

# Infield grass production at northern latitudes: farmers' adaptations to climate change

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**ABSTRACT:** Livestock production at northern latitudes involves many stages that each can be affected by climate change. The infields around the farms are typically used for producing grass for winter fodder. We analysed a unique dataset from the Norwegian dairy farmers association (TINE) from 1993 to 2009 on timing of the 1st infield harvest, the proportion of multiple harvests in a season, and the quality of the harvest in terms of protein content. We selected data from farmers using Setesdal (n = 4475), Hardangervidda (n = 658) and Forollhogna (n = 2719) in Norway as their outfield alpine summer ranges. Average timing of the 1st harvest became earlier in all areas over the last 2 decades, but more so in the northernmost area (Forollhogna). This allowed an increase in the proportion of farmers with a 2nd infield harvest in the north (Forollhogna) and a 3rd harvest in the south (Setesdal), but with no change in the middle (Hardangervidda). Timing of the 1st harvest was not related to May temperatures but was marginally earlier when previous winter conditions were mild and there was little snow (high value of the North Atlantic Oscillation), except for Hardangervidda. The quality of the 1st harvest showed no clear pattern of development over time. Our study quantifies how farmers are adapting to climate change by timing their infield harvest to an earlier arrival of spring. We highlight the necessity of considering all stages of the production cycle of livestock when assessing the effect of climate change at northern latitudes.

**KEY WORDS:** Climate · Sheep · Livestock · Infield · Grass production · Phenology

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## 1. INTRODUCTION

Human food production is likely to be affected by current climate change, although the extent of this effect is uncertain (Battisti & Naylor 2009, Herrero et al. 2010). Climate change has already affected the production of a variety of crops (Olesen & Bindi 2002, Supit et al. 2010, Bindi & Olesen 2011). Livestock production involves many stages that each can be affected by climate change. At northern latitudes or at high altitude alpine habitats, sheep production normally involves both infield and outfield grazing, in addition to winter feeding with commercial concentrate and forage produced on infields the previous summer. Currently, most attention has been paid to how climate affects the outfield grazing season for the pro-

duction of cattle (Craine et al. 2010) and sheep (Mysterud et al. 2001b, Nielsen et al. 2012). It is also central to know how farmers might adapt to change the infield part of the production cycle (Crane et al. 2011).

Timing is crucial for agricultural production that faces a short growing season and the harsh northern climate. An agro-pastoral based production system has evolved to facilitate utilization of a limited amount of cultivated land but extensive lush summer pastures. In Norway, 44 % of the country is mountainous with rangelands, while infield agricultural pastures account for only 3.2 % of the area (Statistics Norway [www.ssb.no/emner/01/01/areal/](http://www.ssb.no/emner/01/01/areal/)). The infields are crucial for husbandry as the grass used for winter fodder for both cattle and sheep are produced there. The long winter period (October to April) con-

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sists of indoor feeding mainly with forage produced in the infield during summer. Roughage (silage) of high quality is crucial to reduce input of concentrate and hence secure a sustainable and economically viable industry based on locally produced resources. The infields thus play an important role in the production cycle, but how climate and timing of spring affect the infield production system has not been quantified in detail. Phenological development of pasture grasses is a product of both mean daily temperature and daylight length. Over the last 3 decades, productivity—as measured by the Normalized Difference Vegetation Index (NDVI)—has increased at northern latitudes (Myneni et al. 1997, Slayback et al. 2003, Karlsen et al. 2009), and spring has come earlier, in particular at low altitudes. It is therefore likely that infield production rates will increase, which may affect forage quality and yield.

