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FEEDLOT MANURE AS AN ENERGY SOURCE

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SUMMARY:
Utilization of feedlot manure as a fertilizer and as a feed ingredient for feedlot cattle under Texas High Plains conditions would save 0.7 million and 6.5 million BTU's per ton of dry solids, respectively. Net energy available from direct combustion and partial oxidation for anhydrous ammonia production is estimated at 4.3 million and 16 million BTU's per ton (dry solids).

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"Feedlot Manure as an Energy Source"

by John M. Sweeten, Don L. Reddell,
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The demand for feedlot manure in the last 12 months has reached an all-time high as a result of fertilizer shortages caused in part by the energy crisis. In 1973 when Texas reached its peak fed cattle production of 4.41 million head, most of the 4 million tons of manure produced, plus carry over from previous years, was utilized on cropland by High Plains farmers. Today, with Texas feedlots operating at only 56% of capacity (Texas Cattle Feeders Association 1974), nearly all feedlots are "current" and some have a backlog of orders for manure.

With the public demanding more energy and less pollution, alternate means of producing or savings energy from manure utilization are naturally being examined. In this paper we will attempt to quantify the amount of energy that can be saved by using manure as a fertilizer or as a feed ingredient. We will also examine certain capital-intensive processes through which manure can either be made into a fuel or used as a substitute for fossil fuels.

For a similar, recent review of this topic, the reader is referred to Fairbank (1974).

Fertilization of Crops with Feedlot Manure

Various researchers, including Mathers et al. (1973) and Reddell (1974) have shown that manure can be applied to High Plain soils at rates in excess of 100 ton/acre without significantly impairing crop yield. And yields of grain sorghum, corn silage, and wheat were just as high with manure at 10 ton/acre as they were with commercial fertilizer applied at the optimum rate based on a soils test. Most soil scientists now recommend that manure be applied at rates that do not greatly exceed the nitrogen requirement of the crop to: (a) avoid forage nitrate problems, (b) lessen the potential for nonpoint source water pollution, and (c) attain the most economical yield. Since only about one-half the nitrogen becomes available during the first crop year, heavier amounts can be applied initially.

Use of manure where available on cropland could save enormous quantities of energy that is now expended in fertilizer manufacture and distribution. The following analysis attempts to quantify this energy savings.

Energy for Commercial Fertilizer Consumption

Table I shows Texas' annual consumption of major fertilizers (Hargett 1973) and the extent to which their usage could be supplanted by feedlot manure. These values range from 73,000 tons of ammonia to 400,000 tons of 12-12-12 fertilizer. Note that these hypothetical values represent the amount of only one fertilizer compound rather than the entire list.

The amount of energy required to manufacture one ton of each of these fertilizers is given in Table II (Pimental et al. 1973) (Sherff 1974). The manufacturing

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requirement completely overshadows the amount of energy needed to distribute the product to retail stores and ultimately onto fields. The most concentrated fertilizer--anhydrous ammonia--requires the most energy to produce (39 million BTU/ton). Ordinary superphosphate requires only 1/5 as much energy to produce, but is less than 1/5 as concentrated.

On the other hand, a considerable amount of energy is required to collect, stockpile, and distribute feedlot manure. Collection requirements were estimated at 40,000 BTU/ton, regardless of application rate. This figure is based on observed machine operating times and fuel consumption rates.

The amount of energy required to haul and distribute manure using available spreader trucks is shown in Figure 1. For example, one-way haul distances of 5 and 10 miles require an energy input (including deadhaul) of 40,000 BTU/ton and 80,000 BTU/ton, respectively.

Thus, the total energy expended in feedlot manure collection, transportation, and application is estimated at 80,000 BTU/ton for 5 mile haul and 120,000 BTU/ton for 10 mile haul. Total costs and energy requirements per acre for application rates of 10 to 100 tons/acre/year are summarized in Figure 2.

Comparison of Energy Requirements--Manure vs. Fertilizer

Finally, total energy requirements for commercial fertilizer versus feedlot manure are compared in Table III. Apparently, use of feedlot manure could save 4.5 million BTU's of energy per acre (or 0.7 million BTU's/ton of dry solids).

On a per acre basis, this is a significant energy savings. On a statewide basis, however, only 400,000 acres of land can be fertilized with feedlot manure (at 10 tons/acre), amounting to a total savings of 1.8 X 10^{12} BTU's of energy per year. This represents only 10% of the energy required to produce and distribute only the anhydrous ammonia used in Texas. The estimated total energy for production and distribution of all fertilizers used in Texas is 52 X 10^{12} BTU's per year. Thus, the energy saved by using manure is only about 3.5% of the total fertilizer energy requirement of the state. Nevertheless, manure can be a significant energy saver in the localized areas where it is available.

