AGRICULTURAL ENERGY CONSUMPTION, BIOMASS GENERATION, AND LIVESTOCK MANURE VALUE IN THE SOUTHERN HIGH PLAINS

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INTRODUCTION

The Texas High Plains Trade Area covers 26 counties in the Panhandle of Texas, with the Counties of Parmer, Castro, Swisher, Briscoe, Hall, and Childress serving as the southern border of the area (Amosson, 1996). Agriculture is big business in the Texas High Plains Trade Area, with average annual cash receipts from agriculture of $3.25 billion in recent years (Amosson, 1996). Agricultural production and biomass production are similar in areas of western Oklahoma, southwestern Kansas, and eastern New Mexico as well as in the 26-county Texas High Plains Area. We refer to this combined region as the "Southern High Plains" in this paper (Figure 1).

In the first part of this paper, we present information on agricultural energy consumption and biomass production as related to concentrated animal feeding operations (CAFOs) in the Southern High Plains Region delineated in Figure 1. In the latter part, we discuss various methods for assessing the value of livestock manure, and use several methods to assign values to manure produced in beef cattle feedlots in the region. The purpose of this paper is neither to promote nor condemn any of the energy and utilization processes that will be presented in today's workshop, but rather to provide educational material and "fuel for thought" for future discussions involving energy production from agricultural waste.

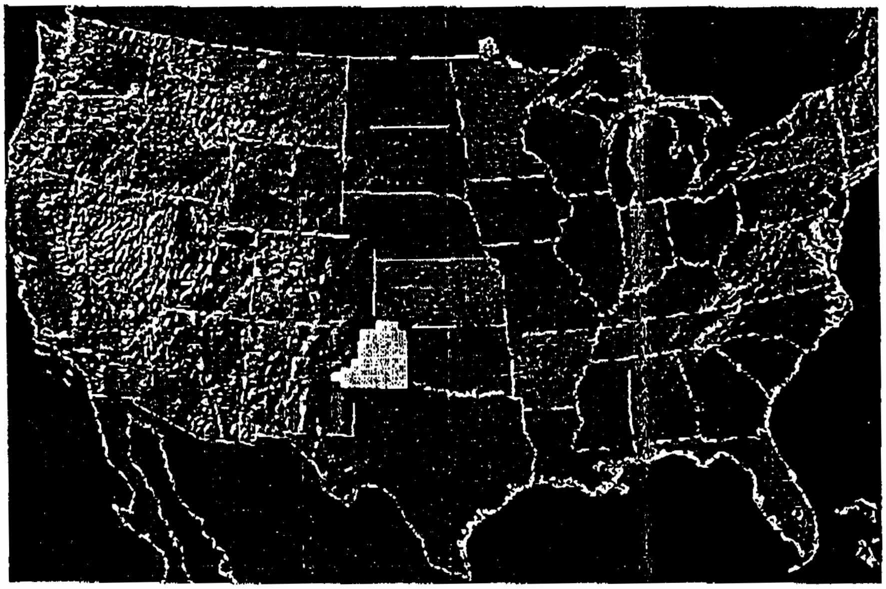

FIGURE 1. The Southern High Plains Region, Covering Twenty-Six Counties in Texas, Two Counties in New Mexico, Three Counties in Oklahoma, and Three Counties in Kansas

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TERMINOLOGY

Livestock waste and energy production professionals use unique terminology that may be new to some people attending this workshop. To assist the readers of this paper and the papers that follow, several scientific terms are defined along with brief discussions about why they are important in the livestock waste and energy production areas. Additional definitions can be found in ASAE (1996).

Anaerobic Treatment - The decomposition of livestock waste in an environment devoid of free oxygen. Anaerobic treatment results in breakdown of the manure and the resultant release of biogas. Biogas is sometimes collected during treatment conducted in a digestor or a covered lagoon.

Biogas - Gas produced during anaerobic digestion, composed primarily of 55-65% methane and 35-45% carbon dioxide, with traces of hydrogen, nitrogen, and hydrogen sulfide. Biogas can be burned for its direct heating value, or it can be used as fuel in an internal combustion engine in combination with a generator to produce electricity (co-generation).

Biomass - Organic matter that has been grown by photosynthetic conversion of solar energy (ASAE, 1996).

Concentrated Animal Feeding Operation - The definition of a CAFO varies from state to state. In Texas, a CAFO is defined as a concentrated, confined livestock facility operated for meat, milk or egg production, growing, stabling, or housing, in pens or houses wherein livestock or poultry are fed at the place of confinement and crop or forage growth or production of feed is not sustained in the area.

Digestor - A closed vessel used for digesting manure and producing biogas.

Feedlot - A term used most often for beef cattle feeding operations, where animals are kept outside on open, soil-surfaced lots. Feedlots are also called feedyards.

Lagoon - A waste containment facility designed specifically for the biological treatment of agricultural waste. Lagoons can be aerobic (with oxygen) or anaerobic (without oxygen). Anaerobic lagoons are distinct from storage ponds with respect to hydraulic retention time and operating depth.

Manure - The fecal and urinary excretion of livestock, and a byproduct of the livestock feeding industry. Often includes waste feed, hair and bedding materials.

Mesophilic Bacteria - Bacteria which thrive in a temperature range of 68-113° F (20-45° C).

Methane - A colorless, odorless gas composed of one carbon and four hydrogen atoms. The chemical formula for methane is CH_4.

Packing Plant- A place where animals are slaughtered and the meat is processed. Packing plants are also called slaughterhouses or abattoirs.

Storage Pond - A containment facility designed to capture and store runoff from a confined animal feeding operation. Storage ponds are used most often in open beef cattle feeding operations, while lagoons are used in dairy and swine operations. In the Southern High Plains area, some playas (natural lakes) are used for storing feedlot runoff. Storage ponds are characterized by short hydraulic retention time and fluctuating depths.

Thermophilic Bacteria - Bacteria which thrive in a temperature range of 113-140°F (45-60°C).

