Synergies between mitigation and adaptation to Climate Change in grassland-based farming systems

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Abstract

Climate change mitigation and adaptation have generally been considered in separate settings for both scientific and policy viewpoints. Recently, it has been stressed (e.g. by the latest IPCC reports) the importance to consider both mitigation and adaptation from land management together. To date, although there is already large amount of studies considering climate mitigation and adaptation in relation to grassland-based systems, there are no studies that analyse the potential synergies and tradeoffs for the main climate change mitigation and adaptation measures within the current European Policy context. This paper reviews which mitigation and adaptation measures interact with each other and how, and it explores the potential limitations and strengths of the different policy instruments that may have an effect in European grassland-based livestock systems.

Keywords: Mitigation, adaptation, resilience, climate change, grassland-based, livestock

Introduction

In the last IPCC report (AR5-WGIII: IPCC, 2014b), for the first time, most of the terrestrial land comprising agriculture, forestry and other land use (AFOLU) was considered altogether. Moreover, it was also highlighted in the AFOLU chapter (IPCC, 2014b) the importance to consider the systemic feedbacks and interactions between mitigation and adaptation options from land management (Separate sub-section: 11.5). In grassland-based systems, however, the potential interactions between mitigation and adaptation options, compared with forest or arable systems, have received much less attention and this has been reduced to changes in carbon (C) stocks and pasture productivity. Changes in biogeochemical cycles (mainly C and N) and water cycles are expected to exert large impacts on livestock productivity and N and C emissions from grassland-based systems (i.e. CO_2, CH_4 and N_2O). Climate change impacts on livestock will include effects of forage and feed quality and productivity, direct impacts of changes in temperature and water availability on animals, and indirectly through livestock disease increase (IPCC, 2014a). However, socio-economic changes are expected to have a still greater effect on mitigation and adaptation potentials (Schmidhuber and Tubiello, 2007).

Climate mitigation options in grassland systems mainly include practices that increase soil C stocks or can help to reduce GHG (greenhouse gases) emissions at the soil, feed, animal or manure management level. However, at a wider context, demand-side measures (e.g. human dietary changes, reducing losses and wastes in the agro-food chain) or substitution of fossil fuels by biomass can also play an important role in mitigating climate change. Mitigation options in grassland-based systems need also to be addressed for their potential impact on all other ecosystem/environmental services provided by grasslands for current and future scenarios, as climate regulation is just one of the services amongst a varied list (e.g. food production). Mitigation and adaptation in grassland-based systems are closely integrated through a network of feedbacks, synergies and risk of trade-offs. Mitigation measures may also be vulnerable to climate change or there may be possible synergies and trade-offs between mitigation and adaptation options (IPCC, 2014b).

Many policies are directly (e.g. Kyoto Protocol) and indirectly (e.g. Common Agricultural Policy: CAP) affecting the potential success of implementing measures that both reduce GHG emissions and help to adapt grassland-based livestock systems to Climate Change. There is however a need for a more integrated and scientifically–based regulatory approach. Although there are already many studies that have reviewed measures regarding grassland-based systems on GHG mitigation (e.g. Smith et al., 2007; Verge et al., 2007) or Climate Change adaptation (e.g. Bryan et al.,2009; Olesen et al., 2011; Tingem et al., 2009), only few sudies have assessed the benefits and trade-offs of their synergistic effects (e.g. Lal et al., 2011).

The main objective of this paper is to provide a high-level assessment of synergies and trade-offs for the main potential Climate Change mitigation and adaptation measures in grassland-based livestock systems within the current European Policy context.

