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Energy requirements for transport and surface application of liquid pig manure in Manitoba, Canada

M.J. Wiens [a], M.H. Entz [a,*], C. Wilson [b], K.H. Ominski [b]

[a] Department of Plant Science, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2
[b] Department of Animal Science, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2

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ABSTRACT

The objective of this study was to conduct a thorough accounting of energy used to transport liquid pig manure from farm storage to the field and to surface-apply the manure. Energy consumption was determined using both energy data from the literature plus data from field-scale research. Energy consumption was compared between two manure application systems (the drag hose and the slurry wagon systems) and two application timing treatments (single vs. twice-annual manure application). The single annual application of liquid pig manure applied at 81.5 m^3 ha^{-1} and transported 1.8 km from storage to field consumed 2180 MJ ha^{-1} with the drag hose system and 2185 MJ ha^{-1} with the slurry wagon system. The twice-annual manure application regime used 2726 and 2209 MJ ha^{-1} for the drag hose and slurry wagon systems, respectively. When energy use was calculated on the basis of MJ per kg of available N, liquid pig manure applied once annually with the slurry wagon system provided N at 17.76 MJ kg^{-1} of available N, which was 33% of the energy cost of N from anhydrous ammonia and 23% of the energy cost of N from urea. Manure transport distance could be increased to 8.4 km before the energy cost per kg of available N from pig manure was equivalent to anhydrous ammonia, and up to 12.3 km before the energy cost of manure N was equivalent to urea N. Despite the high energy cost to deliver liquid pig manure from storage to field, the much lower cost per kg of available N compared to inorganic fertilizer N highlights the opportunities that exist for improving the energy efficiency of industrial agriculture by replacing inorganic fertilizers with manure.

1. Introduction

There are both financial and environmental reasons to improve energy efficiency in agriculture. From a financial perspective, energy usually costs money. From an environmental perspective, energy use is associated with carbon dioxide emission which has serious implications for global climate change (IPCC, 2001). Energy consumption is also indirectly responsible for negative impacts on indigenous communities and natural ecosystems during fossil fuel extraction (Goddard, 1991; Griffiths et al., 2006).

In agriculture, the availability of large quantities of liquid manure from hog production facilities presents an opportunity for some farmers to dramatically reduce energy consumption by replacing energy-intense synthetic fertilizer with manure. Fifty to 70% of the energy used for grain production may be embodied in the manufacture of chemical fertilizer (Swanton et al., 1996; Nagy, 2001; Hoeppner et al., 2006). Pig manure is sometimes viewed as a waste product by the pig farmer and in these cases may be considered free of any energy costs for its production.

McLaughlin et al. (2000) calculated an energy saving between 36% and 52% if liquid manure were used instead of inorganic fertilizer in corn production in Ontario, Canada. When corn was produced with inorganic fertilizer, between 33% and 54% of the total crop production energy use was associated with inorganic fertilizer. In contrast, corn produced with manure used between 3.5% and 6.3% of total energy for manure application and no additional fertilizer was required (McLaughlin et al., 2000). However, energy consumption associated with manure transportation or for energy embodied in machinery was not considered in this study.

Energy use is often described as the sum of direct (e.g. diesel fuel consumption) and indirect (e.g. energy for production of fertilizer or machinery) energy use (Dalgaard et al., 2001). In the case of crops fertilized with liquid hog manure, direct energy use includes diesel fuel used for activities such as manure agitation, transportation and application while indirect energy use includes energy used to produce tractors, slurry wagons, drag hoses, etc.

A major limitation to the use of liquid manure as fertilizer is its high water content and associated high transport costs; manure transportation is expensive both financially and energetically. An important question is whether the energy expended to transport manure cancels the energy saved by replacing synthetic fertilizers.

* Corresponding author.
E-mail address: m_entz@umanitoba.ca (M.H. Entz).

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Previous research estimated that the energy required to manufacture the equivalent amount of nitrogen (N) in the form of urea as is contained in 1 t of liquid pig manure would be sufficient to transport 1 t of liquid pig manure up to 66 km (Ceotto, 2005). Energy required for manure transportation will vary depending on the nutrient concentration of the manure, and perhaps also the manure application approach (e.g. slurry wagon vs. pipeline drag hose system). Manure with high N concentration will require less transportation energy than low N concentration manure to achieve the same N application rate. In a survey of Canadian pig farms, N concentration in the pig slurry averaged 3.1 kg/1000 l, but ranged widely (0.40–6.8 kg/1000 l) (Manure application and use guidelines, 2006). Similarly, crops with high nutrient demands will enable high manure application rates and therefore low energy requirements for manure transportation.

Energy required to transport liquid manure should also be considered in the context of the crop-livestock system. Russelle et al. (2007) argued that crop-livestock integration can successfully occur at different scales: (1) a local, on-farm scale; and (2) an area-wide scale where distant farms share nutrients by moving crops and manure between farms. One measure of a successful area-wide integration is the relative energy cost of nutrients delivered with manure compared with inorganic fertilizer.

