Agriculture in Greenland

– possibilities and needs for future development and research

Synthesis Report for Greenland Agricultural Initiative (GRAIN) in cooperation with Greenland Perspective

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Colophon

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Front page: Farm in Qassiarsuk Photo: Visit Greenland

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Preface

Agriculture in Greenland faces an uncertain future impacted significantly by a changing climate. It will influence the way farming in Greenland is carried out and the scope of agricultural development. Higher temperatures allow for better crop yields and feed production capability for livestock, as well as new crop, but are mixed with a higher degree of unpredictable weather and droughts, as well as the potential introduction of invasive species and pests. Agricultural management on a local and national level thusly is under pressure to create a framework within which the sector can adjust effectively and continue to contribute to the political ambitions of higher levels of local food production in Greenland.

Modern agricultural farming in Greenland has a history of around 100 years. Sheep farming and grass production for fodder has been the focus of production but in recent years crops, such as potatoes and turnips, have been grown commercially and cattle introduced as a niche meat-producing livestock. All land in Greenland is public owned and no private property right exists. Hence, farmers do not own the land they manage. By that, privately (and family) owned farms and Governmental administered sector management is tightly interwoven.

In recent years the Government of Greenland has published reports documenting the production conditions under which Greenlandic farmers operate at present, emphasizing the sector organization and production outputs. Also, a climate change report for Southern Greenland and a climate change adaptation report has been published. Most of the past work has been on documenting the current status for selected parts of Greenlandic agriculture. Despite the knowledge base which has been built up in recent years, it is also acknowledged that there is a need for interdisciplinary in-depth analyses on how to tackle current as well as future challenges, and apparent, that a need for more knowledge coordination in Greenland exists.

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Facilitated by Greenland Perspective (an interdisciplinary platform for research cooperation in Greenland established by the University of Copenhagen and Ilisimatusarfik, the University of Greenland), the agricultural research network Greenland Agricultural Initiative (GRAIN) was formed in 2017 in order to initiate the formation of this interdisciplinary knowledge base on agriculture in Greenland. Since sheep production is at the center of Greenlandic agriculture, this has been the point of departure leading to the identification of five areas of concern influencing sheep production and constituting the broad and inter-disciplinary approach being sought for. These areas are: A) Agricultural fields and soils, B) Plant pests and diseases in agricultural areas, C) Livestock production systems, D) The agricultural community – sustainability perspectives and E) Nature areas. Production economics and legal frameworks are important as well but are not dealt with in depth here, since it is covered in other reports.

Four of the five areas (A, B, C and D) are dealt with in background reports written by researchers participating in GRAIN. These reports in themselves constitute independent publications, and also serve as input to the chapters in this synthesis report. The objective of this report is to provide more insights into possibilities and needs for future research for the development of agriculture in Greenland.

It is the hope of the authors that the institutions supporting the agricultural sector, decisionmakers and the sector itself will gain more insight into the issues already influencing Greenlandic agriculture and will even more so going forward. The pillars supporting Greenlandic agriculture 50 years into the future are in motion, and we urgently need to understand the dynamics of change, ways to adapt & manage as well as establish links between science, administration and business and facilitate agricultural knowledge production to the benefit of farmers as well as the public agricultural administration.

Contents

Main findings and future work

Soil

Regarding soils, one major finding, despite based on preliminary results, is that commonly applied predictive functions of soil properties do not apply to the soils in South Greenland. The soils show large volume of plant available water, a high degree of water repellency and low ability in gas exchange with the atmosphere. These differences are probably due to very high content of weakly-decomposed organic matter in combination with almost total absence of clay minerals. Further studies on this topic are highly needed in order to facilitate, e.g. irrigation planning and determine the drought resistance of the fields.
With regards to improving the quality of the agricultural soils, we underline the importance of using systematic soils tests as the bases for liming and fertilizing the soils.

Manure is an important resource for improving the soil quality and critical for the recycling of nutrients in the farming systems in Greenland. At present this resource is often piled and remains unused or is spread sporadically. It is imperative to study how best to apply animal manure and improve its use. We also suggest more innovative possibilities for soil improvement such as addition of seaweed or glacial rock flour.

In many mountainous areas around the world permanent pastures are both irrigated and fertilized, this might also be possible in south Greenland. If irrigated and fertilized, these areas, often located in connection with arable fields, can be used for grass production in dry years, or as fenced pastures for production of winter feed as a supplement to the feed production from arable fields.

Pests and diseases

Crop production in Greenland is focused on crops providing fodder for the sheep. Changes in climate during recent decades have led to favorable conditions for cultivation also of edible crops such as potatoes and turnip and more species could be of future consideration.

Hence it is important to protect Greenland from introduction of pests and diseases which represent a severe threat to agricultural production. A number of pests and pathogens which cause considerable losses elsewhere have not yet been observed in Greenland, although searched for, of these some are by EU categorized as quarantine pests. Greenland has no legislation regulating import of plants and plant material. It is strongly recommended to initiate the preparative work that may lead to a plant health legislation for Greenland - preferably including a system for regular surveillance for pests and diseases within Greenland.
It is strongly recommended to introduce systematic crop rotation since this will significantly reduce the possibility for many pests and diseases to establish and spread. In order to support development of crop rotation schemes and expand the knowledge of local suitability of crop types it is recommended to strengthen and expand the cultivar trial activities at Upernaviarsuk research station. Equally important is the dissemination of the trial results to farmers in order to facilitate a real impact of trials. In addition, small-scale field experiments locally at farms should be encouraged.
There is a general shortage of suitable storage facilities at the farms. Due to that potatoes and other harvest products are often destroyed during winter. Construction of properly insulated, ventilated and heated storerooms should be considered.

Livestock

Feed costs account for a major part of the total production costs, but, actually, little is known of the nutritional quality of grown forages or imported feedstuffs. This challenges farmers and advisors in ensuring that livestock have their requirements for energy, protein, amino acids and minerals met, and it challenges the sourcing of the most appropriate supplemental feedstuffs in the right amounts and at the right price. We, therefore, recommend an investigation of the nutritional quality of grown forages on a number of farms to account for geographical differences, as well as a more systematic approach to feedstuff import.
The Icelandic breeding scheme Fjárvis is already used successfully on some farms in Southern Greenland (Landbrugskommisionen, 2014), but a strengthening of this work and an adaptation of the system to better meet Greenlandic needs is strongly recommended.

Structured on-farm experiments and investigations at the Upernaviarsuk research station in cooperation with dedicated agricultural research support from the Institute of Natural Resources should supplement systematic analyses of forage quality, including a variety of alternative crops and efficient growth, irrigation, fertilization, harvest methods and plant health. This combined with a social and economic focused agricultural research would ensure a more holistic approach to agricultural research in Greenland.

Building up such research competence and capacity at a national level is needed in order to support, anchor, coordinate and disseminate knowledge building and strengthen the relation between the agricultural sector, agricultural research as well as Naalakkersuisut (the Government of Greenland). Such an agricultural research unit could be organized under the Greenland Institute of Natural Resources (GINR) in order to facilitate knowledge transfer of the work carried out there and abroad.
The agricultural advisory services in Greenland already collect every year a range of different information from the private farms, which could be used for benchmarking the different farms within and across geographical regions. Benchmarking is advantageous because it allows a direct comparison of the individual farm with the remaining farms, and hence make it possible for the individual farmer to assess areas for improvement. Benchmarking can be realised by systematising the data that the agricultural advisory services already collect and couple it with data from the slaughterhouse Neqi in Narsaq.

Introduction

Modern agriculture production has been practiced in Southern Greenland through the last 100 years and is today dominated by sheep farming. Of the 1,109 ha cultivated area (in 2014), approximately, 99 % was cultivated with grass for winter fodder, and 1 % was used for growing potatoes (Lehmann et al., 2016). An additional 242,000 ha of permanent pastures were used for extensive grazing in the summer period. Of the arable lands, 68 % is near Narsaq, 17 % is near Nanortalik, and 13 % is near Qaqortoq. The number of farms and ewes have steadily decreased in recent years, but a major part of the winter fodder for livestock still has to be imported (Lehmann et al., 2016). Climate change is rapidly transforming ecosystems around the world, especially the Arctic, where the temperature has increased at twice the rate of the global average (Kirtman et al., 2013). The change in the Arctic climate is already imposing vast physical, ecological, social and economic changes in the region and the rate of change is projected to increase throughout the 21st century (Hassol, 2004). A change toward a warmer climate presents an opportunity for increased agricultural productivity in South Greenland but also poses challenges for current practices. The average annual temperature is projected to increase with 1.8 to 3.9 °C, extending the current growing season of 100 days by 27 to 127 days (Christensen et al., 2016). Such a change in temperature regime could likely enable Greenlandic farmers to grow a wider variety of crops and increase self-sufficiency (Lehmann et al., 2016). On the other hand, more extreme weather conditions are also to be expected with periods of drought, winter thawing or heavy and excessive rain fall (Christensen et al., 2016). Also, new crop species and an uncontrolled import of new plant material constitutes a challenge since new pests and diseases may be introduced alongside.