Economics of Manure Utilization

Use of feedlot manure where available can also result in a significant monetary savings. As shown in Table IV, these savings could amount to $15 to $20 per acre for farmers within 10 miles of a feedlot. However, commercial fertilizer becomes more profitable at haul distances greater than about 40 miles from a feedlot.

Refeeding of Feedlot Manure

Feedlot manure can be used as an ingredient in fattening rations for beef cattle. This has appeal from a total ecological standpoint since some of the resource inputs now needed to produce cattle feed could be diverted to other purposes.

TABLE II

ENERGY REQUIRED TO PRODUCE AND DISTRIBUTE COMMERCIAL FERTILIZERS

Fertilizer	Energy for Production Million BTU/ton	Energy for Distribution To Retail Outlets Million BTU/ton	Energy for Distribution Onto Fields Million BTU/ton	Total Energy Million BTU/to
Anhydrous Ammonia	39	4	0.1	43
Ammonium Nitrate	18	4	0.1	22
Ammonium Sulfate	13	4	0.1	17
Nitrogen Solutions	16	4	0.1	20
Ammoniated Phosphates	17	4	0.1	21
Urea	28	4	0.1	32
Concentrated Superphosphate	8	4	0.1	12
Ordinary Superphosphate	4	4	0.1	8
10-20-10	9	4	0.1	13
12-12-12	9	4	0.1	13
18-46-0	17	4	0.1	21
16-6-12	9	4	0.1	13

TABLE I

TEXAS FERTILIZER CONSUMPTION REPLACEABLE BY FEEDLOT MANURE

Fertilizer	Chemical Form	Nutrient Content %	Texas Fertilizer Use, 1972 Tons	Equiv. Tons Manure Per Ton Fertilizer*	Tons Fertilizer Replaceable by Feedlot Manure**
Anhydrous Ammonia	Liquid NH_3	82%	395,200	55	73,000
Ammonium Nitrate	NH_4NO_3	33%	256,126	22	182,000
Ammonium Sulfate	$(NH_4)_2SO_4$	21%	141,191	14	286,000
Nitrogen Solutions	NH_4NO_3 in NH_4OH or Urea in NH_4OH	37-45%	128,506	25-30	148,000
Ammoniated Phosphates (Ammo-phos)	$NH_4H_2PO_4$ and other ammonium salts	(11%N and 48%P_2O_5)	119,930	38	105,000
Urea	$CO(NH_2)_2$	42%	63,966	28	143,000
Concentrated Super Phosphate	$Ca(H_2PO_4)$ and $CaHPO_4$	42% P_2O_5	21,642	34	118,000
Ordinary Super Phosphate	$Ca(H_2PO_4)_2$ and $CaHPO_4$	16% P_2O_5	10,000	13	308,000
10-20-10			154,009	16	250,000
12-12-12			91,875	10	400,000
18-46-0			85,328	37	108,000
16-6 -12			69,069	11	364,000

*Assume 30#N/ton manure; 25#P_2O_5/ton manure; and 35#K_2O/ton manure.

**Assumes that all 4,000,000 tons/year of feedlot manure produced in Texas is used to replace the given commercial fertilizer; values are mutually exclusive.