Total solids - The residue remaining after a moist sample is dried at 217° F (103°C) for 24 hours.

Volatile solids - The portion of total solids driven off as combustible gases at 1022°F (550°C) for at least one hour. It provides an approximation of the organic matter content of the manure.

BIOMASS PRODUCTION

The Texas Committee on Agriculturally Derived Fuels defined biomass in 1985 as "the volume of living material or residues of living material available in Texas for conversion into energy" (TREIA, 1985). The American Society of Agricultural Engineers defines biomass as "organic matter that has been grown by photosynthetic conversion of solar energy." It can be argued that livestock manure fits these definitions of biomass, because livestock manure is composed of organic matter originated from living plant material. Therefore for purposes of this paper livestock manure is included in the definition of biomass. Although waste from meat packing plants may not fit the strict definition of biomass, it is considered in this paper because of its potential for energy conversion.

In the Southern High Plains, agricultural biomass is produced at confined animal feeding operations (beef cattle, swine, and dairies) in the form of manure, at meat packing plants in the form of animal byproducts (offal), and from crop production in the form of stubble, harvesting and processing byproducts. Crops grown in the region primarily consist of corn, wheat, and sorghum (milo), with cotton grown in the southern part of the region.

Soil scientists generally recommend that farmers leave as much biomass as possible on their fields to prevent erosion and enhance the organic matter content in soil (Stewart, 1995). Although there are a few small dairies in the region, most of the livestock production consists of beef cattle and swine. Therefore, the primary regional biomass production that will be discussed in this paper is 1) beef cattle and swine manure from concentrated animal feeding operations, and 2) packing plant waste from beef cattle and swine meat processing.

In the sections that follow, information is presented on waste from each of these sectors. Additional data on manure quality, quantity, and transportation are covered by Sweeten et al. (this proceedings).

Biomass Production at Beef Cattle Feedlots - Approximately 4.8 million beef cattle are fed per year in the Texas High Plains Area, which accounts for 85% of the state's total (Amosson, 1996). When three counties in the Oklahoma Panhandle and one county in eastern New Mexico are included, the number rises to more than 6.3 million cattle fed per year in the region. There are 107 feedlots in the region, with a one-time capacity of 3.13 million (SPS, 1996). Sales of fed beef in the area total about $1.37 billion per year.

About 35.8 billion pounds of fresh wet manure are produced annually at beef cattle feedlots in the region (Table 1). The data in Table 1 were generated using daily manure production values (USDA, 1992), based on 6.3 million cattle produced annually, with each calf on feed for an average of 120 days. This is equivalent to an average of 2.07 million head on feed continuously for 365 days per year. The actual feeding period varies from year to year depending on the price and availability of cattle and feed (Schake and Schake, 1996). Unless otherwise noted, whenever "per head" values are referred to in this paper this relates to the number of head produced (marketed) annually, and not to "per head of feedlot capacity."

Biomass Production at Swine Farms - Swine production continues to increase in the region, with ongoing expansions at swine feeding operations in Texas, Oklahoma, and southwestern Kansas. During each of the last three years, an additional 100,000 hogs were produced in Texas. In 1992, 10% of the state's hogs were grown in the High Plains area, and that grew to 40% by 1994 (Amosson, 1996). With a large corporate swine farm currently under construction near Perryton, TX (27,000 sows with 550,000 hogs marketed annually), and another corporate swine farm currently operating near Guymon, OK (two million hogs marketed annually on 158 farms), it is estimated that by the end of 1997 the region will have about 200 000 sows with more than 3.4 million hogs produced annually. The hogs at these facilities are grown in what is termed "farrow to finish" operations, meaning the pigs are born (farrowed) and grown (finished) at the same owner's facilities. Total estimated swine manure production (fresh) from the 3.5 million market hogs and the 200,000 sows in the region is shown in Table 1. Approximately 5.56 billion pounds of fresh wet manure are produced annually at swine farms in the region.

TABLE 1. ANNUAL FRESH MANURE BIOMASS AND NUTRIENT GENERATION IN THE SOUTHERN HIGH PLAINS

Source	Number of Animals	Total Manure (wet basis)	Total (Dry) Solids	Volatile Solids	Total N	Total P	Total K
		Billion lbs.					
Beef Cattle	6.3 million feeders*	35.8	4.13	3.80	0.240	0.0657	0.147
Swine	200,000 sows 3.4 million growers*	5.56	0.642	0.518	0.0410	0.0153	0.022

* Refers to number of animals grown and sold annually

In the past, large swine operations have raised hogs in buildings, which concentrated the manure making it easy to collect and treat. Some weaner pigs in the region are now being produced in what is called "intensive outdoor pig production," where the breeding, gestation, and farrowing are all conducted in a pasture-like setting, with small shelters spread throughout the pasture far enough apart that there is continuous natural vegetation (grass) in the pasture (PIC, 1997). Land requirements range from 40-50 acres for every 300 sows. In outdoor pig production, the manure is deposited over a wide area in the pasture and cannot be collected as easily as with confinement operations. Therefore, the actual volume of swine manure available for energy conversion in the region is less than the 5.56 billion pounds shown in Table 1.

Biomass Production at Beef Cattle Packing Plants - There are thirteen major beef-packing plants in the region. The four largest plants have annual capacities ranging from 980,000 to 1.76 million head, and the remainder have annual capacities of 2,600 to 210,000 head. Total capacity of all thirteen beef packing plants is 5.3 million head, with 5.14 million beef cattle actually slaughtered in these thirteen plants in 1996 (SPS, 1996).

Animal byproducts produced at beef packing plants account for about half of the gross weight of the cattle as received at the plant. The paunch material, which is the undigested feed in the animal's rumen (stomach), accounts for about 20 pounds per beef animal slaughtered. The paunch material is either land applied or ensiled and used as animal feed (Christensen, 1997). Blood and bone meal are typically dried and used for animal feed. The viscera (stomach, lungs, intestines) are generally rendered into tallow and pet food at off-site rendering plants (Christensen, 1997; Hansen and George, 1983). A few packing plants have recently installed wastewater treatment systems consisting of sequential batch reactors with methane collection. however, most packing plants in the Texas High Plains region use conventional lagoon systems with land application of the wastewater. Clarifier solids from the wastewater treatment plant are sometimes composted and/or land applied.