The current agricultural sector in Greenland consists of 37 farms (Naalakkersuisut 2016). An analysis of the Greenlandic farmers' economic performance, based on 2014 financial accounts, showed that only 5 out of 27 farms produced a net result above 500.000 DKK. (Jervelund et al., 2016). These figures do not include maintenance and investments in own production facilities and in some cases also salaries (Naalakkersuisut 2016). In total this demonstrates that business conditions for Greenlandic farmers are difficult and hence this gives rise to more fundamental considerations about what the objectives of future agriculture in Greenland should be.
The Greenlandic agriculture excels unique conditions. The basic physical and biological conditions under which production takes place are harsh and are expected to fluctuate even more in the future, increasing uncertainties in production. Distances (both physical distance and in terms of accessibility) between farms and towns (Narsaq, Qaqortoq or Nanortalik) with access to input resources and sales possibilities, are larger than many places elsewhere in the world. At the same time yield per ha is low, compared to other Arctic/ Nordic regions, meaning that relatively large and scattered areas need being maintained in order to achieve sufficient crop output.
This report addresses both the challenges ahead given the conditions mentioned above but is also discusses the possibilities to alter some of the basic production conditions taking into account statements from farmers about their wishes and hopes for how a future farming lifestyle in Greenland could be like.

Chapter 1 - Agricultural fields and soils in Southern Greenland: Properties and Possibilities

Chapter 1 is based on the background report by Jensen, et al., 2018

Geology and soil development

In the "Soil Atlas of the northern circumpolar region" (2010) the authors suggested podzols and arctic brown soils, as the dominant soil types of South Greenland. Commonly, glacial till, and alluvial or aeolian sand deposits are the parent material of podzols. The artic brown soils are very coarse soils dominated by in situ weathering of the primary minerals.

Soil Properties

Relatively little knowledge has been available on the physical properties of the Greenlandic agricultural fields. During field campaigns in 2013, 2015 & 2017, Jensen (2018) undertook the first step towards a broad characterization of the soil resources, where twelve fields were sampled and characterized for e.g. soil texture, organic carbon, particle density, bulk density, pH, soil-water retention and gas diffusion. The investigated fields span the inner parts of SW Greenland along the Tunulliarfik and Igalikup Kangerlua, namely the areas of Igaliku (IG), Sdr. Igaliku (SI), Upernaviarsuk (UP), and Qassiarsuk (QA) (Fig. 1).

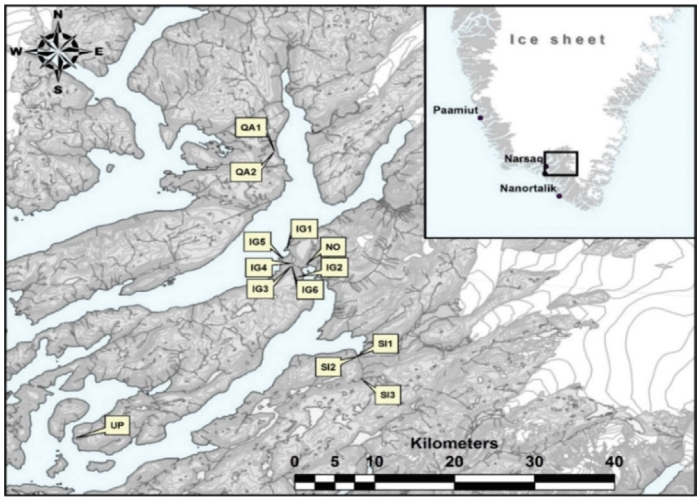

Figure 1. *Location of the 12 fields investigated in 2013, 2015, and 2017. Names of the fields denote the region in which they were sampled where, QA, IG, SI, and UP denote Qassiarsuk, Igaliku, Sdr. Igaliku, and Upernaviarsuk, respectively.*

The investigated fields lie within the boundaries of the newly selected Kujataa UNESCO world heritage site and encompass a large variation with regard to soil type and micro-climatic conditions.

Soil texture and nutrient content

The investigated soils cover a wide range of textures, i.e. particle size distributions, but largely consists of sand. Normally, soils exhibit a positive correlation between clay, silt, and organic matter (SOM). Compared to agricultural soils from lower latitudes, the Greenlandic soils contain a low amount of clay (2-10%), cf. Table 1, whereas the silt and SOM content are generally high.

Despite the very high organic matter contents, there is no strong

Mark	Clay kg kg^{-1}	Silt kg kg^{-1}	Sand kg kg^{-1}	SOM kg kg^{-1}	pH -
IG1	44	316	526	114	4,99
IG2	65	271	434	231	4,82
IG3	101	331	418	150	4,81
IG4	47	215	664	76	5,20
IG5	49	318	532	102	4,97
IG6	87	299	512	103	5,01
SI1	329	215	717	39	5,32
SI2	22	237	715	26	5,87
SI3	40	244	659	59	5,54
QA1	84	283	309	324	6,21
QA2	91	334	521	54	7,78
UP	44	316	596	70	5,7

Table 1. *Soil Characteristics of twelve selected agricultural fields (Fig. 1) in South Greenland.*

soil structure development, which otherwise would increase the nutrient availability in the soil. This is most likely due to the low contents of clay-sized soil particles, the negative influence of temperature on biological activity, and the tendency of organic matter to induce water repellency under certain dry conditions. The soil pH is rather low and generally decreases with increasing soil organic matter (SOM) contents. Crop growth and most of the soil processes are favored by a soil pH range of 5.5 – 8. In acid soils, plant nutrients may become unavailable, or only available in insufficient quantities. Plants can then show deficiency symptoms despite of fertilizer application.

The stone and gravel content vary significantly across and within the investigated fields. Very large stone and gravel contents inevitably affect the soil water retention negatively and may cause mechanized vegetable production to be unfeasible.

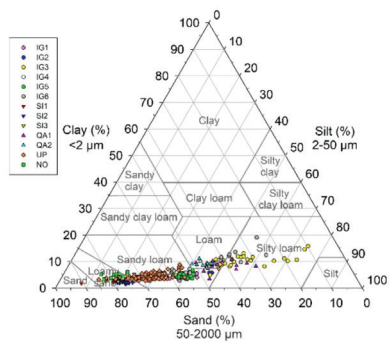

Figure 2. *Soil texture.*

The soils nutrient content of the South Greenland soils is largely unknown, except from a few soil samples, representing average values reported by Jensen et. al. (2018). This data is too scarce to

generalize upon nutrient content, but knowledge hereof will be of tremendous value for the farmers and it is recommended to determine and follow closely the soil nutrient content development.

Further, studies into the properties of the soils organic fraction is highly needed, due to its principal role for soils function, e.g., water retention, aeration, and soil water repellency as well as chemical properties such as pH and nutrient retention and availability.

Plant available water

The perhaps most important functional property of agricultural soil is its ability to retain and supply water to the crops throughout the growing season. The measure of how much water a soil can retain at an available state for plants is termed "plant available water" (PAW). The PAW is typically inferred from existing models based on, e.g. texture, organic matter, and stone content. Following this approach, it could be expected, that the PAW of the Greenlandic soils is low due to their coarse texture and high stone content (Caviezel et al., 2017; Lehmann et al., 2016).

Recently, Jensen (2018) provided the first full measurements of the soil water retention curves for Greenlandic topsoils originating from five agricultural fields. The results showed that all fields exhibited mean PAW values in excess 0.316 cm3 cm-3, which is significantly higher than what would be expected based on the soil composition, especially for the less-organic and coarse-textured soils. The large volume of PAW in the Greenlandic soils may likely be due to a porous quality of the "Arctic" soil organic matter, and further studies on this topic are highly needed in order to facilitate, e.g. irrigation planning and determine the drought resistance of the fields. It should also be stressed that high stone contents and shallow soil/rooting depths potentially may severely decrease the actual plant available water in the Greenlandic fields.

Soil aeration

The lack of a well-developed soil structure and highly organic nature of the Greenlandic soils also affect their ability to perform gas exchange. Exchange of gases, e.g. CO_2 and O_2 between the soil and the atmosphere is a prerequisite for proper plant growth.

The relative diffusivity measured across six fields from Sdr. Igaliku, Upernaviarsuk, and Igaliku were reported in Jensen et al., 2018. The relative diffusivity of the Greenlandic soils increases non-linearly with the air-filled porosity, but at a slower rate than what would be expected for e.g. Danish soils. This is particularly due to the organic matter creating a tortuous and complex pore structure. The lower ability of the Greenlandic soils to perform gas exchange warrants careful consideration of, e.g. irrigation and drainage planning, as poor aeration may occur faster than expected.

Rooting depth

The rooting depth of the soils is primarily limited by the soil depth (the distance to the underlying rock), the soil texture, and in some wetlands, the depth of the water table. No studies have been made specifically on the rooting depth of the Greenlandic soils, but based on knowledge from Danish soils, the maximum rooting depth of coarse-textured Aeolian deposits such as SI2

Figure 3a. *Aeolian soil profile from SI2.*

Figure 3b. *A shallow soil profile from Qassiarsuk.*
Fotos: Mogens H. Greve and Peter Weber Jensen

(Figure 3) would not exceed 50 cm.
The soil depth of the areas used for summer grazing is generally very shallow albeit with a large degree of variation. The cultivated areas are primarily situated on the soils with the largest soil depth, but even some of the most productive areas exhibit limited soil depths (Figure 3), and the underlying rock is often exposed.