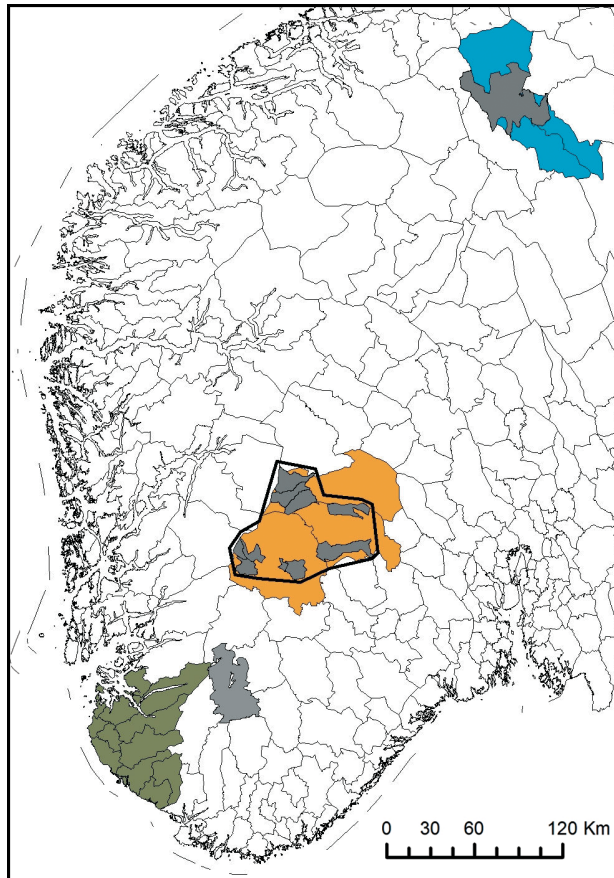


Fig. 1. Municipalities in southern Norway with registered infield grazing and winter fodder production. Blue: Forollhogna; yellow: Hardangervidda; green: Setesdal Vesthei; grey: outfield grazing. Thick black line: total extent of eastern part of Hardangervidda mountain range. Note that the outfield grazing areas are totally separated from municipalities where the infield grazing takes place in Setesdal while there is an overlap in Hardangervidda and Forollhogna

In this study, we analyse a unique dataset from the Norwegian dairy farmers' cooperative association (TINE) on the timing, number, and forage quality of infield harvest from the period 1993–2009. We focus on data from areas with sheep-farm infield pastures; these farms use 3 main alpine ranges in southern Norway as their summer outfield pastures: Setesdal Vesthei in the south, Hardangervidda in the central region and Forollhogna in the north (Fig. 1). We quantify if farmers adapt to current climate change, and test the hypotheses (H) that the timing of harvesting of the infield have become earlier over the last 2 decades ( $H_{1a}$ ), and more so in the north (Forollhogna) than in the south (Setesdal) ( $H_{1b}$ ); that earlier first harvest may allow for 2nd or 3rd harvesting of the infield (i.e. increased yield) ( $H_2$ ), and that this may have a negative effect on forage quality (measured by protein content) ( $H_3$ ). Lastly, we test whether these changes are either related to winter conditions (such as the winter index of the North Atlantic Oscillations [NAO]; Hurrell 1995, Hurrell et al. 2003) ( $H_{4a}$ ) or temperature in early summer ( $H_{4b}$ ).

## 2. MATERIALS AND METHODS

### 2.1. Study areas

Our study areas were chosen according to the location in southern Norway of sheep-farm infields and the adjacent mountain ranges used as summer pastures: Setesdal Vesthei, Hardangervidda and Forollhogna (Fig. 1).

Sheep farmers using Setesdal Vesthei (hereafter Setesdal) as summer pastures have infields on Jæren in Rogaland county, the municipalities Egersund, Sandnes, Sokndal, Lund, Bjerkreim, Hå, Klepp, Time, Gjesdal, Sola, Randaberg, Forsand and Strand. These are coastal areas at low altitude and latitude quite far from the summer grazing areas, with a mean elevation of 40 m and ranging from 0 to 1304 m above sea level (a.s.l.). The infields are at low altitude compared to the outfield areas. This tradition of long-distance moving of livestock from Jæren to Setesdal is more than a century old (Myserud & Myserud 1999).

Hardangervidda is the largest mountain plateau in southern Norway. Sheep farmers using these outfield summer pastures come from both the eastern and western side of the mountains, which have very different climates. Data from western parts (municipalities Ullensvang, Eidfjord and Odda) were extremely limited, and therefore excluded from analysis. The

results presented here are thus all from the eastern inland side of Hardangervidda, municipalities Vinje and Tinn in Telemark, and Nore og Uvdal in Buskerud county. The mean elevation of these municipalities is 1110 m a.s.l., and range from 200 to 1880 m a.s.l. The municipalities for users of Hardangervidda have infield production further inland, more similar to those in Forollhogna, and at a much higher altitude than those in Jæren/Setesdal.