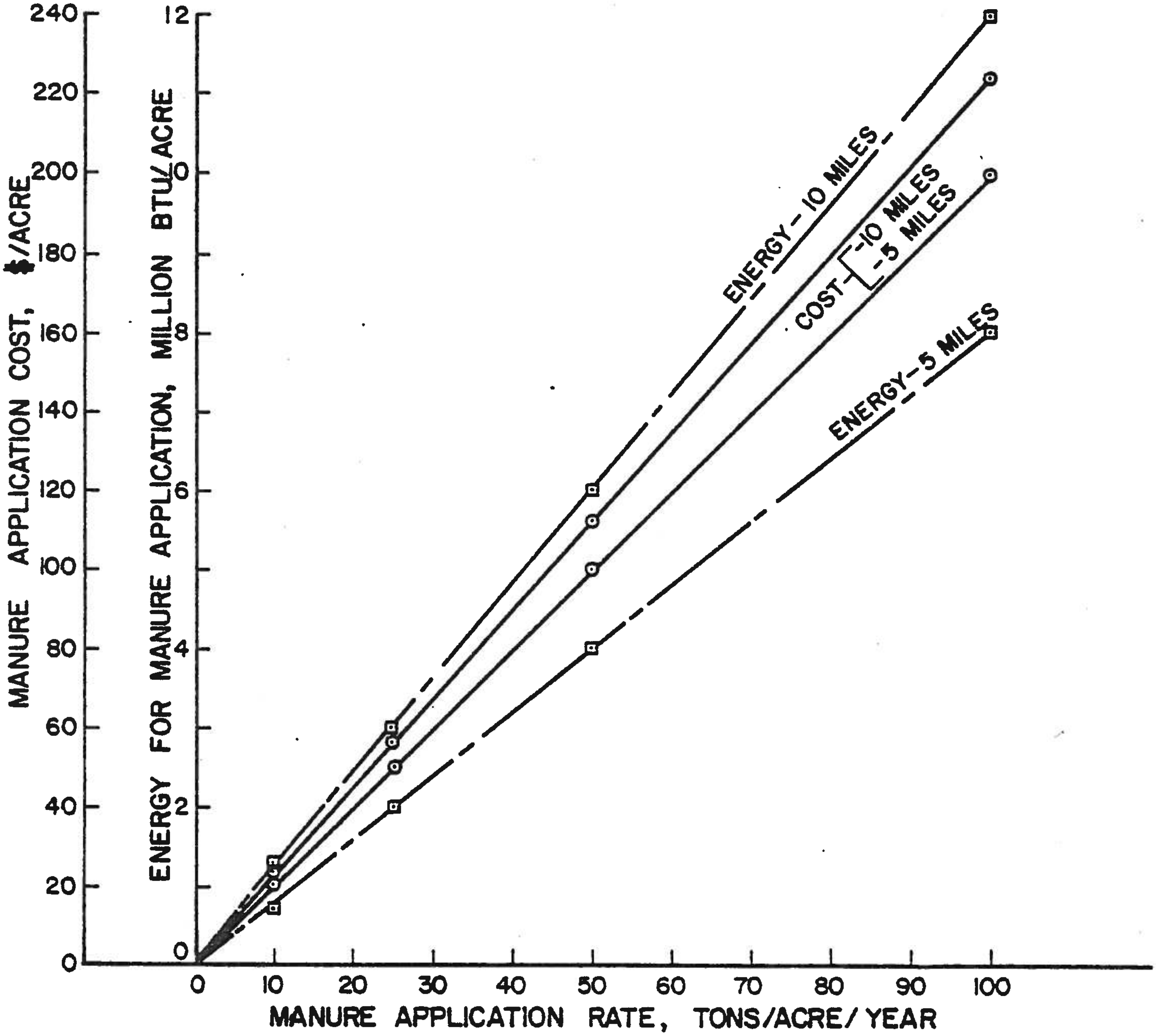

FIGURE 2. COST AND ENERGY REQUIREMENT FOR HAULING & SPREADING MANURE AT VARIOUS APPLICATION RATES (5 AND 10 MILE HAUL DISTANCES)

