

Agricultural Residues, Including Feedlot Wastes

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INTRODUCTION

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Agriculture is the only industry that produces more energy than it consumes. For example, Pimmentel et al. [1] calculate the ratio of energy recovered to energy input for corn in 1970 was 2.82—a value that has decreased by 25% during the past 25 years because of our increased use of energy for fertilizers, pesticides, and grain drying. The grain that we harvest is actually less than 50% of the solar energy captured by cultivated plants. The remainder is in the aerial parts left in the fields after harvesting and is primarily disposed of by plowing or burning. Combined with animal wastes, these residues amount to more than 600 million tons annually. Conversion of this quantity of organic matter to useful industrial or agricultural products would essentially double our nation's agricultural capacity with little increase in input energy—a commodity becoming increasingly in short supply.

Several possibilities exist for utilizing the energy stored in plant residues: acid or enzymic hydrolysis to sugars [2, 3], methane generation [4], and conversion to a highly digestible ruminant feed by chemical or mixed culture fermentation [5] techniques. In the first method the rate of hydrolysis, yield, and sugars recovered depend on the substrate source, but all products are available for both human and animal consumption, as well as for industrial raw materials. Methanogenesis can recover approximately 50% of the energy in waste fibers as methane, a readily usable gas; if all our agricultural residues were fermented to methane, they would supply some 10% of our national energy needs. No nitrogen is lost in the fermentation

system and the residual solids may serve as an animal feed supplement. Converting residues into a highly digestible ruminant feed would greatly increase our human food supply. For example, increasing the digestibility of these fibers to 80% would provide enough feed to double our present cattle population and subsequently release enough grain to feed 700 million more people (based on 2400 kcal per person per day).

All three of these approaches have a potential capability of expanding our agricultural productivity and world food supply. However, much developmental work still remains before the most efficient or practical methods are determined for each of the wide variety of agricultural practices pursued throughout the United States.

Let us look at the kinds, quantities, and composition of residues produced by our vast agricultural industry. Also, we must understand the economics of collecting and storing these residues, as well as some of the potential problems of residue removal on soil productivity, something that concerns me as a scientist and a farmer.

LAND USE IN THE UNITED STATES

Actual tillable cropland in this country constitutes approximately one-fifth of the total land area (Table I). The remainder is nontillable pasture land, woodlands, and land used for urban centers and for transportation. Stripmined land appears to be rather insignificant, involving only about 0.16% of our land mass. Any significant accumulation of residues would, therefore, be confined to those areas where intensive cropping occurs. Even so, these residues are rather thinly distributed. Since there are between 300 and 550 million tons of crop residues produced each year, (Tables II and III), about 1 to 1.5 tons per acre are available for collection—a factor strongly affecting the cost of recovery.

All crops produce collectable residues. These crops are categorized as major crops (Table II) and minor crops, (Table III) based on acreages. Hay has been included in Table II even though it is not a residue but because of the extensive acreage involved and of its low ruminant digestibility, 50–60%. In Table III, all the different fruits and vegetables have been lumped into their respective categories rather than as individual crops. The residues produced by most of the crops included in Tables II and III are left scattered in the fields in

TABLE I
Land Use in the United States

Major land uses	Million acres ^[6] 1969
Land in farms (tillable)	
Cropland	336
Idle or cover crops	51
Pasture only	88
Grassland pasture (non-forested)	452
Forest and Woodland	
Pastured	62
Not pastured	50
Farmsteads, roads, etc.	<u>25</u>
	Total in farms---- 1064
Land not in farms	
Grazing land	287
Forest--not grazed	476
Other land--cities, railroad, wasteland, etc.	<u>437</u>
	Total not in farms-- 1200
	GRAND TOTAL----- 2264
Strip-mined land--1971	3.65 ^[7]
Strip-mined land reclaimed--1971	1.46 ^[7]

their particular growing areas. With only a few—sugarcane, vegetables, fruit, rice hulls, and peanuts—is there any significant accumulation at specific processing sites. Although the volume of accumulated residues is small by comparison to the overall total, it still affords an opportunity for establishing plants to process these wastes.

Primary crop-growing areas in the United States are illustrated graphically for several major crops (Figs 1-5). The most productive farmland and most intensively cultivated area lies in the upper Mississippi Valley, the Corn Belt. In this region, the yield of residues

TABLE II
Major Crops—1973 [8]

Commodity	Acres harvested X 10 ⁶	Tons/acre	Residue, dry wt.	
			Total X 10 ⁶	
			Minimum	maximum
Corn	62	2-3	124	186
Hay	62	3-7	186	434
Soybeans	56	1-2	56	112
Wheat	54	1-2	54	108
Sorghum	16	2-3	32	48
Oats	14	1-2	14	28
Cotton	12	1-2	12	24
Barley	11	1-2	11	22
Total	287		303 ^a	528 ^a

^a Total yields do not include hay crop.