Forollhogna is the northernmost area, and is at a slightly lower altitude. The users come from the municipalities Os and Tolga in Hedmark and Midtre Gauldal in Sør-Trøndelag, with a mean elevation of 818 m, ranging from 60 to 1600 m a.s.l.

For the period 1992–2007, average temperatures were 3.7°C in Forollhogna, 6.8°C in Hardangervidda and 8.9°C in Setesdal; annual precipitation was 34.9, 46.2 and 110.3 mm respectively in Forollhogna, Hardangervidda and Setesdal. Growing degree days (GDD, the amount of time with temperature >5°C) was 58.1, 131.4 and 182.5 GDD for Forollhogna, Hardangervidda and Setesdal, respectively (Nielsen et al. 2012).

## 2.2. Data on infield harvesting

TINE established a service for measuring quality of forage in 1993: farmers can send in their silage/roughage samples, which are measured for crude protein (CP), fibre, neutral detergent fibre (NDF, the fraction remaining after dissolution of non-fibrous material with a neutral detergent solution), digestible energy (feed units; 1 unit = digestible energy of 1 kg barley), and dry matter content. Data also include forage type, harvesting/cutting dates and whether it was 1st, 2nd or 3rd harvest. We limited analysis here to silage, as this is by far the most dominant feed type in all areas, and is most relevant for sheep production. Sample sizes were 4475 for Setesdal, 658 for Hardangervidda and 2719 for Forollhogna for 1993–2009 (see Table S1 in the supplement at [www.int-res.com/articles/suppl/c053p055\\_supp.pdf](http://www.int-res.com/articles/suppl/c053p055_supp.pdf)). We only included data sampled between 15 May and 27 September. Each sample represents 1 silage sample from 1 harvest from 1 farmer. Note that these samples come from dairy farmers that may or may not have sheep on the farm. Farmers produce fodder for sheep and cattle in the same way, so it is highly likely these are representative for all grass production in each region. Among the dairy farmers, 42% in Setesdal, 9% in Hardangervidda and 11% in Forollhogna also had ≥10 adult sheep (statistics based on those applying

for production of both species; Norwegian Agricultural Authority). However, as we discuss in Section 4, dairy and sheep farmers may differ in their use of infields for spring and autumn grazing, which may affect the pattern of harvesting.

## 2.3. Climatic data

We retrieved data on average temperature in May from weather stations run by the Meteorological Institute of Norway (station numbers—Setesdal/Jæren: 46910 Nedre Vats; Hardangervidda: 37230 Tveit-sund; Forollhogna: 16610 Fokstugu). Weather data were missing in 1998 for Setesdal. We therefore used an estimated value for 1998 with the aid of a linear regression on data from a neighbouring weather station (Sirdal, station no. 42920;  $r = 0.925$  for common years). Data on winter indices of the NAO (both station- and PCA-based for months December to March) were downloaded from the webpages of J. Hurrell ([www.cgd.ucar.edu/cas/jhurrell/indices.html](http://www.cgd.ucar.edu/cas/jhurrell/indices.html)). The NAO winter index was chosen based on its reported strong influence on winter conditions in southern Norway (Mysterud et al. 2001c). As there was a high correlation between the station- and PCA-based index ( $r = 0.925$ ), we only report estimates using the PCA-based index.

## 2.4. Statistical analyses

We used generalized linear mixed models for analyses in the library 'lme4' (Bates & Maechler 2009) in R version 9.2.0 (R Development Core Team 2010). We used generalized linear models for plotting. When testing for time trends ( $H_{1,3}$ ), we entered 'year' as a continuous term (scaled to start at year 1993) and 'area' as a 3 level factor (Setesdal, Hardangervidda, Forollhogna). In all models, we used 'municipality' and 'year' as random terms. We compared models using the Akaike Information Criterion (AIC): lower values indicate a more parsimonious and better model in the sense of balancing explained variance with complexity of the model (Burnham & Anderson 2002).

Model fit of logistic regression models (i.e. binary response) was tested using goodness-of-fit with the library 'Design' in R. We tested model fit for models lacking random terms, as testing fit of mixed-models is not straightforward. If fit of such a simpler model is adequate, a more complicated model including random terms will fit the data even better.