Climate Change mitigation now and in the future in grassland-based livestock systems

The main aim of the mitigation options in grassland-based systems is to reduce emissions of CH_4 or N_2O and/or to increase soil C storage, especially by soil as grasslands account for 75% of C in the terrestrial ecosystems (Lal, 2005; Dresner et al., 2007). Recently, more or less comprehensive reviews on GHG mitigation from grassland-based systems have been produced (e. g. Project ANIMALCHANGE: Van den Pol-van Dasselaar, 2012; UNEP, 2013; Havlík et al., 2014; Del Prado et al., 2013a). Nitrous oxide is formed in the soil through nitrification and denitrification (Wrage et al., 2001) and controlled by a number of site-specific factors, including soil moisture content (Del Prado et al., 2006), temperature (Dobbie et al., 2001) and also, management factors such as fertilizer (Cardenas et al., 2010) and management of soil organic matter content (Mosquera-Losada et al., 2011a) and grazing (Van den Pol-van Dasselaar et al., 2008). Carbon sequestration also depends on edaphoclimatic conditions (Theng et al., 1989), the presence of trees (Mosquera-Losada et al., 2011a) and the organic matter quality and quantity (Mosquera-Losada et al., 2011a and 2011b). Methane can be produced via enteric fermentation, which depends greatly on the level of feed intake, the quantity of energy consumed and feed composition, or can be produced at the manure management level, which increases with temperature, and with increased biodegradability of the manure (Monteny et al., 2006).

As highlighted in the last IPCC report on mitigation of Climate Change in the AFOLU sector, there is an emerging scientific activity on prediction of the likely impact of the Climate Change on the potential to reduce net GHG emissions (i.e. impacts on N_2O and CH_4 emissions and on the rates of C sequestration) in the AFOLU sector in general, and in grassland-based systems in particular. Mitigation options available today in the grassland-based farming sector may not be available or as effective with further global warming. Soil C storage has been shown to be vulnerable not only to climate change but more importantly, to changes in the disturbance regime, both natural and human-induced. Land use projections indicate large changes in land use and potentially this change will exacerbate the release of CO_2 from soils including grasslands. Increasing temperatures, when water is not limiting, are expected to accelerate soil organic matter (SOM) decomposition rates but result in an increase of C returns through plant residues considering the CO_2 fertiliser effect and the lengthening of the growing season (Bindi and Olesen, 2011). Increasing SOM will enhance soil C storage and may also increase above and belowground biomass production or at least improve yield stability (Pan et al., 2009). However, biological processes resulting in N_2O emissions (i.e. denitrification) could be stimulated by greater SOM. Moreover, increased variability and higher frequency of extreme events will negatively impact soil C storage, by both decreasing production levels and enhancing soil C losses. At the manure level, GHG emission changes are expected in relation to temperatures and sometimes indirect effects driven by changes in the composition of the feed (e.g. digestibility). .

Main climate change effects on European grassland-based livestock systems

During the last century, the climate in Europe has changed more than in other areas of the world (IPCC, 2007). Compared to the pre-industrial era, when the mean annual temperature increased by 0.8°C globally, it increased by 1.2°C in Europe. Based on theoretical models, a further increase of 1.0–5.5°C is expected by the end of the twenty-first century (Christensen et al., 2007). The increase in temperature has been most apparent in mountainous areas such as the Alps, which tend to have high biodiversity and where temperature increased by 2°C during the twentieth century (EEA, 2009). This is twice the average temperature increase for the northern hemisphere. In addition, the quantity and distribution of precipitation have also changed in Europe during the twentieth century. Although there has been a 20% decrease in rainfall in southern Europe, there has been a 10–40% increase in rainfall in northern Europe. Furthermore, an increase in the frequency of extreme weather events is predicted across the European continent (EEA, 2008).

The most important impacts of climate change on grassland-based farming systems in Europe are expected to be through changes in pasture productivity and forage quality, therefore potentially affecting the duration of the grass growing season and the forage supply to ruminants. An example about how different intra-year temperature and precipitation regimes affect total and also seasonal distribution of pasture was found by Mosquera-Losada and González-Rodríguez (1998) in dairy systems. This paper highlights the importance of having flexible grazing systems, which affects annual and instantaneous stocking rate. The intensification of the hydrological cycle caused by more intensive rainfall and longer dry periods is expected to result in higher risks of soil erosion and nutrient leaching in currently wet temperate climates. Changes in precipitation patterns in drier areas will lead to higher dependency on stored soil moisture storage and seasonality for supporting grass growth. Elevated concentrations of CO_2 may also increase water use efficiency through reduced plant stomata aperture, but increase run-off risk through reduced plant transpiration, thus resulting in excess water at the land surface (Betts et al., 2007). Biological and physical processes regulating nutrient cycling in grassland-based farming systems may actually be more sensitive to extreme events rather than changes in average climatic conditions. For Europe, an increased risk of low forage production in summer due to severe summer droughts events is expected to be offset by the appearance of new opportunities for forage production in other seasons due to warming effects. For southern latitudes, higher evapotranspiration rates will negatively affect grass yield and the period of grass growth will be shorter unless the grassland is irrigated. In general, poorer grass nutritional qualities, e.g. lower grass digestibility, can also be expected.

