



The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search

<http://ageconsearch.umn.edu>

aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

No endorsement of AgEcon Search or its fundraising activities by the author(s) of the following work or their employer(s) is intended or implied.

ENVIRONMENTAL AND ECONOMIC ASPECTS OF RECYCLING LIVESTOCK WASTES— ALGAE PRODUCTION USING WASTE PRODUCTS

John B. Martin and Carl E. Madewell*

Attention is now focused upon problems confronting our Nation in the area of environmental pollution. There is a close correlation between industrial and agricultural expansion and increases in population over the last few decades. There is also a pronounced association between increases in population and the magnitude of pollution problems. As an example, there is some concern about environmental pollution associated with power production which is rapidly expanding to meet the demands for electricity of an increasing population and industrial complex. Power production expansion is occurring largely in areas which already have high population densities.

The same trend holds true for the livestock industry. Expansion of this agricultural enterprise to include large confined feeding operations is potentially a pollution problem with respect to waste disposal and nitrate contamination of local water sources, especially in more heavily populated humid areas. This expansion has occurred to meet the demands for livestock products by increasing numbers of people. For example, 15.4 billion pounds of beef, 11.7 billion pounds of pork, and 5.3 billion pounds of poultry were consumed in the United States in 1960. In 1968 consumption increased to 22.0 billion pounds of beef, 13.3 billion pounds of pork, and 8.2 billion pounds of poultry. Projected consumption in 1980 is 36.2, 16.2, and 14.5 billion pounds, respectively [2]. So, it is evident that the livestock industry will most likely expand in concentrated units. From an environmental pollution viewpoint, such an expansion will have to be compatible with a rapid increase in population.

We will discuss herein the economic feasibility of simultaneously increasing food production and decreasing potential pollution problems by producing algae (a high protein feed source) from nutrients in waste disposal systems. This could convert a potential

livestock waste pollutant into an economic resource while reducing fertilizers needed and other potential pollutants.

WASTE DISPOSAL PROBLEM

The magnitude of waste disposal problems from confined feeding operations, as well as sources for nutrient elements, is illustrated in Table 1 [7].

Livestock wastes in the United States are in excess of a billion tons of fecal waste per year, including over 400 million tons of liquid effluent. Probably half of this waste is produced under concentrated conditions which in certain cases might cause problems in environmental pollution. Nutrient elements in this quantity of agricultural wastes could produce phenomenal quantities of algal protein through a recycling system.

In the past, manure disposal involved spreading on cropland, but with confined feeding operations, particularly in highly populated areas, land for this disposal is becoming limited and supplies concentrated, so it is essential that other disposal alternatives be evaluated. One system that has been proposed involves using nutrient elements contained in livestock wastes for algae production in a series of lagoons or ponds. Such a system integrated into a feedlot operation should reduce the accumulation of nitrates in ground water and also in nearby lakes and streams, thereby decreasing the potential for more acute eutrophication. The algae, or maybe other plants produced hydroponically, could be harvested and processed into a high protein feed source for livestock. With proper processing, algae may have some merit for human consumption.

*Agronomist and agricultural economist, respectively, Agricultural Resource Development Branch, Tennessee Valley Authority, Muscle Shoals, Alabama.

TABLE 1. ORGANIC AND MAJOR FERTILIZER ELEMENTS IN THE COMPLETE ANIMAL EXCREMENT PER 1,000 POUNDS OF LIVE ANIMAL WEIGHT

	Hens		Hogs		Cattle	
	Lbs./day	Lbs./yr.	Lbs./day	Lbs./yr.	Lbs./day	Lbs./yr.
Wet manure	56	32,200	70	22,400	64	20,600
Total mineral matter	3.9	1,400	1.8	600	2.1	800
Organic matter	12.2	4,400	9.4	3,400	8.2	3,000
Nitrogen (N)	0.93	333	0.50	185	0.38	138
Phosphorus (P ₂ O ₅)	0.69	253	0.26	110	0.11	41
Potassium (K ₂ O)	0.34	118	0.48	172	0.31	112

RESOURCE POTENTIAL OF POLLUTANT

The tremendous potential for production of protein using algae has been illustrated by Oswald and Golueke [6]. They produced 20 tons of algae (50 percent protein) per acre of pond with domestic sewage in large-scale pilot plants at Richmond, California. They reported that protein and energy yields from algae were much greater than from agronomic crops (Table 2). For the 283 million acres of traditional cropland shown in Table 2, less than 5

million acres would yield equivalent protein.

Beall discussed systems, including greenhouse-poultry-algae operations, that could be conducted to utilize waste heat near nuclear steam generating plants [1]. He estimated yields of 1.5×10^6 pounds of algae per year from a 50-acre culture and valued the algae at three to five cents a pound if incorporated into fish or animal feeds. Such an operation could be even more impressive if credited with an economic value for treating waste sewage or utilizing waste heat from steam plant effluent.

