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Research article

The environmental impact of dairy production on poorly drained soils under future climate scenarios for Ireland

Pooja Sharma[a,*], James Humphreys[b], Nicholas M. Holden[a]

[a] UCD School of Biosystems and Food Engineering, University College Dublin, Belfield, Dublin 4, Ireland
[b] Animal & Grassland Research and Innovation Centre, Teagasc, Moorepark, Fermoy, Co. Cork, Ireland

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ABSTRACT

The environmental impact of dairy production in Ireland has been widely studied and it is known that regional differences in management and impact are driven by climate. Climate change projections for Ireland predict increasing temperature, change in rainfall patterns and decreasing in solar radiation, varying by agroclimatic region. This study evaluated the environmental impacts of low-cost, grass-based, rotational-grazing dairy production on poorly drained soils under climate change. The *Dairy_sim* model was used to determine the theoretical optimum dairy system management for five different locations in Ireland assuming a poorly drained soil resource under baseline (1981–2000) and future climate scenarios (2041–2060, high and low emissions scenarios). An optimum system was defined as having maximum grass production and grazed grass in the diet, minimum necessary silage, minimum imported feed, minimum housing days and a very small silage surplus. Life cycle assessment was then used to quantify the environmental impacts (climate change, eutrophication and acidification) for all scenarios. The dairy production systems were predicted to be more productive in the future, with climate change impacts per unit milk reduced or the same, acidification impacts reduced and eutrophication impacts reduced. The absolute emissions driving climate change and eutrophication were predicted to significantly increase for the future low emission scenario, and emissions driving acidification were predicted to slightly increase. The predictions indicate that system adaptation to mitigate absolute emissions are needed rather than just policies that focus on impacts per unit output.

1. Introduction

To meet the demands of increasing global population over the next century, the challenge for agriculture is to increase production in warmer climates and satisfy climate change policy requirements (Cullen and Eckard, 2011). Livestock is currently one of the fastest growing agricultural sectors, projected to increase globally by 80% by 2050 compared with 2005 (Alexandratos and Bruinsma, 2012), but at the same time accounting for 11% of global greenhouse gas (GHG) emissions (Llonch et al., 2016). World milk production is projected to increase by 25% compared to 2013 to 2015 (OECD/FAO, 2016). The Irish Environmental Protection Agency (EPA) estimated an increase of 6% in GHG emissions from agriculture sector mainly in the period 2014 to 2020, due to the Irish dairy expansion (EPA, 2016a). Dairy production is one of the most profitable agricultural enterprise in Ireland (McDonald and Macken-Walsh, 2016), being based on a predominately low-cost, grass-based, rotational-grazing system (O'Brien et al., 2014). As grazed grass is the main source of herd nutrition, dairy production may be vulnerable to climate fluctuations (Kalaugher et al., 2017) compared to systems that rely on imported feed (Clark et al., 2012), and to the water status of the available soil resource (Schulte et al., 2012; Shalloo et al., 2004). Temperature and rainfall influences the length of grazing season and summer soil water deficit influences the stocking rate (Fitzgerald et al., 2005). Solar radiation influences all of these factors to some degree, and is projected to decrease in future (Fealy and Sweeney, 2008). Soil water deficit influences grass grown (limiting when too wet or dry), machine trafficability, animal treading damage and nutrient use efficiency (Schulte et al., 2006). The interaction of climate and poor drainage makes dairy management more difficult due to slower regrowth and recovery after grazing and field events (Drewry, 2006). Around 30% of Irish milk is produced on poorly drained soil (O'Loughlin et al., 2012) so understanding the interaction of poorly drained soils and future climate scenarios has significant implications for both production policy (Food Wise 2025 (DAFM, 2015),) and environmental impacts (EPA, 2016a; EPA, 2017).

Climate is a major factor of any agricultural production system (Kalaugher et al., 2017) and the impacts of climate change are already being seen around the world due to rising temperatures and change in

* Corresponding author.
E-mail address: pooja.sharma@ucdconnect.ie (P. Sharma).

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precipitation patterns (Pachauri and Meyer, 2014). Evidence of climate change is emerging in Ireland and projections indicate increasing temperature and changes in precipitation spatial and temporal distribution (Caffarra et al., 2013). An increase of 1.0–1.6 °C in mean annual temperature by mid-century is projected, with the largest increase in east of the country, along with a significant decrease in average precipitation (Nolan, 2015). Fitzgerald et al. (2009) predicted that Irish dairy production would be able to adapt to climate change, but the overall effect is also uncertain due to regional variations in resources and climate (Cullen et al., 2009). It is important to better understand how farms with poor soil resources might adapt to climate change as it is some of this land bank that will be needed to produce milk to meet production targets (DAFM, 2015). Grass production is predicted to decrease in the east and increase the west (Holden and Brereton, 2002), but the system is predicted to be able to adapt, even on poorly drained soil (Fitzgerald et al., 2009). The implications of future climate on the environmental impacts of dairy based systems in Ireland had not been studied.

The approach taken for this work was to use a mechanistic simulation model to find an optimum system of management for a given soil and climate combination, and to then use the model output as activity data for a life cycle assessment to calculate environmental impact. Farm level models have been used to evaluate GHG emissions from dairy farms under future climate scenarios (Cullen and Eckard, 2011; Del Prado et al., 2013; Rotz et al., 2015) and life cycle assessment (LCA) is widely used to evaluate the environmental impacts of dairy farms (Yan et al., 2011). A combination of farm level model and LCA have been previously used for evaluating environmental impacts of livestock sector in the UK (Chatterton et al., 2015).