Potential synergies and tradeoffs between strategies to adapt to Climate Change and measures to mitigate GHG emissions

GHG emission mitigation choices may further enhance or reduce resilience to climate variability and change in terms of ecosystem goods and services provision, and thus influence the potential of grassland-based systems to adapt to Climate Change. Climate change may affect climate adaptation and mitigation strategies through changes in feed supply, animal diet composition, animal and plant breeding, soil management, enhancement of floral biodiversity and via more resistant and resilient production systems against climate change (e.g. agroforestry systems).

Climate change affecting feed supply (grazing and forage)

Spring growth, provided that water resources for grass growth are available, and winter production may benefit from mild climate conditions. This can contribute to improve the farm´s degree of forage autonomy and security of livestock systems when facing more hazardous climate conditions (e.g. summer droughts) through the extension of the grazing season and the reduction of forage requirements (Graux et al., 2013). For example, forage resource usually stored for over-wintering livestock could be partially redistributed in summer to deal with increased risk of forage deficits (Graux et al., 2013). However, for southern latitudes and dates getting closer to the XXII century (e.g. UK: Del Prado et al., 2009) the projections suggest that grazing activity will be constrained due to too high temperatures and excessive drought in Europe. Extending grazing seasons by e.g. the presence of shelter/shade belts of trees would reduce the wind speed and therefore evapotranspiration (ETP). The presence of trees at low density would also increase the duration of the growing season due to their presence, which may partly reduce GHG emissions (Tackas and Frank, 2009) through improving soil N recovery by trees, but may also become hot-spots for N_2O from overlapping urine patches, and soils could become eroded due to the action of hooves in camping areas used by livestock for shelter/shade. Extending the grazing season in some cases may also be limited by the bearing capacity of the soil driven by good soil structure degradation (e.g. poaching caused by trampling cattle or/and severe summer droughts, etc.) and therefore, it may, in some cases be impractical. Hence, avoiding compaction by traffic, tillage (Pinto et al., 2004) and grazing livestock (De Klein and Ledgard, 2005) may help to maintain grasslands in good conditions and also to reduce N_2O emissions.

Poorer grass nutritional qualities, e.g. lower grass digestibility, will lead to higher CH_4 emissions from enteric fermentation of cattle (Hart et al., 2009). Although if lower forage quality would mean reduced livestock ‘yields’ and/or quality then market reaction would be to import feeds. For those systems extending the grazing season (e.g. Figure 1: UK: Misselbrook et al., 2013), smaller volumes of manure storage could lead to a reduction in CH_4 emissions from manure handling. However, the rise in average and extreme temperatures, should the frequency of manure removal from the storage remain unchanged or no additional structural measures are implemented to either lower the manure storage temperature or to aerate the slurry, could increase the amount of CH_4 per kg of volatile solid of manure and therefore, lead to similar total CH_4 emissions from manure management. Moreover, even if the CH_4 emissions from manure management were smaller, this value (in CO_2 equivalents) would be partially offset or accentuated by an increase in N_2O emissions promoted by the increase in grazing activity.

Climate change affecting feed supply (purchased feed and different crop rotations)

Changes in grassland productivity will affect either animal productivity or the amount of purchased feed required (Mosquera-Losada and González-Rodríguez, 1998). For semi-arid regions (e.g. south of Europe), a reduction in annual grass productivity will lead to lower animal productivity or will have to be compensated with a larger share of imported feedstock with associated monetary and environmental costs, which may translate into a potential loss of resilience in grassland-based livestock systems. In some of these regions tree presence to feed animals with acorns, could supply part of these needs (Moreno and Pulido, 2009).
An increase in the establishment of rotations best suited to the area or crop rotations with legumes annual crops (Bryan et al., 2011) may also occur as an adaptation strategy. Some crops that currently grow mostly in southern Europe will become more suitable further north or in higher altitudes areas in the South. For example, forage maize, may become more common across in the boreal regions of Europe. Maize forage, however, tends to make the management system less flexible to inter-annual temperature/precipitation variations.