For analyses of forage quality, we first performed a Principal Component Analysis (PCA) to see how related the quality measures were (see Fig. S1 in the supplement at [www.int-res.com/articles/suppl/c053p055\\_supp.pdf](http://www.int-res.com/articles/suppl/c053p055_supp.pdf)). The first axis (PCA1) explained 57.4% of the variation, and loadings suggested that feed units (−0.415), fibre (0.523), NDF (0.542) and protein content (−0.469) were all positively or negatively correlated with PCA1, while the 2nd axis (PCA2) was mainly determined by the level of dry matter (loadings: PCA1 = −0.202, PCA2 = −0.938). Due to much lower sample sizes of feed units and NDF, we therefore analysed protein content as a proxy also for these. As protein content was given as a percentage, we arcsin-square-root transformed the variable before analyses.

### 3. RESULTS

#### 3.1. Timing of harvest

As predicted by  $H_1$ , the infield harvesting has come earlier over the last 2 decades (Fig. 2). This trend was more marked in the northernmost area of Forollhogna, supporting  $H_{1b}$ . Harvesting of the infield came earlier in the south (Jæren) using Setesdal as their summer outfield grazing area, and latest in the northernmost area, Forollhogna (Fig. 2, Table 1). Temperature in May was not included in the best models and was not a significant predictor of timing of the harvest (see Table S2 in the supplement at [www.int-res.com/articles/suppl/c053p055\\_supp.pdf](http://www.int-res.com/articles/suppl/c053p055_supp.pdf)); thus  $H_{4a}$  was rejected. The inclusion of the winter-

NAO and its interaction between areas marginally improved AIC (Table S2 in the supplement). The effect of the NAO and its interaction between areas was not quite significant, but there was a tendency for earlier harvesting after high NAO in Forollhogna and Setesdal, but not in Hardangervidda (Table 1).

#### 3.2. Proportion of multiple harvests

We found support for  $H_2$ : earlier 1st harvesting enables farmers to have a higher proportion of multiple harvests in more recent years. The trend over years was a higher proportion of multiple infield harvesting in Setesdal (Jæren) and Forollhogna, while there was no clear trend for Hardangervidda (Table 2, Fig. 2). Adding an interaction term between year and area resulted in a more parsimonious model (see Table S3 in the supplement at [www.int-res.com/articles/suppl/c053p055\\_supp.pdf](http://www.int-res.com/articles/suppl/c053p055_supp.pdf)). Multiple harvesting was much more common in the south (Setesdal/Jæren) than for areas surrounding Hardangervidda or Forollhogna further north. Indeed, while the year trend in Forollhogna was due to farmers increasing from 1 to 2 harvests, the trend was driven by a transition from 1 to 2 to 3 harvests for Setesdal/Jæren (Table S1 in the supplement). The model had a good fit to the data, as assessed using a goodness-of-fit test on a model without the random terms ( $Z = 1.640$ ,  $p = 0.101$ ). There was no effect of either May temperature nor the NAO on the proportion of multiple harvesting, as inclusion of their effects largely increased the AIC value (Table S3 in the supplement).

