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Tradeoffs between production and perennial vegetation in dairy farming systems vary among counties in the northeastern U.S.

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ABSTRACT

Dairy farms that grow more perennial vegetation as grazing pastures or conserved forages can offer many environmental benefits but may show reduced milk production relative to farms feeding higher amounts of grain and corn silage. Because yields of annual and perennial crops vary with soil type, an accurate comparison of the productive potential of these systems over county or regional scales may require taking into account spatial variation in soil quality. In this study, we present a novel approach to calculate the production from dairy systems that adjusts average crop yields to the productive potential of local soils using the National Commodity Crop Productivity Index (NCCPI). We used on-farm survey data to define confinement and grazing systems with varying amounts of perennial forage and applied our method to a sample of five counties in the northeast United States. High corn silage farm systems produced 21 to 168% more milk per hectare of farmland than grazing-based farm systems, but variation among counties was greater than variation among systems, with the best (Lancaster, PA) producing as much as 5.3 times more than the least (Orange, VT). Adjusting yields for soil productivity had smaller effects on milk production than differences in farm system or county. On average, grazing farm systems generally produced slightly more milk when yields were adjusted using the NCCPI (8%) while high corn silage systems showed a moderate decrease (13%). Compared to scenarios of all local crop production, scenarios with unlimited corn and soybean imports often more than doubled county-scale milk production. Restricting grain imports to prevent excess phosphorus resulted in a 3–15% decrease in milk production relative to unlimited imports, but still produced far more milk than in the all local production scenarios. Sensitivity analysis of the model showed that milk production in each county was very responsive to changes in perennial forage yields (especially for grazing systems), responsive to changes in average daily milk production per cow, and generally not responsive to changes in the productive lifetime of lactating cows. This study demonstrates a persistent tradeoff between perenniality and production in dairy systems, but suggests that opportunities may exist to maintain current milk production levels in the Northeast while also expanding land cover in perennial vegetation.

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1. Introduction

To better navigate current and future challenges in sustainable agriculture, land managers, governments, and citizens will need an accurate and nuanced understanding of the productive potential of different farming systems in working landscapes. Global demand for agricultural products is likely to increase substantially over the next several decades (Davies et al., 2009; FAO, 2009; Foley et al., 2011; Godfray et al., 2010). At the same time, there has been a growing interest in developing regional food systems that can more closely link farms and farmers with markets and consumers in nearby urban areas (Griffin et al., 2014; Kloppenberg et al., 1996; Peters et al., 2008). Growing awareness of the environmental costs of modern intensive farming systems has stimulated substantial innovation in practices that can improve environmental outcomes (Boody et al., 2005; Gliessman, 2011; Kremen et al., 2012), but many of these techniques may potentially result in decreased food production per unit area (Badgely et al., 2007; Capper et al., 2008; Seufert et al., 2012). Because farmland will remain a finite resource, a clearer picture of how much food different farming systems deliver can provide a basis for weighing potential tradeoffs between production and environmental quality.

Dairy farms contribute to food security and the healthy functioning of agroecosystems. Milk, other dairy products, and beef from dairy cows are valuable sources of protein, vitamins, and minerals and can be a key component of a balanced human diet (Capper and Bauman, 2013; Heitschmidt et al., 1996; Oltjen and Beckett, 1996). Furthermore, as ruminants that can digest plant fibers and cellulose, dairy cows offer farmers a pathway to make use of perennial vegetation not directly consumable by humans (Oltjen and Beckett, 1996). Most of the human food supply is based on annual grain or legume crops that require intensive soil disturbance, fertilizers, and other inputs every year to sustain output. As a result, annual crops involve heavy costs in terms of soil erosion and degradation, energy use, greenhouse gas emissions,

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agrochemical pollution, and biodiversity loss. In contrast, perennial forages, either as permanent pasture or as harvested hay or silage crops, can provide numerous benefits for soil conservation, water quality, carbon sequestration, and nutrient retention (Boody et al., 2005; Burkart et al., 2006; Ghebremichael et al., 2008; Jha et al., 2010; Rotz et al., 2009; Schulte et al., 2006) while also providing habitat for plants, birds, and other wildlife (Egan and Mortensen, 2012; Hill et al., 2014; Morandin et al., 2007; Sayre et al., 2012). In light of these benefits, the land cover in perennial forages can be viewed as an important indicator of the overall environmental quality achieved by a dairy farming system.

While historically dairy cows have provided humans access to the nutrition embedded in perennial forages, modern dairy systems have been able to substantially increase milk production per cow by feeding an energy and protein rich diet including increasing amounts of annual grains and legumes (Capper and Bauman, 2013; Capper et al., 2009). Because stored grain crops are low in moisture and high in density, they can also be readily shipped long distances. This spatial separation of crop and animal production has enabled dairy farmers feeding higher grain diets to exceed their local land base's capacity to support dairy cows (Bacon et al., 1990; Naylor et al., 2005). Modern dairy farming has also increased production by raising the proportion of a cow's diet that is allocated to growth or milk versus physiological maintenance (Capper and Bauman, 2013). Greater dietary allocation to production has been achieved both through improved genetics and by feeding cows precisely formulated diets in a confinement facility, such that animals have limited ability to move about or actively graze. While dairy manure can provide soil fertility for crop production, when animal populations exceed the capacity of the local land base, excess manure can pollute water with nitrogen and phosphorus (Dawson and Hilton, 2011; Lanyon, 1992; Nord and Lanyon, 1999). Moreover, as use of annual crops in dairy rations has increased, the soil erosion, fertilizer and pesticide inputs, and fossil fuel energy use connected to dairy production have also increased (Belflower et al., 2012; Benbrook et al., 2010; Hafla et al., 2013; O'Brien et al., 2012; Olesen et al., 2006; Rotz et al., 2009; Rotz et al., 2010; but see Capper and Bauman, 2013).

