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Consistent ozone-induced decreases in pasture forage quality across several grassland types and consequences for UK lamb production

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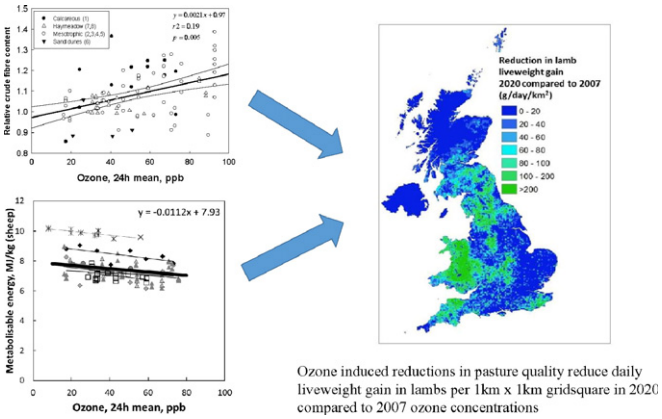
HIGHLIGHTS

- Ozone decreased pasture quality across a range of vegetation types.
- An ozone exposure–response function for metabolisable energy of grassland was derived.
- Potential lamb production in the UK could be reduced by 4% in 2020 compared to 2007.
- Production losses could be mitigated by additional supplementary feeding.

GRAPHICAL ABSTRACT



Ozone induced reductions in pasture quality reduce daily liveweight gain in lambs per 1km x 1km gridsquare in 2020 compared to 2007 ozone concentrations

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ABSTRACT

In this study we have demonstrated that rising background ozone has the potential to reduce grassland forage quality and explored the implications for livestock production. We analysed pasture samples from seven ozone exposure experiments comprising mesotrophic, calcareous, haymeadow and sanddune unimproved grasslands conducted in open-top chambers, solardomes and a field release system. Across all grassland types, there were significant increases in acid detergent fibre, crude fibre and lignin content with increasing ozone concentration, resulting in decreased pasture quality in terms of the metabolisable energy content of the vegetation. We derived a dose-response function for metabolisable energy of the grassland with ozone concentration, applicable to a range of grassland types, and used this to predict effects on pasture quality of UK vegetation at 1 km resolution using modelled ozone data for 2007 and for predicted higher average ozone concentrations in 2020. This showed a potential total reduction in lamb production in the UK of approximately 4% in 2020 compared to 2007. The largest impacts were in geographical areas of modest ozone increases between the two years, but where large numbers of lambs were present. For an individual farmer working to a very small cost margin this could represent a large reduction in profit, both in regions where the impacts per lamb and those where the impacts per km^2 of

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Metabolisable energy
Sheep
Lambs

grazing land are largest. In the short term farmers could adapt their lamb management in response to changed forage quality by additional supplementary feed of high metabolisable energy content. Nationally this increase in annual additional feed in 2020 compared to 2007 would be 2,166 tonnes (an increase of 0.7%). Of added concern are the longer-term consequences of continual deterioration of pasture quality and the implications for changes in farming practices to compensate for potential reductions in livestock production capacity.

1. Introduction

Current ozone concentrations are known to decrease crop yields and affect crop quality, with global agricultural economic losses estimated to be $17–$35 billion annually (Avnery et al., 2011). Crops that have been demonstrated to be sensitive to ozone include wheat (e.g. Piikki et al., 2008, Pleijel et al., 2007), potato (e.g. Donnelly et al., 2001, Vandermeiren et al., 2005) and tomato (e.g. Bermejo, 2002, Calvo et al., 2007). However, in addition to effects on agricultural crops that are used directly as a food source, several individual experiments have shown effects on yield and quality of component species of pasture used for animal grazing. Globally, in 2000, the area of pasture and fodder crops was 3.5 million km^2, representing 26% of the world land area and 70% of the world agricultural area (FAOSTAT). Across Europe, the total fodder area (grasslands and fodder crops) comprises 43% of the utilised agricultural area. This land is grazed by approximately 100 million sheep and 89 million cattle (including 23 million dairy cattle), the majority of which are dependent on managed pasture or grassland for a significant portion of their diet (FAOSTAT). In this study, for the first time, ozone impacts on pasture quality from experiments on different types of grassland have been analysed using common methodology to allow development of common dose-response functions. To demonstrate the potential spatial extent of ozone-induced reductions on pasture quality and consequent effects on lamb production, worth £980 million in the UK in 2010 (UK agriculture) and contributing 9.5% of global sheepmeat exports in 2012 (nationalsheep.org.uk), the response functions have been applied to UK data at 1 km^2 resolution.