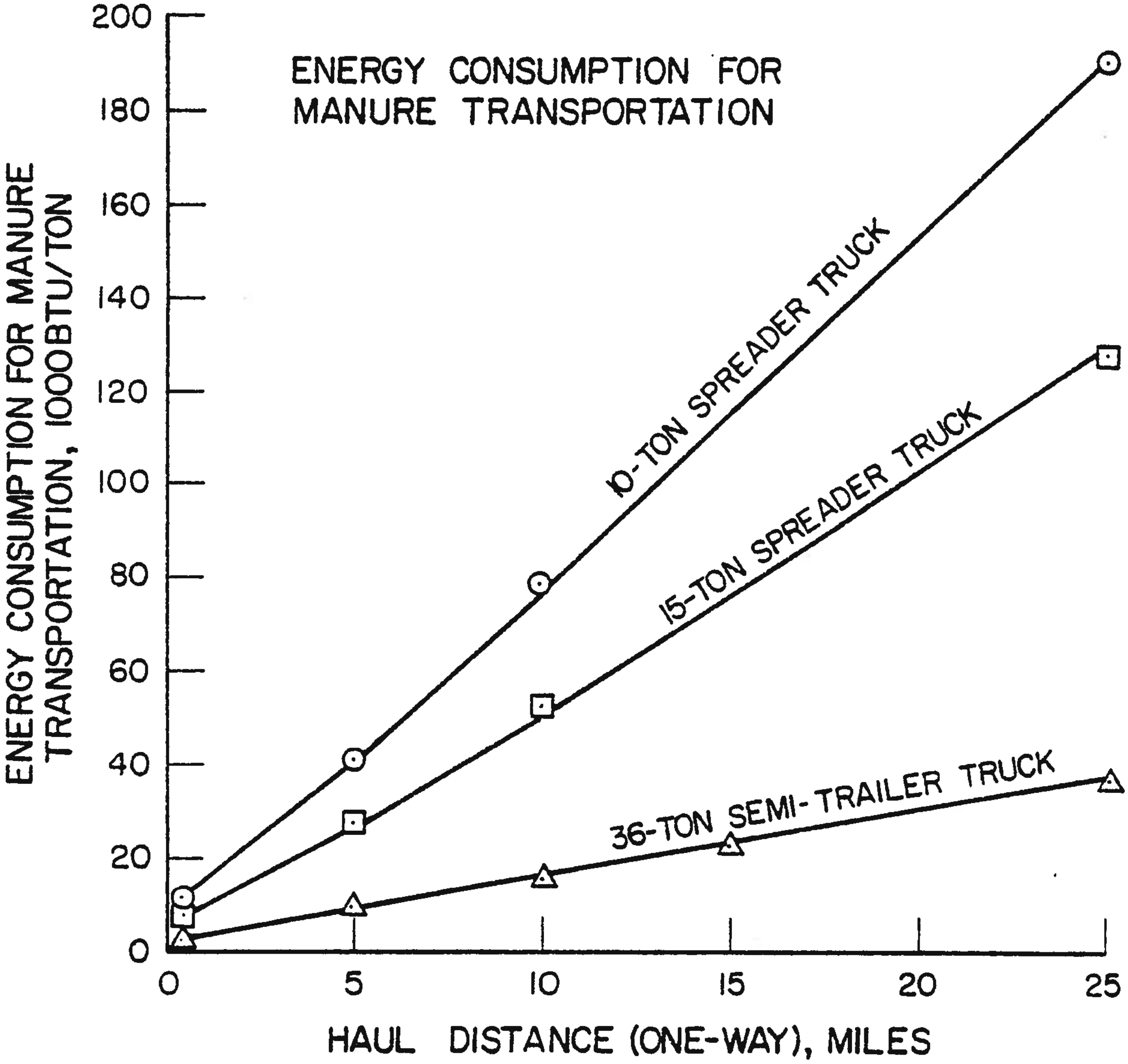

Figure 1. Amount of energy consumed (roundtrip) in hauling manure in spreader and semi-trailer trucks.

TABLE III

COMPARISON OF ENERGY REQUIREMENTS FOR COMMERCIAL FERTILIZER VS. FEEDLOT MANURE ON GRAIN SORGHUM AND CORN SILAGE

Haul Distance, miles	Energy for Comm. Fert. (180-60-0)* Million BTU/Acre	Energy for Feedlot Manure (10 ton/acre) Million BTU/Acre	Energy Savings from Feedlot Manure Million BTU/Acre
5	5.58	0.80	4.78
10	5.58	1.20	4.38

*Assumes nitrogen applied as anhydrous ammonia and phosphorus as concentrated superphosphate.

TABLE IV

COMPARISON OF COST FOR COMMERCIAL FERTILIZER VS. FEEDLOT MANURE ON GRAIN SORGHUM AND CORN SILAGE

Haul Distance Miles	Cost of Com'l Fertilizer* (Applied) $/Acre	Cost of Manure (Applied) $/Acre	Cost Savings for Feedlot Manure $/Acre
5	$39.00	$20.00	$19.00
10	39.00	22.50	16.50

*Assumes 15¢/lb. for N and 20¢/lb. for P_2O_5.

Manure as a Ration Ingredient

Fresh cattle manure sometimes contains more than 23% crude protein (or 3.75%N) on a dry weight basis (Table V). At that level, manure contributes protein to the ration. Various refeeding programs have been devised for utilizing fresh feedlot manure (Anthony 1971) (Stone et al. 1971).

However, biodegraded feedlot manure often contains only 8.4% crude protein (i.e. 1.34%N) (Mathers et al. 1973) (Wells 1973). Nitrogen is lost through volatilization before the manure is collected from the feedlot surface at 120 to 365 day intervals. In fact, Berg et al. (1973) reported a 12% decrease in manure protein content after a storage period of only 4 days.

Hence, because of its low protein and energy content, feedlot manure is looked upon as a substitute for roughage rather than for grain. Albin (1974) stated that manure can be directly substituted in the feedlot ration for low quality roughages such as cotton burs or gin trash, which frequently are included in the ration at levels up to 6%. This substitution will have no effect on cattle performance. However, if manure is used to replace high quality roughages such as alfalfa hay, expensive protein and energy supplements must be added to the ration to maintain acceptable cattle performance.

Parrott (1974) concluded from least-cost ration programming, that feedlot manure can be fed at the 5% level (replacing half the alfalfa) with only a 2% gain penalty. A 10% gain penalty would result, however, from replacing the entire 10% alfalfa fraction with manure. Albin (1974) similarly concluded that 7.5% is the maximum level at which feedlot manure can be feasibly included in a feedlot ration.