Moreover, maize area cannot be used for grazing during the summer or autumn if no grass is available during this period. In contrast, grass areas can be open or harvested for silage if a restriction or an excess of grass production happens (Mosquera-Losada and González-Rodríguez, 1998). At the animal level, forage maize animal intake is generally promoted at the expense of grass due to a better balance between protein intake and soluble carbohydrates (e.g. through increasing starch concentration in the diet), which additionally may help to increase animal energy use efficiency and decrease CH_4 emissions per kg DM intake. However, this CH_4 reduction may be offset by larger N_2O emission losses and a larger CO_2 release of converting some grassland into arable land (Vellinga and Hoving, 2011).

Conversely, converting crops to pasture has been found to reduce N_2O emissions (Eagle et al., 2012) and also contribute to sequester soil C, especially in the first years after conversion. Leguminous species are well adapted to future conditions of climate change (Kreyling et al., 2012) considering that their optimum temperature is higher than non-leguminous crops and that they also have more positive responses to elevated concentrations of CO_2 (Soussana and Lüscher, 2007) than non-legume species. In a situation with a larger share of mixed legume/grass pastures, in addition to presenting climate adaptive advantages over conventional pastures, these systems have lower requirements for N fertilizer through the use of biological N fixation of nodules on the roots of legumes, which would lead to energy savings and GHG emissions reductions from both fertilizer production and use (Del Prado et al., 2011; Zhang et al., 2013).

Climate change affecting feed supply (use of by-products and alternative forages)

Different by-products from agricultural, forestry, agro-industry and bioenergy activities can also be used for feeding ruminants as an adaptive response to forage supply seasonal constraints. Rinne et al. (2012) reviewed different by-products (e.g. camelina meal, tomato pomace) that are currently underutilized but that could potentially be used as feed for low input and organic dairy production systems. Those practices are currently used as part of some livestock systems at a regional level (Correal et al., 2009). These by-products vary in their geographical availability, nutritional value, their effect on rumen CH_4 and N excretion (i.e. effect on GHG mitigation) and have logistic-related challenges. Environmentally speaking (e.g. GHG intensity), the use of some of these by-products as animal feed may not always be the best option in comparison with their use in bioenergy or for soil improvement. In this sense, removal of crop residues from cropping systems for use in bioenergy, if this means that soil C contents are being depleted (e.g. straw: Liu et al., 2014), will bring large risks of negative impacts on adaptation measures and potentially, small or negligible positive effects on the reduction of net GHG emissions. Mitigation and adaptation conflicts may therefore appear as one chooses a particular use of the by-product or another.

Other alternative forage supply may include tree leaves and shrubs, particularly in small-scale livestock farms with dry to semi-arid climates. Such species can alleviate feed shortages, or even fill feed gaps in the winter and especially in the summer, when grassland growth is limited or dormant due to unfavourable weather conditions (Papanastasis et al., 2008). Although some species have leaves with a low content of CP and a high content of fiber and contain high levels of secondary compounds such as tannins, alkaloids, saponins and oxalates which reduce the nutritive value of poor-quality diets, some of these compounds (e.g. condense tannins), when improved temperate forages are fed, can also have substantial benefits for ruminant productivity (i.e. reducing CH_4) and health (Waghorn and McNabb, 2003). Moreover, there are also other species (e.g. *Morus alba*, *Fraxinus excelsior*, *Betula alba*) whose young leaves are rich sources of protein and fibre and generally used in the past to feed animals before modern techniques like fertilizer were used.

