Climate change and grasslands: impacts, adaptation and mitigation

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Abstract. The paper reviews recent evidence on climate change and the role of greenhouse gases (GHG). Historical evidence indicates that climate change is not a new phenomenon and Mediterranean ecosystems have shown considerable resilience to past climate changes. The 21st century can be regarded as an era of climate change in which concerns about climate are accompanied by other drivers relating to globalization, food security and energy and sustainability issues. Carbon dioxide enhancement can have positive and negative effects for forage production. Increased temperatures and water deficits in the Mediterranean zone are likely to impact adversely on production, based on modelled outcomes, especially on maximum-production systems, but climate-adapted and regionally diverse systems of agriculture are suggested as being more resilient to climate change impacts. A range of adaptation strategies at both farm level and at policy/ government level are considered as means of enabling grass and forage systems to be maintained in a changing climate. Livestock agriculture contributes to GHG emissions but a range of mitigation measures are considered that can help offset some of these emissions. It is concluded that an integrated approach is required to respond to climate change. Many challenges remain but there are grounds for cautious optimism for future grass and forage-based farming in the Mediterranean zone.

Keywords. Forage – Greenhouse gas emissions – Livestock farming – Climate history – Mediterranean.

Le changement climatique: les effets, les adaptations et les mesures d'atténuation

Résumé. *Cet article passe en revue l'évidence actuelle du changement climatique et le rôle des gaz à effet de serre. Les preuves historiques indiquent que le changement climatique n'est pas un phénomène nouveau et les écosystèmes méditerranéens sont, par ailleurs, montré une résilience considérable aux changements climatiques passés. Le 21ème siècle peut être considéré comme une ère de changement climatique dans laquelle les préoccupations concernant le climat sont accompagnées par d'autres préoccupations telles que la mondialisation, la sécurité alimentaire, l'approvisionnement en énergie, et la durabilité. Le dioxyde de carbone peut avoir des effets positifs et négatifs sur la production de fourrage. L'augmentation des températures et des déficits d'eau dans la zone méditerranéenne, basée sur les résultats des modèles, sont susceptibles d'avoir un impact négatif sur la production, en particulier sur les systèmes de production intensive. Au contraire, des systèmes agricoles adaptés au climat et diversifiés sont considérés comme plus résistants aux impacts du changement climatique. Une gamme de stratégies d'adaptation au niveau des exploitations agricoles et au niveau des politiques gouvernementales peut permettre aux systèmes herbager et fourrager de se maintenir malgré les changements climatiques. L'élevage contribue aux émissions de gaz, mais une série de mesures d'atténuation sont prises pour aider à compenser certaines de ces émissions. Il est conclu qu'une approche intégrée est nécessaire pour répondreau changement climatique. De nombreux défis demeurent, mais l'optimisme pour l'avenir de l'agriculture des prairies dans la zone méditerranéenne demeure.*

Mots-clés. *Fourrages – Élevage – Émissions de gaz – Histoire climatique – Méditerranéenne.*

I – Introduction

Climate change has become a topic high on the political agenda and one that has serious potential implications for agriculture and land use, particularly in zones that are already affected by seasonal high temperatures or water deficits (FAO, 2006). Climate change is not just a recent phenomenon, and during the history of human civilization there have been several alternating periods of warming and cooling of the climate. The reasons for climate change are imperfectly understood but include both natural (changes in solar radiation, volcanic activity) and anthropogenic causes (increased emissions of CO_2 and other greenhouse gases (GHG)). The Third and Fourth Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC, 2001a, b; 2007) conclude that recent global warming is "unequivocal" and that most of the increase in global average temperature since the mid-20th century is "very likely" (>90% probability) due to increased concentrations of GHGs - principally carbon dioxide, methane and nitrous oxide – anthropogenic emissions of which have increased greatly since the 19th century. Carbon dioxide (CO_2) is the main GHG due to its relatively high atmospheric concentration (at the present time 390 ppmv; having increased by over 30% since the mid-18th century. Methane (CH_4) and nitrous oxide (N_2O) have also increased by similar proportions over the same period. Although they are less abundant in the atmosphere (at *ca.* 1800 ppbv and 323 ppbv) their global warming potential is respectively 23 and 296 times greater than CO_2 over a 100-year timescale; importantly, a high proportion of their emissions are derived from agriculture. Improving agricultural management to reduce emissions of these gases is therefore part of the overall package of measures to limit the extent of future climate change.