The present study offers a detailed accounting of the energy costs of applying liquid hog manure in large-scale pig production in Manitoba, Canada. The objectives of this study were to examine surface application of liquid hog manure in order to determine: (1) the amount of energy used; (2) the allocation of energy consumption to the various activities of manure application; (3) the nitrogen energy cost of manure vs. inorganic fertilizer N; and (4) the maximum manure transport distance.

2. Data and methods

The energy analysis discussed here is based on manure application data from a field-scale experiment conducted near La Broquerie, Manitoba (49°31′N, 96°30′W) between 2003 and 2006. The purpose of the field-scale study was to measure the productivity of crop growth with or without liquid hog manure. The present analysis only considers the energy balance of moving manure from the farm storage to the field, plus the energy associated with manure spreading. The field experiment included a split manure application (50% applied in spring and 50% applied in fall), and a full manure application (100% applied in spring), and both manure application treatments were compared in the energy analysis. Liquid hog manure was surface-applied to cropland at a rate calculated to supply a total of 123 kg of N/ha to the forage crop. Energy use for manure application was estimated by investigating typical liquid hog manure application systems in Manitoba (Table 1).

2.1. Energy inputs

Energy input was investigated for two different manure application methods. The drag hose manure application system is becoming more common in Manitoba and therefore is likely to be used when applying manure to forage or crop land. The slurry wagon system was included because it is still commonly used by farmers in the region and it is easier to use in grazing systems where fences cause problems for the drag hose system.

Efforts were made to account for all energy use in applying liquid hog manure from an earthen manure storage structure to farmland. Energy coefficients for the various raw materials used in the machinery were based on work done by Baird et al. (1997). Coefficients for embodied energy of tractors, tractor fuel consumption, and tractor lubrication energy are from Nagy (1999), with some modifications made to fuel consumption coefficients based on local conditions (Gallup, 2006 – personal communication). For each operation energy consumption was divided into three categories: fuel energy, machine energy (energy embedded in machine including machine construction), and lubrication energy. Local operators of commercial manure application equipment provided estimates of the amount of time required for each operation (Gallup, 2006 – personal communication; Penner, 2006 – personal communication).

The input variables used to develop the energy use budget were based on a typical contemporary feeder pig barn system in Mani-

Table 1
Input variables for manure production, manure storage, and manure application of a typical industrial-scale Manitoba pig production system

Parameter	Units	Amount
Manure production		
Feeder hogs on site	Number	10,000
N production (including feed wastage)	kg/hog/day	0.0403[a]
Duration of a pig's stay in the barn	Days	114[a]
Batches of pigs per year	Number	2.5
Annual feeder hog production	hogs/yr	25,000[b]
Total annual manure production	million l/yr	29.56[c]
N loss and availability		
Total N entering storage	kg/yr	114,855[d]
N concentration of manure entering storage	kg/1000 l	3.88[e]
N lost during storage	%	30[f]
N concentration of manure leaving storage	kg/1000 l	2.72
Proportion of N in storage in ammonium form	%	61[g]
Ammonium–N loss during surface application	%	25[g]
Organic-N loss during surface application	%	0[g]
Ammonium–N availability in year of application	%	100[g]
Organic-N availability in year of application	%	25[g]
Available N after storage and application losses	kg/1000 l	1.51[h]
Manure application		
Desired N application rate (available in year applied)	kg ha^{-1}	123
Manure application rate	m^3/ha	81.49[i]
Total land area covered by manure	ha	362.8[j]
Distance from storage to field	km	1.81
Drag hose system energy use		
Area covered during a set with drag hose system	Ha	16.19[c]
Pumping rate for drag hose system	m^3/min	3.77[c]
Application width in drag hose system	M	9.14[c]
Maximum field speed for tractors in drag hose system	km/h	11.27[c]
Tractor and engine energy use (see Table 2)		
Additional machinery (see Table 3)		
Slurry wagon system energy use		
Slurry wagons – quantity	Number	5[k]
Slurry wagons – capacity	m^3	28[k]
Functional capacity of wagons	%	94[k]
Total functional capacity of wagons	m^3	131.6[l]
Loading rate for wagons	m^3/min	9.09[k]
Application width in slurry wagon system	M	18.29[k]
Unload rate for wagons	m^3/min	9.09
Maximum road speed with slurry wagons	km/h	32[k]
Maximum field speed with slurry wagons	km/h	14.48[k]
Travel time with slurry wagons	min km^{-1}	2.18
Loading time for slurry wagons	min/load	3
Land covering time	min/load	3
Tractor energy use (see Table 5)		
Additional machinery (see Table 6)		

[a] From Fabian et al. (2004).
[b] 10,000 hogs × 2.5 baches per year.
[c] Gallup, 2006 – personal communication.
[d] 25,000 hogs × 114 days × 0.0403 kg N/hog/day.
[e] 144,855 kg N ÷ 29,560 thousand l.
[f] Sutton (2001).
[g] Manure application and use guidelines.
[h] Total manure N minus loss and unavailable N.
[i] 123 kg N/ha ÷ 1.51 kg N/1000 l.
[j] 29,560 m^3 ÷ 81.49 m^3 ha^{-1}.
[k] Penner, 2006 – personal communication.
[l] 5 wagons × 28 m^3/wagon × 94%.