Ecological Indicators 95 (2018) 851–861

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original Articles

Modelling regional environmental efficiency differentials of dairy farms on the island of Ireland

Adewale Henry Adenuga[a,b,d,*], John Davis[a,b], George Hutchinson[a], Trevor Donnellan[c], Myles Patton[b]

[a] Gibson Institute for Land Food and Environment, School of Biological Sciences, Queen's University, Belfast, United Kingdom
[b] Agri-Food and Biosciences Institute (AFBI), Newforge Lane, Belfast, United Kingdom
[c] Teagasc, Rural Economy and Development Centre, Co Galway, Ireland
[d] Department of Agricultural Economics and Farm Management, University of Ilorin, Ilorin, Nigeria

ARTICLE INFO

Keywords:
Dairy
Ireland
Truncated regression
Data development analysis
Eutrophication
Environmental efficiency

ABSTRACT

Environmental pressures associated with nitrogen (N) and phosphorus (P) are likely to be an important policy issue on the island of Ireland, made up of Northern Ireland and the Republic of Ireland following the abolition of the European Union (EU) milk quota system in 2015. In this study, we assessed the environmental performance of dairy farms in terms of N and P efficiency in the four regions of the island of Ireland using a novel environmental data envelopment analysis (DEA) approach. The determinants of environmental efficiency were also analysed in a second stage analysis, using a truncated linear regression model with bootstrapped non-parametric DEA environmental efficiency estimates as the dependent variable. We find regional differences in environmental performance across the four regions of Ireland with greater nutrient surpluses in Northern Ireland compared to the three regions in the Republic of Ireland. However, computed indices from the environmental DEA technology which simultaneously accounts for the expansion of desirable outputs (milk and other outputs) and reduction in undesirable outputs (N and P surpluses), showed higher environmental performance index for Northern Ireland compared to the regions of the Republic of Ireland. Utilized agricultural area, forage grazed per hectare and adoption of milk recording were found to be significant factors influencing environmental efficiency in the Republic of Ireland while only forage grazed per hectare was statistically significant for Northern Ireland.

1. Introduction

Nitrogen (N) and phosphorus (P) nutrients are components of animal feed required for growth and development. While N is a part of amino acids that form proteins, P is needed for bone development and other bodily functions. They are also useful as soil nutrients for raising crop and forage productivity. However, any application of these nutrients in excess of immediate animal, crop and forage needs can have two specific consequences. The first is the economic consequence to the farmer resulting from increased production costs to outputs ratio, and secondly, the costs to the society in the form of potential harm to the environment (European Environment Agency (EEA), 2017; Buckley and Carney 2013). In particular, N and P surpluses that accompany dairy production are regarded as negative externalities (undesirable outputs) given their potential damaging effect to water quality and lack of internalisation of the associated costs in the production process. Farmers often find it easier to apply excess N or P ignoring the downstream costs caused by leached or eroded nutrients.

Efficient management of N and P nutrients are essential factors in ensuring profitable and sustainable dairy production. Although the term "sustainability" in agricultural production goes beyond N and P dynamics, (encompassing other indicators such as biodiversity, carbon footprints, soil health, soil erosion, ground water recharge, etc) (Gu et al., 2011), this paper focuses on N and P as critical indicators of agri-environmental sustainability and profitability of dairy production systems on the island of Ireland. The term "environmental efficiency" has also been used interchangeably with N and P efficiency in the context of our analysis. This is because these nutrients are relevant both as an input factor affecting dairy production and as a critical component for pollution of the aquatic, marine, terrestrial and atmospheric environments (McLellan et al., 2018). For example, excess N usually results in environmental issues such as leaching of soil nitrate to groundwater and losses of nitrous oxide, a potent greenhouse gas. On the other hand, P is usually associated with growth of algae and some floating plants

* Corresponding author at: Gibson Institute for Land Food and Environment, School of Biological Sciences, Queen's University, Belfast, United Kingdom.
E-mail address: aadenuga01@qub.ac.uk (A.H. Adenuga).

https://doi.org/10.1016/j.ecolind.2018.08.040
Received 3 October 2017; Received in revised form 14 August 2018; Accepted 16 August 2018
1470-160X/

which have negative impact on water quality and consequently results in losses in productivity of fish, crabs, and other bottom dwellers (McLellan et al., 2018; Magdoff and Van Es, 2009).

N and P surpluses are sources of environmental concern in dairy production across the island of Ireland. While it is acknowledged that in most cases, the same management systems can be applied to both N and P, it is important to note that major differences do occur with respect to their behaviours in soils. For example, Nitrate, the primary form in which plants absorb N from the soil, is very mobile in soils, while P movement in soils is very limited. More importantly is that, our study covers the four regions of the island of Ireland with relative differences in dairy systems nutrient management. For example, while excess use of P is a more critical issue in Northern Ireland, N surplus is of great concern in the Republic of Ireland. (Adenuga et al., 2018; Buckley et al., 2016; Bailey, 2016).

