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Energy and greenhouse gas analysis of northeast U.S. dairy cropping systems

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ABSTRACT

Dairy farms in the northeast typically produce their own forage, import grain crops, and rely heavily on other inputs. Feed production inputs include fertilizers, herbicides, pesticides, and fuel that require fossil energy and produce greenhouse gas (GHG) emissions during their manufacture and transport. This study uses the Farm Energy Analysis Tool (FEAT) to compare and contrast the fossil energy consumption, energy efficiency, and GHG emissions for three different Pennsylvania dairy cropping systems that vary in their reliance on imported grains and fuel, and thus, land area to produce the same quantity of milk. One novel cropping system, implemented at Penn State University, includes a diverse rotation designed to produce forage, grain, and fuel on-farm (NSVO). The 'NSVO' cropping system employs a number of best management practices, including manure injection, cover crops, and integrated pest management. The two modeled-systems require fewer hectares than 'NSVO' because they do not produce fuel on-farm but produce forage only (FOR), or forage and grain (FORGr), while producing the same amount of milk. Relative to the 'FOR' system, even while requiring larger land areas locally, we found that the 'NSVO' and 'FORGr' systems lowered total fossil energy inputs per Mg of milk produced by 18% and 15% respectively, largely by importing 77% and 71% less feed crops that would have been grown elsewhere. GHG emissions were similar among farms, on the order of 229 kg CO_2e Mg-milk^{-1}. On-farm fuel production in the 'NSVO' system lowered fossil energy inputs but required more land area and may not provide economic savings with current diesel fuel prices. To reduce the fossil energy impact of their operations, dairy farmers in the Northeast should consider growing more livestock grain on-farm.

1. Introduction

Dairy farms are important to the Northeast's economy, with Pennsylvania ranked 5th and New York ranked 4th for milk production in the U.S. (USDA ERS, 2013). Dairy farms rely heavily on fossil energy inputs like fuel, fertilizers, herbicides, and pesticides, which contribute directly to greenhouse gas (GHG) levels in the atmosphere (Robertson et al., 2000; Cruse et al., 2010; Woodhouse, 2010; Gelfand et al., 2010; Davis et al., 2012). For several decades the number of dairy farms in this region has been decreasing, bifurcating into both larger consolidated operations as well as smaller owner-operated farms (Winsten et al., 2010). At the same time there has been an increase in specialized crop farms without animals, while livestock farms are housing more animals on smaller areas of land. Decoupling of nutrient flows between crops and livestock, as well as reducing the diversity of cropping systems, are both exacerbating regional nutrient imbalances (Lanyon, 1992; Hilmire, 2011). As a result, expensively priced grain (Ghebremichael et al., 2009) is produced with synthetic and mineral fertilizers and imported to the dairy farms (Bacon et al., 1990; Ribaudo et al., 2011). When imported to concentrated animal farms, more manure is produced than can be used efficiently on farms, resulting in significant losses of nitrogen to terrestrial and aquatic ecosystems (MacDonald and McBride, 2009).

Integrated crop/livestock systems, where animal numbers are in balance with the quantity of feed crops grown on-farm, could help farmers contain the cost and dependence on imported feed and the associated fossil energy use and GHG emissions, minimize environmental degradation, and increase biodiversity through growing a mixture of grain and forage crops (Granstedt, 1995; Bos et al., 2007; Thelen et al., 2010; Hilmire, 2011). Potentially, further reductions in fossil energy-intensive inputs of diesel fuel, fertilizer, and pesticides could also be achieved through conservation farming practices (Smith et al., 2007), while also lowering GHG

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emissions (Smith et al., 2008). For instance, fossil energy inputs were reduced 32% with no-tillage farming in Northern Italy due to a 61% reduction in fuel consumption per hectare relative to a conventionally managed system (Borin et al., 1997). Carbon dioxide (CO_2) emissions were reduced by 68% using reduced tillage compared to conventional tillage for growing corn in the U.S. in the 90s (West and Marland, 2002).

Although the contribution of imported dairy feeds to energy use and GHG emissions varies with farm management and the type and quantity of imported feed, others have found that reducing imported feeds lowered fossil energy inputs and GHG emissions. In one study of three no-tillage Pennsylvania dairy farms growing corn grain, corn silage, and/or other crops, the imported grain feed fraction of the total farm energy was 6%, 20%, and 23% for corn-soy, 2yr corn-3yr alfalfa, and continuous corn crop rotations respectively (Vinten-Johansen et al., 1990). In Denmark, Refsgaard et al. (1998) determined that importing feed concentrates on organic and conventional dairy farms contributed 21% and 42% respectively of the total energy use. Partly due to organic farms relying less on concentrates than conventional farms, in the Netherlands, Bos et al. (2007) found that organic dairies used only 80% of total energy and emitted 90% of the GHG emissions of conventional dairy farms normalized on a milk production basis.