Changes in fertiliser management, diet and genetics to increase N use efficiency

Manipulating the diet (e.g. feeding nitrification inhibitors: Ledgard et al., 2008 or salt supplementation) during the grazing period has also been proposed as a means to reduce N_2O emissions. Improving fertiliser efficiency, optimising methods, timing and rates of applications (Brown et al., 2005), using NH_4^+-based fertilisers rather than nitrate-based ones (e.g. Dobbie and Smith, 2003) and employing nitrification chemical inhibitors (e.g. Zaman et al., 2009) may also have a role in both mitigation (i.e. reduction of direct and indirect soil N_2O emissions) and adaptation (through a better N use efficiency at the soil-plant level). New traits in animals and grasses may also assist farmers to both mitigate and adapt to Climate Change. Del Prado and Scholefield (2008), for example, using a farm modelling approach, evaluated the scope for different animal and plant genetic traits, some existing and other theoretical, to help reduce GHG emissions on UK dairy farms. More efficient animals in utilising N (Alford et al., 2006) have also been proposed to decrease the impact of urinary N during grazing. Some of the traits, e.g. improved N use efficiency in grasses (e.g. high sugar grasses: Wilkins et al., 2000) could actually be both potentially useful for Climate mitigation and may also promote Climate adaptation as they may reduce GHG emissions from urine-related N_2O emissions and improve the quality of the forage, which may be beneficial in future scenarios where climate has a detrimental effect on grass nutritional properties.

Soil management, plant biodiversity and new plant breeds to improve system resilience against environmental stress conditions and prevent soil erosion

Other strategies to both mitigate and adapt to Climate Change may involve management practices that target directly to the soil, both improving the capacity to store water and to prevent soil erosion. By increasing the ability of soils to hold soil moisture and to better withstand erosion by enriching biodiversity through more diversified cropping systems, grassland systems will be able to sequester more soil C and also to better resist extreme events such as droughts and /or floods, both of which are projected to increase in frequency and severity in future warming climates (Rosenzweig and Tubiello, 2007).

The measures for the conservation of soil moisture may also include changes in tillage practices. Reduced tillage, for example, increases the resilience to climate change through improved soil fertility and increased capacity for water retention in the soil. This improvement is expected in the long-term productivity potential when tillage is reduced (Olesen et al., 2011). The reduced tillage at pasture reseeding promotes C sequestration and preservation in pastures and is considered to be more effective under conditions of water deficit (Alvaro -Fuentes et al., 2011). It leads also to significant savings in CO_2 emissions produced by machinery. However, the impact on N_2O emissions under different conditions is unclear (Estavillo et al, 2002; Pinto et al, 2004). Nitrous oxide emissions appear to be strongly influenced by soil water content immediately after nitrogen fertilization (Del Prado et al., 2006). In view of this dominant effect of a particular soil moisture level coinciding with tillage and fertilization, it is key to find the best timing for the renewal of pasture. Velthof et al. (2010), for example, considering average Dutch climatic season conditions, suggest that this pasture renewal should take place in spring rather than fall because Dutch autumn, compared with spring is generally wetter and N uptake by the reseeded grass is lower. The effect of reduced tillage has also been observed by increasing the periods between which a pasture is renewed. Vellinga et al. (2004), for example, found that although tillage increased N_2O and CO_2 in the intensively managed pastures in the studied year, in the long run, the renovation of the pastures was more important to prevent the deterioration in pasture quality and thus, to prevent from soil loss and large productivity losses.

For areas which are subject to severe or extremely severe environmental stress conditions the establishment of a community of pastures formed by species that ensure ecological stability, both in ecosystem resistance and resilience, is key as an adaptation measure to Climate Change (Volaire et al ., 2014). Additionally the species composition of the pasture is expected to undergo changes, as for example, warming will favour C4 species over C3 species (Howden et al., 2008). Biodiversity should act as a safeguard of ecosystem functioning, thus promoting a more stable ecosystem to avoid fluctuations arising from adverse climatic fluctuations (Volaire et al., 2014). Promoting biodiversity could also have an effect on the mitigation potential of pastures and in some occasions of rumen methane. Considering that N remains one of the main elements that determines the diversity of plants, the application of less fertilizer should be a requirement to increase diversity in different floral species in grasslands (Mountford et al., 1993). This reduced input fertilizer would be necessarily associated with lower emissions of N_2O per ha and potentially a greater amount of C accumulated in the soil.

