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# Opportunities to improve sustainability on commercial pasture-based dairy farms by assessing environmental impact

Craig Galloway[a,*], Beatrice Conradie[e], Heidi Prozesky[c,d], Karen Esler[a,b]

[a] Department of Conservation Ecology and Entomology, Stellenbosch University, Private Bag X1, Matieland 7602, South Africa
[b] Centre for Invasion Biology, Stellenbosch University, Private Bag X1, Matieland 7602, South Africa
[c] Centre for Research on Evaluation, Science and Technology, Stellenbosch University, Private Bag X1, Matieland 7602, South Africa
[d] DST-NRF Centre of Excellence in Scientometrics and STI Policy, Stellenbosch University, Private Bag X1, Matieland 7602, South Africa.
[e] School of Economics and Centre for Social Science Research, University of Cape Town, Private Bag X1, Rhodes Gift 7703, South Africa.

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ABSTRACT

For pasture-based dairy farming to become more sustainable, the negative environmental impacts associated with milk production must be minimized. These negative impacts include eutrophication, ammonia emissions and greenhouse gas (GHG) emissions. Two tools, a nutrient budget and a carbon footprint calculator, allow farm-level assessments of these negative impacts. In this study, a nutrient budget was used to calculate the efficiency of nitrogen and phosphorous use, and a carbon footprint calculator was used to calculate GHG emissions. Farm system descriptors were used to identify the farm systems that had the lowest environmental impact. Soil carbon was measured as an indicator of soil health, and the link between soil health, nutrient use efficiency and GHG emissions was examined. Nitrogen and phosphorous were not efficiently utilized on the farms included in this study, with a large excess of nutrients imported onto the farms each year. The average use efficiency was 29% for nitrogen, and 36% for phosphorous. The GHG emissions per liter of milk production were higher on the farms included in this study than found in previous studies on dairy farms, with an average of 1.39 kg of carbon dioxide equivalents emitted per kilogram of energy-corrected milk. Farm systems which optimized milk production on the available land, while applying the least amount of fertilizer and feeding the least amount of purchased feeds per milk produced, had the lowest environmental impact. Farms with higher soil carbon levels had higher nitrogen use efficiencies and lower GHG emissions. This is the first South African research to examine environmental impact on pasture-based dairy farms in this manner. It is possible for pasture-based dairy farmers to reduce the environmental impact of milk production by adopting some of the principles identified in this study.

## 1. Introduction

It has become apparent over the past 30 years that the agricultural sector faces a challenge to increase production without an associated increase in negative environmental impacts (Tilman et al., 2002). Farming has many potentially negative environmental impacts, including loss of biodiversity, eutrophication, ammonia emissions, greenhouse gas (GHG) emissions and inefficient resource use (Food and Agriculture Organization of the United Nations (FAO), 2010). By understanding and assessing the negative environmental impacts of dairy farming practices, ways to mitigate these impacts can be identified, while maintaining/increasing production (Thomassen and De Boer, 2005; Capper et al., 2009; Food and Agriculture Organization of the United Nations (FAO), 2010). Viewed from the perspective of the triple bottom line of economic, social and ecological sustainability (Rigby et al., 2001; Van Calker et al., 2005), reducing these impacts through appropriate farm management is directly related to the ecological aspect, but also significantly impacts the economic aspect (Galloway et al., 2018), while being a farmer's social responsibility.

There are two, broad types of dairy farm. The one type is a total mixed rations (TMR), full feed or confinement dairy farm where dairy cows are kept in a confined space and their entire required feed is provided as a mixed ration (O'Brien et al., 2014). The other is a pasture-based dairy farm where the majority of a cow's nutritional requirement is met through grazing pastures, which are grown on the farm and supplemented by purchased grain-based concentrates and dried or conserved forage (roughage). The two farm types employ very different practices and mechanisms to reduce environmental impact and improve efficiency, but comparisons between them are few (Scholtz et al., 2013; O'Brien et al., 2014). The two types are also not always operated

* Corresponding author.
*E-mail address:* craig@traceandsave.com (C. Galloway).

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exclusively of each other. For example, some farmers implement TMR through winter, while implementing pasture-based through the rest of the year. The focus of this study is on pasture-based dairy farms.

Two tools, a nutrient budget and a carbon footprint calculator, are useful in assessing aspects of agriculture's environmental impacts (Cichota & Snow, 2009; Food and Agriculture Organization of the United Nations (FAO), 2010; Rotz et al., 2010; Gourley et al., 2012). Numerous other agri-environmental indicators exist (Halberg et al., 2005; Langeveld et al., 2007), but these two indicators are relevant to this study as they meet four important criteria: 1) they are established, widely applied measures of environmental impact, 2) they are sensitive to changes in farm management, 3) they assess the whole-farm system, and 4) they are easily understood by farmers. Although many studies have used nutrient budgets or carbon footprints, currently only Thomassen and De Boer, 2005and Pérez Urdiales et al. (2016) have incorporated both into an assessment of the environmental impact of dairy farming (in the Netherlands and Spain respectively). The limitation of using a nutrient budget and a carbon footprint calculator is that they do not assess the full extent of environmental impacts associated with dairy farming (Thomassen and De Boer, 2005).