This paper first considers the historical background relating to climate and environmental change and focuses on the issues of present-day concerns as they relate to grasslands in Europe, particularly the Mediterranean zone. The potential impacts on grassland and grassland agriculture are considered in terms of the scenarios reported in *Climate Change 2007*, the Fourth Assessment Report of the UN Intergovernmental Panel on Climate Change (IPCC). At the farm scale, as well as at landscape scales and in policy development, there is scope for adapting grasslands to potential changes that might arise due to shifts in temperatures and precipitation. Grassland also has an important potential role in contributing to the mitigation of the effects of climate change – at least in terms of reducing or offsetting net GHG emissions. This paper reviews the evidence on the causes of climate change, its possible impacts on forage production, quality and utilization, and the opportunities for changes in integrated management to adapt to the effects of climate change and to reduce the emissions of GHGs associated with forage and ruminant production.

II – Historical background to climate change

Around 12000 years BP, the Northern hemisphere, and Europe in particular, experienced an abrupt and relatively brief (1000-year) cold-climate period, the "Younger Dryas", which interrupted the post-glacial warming trend than began about 20000 years BP. One consequence was the sudden onset of drought in the eastern Mediterranean (Levant). This has since been linked (though controversially) with the onset of settled farming among the Natufian culture: the "dawn of agriculture". Around 9000 years BP (onset of the Holocene Climatic Optimum) there was a widespread global warming with snowmelt and flooding in Europe on a massive scale. In the eastern Mediterranean there is evidence of climatic oscillations (wet and arid periods) coinciding with archaeological developments and adaptive strategies that transformed human cultures (Finne *et al*., 2011; Roberts *et al*., 2011). More recently, around 950 to 1250 AD, the Medieval Warm Period (MWP) led to further changes in agriculture, with Mediterranean crops like grapes being grown even in north-west Europe. The MWP may have experienced greater temperature rise (as argued by McIntyre and McKitrick, 2005) than in the late 20th century (as previously argued by Mann *et al*., 1998). The end of the MWP marked the onset of so-called Little Ice Age (LIA) which lasted until around 1850, a period that necessitated improvements in agriculture, particularly in livestock production for meat. Our present-day concerns about climate change and global warming date from only the late-1980s (previously, environmental signals were interpreted as indicating a likely future glacial period), but the end of the LIA is now taken as coinciding with the onset of industrialization, land-use change and greatly increased emissions of carbon dioxide and other GHGs (anthropogenic forcing) that are attributed, at least in part and by many scientists and politicians, as the cause of recent global warming. I have highlighted these trends (over what is a relatively short period of the history of human civilization; much greater environmental changes are evident over longer timescales ('t Mannetje, 2007)) to emphasize that (i) climate change always has been, and still is, taking place, and we have only imperfect understanding of its causes; and (ii) agriculture and land use are inextricably linked to climate and weather, and changes in climate have been important drivers of agricultural change.

III – The 21st Century – an era of climate change

Climate change has risen as a priority on the international political agenda and has entered the public consciousness as an issue of compelling global environmental importance. IPCC projections of future climate change suggest further warming (of between 1 and 3° C by 2100, but locally, as in the hinterlands of the Mediterranean zone, increases could be much higher, as reviewed by t'Mannetje, 2007). In addition, changes in the distribution of precipitation, with decreased rainfall over parts of southern and eastern Europe, and an increase in the frequency of some extreme events like heat waves and floods are also likely (IPCC, 2001a,b; 2007; Olesen *et al*., 2011). Despite measures to reduce carbon emissions, atmospheric CO_2 concentrations will increase appreciably (very high level of certainty).