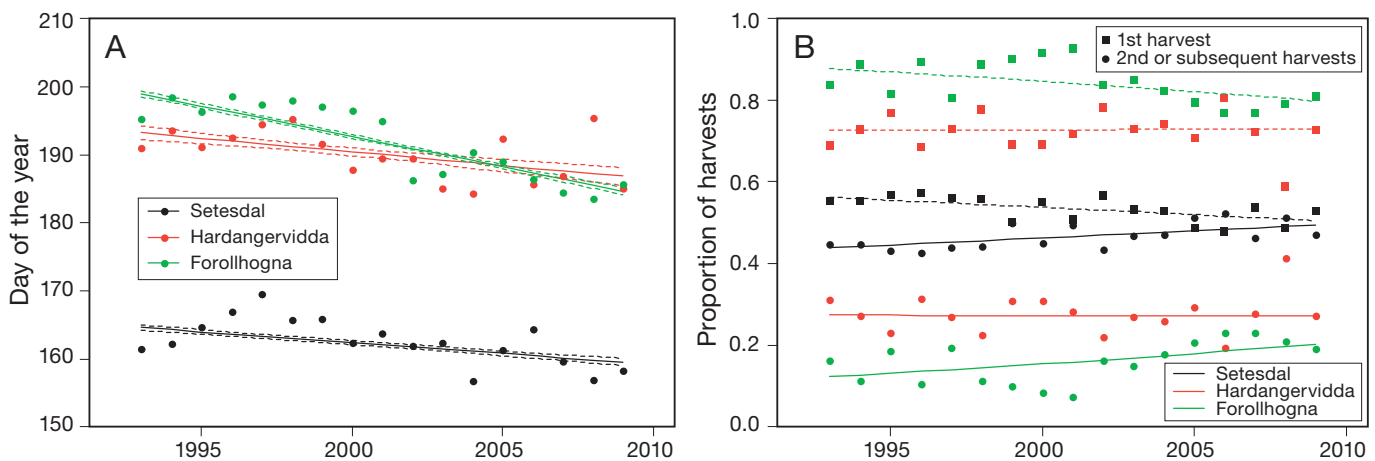


Fig. 2. (A) Timing of 1st annual harvesting of infields has changed over the last decades in Norway. This trend was more marked for the northernmost area: Forollhogna. Note that infield data are from the lowland areas surrounding the named alpine areas used for summer pastures. Solid lines: predicted values; dashed lines: SE. (B) Proportion of farmers harvesting more than once a year has increased in Norway following global warming. Solid lines: 1st harvest; dashed lines: 2nd harvest

Table 1. Linear mixed effects (LME) analysis of how timing of 1st harvesting of infield has changed over time (1993–2009) for users of outfield grazing ranges in Setesdal (Jæren), Hardangervidda and Forollhogna, Norway. Municipality and year were entered as random terms. NAO: North Atlantic Oscillation

	Estimate	SE	Lower limit	Upper limit
Intercept	193.6327	1.99442	189.644	197.622
Area (Hardangervidda vs. Forollhogna)	-5.32152	2.78668	-10.895	0.252
Area (Setesdal vs. Forollhogna)	-29.4828	2.16656	-33.816	-25.150
Scale(year)	-5.16248	0.54616	-6.255	-4.070
Winter-NAO	-1.10343	0.58359	-2.271	0.064
Scale(year): area (Hardangervidda)	3.11343	0.69055	1.732	4.495
Scale(year): area (Setesdal)	2.99097	0.36597	2.259	3.723
Winter-NAO: area (Hardangervidda)	1.23311	0.63688	-0.041	2.507
Winter-NAO: area (Setesdal)	-0.04261	0.40209	-0.847	0.762

Table 2. Generalized linear mixed model analyses of changes in proportion of single vs. multiple ( $\geq 2$ ) infield harvests (1993–2009) for users of outfield grazing ranges in Setesdal (Jæren), Hardangervidda and Forollhogna, Norway. Municipality and year were entered as random terms

	Estimate	SE	Lower limit	Upper limit
Intercept	-1.723	0.094	-1.911	-1.535
Area (Hardangervidda vs. Forollhogna)	0.780	0.153	0.475	1.086
Area (Setesdal vs. Forollhogna)	1.531	0.107	1.317	1.745
Scale(year)	0.184	0.053	0.077	0.291
Scale(year): area (Hardangervidda)	-0.180	0.113	-0.407	0.046
Scale(year): area (Setesdal)	-0.124	0.062	-0.247	-0.001

### 3.3. Quality of the harvest

The forage quality of the harvest was not markedly affected by recent climate change, rejecting  $H_3$ . We found no variable that was related to protein content in the 1st harvest, as the baseline model (with only a constant) largely outcompeted models including area, day of the year of harvest, year as a trend (see Fig. S2 in the supplement at [www.int-res.com/articles/suppl/c053p055\\_supp.pdf](http://www.int-res.com/articles/suppl/c053p055_supp.pdf)), May temperature, or the NAO winter index (see Table S4 in the supplement at [www.int-res.com/articles/suppl/c053p055\\_supp.pdf](http://www.int-res.com/articles/suppl/c053p055_supp.pdf)).