ENERGY CONSUMPTION

Energy Consumption at Beef Cattle Feedlots

Beef cattle feedlots consume energy from the processing and distribution of feed, pumping of drinking water, lighting, and live animal processing. Sweeten (1996) prepared a comprehensive summary of energy consumption at beef cattle feedlots in Texas and Kansas. Based on information from Texas Cattle Feeders Association surveys conducted in 1979 and 1984-85, feedlots had an average annual energy consumption of 1.22-1.28 million BTU per head (of feedlot capacity), while a Kansas State University survey reported an annual consumption of 0.90 million BTU per head of feedlot capacity (Table 2). The average annual energy cost per head (of feedlot capacity) was $5.24 based on the 1985 TCFA survey.

TABLE 2. ENERGY USAGE AT CATTLE FEEDYARDS IN TEXAS AND KANSAS (Sweeten, 1996)

		Natural Gas		Electricity		Total Energy
	No. Feedlots	ft³/hd/yr x10³	BTU/hd/yr x10⁶	kWh/hd/yr	BTU/hd/yr x10³	BTU/hd/yr x10⁶
1979 TCFA Survey						
a. Steam Flaking	25	1.01	1.01	60	0.21	1.22
b. Dry Heat	4	1.13	1.13	43	0.15	1.28
1984-85 TCFA Survey	50	1.01	1.01	77.2	0.26	1.27
1972-75 KSU Survey	--	0.75	0.75	43.7	0.15	0.90

* All "per head" numbers based on "per head of feedlot capacity" and not "per head grown annually at the feedlot."

Energy Consumption at Beef Packing Plants

Information on five months of energy usage at a Texas High Plains beef packing plant with an annual capacity of about 1 million head is shown in Table 3. Annual energy consumption at the plant, extrapolated from the monthly average to a 12-month period, was 8.90x10^{11} BTU. This equates to 805,000 BTU per head or about 767,000 BTU per thousand pounds of live weight slaughtered.

Energy Consumption at Swine Packing Plants

Information on energy usage at a medium sized swine packing plant in the Midwest is shown in Table 4. The data are for a twelve month period in 1978 and 1979 during which time the plant slaughtered 1.4 million hogs (Hansen et al., 1984). Annual energy consumption at the plant was 5.17 x 10^{11} BTU, which equates to 365,600 BTU per head slaughtered, or about 1.52 million BTU per thousand pounds of live weight (almost twice the energy consumption per thousand pounds live weight in the beef packing plant).

TABLE 3. ENERGY CONSUMPTION AT A BEEF PACKING PLANT

Month/Yr	Natural Gas (million cubic feet)	Natural Gas Energy (million BTU)	Electricity (million kWh)	Electricity Energy (million BTU)	Total Energy (million BTU)	Number of Beef Slaughtered	Energy per Head (BTU/hd)
Dec-96	60.79	60,790	4.2	14,330	75,120	87,150	861,962
Jan-97	63.98	63,980	4.2	14,330	78,310	84,160	930,490
Feb-97	60.79	60,790	4.5	15,350	76,140	106,560	714,527
Mar-97	52.95	52,950	4.4	15,010	67,960	85,160	798,027
April-97	57.37	57,370	4.7	16,040	73,140	97,510	750,077
5-Month Total	295.88	295,880	22.0	75,060	370,670	460,540	
Monthly Mean	59.18	59,176	4.4	15,012	74,134	92,108	
Extrapolated Annual		710,100		180,140	890,260	1,105,300	805,000

TABLE 4. ENERGY CONSUMPTION AT A SWINE PACKING PLANT (Adapted from Hansen et al. 1984)

Month/Yr	Natural Gas (million cubic feet)	Natural Gas Energy (million BTU)	Electricity (million kWh)	Electricity Energy (million BTU)	Total Energy (million BTU)	Number of Hogs Slaughtered	Energy per Head (BTU/hd)
May-78	33.64	33,640	1.37	4,674	38,314	103,000	371,981
June-78	37.65	37,650	1.73	5,903	43,553	111,000	392,369
July-78	31.83	31,830	1.52	5,186	37,016	100,000	370,160
Aug-78	31.14	31,140	1.58	5,391	36,531	99,000	369,000
Sept-78	42.85	42,850	2.03	6,926	49,776	136,000	366,000
Oct-78	33.65	33,650	1.67	5,698	39,348	113,000	348,212
Nov-78	38.13	38,130	1.51	5,152	43,282	120,000	360,683
Dec-78	47.86	47,860	1.73	[illegible]	[illegible]	112,000	[illegible]
Jan-79	NA	NA	1.81	6,176		96,000	
Feb-79	31.75	31,750	1.23	4,197	35,947	104,000	345,644
Mar-79	47.36	47,360	1.79	6,107	53,467	146,000	366,212
April-79	37.76	37,760	1.57	5,357	43,117	132,000	326,644
Total	413.63	413,620	19.55	66,704	474,148	1,393,000	
Monthly Mean	37.60	37,600	1.63	5,559		116,000	
Extrapolated Annual		451,200		66,700	517,250	1,393,000	365,581

Energy Consumption From Fertilizer Production

Fertilizer production in the U.S. accounts for about 0.8% of the total annual consumption in the U.S. (Stout, 1984). The three primary macronutrients (fertilizer nutrients) added to soil in the form of commercial fertilizer are nitrogen, phosphorus, and potassium (Brady, 1974).