One of the principal constraints imposed by the shallow soil/rooting depth pertains to the reduced root zone capacity, i.e. total volume of plant available water in the root zone. The Greenlandic fields may thus have a highly limited water storage capacity despite the excellent water retention of the topsoil.

Water repellency

The rather high content of non-degraded organic matter in the South Greenlandic soils in combination with the coarse grain sizes may lead to the soil becoming water-repellent during the dry summer periods with reduced precipitation. In these periods, the soil water contents can decrease drastically in the farmed areas, if irrigation is often not available.

Soil water repellency (SWR) can significantly impact the functional properties of soil and have been shown to induce surface runoff and erosion, decrease the infiltration rate, and initiate finger flow (Figure 4).
Of the investigated South Greenlandic soils, 99% showed potential for water repellency during dry periods. Preliminary investigations of the Greenlandic soils clearly found that with increasing soil organic matter (SOM) content, the intensity of SWR increases as well as the water content at which zero SWR occurs. These strong correlations constitute a promising result, which can be further developed into a decision-support tool to advise farmers on the field-specific timing and need for irrigation.

Challenges and opportunities

Soil Samples

Throughout the world, it has for many years been best practice to take soil samples on a regular basis. The analytical results guide the farmers in planning of application of fertilizer and lime. Soils sampling on a regular interval helps to track the deployment in both soil nutrient status and soil pH. Soil testing is a vital component of sustainable farming practices that are profitable and efficient. Soil nutrient status changes relatively slowly and therefore one should base fertilizer advice on soils tests every 4 to 5 years.

Generally, a standard soil test will have values on pH, lime, phosphorus (P) and potassium (K). There is a huge difference in the underlying geological parent material in South Greenland, which makes it important to establish a baseline for the content of micronutrients to avoid deficiency of micronutrients. It is therefore recommended that analysis of micronutrients (Mg, Mo, Cu, Mn, Zn, Ar & B) is done on all fields in order to avoid nutrient deficiencies.

It is recommended that samples are taken in late summer and fall to allow ample time for analysis and planning, which enables farmers to apply the right fertilizer and lime at the right rate, time and place. It is recommended to take a soil sample every 1 to 2ha and to divide fields based on soil type, cropping history, known growth differences / previous performance etc.
It is also recommended to take some soil samples of the soil in the summer pasture areas to ensure sufficient micronutrient for the animals in the summer period.

Soil Improvement

Liming

Preliminary investigations of agricultural fields in South Greenland has shown high variations in Soil pH. Some fields show severe signs of soil acidification, which is a serious issue for crop health and yield. Without treatment, soil acidification can also extend into subsoil layers posing serious problems for plant root development and nutrient uptake. Applying lime is an efficient way to reverse soil acidification. A systematic program for measuring soil pH and applying lime should be established.

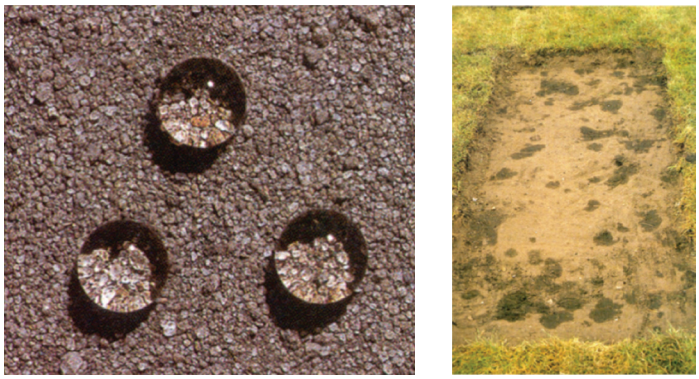

Figure 4: *Left: picture of water droplets beading on a water-repellent Jyndevad soil. Right: picture of finger flow in an infiltration experiment performed on a water repellent soil. Photos: Lis Wollesen de Jonge.*

Animal manure

Soil receiving manure generally has a higher content of organic matter and higher microbial activity than soil fertilized with chemical fertilizer. Manure is usually rich in phosphorous (P), potassium (K), Calcium (Ca), Magnesium (Mg) and nitratnitrogen (NO3-). These soils normally also have a lower bulk density and a higher porosity and better aggregate stability compared to soil fertilized with chemical fertilizer. Livestock manure is an important resource for improving the soil quality and critical for the recycling of nutrients in the farming systems in Greenland. It is imperative to study how best to apply animal manure and improve its use.

Seaweed

Seaweed is well known as a soil amendment in both in horticulture and agriculture to stimulate plant growth and increase productivity (Khan et al., 2009). Seaweed contains many macro- and micro-nutrients and organic compounds.
Seaweed requires composting to remove the relatively high salt content from the sea and transform the organic material and release the nutrients. The size of the resource in South Greenland is unknown (Lehmann et al. 2016).

Glacial rock flour

Some of the world's most fertile soils have a high content of silt. The grain size of glacial rock flour resembles that of silt and may result in much higher fertility and content of plant-available water if added to the coarse soils in Greenland.
Glacial flour (Fig. 5) washes out from under the glacier and is found, either as historic deposited terrestrial or more recent marine deposits within the fjords, near the outlets of the glacial rivers.

Glacial rock flour contains a wide range of minerals and a spectrum of trace elements and may help to neutralize acidity, improve soil structure, promote microbial activity, and slow down soil depletion. Results from a recent study suggest improved soil mechanical properties and stability (Igwe and Adepehin, 2017). Studies on soil amendment with glacial rock flour have primarily focused on crop nutrient supply and crop growth. These studies on soil re-mineralization generally imply a slow and rel-

atively constant release of nutrients and improved soil chemical characteristics, resulting in marked improvements in crop yield (Van Straaten, 2006).

Figure 5. *A terrestrial glacial rock flour deposit by Igaliku, South Greenland (2017).*

Glacial rock flour from the fjords contains sea-salt, which has a negative influence on crop growth and soil structure development. Consequently, desalinization strategies for the saline glacial rock flour must be developed before they can be utilized as a soil improvement additive.

During 2017 and 2018, mapping activity of deposits of glacial rock flour has taken place at Tunulliarfik and Igalikup Kangerlua in South Greenland (Jensen et al., 2018). At each location where glacial rock flour was found, samples were taken for preliminary characterization. Table 2 shows huge differences in properties of the deposits. It will be very important to consider this before applying the glacial rock flour to the agricultural fields and further studies are needed.

Establishing windbreaks to protect soil and crops

Windbreaks are barriers formed by trees and other plants establishing favorable microclimate and preventing wind induced crop damage and soil loss due to wind erosion. In South Greenland destructive katabatic winds (locally referred to as Sydost) coming from the glaciers occur. Studies found that yield were as much as twenty percent higher in fields protected by windbreaks compared to fields without them. Windbreaks of spruce and willow (Picea glauca and Salix spp.), have been planted in Upernaviarsuk for protecting the crops. Other spruces (Picea engelmanni, hybrids between P. glauca and P. engelmannii and between Picea sitchensis and P. glauca) have been found to be well adapted (Kenneth Høegh pers. comm.) and these tree species may be preferred for future windbreaks (Harding and de Neergaard, 2019.)

Use of windbreaks could be more widely applied in the future in relation to increasing crop cultivation. Further, several farmers express an interest in planting trees at their farms.

Figure 6. *Small field protected by windbreaks at Upernaviarsuk research station.*

Finally, as was also discussed by Lehmann et al., (2016), there is a need for more work on both fertilization and irrigation strategies that can support the growing of both fodder and cash crops. The soil improvement potential of livestock manure is discussed in a previous section of this report, but there is also a potential in balancing fertilization value of livestock manure with mineral fertilizers as this is often not done today. Hence, this may reduce the need for imported mineral fertilizer.

Growing and harvest strategy for fodder crops

In Southern Greenland, forage crops including grasses and green cereals are typically harvested only once per year, ensiled and stored as wrapped round bales. The advisory services collect information every year on the production of bales on each farm, but little is known of the weight and quality of the harvested bales (See also chapter 3). Hence, there is a great deal of uncertainty regarding the harvested forage, which could be reduced by systematic sampling and analysis of grown forages.

