Feed back and Feed-Forward Interactions between Climate Change and Grassland-Based Agriculture

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Abstract

This paper explores the possibility of identifying land management strategies for economically productive agricultural grassland in temperate regions that enable carbon sequestration as well as reductions in the trace greenhouse gases nitrous oxide and methane. The best overall strategy is one that involves de-intensifying to a moderate level of nitrogen use from the highest levels. This would also be compatible with the need to comply with other constraints, such as water quality legislation. Identification of similar win-win strategies for other land-use types will require development of appropriate modelling systems together with the acquisition of field data.

1. Introduction

The Kyoto Protocol encourages soil carbon (C) sequestration as one component of a series of measures that will be required to stabilise the world's climate at a temperature that will avert major catastrophies. However, there is growing awareness that all of these components may need to be considered in concert if one set of measures is not to negate benefits of another. In particular, it is now well recognised that there could be such antagonisms between any strategies of land management implemented for increased C sequestration and effects on trace greenhouse gases such as nitrous oxide (N_2O) and methane (CH_4).

Temperate grassland agriculture is responsible for much of the world's production of meat and dairy produce. It occupies about 20% of the land area of Europe and has some potential to sequester C into soil [1,2]. However, it can also cause high emissions of the greenhouse gases nitrous oxide (see Brown et al., 2002 for UK data, [3]) and methane, which have global warming potentials of 62 and 275 times that of carbon dioxide (CO_2), respectively, over a 20 year time span. Nitrous oxide is a product of nitrification and denitrification in soils and manures and CH_4 is produced in the rumen of farm livestock and emitted from excreta and wet soils under anaerobic conditions.

Although some grassland managements have a high potential to sequester atmospheric C, it is suspected that some of the effective managements for increasing the soil C stocks of temperate grasslands may also exacerbate N_2O emissions [2,4,5]. Conversely, it is possible that management strategies that are currently being identified for reducing N_2O and CH_4 emissions may cause net loss of C from the system through greater soil respiration. A further complication arises from the growing pressures for identification and implementation of strategies to adapt to and cope with climate change impacts on grassland agriculture [6]. These may not be synergistic with strategies for either increased C sequestration or reduced N_2O and CH_4 emissions. Clearly, all potential benefits will not be additive and there is a need to develop an integrated approach to optimise grassland management for achieving maximum contribution to stabilising the climate.

In this paper we consider the 3 sets of criteria for management change with the objective of identifying those strategies offering maximum potential for reductions in global warming. The best strategies are identified through a combination of modelling and use of available published data and information. Although we focus on temperate grassland agriculture, this is merely to exemplify the problems and as a vehicle to demonstrate generic approaches that could probably be applied to maximise influence on climate stabilisation of several other land use sectors.

2. Carbon sequestration potential of temperate grassland agriculture

The potential of productive grassland agriculture to sequester C in soil depends on several factors:- soil, plants, physical conditions, climate, the starting conditions and the nature of the management transition. While it is generally agreed that soil has a finite capacity to sequester extra organic C, that amount depends on how the aforementioned factors determine the balance between primary production and respiration. The availability of other soil nutrients such as N, relative to the amount of microbiologically labile C, is of major importance in this. The highest accumulations of organic matter are found on cool, wet, nutrient poor and botanically diverse sites, where there is low productivity but even lower rates of degradation of plant derived organic matter. Any perturbation of this state such as physical disturbance, drainage or increased nutrient input, would result in C loss. Sousana et al., (2004), [2] used a simple 2-pool C cycling model to suggest that such losses could be as great as 20 t C ha^{-1} at rates of 1.1 t C ha^{-1} yr^{-1}. On the other hand, some agriculturally productive grassland managements can be shown to be more C conserving than others. Tyson et al., (1990) reported an experiment comparing the divergence of soil C levels from a common starting position under either arable cropping (spring and winter barley) or permanent white clover-ryegrass pasture (sheep grazing) over a 30-year period. The pasture management resulted in a 1.0 t ha^{-1} yr^{-1} increase in soil C during the first 10 years but little further sequestration, while the arable system resulted in an average and continuous rate of C loss of 290 kg ha^{-1} yr^{-1}. Changing to moderate from intensive N use (whether the N is supplied from fertilisers or fixation) can result in C sequestration of 0.3-0.5 t C ha^{-1} yr^{-1}, as the rate of supply of C to the soil exceeds its rate of mineralization [2,7]. The other really effective management strategy is decreasing the frequency of cultivations for pasture reseeding, which again is calculated to achieve sequestration rates of 0.2-0.5 t C ha^{-1} yr^{-1}, depending on the initial reseeding regime and site factors.