In light of some of these challenges with highly productive confinement systems, there has been a recent renewal of interest in management-intensive grazing systems (Benbrook, 2009; NRCS, 2007; Soder and Muller, 2007). In these farm systems, cows actively graze pastures during the growing season and are fed a mixture of harvested forages and some grain concentrates during a winter season (NRCS, 2007). Management-intensive grazing systems may provide many of the environmental benefits associated with perennial vegetation. Management-intensive grazing systems may also improve animal health and well-being (Benbrook, 2009) and profit margins (Dartt et al., 1999; Hanson et al., 2013). On the other hand, grazing systems typically have substantially lower milk production per cow due to the lower energy density of their diets, increased exercise during grazing activities, and a lower level of genetic improvement in breeds well-adapted to grazing lifestyles. Grazing dairies may also show lower per hectare milk production due to the reduced dry matter, energy, and protein yields of perennial crops relative to annual grains or annual forages such as corn silage. Thus, there appears to be a pronounced tradeoff in dairy farming between milk production and the environmental benefits from perennial land cover (Oltjen and Beckett, 1996; Russelle et al., 2007; Schiere et al., 2002).

To date, comparisons of alternative farming systems, including comparisons of confinement versus grazing dairies, have primarily been conducted at a field or farm scale (O'Brien et al., 2012; Rotz et al., 2009, 2010; Stiglbauer et al., 2013). Yet conclusions from field or farm scale studies may not always be translatable to landscape or regional scale realities. For instance, because annual crops are best-suited to relatively flat, well-drained, and productive soils, the output achieved by some confinement systems on high-quality soils may not be achievable over a larger land area where soil quality is more variable. In contrast, many perennial forages can be grown on poorer quality land, suggesting that dairy systems that incorporate more forage can achieve consistent, but lower, output over a broader land area. Consequently, to more fully understand the relative productive potential of dairy systems at landscape or regional scales, it may be important to incorporate information about the spatial distribution and variability of soil resources.

In this study, we present a novel method for comparing tradeoffs between production and perenniality in dairy systems at landscape scales, focusing our analysis on a set of five dairy producing counties in the northeastern United States (Fig. 1). We set our analysis in the Northeast because it has variable soil resources and dairy farming is the most economically-significant agricultural enterprise. Many rural counties in the region are also encountering significant agricultural nutrient pollution challenges, making questions about tradeoffs between perennial cover and production especially relevant. Our analysis addressed the following objectives: 1.) compare the milk production of dairy farm systems using varying amounts of perennial forage; 2.) assess how spatial variation in crop yields and soil resources effect estimates of milk production at a county scale; 3.) assess how grain imports effect milk production and phosphorus balances at a county scale; and 4.) evaluate options for increasing milk production per unit area by improving perennial forage yields, daily milk production, or productive lifetime of lactating cows.

2. Methods

2.1. Dairy farming systems and animal rations

We used several data sources to estimate the total dry matter intake (DMI) of various forage and grain crops for a range of confinement and grazing dairy farm systems in the Northeast.

First, we acquired a sample of dairy rations representative of intensive, confinement Holstein dairy operations by consulting with the principal herd managers for the research and teaching dairy farms at land grant universities in the region. We received data from managers at Cornell University, Pennsylvania State University, University of

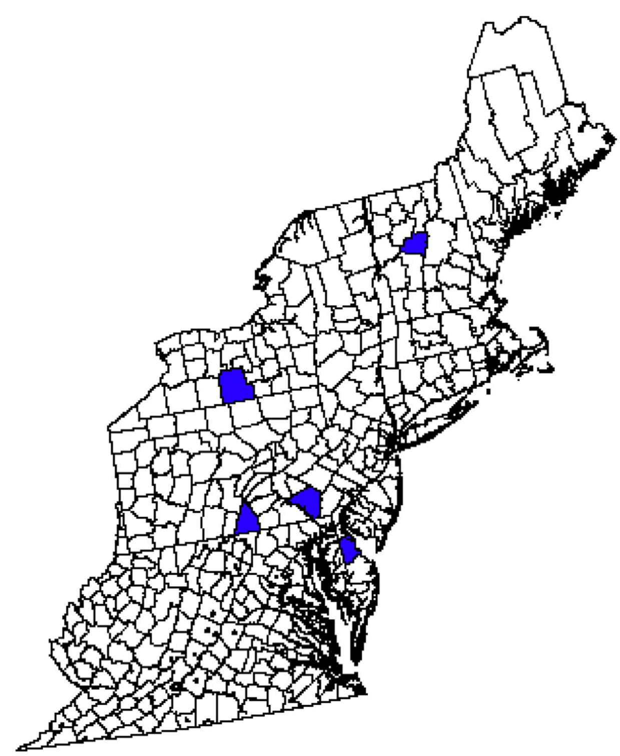

Fig. 1. Sample of five top dairy producing counties in the northeastern United States. The selected counties filled in blue are from South to North: Kent, DE; Franklin, PA; Lancaster, PA; Steuben, NY; and Orange, VT. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)