Economics of Manure Refeeding

Let us examine the potential reduction in ration cost and in energy needed to produce the ration that would result from inserting feedlot manure into the ration at the 5% level, as suggested by Parrott (1974). The use of 100 lbs per ton of feedlot manure (wet basis) in a \$130/ton ration would save 100 lbs of cubed alfalfa, which presently costs \$70/ton. If manure is charged at \$0.75/ton--the cost of collection, loading, and bulk storage--this would lower the ration cost to \$126.54/ton. Taking into account the 2% reduction in gain from the manure ration, gain costs would be as follows:

Standard Ration

$$(\text{Gain Cost})_1 = (\text{Conversion Ratio, lbs feed/lb gain}) \times (\text{Ration Cost, \$/lb})$$

$$= 8.0 \times \frac{\$130/\text{ton}}{2000\ \text{lbs/ton}} = \underline{\underline{\$0.52\ \text{per lb gain}}}$$

5% Manure Ration

$$(\text{Gain Cost})_2 = \frac{(8.16\ \text{lbs feed})}{(\ 1\ \text{lb gain}\ )} \times \frac{(\$126.54/\text{ton}\ )}{(2000\ \text{lbs/ton})} = \underline{\underline{\$0.52\ \text{per lb gain}}}$$

TABLE V

Characteristics of Cattle Manure Collected from Slatted Floor, Shallow Pit Confinement Unit and from Surface of Open Feedlot (Wells 1973)

(800 lb. Average Liveweight)

Parameter	Slatted Floor lb/head/day	Open Feedlot lb/head/day
Total (wet solids)	48.0	8.0
Moisture	40.8	2.26
Dry Solids	7.2	5.74
Volatile Solids	5.8	3.96
pH	7.3	7.6
BOD_5	1.0	0.68
COD	3.5	2.40
Ash	1.7	1.78
Total Nitrogen	0.27	0.18
Ammonia Nitrogen	0.08	0.07
Nitrate Nitrogen	0.04	0.03
Total Phosphorus	0.07	0.09
Total Potassium	0.18	0.13
Magnesium	0.04	0.04
Sodium	0.08	0.08

Hence, feedlot manure can be fed successfully at the 5% level at today's feed prices. However, feeding manure at the 10% level (replacing all the alfalfa) would increase the gain cost to $0.54/lb because of poorer cattle performance.

Energy Savings with Manure Refeeding

The energy saved by refeeding one ton of feedlot manure is equivalent to the energy required to produce one ton (or 1/6 acre) of alfalfa in the western High Plains area, less the energy required to preprocess the manure in a hammermill (about 6000 BTU/ton dry solids). Importantly, freshly collected feedlot manure would not have to be predried to allow refeeding at these low levels.

The amount of fuel and energy required to establish, produce, harvest, and market one acre of alfalfa in that area is shown in Table VI to be 25.1 million BTU's per acre. Thus, the net amount of energy saved by using 5% manure in a feedlot ration is 4.2 million BTU's per ton of manure (wet basis) or 6.5 million BTU's per ton of dry solids. This compares to the thermochemical heat value of manure of 12.6 million BTU's/ton of dry solids.

Other Benefits of Refeeding

A refeeding program might encourage practices which improve odor conditions in feedlots. For example, frequent manure collection would help retain the manure's protein value. To keep ash and moisture contents low, only loose surface manure would need to be removed. This would eliminate the need to excavate the odorous anaerobic layer or "manure pack". And, use of solid concrete flooring to enhance collection of a high quality manure might lead to closer cattle spacing and a lower volume of feedlot runoff.

More frequent collection of manure and/or different types of feeding programs could lead to much higher levels of manure in cattle rations that indicated above, reducing the overall quantity of manure for terminal disposal. (For example, Hull & Dobie (1973) successfully wintered pregnant beef cows on dry native range grass using "range cubes" containing 75% feedlot manure and 25% barley). Moreover, feeding manure to range cattle would provide the vehicle for ultimate disposal on pastures, in contrast to the continuing need for ultimate disposal with refeeding programs at the feedlot.

Energy Production From Manure

Whetstone et al. (1974) observed that "diamonds could be made from manure, but only an infinitesimal amount of manure could be disposed of in this manner." To utilize as much manure as possible, it is more productive to think in terms of commodities that have a relatively low value but large potential market. Three such commodities are energy, fuels to make energy, and fertilizer.

Several basic thermochemical processes have been proposed to utilize the energy potential available in the organic fraction of manure. Three of these processes are complete combustion, partial oxidation and pyrolysis. The main difference between them is the amount of oxygen present in the reactor (Halligan and Huffman 1974).

