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Review

How can forage production in Nordic and Mediterranean Europe adapt to the challenges and opportunities arising from climate change?

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ABSTRACT

Climate change and its effects on grassland productivity vary across Europe. The Mediterranean and Nordic regions represent the opposite ends of a gradient of changes in temperature and precipitation patterns, with increasingly warmer and wetter winters in the north and increasingly warmer and drier summers in the south. Warming and elevated concentration of atmospheric CO_2 may boost forage production in the Nordic region. Production in many Mediterranean areas is likely to become even more challenged by drought in the future, but elevated CO_2 can to some extent alleviate drought limitation on photosynthesis and growth. In both regions, climate change will affect forage quality and lead to modifications of the annual productivity cycles, with an extended growing season in the Nordic region and a shift towards winter in the Mediterranean region. This will require adaptations in defoliation and fertilization strategies. The identity of species and mixtures with optimal performance is likely to shift somewhat in response to altered climate and management systems. It is argued that breeding of grassland species should aim to (i) improve plant strategies to cope with relevant abiotic stresses and (ii) optimize growth and phenology to new seasonal variation, and that plant diversity at all levels is a good adaptation strategy.

1. Climate change and Nordic versus Mediterranean grasslands

The most contrasting regions of Europe in terms of climate are the Mediterranean and the Nordic regions, representing a latitudinal gradient in temperature (Metzger et al., 2005). Within these regions, there are gradients in both oceanicity and precipitation. According to the environmental classification and stratification of Europe made by Metzger et al. (2005), the largest environmental zones in the Nordic region are the Alpine North and the Boreal zones, but in the southern part of this region there are also Nemoral, Atlantic North and Continental zones. There is a strong west to east gradient of decreasing precipitation in the Nordic region. The Mediterranean region of Europe has a complex pattern of environmental zones (Mediterranean South, Mediterranean North and Mediterranean Mountains), largely determined by temperature (Metzger et al., 2005). While forage production from grasslands are limited by cold and dark winters in the Nordic region, it is limited by hot and dry summers in the Mediterranean region. Across Europe, climate change could raise significant challenges for grassland-based food production and other ecosystem services provided by grasslands, but may also imply some opportunities. The observed and projected climate change differs between Northern and Southern Europe (Kovats et al., 2014, Table 1). The average temperature over land surface during 2002–2011 was 1.3 °C above the 1850–1899 average, with substantial differences between regions and seasons. In the Nordic region, both the observed and predicted warming is more rapid than the global average warming. Annual average temperatures have increased with more than 2 °C during 1847–2013, almost twice the global average increase, and both the observed and the predicted temperature increase is highest during late autumn, winter and spring (Uleberg et al., 2014; Mikkonen et al., 2015;

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Table 1
The main climatic changes and their effects in Nordic vs. Mediterranean grasslands during the growing season and the unfavorable season.

Growing season	Current timing	Nordic April–early June to Mid-September–early November[1]	Mediterranean October–June
	Predicted seasonal changes	1) Extension of thermal growing season by 1–3 months by the end of the century[2,3] 2) Increase in temperature and precipitation[a,3−7]	1) Growing season will shift towards winter[17,18] due to drier summers and warmer winters 2) Higher temperatures and more frequent droughts[4,20−22]
	Effects on productivity	1) Increase in productivity if plant available water does not become limiting[1] 2) Lengthening of growing season can be utilized mostly in spring due to lack of light in late autumn[8,9] 3) One extra cut per year in many regions[1]	1) Increase in productivity when water is not limiting, higher CO_2 concentration will limit yield reduction due to drought stress[17,18,23]
	Plant material and breeding needs	1) More intra- and interspecific diversity, broader genetic material with more response diversity[10,11] 2) Higher regrowth capacity 3) Maintenance of growth in water-saturated soils and during dry spells	1) More intra- and interspecific diversity[24−26] 2) Utilization of cooler parts of the year for increased growth 3) Maintenance of growth under moderate drought

Unfavorable season	Current timing	Nordic Mid-September–early November to April–early June[1]	Mediterranean June–early October
	Predicted seasonal changes	1) Shorter winters with more precipitation and higher temperatures[4,5,7,12] 2) Delayed cold acclimation/growth cessation and earlier deacclimation/spring regrowth[9] 3) Decrease or increase in snow cover, soil frost and ice encasement, depending on temperature level, precipitation and interactions between them[13−16]	1) Longer summers with higher temperatures and more frequent and severe droughts and heat waves[4,20,21] 2) Altered timing or conditions during critical phases of life and growth cycles[27−29]
	Effects on productivity	1) Increased or decreased winter mortality due to higher or lower stress levels and changes in growth cycle, plant C and N acquisition and use, acclimation and deacclimation[1,9,17]	1) Decreased productivity or longer non-productive dry season, higher summer mortality[17,18]
	Plant material and breeding needs	1) More intra- and interspecific diversity, broader genetic material with more response diversity[10,11] 2) Utilize earlier spring and later autumn without losing ability to survive winters[9]	1) More intra- and interspecific diversity[24−26] 2) Stronger summer dormancy and active recovery after drought in perennials[30−32] 3) more persistent seed banks of annuals[33−35]