Growing and harvesting forages for livestock must meet a twofold objective as maximum yield of optimal quality should not impair the ability of the crop to sufficiently regrow and survive the coming winter. To our knowledge, no experiments have been carried out in Southern Greenland where different timings of the harvest, harvesting multiple times per year, cut length

Glacial rock floor	% Clay (<0,002mm)	% Silt (0,002-0,02mm)	% Sand (0,02-2mm)	S SA (m^2 g^{-1})
Igaliku 1	16.3	24.3	59.4	33.9
Igaliku 2	20.7	27.1	52.1	18.1
Sdr. Igaliku 1	20.1	25	54.9	not relevant
Kangerluarsunnguaq (Terrestial)	32.2	31.2	26.5	25.1
Kangerluarsunnguaq (Marine)	67.6	28.7	3.5	28.4

Table 2. *Clay, silt, sand content and specific surface area of rock flour samples from 5 sites in South Greenland (after Jensen et al., 2018).*

at harvest and survivability of the crop have been investigated. Both cut length (e.g. Lee et al., 2008) and interval between cuts (e.g. Pembleton et al., 2017) affect yield of dry matter and energy as well as the nutritional quality of the harvested forage.
However, there is little if any published studies on different management strategies for fodder production and harvest strategies under Arctic conditions where the end goal was to produce feed for captive livestock. There is likely a build-up of practical knowledge among farmers as well as current and former agricultural extension officers, which could be systematically collected and used as a foundation for experiments at Upernaviarsuk research station and on private farms. Furthermore, farmers in places such as Iceland and Northern Norway farm in some areas under circumstances similar to those of Southern Greenland, and both farmers and consultants that work in these areas may hold valuable experiences for the Greenlandic farmers.
Figure 7 shows a schematic overview of important factors affecting the production outcome of a forage crop, and they illustrate the complexity, which needs to be considered. The farmer can manipulate, directly or indirectly, some of these factors to a larger or lesser extent within the constraints given by natural conditions and the production foundation. Because growing conditions in Greenland are as difficult as they are, there is a need for specific and updated knowledge on growing strategies in these areas as well as on how these strategies are affected by the remoteness of the farms and arable fields. Any input required for the farm and output sold from the farm may incur a significant transportation cost.

Synergy between arable lands and greenhouses

Some farmers already grow potatoes for human consumption, and a few have constructed greenhouses where a range of different vegetables are produced. Greenhouses alone hold a substantial potential for producing food in remote areas in Southern Greenland, but there is also a potential synergy between farming arable lands using greenhouses.

The growing season in Southern Greenland is relatively short around 100 days, and greenhouses could be used to produce seedlings, which can be transplanted out on to the arable lands, once the weather and soil temperature permits it. Hence, it artificially extends the growing seasons, which may allow for a broader range of different vegetables to be produced. Moreover, it may allow for a higher survival rate of the plants as they spend a proportion of their most vulnerable time in a more protected environment. Furthermore, greenhouses can be built on a rock-

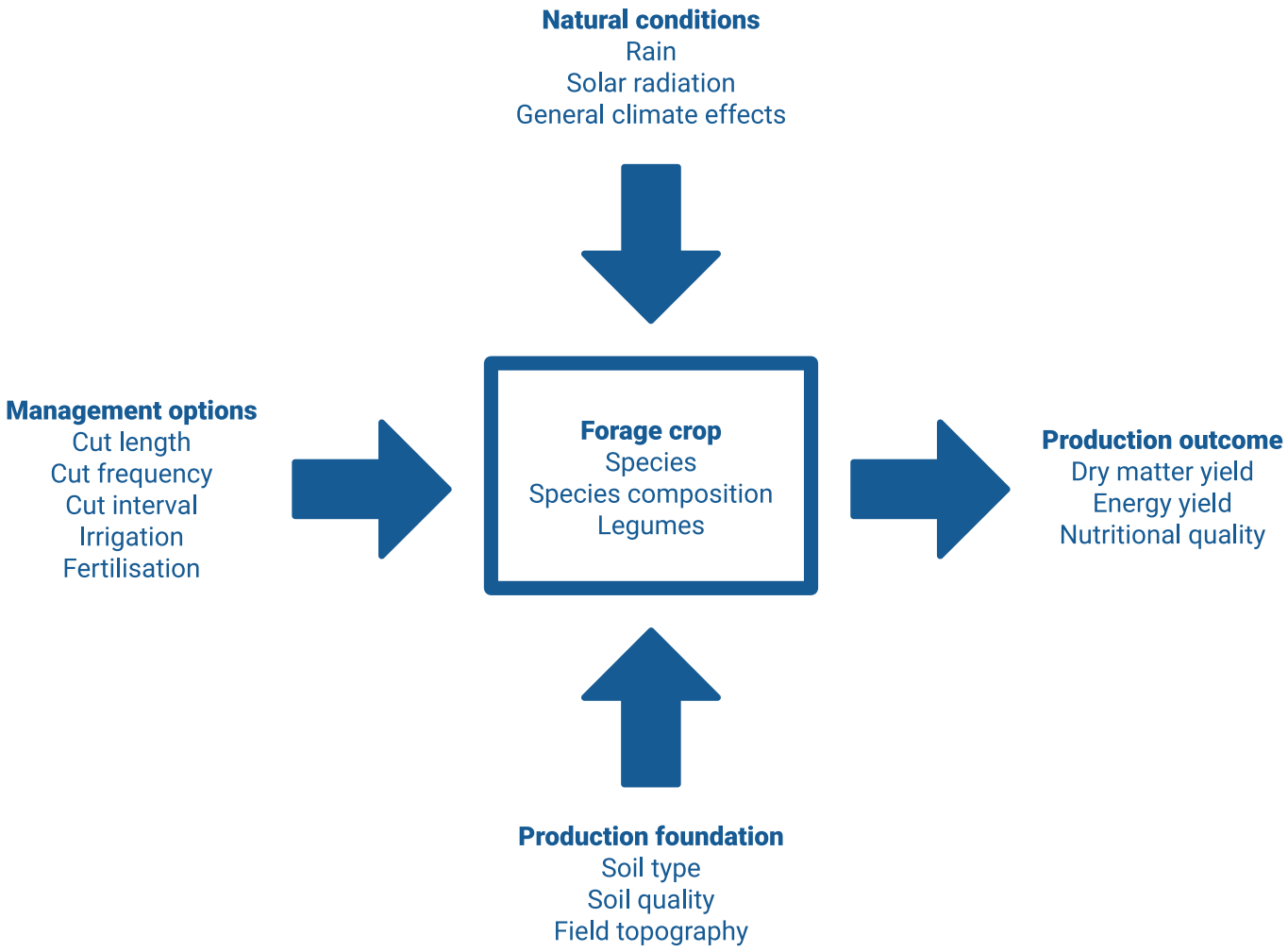

Figure 7. *A schematic overview of important factors affecting a forage crop and its yield of dry matter and energy as well as nutritive value.*

ier surface and hence expand the total growing area of a farm by adding more area inside.

Growing winter feed on permanent pastures

The agricultural area in Southern Greenland include both arable fields and permanent pastures (cf. Figure 10 chapter 3), located in connection with arable fields. However, further classifying the permanent pastures into two different categories (permanent grasslands and grazed natural areas) may prove useful for both farmers and authorities in Greenland. Parts of the permanent pastures close to the farm may be used for feed production without tillage but with irrigation and possibly fertilization. There are small lakes scattered around in the landscape, so water or irrigation may not need to be transported far, and it could be accomplished with small solar-driven pumps. Mineral fertilizers can be distributed with an ATV. These areas would, like the arable fields, need to be fenced off to prevent livestock from grazing there, and the build-up biomass could be either harvested for winter feed or grazed by lambs in early autumn before slaughter to achieve higher slaughter weights. Hence, a few management changes would have the potential to increase production potential of selected areas, and these areas could be classified as permanent grasslands.

Thus, the remaining permanent pastures could be classified as grazed natural areas, but the distinction between permanent pastures and natural areas will need a careful assessment of what areas can stand this change from pure sheep grazing to addition of water and fertilizer. Some areas may hold valuable nature, sensitive plants and protected species that would not tolerate the extra water and fertilizer, and this needs to be considered before mountain areas are allocated to this type of management. Moreover, the feeding potential of permanent pastures has previously been extensively studied (Thorsteinsson, 1983), albeit more recent work using remote sensing techniques may improve our knowledge of these areas (e.g. Westergaard-Nielsen et al., 2015).

Figure 8. *Greenhouse and seedlings inside the greenhouse at Upernaviarsuk research station. Photos: Jesper O. Lehmann.*

Chapter 2 - Plant health in agricultural areas in Southern Greenland - pests and diseases

Chapter 2 is based on the background report by de Neergaard and Harding, 2019

Although modern agricultural farming has a history of around 100 years in Southern Greenland, studies of pests and diseases of the crops are, however, surprisingly few. Observations of pathogenic fungi and insects associated with the natural vegetation in Greenland have been published for more than 130 years (e.g. Conners 1967, Böcher et al., 2015), and remains of herbivorous insects are recorded from the time of the Norse (e.g. Böcher 1998; Iversen 1934; Panagiotakopulu & Buchan 2015).
In the light of the growing concern about climate change and the potential consequences for agriculture in Greenland, a series of studies on the development of plant diseases and later also pests in the sheep farming region in Southern Greenland was initiated in 2007. Constraints, such as diseases and pests in potato production was the primary focus of the investigations, but the activities were, however, soon extended to grass fields, vegetable production and forest tree plantations. Consequently, this chapter focuses on fodder crops and potatoes as well as perspectives on future potentially introduced crops and considerations on the associated pests and diseases.

Fodder crops

Grass and cereals

The arable fields are cultivated with a number of grass species or cereals harvested green for winter feed as hay or silage. Perennial hayfields are often maintained for extended periods, generally much longer than in Europe. Cultivation is established by sowing mixtures of Timothy (Phleum pratense), Common Bent (Agrostis tenuis), Smooth Meadow Grass (Poa pratensis) and Red Fescue (Festuca rubra) or Timothy as monoculture. Generally, the assortment offered by the suppliers includes two standard mixtures with different ratios of the individual species; one for dry soil conditions and one for soils with better water retention, which instead of Red Fescue contains White Clover (Trifolium repens) (Daniel Egede Svenningsen pers. comm.). Recently more drought tolerant species such as Bromus inermis, have been introduced as part of the mixture for dry soils.
Ryegrass (Lolium multiflorum var. westerwoldicum) too is an esteemed crop, due to its fast growth and extensive root system which rapidly takes up nutrients, often used as a cover crop to stabilise the soil until other species in a "meadow mixture" have established.