TABLE III
Minor Crops—1973 [8]

Commodity	Acres harvested X 10 ⁶	Tons/acres	Residue, dry wt.	
			Total X 10 ⁶	
			Minimum	maximum
Vegetables	3.3	1-2	3.3	6.6
Fruit	3.1	1	3.1	3.1
Rice	2.2	1-2	2.2	4.4
Flax	1.8	1	1.8	1.8
Peanuts	1.5	1-2	1.5	3.0
Sugar beets	1.2	1-2	1.2	2.4
Sugar cane	1.1	6-10	6.6	11.0
Rye	1.0	1-2	1.0	2.0
Total	15.2		20.7	34.3

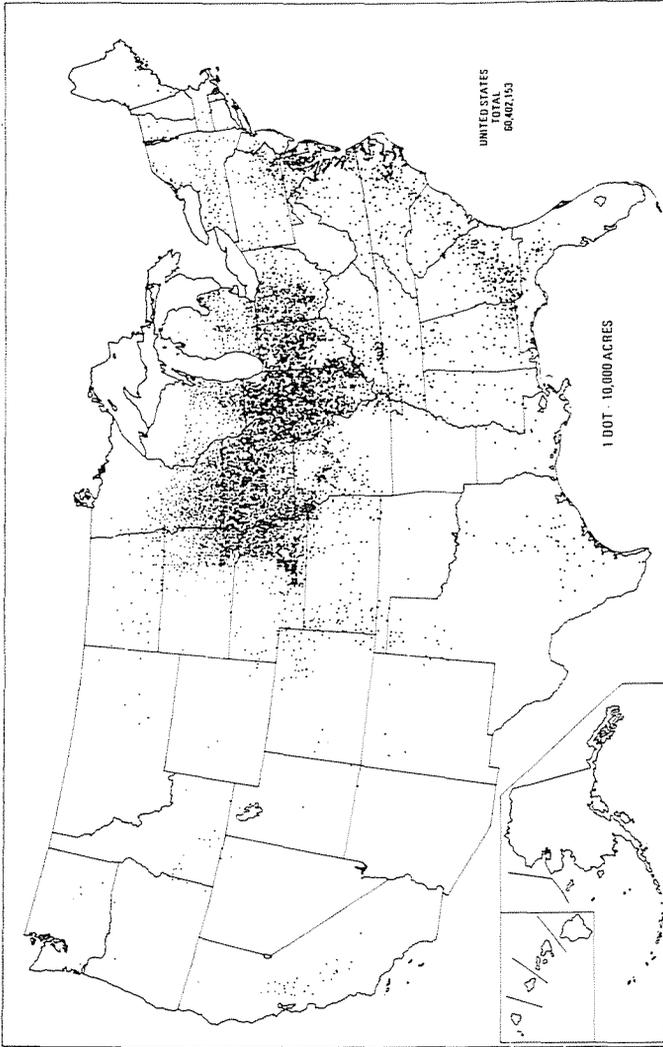


Fig. 1. Corn harvested for grain, 1969 [9].