References: Höglind et al. (2013)[1], Ruosteenoja et al. (2011)[2], Hanssen-Bauer et al. (2015)[3], Lehtonen et al. (2014)[4], Uleberg et al. (2014)[5], Mikkonen et al. (2015)[6], Ruosteenoja et al. (2016)[7], Ruosteenoja and Räisänen (2013)[8], Ergon (2017)[9], Mäkinen et al. (2015)[10], Mäkinen et al. (2016)[11], Ruosteenoja et al. (2007)[12], Källomäki et al. (2010)[13], Räisänen and Eklund (2011)[14], Johansson et al. (2011)[15], Bjerke et al. (2015)[16], Rapacz et al. (2014)[17], Graux et al. (2013)[18], Dono et al. (2016)[19], Giorgi and Lionello (2008)[20], Giannakopoulos et al. (2009)[21], Hoerling et al. (2012)[22], Roy et al. (2016)[23], Porqueddu and Maltoni (2014)[24], Maltoni et al. (2007)[25], Barkaoui et al. (2016)[26], Ooi (2012)[27], Cosentino et al. (2014)[28], Long et al. (2015)[29], Volaire et al. (2014)[30], Norton et al. (2016)[31], Kallida et al. (2016)[32], Sulas (2005)[33], Salis et al. (2012)[34], Porqueddu et al. (2016)[35].
[a] change associated with high uncertainty.

Ruosteenoja et al., 2016). The length of the thermal growing season has increased with about 1–2 weeks during the last 30 years, and has been predicted to become 1–3 months longer by the end of the century as compared to the period 1971–2000 (Ruosteenoja et al., 2011; Hanssen-Bauer et al., 2015). Annual precipitation in the Nordic region is predicted to increase considerably (up to around 20% relative to 1971–2000 in some regions) by the end of the century, with more frequent episodes of extreme precipitation, and especially during winter (Lehtonen et al., 2014; Hanssen-Bauer et al., 2015). In the Mediterranean region, the climate is expected to become warmer and drier, particularly in summer (Giorgi and Lionello, 2008; Giannakopoulos et al., 2009; Lehtonen et al., 2014). Winters are also expected to become warmer, but to a lesser extent than summers, while winter precipitation may vary between regions (Giorgi and Lionello, 2008; Giannakopoulos et al., 2009; Hoerling et al., 2012). Increased inter-annual variability in summer and winter precipitation, as well as in summer temperatures, is also expected (Giorgi and Lionello, 2008). Changes in atmospheric CO_2 concentration, temperature and precipitation patterns are expected to affect plant productivity in a complex manner due to a set of mechanisms and interactions at different scales from the individual leaves to agroecosystems (Hatfield and Prueger, 2011; Xu et al., 2013). For grasslands, there are also important complicating factors such as plant competition and other plant–plant interactions, perennial growth habits, seasonal productivity patterns, and plant-animal interactions (Porter et al., 2014).

Grasslands comprise a variety of vegetation types and management systems (e.g. Allen et al., 2011; Huyghe et al., 2014; Peeters et al., 2014). A distinction is made between temporary and permanent grasslands. Temporary grasslands, also termed forage crops, are regularly re-established (annually or at longer intervals), or constitute an element in a crop rotation. Permanent grasslands are grasslands that have either never been ploughed or not been ploughed for at least five to ten years (definitions vary). Permanent grasslands can range from natural and semi-natural (not managed by other means than grazing or mowing) to agriculturally improved permanent grasslands (i.e. improved by fertilization). Both temporary and permanent grasslands may be harvested by mowing (meadows), grazing (pastures) or a combination, and consist of perennial, biennial and/or annual forage species, mainly grasses and legumes. Overviews of grassland production in the Nordic and Mediterranean regions of Europe were recently given by Helgadóttir et al. (2014) and Porqueddu et al. (2016). Nordic grasslands are dominated by perennial grasses, with a few perennial legume species also present. Annual species are used only to a limited extent. There are both permanent and temporary grasslands, which are grazed or mown. Due to the lack of plant growth during winter, there is a strong reliance on harvested and conserved forage. In Mediterranean Europe, grasslands can be grazed from autumn to spring and may be mown in spring for hay production. Permanent grasslands can be dominated both by perennial and annual grasses, while temporary grasslands are often dominated by annual species. In summer, forage production can be completely or very limited by drought. Agro-silvo-pastoral systems are important in some areas. Annual and perennial grasses and legumes such as alfalfa (*Medicago sativa* L.) are to some extent cultivated as forage crops, which are sometimes irrigated. We