The effect of soil conditions on the potential to lose or sequester C is generally thought to be large. However, there is little evidence at the field scale that any differential capacity of agriculturally productive grassland soils for C sequestration according to soil conditions can be exploited. This possibly because clay soils are not disturbed so frequently as sandy soils to preserve structure and ensure traffickability and so often accumulate greater organic C reserves.

3. Mitigation of N_2O and CH_4 emissions from grassland

The most effective strategy for reducing both N_2O and CH_4 emissions is to reduce intensity of N use, which reduces both the rates of nitrification and denitrification and also the livestock carrying capacity of the farm. Figure 1 shows an example of simulations made with the NGAUGE grassland model [8] of the effects of changing N input to a dairy farming system with sandy or clayey soil on N_2O emissions. On the sandy site emissions of N_2O-N with intensive management (350 kg N ha^{-1}) were calculated to be 5 kg N ha^{-1} yr^{-1}, whereas with moderately intensive management (175 Kg N ha^{-1}) the N_2O emissions were about one quarter, a reduction of 3.8 kg N_2O-N ha^{-1} yr^{-1}. On the clayey site emissions were about 5 times greater than on the sandy site, with reduction in emission on reducing management intensity from high to moderate of about 18 kg N_2O-N ha^{-1} yr^{-1}.

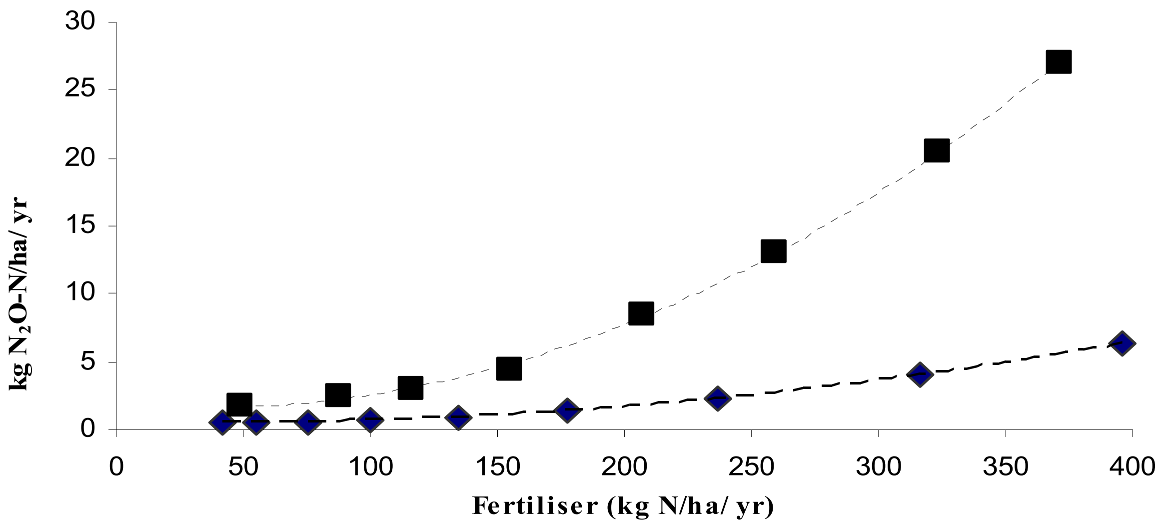

Figure 1. Effects of management intensity (fertiliser N input) on emissions of N_2O from a dairy farm in a maritime temperate location with either a poorly drained clay soil (■) or a well-drained sandy loam soil (♦); modelled using the NGAUGE model, taking account of all processes.