TABLE 2. COMPARISON OF LAND USE FOR FOOD AND ANIMAL FEED PRODUCTION WITH CONVENTIONAL CROPS AND WITH ALGAE

Crop	Land Use Total Area (millions of acres)	Area of Micro-algae Culture Required for Equal Production (millions of acres)	
		Total Free Energy Basis	Protein Basis
Corn	82	4.1	1.67
Hay	69	3.2	1.00
Wheat	53	1.1	0.55
Oats	27	0.8	0.25
Soybeans	23	0.4	1.10
Sorghum	15	0.4	0.20
Barley	14	0.3	0.14
Total	283	10.3	4.91

Production of algae competes favorably with conventional uses of water in production of agronomic crops. Generally, one acre-foot of water produces about 288 pounds of protein with soybeans, 120 pounds of protein with corn, and 90 pounds of protein with wheat. The same quantity of water produces about 5,000 pounds of protein with algae culture (Table 3) [6].

Production of one gram of algae requires 0.4 gram carbon, 0.1 gram nitrogen, and 0.01 gram phosphorus, and certain amounts of secondary and micro-nutrients. Animal wastes should be an excellent source of nutrients for algae. In addition to nitrogen, phosphorus, and potassium contained in animal wastes (Table 1), considerable amounts of other elements essential for plant growth are also present (Table 4) [7].

TABLE 3. COMPARISON OF WATER USE FOR PROTEIN PRODUCTION WITH AGRONOMIC CROPS AND WITH ALGAE

Crop	Annual Protein Yield, lbs./acre	Annual Consumptive Water Use, Acre-feet per acre	Lbs. of Protein per acre-foot
Soybean	576	2.0	288
Corn	240	2.0	120
Wheat	135	1.5	90
Algae	20,000	4.0	5,000

TABLE 4. POUNDS OF SECONDARY AND MINOR ELEMENTS IN 1,000 GALLONS OF FRESH ANIMAL MANURES

Manure	Calcium	Magnesium	Sulfur	Iron	Zinc	Boron	Copper
Hen	300.0	24.0	26.0	3.9	0.75	0.50	0.12
Hog	47.0	6.6	12.0	2.3	0.50	0.35	0.13
Cattle	17.0	8.7	5.8	0.33	0.12	0.12	0.04

COMPARATIVE PRODUCT VALUE

Prospects look favorable that the expected need for plant proteins, as well as the vitamins and minerals, can be met rather economically by the culture of new plants and animals such as algae, yeast, and fish (Table 5).

If these new farming operations prove commercially feasible, good quality protein, along with vitamins and minerals, should become more available to poor elements of our population, especially the children, and also to the poverty-stricken in less developed countries.

Mattoni, et al., also showed algae to be an excellent protein source when compared with soybeans, corn, and sugarcane (Table 6) [4].

From 1960-66, feeding trials were conducted at the University of California (Davis) to evaluate the use of algae as an animal feed. A pelletized mixture of barley and algae (10% algae in mixture) with small quantities of vitamin B₁₂ was as efficient as barley and fish meal for swine production. Rations containing 10 percent algae were rated excellent for sheep production. In studies with cattle, it was found that ruminants digested algae more readily than non-ruminants.

Other aquatic plants may have a potential for livestock feed. Martin analyzed three locations in Pickwick Reservoir in 1966 and found Najas, a rooted submerged species, to contain from 16.0 to 20.0 percent protein and rather high concentrations of other elements (Table 7) [3]. Yields of over 600 pounds per acre-foot were observed under existing stream conditions. Such yields might be multiplied in

solutions enriched with livestock wastes.

ESTIMATED PRODUCTION COSTS

It was estimated that algae production on domestic sewage at Lancaster, California, would recover about 1.2 billion gallons and produce about 2,400 tons of algae (40-50% protein) annually. The esti-

TABLE 5. ESTIMATED MARGINAL COST FOR PROTEIN PRODUCTION [5]

	Anticipated Cost of Protein (per lb.)	Investment Required (Annual ton)
Fish farms	\$.40-1.00	\$ 1,000-2,500
Cane Juice: Food yeast	.35- .50	600-1,200
Fatty yeast	.70-1.00	1,200-2,000
Chlorella	.10- .20	300- 600
Blue-green algae	.05- .15	300- 600

TABLE 6. PROTEIN YIELDS PER ACRE WITH VARIOUS CROPS AND ALGAE

Crop	Nitrogen %	Protein %	Dry Matter Yield per acre per yr. (lbs.)	Protein Yield per acre per yr. (lbs.)
Soybeans	2.6	16.25	12,230	1,987
Corn	1.2	7.5	26,500	1,988
Sugarcane	0.285	1.78	111,579	2,879
Algae (mixed) principally Scenedesmus	8.19	51.2	100,000	51,200

TABLE 7. YIELD AND NUTRIENT CONCENTRATION OF NAJAS COLLECTED FROM THREE LOCATIONS IN THE TENNESSEE RIVER

Location	Pounds of Oven-Dry Plant Material Per Acre-Foot of Water	Ca	Mg	K	Protein	P	Fe	Mn	Zn	Cu
Bruton Branch, Pickwick Lake	744	1.2	0.39	6.2	16.0	0.36	0.56	0.82	0.004	0.0015
Cane Creek, Pickwick Lake	760	1.2	0.34	6.8	20.0	0.73	0.52	0.46	0.018	0.0074
Town Creek, Wilson Lake	623	1.0	0.32	3.7	19.4	0.32	1.30	2.00	0.010	0.0019

mated costs of a plant for this type production would be about \$350,000 per year to operate and amortize, giving a production cost of \$150 per ton for algae. Not included in these computations are the beneficial effects of recovering 1.2 billion gallons of water and avoiding the cost of a conventional sewage disposal system.