Annual cereals for winter feed production include Spring Rye, Triticale, Oats and - to a smaller extent - Barley. Of these, Rye and Triticale are especially drought tolerant (Agricultural Extension Service, Qaqortoq, pers. comm.).

Forage radish

Forage radish was for a period successfully cultivated by farmers in South Greenland. This crop is of great value in a crop rotation scheme. Fodder radish furthermore has a capacity of limiting certain soil borne diseases (Jabnoun-Khiareddine et al., 2016) and nematodes (Vleugels et al., 2014). However, the cultivation of fodder radish has declined, not because of poor yield, but due to insufficient storage facilities (Aqqalooraq Frederiksen, pers. comm.).

Pests

In grasses, the winter grain mite (Penthaleus major) and clover mite (Bryobia praetiosa) as well as the anthomyiid fly (Delia fabricii) are major and regularly occurring pests. Furthermore, leafhoppers and, at intervals, noctuid larvae occur in immense numbers.

The winter grain mite is most important in perennial hayfields of Timothy, especially in old and fertilized hayfields, where yield loss by around 50 % due to mite attack were recorded (Nielsen 1984). On the contrary, no damages were recorded in permanent pastures (Nielsen 1984).

Mite damages are most severe in warm and dry summers. Under these conditions the grass is drought-stressed, growth is damaged, and the plants are unable to compensate for loss of water and nutrients due to mite feeding. In wet summers, mites are of no importance (Aqqalooraq Frederiksen pers. comm., own observations). In subarctic regions, P. major overwinters in the egg stage in the litter (Nielsen 1984, Johansen & Haug 2002), and it spends dry periods in the litter. Control by removing the litter has therefore been suggested (Nielsen 2010). This control method will reduce mite numbers but have a negative impact on the amount of humus and nutrients and retention of humidity. If removal of the litter is undertaken by re-ploughing, the risk of erosion should be considered.
Based on experience from Norway, Iceland and Greenland, we suggest that mite control in the hayfields focus on cultivation practices and improving compensatory growth as well as irrigation during dry periods and multiple applications of fertilizer rather than one single during the growth period. Effects on vegetation and environment must, however, be considered.

Diseases

The most frequently observed leaf spot pathogen in Greenland is by far Cladosporium (Heterosporium) phlei causing eye spot on Timothy (own observations). Powdery mildew (caused by Blumeria graminis) is frequently observed, in particular on smooth meadow grass (Poa pratensis) and Ryegrass (Lolium sp.), where leaves occasionally are almost completely covered by sporulating structures. No assessment of yield losses in Greenland in these crops has been made but spread and dispersal of powdery mildew are favored by dry weather conditions, which may be more frequently occurring under future climate scenarios for South Greenland, with more extreme weather conditions. Powdery mildew attacks on cereals is generally recognized to cause considerable losses worldwide and by that it constitutes a potential risk to important crops in Greenland.

Diseases caused by smut and bunt fungi (Ustilaginales) are extremely abundant in plants in the natural vegetation in Greenland, e.g. on species belonging to Polygonaceae and Cyperaceae (de Neergaard, own observations). They are, however, not recorded in grasses or cereals, probably because most smut and bunt fungi are seed-borne and commercial seed production does not take place in Greenland.

Abiotic factors

Damages of the grass vegetation due to cool/frost seem to be an increasing problem (David Poulsen, pers. comm.). Low temperatures in areas not covered by snow cause injury to plant tissue, as does shift between temperatures resulting in the formation of an ice-cover on the snow, leading to oxygen deficiency at the surface of the ground. According to NJF (1979), "most damage occurs where surface water cannot run away as when the soil is poorly drained or when the ground is frozen. Level area or depressions in the ground are most affected, but if frost occurs immediately after a mild period, slopes can be covered with ice."

Figure 9a. *Turnip attacked by the cabbage root fly. Photo: Eigil de Neergaard.*

Edible crops

Potatoes

Potatoes are cultivated on a commercial scale by a limited number of farmers: in 2018 at only 6 of the registered farms. Furthermore, small scale production for private consumption takes place at many locations including gardens in towns and settlements.

In Greenland the amount of sowing material applied is 1,3-2,5 t /ha. The cultivated area is not more than 10 ha and varies from year to year. Seed potatoes are imported from Denmark or Norway. The farmers select cultivars from the assortment offered by the suppliers, and they can base their choice on personal experiences or on results obtained from the cultivar trials at Upernaviarsuk research station. During the last decade the most commonly applied cultivars were Solist, Marabel, Folva and Ballerina. However, a number of other cultivars evaluated in the trials have shown highly promising results in terms of earliness, yield, quality, and resistance towards diseases.
The average yield is 16-20 t /ha (in Denmark 40 t/ha, in Sweden Norway and Finland 22-25 t/ha). In 2017 the total production in Greenland was 110 t.

Brassicaceous crops - turnip, cabbage, cauliflower, etc.

Turnip is mainly grown by farmers for own consumption. The cultivar applied offers a delicious product which is highly esteemed and considered a delicacy in the Greenlandic cuisine.
More types of Cabbage as well as Cauliflower, Brussels sprout, Kale, etc., are commercially cultivated at Upernaviarsuk research station as well as at a few farms. Brassicaceous cash crops may become more important in future agriculture in South Greenland.

Pests

No pests have been observed so far in the potato fields in South Greenland. In plant pathological surveys undertaken in 2007-2013, no insect pests were recorded (de Neergaard 2013), although in 2009 tunnel-like cavities were observed in the tubers that might be caused by slugs.

Figure 9b. *Black leg disease in potato. Photo: Eigil de Neergaard*

During the summers 2017 and 2018, sweep net sampling in potato fields was specifically targeted at aphids, as they can be important vectors of potato virus Y (see below). Farmers as well as current and former extension officers (including officers from the farmers organization SPS and the district veterinarian) unanimously confirm the apparent absence of aphids feeding on potatoes. No studies of insect damages were, however, made on potato tubers at the time of harvest.

The two potato cyst nematodes Globodera rostochiensis (yellow potato cyst nematode) and G. pallida (white potato cyst nematode) have been specifically searched for, but not found, in Greenland. These nematodes are of major concern in all potato growing regions in Europe and are present in Iceland, Labrador and Newfoundland.

Cabbage root fly is a pest attacking brassicaceous crops such as turnip as well as forage radish. Studies of its distribution and apparent temporal spread along the Tunulliarfik-fjord suggests that the insect has been introduced into Narsaq, settled in the

Qassiarsuk-area, and hereafter it gradually spread over the Narsaq-peninsula. Consequently, it might be concluded that the cabbage root fly represents an example of a pest problem which is due to uncontrolled plant import.

Springtails (Collembola) attack seedlings of different cruciferous crops, among others white cabbage (Brassica rapa), turnip (Brassica campestris ssp. rapifera) and radishes (Raphanus sativus), when grown under highly humid conditions. In 2017 extensive damages and plant mortality were reported in seed plants of white cabbage grown under horticultural fleece at Upernaviarsuk.

Diseases

The majority of important diseases of potato known from Denmark are observed in Greenland as well, and in many cases developing quite as vigorously, e.g. blackleg/softrot, common scab and Rhizoctonia canker. This is remarkable since agriculture in Greenland is characterised by isolated arable fields, often situated far from each other, few alternative hosts, and cold winters where tubers left in the soil hardly survive.
Late blight seems not to be established in Greenland, probably due to the dry climate. Five different vira were identified, apparently developing to the same level as in Denmark (de Neergaard et al., 2014). The most frequent virus demonstrated was potato virus Y which was present at 7 of the 15 studied locations. This virus is considered to be one of the most important potato vira in Europe.

Soil samples from potato fields have been studied with regards to microbiological suppressiveness by analysing their antifungal capacity (Jensen et al., 2008). However, no effect under field conditions has been demonstrated. Still, these studies have led to the commonly accepted and widespread viewpoint that potatoes cultivated in Greenland are considered disease free. This is contradicted by the distribution and significance of viral, bacterial and fungal diseases - and in particular abiotic diseases - developing to a level like in Denmark, as demonstrated in the farming region in Southern Greenland in surveys 2007-2010 (Harding and de Neergaard 2019).

Abiotic factors

A number of disorders caused by abiotic factors have been observed in potato fields in Greenland. By far the most significant is hollow heart, which in certain years occurs extensively. The disorder is caused by fluctuations in water supply to the plants. The widespread application of irrigation systems in combination with the use of culture cover by horticultural fleece (such as "Lutrasil") makes potato cultivation under subarctic conditions a highly demanding task for the farmer.