Anhydrous ammonia is made from natural gas through the Haber Process, with about 38,000 cubic feet of gas required per ton of NH_3 produced (Davis and Blouin, 1977). In this process, 40% of the natural gas is burned as fuel, and the remaining 60% is used as feedstock to produce hydrogen. The hydrogen is reacted catalytically with the nitrogen from the atmosphere at elevated temperature and pressure to produce ammonia. Ammonia that has been liquefied under pressure is called anhydrous ammonia. As of 1975, there were seven ammonia (NH_3) plants in the Southern High Plains. The nearest phosphorus is mined from deposits in Florida and Idaho. The nearest potassium is mined from potash salt beds located in New Mexico and Utah. Approximately 60% of the potash used for producing fertilizer is imported from Canada (Davis and Blouin, 1977).

The energy required to produce nitrogen, phosphorus, and potassium fertilizers is presented in Table 5. Energy consumption is divided into 1) the transportation of raw materials, 2) the processing of the fertilizer (processing does not include energy from human effort or energy consumed in the fabrication of the manufacturing equipment), and 3) transportation of the finished product. For the transportation of raw materials, it was assumed that natural gas for ammonia production would be transported 200 miles by gas pipeline (Davis and Blouin, 1977), and that no energy was required for potassium since it is produced where the potash is mined. For the transportation and distribution of the finished products, it was assumed that anhydrous ammonia would be transported 105 miles by truck, phosphates would be transported 1,000 miles by rail and 210 miles by truck, and potassium would be transported 315 miles by truck.

TABLE 5. ENERGY REQUIRED FOR FERTILIZER PRODUCTION
(Adapted from Davis and Blouin, 1977)*

	Transportation of Raw materials	Processing	Transportation of Products	Total
Nitrogen (N)	Million BTUs per ton of N Produced			
Ammonia (82-0-0)	0.1	42	3.1	45.2
Ammonium Nitrate	0.1	50	3.1	53.2
Urea	0.1	49	3.1	52.2
Phosphorus (P_2O_5)	Million BTUs per ton of P_2O_5 Produced			
Triple Superphosphate (0-46-0)	0.9	11	3.1	15.0
Ammonium Phosphate	0.9	15	3.1	19.0
Normal Superphosphate (0-20-0)	0.9	2	3.1	6.0
Potassium (K_2O)	Million BTUs per ton of K_2O Produced			
Potash (0-0-60)	None	4	2.6	6.6

* (Does not include energy from human effort or fabrication of equipment.)

UTILIZATION AND TREATMENT OF LIVESTOCK WASTE

There are many methods for treating, utilizing, or disposing of livestock waste products, including land application of waste and wastewater, solids separation, composting, anaerobic lagoons, aerobic lagoons, anaerobic digestion, combustion, and evaporation (USEPA, 1971). In the Southern High Plains, land application of solid manure is the primary waste utilization method used at beef cattle feedlots, while swine operations primarily employ land application of wastewater, aerobic and anaerobic lagoons, and evaporation. With the many different options available for dealing with livestock waste, it is sometimes difficult to decide on the best treatment and utilization method. There are several deciding factors when selecting a best method, all of which rely to some point on assessing the value of the livestock waste at a particular operation.

ASSESSING THE VALUE OF LIVESTOCK WASTE

Regardless of the end use, the "value" of livestock waste is often discussed in general terms (USEPA, 1971; USEPA, 1973; Klausner et al., 1984; Stewart. 1995; Wyatte et al., 1995; ASAE, 1996). The value of livestock waste can be assessed a variety of ways in terms of 1) dollar value (economics), 2) energy content, 3) environmental impacts, 4) politics and governmental regulations, 5) personal opinion, 6) site specific conditions, and 7) combinations of the above. The ranking of waste uses varies depending on the method of assigning value to manure. This is one reason that opinions often differ as to the best waste utilization method, though most producers often rate economics as their primary concerns.

Assigning value to livestock manure is difficult. First, livestock manure characteristics are highly variable, and there is no standard method for assigning value to this variability. We leave this topic for future work and discussion. Second, some of the quality parameters are qualitative rather than quantitative. We also leave the assessment of qualitative value to future studies, and will focus on illustrating the different methods of assessing the ***quantitative*** value of livestock manure. To achieve this purpose, we have calculated values in terms of economics (dollar value) and energy saved or produced (energy value) for fresh and aged ***beef cattle*** manure produced in the Southern High Plains. In assessing these values, the costs associated with field application of commercial fertilizer or livestock manure are not included.

Economic Value of Beef Cattle Manure

Fresh Manure Value - Dollar Value of Equal Amounts of Nutrients in Commercial Fertilizer Production

The nutrient content of commercial fertilizer is expressed as percent N, P_2O_5, and K_2O. For example, a 50-25-10 fertilizer contains 50% N, 25% P_2O_5, and 10% K_2O.

Currently (Summer, 1997), the price of anhydrous ammonia (82-0-0) in the region is $240/ton. Phosphorus fertilizer is sold in solid form for broadcasting (11-52-0) for $265/ton, or in liquid form for banding (10-34-0) for $240/ton. The dollar value of the P_2O_5 alone in the 11-52-0 fertilizer was calculated to be $233 per ton of fertilizer. Potassium fertilizer is used by only a few farmers in the region, but is available (7-21-7) for $148/ton (Anderson, 1997). The dollar value of the K_2O alone in the 7-21-7 fertilizer was calculated to be $78 per ton of fertilizer.