Concerns about climate change also coincide with the impacts of globalization, population growth, environmental degradation and resource depletion, energy security and food security (Royal Society, 2009) and the present century has been labelled as an "era of climate change" (e.g. Winter, 2009). The term "dangerous climate change" has been used to describe possible outcomes in which ecosystems and food productions systems cannot adapt and sustainable economic development is threatened (see Schneider and Lane, 2005). Projected population and socio-economic growth is predicted to greatly increase food demand by 2050 (FAO, 2008). World prices of grain and other livestock feedstuffs have risen appreciably in recent years, propelled by rising demand from developing countries and exacerbated by production deficits linked to biofuel crops in exporting countries. In the context of European agriculture the economic value of grass and forage crops for ruminants is likely to increase, as grain and other commodities are required for human consumption or as feed for pigs and poultry. Agriculture will need to embrace new technologies and adapt to policies and practices aimed at raising production sustainably while at the same time delivering on increasing standards for environmental protection and food quality (Royal Society, 2009).

IV – Climate change impacts

1. Climate change impacts for grassland and forage production

An increase in atmospheric CO_2 concentration is one of the most certain outcomes and one that may have both positive and negative consequences. Carbon dioxide is the major resource for photosynthesis and several reviews have concluded that elevated CO_2 concentrations stimulate photosynthesis, leading to increased plant productivity and modification of water and nutrient cycles (Kimball *et al*., 2002; Nowak *et al*., 2004; Soussana and Lüscher, 2007). Experiments under optimal growing conditions have shown that doubling CO_2 concentration can lead to a 0.30-0.50 increase in leaf photosynthesis in C_3 plants, and an increase of 0.10-0.25 in C_4 plants, with above-ground canopy increases in excess of 0.17 occurring in grassland ecosystems (Soussana and Lüscher, 2007, and references therein). Plant functional groups also differ in their response to enhanced CO_2, and both legumes and non-legume forbs are reported to be more responsive than grasses and increase in abundance (Lüscher *et al*., 2005). The effects of sustained temperature increases on grasslands are less clear, as increased temperatures not only increase photosynthesis but also cell respiration and possibly the rates of loss, through respiration, of sequestered soil carbon (Parsons *et al*., 2011, and references therein).

For most parts of Europe changes in mean annual precipitation are expected to be small, and under most of the future "emissions scenarios" these are within the range of natural variability. However, shifts towards a higher proportion of the annual rainfall in winter (notably so in most of the Mediterranean area) and less rain in summer, have the potential to increase the frequency of years with summer drought stress, leading to reduced security of crop yields on non-irrigated land. This is exacerbated by higher temperatures which lead to increased evapotranspiration. Future predictions for the Middle East region (Turkey, Syria, northern Iran and northern Iraq) suggest a loss of 170,000 km^2 of rain-fed agricultural land by 2100, and reduced length of grazing season on rangeland (Evans, 2009). Perhaps of greater impact across the Mediterranean and adjacent regions is the possible increased frequency of extreme events: rainfall occurring in storms that can lead to soil erosion and flooding, and increased leaching of nutrients. At other times of year, there is an increased likelihood of more exceptional and prolonged hot, dry spells that pose risks for feed budgeting, and increased risks of wildfires, the impacts of which are potentially most serious in Mediterranean and southern Europe. These impacts present additional pressures in areas that are already affected by abandonment of marginal grazing land. The problem of supplying forage during the summer dry season in many areas of the Mediterranean region is likely to become greater. Water limitations will prevent potential benefits of CO_2 enhancement from being realized. Irrigation offers a practical measure for greatly increasing the production of grasses and forage legumes such as lucerne; however, under future scenarios with higher temperatures and more frequent droughts, combined with other demands on water supplies, this cannot be relied upon as a sustainable option. While grassland production on a Europe-wide scale is likely to be enhanced rather than reduced by ongoing climate change, the productivity in southern Europe is likely to be reduced under hotter, drier and more variable conditions ('t Mannetje, 2007; Trnka *et al*., 2011).