Pests and diseases of future concern

The European crane fly (Tipula paludosa) has not been reported from Greenland. It has, however, spread to North America incl. Canada and has recently been introduced to Iceland, where it in few years has become a pest in several crops (Náttúrufræðistofnun Íslands, Gudmundur Halldórsson, pers. comm.). In other regions, it is an important pest of permanent pastures, in some years being highly destructive to arable fields (e.g. Fyens Stiftstidende 2017). Introduction and establishment in Greenland can be anticipated, e.g. via import of turfgrass rolls.

The dipterans Nanna flavipes and Nanna armillata are associated with Timothy on which they feed before earing. Problems are most pronounced, when Timothy is grown perennially (Hofsvang 2018). Both species are distributed in Northern Norway and may be introduced to Greenland, where they may develop into pests in the perennial crops such as Timothy.
Leaf scald (Rhynchosporium secalis) is in Denmark the most important disease in rye, and a major problem in barley cultivation as well (Lisa Munk, pers. comm.). In Iceland, too, scald causes considerable problems in barley with yield losses exceeding 35% (Hermansson 2004).

Although not reported, Eurois occulta may during outbreaks undoubtedly feed on potatoes. The noctuid Euxoa ochrogaster ssp. islandica is a pest of potatoes in Iceland (Halldórsson pers. comm.), and it is most relevant to be aware of this species in Greenland (de Neergaard and Harding 2019). Also, slugs may be a major threat to potato farming as seen in Denmark, Norway, Iceland and North America. Unidentified slugs – possibly field slug, Deroceras agreste (or D. reticulatum) – appear in vast numbers in private gardens in Qaqortoq and in Upernaviarsuk, feeding intensively on leaves of cabbage, lettuce and rhubarb. Slugs have probably been recently introduced to Greenland via potted plants (Lasse Bjerge pers. comm.).

Nematodes should as well be of future concern. For different nematodes the host range includes oats, barley, wheat, triticale, many grass species as well as potatoes. Despite not being found at present a number of species (e.g. cyst nematodes) will most likely thrive in Greenland and once introduced, be extremely difficult to eradicate. Different Cysts can survive in soil (in Denmark) for 15 years or more and some species (e.g. Meloidogyne hapla) are shown to be extremely cold resistant (Wu et al., 2018).

Recommendations

Legislation and change of farming practices

The Kingdom of Denmark has adopted the International Plant Protection Convention (IPPC), which works to secure coordinated, effective action to prevent and control the introduction and spread of pests of plants and plant products (Council Directive 2000). However, Greenland is, since 2005, no longer encompassed by the convention. Consequently, the borders of Greenland are legally open for any import of plants and products derived from plants, such as potted plants, plants for planting, seeds, tubers (including seed potatoes), cuttings, Christmas trees, turfgrass rolls, wood packaging material and soil and growth media etc. Once a plant pathogen or pest is introduced, it may rapidly establish, and subsequently be extremely difficult

and expensive to control or eradicate. Many crop damaging organisms and vira are able to develop and establish in the agricultural region in South Greenland (de Neergaard and Harding 2019, Munk et al., 2008).

It takes a long time to prepare a legislation on plant health including import regulations, and even longer to implement it. In the light of anticipated rising temperatures, and the current expectations to further develop and extend agricultural activities over the next decades, it is strongly recommended to initiate the preparative work leading to a plant health legislation for Greenland - preferably including a system for regular survey for pests and diseases in Greenland.

Crop storage and crop rotation

At the farms where potatoes are kept for use as seed potatoes the following year, these are frequently lost during winter due to lack of sufficiently insulated and ventilated storage facilities. Also fodder radish and cash crop products intended for supermarkets are often destroyed in the period after harvest. Pitting potatoes or other harvest products like in Europe is not a tradition in Greenland. We recommend development of isolated storage facilities, perhaps utilizing sheep wool which is otherwise destroyed. This might also encourage the cultivation of fodder radish, which would be a highly welcomed contribution to crop rotation and have a beneficial effect on pests and diseases.

In a changing climate where more and new pests and diseases are prone to occur, crop rotation is an important measure to reduce the susceptibility towards pests and diseases as well as lowering the risk of soil depletion. An efficient crop rotation scheme can also include new crop species, e.g. fodder lupin cultivars, though such introduction to Greenland should be done with caution and awareness of the potential pests and diseases associated with them. By that the recommendations regarding plant health legislation and surveying becomes even more important.

Strengthening of local experimental research

The agricultural experimental station in Upernaviarsuk offers excellent facilities for intensive research on pests and diseases and the interactions with host plants under various cultivation regimes. We recommend that the activities at Upernaviarsuk be strengthened and expanded. Activities are suggested to include further development of the domestic cultivar trials - particular for potatoes but also for cabbage, lettuce and other vegetable crops. Previously, assessment of quantity, quality, earliness and attack of pests and diseases were recorded (also during the growth season) and results communicated to farmers. We suggest this activity to be resumed. Here it is imperative to develop systematic experimental protocols and keep documentation of results for consecutive years.

In addition, local field experiments at farms and production sites in different regions are recommended to elucidate differences in pest dynamics and effects of climate and soil conditions on plant health. Specifically concerning cultivation of potatoes, it is recommendable to establish experimental plots at a production site in the innermost part of a fjord (e.g. Tunulliarfik) to compare the influence of local climate on yield, quality and disease tolerance of the individual cultivars with that of Upernaviarsuk (continental/coastal). In general, farmers should be encouraged to harbour small-scale experiments on e.g. susceptibility of cultivars to pests and diseases, preferably coupled to productivity studies.

Dissemination and capacity building

Furthermore, dissemination of results from Upernaviarsuk and experience from farmers is of utmost importance. Farmers have asked for regularly updated information on trial results and experience from Upernaviarsuk. We recommend a current information system to be organized at the agricultural extension service (homepage, Facebook groups, apps). The extension service already now collects experience and data from individual farms, and systematization of experience and data could – in combination with information from Upernaviarsuk – form an internet-based support in plant protection to individual farms. In addition, this information and knowledge gathered could be included in the development of teaching material for the training of students at Upernaviarsuk.

Chapter 3 - Livestock production systems in Southern Greenland: Challenges and prospects

Chapter 3 is based on the background report by Lehmann and Kristensen, 2018

Livestock as a part of a farming system

A farm with livestock and feed production is a complex entity with outward flows of products including meat, wool and cash crops as well as inward flows of resources including feed, fertilizer and irrigation. At the same, there are internal flows and interactions between the livestock and the feed production where feed is exchanged with manure. Figure 10 shows a simplified schematic overview of these flows on a typical Greenlandic sheep farm with nature areas and permanent pastures for summer grazing and arable lands for producing winter feed and possibly a cash crop. In this context, nature areas are only affected by the grazing of livestock whereas selective fertilisation and irrigation can improve productivity of permanent pastures. However, a careful investigation should be initiated prior to fertilisation and irrigation of permanent pastures as it may change species composition and richness as well as have adverse environmental effects.

Livestock produces manure that is either brought to arable lands or defecated during grazing of nature areas and permanent pastures.

The farmer manages these flows and interactions, and deliberate changes somewhere may lead to changes elsewhere because of these connections. Hence, indirectly affecting the productivity of the livestock through changed practices on the arable lands is a possibility if these changes lead to improved nutritional quality of the feed.

Livestock farms and the surrounding infrastructure

Livestock farms rely on the surrounding public infrastructure to bring in supplies including feed, fertiliser and energy as well as bring out products including sheep, lambs and cash crops. In Southern Greenland, this infrastructure is characterized by difficult conditions, remote locations and long distances, and the capacity of this infrastructure likely require upgrading if a larger food production is to be achieved. Increasing national food production is a political objective for the Government of Greenland (Landbrugskommissionen, 2014) and this goal comes at a time when the number of active farms is declining (Statistics Greenland, 2016).

This raises several questions including: Can and should existing farms expand production to compensate for the reduced number of farms? And, should new winter barns be built near villages to allow the next generation of farmers to live in communities?