## 4. DISCUSSION

The long winter season at northern latitudes has historically necessitated extensive collection of rough-

age based forage, mainly grass in form of hay, often collected from semi-natural grasslands. Today, winter forage in the cattle and sheep farming industry is based on roughage harvested from perennial cultivated grasslands. We provide evidence that farmers are adapting their infield production system by earlier 1st harvesting, enabling also a higher proportion of multiple harvests. Harvesting is coming earlier both in the south (Setesdal) and the north (Forollhogna), though the effect is strongest in the north. This is consistent with earlier plant phenological development at these latitudes, as has been expected due to shorter winters and earlier springs at northern latitudes (Kausrud et al. 2008) and assessed by the NDVI (Myneni et al. 1997, Slayback et al. 2003, Karlsen et al. 2009). An average of  $0.27 \text{ d yr}^{-1}$  earlier onset of growing season was found for all of Fennoscandia using the NDVI, with up to  $1 \text{ d yr}^{-1}$  in southern and oceanic regions (Karlsen et al. 2009). In our areas, it was 0.89, 0.40 and  $0.32 \text{ d yr}^{-1}$  earlier onset for Forollhogna, Hardangervidda and Setesdal, respectively (Fig. 2). This provides the first evidence that farmers at northern latitudes are adapting to and benefitting from climate change, as has been predicted (Olesen & Bindi 2002). We found no clear evidence in the importance of early summer temperature ( $H_{4b}$ ), but some evidence that winter NAO ( $H_{4a}$ ) affects the timing of the 1st harvest. This suggests that farmers are only to a limited degree responding to the current year weather conditions.

The largest effects of climate change are predicted at the lowest elevation in the Alps and Fennoscandian mountains (Guisan et al. 1995). The agropastoral livestock production in these systems has always involved seasonal migration of the herd from near farm areas in the valley bottoms during winter to alpine, high-altitude ranges during summer (Kvamme 1988, Moe et al. 1988). Mysterud et al. (2001b) demonstrated that sheep body growth is affected by winter snow deposition in the mountains in regions where summer foraging is in coastal areas along the south-west coast of Norway. Lamb body mass in autumn is higher after winters with a high index of NAO, likely due to the positive effect of delayed phenology on late summer plant quality (Albon & Langvatn 1992, Mysterud et al. 2001a, Hebblewhite et al. 2008). Cervids in Norway are also



affected by the winter NAO (Mysterud et al. 2001b, Grøtan et al. 2005, Herfindal et al. 2006), including semi-domestic reindeer (Weladji & Holand 2003). Nielsen et al. (2012) have recently expanded these analyses considering the Setesdal, Hardangervidda and Forollhogna alpine ranges, yielding evidence that the NAO operates mainly through snow depth. Currently, global change has resulted in slightly more snow in the mountains of Norway, but with spring arriving earlier (Kausrud et al. 2008). However, given the projected disappearance of snow-covered areas remaining over summer at altitudes of ~1000 m elevation within the next century (Guisan et al. 1995), the longer-term consequences of climate change on outfield grazing may be negative, as these are important summer grazing areas due to newly emergent, high quality forage late in the growing season. The increased infield production reported here, in terms of number of harvests, might therefore become even more important in the future as it has the potential to buffer reduced alpine outfield production.

New cutting and conservation (preservation) techniques have revolutionized grass harvesting over the last decades, and may also play a role for the development in harvesting schedules. The increased harvesting capacity rate enables farmers to time the harvest accurately, and to potentially increase the number of cuttings. We provide evidence that farmers on Jæren/Setesdal and Forollhogna indeed have increased the proportion of multiple harvesting during summer now that climate conditions are becoming more favourable for such production. There was no such development for farmers around Hardangervidda. It is currently not clear whether this is due to the fact that 1 harvest is sufficient for most farmers around Hardangervidda to sustain their current livestock, or whether they use the infield more in spring and autumn for grazing, allowing for only 1 harvest. Many sheep farmers have to trade-off between using the infields for grazing in spring and autumn, and how many cuttings of the infields they should take during summer. The increase in proportion of cuttings may therefore also be driven partly by dairy farmers not having such constraints. Unfortunately, we have no data on the size of the 1st harvest itself, which is also an important measure of yield that may be affected by climate change. There is also a market for selling forage, but this is highly variable among years depending on the total annual production.

Agro-pastoral livestock production systems at northern latitudes have a complex cycle in which all steps will be affected by future global change. The

infield production cycle seems to benefit from increased temperatures, and more so in the northernmost areas. However, we need to consider all stages of the production cycle of livestock before concluding how climate change will affect livestock production in these northern ecosystems.

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