TABLE VI

ANNUAL FUEL AND ENERGY CONSUMPTION FOR ONE ACRE OF ALFALFA PRODUCTION [1/]

Form of Energy Input	Establishment Phase		Production and Harvest	Transportation*	Total Amount of Fuel	Equivalent Energy Consumption** BTU/acre/yr
	Total Input	Annual Input				
1. Diesel Fuel (tractor), gal	10.9	2.2	17.1	-	30.2	4.2×10^6
2. Natural gas (irrigation), 1000 ft^3	5,300	1,100	9,100***	-	15,500	15.5×10^6
3. Gasoline (Pickup or trailer truck), gal	1.8	0.4	2.9	5.6	10.7	1.3×10^6
4. Fertilizer						
a) Nitrogen, lbs	-	20	-	-	20	0.5×10^6
b) P_2O_5, lbs	-	100	120	-	220	2.1×10^6
c) K_2O, lbs	-	-	60	-	60	1.5×10^6
					TOTAL	25.1×10^6 BTU/acre/yr

[1/] Sprott 1974; Texas Agricultural Extension Service, 1974.

*Assumes one-way haul of 50 miles and 36 tons per load.

**The following energy values were assumed: diesel fuel = 138,000 BTU/gal; gasoline = 124,000 BTU/gal; natural gas = 1000 BTU/cu ft; nitrogen = 23,800 BTU/lb; P_2O_5 = 9,500 BTU/lb; and K_2O = 25,000 BTU/lb.

***The annual irrigation requirement could easily be as high as 41×10^6 BTU/acre under dry-weather conditions which include 36" water application; 300 ft water table; and use of center pivot sprinkler system operating at 70 psi and 750 gpm (New 1974).

Combustion

Direct combustion of manure as a boiler fuel would permit recovery of energy as electrical power (Whetstone 1974). Elemental analyses of manure indicate similar characteristics, for example, as lignite from the Beulah seam in North Dakota. Manure has a lower oxygen content (an advantage) but a higher ash content (a disadvantage).

The gross heating value of feedlot manure typically ranges from 5750 to 6730 BTU per lb of dry solids (Halligan and Huffman 1974). This is slightly higher than the 4500 BTU/lb reported for municipal solid waste, but well below the 12,000 BTU per lb for coal. Some authors suggest that manure be mixed with coal to help attenuate the variations in fuel value of manure and to increase plant flexibility (Whetstone 1974). Since manure is a low-sulfur fuel, coal with higher-than-normal sulfur content could be used with manure to stay within the sulfur dioxide emission standards.

Feedlot cattle typically generate 5.7 lbs collectable solids per day (Table V). This "fuel" has a gross energy value of 36,000 BTU/day. The gross heating value per ton of feedlot manure obviously depends upon moisture and ash contents, which are a highly variable factor. Manure from 23 High Plains feedlots ranged in moisture content from 21 to 55%, with an average value of 35% (Mathers et al. 1973). Manure hauled from the feedlot would thus have an average gross heating value of 8.2 million BTU/ton wet basis, or 12.6 million BTU/ton of dry solids.

Experience with an operating poultry manure dehydration plant in Texas has shown an energy consumption of 1440 BTU/lb water evaporated (Duske 1974). In addition, electrical energy to convey and recirculate manure (wet and dry) inside the plant amounts to 0.35 million BTU/ton dry solids output. Operation of the afterburner for odor control consumes another 14.8 million BTU/ton dry solids (without heat exchanger) or 5.4 million BTU/ton dry solids (with heat exchanger).

Consequently, the energy consumed in transporting, handling, and igniting feedlot manure could be at least 4,780,000 BTU/ton of feedlot manure processed, (or 7.35 million BTU/ton of dry solids) for a plant with heat exchanger. Hence, the net energy consumption would be estimated at 5.3 million BTU/ton of dry manure solids (Table VI).

This is a slightly lower energy yield than can be realized from manure refeeding to feedlot cattle, yet it does not account for the obvious disadvantages of centralizing manure for such a capital intensive operation. Direct combustion may be practical only when used in conjunction with coal fired steam production systems. As with most power generating installations, pollution control and specialized equipment requirements indicate considerable effect of scale on initial investment and expected economic feasibility.

Gasification for Ammonia Production

Anhydrous ammonia (NH_3) can be produced through partial oxidation of manure. This would have obvious regional advantages because of the proximity of feedlots to feed grain sources.

