Effects of Climate Change on Grassland Biodiversity and Productivity

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Editorial

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Associated with livestock farming, grasslands with a high diversity of plant species are at the core of low-input fodder production worldwide. When properly managed, they also provide multiple additional ecosystem services, such as soil carbon storage, erosion control, provision of quality infiltration water (with little or no nitrates and pesticides), and habitat for pollinators and wildlife. The ability of grasslands to continue to provide multiple ecosystem services in the face of climate change and variability underlines the importance of plant biodiversity, which is known to be closely linked (via complex ecological mechanisms) to soil health and functioning through its beneficial effects on soil microorganisms and animal species. Biodiversity is thus central to grassland-livestock production systems, both as a production tool (substitution of inputs by biological regulation) and as an objective (conservation of the living heritage). Greater recognition of the importance of grasslands for soil conservation, promoting biodiversity, stabilising farming communities and providing a multitude of natural ecosystem services is driving renewed interest in grasslands at the turn of the 21st century. The increasing demand for high-quality animal products that comply with health, ethical and environmental standards requires sustainable grassland management, particularly in the face of climate change. Traditional management practices (e.g., grazing, mowing, fertilisation, species-mix sowing, shrub control) are major drivers of vegetation dynamics, species distribution and biodiversity but the combined effects of management practices and climate change often remain unclear. Also, tools for quantifying grassland resilience to disturbances, both in the short-term (i.e., a single unfavourable season/year) and the long-term (i.e., climate change), are poorly developed. The challenge is for agro-environmental and ecological research to propose optimised solutions that are profitable, adaptive and evolving with technological and social innovations. For instance, innovative systems at the interface of grassland and cereal production hold promise for reconciling production objectives with the preservation of biodiversity and soil-water-air resources, and pave the way for a multifunctional, sustainable and more climate-resilient agriculture. However, successful research on complex systems such as species-rich grasslands requires several agroecology-related approaches, accompanied by management targets, new monitoring tools, low carbon emission and socio-economic development. Eight refereed articles in the Special Issue of *Agronomy* entitled "Effects of Climate Change on Grassland Biodiversity and Productivity" identify and characterize the effects of climate perturbations on production and on the provision of biodiversity-mediated ecosystem services.

Three studies in Eastern Europe cover a relevant topic of sustainable land use by addressing aspects related to grassland fertilisation. In the first, Ranta et al. [1] identified a balanced management in support of biodiversity and productivity of species-rich permanent grasslands in mountainous areas of Romania. Considering that fertilisation practices can induce changes in grassland productivity, forage quality and species composition (which is essential for biodiversity management and conservation), the authors recommend moderate fertilisation with urea ammonium nitrate liquid fertilization (up to

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50 kg N ha^{-1} yr^{-1}) for the semi-natural grasslands in the region. The regional focus is important, Romania being one of the largest grassland areas in Europe and still managed with traditional methods like most grasslands in south-eastern and central Europe. Low levels of intensification and small-scale agriculture allow the preservation of prominent grassland areas in the region, where regularly grazed or mown vegetation may contain some of the highest plant densities in Europe, and where the adoption of appropriate management for these ecosystems should be given the utmost importance. In the same line of action, two experimental studies in Poland point to the resource-efficient alternative of organic fertilisers to support climate resilience. The addition of silicon to grasslands is the topic addressed by Mastalerczuk et al. [2], who demonstrated the beneficial effect of silicon (applied alone or with a multicomponent fertilizer) on the performance of a grass–clover mixture in Poland. While increasing root mass, silicon application also decreased plant flavones concentration and increased chlorophyll index values, and indicated the potential of silicon fertilizer application to improve forage quality (crude protein, organic matter digestibility, potassium and phosphorus content). These results provide direct support for the practice of organic farming fertilisation to improve grassland productivity and compensate for yield losses under low rainfall conditions. In recent years there has also been increasing interest in cross-genus and cross-species hybrids within the *Lolium*–*Festuca* complex. The combination of the complementary traits of these grasses in a single genome brings several advantages to agricultural practice, as highlighted by Malinowska et al. [3] for *Festulolium braunii*, a hybrid of *Festuca pratensis* (meadow fescue) and *Lolium multiflorum* (Italian ryegrass) with high yield potential, which benefits from the foliar application of growth regulators and amendments that could replace or supplement nitrogen fertiliser and increase soil fertility. Thanks to these hybrids, it is possible to produce fodder efficiently under stressed conditions such as drought.

Based on an original experiment, Magandana et al. [4] investigated the impact of a reduced precipitation regime and two rest periods on the seasonal change of herbaceous vegetation structure and biomass production of rangelands in semi-arid areas of South Africa. Above-ground herbaceous biomass showed resilience up to a 15% reduction in rainfall, but became progressively less resilient as rainfall reduction exceeded 30%, resulting in the dominance of forbs over grasses species. These results add to the knowledge of applied plant science and agronomy on a topic of great interest for grassland management, as significant reductions in precipitation amounts are especially critical for semi-arid areas, where an extension of the spring-summer rest (e.g., three months or more) may be required to improve biomass productivity.

