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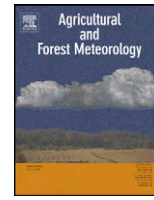

Assessing winter survival of forage grasses in Norway under future climate scenarios by simulating potential frost tolerance in combination with simple agroclimatic indices

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ABSTRACT

Norwegian agriculture is mainly dominated by grass-based milk and livestock production, so winter damage to overwintering grasses may have large economic consequences. We assessed the impact of climate change on the winter survival of timothy (*Phleum pratense* L.) and perennial ryegrass (*Lolium perenne* L.) under Norwegian conditions using agroclimatic indices and a simulation model of frost tolerance. This study was based on locally adjusted future climate scenarios (two for the period 2071–2100; one for the period 2020–2049) for six important agricultural regions, represented by one location each. We proposed and validated a rough way to estimate the daily minimum air temperatures from scenario data. Compared with the control period 1961–1990, the future hardening period will be shortened by up to 21 days. As a consequence, the modelled maximum frost tolerance is expected to be reduced by up to 3.9 °C and 1.9 °C for timothy and perennial ryegrass, respectively, under the warmest scenario. In spite of this reduction, the plants are expected to be hardy enough to withstand the predicted autumn frosts, and we also expect a general reduction in the risk of winter frost injuries. The plant data available to this study suggest that agroclimatic indices developed for Canadian conditions can be useful for assessing the hardening status in timothy and perennial ryegrass. However, such indices are less suitable for assessing the risk of plant injury related to frost and ice encasement in Norway, since they do not account for the dynamics of cold adaptation. Although less snow is expected, in most cases this will not be accompanied by an increase in the risk of ice encasement injuries. However, a slight increase in the number of ice encasement events was predicted for one location. An earlier start of growth was predicted for all locations, accompanied at one coastal location by a slightly increased predicted risk of spring frosts. There is little risk of winter injuries related to frost and ice encasement in the hardier grass species timothy. The better overwintering conditions in general indicate that it will be possible to grow perennial ryegrass in areas where it is not grown today, provided the risk of fungal diseases does not increase.

1. Introduction

Two of the most important sectors in Norwegian agriculture are grass-based milk and livestock production. In 2007 these sectors accounted for 70% of the total income in Norwegian agriculture (Rognstad and Steinset, 2008). Poor overwintering of forage grasses often has negative economic consequences due to substantial yield losses and subsequent costs related to the re-establishment of grass swards and the purchase of supplementary feedstuffs. The global climate is changing, and during the next 100 years the global temperature is expected to increase by 1.4–5.8 °C. In Norway, this temperature increase is likely to be larger in northern areas of the country than in the south, and the winter weather is projected to include milder temperatures with more precipitation as rain (Hanssen-Bauer et al., 2009). These changes may affect the winter survival of perennial crops (Bélanger et al., 2002), although no scientific analysis has yet been carried out on the consequences of climate change for overwintering of forage grasses in Norway or in the rest of Scandinavia.

A quick way to characterise plant-climate interactions is by calculating agroclimatic indices (often based on degree-day heat units, which are related to plant growth and development) as opposed to using process-based models for this characterisation (Eitzinger et al., 2008). Bélanger et al. (2002) assessed the potential impact of climate change on overwintering of perennial forage crops in Eastern Canada using agroclimatic indices reflecting the risks of

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winter injuries. The results suggested that the risk of winter injury in that area will likely increase because of less cold hardening during autumn and reduced protective snow cover during the cold period, which will increase the exposure of plants to killing frosts, soil heave and ice encasement. Similar calculations have not been performed for future Norwegian climate conditions. In addition, the climate in the area studied by Bélanger et al. (2002), eastern Canada, is different from the Norwegian climate in many ways. This study therefore investigated the indices proposed by Bélanger et al. (2002) for Norwegian climatic conditions.

In the study, we considered two of the most important forage grasses in Norway, timothy (*Phleum pratense* L.) and perennial ryegrass (*Lolium perenne* L.), to investigate how the changing climate will affect their winter survival abilities. Grass plants prepare for winter by re-allocating sugars produced during photosynthesis to storage organs, along with other physiological adjustments aimed at increasing their tolerance to sub-zero temperatures and other abiotic and biotic winter stress factors (Andrews, 1987). The process of acquiring frost tolerance is often referred to as cold acclimation, or cold hardening. When springtime comes, or during mild spells in mid-winter, the plants de-acclimate (deharden), and if the mild period is long enough or the temperature high enough, growth is resumed and dehardening becomes irreversible (Kalberer et al., 2006). The more hardened plants are, the better they survive stressful winter conditions. The state of frost tolerance of plants, i.e. their hardening status, can be characterised by their LT50 value, i.e. the temperature at which 50% of the plants are killed. Thorsen and Höglind (in preparation) proposed a model which simulates LT50 in timothy, and this model was used here for assessing the risk of frost-related injuries under future climate scenarios.

