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Environmental efficiency of alternative dairy systems: A productive efficiency approach

L. Toma,* M. March,†[1] A. W. Stott,‡ and D. J. Roberts†
*Land Economy and Environment Group, Scotland's Rural College (SRUC), King's Buildings, West Mains Road, Edinburgh, EH9 3JG, United Kingdom
†Future Farming Systems Group, SRUC, Hestan House, The Crichton Business Park, Dumfries, DG1 4TA, United Kingdom
‡Future Farming Systems Group, SRUC, King's Buildings, West Mains Road, Edinburgh, EH9 3JG, United Kingdom

ABSTRACT

Agriculture across the globe needs to produce "more with less." Productivity should be increased in a sustainable manner so that the environment is not further degraded, management practices are both socially acceptable and economically favorable, and future generations are not disadvantaged. The objective of this paper was to compare the environmental efficiency of 2 divergent strains of Holstein-Friesian cows across 2 contrasting dairy management systems (grazing and nongrazing) over multiple years and so expose any genetic × environment (G×E) interaction. The models were an extension of the traditional efficiency analysis to account for undesirable outputs (pollutants), and estimate efficiency measures that allow for the asymmetric treatment of desirable outputs (i.e., milk production) and undesirable outputs. Two types of models were estimated, one considering production inputs (land, nitrogen fertilizers, feed, and cows) and the other not, thus allowing the assessment of the effect of inputs by comparing efficiency values and rankings between models. Each model type had 2 versions, one including 2 types of pollutants (greenhouse gas emissions, nitrogen surplus) and the other 3 (greenhouse gas emissions, nitrogen surplus, and phosphorus surplus). Significant differences were found between efficiency scores among the systems. Results indicated no G×E interaction; however, even though the select genetic merit herd consuming a diet with a higher proportion of concentrated feeds was most efficient in the majority of models, cows of the same genetic merit on higher forage diets could be just as efficient. Efficiency scores for the low forage groups were less variable from year to year, which reflected the uniformity of purchased concentrate feeds. The results also indicate that inputs play an important role in the measurement of environmental efficiency of dairy systems and that animal health variables (incidence of udder health disorders and body condition score) have a significant effect on the environmental efficiency of each dairy system. We conclude that traditional narrow measures of performance may not always distinguish dairy farming systems best fitted to future requirements.
Key words: environmental efficiency, experimental dairy farm, nonparametric data envelopment analysis

INTRODUCTION

During the second half of the 20th century, the agriculture industry harnessed technology that has resulted in crop and animal productivity increases of around 2% per annum (Duvick, 1986; Ludena et al., 2007), mainly from advances in genetics, management practices, and forage improvements (Pryce et al., 2004). However, significant challenges are yet to be addressed, as global warming effects are apparent and unsustainable food production systems are causing environmental degradation (Foresight, 2011). Against a background of population growth and food security concerns at the global level, the UK population is forecasted to increase by 14% by 2033 (ONS, 2012); if productivity gains continue at the same rate, then UK domestic demands could be met. However, UK dairy farming has been in decline for over 30 yr. During this time, the national milking herd has contracted by 43% (since 1980), yet efficiency has increased as total UK production fell by 20% over the same time period (Defra, 2011). Average UK yields per cow continue to increase while the overall number of farms continues to decrease (DairyCo, 2011). In addition to population growth and environmental concerns, further challenges for the future of food production include increased competition for land, energy, and water resources; maintaining food security; and managing changes in consumer behavior. These forces of change require the food system to be radically redesigned to achieve production in the long term (Foresight, 2011), but which dairy systems are optimal for delivering milk production that is sustainable?

In global terms, milk production systems are responsible for approximately 2.7% of all anthropogenic greenhouse gas emissions. As demand for dairy and

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[1]Corresponding author: maggie.march@sruc.ac.uk

meat products is expected to double by 2050, it is crucial for the dairy industry to aim toward more sustainable low-carbon methods of production (FAO, 2010). Dairy systems are also a source of nutrient losses to the wider environment. Livestock excrete nitrogen (N) and phosphorus (P), which have ecological impacts (Erisman et al., 2007), such as water pollution caused by nitrate leaching, eutrophication of surface waters due to N and P enrichment, and soil acidification and plant damage from ammonia emissions (Amon et al., 2011). Moreover, the Haber process used to manufacture N is energy intensive, which incurs CO_2 emissions, and P is a nonrenewable, depleting resource.