High nutrient surpluses increases the vulnerability of soils to leaching which can lead to significant ecological impacts, constituting potential risk to ground and surface water quality (Environmental Protection Agency (EPA), 2010; Department of Environment (DOE)., 2014). For example, Bailey (2016) has shown that a P surplus above 5 Kg/ha/year increases the risk of P losses to water. Elevated nutrient concentrations contribute significantly to the widespread water quality issues on the island of Ireland, with some of the water bodies usually exceeding the 50 mg/litre limit on the levels of nitrate allowable in drinking water. Agriculture account for more than 30% of the incidence of water pollution on the island of Ireland (Cave and McKibbin, 2016; Kleinman et al., 2015; Summary of Findings of Northern Ireland, 2012; Environmental Protection Agency (EPA), 2017). In Northern Ireland, about 50% of farmed grassland have plant-available P (Olsen-P) values greater than the critical value of 25 mg/kg (Bailey, 2015; Kleinman et al., 2015, Cave and McKibbin, 2016; Smith et al, 2003). Also, more than 50% of all rivers in Northern Ireland are classified as “moderate or poor status”. and about 70% of lakes are still classed as eutrophic (with annual average P concentrations in excess of 0.02 mg/l, the level above which it is considered to be at risk from eutrophication) under the “water framework directive” (Cave and McKibbin, 2016; Kleinman et al., 2015; Summary of Findings of Northern Ireland, 2012). The situation is similar in the Republic of Ireland where about 69% of the transitional water bodies, 43% of rivers and 54% of lakes are classified as moderate or worse status (Environmental Protection Agency (EPA), 2017). The quality of surface waters in the region has remained relatively static in the last few years and the objective of the water framework directives to achieve a 13% improvement in surface water standards between 2010 and 2015 has not been achieved (Environmental Protection Agency (EPA), 2017).

Although, dairy farms make up only about 11% and 12% respectively of the total number of farms in Northern Ireland and the Republic of Ireland, it contributes about 32% of the total agricultural output in both countries (Department of Agriculture, Environment and Rural Affairs (DAERA), 2017; Central statistics office (CSO), 2018). However, compared to other agricultural enterprises, the dairy sector has the highest stocking densities and high fertilizer inputs, putting pressures on the aquatic environment (Adenuga et al, 2018; Buckley and Carney, 2013). Dairy production intensity across the island is diverse with respect to production systems and level of production. The relationship between the level of dairy production and environmental performance is a vital issue that must be given due consideration in dairy production studies. This is because, while most farms might be efficient in terms of input-output productivity, there are reasons why they might not be efficient from an environmental point of view (Tyteca, 1996).

The goal of this paper is to evaluate the differences in environmental efficiency of dairy farms across the regions of the island of Ireland, incorporating N and P surpluses as undesirable outputs into an environmental DEA technology. It is believed that the typical measures of production performance such as technical efficiency may not always distinguish farming systems best fitted to future requirements (Toma et al., 2013). It is important that the agricultural sector improve environmental performance while maintaining competitiveness and economic efficiency as much as possible. Environmental performance measurement provides the basis for quantitative, empirically grounded and systematic environmental policy analysis and decision making (Hsu et al., 2014).

Studies on efficiency measurement in dairy farms on the island of Ireland have focused on input-output productivity, with less emphasis on measuring environmental efficiency. Examples of such studies include: Kelly et al. (2012) and Newman and Matthews (2007). The few studies that have tried to measure environmental performance include: Ryan et al. (2016), who following Hennessy et al. (2013), employed farm-level sustainability indicators to measure sustainability across different farming systems in the Republic of Ireland. They showed that, the top-performing dairy farms had greater profitability as well as lower negative environmental outputs. Buckley et al. (2015a), developed environmental sustainability indicators in the use of N and P across a range of farm systems in the Republic of Ireland. They found from their study that N use efficiency was generally lowest across milk producing systems compared to livestock rearing and tillage systems. Mihailescu et al. (2015a) assessed P balance and P use efficiencies on 21 intensive grass-based dairy farms in the South of the Republic of Ireland. They obtained a mean P surplus and P use efficiencies of 5.09 kg P/ha and 70% respectively. Ruane et al. (2014) examined farm-gate P balances and soil test P (STP) concentrations on 21 dairy farms in the south west of the Republic of Ireland over four years, from 2003 to 2006 inclusive. They obtained a mean annual P balance per farm of 9.4 kg/ha and a mean P use efficiency of 71%.

For most of the reviewed studies, environmental performance indicators which reflect only segmental characteristics of environmental performance have been employed. These indicators involve the use of multiple ratios, which has the tendency of complicating decision making (Zhou et al., 2008). The studies are also limited in terms of coverage. In fact, this is the first study, to the best of our knowledge, that estimates and compares environmental efficiency of dairy production systems across the four regions of the island of Ireland. The DEA-based model employed in our study is able to provide a standardized environmental performance index for each decision-making unit (dairy farms in this case) (Tyteca, 1996; Zhou et al., 2016). In addition, unlike previous studies, our use of the bootstrap truncated maximum likelihood estimation approach in investigating the determinants of environmental efficiency enabled us to overcome the problem of inherent dependency among the DEA efficiency scores and hence yields robust results (Simar and Wilson 2007; Tauchmann, 2016). As against the farm gate approach, our use of the OECD/Eurostat soil-surface balance methodology in the estimation of N and P balances, provides a more representative indication of environmental losses and therefore embodies more meaningful assessment of aquatic risk (Eurostat, 2013). Also, none of the studies analysed the determinants of environmental efficiency incorporating N and P surpluses into an environmental DEA technology.

Reinhard et al. (2000) is one study which in addition to the stochastic frontier methodology have employed the Environmental DEA technology to analyse the environmental efficiency of dairy farms incorporating N and P surpluses and energy used as environmental variables in the Netherlands. However, the environmental variables were treated as undesirable inputs rather than outputs. This is not in line with the reality of production process (Färe and Grosskopf, 2003). The directional output distance function employed in our study treats the N and P surpluses as undesirable outputs in a way that is more consistent with public policy goals that seek to reduce pollution and increase production of desirable outputs simultaneously (Färe et al., 2006; Hailu and Veeman, 2000; Chung et al., 1997; Färe and Grosskopf, 2004; Zhou et al., 2016; Zhou et al., 2008).

The remainder of the article is structured into four sections: Section two gives a description of the data and methodology for the study. The