yields.

Our study contributes to understanding some of the effects of recent changes in climate on the potential for barley cultivation in the Faroes. It highlights the need for more extensive information on the TR of barley for producing mature grain and silage, particularly from a wider range of sites and varieties. It would be particularly valuable, for a better understanding of the impact of climate change, if such trials could be co-ordinated with research in neighbouring countries.

Although this study focused on spring barley, the warming trends we describe also have important implications for the growth of a wide range of other plant species in the Faroes.

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