ASAE defines the fertilizer value of manure as "an estimate of the value of commercial fertilizer elements (usually N, P, K) that can be replaced by manure . . . ." There are several ways to look at fertilizer value. First, you can look at the value of all N, P, and K in the manure (i.e. the additive value). The additive fresh manure fertilizer value is shown in Table 6. In this case, the additive fresh manure fertilizer value is about $163.8 million or $26.00 per head produced. However, the additive value is not a realistic value of the manure because fertilizer value is actually limited by the most limiting nutrient (you cannot separate the N from the P). For example, applying manure to meet the nitrogen requirements of the crop most often results in over-application of phosphorus. Thus, the true manure fertilizer value is crop and site dependent because different crops require different ratios of nitrogen to phosphorus. The true manure fertilizer value can be expressed as:

$$FMFV = VN + \alpha (VP_2O_5) + \beta (VK_2O) \qquad [1]$$

where FMFV is the fresh manure fertilizer value ($/ton), VN is the value of the nitrogen, VP_2O_5 is the value of the P_2O_5, VK_2O is the value of the K_2O, and α and β are value coefficients (modifiers) which are crop and soil specific. In the Southern High Plains, if manure is applied at a rate to meet the N requirement, then $\alpha < 1$ and $\beta = 0$. Typical N and P application rates for irrigated corn in the region are 240 pounds N and 60 pounds P_2O_5 per acre (Marek, 1997). If fresh manure is applied to meet the requirement for N, then about 65 percent of the P_2O_5 is over-applied. Only 35 percent of the P_2O_5 is utilized, so $\alpha=0.35$. Because K_2O is rarely applied, we will assign $\beta = 0$. Applying the coefficients, the true fertilizer value of the fresh manure if applied to corn at the nitrogen requirement is about \$42.5 million or \$6.75 per head produced. Manure can also be applied to meet the phosphorus requirement, so that we can account for the full value of the N and P_2O_5 with zero value for the K_2O, in which case the true annual fertilizer value would be about \$64.4 million or \$10.23 per head produced. If manure is applied to meet the phosphorus requirement, then additional nitrogen must be supplemented with commercial fertilizer. The cost of applying additional commercial fertilizer is not included in these value assessments, nor is the cost of applying the manure.

TABLE 6. EQUIVALENT DOLLAR VALUE OF FRESH MANURE AS COMMERCIAL FERTILIZER (ADDITIVE AND TRUE VALUES)

Nutrient	Amount (billion lbs.)	Equiv. Dollar Value (region)	Equiv. Dollar Value (per head produced)
Additive Value			
Nitrogen (as N)	0.210	\$30,732,000	\$4.88
Phosphorus (as P_2O_5)	0.150	33,684,000	5.35
Potassium (as K_2O)	0.177	99,393,000	15.78
	Total "Additive" Value	\$163,809,000	\$26.00
True Value (applied at N requirement)			
Nitrogen (as N)	0.210	\$30,732,000	\$4.88
Phosphorus (as P_2O_5)	0.098 useable	11,789,400	1.87
Potassium (as K_2O)	0 useable	0	0
	Total "True" Value	\$42,521,000	\$6.75
True Value (applied at P_2O_5 requirement)			
Nitrogen (as N)	0.210	\$30,732,000	\$4.88
Phosphorus (as P_2O_5)	0.150	33,684,000	5.35
Potassium (as K_2O)	0 useable	0	0
	Total "True" Value	\$64,416,000	\$10.23

Aged Manure Value - Dollar Value of Equal Amounts of Nutrients in Commercial Fertilizer Production

In beef cattle feedlots, the manure that is deposited on the ground is scraped and removed about every 120 to 365 days, as opposed to swine and dairy operations that scrape or remove manure as often as every day. During this "aging" process, nutrients are lost as a result of ammonia volatilization, runoff, and leaching. Mathers et al., 1972 determined average nutrient concentrations in aged manure ready for land application from 23 beef cattle feedlots in the Texas High Plains (Table 7). Mathers' values were converted to a dry basis for comparison to the fresh manure nutrient values shown in Table 1.

TABLE 7. PERCENTAGE OF NUTRIENTS IN FRESH AND AGED BEEF CATTLE MANURE

Nutrient	Fresh Manure (88% moisture)	Aged Manure (34% moisture)
	Percent (dry basis)	
Nitrogen (as N)	5.08	2.05
Phosphorus (as P)	1.59	0.81
Potassium (as K)	3.55	2.29

Based on this comparison, the aged manure nitrogen concentration is 40.3 % of the fresh manure value, while phosphorus and potassium are 50.9% and 64.5% of their original values, respectively. Reducing the dollar value of the nutrients in the aged manure by the ratios in Table 7 results in estimated dollar values shown in Table 8.

The additive annual dollar value of the aged beef cattle manure in the region, expressed as the dollar value of cost to purchase commercial fertilizer, is $93.6 million or $14.86 per head, which is roughly half of the dollar value of the fresh manure.

TABLE 8. EQUIVALENT DOLLAR VALUE OF AGED MANURE AS COMMERCIAL FERTILIZER (ADDITIVE AND TRUE VALUES)

Nutrient	Amount (billion lbs.)	Equiv. Dollar Value (region)	Equiv. Dollar Value (per head produced)
Additive Value			
Nitrogen (as N)	0.0846	$12,385,000	$1.97
Phosphorus (as P_2O_5)	0.0764	17,145,000	2.72
Potassium (as K_2O)	0.1140	64,108,000	10.18
	Total "Additive" Value	$93,638,000	$14.86
True Value (applied at N requirement)			
Nitrogen (as N)	0.0846	$12,385,000	$1.97
Phosphorus (as P_2O_5)	0.021 useable	4,801,000	0.76
Potassium (as K_2O)	0 useable	0	0
	Total "True" Value	$17,186,000	$2.73
True Value (applied at P_2O_5 requirement)			
Nitrogen (as N)	0.0846	$12,385,000	$1.97
Phosphorus (as P_2O_5)	0.0764	17,145,000	2.72
Potassium (as K_2O)	0 useable	0	0
	Total "True" Value	$29,530,000	$4.69

If aged manure is applied to meet the N requirement, then about 72 percent of the P_2O_5 is over-applied, so α=0.28. Assuming $\beta = 0$ as before, the true fertilizer value of the aged manure if applied to corn at the nitrogen requirement is about $17.2 million or $2.73 per head produced. Aged manure applied to meet the phosphorus requirement would have a true annual fertilizer value of about $29.5 million or $4.69 per head produced.

Manure Value - Dollar Value of Equal Amounts of Natural Gas

Biogas production from manure collected on soil-surfaced lots ranges from 4.0 to 7.0 cubic feet per pound of volatile solids (0.25 to 0.44 m^3/kg volatile solids) (Fischer et al., 1986; Hashimoto, 1982). The large range in values is partially a function of variable manure characteristics. As discussed earlier, there is a large variation in nutrient content between fresh manure and manure that has aged on the feedlot surface. Likewise, there is a large variation in the energy content of the fresh and aged manure. Other factors such as animal diet, digestor type, temperature, retention time, loading rate, and moisture content also cause variations in the amount of biogas production.