In comparable temperate areas studies have indicated different trends. For New Zealand, a projected 18% decrease in average annual grass production was reported under climate change scenarios which was interpreted as having a negative impact on pasture based dairy production (Kalaugher et al., 2017). A similar study showed an increased productivity of dairy farms in the UK (Del Prado et al., 2009). This study also reports a decrease in GHG emissions and increase in acidifying gases and nitrate leaching. There is evidence that the impact of climate change will vary regionally (Kalaugher et al., 2017; Shrestha et al., 2014) and will depend on the time scale and spatial extent of the study area (Del Prado et al., 2009).

The aim of this study was to evaluate the future environmental impacts of milk production in Ireland subject to climate change and the worst case scenario of production on poorly drained soil. Dairy production was modelled as theoretical dairy units in different agro-climatic regions in Ireland (Holden and Brereton, 2004) using the *Dairy_sim* system simulation model (Fitzgerald et al., 2005, 2008) and the environmental impact quantified using the dairy LCA model of Sharma et al. (2018).

2. Materials and methods

2.1. Dairy system optimisation and location

A typical Irish spring calving, low-cost, grass-based, rotational-grazing dairy system (Sharma et al., 2018) assuming poorly drained soil was modelled at five locations in Ireland. The starting point for all the farms was assumed to be a 20 ha dairy unit with 40 lactating cows (2 live unit/ha, in compliance with the Good Agricultural Practice Guidelines (EU, 2014)), producing 5545 kg milk/year (Chen and Holden, 2017). Housing date, live weight, dates for closing of paddocks for 1st and 2nd and 3rd cut for silage were taken from Sharma et al. (2018) for poorly drained soils. The study used the same sites as Sharma et al. (2018) (i) east Co. Cork (Fermoy), (ii) south west Co. Offaly (Birr), (iii) west Co. Clare (Kilmaley), (iv) northeast Co. Cavan (Ballyhaise) and (v) central Westmeath (Mullingar). The *Dairy_sim* model (Fitzgerald et al., 2005) was then used to find optimum farm management at each location using daily climate data, soil type (poorly drained soil) and farm activity data. *Dairy_sim* had been previously tested for well-drained soil (Fitzgerald et al., 2005), poorly drained soils (Fitzgerald et al., 2008) and artificially drained soil (Sharma et al., 2016). The optimisation target was to maximise grass production and utilisation with minimum housing days and neither surplus nor deficit of silage production (Fitzgerald et al., 2009). As *Dairy_sim* does not allow dairy cows and machinery to access fields under wet conditions, poaching damage from grazing and soil compaction from machinery was not simulated. In *Dairy_sim*, poorly drained soils were defined using soil drainage class as defined by soil moisture deficit (SMD) model described in Schulte et al. (2005) and Schulte et al. (2015). The parameters of the model were defined by SMD_{max}: maximum possible soil moisture deficit, SMD_{min}: extent to which soil can saturate water, SMD_c: soil moisture deficit at which grass begins to experience water stress and $Drain_{max}$: maximum drainage rate in mm/day (Schulte et al., 2005). The values for poorly drained soils in the model were: $SMD_{max} = 110$; $SMD_{min} = -10$; $SMD_c = 10$ and $Drain_{max} = 0.5$ mm/day (Schulte et al., 2005, 2015).

2.2. Future climate scenarios

Global Climate models (GCMs) are widely used to predict future climate, but with a relatively coarse grid they are not suitable for making predictions at local level (Fitzgerald et al., 2009). There are two methods of downscaling the data: (i) statistically downscaling as used in previous studies to provide future predictions (Fealy and Sweeney, 2008) and (ii) dynamical downscaled used in recent studies, which provide very high resolution data in Ireland (Nolan et al., 2017; O'Sullivan et al., 2016). The later studies have used a combination of GCM and high resolution regional climate models (RCM) to predict future climate data, which exhibits greater variability over Ireland than statistically downscaling methods (O'Sullivan et al., 2016).

The climate scenarios used for this study (summarized in Table 1) were developed for the ensemble of regional climate model projections for Ireland by the Irish Environmental Protection Agency (Nolan, 2015) using two high resolution dynamically downscaled regional climate models (RCM), within a set of two global climate model (GCM) simulations. The RCMs used for this work were Consortium for Small Scale Modelling, Climate Limited Area Modelling model (CLM4) and the Weather Research and Forecasting (WRF) model. The GCMs used were Hadley Centre Global Environment Model version 2 Earth System configuration: HadGEM2-ES and the EC-Earth consortium.

The fields were generated using most recent Representative Concentration Pathway (RCP) 4.5 and 8.5 emission scenarios to generate data for two time periods 1981 to 2000 (baseline period) and 2041 to 2060. Thus there were three cases: baseline, low emission and high emission. These periods were chosen as these were the longest decadal time period common for the simulations. RCP4.5 is a medium-to low-emission and RCP8.5 is a high-emission scenario. RCP4.5 and RCP8.5 are the most recent emission factors recommended by IPCC (Pachauri and Meyer, 2014). A different number of runs and slightly different initial conditions were used for each GCMs. The GCM outputs

Table 1
Details of all the simulations used, the driving GCM/RCM, the RCP and number of realisations (running the same GCM with slightly different conditions) for historical (1981–2000) and future (2041–2060) used for future climate data.

Driving GCM	RCM	Number of realisations
HadGEM2_ES	CCLM4	Historical (1) RCP4.5 (1), RCP8.5 (1)
EC-Earth	CCLM4	Historical (3) RCP4.5 (3), RCP8.5 (3)
EC-Earth	WRF	Historical (3) RCP4.5 (3), RCP8.5 (3)