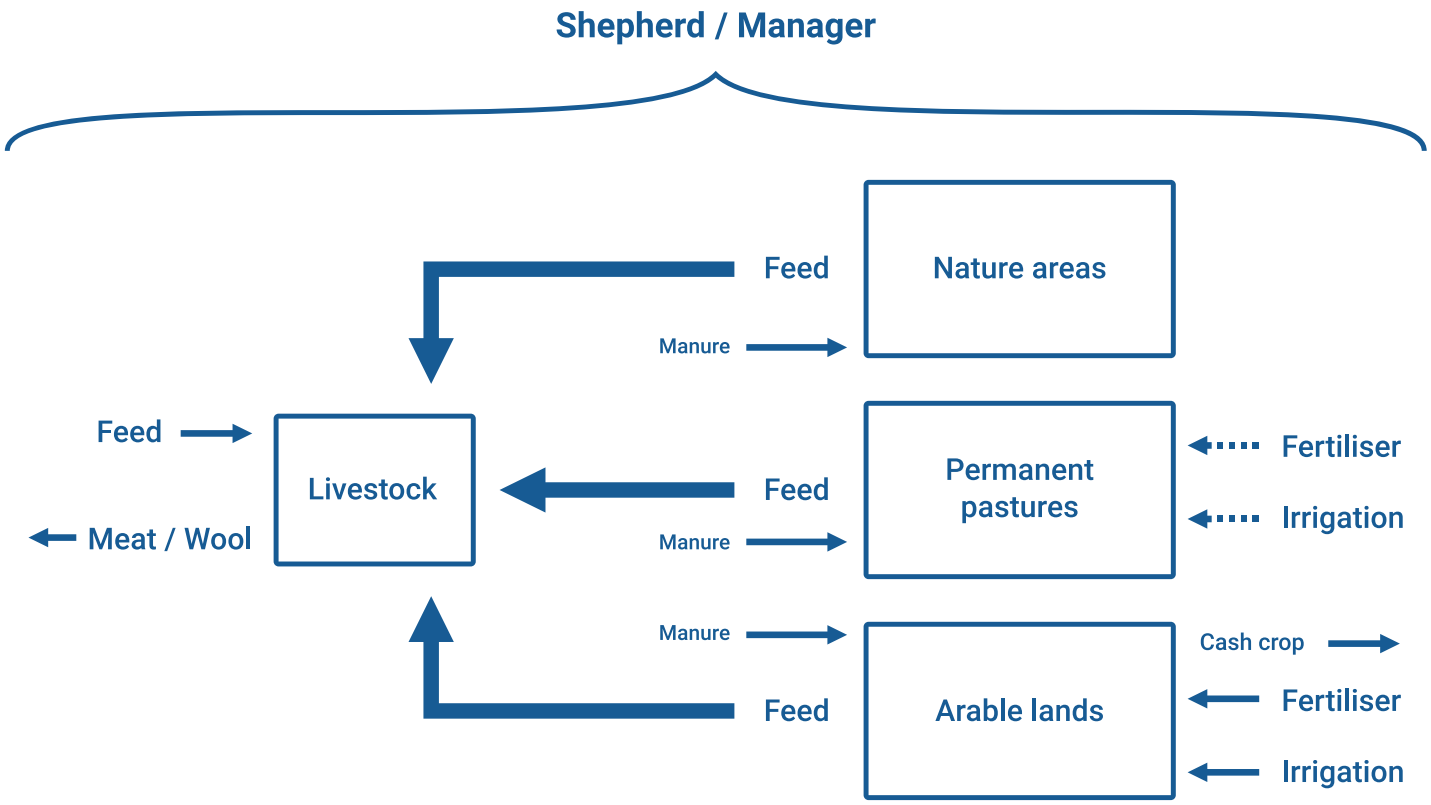

Figure 10. *Simplified overview of flows of production resources and products on a typical Greenlandic sheep farm. Livestock produces manure that is either brought to arable lands or defecated during grazing of nature areas and permanent pastures.*

The latter would require sheep, lambs and cattle to be transported by ship to summer grazing areas. Furthermore, are some locations more suitable for sheep, cattle or reindeer? Where could new farms be located? Moreover, how does the desire to expand food production interact with possibilities for increased tourism activities? Finally, how can new farmers be attracted? These questions cover a wide range of technical and production related aspects of Greenlandic agriculture, but potential environmental consequences of climate changes need to be taken into account.

Hence, addressing these questions both require further studies and analyses as well as political discussions and decisions about the future of the agricultural sector including type, characteristics, size and location of the farms. Both older (Thorsteinsson, 1983) and more recent work (Westergaard-Nielsen et al., 2015) suggest that there is a potential for an expanded sheep production in parts of Southern Greenland, and that this expansion depends on infrastructural development (Westergaard-Nielsen et al., 2015).

Feed production

Imported feed and fertiliser (52 % of total) as well as fuel (22 % of total) are the two largest production expenses for Greenlandic sheep farmers (Departement for Fiskeri, Fangst og Landbrug, 2016) amounting to 293 and 125 DKK per produced lamb, respectively (based on 2014-figures). Both are directly related to feeding of their livestock. Farmers grow fodder crops for winter-feeding whereas most rely exclusively on permanent pastures during summer. However, the majority of farmers cannot grow sufficient amounts of winter-feed to meet requirements for energy, protein, minerals and other nutrients, and hence have to import feedstuffs to meet the needs of the herd.

Growing fodder and cash crops in Southern Greenland

Chapter 1 of this report focused on ways to improve soil quality as a foundation for growing crops, and these measures may support and improve the yield and quality of the crops currently grown in Southern Greenland. However, other work should investigate the possibility for growing new varieties of currently grown crops and new crops that may be grown in Southern Greenland.

Furthermore, over the years, several different varieties of forage crops have been tested at Upernaviarsuk research station, and these different tests should be used as a foundation for testing new varieties at both Upernaviarsuk and on private farms.

The following two sections serve to provide a few points on how both arable crops and rangeland areas do and could serve as sources of nutrition for livestock.

Arable crops

In 2014, fodder crops and to a minor extent cash crops were grown on a total of 1,109 ha of arable land (Statistics Greenland, 2016). Swards dominated by grasses and cereals harvested green as a part of a renewing of a grass crop are the main fodder crops harvested as silage, and often only one cut is realized during a growing season. Hence, farmers need to import mainly energy and protein; either as a mixed compound feed or as separate energy and protein feedstuffs such as barley and soybeans, respectively. From 2010 to 2017, Greenland imported 752 t cereals annually, which is the equivalent of 37.7 kg per ewe per year, but other feedstuffs including forages are not reported separately (Statistics Greenland, n.d.).

Both barley and wheat have been grown north of the Arctic Circle (Sjogren and Arntzen, 2013), and a more recent study have looked at growing different cereal crops across countries around the north Atlantic (Martin et al., 2016). Potatoes are currently grown on a limited area, as also discussed in Chapter 2, and there is likely potential for more vegetable growing as well as growing a variety of legumes for feed, which could reduce the reliance on imported feedstuffs. A current project by the Nordic Genetic Resource Centre ("Peas – a genetic resource for sustainable protein production in the Arctic") explores growing of different varieties of peas under arctic conditions. Furthermore, climate change in combination with irrigation, fertilisation and improved management may allow for improved forage yields and possibly more than one cut, which could significantly reduce the reliance on imported feedstuffs.

Permanent pastures

Summer grazing permanent pastures in pristine environments is a major source of nutrition for sheep in not only Greenland but also across the north Atlantic region. Hence, ecological and environmental impacts have been given much attention (Austrheim et al., 2008a, Nordisk Ministerråd, 2007). Both livestock species (Wehn et al., 2011) and livestock density (Austrheim et al., 2008b, Mysterud et al., 2014) influence vegetation growth and composition in these areas. Thus, there is a fine balance between the number of sheep that a given area can support and feed in the short and long term, respectively.

A thorough assessment of vegetation growth, composition and nutritional quality for sheep was undertaken in the late seventies (Thorsteinsson, 1983), and this showed that there was a substantial potential for feeding more sheep during summer, although this does not account for the ability to produce sufficient winterfeed. More recently, the potential for new sheep farms and a greater production was explored with remote sensing and climate change forecasting techniques (Westergaard-Nielsen et al., 2015), but the effect of climate change may be highly locally dependent based on a study from northern Norway (Uleberg et al., 2014). However, focus is often on either feed supply with dry matter or energy, and future work should look into supply of especially proteins, amino acids and minerals as they may be limiting lamb growth and survival.

Greenlandic livestock

Cycles of production

The main purpose of the Greenlandic livestock is meat production based mainly on the Greenlandic sheep, which is a descendant of the Icelandic sheep (Landbrugskommisionen, 2014) and classified as a short-tailed breed (Dýrmundsson and Ninikowski, 2010). Lambs and sheep account for 93.2 % and 6.5% respectively of all slaughtered animals in Greenland from 2005 to 2016 (Statistics Greenland, n.d.; Figure 5).

Figure 11. *Henrik Knudsen owner of Sillisit sheep farm and his partner Elna. Jensen, May 2018.*
Photo: Anne Merrild Hansen.

In contrast, reindeer and cattle (Dexter and Galloway breeds) account for only 0.2 and 0.04 % of slaughtered animals, respectively, and hence sheep is presently by the far the most important livestock species.
All livestock go through different phases of growth, and female animals not slaughtered go through cycles of pregnancy, birth, lactation and a dry period followed by the next cycle. In contrast to the majority of intensive systems, farmers in Greenland rely on the seasonality of vegetative growth, which require timing of reproductive cycles with birth in spring where vegetation in the permanent pastures start to grow more rapidly.

Sheep have the longest time to recover after giving birth, and only sheep can be bred after returning from summer grazing on the permanent pastures. Hence, farmers can tightly manage feeding of ewes before and during the pregnancy period as well as manage a breeding scheme that allows for controlled genetic progress. The Icelandic breeding scheme Fjárvis is already used successfully on some farms in Southern Greenland (Landbrugskommisionen, 2014), but a strengthening of this work and an adaptation of the system to better meet Greenlandic needs is strongly recommended.

Nutrient requirements throughout the year

Growth, pregnancy and lactation are life functions, which animals are able to prioritize nutrients towards, depending on the stage of the life function and the availability of nutrients from either summer pasture or winter-feeding. This has been shown for cattle (Martin and Sauvant, 2010a, Martin and Sauvant, 2010b) and likely applies to both sheep and reindeer as well.
Both sheep and cattle are able to exhibit compensatory growth later in life and hence have the ability to compensate for a previous lack of sufficient nutrients (Ryan et al., 1993a, Ryan et al., 1993b), even without a negative effect on meat quality (Ponnampalam et al., 2003, Thatcher and Gaunt, 1992, Thornton et al., 1979). This mechanism can be actively utilized by farmers.