Another way to reduce fossil fuel inputs for field operations is to replace diesel fuel with renewable sources of energy, such as straight vegetable oil (SVO) fuel (Fore et al., 2011). SVO can be produced on-farm with minimal processing using a mechanical oilseed press and filter and used in a standard tractor with modifications to run on SVO (Baquero et al., 2011). The oilseed crop used to produce SVO fuel on an integrated crop-livestock farm can utilize manure nutrients to partly offset mineral fertilizers, while the oilseed meal can be used in livestock rations as an alternative to an imported protein source (Newkirk, 2009). Considering both the tractor conversion and meal co-product value, SVO has been found to be more economically viable than biodiesel for small to mid-sized farms, but without subsidies was comparable or somewhat more expensive than petroleum diesel (Fore et al., 2011; Baquero et al., 2011).

Previous studies have also shown that reducing pesticide use via best management practices can improve energy efficiency and reduce GHG emissions while remaining as or more productive than conventionally managed systems (Cruse et al., 2010; Alluvione et al., 2011; Crosson et al., 2011; Davis et al., 2012). In Iowa, using integrated pest management in low input, diverse farming systems resulted in significantly lower pesticide use and toxicity potential per system (Davis et al., 2012) and between 23% and 56% lower fossil energy input in those systems compared with a 2-year, conventionally managed, corn-soy rotation (Cruse et al., 2010).

Further, better management of nutrients on integrated crop-livestock farms can also reduce fossil energy inputs. Manure can be used to replace fertilizer nutrients, although with no-till practices there are often significant losses of nutrients using conventional manure surface application. Using manure injection can potentially conserve more nitrogen and phosphorus in the soil for crop uptake and release less ammonia to the atmosphere, but with potential for smaller amounts of nitrogen loss via denitrification (Lesschen et al., 2011; Rotz et al., 2011). In addition to efficiently using manure nutrients, integrating legume and perennial crops into rotations of annual crops can increase a range of ecosystem services and contribute to the reported 37–50% decrease in total fossil energy inputs by replacing fertilizer that would have otherwise been needed (Hoeppner et al., 2005; Glover et al., 2010; Camargo et al., 2013).

Predicting how GHG emissions are impacted by tightening nutrient cycling on-farm is complicated by complex nitrogen interactions. As synthetic nitrogen inputs are reduced, GHG emissions associated with those inputs tend to be reduced. However, N_2O emissions coming from manure, fertilizers and crop residues can be significant (Robertson et al., 2000; Adler et al., 2007) and are difficult to quantify, with high levels of uncertainty around the emission factors for managed soils (Klein et al., 2006; Webb et al., 2010). In general, N_2O emissions are variable depending on whether mineral fertilizer or animal manure is applied, and which fertilizer/manure application technique is used (Lesschen et al., 2011; Rotz et al., 2011). Additional biomass in diverse systems, such as winter cash and cover crops, affects N_2O emissions in different ways depending on the C:N ratio of crop residues and how much residue is left in the field (Huang et al., 2004; Klein et al., 2006).

In this paper, we used the Farm Energy Analysis Tool (FEAT) to test the hypothesis that dairy farms that grow forage crops, while importing grain and fuel would require more fossil energy, be less energy efficient, and produce more GHG emissions from crop production inputs than farms requiring larger land areas that either do not import grain or farms that do not import grain or fuel. We made the comparisons in no-tillage cropping systems for three integrated crop/dairy operations, varying in their reliance on imported grain and fuel, which each support a 65-milking cow herd (the Pennsylvania state average, Center for Dairy Excellence, 2011) and produce the same amount of milk. Pennsylvania State University's NESARE dairy cropping system is used to represent a novel approach to producing forage, grain, and fuel on a dairy farm; and this study is the first to compare that system with alternatives that could support the same size dairy herd.

2. Methods

2.1. NESARE Dairy Cropping Systems' study site characteristics

The NESARE Dairy Cropping Systems (NSVO) were designed to provide all forage and most grains for a 65 milking cow herd, while also producing fuel on-farm. The trial was initiated in the spring of 2010 at Penn State's Russell E. Larson Agronomy Research Center at 1/20th the required farm area (i.e., 97 ha). Crops are grown on Murrill or Hagerstown soil series and the site average daily temperature and precipitation are 10.3 °C and 2.89 mm respectively (1992–2012; The Pennsylvania State Climatologist, 2014). The diverse 'NSVO' cropping system comprises two 6-year rotations that include a mixture of grain and forage crops, canola grain for straight vegetable oil (SVO) fuel with the co-product canola seed meal for feed, and cover, green manure, annual legume, and perennial legume-grass crops (Table 1). Green manure and legume crops are grown before high nitrogen demanding crops, such as corn silage (*Zea mays* L.) and canola (*Brassica napus* L.) to reduce, although not eliminate synthetic nitrogen fertilizer applications. Winter wheat (*Triticum aestivum* L.) is grown for grain to be sold, straw to be used for bedding, and red clover (*Trifolium pratense* L.) underseeded in the wheat in spring as a green manure crop. Other conservation practices include no-tillage, manure injection to conserve nitrogen, and a suite of weed management strategies to reduce herbicide use. These weed management strategies include banding herbicide over row crops followed by two high residue cultivation events (Bates et al., 2012), creating a weed suppressive mat of rye before soybean (*Glycine max* L.) with a roller crimper (Mirsky et al., 2009), and planting annual companion crops with alfalfa (*Medicago sativa* L.) and orchardgrass (*Dactylis glomerata* L.) at establishment in lieu of a broadleaf