New grass breeds have already been tested to improve water use efficiency. For example, McLeod et al. (2013) tested in the UK a novel grass *Festulolium* hybrid capable to reduce runoff by 40-50% compared to a leading UK nationally recommended L. *perenne* cultivar and F. *pratensis* over a two year field experiment. The rapid growth and turnover of roots in the hybrids resulted in greater soil water storage capacity in the plots with observed lower rainfall runoff. This may, in turn, have significant effects on N_2O emissions and soil C storage.

Agroforestry systems

Agroforestry is a well-founded example of mitigation and adaptation synergy (e.g. IPCC, 2014b; EU forest strategy: EU, 2013) since trees planted and grassland soils sequester C and tree and grassland products provide livelihood to communities, especially during drought years (Verchot et al., 2007). Agroforestry in general and silvopastoral systems in particular lead to greater resilience to climate change due to improved soil conditions and management efficiency in water use (Kumar et al., 2011). Its characteristics are able to reduce evapotranspiration and thus improve the maintainability of soil water (Tackas and Frank, 2009). These practices also have a great potential to offset GHG emissions through the sequestration of C in soil and tree biomass and avoiding the release of NO_3 leaching (indirect N_2O emissions) (Rigueiro et al., 2009). Moreover, these systems also improve the N use efficiency of the system and offer large resilience against climate change stress conditions through the reduction of temperature of the system (Rigueiro et al 2009). It can also help reduce erosion of adjacent fields handled more intensely (Verge et al., 2007).

Policy implications

Climate mitigation policies and measures may exhibit synergies and risk trade-offs with climate adaptation (Bates et al., 2008). However, policies of mitigation and adaptation are often being considered in separate settings, resulting in potential conflicts. An integrated adaptation and mitigation framework is important to ensure that trade-offs between the two are minimized and synergies encouraged (Wreford et al., 2010). However, this is not easy as mitigation and adaptation may occur simultaneously, but differ in their spatial, timing and geographical characteristics (Smith and Olesen, 2010).

Amongst the number of policies affecting Climate Change mitigation and adaptation in grassland-based systems in Europe, the newly reformed EU Common Agricultural Policy (CAP), in principle, has made a decisive move towards promoting a greener and climatically friendlier EU agricultural sector. The new CAP has introduced direct payments associated to different practices that, in some cases, are expected to enhance GHG mitigation and adaptation to Climate Change. Namely, new payments within Pilar I associated to the diversification of crop rotations, maintaining permanent pastures and ensuring Ecological Focus Areas should be targeting, in part, climate-friendly or climate-smart agriculture. Permanent pasture maintenance is an important way to prevent N emissions through avoiding plough management and conversion of permanent grasslands into arable lands (EU Regulation 1307/2013). Leguminous species are mentioned explicitly in the areas of ecological interest (N-fixing species) but there is no special plan for their promotion. Other practices, such as those mentioned in previous sections, grazing, for example, is encouraged directly through the support of agroforestry systems and forests with fire risk areas (through the Rural Development Programme (Pilar II)), avoiding huge amounts of C release and through cross-compliance via for example promotion of good standards for animal welfare. Floristic biodiversity should also be encouraged but are not explicitly mentioned within the new PAC to safeguard ecosystem functioning against adverse climatic fluctuations.