Some deleterious effects of ozone on yield of pasture have been previously demonstrated (e.g. Pleijel et al., 1996). Most such studies have focussed on reductions in the legume fraction as this could affect productivity of ruminant herbivores that feed on the pasture either directly via grazing or through silage production due to the higher nitrogen content of legumes. Reductions in the legume fraction, but not the grass fraction, of harvested biomass as a result of ozone exposure have been demonstrated using both intact managed pasture (Fuhrer, 1994, Fuhrer et al., 1994), *Trifolium repens–Lolium perenne* mixtures established in field conditions from seed (Wilbourn et al., 1995), and *T. repens–L. perenne* established in mesocosms (Hayes et al., 2009). Similarly, reductions in the clover:grass ratio due to ozone have been reported by Nussbaum et al. (1995) and Heagle et al. (1989) using *T. repens* and *L. perenne* and *T. repens* and *Festuca arundinacea* respectively, which can also occur if the above-ground biomass of the grass component increases due to reduced competition from the legume content. Reductions in N-fixation in clover in response to increasing ozone concentrations have also been shown (Hewitt et al., 2014), implying a reduced nitrogen content of the clover component of the pasture.

Forage quality is influenced by combinations of several factors including content of desirable nutrients e.g. protein as well as the composition of the cell wall, which must be broken down as part of the digestive process for the nutrients to be released. Any ozone-induced decrease in forage quality could be via changes in species composition, changes to individual component species such as altered plant structure or changes to biosynthesis or partitioning of secondary metabolites. One of the measures that integrates the nutrient content and digestibility aspects of forage quality is 'Relative Feed Value' (RFV). It has been demonstrated that early season ozone exposure (non-filtered air + 50 ppb) of *Poa pratensis* in mesocosms decreased RFV by 8%, despite no reduction in biomass production (Bender et al., 2006). Nutritive quality of *Trifolium subterraneum* was decreased by 20% with ozone concentrations of approximately 56 ppb compared to charcoal-filtered air (Sanz et al., 2005), in addition to a decrease in biomass. The change in nutritive quality in the Sanz et al. (2005) study was shown to be due to increased concentrations of "acid detergent fibre" (ADF), "neutral detergent fibre" (NDF) and lignin. In addition, the RFV of clover monocultures has been shown to be 2.4 times greater than that of equivalent grass (*L. perenne*) mesocosms (González-Fernández et al., 2008), implying that a decrease in clover content of pasture would cause a decrease in RFV. However, these studies have assessed impacts on vegetation representative of high quality, productive grasslands. To date there have been no studies on ozone effects on the overall quality of pasture in low production semi-natural grasslands, where species such as clover would constitute a much smaller component.

Quality of forage has been shown in previous studies to be an important factor influencing liveweight gain of lambs, with liveweight gain being much lower (86 g per day) when grazing grass compared to clover (123 g per day, Court et al. 2008). Several other studies have shown a link between the metabolisable energy of the feed and liveweight gain of sheep and/or lambs, but these often compared only two metabolisable energy feeds, which were contrasting in species composition, making these unsuitable to derive a response relationship (e.g. Black et al., 2007 using grass compared to clover, Ramirez-Restrepo et al., 2004 comparing *Lotus* spp. to a *Lolium*/*Trifolium* mixture, and Speijers et al., 2005 comparing *Lotus*, red clover and rye grass). A feeding trial in Oman, with the chemical composition of the different feeds balanced in terms of crude protein and vitamins and minerals, showed that for Omani lambs the relationship between metabolisable energy and liveweight gain was linear with diet formulations between 8.67 and 11.2 MJ ME/kg DM (Mahgoub et al., 2000), with the rate of growth also being linear throughout the trial for each of the different diets.

To date, the majority of studies investigating the effects of ozone on pasture quality have used highly productive grass-clover mixtures; however, a considerable amount of grazing occurs on lower-quality grasslands. In the UK 5.6 million ha (23% of the UK land area) is 'rough grazing', comprising many different species, including grasses and related vegetation, and is largely grazed by sheep. The vegetation present is variable and depends on soil type, climate (particularly rainfall) and management. This compares to 6.1 million ha of 'permanent grassland and pasture' of higher quality and widely used for sheep, beef and dairy production, and 1.2 million ha of 'rotational grassland' of highest quality and suited to silage making or feeding to milking cows (ukagriculture.com). The large proportion of rough grazing land shows that it is therefore also important to consider the impact of ozone on lower quality grasslands when investigating potential damage to pasture quality caused by ozone pollution, and that on this type of land sheep production is more likely to be affected than other livestock.

In previous studies where pasture quality has been investigated, typically only two or three ozone treatments were used in an individual study, and the parameters measured and the methodology for forage quality analysis varied between studies. In addition, the size of effects of ozone on quality may be influenced by the species composition of the vegetation, for example, it has been shown that the size of the effect of ozone on nutritive quality of *P. pratensis* varied according to the species that it was grown with (Bender et al., 2006). In this study, pasture samples were taken from ozone experiments on seven semi-natural grasslands using *in-situ* or mesocosm approaches to test the hypothesis that exposure to ozone decreases pasture quality. By using the