The economics of algae production from livestock wastes integrated into a feedlot operation have not been evaluated experimentally. Potential yields of algae with the nutrients in manure from a 1,000-capacity hog feedlot were estimated on the basis of data given in Table 1. During a one-year period, assuming the feedlot operated at maximum capacity, about 3 million pounds of manure, containing about 25,000 pounds of nitrogen and 7,000 pounds of phosphorus, would be produced. On the basis of carbon, nitrogen, and phosphorus requirements of algae, this quantity of manure has the potential (assuming 100% utilization of nutrients) for pro-

ducing in excess of 300 tons of algae with nitrogen-fixing cultures and in excess of 100 tons with non-nitrogen-fixing cultures.

An estimated production cost for algae in an underdeveloped area was about \$70 per ton (Table 8) [5]. This estimate included about \$300 per hectare (\$121.41 per acre) per year for nutrients and water which would not be included in an integrated feedlot-algae production system as the animal waste would be supplying the nutrients.

RESEARCH NEEDS

Considerable research is needed on harvesting and processing of algae to make this an economically feasible operation. However, cost of production, harvesting, and processing would offset conventional costs of manure disposal. Methods for harvesting algae from domestic sewage have been investigated [6]. The algal suspension is concentrated, the re-

TABLE 8. PROSPECTIVE ECONOMIC CHARACTERISTICS OF BLUE-GREEN ALGAE PRODUCTION

Estimated for a Typical Location in an Underdeveloped Area

Assumptions as to Yield

50 tons/hectare (45,000 lb./acre) dry wt., 90%
of available minerals are utilized

Capital Costs

Land leveling (or shore installations)	\$ 1,000/hectare
Pump-aeration units (50/hectare)	10,000
Piping and valves (300 m/hectare)	2,000
Frames, channels, repair jigs, etc.	2,000
Central facilities (pro-rated)	1,000
(\$6,500 per acre)	<u>\$16,000/hectare</u>

Operating Costs

Labor (50 workers per 1,000 hectares, \$1,000 annual wage)	\$ 50/yr./hectare
Water and minerals	200
Power (at 1-2 ¢ per kwhr)	300
Plastics replacement and materials for repair	<u>150</u>
	\$ 700/yr./hectare

Total Costs

(10-yr. amortization, 8% interest on capital)	\$ 3,500/yr./hectare*
	(\$ 1,400/yr./acre)
	or about \$70/ton

*The product from such a plant is moist and very perishable, ready for some nearby food-processing unit. Dried product for storage will cost somewhat more.

sulting slurry dewatered and further concentrated, and the slurry dried for storage and handling.

While these estimates are of necessity tentative, they are subject to empirical tests. Some of the main elements of risk or uncertainty are (1) the development of an economical system of harvesting, processing, and marketing both from a private and social viewpoint, (2) maintaining a proper culture environment for maximum production, (3) disease and insect

control, (4) weather, (5) producing a product that is palatable for livestock consumption, and (6) maintaining high levels of management skills.

The Tennessee Valley Authority proposes to begin empirical tests to determine the feasibility of an integrated livestock-algae producing system to utilize nutrients from livestock wastes and thermal energy from a nuclear power generating plant.

REFERENCES

1. Beall, Sam E. Jr., "Uses of Waste Heat," pp. 1-18, presented at Oak Ridge National Laboratory, Reactor Division, Technical Seminar on Thermal Pollution, Oak Ridge, Tenn., Aug. 5, 7, and 12, 1969.
2. Heady, Earl O. and Leo V. Mayer, *Food Needs and U.S. Agriculture in 1980*, pp. 11-32, National Advisory Commission on Food and Fiber, Washington, D. C., Aug. 1967.
3. Martin, J. B. Jr., B. N. Bradford, and H. G. Kennedy, *Factors Affecting the Growth of Najas in Pickwick Reservoir*, 47 pp., TVA Publ. F70 ACD2, Tennessee Valley Authority, Muscle Shoals, Ala., 1969.
4. Mattoni, R. H. T., E. C. Keller, Jr. and H. N. Myrick, *Industrial Photosynthesis, a Means to a Beginning*, pp. 403-407, Bioscience 15, 1965.
5. Meier, Richard L., *Science and Economic Development: New Patterns of Living*, Second edition, pp. 35-78, The MIT Press, Jan. 1966.
6. Oswald, William J. and Clarence G. Golueke, "Large-Scale Production of Algae," pp. 1-42, presented before the International Conference on Single-Cell Protein at MIT, Cambridge, Mass., Oct. 1967.
7. Taiganides, E. P., *Disposal of Animal Wastes*, Part One, pp. 281-290, Industrial Waste Conference, Purdue University, 1964.