2. Climate change impacts for livestock production and grassland utilization

Elevated CO_2 is likely to affect feed quality for grazing, both in terms of fine-scale (crude protein concentration and C:N ratio) and coarse-scale changes (C3 species vs. C4 species) although there are strategies to overcome this particularly through the greater use of legumes (Soussana and Lüscher, 2007). At the farm scale, the consequences for feed budgeting are increased under situations of uncertainty, requiring a greater area allocated for conserved feed to support livestock during periods with little or no forage production. Heat stress affecting livestock is another serious potential impact affecting the livestock sector, as this can lead to reduced intake and liveweight gain / milk production. Changing climate also presents risks of increased spread of vectors of livestock diseases. These are important impacts in the context of seasonally hot, dry regions, like the Mediterranean (Morgan, 2005; Bindi and Olesen, 2011).

V – Adaptations to climate change

Adaptation is an important component of the response to climate change impacts, both at farm level and policy level: vulnerabilities can be reduced and potential opportunities realized (Moriondo *et al*., 2010). Farmers, assisted by governments and other supporting institutions, can plan to adapt to climate change but improved understandings of adaptation are needed to respond to future impacts through low-risk strategies (Morgan, 2005; Reidsma and Ewart, 2008). Bindi and Olesen (2011) distinguish between "autonomous adaptations", which can optimize production without major system changes, such as varying sowing dates, stocking rates or fertilizer rates, and "planned adaptations", such as land-use change, breeding new plant varieties, or installation of irrigation systems.

In the specific context of Mediterranean grass and forage situations, we can identify a number of potential adaptations to impacts on primary production and feed quality. These include: farm-scale adaptive responses of greater reliance on conserved feed for housed livestock, increased use of drought-tolerant species including C_4 grasses and maize (Morgan, 2005), greater use of forage legumes in place of N-fertilized grass (Sulas, 2005), changes in dates of sowing, improved manure storage and applications, improved soil management to increase soil organic carbon and soil structure and moisture conservation through minimum-till systems or organic amendments (Diacono and Montemurro, 2010) and provision of irrigation – although this last option may be unavailable or uneconomic in many areas (García-Ruiz *et al*., 2011).

At the scale of policy-makers and institutions, longer term adaptations can be developed through improved plant breeding to meet agronomic and other goals in response to climate change impacts. New forage resources are required that are adapted to higher temperatures, drought, and increased CO_2. This might be achieved through exploitation of traits for dehydration tolerance and summer dormancy, either in novel species or for introducing traits into existing widely used grasses and legumes (Volaire *et al*., 2009). In addition to new legumes, a shift to communities with more C_4 grass species is a likely successional outcome in semi-natural Mediterranean grasslands but their feeding value is lower than C_3 species ('t Mannetje, 2007). There is a need to develop strategies for incorporation of C_4 grasses, ideally with improved germplasm, into ruminant production systems.

An integrated land management approach will be needed to maintain agriculture in the Mediterranean zone. This will need to incorporate soil and water protection, management to reduce the risk of wildfires in shrub and browse communities, and greater use of high quality silage to support utilization of low quality forage in dry periods. The Mediterranean zone has a traditional farm management culture that is often already well adapted to climatic variability, rather than to maximizing productivity. Some authors (Blondel, 2006; Reidsma and Ewart, 2008) have argued that the view of Mediterranean agriculture being highly vulnerable to climate change, based on modelled outcomes, needs to be refined to take account of local adaptations. The existence of regional farm diversity can be developed further as a promising adaptation strategy to reduce vulnerabilities to unfavourable conditions. Reidsma and Ewart (2008) further suggest that measures such as subsidy and incentives should support the increasing diversity of farming systems. The arguments of Blondel (2006) draw on an historical perspective, and challenge the "Lost Eden" or "Ruined landscape" view of Mediterranean ecosystems. Examples of the "Sylva-Saltus-Ager" system that was widespread in the Roman Empire, and the Dehesa-Montado of the Iberian Peninsula and some islands are used to illustrate the high degree of resilience, productivity and biodiversity of farmed Mediterranean landscapes in response to continuous human disturbance of fluctuating regimes and intensity over many millennia.