The replacement of permanent grasslands by forage maize is no longer allowed by the CAP as penalties are included in the last CAP if destruction above 5% is present. The new CAP, however, does not explicitly address the worrying import of feed in grassland-based intensive systems. In fact, in some countries, this is still indirectly encouraged through additional payments to more intensive systems. The CAP has been blamed for distortion of global markets in this sense. Khatun (2012) points at the absence of tariffs for animal feed as a key driver for fueling EU cheap imports of animal feed from Latin America and consequently, for the effect on land use, land use change, and forestry (LULUCF) outside of the EU and, thereby preventing from a huge potential for mitigating climate change by reducing emissions from deforestation and forest degradation (REDD+ programme) outside Europe. Policies, hence, can create both positive and perverse incentives for mitigation or adaptation (Wreford et al., 2010). A number of recent studies (e.g. Lassaletta et al., in press in Spain) suggest that many European Countries, either assisted by specific regulations (e.g. Kyoto, CAP) or fuelled by market pressures, are displacing large amounts of GHG emissions from their national primary sectors (e.g. grassland-based farming) to other countries via agricultural goods importing. For example, cattle farming in Europe, whose feed system was traditionally based mainly on-farm forage (e.g. grass) production, in the recent decades has shift to heavily depend on cheap imported protein (e.g. soybean) from South America, resulting in a reduction of GHG emissions in the European GHG inventories but more than offsetting this potential mitigation by a consequential increase of GHG emissions by mainly land use change in South America. Much of these emissions are produced in non- Annex B countries and consequently, C leakage is being produced in Europe. Displacing agricultural productivity may indeed be an adaptation choice for countries, but this is certainly against securing Food Sovereignty and therefore, this jeopardizes the future resilience of the European food system. For example, if the conversion of annual crops to pasture is accompanied by a demand to grow annual crops outside Europe, this would not represent a net mitigation but merely a shift in emissions and, in some cases, this would be an example of C and / or N_2O leakage.

Furthermore, a large part of the mitigation potential of grasslands is also subject to challenges in relation to effectiveness over different time-scales. For example, whereas certain types of mitigation activities (e.g. N_2O reduction from reduced N fertilization, CH_4 reduction in the rumen through animal diet changes, bioenergy) are effectively permanent since the emissions, once avoided, cannot be re-emitted (IPCC, 2014b), some activities that helped to sequester C (e.g. reducing tillage), can be reversible and non-permanent. Moreover, some of these practices to sequester soil C may also be constrained due to the saturation of grassland soils to sequester C indefinitely. Therefore protecting the large C stocks in grasslands should be an important management and policy target, rather than necessarily trying to increase the C stocks (Smith, in press) since it is easier and faster for soils to lose C that it is for them to gain C (Johnson et al. 2009).

Mitigation options for any of the GHG gases must also be tailored to the specific soil, climatic and production system conditions (Bustamante et al., in press). There will be very few strategies that are universally applicable for all systems and under any climatic circumstances. All mitigation options certainly affect and are affected by the cycles of C and N. Nitrogen and C cycles are also currently decoupled for most intensive grassland systems (Soussana and Lemaire, 2014), these systems release by ruminants bound-C digestible as CO_2 and CH_4, and return digestible N in high concentrations (urine patches). The coupling / decoupling of C and N makes an added difficulty to analyze the effectiveness of mitigating measures as sometimes some of the measures that increase soil C storage, for example, addition of manure, can also increase losses of N_2O by increasing soluble C in the system. In contrast, measures that promote the reduction of N_2O can cause a net loss of C from the system through increased soil respiration (Scholefield et al., 2005). Moreover, some of the mitigation methods lead to pollution swapping (e.g. NH_3 volatilization , leaching of NO_3^-), and losses in biological diversity and / or productivity (Del Prado and Scholefield , 2008), and also can cause numerous interactions between mitigation measures so that their effect in the case of using multiple measures simultaneously are not necessarily additive (Del Prado et al. , 2010).

Also, the reference unit to which GHG emissions relate within the CAP is commonly the forage area, which may not, in some cases, coincide with the preferred reference unit used by the agroindustry (C footprint or GHG per unit of product). The emphasis therefore seems to have been diverted from what the consumers and markets dynamics are essentially promoting. Preferably, one should consider more than one reference unit or functional unit (e.g. per hectare and per unit of output) at the same time to avoid conflicts of interpretation about what is true / false mitigation (Del Prado et al., 2010). Agroindustry generally uses the Life Cycle Assessment (LCA) as the methodology choice in order to report GHG emissions from the full cycle of the production of a food. A key element still unsolved is the way LCA assigns different amounts of GHG emissions to different goods according to its market-based value. Given a specific policy context, the farmer may choose among the most cost-effective and easier-to-adopt options. Ecosystem services which currently have no market value may become valuable also in monetary terms in the future. Some farmers may, therefore, in the future also seek to maximize the ecosystem service value. Alternative methodologies are already suggesting that, for products that are produced through extensive and in some cases greener conditions, these emissions should be split according to not only market but non-market (e.g. ecosystem services) values (Ripoll-Bosch et al., 2013) as well.