It is estimated that 1.52×10^{10} to 2.68×10^{10} ft^3 of biogas could be produced from the 3.8×10^9 lb. of volatile solids available in the region. The current cost (Summer, 1997) of natural gas is $0.81 per 1,000 cubic feet (Energas, 1997). Assuming the biogas is 60% methane, then the equivalent dollar value of the manure would be $7.4 to $13.0 million or $1.17 to $2.07 per head produced.

Manure Value - Electricity Produced From Biogas Production Expressed as Dollar Value of Equal Amount of Electricity Purchased From Power Company

Assuming that the biogas is converted to electricity at 20% efficiency (MWPS, 1985), then 5.36×10^8 to 9.44×10^8 kWh of electricity could be produced. Using an electricity value of $0.07/kWh (Bearden, 1997), then the annual dollar value of electricity savings would range from $37.5 to $66.1 million, depending on the efficiency of the biogas production, which equates to $5.95 to $10.49 per head produced.

Manure Value - Dollar Value of Composted Manure

Compost value varies widely from region to region depending on demand for the compost. One dairy in eastern New Mexico sells compost for $17.00 per ton delivered and spread on the field. The price of beef cattle compost in the region ranges from about $10.00 to $20.00 per ton. The water content of compost is usually about 25%, meaning that the price is about $13.30 to $26.70 per dry ton. Based on the 4.13 billion pounds of dry manure produced annually in the region (Table 1), the annual dollar value of the compost would be $27.5 to $51.1 million if all of the manure were composted. This equates to $4.36 to $8.75 per head produced.

Energy Value of Beef Cattle Manure

Fresh Manure Value - Energy Required to Produce Equal Amounts of Nutrients in Commercial Fertilizer Production

The equivalent energy value of the fresh manure was calculated by taking the nutrient content in the fresh beef cattle manure and converting it to the energy required to produce equal amounts of nutrients in commercial fertilizer. As demonstrated previously in calculating the economic fertilizer value, the energy values were calculated using both additive and true energy values. The values shown in Table 9 do not include the energy required for field application of the fertilizer.

Based on this value assessment, the fresh beef cattle manure in the region has an additive annual energy value as commercial fertilizer of 6.46×10^{12} BTU, or 1,025,000 BTU per head produced. If applied to corn to meet the N requirement, then the fresh manure has a true annual energy value of 5.14×10^{12} BTU, or 815,000 BTU per head produced. If applied to meet the P requirement, then a true annual energy value of 5.87×10^{12} BTU is obtained, or 932,000 BTU per head produced.

TABLE 9. EQUIVALENT ENERGY VALUE OF FRESH MANURE AS COMMERCIAL FERTILIZER (ADDITIVE AND TRUE VALUES)*

Nutrient	Amount (million lbs.)	Equiv. Energy Value (billion BTU's entire region)	Equiv. Energy Value (BTU per head produced)
Additive Value			
Nitrogen (as N)	0.210	4,740	752,000
Phosphorus (as P_2O_5)	0.150	1,134	180,000
Potassium (as K_2O)	0.177	582	92,000
	Total "Additive" Value	6,456	1,025,000
True Value (applied at N requirement)			
Nitrogen (as N)	0.210	4,740	752,000
Phosphorus (as P_2O_5)	0.052 useable	397	63,000
Potassium (as K_2O)	0 useable	0	0
	Total "True" Value	5,137	815,000
True Value (applied at P_2O_5 requirement)			
Nitrogen (as N)	0.210	4,740	752,000
Phosphorus (as P_2O_5)	0.150	1,134	180,000
Potassium (as K_2O)	0 useable	0	0
	Total "True" Value	5,874	932,000

*Values do not include energy requirements for field application of fertilizer.

Aged Manure Value - Energy Required to Produce Equal Amounts of Nutrients in Commercial Fertilizer Production

As calculated earlier, the aged manure contained 40.3, 50.9, and 64.5 percent of the fresh manure nutrient values for nitrogen, phosphorus, and potassium, respectively. Applying these ratios to the equivalent energy value of the aged manure results in the estimated energy values shown in Table 10.

Based on this value assessment, the aged beef cattle manure in the region has an additive annual energy value as commercial fertilizer of 2.86×10^{12} BTU, or 454,000 BTU per head produced. If applied to corn to meet the N requirement, then the fresh manure has a true annual energy value of 2.07×10^{12} BTU, or 329,000 BTU per head produced. If applied to meet the P requirement, then a true annual energy value of 2.48×10^{12} BTU is obtained, or 395,000 BTU per head produced.

Manure Value - Energy in Biogas Acquired From Anaerobic Digestion

From the estimated 1.52×10^{10} to 2.68×10^{10} ft^3 of biogas that could be produced annually, and based on an energy value of 600 BTU/ft^3 for biogas, this equates to annual manure energy values of between 9.14×10^{12} and 1.61×10^{13} BTU for the region, or 1,451,000 to 2,552,000 BTU per head produced. These values do not take into account energy used in the fabrication or construction of the biogas system.

TABLE 10. EQUIVALENT ENERGY VALUE OF AGED MANURE AS COMMERCIAL FERTILIZER
(ADDITIVE AND TRUE VALUES)*

Nutrient	Amount (million lbs.)	Equiv. Energy Value (billion BTU's entire region)	Equiv. Energy Value (BTU per head produced)
Additive Value			
Nitrogen (as N)	0.0846	1,910	303,000
Phosphorus (as P_2O_5)	0.0764	577	92,000
Potassium (as K_2O)	0.1140	375	59,000
	Total "Additive" Value	2,862	454,000
True Value (applied at N requirement)			
Nitrogen (as N)	0.0846	1,910	303,000
Phosphorus (as P_2O_5)	0.021 useable	162	26,000
Potassium (as K_2O)	0 useable	0	0
	Total "True" Value	2,072	329,000
True Value (applied at P_2O_5 requirement)			
Nitrogen (as N)	0.0846	1,910	303,000
Phosphorus (as P_2O_5)	0.0764	577	92,000
Potassium (as K_2O)	0 useable	0	0
	Total "True" Value	2,487	395,000

*Values do not include energy requirements for field application of fertilizer.