In the present study, we assessed the impact of climate change on winter survival in timothy and perennial ryegrass in Norway (i) by calculating three of the agroclimatic indices suggested by Bélanger et al. (2002) reflecting the conditions for hardening in autumn, the risk of dehardening in winter and the risk of injuries related to rain in winter; and (ii) by calculating the risk of frost and ice encasement-related injuries using a model that simulates LT50 in timothy and perennial ryegrass (Thorsen and Höglind, in preparation), together with a model for soil surface temperature and the development of snow and ice in the field (Thorsen et al., 2010). In addition, we calculated the length of the autumn hardening period, the winter period and the starting day of the thermal growth period. The calculations were carried out for six locations and three climate scenarios (one for the period 2025–2040; two for 2071–2100). The resulting risks of injuries were compared against those obtained from similar calculations performed using a control period (1961–1990). Neither models nor indices can provide 100% reliable answers, but they can serve as alternative approaches to the problem at hand – assessing the risk of winter damage to forage grasses.

2. Materials and methods

2.1. Definition of autumn, winter and thermal growth periods

We assumed that the plant year consisted of three periods: the thermal growth period (GP), the hardening period (HP) and the winter period (WP). The hardening period was defined to start at the end of the thermal growth period, and the winter period was defined to end at the start of the thermal growth period. The literature mentions several ways to define the thermal growth period (e.g. Walther and Linderholm, 2006), and thus implicitly the hardening and winter periods. According to Bonesmo (1999), the start of the thermal growth period for timothy can be estimated as being the fifth day of the first five-day spell with daily mean air temperature above 5 °C on snow-free ground. We used this definition by Bonesmo (1999) to estimate the start of the growing period, GP_{start}. In the field, hardening is initiated when the daily mean air temperature drops below approximately 10 °C, and increases as the air temperature continues to drop below 5 °C (Bélanger et al., 2002). We assumed that the end of the thermal growth period could be approximated in the opposite way to the start and thus we defined the start of the hardening period, HP_{start}, as the fifth day of the first five-day spell when $T_{air} \leq 5$ °C. For the plants to achieve maximum frost tolerance, a final phase of sub-zero temperatures is required (Kacperska-Palacz, 1978). According to frost tolerance experiments carried out in Norway (Larsen, 1994; Höglind et al., 2006), grass plants usually reach maximum frost tolerance towards the end of the year. To estimate the end of the hardening period, HP_{stop}, we used simulations of LT50 produced using the model developed by Thorsen and Höglind (in preparation). This LT50 model calculates daily rates of hardening and dehardening as a function of climatic variables, and it is a simplified version of a similar frost tolerance model for winter wheat developed by Bergjord et al. (2008). We located the day of the year when the lowest simulated LT50 occurred and defined this day as HP_{stop}. We defined the start of the winter period, WP_{start}, as the day following HP_{stop}. The end of the winter period, WP_{stop}, was defined as the day prior to GP_{start}. The three periods HP, WP and GP, and the agroclimatic indices used in this study are presented in Table 1.

Table 1
Description of periods and agroclimatic indices used in this study. Units in brackets.

Period	Description
HP	Autumn hardening period (d)[a]
WP	Winter period (d)[a]
GP	Thermal growth period (d)[a]
Index	
FH-COLD	Net accumulation of cold degree-days during HP (°C d)[b]
W-THAW	Mean daily accumulation of degree-days during WP (DD0 d^{-1})[b]
W-RAIN	Mean daily rainfall during WP (mm d^{-1})[b]
AF	Autumn frost, number of days with lethal temperatures during HP (d)[c]
WF	Winter frost, number of days with lethal temperatures during WP (d)[c]
ID	Ice damage, number of incidents with ice damage conditions during WP[c]
SF	Spring frost, number of days after start of growth when frost occurs (d)[c]

[a] Defined in Section 2.1.
[b] Defined in Section 2.2.1.
[c] Defined in Section 2.2.2.

2.2. Agroclimatic indices

2.2.1. Previously proposed agroclimatic indices

Bélanger et al. (2002) proposed five agroclimatic indices for assessing the relative risks associated with climatic causes of damage to perennial forage crops during autumn and winter. Two indices express the influence of temperature and rainfall on the acquisition of frost hardiness during fall (FH-COLD, FH-RAIN), and three indices reflect the loss of hardiness due to high temperatures (W-THAW), damage due to frost exposure (W-COLD) and damage due to frost heave and ice encasement during winter (W-RAIN). For the present study, we chose the indices FH-COLD, W-THAW, W-RAIN, and ignored the other two.

The fall hardening index FH-COLD is calculated as the net accumulation of cold degree-days during the autumn (see McMaster and Wilhelm (1997) for interpretation of degree-days). The assumption underlying FH-COLD is that degree-days above 5 °C (DD5) (the temperature sum using 5 °C as base temperature) and