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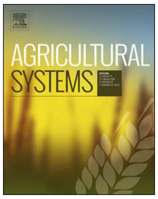

Energy use and greenhouse gas emissions in organic and conventional grain crop production: Accounting for nutrient inflows

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ABSTRACT

Agriculture is a large source of greenhouse gas (GHG) emissions and has large energy requirements. Previous research has shown that organic farming and conservation tillage practices can reduce environmental impacts from agriculture. We used the Farm Energy Analysis Tool (FEAT) to quantify the energy use and GHG emissions on area (ha) and crop yield (kg crop) bases for five cropping systems that comprise the Farming Systems Project (FSP) at the USDA-Agricultural Research Service (ARS), Beltsville Agricultural Research Center in Maryland, US. The FSP consists of five grain cropping systems that mimic those used in the mid-Atlantic region of the US: 1) a 3-year conventional no-till corn (*Zea mays* L.)–soybean (*Glycine* max (L.) Merr)–wheat (*Triticum aestivum* L.)/ soybean rotation (NT), 2) a 3-year conventional chisel-till corn–soybean–wheat/soybean rotation (CT), 3) a 2-year organic corn–soybean rotation (Org2), 4) a 3-year organic corn–soybean–wheat rotation (Org3), and 5) a 6-year organic corn–soybean–wheat–alfalfa (*Medicago sativa* L.) rotation (Org6). We accounted for nutrient inflows into organic systems by using a mass-energy allocation method, which accounts for the total energy and GHG emissions from the original production of nutrients found in poultry litter through synthetic fertilizer production (N) and nutrient mining (P and K). We believe this is the first attempt to quantify energy use and GHG emissions from nutrients applied in organic systems that originated through industrial processes used in conventional agriculture. Energy use was greatest in the conventional systems when expressed on a per area basis, with energy costs of producing synthetic N fertilizer accounting for 45 to 46% of total energy use. When expressed per unit of crop yield, energy use was greatest in Org2, lowest in Org6, and similar in Org3, NT and CT. Energy use decreased with increasing crop rotation length and complexity among organic systems whether expressed on an area or yield basis. Greenhouse gas emissions were higher in the Org2 and Org3 systems than in the conventional systems and were lowest in Org6 whether expressed on an area or yield basis. Our results indicate that organic management consistently had lower energy use than conventional management on an area basis, but not when expressed on a crop yield basis. Of particular interest is that diversifying grain cropping systems to include perennials was a more effective management strategy than organic management per se to reduce energy use and GHG emissions in agriculture.

1. Introduction

Increasing energy efficiency and reducing greenhouse gas (GHG) emissions to mitigate climate change are two important goals for agriculture (USDA, 2015). In 2015, US agriculture was responsible for 6587 teragrams of CO_2 equivalents (CO_2e.), or 9% of total US GHG emissions, mostly as methane (CH_4) and nitrous oxide (N_2O) (USDA ERS, 2016). Since the EPA accounting method does not allocate CO_2e for the production and transport of agricultural inputs to agriculture but to industrial and transportation sectors, respectively, the impact of agriculture is higher when these products are allocated to the sector in which they are applied. On-farm energy use in the US totaled 0.84 exajoule in 2008, about 0.8% of total energy use in the US (USDA, 2011). Direct energy use (i.e. fuel to operate machinery for field operations) accounted for 63% of farm energy use, with the remaining 37% resulting from production of inputs such as fertilizers and

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herbicides (Beckman et al., 2013). Fertilizer production, particularly nitrogen (N), is energy intensive and is also an important source of GHG emissions (Wood et al., 2004). Several studies estimate that N fertilizer production alone accounts for 1.2% of total worldwide energy use and GHG emissions (Kongshaug, 1998; Swaminathan, 2004) and, along with P and K fertilizers, up to 29% of total energy use in the US agriculture sector (Schnepf, 2004). Management practices and cropping systems that reduce or eliminate synthetic fertilizer inputs could potentially reduce GHG emissions and energy use in agriculture, but holistic assessments of diverse cropping systems are needed to understand tradeoffs between management practices and environmental impacts.

Since organic farming systems prohibit the use of synthetic fertilizers they are often identified as means of decreasing energy use and GHG emissions in agriculture. For example, Smith et al. (2015) analyzed data from nearly fifty studies and found that organic farming systems consistently use less energy than conventional systems when expressed on a unit of area basis. Results vary when expressed on a unit of crop basis due to lower yields for most organic crops. Gomiero et al. (2008) conducted a meta-analysis of comparisons between organic and conventional farming systems and found that organic systems required 10–70% less energy on a unit of land basis and 15–45% less on a unit of product basis. Greenhouse gas emissions from organic systems were also lower, by 32 to 71%, compared to those from conventional systems on a unit of land basis. Production of several organic grain crops, including winter wheat (*Triticum aestivum* L.) in Europe (Küstermann et al., 2008) and certain fruit and vegetable crops (e.g., apples (*Malus pumila* Mill.) and potatoes (*Solanum tuberosum* L.)) (Pimentel et al., 1983), were found to require more energy or emit higher levels of GHGs than conventional counterparts when compared on a unit of product basis, largely due to relatively lower yields in these organic systems.