Manure Value - Energy in Electricity Produced From Biogas Production

The energy content of the electricity, assuming a 20% conversion efficiency (MWPS, 1985) results in annual energy contents of between 1.83×10^{12} to 3.22×10^{12} BTU, or 290,000 to 511,000 BTU per head produced.

Manure Value - Energy From Combustion

There has been some research related to combustion of manure, but there are still some unanswered questions about the feasibility of combustion of manure for energy. One source states that combustion of manure in a fluidized bed combustion chamber at temperatures of 1,100 to 1,500°F might produce 300 to 475 kWh per ton of manure (Sweeten, 1996). Research continues on using feedlot manure blended with coal (Sweeten, 1996). In another research project, steer manure was combusted in laboratory scale pyrolysis reactors, with energy yields of 2-3 million BTU per ton of dry manure (USEPA, 1973). An economic analysis of the scaled-up pyrolysis unit for a 40,000 head beef cattle feedlot showed that the net cost of pyrolysis of 80% moisture manure would be $5.60 per wet ton (i.e. a loss of $5.60 per ton after recovering the energy value).

At an average of 2.5 million BTU per ton of dry manure, combustion of all of the beef cattle manure in the region would produce 5.37×10^{12} BTU, or 852,000 BTU per head.

The net economic value from combustion of manure is negative based on the US-EPA (1973) analysis (i.e. the total costs for the combustion system exceed total revenues).

CLOSING DISCUSSION

Several methods of assigning value to livestock manure have been presented in this paper. As an aid in summarizing and comparing, the economic and energy values of beef cattle manure produced in the region are shown in the bar charts in Figures 2 and 3.

Although we might be tempted to ascertain that a particular waste utilization method is better than another based on the results in Figures 2 and 3, we must be careful to include all known costs and benefits when performing a realistic comparison. As stated previously, many of the value assessment parameters are subjective in nature, and we have not made any attempt to assign subjective values in this paper.

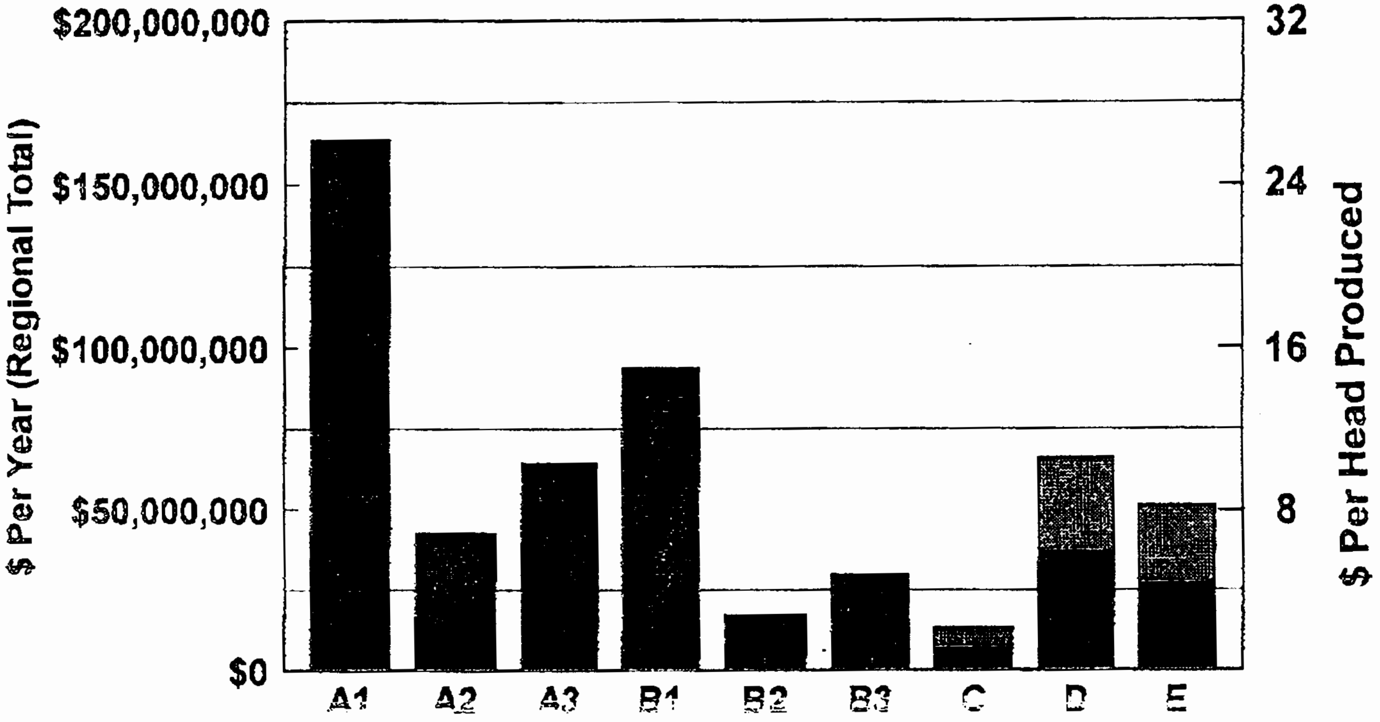
Care must be taken in comparing the results presented in Figures 2 and 3. For example, we might be tempted to state that since the dollar equivalent of natural gas is so low we should discount biogas production as an alternative. However, the numbers presented in Figure 2 do not include land application costs, costs for construction of a biogas or combustion system, or costs of composting, so a realistic comparison cannot be made from these numbers alone. As another example, it might be tempting to state that the energy available from biogas is far greater than any of the other methods, and thus from an energy standpoint biogas production should be the preferred method (Figure 3). However, the numbers presented in Figure 3 only include the energy value in the manure, they do not include the total "global energy usage" that would be required to actually put a system into operation.