Zainelabdeen et al. [5] analysed the processes and mechanisms of grassland degradation as a result of grazing intensity in Inner Mongolia, where progressive intensification has contributed to a decrease in biomass productivity due to selective grazing and mechanical pressure (trampling). Controlling the duration and intensity of grazing management is, thus, important for a sustainable livestock production strategy that protects vegetation and satisfies farmers' economic interests. The authors produced a rich dataset by creating grazing management scenarios and conducting adaptive practices to reconcile ecological functions with production. It is interesting to see the different response of different plant functional groups to grazing intensity: if tall perennial grasses, which include highly palatable mesophytes and mesoexerophytes, declined with grazing intensity, moderately palatable xerophytes and widespread grasses (such as the predominant short perennial grasses) increased with grazing intensity. Some functional groups, such as tall fescue and liliaceous herbs, remained stable, which may be related to changes in the soil environment caused by grazing activities. Obtained for one of the largest temperate grassland areas in the world, these results are valuable for assessing current grazing management schemes and implementing timely adaptation practices to maintain the capacity of temperate grasslands to perform their ecological functions.

Finally, there are three articles with a specific methodological interest in the study of grassland dynamics. In the first one, Dibari et al. [6] applied a machine-learning approach (random forest) and GIS (Geographic Information System) techniques to describe the effect of climate change on the extent and distribution of seven major pasture types (and map their suitability under projected climate change) in the Italian Alps. The alpine mountain range is known to be very sensitive and vulnerable to climatic conditions, which pose several challenges in relation to pasture management. Here, pasturelands are affected by warming and altered rainfall patterns, leading to an upward shift of vegetation, as well as other ecological consequences, such as a reduction in suitable grazing areas, an increase in xeric species and an increase in shrub encroachment. In particular, the general decrease in pasture diversification and a general homogenisation of the landscape are likely to alter the nutritional value of mountain pastures. The expected decline of high-quality forage species such as *Festuca rubra* (red fescue) in favour of *Nardus stricta* (matgrass matgrass), a non-palatable grass, may lead to an overall decline in pasture quality that may require diversification or mixing of livestock species. The contribution from Liebermann et al. [7] is a multi-year modelling of biomass production, soil moisture, and CO_2 and N_2O emissions from a free air carbon dioxide enrichment (FACE) grassland experiment in Germany with a landscape-scale version of the DNDC (DeNitrification-DeComposition) model (LandscapeDNDC). With special attention given to the interrelated cycles of C, N and water, the LandscapeDNDC model simulation of the long-term behaviour of a grassland ecosystem under elevated CO_2 showed the connection between increased N_2O emissions and increased turnover of soil organic matter under elevated CO_2. By indicating the importance of groundwater N input in models for an accurate estimation of C–N ratios in vegetation biomass, the study reveals the behavior of coupled C–N cycling in grassland ecosystems. As such, it represents progress in modelling and provides clues to the need for research in this area. In the third article motivated by methodological interest, Van Oijen et al. [8] provided a review, and a roadmap for research, on the incorporation of plant species dynamics into biogeochemical simulation models to study the underlying processes of grassland functioning. Although there have been major advances in grassland modelling in recent times (as also shown by the contribution of Liebermann et al. [7]), the simulation of biogeochemical cycles is still, in most cases, disjointed from an explicit representation of plant species dynamics, with considerable uncertainty in the quality of predictions. In contrast, ecological models account for plant diversity with approaches adopted from biological demography, without linking sufficiently the dynamics of plant species to the biogeochemical processes occurring at the community level (which is essential to assess resilience against, for instance, drought or nutrient limitation). The review highlights the role of plant diversity in the regulation of ecosystem functions. From an extensive literature survey, it sets out the state of the art with respect to biogeochemical and ecological modelling, and puts emphasis on relatively simple to more complex and technically advanced models reconciling biogeochemistry and biodiversity, and readily applicable to managed grasslands in Europe.

In conclusion, this Special Issue raises awareness of the feedback processes involving grassland biodiversity, which may in turn amplify or diminish the effects of climate change, although the limitations of the body of articles it publishes should be highlighted. It is important that it participates in sketching the future of regions particularly sensitive to climate changes (i.e., Central Asia, South Africa, Eastern and Alpine Europe), particularly in mountain and marginal areas where grassland farming is important and often the only acceptable agricultural practice to maintain biodiversity, but there is still a lack of established studies in several regions of the world (in particular in the tropics and sub-tropics). On the horizon of sustainable management, it is remarkable that the published articles outline tangible solutions to the challenges currently faced by grassland farmers in different parts of the world, leading to the conservation of biodiversity. However, this Special Issue does not fully consider climate-induced biodiversity change and the extent to which population growth, urbanisation, land-use change, consumption lifestyles and resource exploitation threaten grassland biodiversity as key factors directly or indirectly associated with climate change. The growing understanding of the complex interplays between climate change and biodiversity shows that approaching these two planetary boundaries requires both aspects to be considered holistically. In that sense, the modelling works in the Special Issue outline promising research directions. It is hoped that the approaches and data resources presented in this Special Issue will promote future research and encourage consideration of a wide array of scientific sources and possible methods to support decision-making in diverse grassland contexts.

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