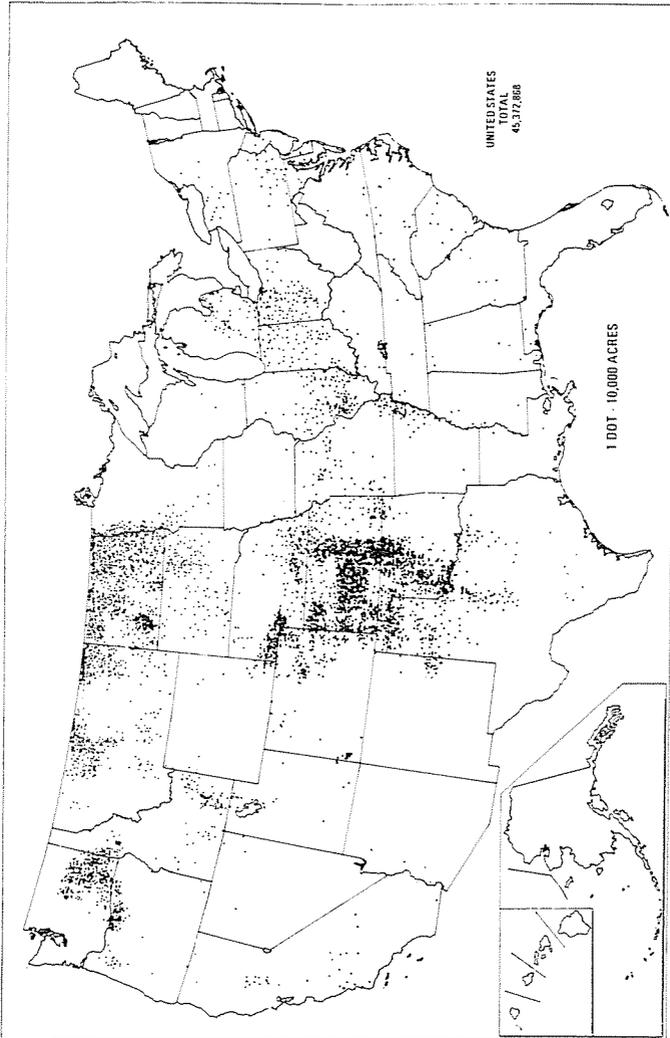


Fig. 2. Wheat harvested, 1969 [9].

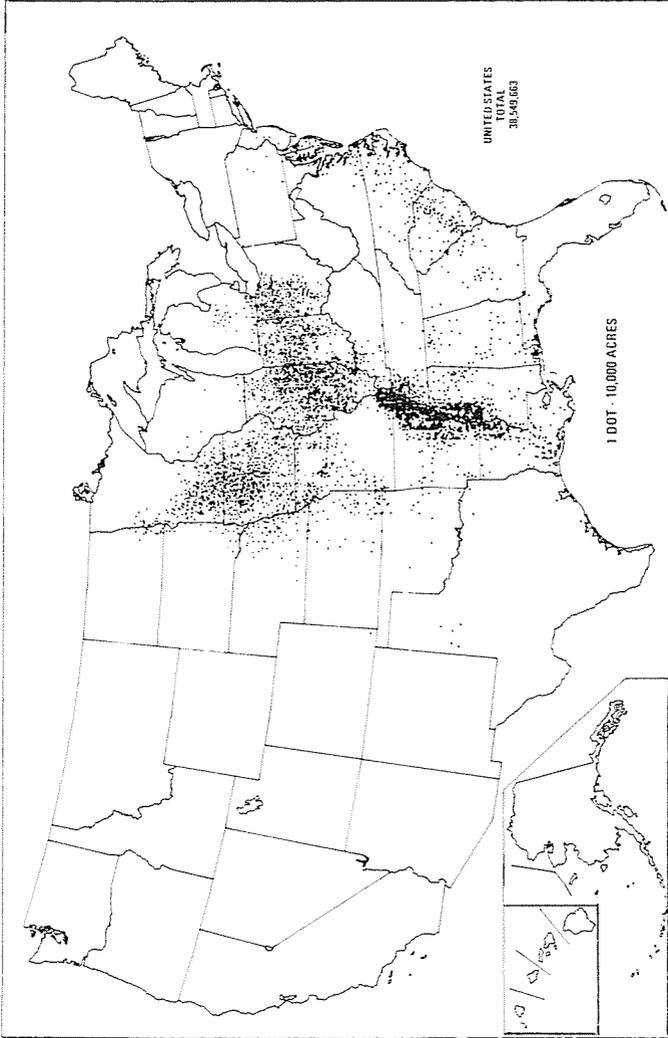


Fig. 3. Soybeans harvested for beans, 1969 [9].