There are two ways to look at energy production: locally and globally. If we are concerned about "greenhouse gases" and so-called "global warming", then we should concern ourselves with the global scale, for although one process may appear to be energy efficient or environmentally friendly at the local scale, when compared to total energy usage of other alternatives it may not be so appealing.

For example, consider an existing feeding operation with an uncovered anaerobic lagoon. Because the lagoon is uncovered, any methane or CO_2 (greenhouse gases) generated in the lagoon are discharged to the atmosphere, which according to some might lead to global warming. If we were to cover the lagoon, collect the biogas, and burn the biogas to produce electricity, then we would reduce the global warming concern on the local scale. On a global scale, we must take into account the fossil fuel that is consumed and the greenhouse gas emissions produced in the following ancillary activities:

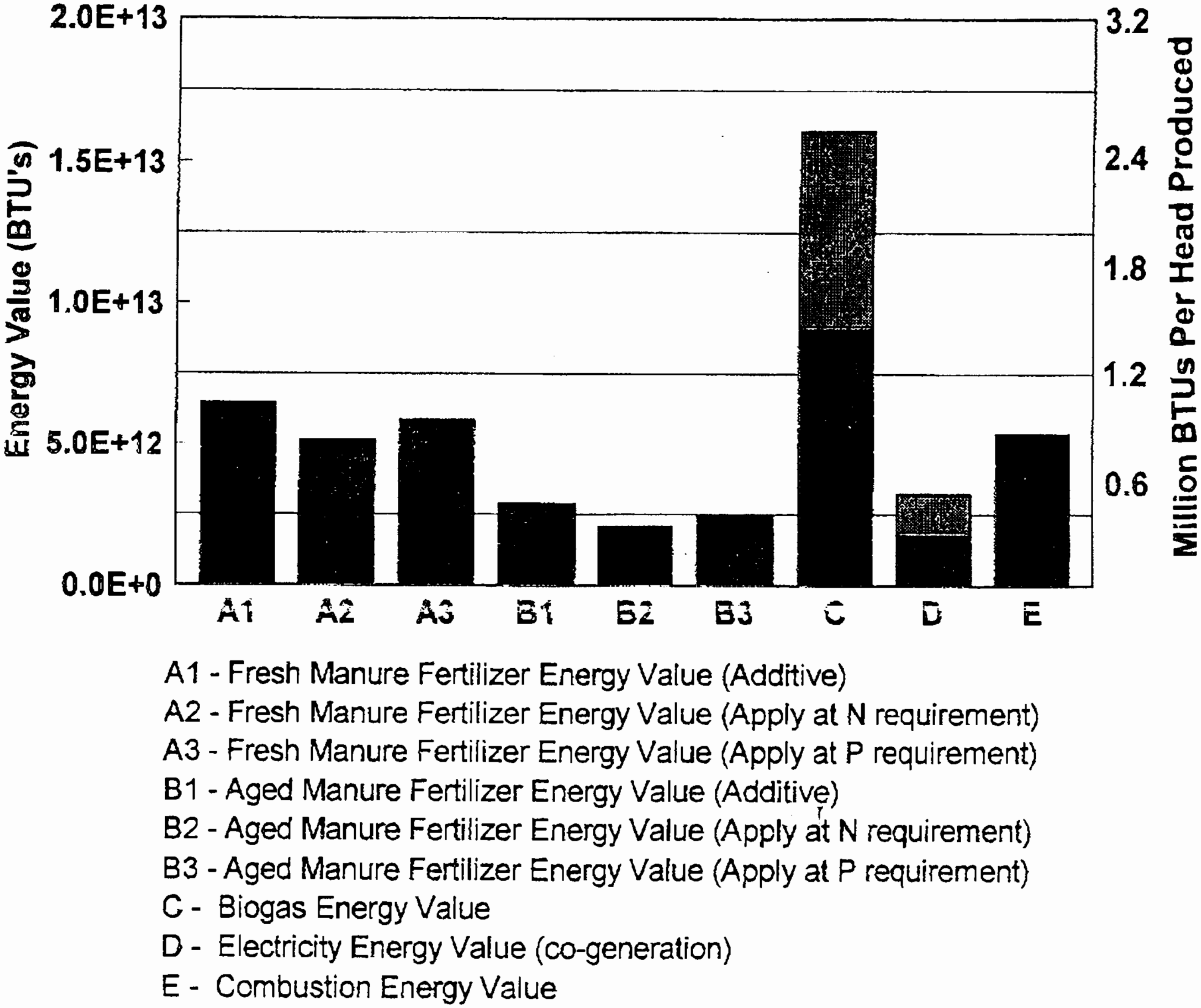
1. Production of the geosynthetic (plastic) liner to cover the lagoon and capture the gas,
2. Production of the internal combustion engine used to convert gas to electricity,
3. Production of electronics, controls, and wire used to conduct the electricity from its point of origin to its point of use, and
4. Fossil fuels used in the heavy equipment used to construct the biogas collection and electric generation plant.

FIGURE 2
ECONOMIC VALUE OF BEEF CATTLE MANURE



A1 - Fresh Manure Fertilizer $ Value (Additive)
A2 - Fresh Manure Fertilizer $ Value (Apply at N requirement)
A3 - Fresh Manure Fertilizer $ Value (Apply at P requirement)
B1 - Aged Manure Fertilizer $ Value (Additive)
B2 - Aged Manure Fertilizer $ Value (Apply at N requirement)
B3 - Aged Manure Fertilizer $ Value (Apply at P requirement)
C - Natural Gas $ Replacement Value (biogas)
D - Electricity Value (co-generation)
E - Composted Manure $ Value

FIGURE 3
ENERGY VALUE OF BEEF CATTLE MANURE



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