The organic matter in manure serves as a source of hydrogen which, when generated,

TABLE VI

NET ENERGY FROM COMBUSTION OF FEEDLOT MANURE AT 35% MOISTURE

(BTU/TON DRY SOLIDS)

Item	Energy Consumption 10^6BTU/ton	Energy Production 10^6BTU/ton
1. Transportation (25 mile haul)	0.04	
2. Dehydration Pretreatment		
(a) Materials Handling	0.35	
(b) Drying	1.56	
3. Afterburner	5.40	
4. Gross Energy Value from Combustion		12.6
5. Totals	7.35	
6. Net Energy from System		5.3

can then be synthesized with atmospheric nitrogen in a conventional ammonia production plant (Young et al. 1973). In this way, manure replaces natural gas as the supplier of carbon monoxide and hydrogen for the synthesis gas. An end-product "char" (rather than natural gas) is combusted to produce steam for a needed shift reaction. No predrying of the feedlot manure is needed.

According to Halligan and Sweazy (1972), the partial oxidation reaction is as follows:

$$\underbrace{C_{3.14}H_{4.6}O_{1.67}}_{\text{Manure}} + \underbrace{0.49\ O_2 + 1.96N_2}_{\text{Air}} + \underbrace{0.49H_2O}_{\text{Water}} \rightarrow \underbrace{3.14CO + 1.96N_2 + 2.79H_2}_{\substack{\text{Synthesis Gas for} \\ \text{Ammonia Production}}} \tag{1}$$

This partial oxidation process itself is adiabatic for all practical purposes (Halligan 1974).

The following shift reaction then takes place inside the ammonia plant in the presence of steam:

$$3.14\ CO + 3.14\ H_2O \rightarrow 3.14\ H_2 + 3.14CO_2 \tag{2}$$

The carbon dioxide produced from this so-called steam reforming process can be separated and collected. This leaves hydrogen and nitrogen gas in almost a perfect 3:1 ratio (Equations 1 and 2).

Other by-products of this reaction include a solid (char), a gaseous mixture, and a liquid condensate. The dry char, produced at the rate of approximately 380 lbs per ton of dry manure solids, has a heat value of approximately 4800 BTU/lb. Thus the char has a gross heat value of 1,824,000 BTU/ton dry manure solids processed. After deducting 634,000 BTU/ton for heat losses due to evaporation, this leaves a net energy production of about 1,200,000 BTU/ton dry manure.

If we assume that the heat value of the char exactly balances the heat energy requirement for the steam reforming process (equation 2) and that the partial oxidation reaction (equation 1) is adiabatic, then the net energy savings of the process is equal to the energy required in conventional ammonia production minus the sum of the energy consumed in manure transportation and by-product redistribution. Production of ammonia by conventional methods requires 39 million BTU's per ton of ammonia yield. The potential yield of ammonia from gasification of feedlot manure is estimated at 825 lbs ammonia per ton of dry manure solids (or 530 lbs per ton of 35% moisture & 25% ash manure) (Halligan and Huffman 1974). Therefore, by producing one ton of ammonia from manure, the fertilizer manufacturer can save 39 million BTU's energy while using 3.75 tons of "wet" manure (2.4 tons of dry manure solids). This would indicate an energy savings of 16 million BTU's per ton of manure solids entering the plant.

For a one-way haul distance of 25 miles, only 40,000 BTU would be expended per ton of manure hauled. This represents only 0.3% of the latent heat energy in manure and a sacrifice in ammonia yield of only 1.6 lbs NH_3 per ton of manure hauled. Redistribution of solid and liquid by-products, if land disposal were entailed, would require an even smaller amount of energy.

The cost of producing ammonia by this method is projected at $19 per ton of NH_3 (Halligan and Huffman 1974). This includes a $3.00/ton manure transportation charge, which is typical of today's 25-mile haul charge, including $0.50/ton paid to the feedlot.

The success of this process would depend upon economics of scale. A plant producing 1000 tons NH_3 per day would cost an estimated $30 - $40 million (Halligan 1974). According to the researchers, a plant of this type would be feasible only if placed within 15 miles of cattle feedlots having at least 600,000 head capacity.

At the present time, gasification of manure is still in the laboratory state. To extend the project through the pilot plant and prototype stages may require much additional research to solve existing and unforseen problems. Nevertheless, this process shows promise for the future.

Pyrolysis

The calculated heating value of gases and char from the pyrolysis of various animal wastes, according to White and Taiganides (1971), are shown in the following table.

Calculated Heating Values of Gases
and Char from Pyrolysis of Animal Wastes

Animal	BTU per lb of wet matter
Swine	430
Beef	830
Dairy	350
Poultry	900

Garner et al. (1972) indicated a somewhat different breakdown, but predicted energy recovery in the form of gas to be about 300-400 BTU/cu ft and recovery of the dry raw manure fuel value at 20 to 30%. His approach was to analyze the pyrolysis process as a means of disposing of animal waste. He concluded that direct incineration was more economical.