Fig. 2 shows the results of model simulations made with NGAUGE to track effects of N input on CH_4 emission from a dairy farm on sandy or clayey soils. These data are calculated only on the basis of animal numbers supported by the forage grown and do not include any considerations of the potential of either animal breeding, feeding or manure treatment strategies in reducing CH_4 emission, all of which been identified as having significant but as yet un-quantified impacts. On the sandy site emissions of CH_4 with intensive management (350 kg N ha^{-1}) were calculated to be 210 kg C ha^{-1} yr^{-1} whereas with moderate management intensity (175 kg N ha^{-1}) it was 165 kg C ha^{-1} yr^{-1}, a reduction of 45 kg C ha^{-1} yr^{-1}. On the clayey soil emissions were about 75% smaller due to the lower stock carrying potential of the land but the reduction in CH_4 emissions due to moderate de-intensification was almost the same as with the sandy soil.

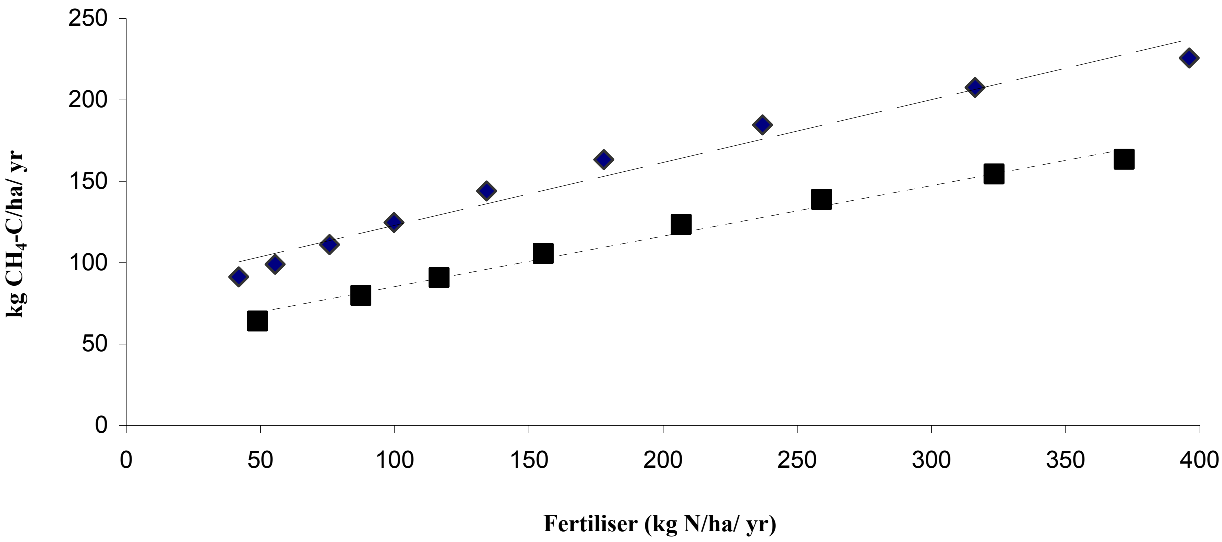

Figure 2. Effects of management intensity (fertiliser N input) on emissions of CH_4 from a dairy farm in a maritime temperate location with either a poorly drained clay soil (■) or a well-drained sandy loam soil (♦); modelled using the NGAUGE grassland model, disregarding emissions from stored and spread manures.

4. Impacts of climate change on grassland agriculture and consequent coping strategies

While the amount of definitive experimental evidence on the impacts of climate change on grassland agriculture is not yet large, there are in this body of evidence strong indications as to the nature and likely extent of them. A recent major study involving sward growth experiments under elevated CO_2 and temperature scenarios linked with the development and application of the LEGSIL grassland model [9,10,11] has revealed the likelihood of several important impacts and highlighted possible farmer responses.