The question, however, is whether a period of reduced growth is a consequence of a low availability of nutrients during summer grazing or a consequence of a deliberately low feeding regime during winter to save costs? If the permanent pastures are plentiful with sufficient nutrients, then it could make sense to feed less nutritious feed during winter. However, this does not account for the feeding of the embryo or ensuring a sufficient supply of selected nutrients that may be lacking during summer. Little if any quantified data exist about the nutrient balance of Greenlandic sheep over the course of a year. In this regard, winter-feeding of sheep is of particular interest as this includes the full pregnancy period and hence the development of the embryo. Embryonic programming of sheep describes feeding of the embryo through the ewe to produce optimal lambs that are capable of performing well (Kenyon and Blair, 2014) and survive a summer in a harsh environment.

Moreover, there is little knowledge of the feed quality produced in Southern Greenland as forages are seldom sampled and analyzed for their nutritional contents and digestibility. There is a need for greater knowledge of quality of forage produced as this account for a major part of the winter feeding of livestock, and it is a requirement of farmers to purchase supplemental feedstuffs and minerals that ensure a sufficient supply of nutrients. Without a more thorough knowledge of forage quality, farmers risk purchasing expensive feedstuffs that do not meet the needs that their livestock have.

Health related challenges for the livestock

The health of animals is partially dependent on a well-functioning immune system, and the ability of the immune system to deal with health-related challenges depends partially on the supply of nutrients and availability of body reserves. Nutrient deficits including mineral deficiencies have occurred in Greenland (Rose et al., 1984b), but the extent will depend on the winter feeding regime and the availability of nutrients from natural vegetation during summer grazing. Rose et al. (1984b) specifically notes that mineral deficiencies occurring during summer is a special challenge that may need new and updated attention. Parasite infections do occur in Greenland when sheep are grazing permanent pastures during summer, but the impact on sheep may be limited (Rose and Jacobs, 1990, Rose et al., 1984a). However, parasites are widespread in the arctic ecosystems, and current and future climate change may alter their distribution and species composition (Kutz et al., 2012). Furthermore, parasite transmission from reindeer to sheep can occur when they share pastures (Manninen et al., 2014), which emphasises the

need to consider parasite dynamics between livestock species as well as the future impact of climate change on parasite communities. Finally, none of the major sheep diseases are found in Greenland, and predators are mainly eagle, raven and arctic fox (Austrheim et al., 2008a).

Production of slaughter animals

Lambs and sheep slaughtered by Neqi, the slaughterhouse in Narsaq in Southern Greenland, are scored at slaughter according to the European EUROP classification system (Commission Regulation (EC) No 1249/2008 of 10 December 2008). The development in both score and slaughter weight of lambs slaughtered by Neqi from 2010 to 2017 vary depending on the farm, which delivered the lamb (Lehmann and Kristensen 2018). This indicates that factors including the location of the farm and its environmental conditions for production, farm management and feed supply likely affect the score and weight at slaughter. Hence, an analysis that examines the spatial distribution of farms, their local environmental and climatic conditions and how these factors relate with lamb score and weight at slaughter may reveal which farms best utilized the available feed resources. Such an analysis could prove useful the advisory services to support them in advising farmers how to manage their farms in Southern Greenland.

Recommendations

Southern Greenland holds the potential for an increased livestock production, and unlocking this potential require an integrated approach to address the needs of the sector.
Feed production and feed procurement is a major cost for livestock farmers, and there is a need for more and updated knowledge of nutritional quality of grown and purchased feeds in order to ensure that the livestock have their nutritional requirements met. This includes forage samples of home-grown forage and of plants grazed during the summer months. Specific attention should be paid towards ensuring a sufficient supply of energy, protein, amino acids and minerals during the pregnancy period of sheep as this could be vital for the production of strong lambs that will endure the conditions of summer grazing on permanent pastures.

Moreover, there is a significant potential in using both the Upernaviarsuk research station and a number of private farms to carry out a range of different experiments. This allows for testing under both more intensive conditions and under different local environmental conditions, which supports farmers in assessing the applicability of these findings on their own farm.

Finally, the agricultural advisory services already collect a range of different data from all farms. Systematizing these data and coupling them with systemic nutrient sampling of grown feedstuffs could be the foundation for benchmarking of the farms, which could both enhance capacity building within the farming sector and support individual farmers in developing their own farms.

Perspectives

A wide range of challenges and possibilities for future initiatives within Greenlandic agriculture is discussed above. The underlying premises for these recommendations are discussed in the introduction and relates to the physical organization of the sector as well as the present and future environmental conditions given in South Greenland.
Through interviews with farmers during the summer of 2019 (Hansen and Hovgaard 2019) gained insight into what the farmers themselves experience as challenges. What is mentioned among other things is:

- Spring arrives later than 10 years ago.
- Infrastructure is difficult
- Permanent pastures are limited
- Pests attack grass fields leading to decreasing grass yields
- School and education possibilities are limited for our children

By the same token farmers were asked what they wish for in the future. Two dominant wishes are:

- Increased development possibilities
- Larger farms with higher yield

As demonstrated through the statements above Greenlandic agriculture is, in many respects, at a crossroad and the urgent question is: "What does the Greenlandic society want with Greenlandic agriculture?" This should be translated into the legislation and incentives framework for the sector, by asking further "What would we like to achieve with our agricultural policy?"

For many years different governments have stated that agriculture is an important part of the Greenlandic society in terms of food production and this should be strengthened in order to increase the degree of self-sufficiency, but also that the cultural heritage is an important part of the benefits, that the agricultural sector provides. The conditions required to support such statements are efficient production leading to profitable businesses as well as attractive living conditions at a general level.
We will conclude this report by presenting thoughts and approaches, that could be considered in future agricultural policy framework analyses, steadying the Greenlandic agricultural sector going forward towards an uncertain horizon.

Increase market driven dynamics in land-use: All land in Greenland is state owned and no private property right exists (Smedshaug 2018). Hence, farmers do not own the land they manage. They have obtained an exclusive user right to it, but that same user right can (though in practice very seldom seen) also be taken away from them (Smedshaug 2018). The location of farmland is carried out through an application process involving municipal officers as well as the agricultural advisory service. By that, a larger part of the decision-making concerning location of farms lies in a political driven decision process and not in a techno-economic process based on financial calculations as seen in most western market-based economies where land can be bought and sold at a market price. If a market-based approach would be introduced the more efficient farmers could buy more land lowering their marginal production costs by exploiting economies of scale and at the same time providing nonproductive farmers a way out of farming business. This farm expansion could either take place within the existing farmland, and hence lead to market concentration or by searching for new agricultural areas and effectively expanding the agricultural land market. As part of such an approach, subsidies from the government should be paid, taking into account political goals by building incentive structures. This can to a much higher degree than today be implemented and by that introducing financial nudging.

Increase coordination of production towards more effective units: A less market-driven and more centralized approach would be that the government identifies the most productive soils and facilitate an increased production at these sites, ultimately moving existing farms from a less productive location to a more productive location. This would also imply establishing stables near Narsaq, where the slaughterhouse Neqi is located.
Shift focus of production oriented incentive structures towards land management: As the current incentive structures rewards increased sheep production in the short run, not paying much attention to the underlying structures facilitating the production (land, soil, nutrients, water, feed etc.), a shift in focus of the incentives structure could be considered. A more holistic approach rewarding the stewardship of the land, soil quality, water management etc.) would provide a different and possibly more solid basis for a sustainable sheep production, which in turn also could be more productive, when all production factors align.

Prioritizing knowledge-driven development and knowledge anchoring in Greenland: More efficient and sustainable production require more knowledge on the production potential at a local scale and by that further knowledge is needed concerning soil conditions in order to locate the more productive sites and investigate how to improve existing agricultural soils.

Greenlandic agriculture is and will continue to be centered around sheep farming. Irrespectively of which systemic changes are carried out at a structural level it is evident, based on this report, that very little is known about nutritional values of feedstuff (farmed as well as purchased) as well as soil conditions, which is the entire foundation for sheep farming. Consequently, there is a profound and urgent need for increased research-based knowledge emphasizing the quality and organization of the input factors going into sheep production as discussed above.
Increased knowledge of these factors will have a direct impact on the performance of farmers and hence their livelihoods. Such research-based competence- and knowledge-building should be anchored locally in Greenland, e.g. at the Greenland Institute of Natural Resources, but it is also evident that competence and knowledge transfer is needed from collaborators outside of Greenland. Such knowledge transfer should be based on long term collaboration and it is therefore highly recommended that a continuous and increased strengthening of the agricultural sector research community in Greenland is supported.

The Greenlandic Government should consider financing a Greenland-based basic level research unit, which then could seek further research funding to establish and strengthen the necessary build-up of competence and capacity in order to better service the government's agricultural administrational and developmental efforts. A research unit could also assist in structuring efficient support frameworks and assist the agricultural sector itself with the knowledge and data required to increase production, expansion and efficiency, as well as supporting a sustainable agricultural development in Greenland, as moving into a new climatic era presents agriculture in Greenland with new challenges and opportunities.

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