VI – Management to mitigate greenhouse gas emissions

Grassland-based agricultural systems contribute to the biosphere-atmosphere exchange of GHGs, with fluxes closely linked to management practices (Soussana *et al.,* 2004). Ruminant livestock farming contributes to GHG emissions mainly through emissions of CH_4 and N_2O, and from direct and indirect use of carbon fuels, but there are opportunities for adapting management to mitigate these emissions.

1. Carbon dioxide

Long term pasture and scrub ecosystems and the maintenance of other farmland vegetation and accumulation of carbon as organic matter in soils can all contribute to the temporary removal, and in some cases to the long-term sequestration, of CO_2 from the atmosphere, thereby enabling grassland-based farming to contribute to GHG mitigation as well as improving the sustainability of the soil (Freibauer *et al*., 2004; Smith, 2004; Lal, 2010). Measures to reduce net-CO_2 emissions include improving efficiency of animal manures and crop residues, reducing soil disturbance, maximizing the C returns in manure, use of deeper rooting species, application of sewage sludge or compost to land, incorporation of biochar (Vaccari *et al*., 2011), extensification, and improved management to reduce wind and water erosion. Permanent pasture and minimum-tillage systems are favoured over annual cultivations. The increase in soil C content after a shift from arable to grassland is partly explained by a greater supply of C to the soil under grass, mainly from the roots, but also from the shoot litter (Soussana *et al.,* 2004). Whereas this rate of increase of soil C after conversion to grassland is slow, the rate of C disappearance from soil after returning grassland to arable is rapid. In terms of future research a major scientific development in the context of plant breeding in recent years has been the focus on plant functional traits (PFT) rather than on cultivars *per se*. PFTs control many terrestrial ecosystem processes including soil C storage; e.g., De Deyn *et al*. (2008) propose a trait-based approach that will help develop strategies to preserve and promote C sequestration. Kell (2011) takes this argument further and suggests that rather than focus on soil C sequestration that is happening now but might be possible through active agricultural invention and needs towards C sequestration at greater depths. Breeding crop plants with deeper and bushy root ecosystems could simultaneously improve soil structure and also its steady-state carbon, water and nutrient retention, as well as sustainable plant yields.

2. Methane

Enteric fermentation is the main agricultural source of methane in Europe, with emissions from livestock manures accounting for most of the rest. Methane is produced as a by-product of digestion of structural carbohydrates, due to the action of rumen microbes. During digestion, mono-saccharides are fermented to H_2, CO_2 and volatile fatty acids (VFAs), and as part of this stage of ruminant digestion some of the microbes (methanogens) produce CH_4. Several studies have formulated abatement strategies to mitigate CH_4 emissions. Mitigations aimed at enteric fermentation may be addressed at three different levels: livestock dietary changes, direct rumen manipulation, and systematic changes. The dietary changes involve measures which enhance the efficiency of feed energy use, and this is one area which has potential implications for forage use in the future (Cardenas *et al*., 2007). Even assuming a constant percentage of methane loss, this strategy will decrease methane loss per unit of product and probably decrease CH_4 emissions in the long term (Johnson and Johnson, 1995). The most natural way to depress CH_4 production would be to manipulate the diet to give high rates of fermentation and/or passage through the rumen, affecting rumen VFAs. These changes in VFA proportions have been associated with a decrease in the fibre content of the diet (e.g. by including maize silage). Ingestion of organic acids and yeast culture have been associated with reduced emissions in total CH_4 per cow and also with beneficial increases in animal product (Hopkins and Del Prado, 2007). The use of some plant extracts (i.e. tannins, saponins) has also been associated with CH_4 reduction. There may be considerable potential for tanniniferous legumes such as *Lotus* species, but further research is needed on their effectiveness.

There are some drawbacks to using dietary supplements. The organic acids are not yet commonly used, and they may also trigger pH problems in the rumen. Plant extracts may also have anti-nutritional effects and even be toxic (Teferedegne, 2000). For instance, in a study by Hess *et al*. (2005), extracted tannins had a positive effect on feed rates and hence a possible reduction of CH_4 per kg product, whereas the use of shrub legumes rich in tannins resulted in decreased feed rates. Yeast culture, on the other hand, although variable, may be promising as a successful mitigation option as it is already in common use. Direct rumen manipulation may offer an alternative to dietary change; for instance, defaunation of protozoa to decrease the number of methanogenic bacteria. However, there are many drawbacks including risks of metabolic disorders. Clearly, many research challenges exist before these approaches can be implemented (Hopkins and del Prado, 2007).