These include:

- Increased yield potential of 10-50%, particularly favouring legumes, with reductions of the growing season during spring and autumn, but with reduced opportunity for harvesting forage then due to wetter soils.
- Change in herbage quality with higher content of water-soluble carbohydrates and lower N content at a given yield.
- Greater incidence of summer drought.
- Leaching may be increased, due to increased winter rainfall, or decreased, due to better N use efficiency of plant and better N capture by animal.

Likely responses to these are:

- Increased reliance on conserved forage and longer housed period for animals. Increased feeding of maize grown on the farm in more northern latitudes, causing decreased CH_4 emissions.

- Increased fertiliser use to replace that lost by increased leaching, or decreased fertiliser use due to more efficient N uptake by plants and less N in excreta. The latter would favour reduced N_2O emissions.
- Increased need to store and spread more manure. Techniques adopted would determine impacts in N_2O and CH_4 emissions.
- Increased use of irrigation in mid-season, causing increased N_2O emissions.

5. Identifying synergistic management combinations

The best strategies for C sequestration by temperate agricultural grasslands involve intensifying from the nutrient poor state or de-intensifying from highly intensive, short-term grass leys to apply moderate inputs of fertiliser N or promote grass-legume swards with infrequent cultivations. Intensification of low input species rich-grassland would not be desirable in many parts of the world, but de-intensifying from the highest levels would be compatible with the need to comply with water quality legislation (e. g. EU Nitrate Vulnerable Zones and Water Framework Directive). This would also result in reduced emissions of N_2O and CH_4, which would augment the modest impacts on climate change of C sequestration alone. The remaining question is whether this strategy would be also synergistic with the farmers' medium-term strategies for coping with climate change impacts.

The pivotal deciding factor is whether climate change impacts prompt farmers to increase fertiliser or not. However, economic and other shorter-term policy pressures, such as those for improved water quality and biodiversity may over-ride any farmer reaction to climate change. Once the potential for soil C sequestration has been realised, further benefits could be obtainable through adopting specific strategies to limit N_2O and CH_4. The former could involve use of ammonium-based fertilisers and field-scale application of nitrification inhibitors, such as DMPP [12]. The latter could involve optimisation of livestock breeding, herd management and feed quality for more productive animals with longer productive lives being fed diets that inhibit CH_4 formation. The latter would include increased use of easily digestible high quality feeds, use of dietary oils and supplements and the possible introduction of immunisation against rumen methanogens [13].

6. Costs and uncertainties

The cost of implementation of the de-intensification strategy identified above derives mainly from reduced farm productivity and animal numbers ha^{-1} on the most intensive farms. However, although only 25-30% of farms belong in this category, these farms are responsible for greatest output and therefore the cost of compensation would be high. These costs may be met from a range of sources as implementation would benefit air and water quality and biodiversity as well as climate stabilisation. The calculated reductions in N_2O and CH_4 by implementation of the best strategy were 75% and 21%, respectively. Cost curve calculations of mitigation of these gaseous emissions on UK livestock farms [14] show that 20% and 15% of N_2O and CH_4 reductions, respectively could be achieved at negligible cost to the industry overall.

There is a moderate degree of uncertainty surrounding the model calculations, but a greater uncertainty attached to the way that farmers will respond to pressures and incentives. Of particular importance here is whether farmers will respond to actual climate change by becoming more nutrient efficient or by applying nutrients to achieve highest yields of forage possible.

7. Summary and conclusions

It appears possible to specify several management changes to temperate grassland farming that would overall result in net sequestration of soil C of between 0.2 and 0.5 t ha^{-1} yr^{-1} over a finite period of about 10 years. One of these, de-intensifying from the highest level of intensity associated with dairy farming to a moderate level of intensity, would also enable substantial reductions in both N_2O (3.8 – 18 kg N_2O-N ha^{-1} yr^{-1}) and CH_4 (45 kg CH_4-C ha^{-1} yr^{-1}) emissions. This de-intensification would be compatible with what would be required to comply with other legislative constraints. Our modelled data show that the practicality and economic ease of implementation and the benefits to climate stabilisation will be different for different soils. It is possible that such benefits to climate stabilisation may be achievable through adopting integrated pollution swapping approaches to other major land-use types. This will require the use of appropriate models and the acquisition of field-scale data.

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