Sources of pollutants arising from dairy farms and associated mitigation strategies are well researched (Defra, 2008; DairyCo, 2009; FAO, 2010) and should be implemented dependent upon system type, location, and historical land use (IPCC, 2007). The focus on food security and climate change has led to increased attention on the measurement of both economic and environmental performance of agricultural production systems. Evidence regarding differences in the overall environmental impact created by a range of dairy farming systems could be improved as there is a need for evaluation of the differences between total resource use across different dairy systems (Alvis et al., 2012). Comparative analysis on the effect of dairy management systems that favor livestock on pasture land or not would aid the understanding of livestock sector impacts (Anderson and Gundel, 2011).

This study applied data envelopment analysis (**DEA**) to measure relative differences in the environmental efficiency of grazing and nongrazing dairy systems across 2 genetic lines of cows to investigate any genotype × environment (**G×E**) interaction and to determine the wider environmental impact of each of the livestock systems while taking milk production into consideration. Types and amounts of undesirable outputs associated with each of the systems were evaluated and compared to identify possible options for mitigation of pollutants, because future legislation may require environmental externalities to be accounted for and reduced. In addition, the analysis estimated changes in the environmental efficiency of each system over time and the effect of independent variables on the efficiency of each system.

MATERIALS AND METHODS

Langhill Feeding Experiments

Data were obtained from the Langhill herd (Crichton Research Farm, Dumfries, Scotland) of Holstein-Friesian dairy cows, which are part of a long-term experiment to assess genetic line × feeding system interactions (Pollott and Coffey, 2008). The herd represents a range of dairy management methods in terms of breeding and feeding systems, and consists of 2 contrasting genetic lines, selected either for increased milk fat plus CP yield (select line, **S**) or to remain close to the average genetic merit for milk fat plus CP yield for Holstein-Friesians evaluated annually in the United Kingdom (control line, **C**; Pryce et al., 1999).

During the experiment, cows were allocated to either a low forage (**LF**) diet consuming 3.0 t of concentrate annually or a high forage (**HF**) diet containing approximately 1.2 t of concentrate (Chagunda et al., 2009). The LF cows remained indoors (i.e., nongrazing), whereas the HF cows were grazed when possible. Both groups were managed so that calving took place all year round. The feeding systems within the herd were defined as low forage control (**LFC**), low forage select (**LFS**), high forage control (**HFC**), and high forage select (**HFS**). Approximately 50 cows in each of the 4 groups were fed a TMR plus concentrate in the milking parlor. Forages fed in both LF and HF diets included grass silage, maize silage, and whole-crop wheat silage. Diets within LF herds consisted of approximately 47% forage, and in the winter months, the HF herd was housed and fed 75% forage on a DM basis (Chagunda et al., 2009). Diets were formulated to provide adequate ME and CP to meet the requirements of a cow within each genetic line × feeding system (Pollott and Coffey, 2008).

Data

The data set used in this analysis consisted of variables from all cows within the experiment between 2004 and 2010, irrespective of their health. Variables were extracted from the database for each cow and aggregated annually at the 4 system levels. Daily milk yields were the sum of 3 milkings daily, and 3-times-daily fat and CP concentrations of the milk were analyzed once per week and averaged. Cows were fed ad libitum, and feed intakes for those cows indoors were recorded for lactating cows using Hoko automatic feed measurement gates (Insentec BV, Marknesse, the Netherlands). Data regarding milk yield, fertilizer application, energy use, and diet were extracted directly from the database, and data for herd dynamics were taken from an annual inventory of the systems. The protocol of the experiment required that cows were kept in the herd for at least 3 lactations unless cow welfare dictated that culling was necessary. Cows could remain in the herd for more than 3 lactations if a suitable heifer of the same genetic line was not available. Culling time was defined as the date on which a cow's productive life ceased, and cows had a maximum of 7 chances to conceive before being culled.