Systematic changes may involve identifying animal breeds which result in a reduction of CH_4 output per animal, though so far no clear evidence has been found (Münger and Kreuser, 2005). Increasing productivity per head (i.e. milk yield per cow or per ewe), or increasing the number of lactations for which the average milking cow or ewe remains economically productive, would decrease CH_4 production per unit of milk. Similarly, reducing the length of the production cycle of meat animals would also reduce the CH_4 production per kg of meat produced; thus, within the framework of production targets would decrease total CH_4 emissions. However, although more intensive forms of animal production tend to decrease total CH_4 output, they might not be compatible with other policy targets.

Mitigations aimed at manure management include opportunities to decrease total CH_4 outputs from farming systems are limited to either increasing the O_2 supply to restrict methanogenesis, minimizing the release of CH_4 to the environment (e.g. covered slurry lagoons/ manure stores) or using anaerobic digesters to produce more CH_4 in a controlled environment and hence use this CH_4 as a source of energy. This last technique could represent a sustainable option, and if the issues of high capital cost can be overcome this may become an important feature of future forage-based systems compatible with low CH_4 emissions.

3. Nitrous oxide

Nitrous oxide is formed in the soil through nitrification and denitrification and is controlled by a number of soil factors, including moisture content, temperature, fertilizer additions, pH, organic matter content, nitrate and ammonium (Hopkins and del Prado, 2007, and references therein).

Nitrate and ammonium in the soil are subject to several process dynamics. In general, N_2O emissions can be reduced by implementing practices aimed at enhancing the ability of the crop to compete with processes that lead to the escape of N from the soil-plant system (Freney, 1997). For instance, there are several methods for increasing the efficiency of the crop to remove mineral N from the soil. These include improving fertilizer efficiency, optimizing methods and timing of applications (Dosch and Gutser, 1996), using ammonium-based fertilizers rather than nitrate-based ones (Dobbie and Smith, 2003) and employing nitrification chemical inhibitors (Macadam *et al.,* 2003). Increasing the soil aeration may significantly reduce N_2O emissions. Avoiding compaction by traffic, tillage (Pinto *et al.,* 2004) and grazing livestock may help to reduce N_2O emissions. Housing system and management will also influence N_2O emissions, e.g. straw-based manures result in greater N_2O emissions than slurry-based ones (Groenestein and Van Faassen, 1996). Minimizing the grazing period is likely to reduce N_2O emissions as long as the slurry produced during the housing period is uniformly spread. Livestock diets also affect the N_2O emissions from slurry subsequently applied to land (Cardenas *et al.*, 2007).

VII – Conclusions: the need for integration of actions for adaptation and mitigation

Forage-based agriculture contributes to the total of GHG emissions but there are many practical and potential solutions that can help reduce these impacts, and some of these can also help agriculture adapt to the direct impacts associated with climate change. Agriculture is also subject to other pressures, including environmental (biodiversity, eutrophication, erosion, and acidification), socio-economic and sustainability issues. Identification of "win-win" strategies requires development of appropriate modelling systems together with the acquisition of field and farm data (Scholefield *et al.,* 2005).

However, GHG and other emissions account for only a part of the whole challenge facing grassland and forage-based systems as we move into an era of climate change. Policy makers are increasingly becoming concerned with energy security, food security and management of water resources and other ecosystem services. Nevertheless, the history of farming the Mediterranean zone shows that systems have evolved in response to changing conditions, and these traditions and their diversity, coupled with technological advances, provide some grounds for cautious optimism. Many research challenges remain. At national and regional scales, policy makers need to ensure that decisions on land and environmental management, and on future food security, are based on evidence-based research and expert advice in order to ensure a sustainable balance of forages, arable crops and other land-use requirements, consistent with broader economic, social and environmental objectives. Research funders also need to ensure that climate change implications are factored into future projects.

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