Nutrient management is an important aspect of sustainable dairy farming. Inefficient nutrient use results in an excess of nitrogen (N) and phosphorous (P) being imported onto a farm, which could harm the environment and reduce profits (Spears et al., 2003; Monaghan et al., 2007; Gourley et al., 2012; Galloway et al. 2018). Excess N causes nitrate contamination in groundwater, and excess P leads to high soil P levels and eutrophication of surface water (Dou et al., 2001; Gourley et al., 2012). Nitrogen from fertilizer and manure is lost to the atmosphere in the form of nitrous oxide gas, contributing to climate change (Spears et al., 2003). Improving nutrient use efficiency (NUE) is therefore imperative in limiting the environmental impact of agriculture (Zhang et al., 2015).

To inform improved nutrient management on farms, measures of NUE and nutrient loss are needed (Spears et al., 2003; Clark et al., 2007). Direct measurement of nutrient loss is, however, challenging and expensive (Cichota & Snow, 2009), as it requires measuring the quantity of the different nutrients in their different forms (e.g. nitrates, ammonium, nitrous oxide, phosphates) from varying sources. An alternative is to quantify nutrient surpluses using a nutrient-budget approach (Oenema et al., 1998; Dou et al., 2001; Ondersteijn et al., 2002; Spears et al., 2003; Cichota & Snow, 2009; Gourley et al., 2012). Nutrient budgets have not been studied in South Africa, and therefore the nutrient use efficiencies of South African dairy farms are unknown.

Another significant environmental impact associated with dairy farming is GHG emissions (Food and Agriculture Organization of the United Nations (FAO), 2010; de De Léis et al., 2015). Greenhouse gas emissions are associated with global climate change, which is one of the most significant environmental challenges of this century (Rotz et al., 2010) and a key challenge facing the South African agricultural sector (Middelberg, 2013). The extent and sources of farm GHG emissions resulting from agricultural practices can be measured using a carbon footprint calculator (Food and Agriculture Organization of the United Nations (FAO), 2010; Rotz et al., 2010). This method has been used extensively in the assessment of the environmental impact of dairy farms (e.g. Food and Agriculture Organization of the United Nations (FAO), 2010; Rotz et al., 2010; Flysjö et al., 2011; De Léis et al., 2015). Currently, there is no evidence of any research on carbon footprints at an individual farm level on dairy farms in South Africa.

When addressing environmental impacts on farms, soil management is important to consider (Paustian et al., 2016). Healthy soil is a critical management goal of sustainable agriculture (Parr et al., 1992; Doran et al., 1996; Doran, 2002; Eisenhauer et al., 2017; Food and Agriculture Organization of the United Nations (FAO), 2017). A prime indicator of soil health is soil carbon (C). Higher levels of soil C improve the biological, chemical and physical properties and functions of the soil (Fageria, 2012; Food and Agriculture Organization of the United Nations (FAO), 2017).

The trade-off that exists between agricultural production and environmental impact is important to consider when addressing agricultural sustainability, as economic and environmental goals often conflict (Tilman et al., 2002). Farm system descriptors such as stocking rate, milk production per cow and nitrogen fertilizer applied per hectare are widely used by dairy farmers and are indicative of the farm system that each farm employs (P Terblanche 2016, personal communication, 1 June). The farm system in this study's context relates to the stocking rate, feeding practices, fertilizer practices, and how these interrelate. Showing the relationship between NUE, GHG emissions and farm system descriptors can assist in rendering environmental impact measures more relatable to farmers and their farm management practices (Halberg et al., 2005).

Here, measures that assess environmental impact, such as nutrient budgets and carbon footprints, were therefore used to study the environmental impact of commercial pasture-based dairy farms in South Africa's Eastern Cape. The measurement of soil C, an indicator of soil health, was included to examine the links between NUE, GHG emissions and soil health. It was further asked which farm system had the least environmental impact. This research therefore provides valuable insights to farmers, researchers and consultants aiming to decrease the environmental impact of pasture-based dairy farms. The inclusion of both a nutrient budget and a carbon footprint, along with farm system descriptors, and soil carbon measures overcomes the benchmarking challenges associated with only assessing nutrient budgets without accounting for different characteristics between farms (Mu et al. 2017).

## 2. Methods

### 2.1. Data collection

The dairy farms included in this study are in the western part of the Eastern Cape, South Africa. The Eastern Cape is the largest milk-producing province in South Africa, contributing more than a quarter of the country's total milk production. The data for this study, secondary data obtained from Trace & Save, were collected on farms that both sell milk to Woodlands Dairy and participate in the Woodlands Dairy Sustainability Project (WDSP). Trace & Save is an independent consulting company that implements the WDSP. Trace & Save aims to encourage and facilitate the implementation of sustainable agricultural practices, and to measure, using proxies for various dimensions of sustainability, the participating farms' changes over time. Farmers can participate voluntarily in the WDSP, as it is provided as an optional service to all farmers who sell milk to Woodlands Dairy. This obviously results in a non-random sample of farms included in this study, especially selecting for farmers which have shown an interest in sustainability.

Secondary data, such as the Trace & Save dataset, are those obtained from a dataset not designed and intended for this specific study. This has the advantage of saving cost and time, is most often high-quality data and provides more comprehensive data from a longer period than what might be possible for an individual researcher to collect (Bryman, 2012). At the time of this study, the Trace & Save dataset was comprised of yearly production data for farms collected over a period between one-and-five-years, depending on how long the farm had been participating in the WDSP. Data relevant to this study are listed in Table 1. To manage the variability in data availability across time, while simultaneously using as much of the collected data as possible, each farm's annual data were treated as a single observation. Although this could potentially result in biases due to certain farm systems being over-represented in the population, there was enough interannual variation on the farms with more than one year of data included, and the climatic conditions differed enough among years, to make this dataset appropriate for the aims of the study. As discussed, there are many advantages to using secondary data, but a disadvantage is that certain