Energy use and GHG emission contributions from organic farming systems are also dependent in part on the use of manure from conventionally raised animals in place of synthetic fertilizer. One important consideration when evaluating the environmental impact of animal manure is how to allocate the environmental burdens from a product (e.g. broiler meat) and its co-products (e.g. poultry litter). The allocation method used to assess the environmental impact of product and co-product can influence results. For example, Casey and Holden (2005) reported that in milk production, allocation based on product and co-product weight led to the attribution of higher GHG emissions than the economic allocation method, which allocates environmental impacts based on the economic value of a product and its co-products.

A review of livestock production assessments found that economic allocation was the most commonly used method for handling animal co-products such as manure (de Vries and de Boer, 2010). Despite its popularity in the literature, economic allocation has been the subject of recent criticism. First, allocation decisions are driven by market forces, which often externalize environmental impacts of production systems, and therefore do not accurately capture the full environmental impacts of a production system. Additionally, the division of impacts can change based on price changes in the market (Pelletier and Tyedmers, 2011). For example, if demand for poultry litter were to rise due to increased costs of synthetic fertilizers or more farmland shifting to organic production in a region, then an increasingly higher share of the environmental impact would be attributed to poultry litter, even if there was no change in poultry litter production and the amount applied to soils. Pelletier (2008) reported that litter management accounts for 9.7% of the energy used to produce chickens but only 1.2% of the GHG emissions. Economic allocation would attribute one constant value for both the energy needs and GHG emissions to litter management despite differences in impact intensities. Capturing the specific environmental impact of the litter is difficult when those impacts fluctuate with market prices and other external economic forces. Finally, economic allocation assumes that poultry litter is always a co-product of poultry production with an economic value; but, depending on geographic and temporal factors the same litter could be considered a by-product or even a waste with little to no economic value. In Maryland, poultry litter is unevenly distributed geographically and the co-product (i.e. poultry litter) can have fertilizer value that exceeds handling costs in one location while the handling costs are greater than the fertilizer value in another location. Such factors make it difficult to assign one constant dollar value to poultry litter, even within a single state.

The International Standards Organization (ISO) provides recommendations on how to allocate co-products. ISO recommends system expansion whenever possible to avoid the need for co-product allocation. System expansion involves expanding the boundaries of an assessment to include indirect impacts of a production system outside the scope of the system in question (ISO, 1998). Using this method, poultry farms would be credited with the environmental benefit of avoided synthetic fertilizer production through the production of poultry litter for fertilizing crops. When system expansion is not realistic and allocation of environmental impacts cannot be avoided, the ISO recommends that allocation reflect physical relationships between a process and its environmental impacts, or some other relationship between products and co-products. Economic allocation is reserved for when other allocation methods are not possible or realistic (ISO, 1998).

The mass-energy approach allocates environmental burdens from litter based on a biophysical relationship between poultry litter and the inputs needed for its production. These inputs include industrially produced or processed fertilizers that were applied in conventional cropping systems to grow feed for poultry. Most of the nutrients found in poultry litter, therefore, originated from conventional production systems. This mass-energy methodology follows the ISO 14044 recommendation that the "inventory is based on material balances between inputs and outputs. Allocation procedures should therefore approximate as much as possible such fundamental input/output relationships and characteristics" (ISO, 2006). Such a method is useful when quantifying the dependence of organic farming systems on conventional production processes since the use of litter is tied directly to the production of nutrients in the litter.

In this paper, we present two allocation methods. We used economic allocation, which assigns values for energy consumption and GHG emissions from poultry litter production based on the economic value of poultry litter, since it has been the most common allocation method used in previous livestock life cycle analyses (LCAs) and therefore allows our results to be compared with previous studies (Thomassen et al., 2008). This method is also appealing since poultry are raised for their meat or eggs, and litter is a co-product that would be produced whether or not it is applied to farms. Therefore, it can be argued that litter should only be charged a proportion of the environmental impacts from poultry production based on the relatively small economic value compared to poultry meat.

Recognizing the limits of economic allocation mentioned above, we also conducted allocation on a mass-energy basis. This method reflects the flow of biologically valuable resources (N, P, and K) and their environmental impacts. The benefit of this methodology is that it directly reflects the relationship between poultry litter and the resources needed to produce that litter. Feed production is the largest contributor to the environmental impact of poultry production (Boggia et al., 2010), and this feed is typically grown in conventional cropping systems that depend on synthetic fertilizer, synthetic herbicides and pesticides. Taking into account the inputs needed to produce poultry litter and the nutrients found in the litter may better reflect the true environmental costs of using poultry litter in both organic and conventional cropping systems.

We chose not to use system expansion since our goal was to allocate the cost of manure nutrients to the organic systems to recognize their dependence on synthetic nutrients and the associated environmental impacts. Additionally, due to the uneven geographic distribution of poultry litter in the Chesapeake Bay watershed, transportation of poultry litter from areas of production to farms across the state is often