A process study by Feldman et al. (1973) of a hydro-gasification plant utilizing cattle manure to produce gas indicates a potential energy production of 9.2 million BTU/ton of dry solids. This process utilized both carbon monoxide and hydrogen, respectively, as synthesis and feed gases for the conversion. A proposed feed rate of 690,000 lb/hr of 30% moisture content manure was used for the plant analysis. The estimated gas cost was 41¢/million BTU. If the plant had to pay $1/ton for the manure, gas cost would increase 15¢/million BTU.

Based on average waste production, the feed rate indicated above would require approximately 1.5 million head of beef cattle. Potential numbers are available in the Texas Panhandle area; however, haul distances would be such that average manure costs would exceed $3 per ton for handling and transportation. Thus the cost for the gas would be equal to or greater than the projected cost of coal gas.

The amount of energy saved by refeeding 5% manure in a feedlot ration is 6.5 million BTU's per ton of manure (dry solids). This is the equivalent energy required to produce 1/6 acre of alfalfa that would otherwise be consumed.

Feedlot manure releases about 12.6 million BTU's per ton (dry solids) upon direct combustion. However, energy requirements for air pollution control systems and moisture evaporation would lower yields of useable heat energy to about 5.3 million BTU's per ton of dry solids.

According to laboratory research, gasification of manure through partial oxidation would result in production of anhydrous ammonia with far lower energy consumption than is now being realized. Indications are that energy savings would exceed 10 million BTU's per ton of dry solids. This would be true unless the energy required for air and water pollutions abatement becomes excessive.

Conclusions

Thus, refeeding appears to offer the maximum potential for energy savings among the presently available processes. But, unless stocker or range cattle markets for feedlot manure can be created, refeeding offers little promise as a method of manure disposal per se.

Land disposal for improved crop production (eg. 10 ton manure/acre) does save energy and allows a needed steady outflow of manure from the feedlot. This alternative is readily available to almost all feedlots and should continue to be exploited.

Thermochemical processing of feedlot manure could result in larger energy savings than are now possible. However, because of the large scale centralization necessary, most Texas feedlots may never have this alternative available to them.

Methane Production

Recovery of methane or "bio-gas" from farm animal wastes through anaerobic digestion is a process which has been utilized to varying degrees in underdeveloped countries and/or where fossil fuels are in short supply.

The process involves utilization of acid-forming and methane-forming bacteria to produce methane (CH_4) and carbon dioxide. Careful control of temperature, feed rate, pH and other factors is very important to proper operation. Based on small research-sized plants, the expected yield of methane gas from various livestock can be predicted as follows (Lindley 1974):

	Livestock	Methane Production cu ft/animal/day
1.	Beef Cattle	15 - 25
2.	Dairy Cattle	35 - 75
3.	Swine	2
4.	Chickens	0.1
5.	Sheep	15
6.	Turkeys	1
7.	Horses	110

Depending on the raw manure characteristics and process operating conditions, bio-gas evolved from an anaerobic digester may be composed of 30 to 95% methane (Merrill and Merrill, 1973) with the remainder being made up of other gases such as CO_2, H_2S, NH_4 and mercaptans. A properly operating system can produce a 60% methane gas with a heat value of approximately 600 BTU/cu ft.

Besides methane gas production, useful by-products of methane production systems include sludge and liquid displaced by daily raw waste inflow. Indications are that the digested residue remaining after methane production will make a valuable fertilizer. All of the potassium and phosphorous and 33 to 100% of the nitrogen will remain in the sludge.

Investment requirements or plant operating expense are difficult to predict because no large scale installations exist at present. However, general estimates show that methane will be produced at above current market prices for natural gas. A further disadvantage pointed out by some is that because of low solids requirements (i.e. high dilution ratio), significantly more waste material must eventually be handled. In addition, methane can be explosive at concentrations higher than about 10% in air.

Summary

A comparison was made of the energy savings available from feedlot manure utilized for the following purposes: (1) fertilizer; (2) roughage substitute in feedlot rations; (3) fuel; and (4) substitute for natural gas in anhydrous ammonia production.

Results showed that use of manure instead of commercial fertilizer could save 0.7 million BTU per ton of manure (dry basis), or 4.5 million BTU's energy per acre under certain cropping situations prevalent in the Texas High Plains. This would result in a total energy savings of 1.8×10^{12} BTU's of energy per year, which is only 3.5% of the total energy consumed in producing and distributing the 1.5 million tons of fertilizer used in Texas each year.

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