An important issue that may not be reflected in the new CAP and in other policies is the alarming growth tendency of feeding ruminants (e.g. dairy cattle: Del Prado et al., 2013b) with a greater amount of feed ingredients which could be used directly in the human food chain (e.g. cereals) (Eisler et al., 2014). This relates very significantly to the potential competitive advantage that pasture-based livestock (ruminants generally are able to use low-quality plant biomass and that is inedible to humans) might have over another livestock (e.g. monogastric animals). Policies therefore should be useful to overturn this trend.

Additionally, non-climate policies and regulations are already in place for other environmental issues (e.g. water quality, NH_3) and have consistently assisted in reducing GHG emissions from the agricultural sector (e.g. EU: Velthof et al., 2014). Nitrate leaching losses, however, are expected to increase for numerous areas that are already constrained in their nutrient use by the EU Nitrates Directive (Anon, 1991) in Europe and for feed commonly used in animal diets, for example wheat (Olesen et al., 2007). This increase in NO_3^- leaching may trigger more stringent regulations and hence affect animal productivity and GHG emissions, which may challenge climate change adaptation also from a policy perspective. Research-oriented policies should and already have a role, for example, in encouraging the study of new grass varieties that can better adapt to climate change and also present properties that can increase the efficiency of use of nutrients and energy in the soil-plant-animal system.

It is therefore imperative that all the policies, from the local to the global levels, are appropriately integrated with the policies relating to climate change, bioenergy, food, waste, research and health in order to promote a net reduction of GHG from the standpoint not only of production (supply) but also of demand in order to avoid possible market distortions and maladaptation practices at all levels.

Acknowledgements

This study was performed thanks to the support of the livestock and grassland theme (LiveM) of the FACCE-JPI knowledge hub and project MACSUR. MACSUR is funded through national funding bodies as part of the EU FACCE-JPI (Joint Programming Initiative for

Agriculture, Climate Change, and Food Security). AGFORWARD and CICYT (Spanish Ministry) projects are also acknowledged.

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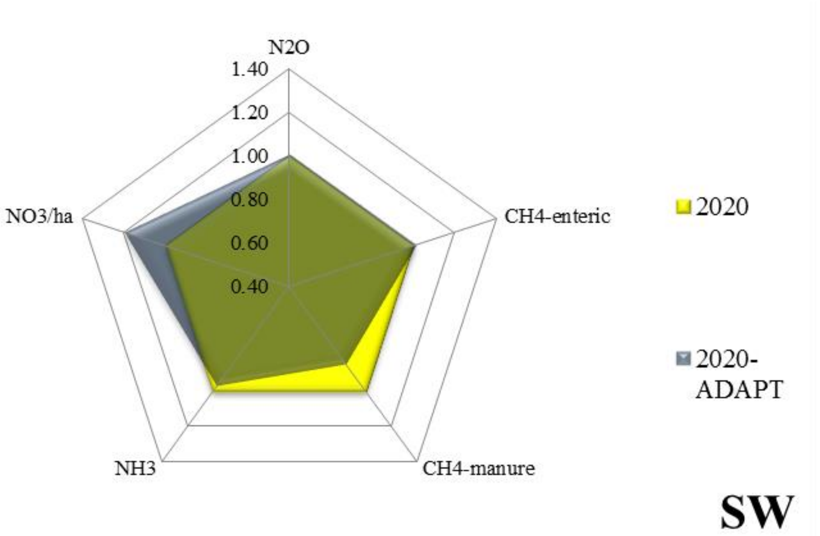

Figure 1. Comparison between adapted (extending one month grazing) and un-adapted typical dairy farms in the south west England (2020) for GHG, NO_3^- leaching and NH_3 emissions. Values for the adapted scenario <1 indicate a reduction in emissions (adapted from Misselbrook et al., 2013).