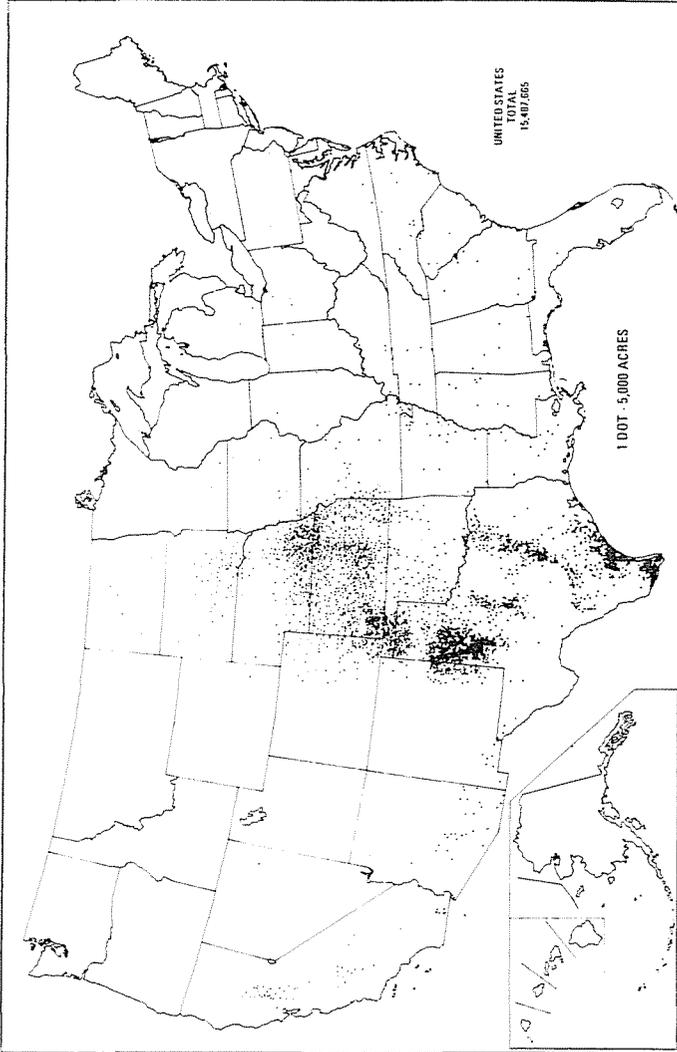


Fig. 4. Sorghum harvested for all purposes except syrup, 1969 [9].

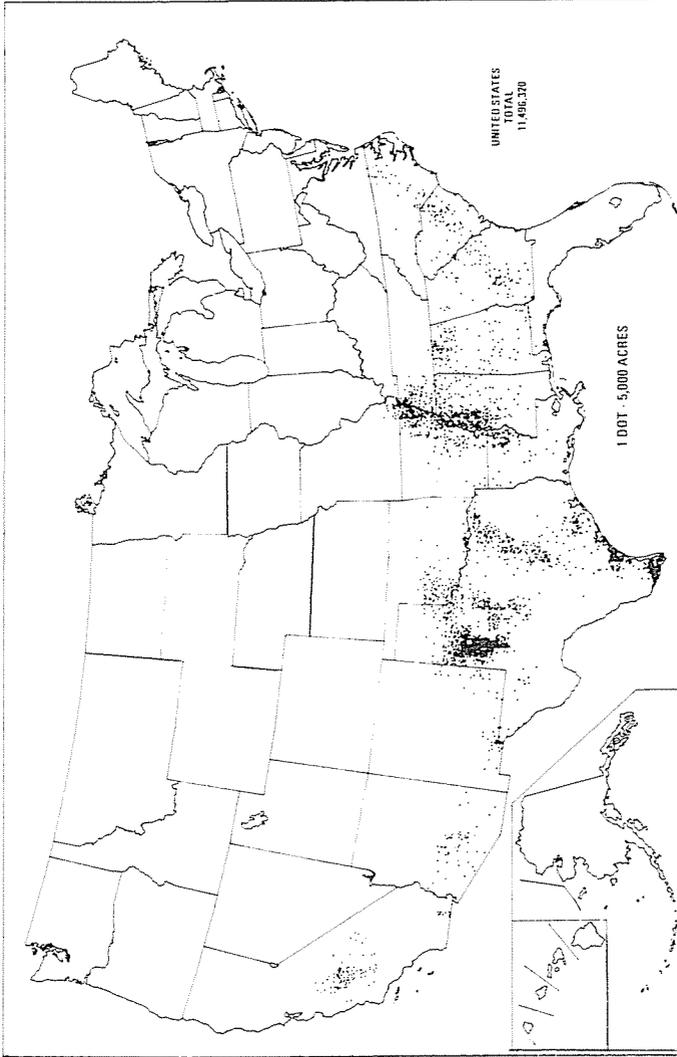


Fig. 5. Cotton harvested, 1969 [9].

should approach 2-plus tons per acre predominately in the form of cornstalks and soybean stubble. Considerable quantities of wheat and oats are also grown there. In the southeast, the major crops are cotton, soybeans, and peanuts; the southwest, wheat and sorghum. But in these areas residue densities will be nearer 1 ton per acre. Farther west and north, wheat with corn in irrigated regions are the principal crops. All other crops are scattered throughout the United States, their location dictated by regional climatic conditions.

Our animal industry generates approximately 250 million dry tons of wastes each year. More than one-half of this tonnage is deposited in densely populated animal-rearing facilities and is, therefore, collectable. The remainder is deposited on many acres of range and pasture land throughout the United States (Table I and Fig. 6). The greatest portion of animal waste is produced by cattle fed out in feedlots of up to 100,000-head capacity, primarily in the central and southern states west of the Mississippi River.

COMPOSITION AND DIGESTIBILITY

The major components in agricultural residues are the structural cell-wall polysaccharides, primarily cellulose and hemicellulose. These polysaccharides constitute 45 to 70% of the weight of the dried plant residue and will vary according to the age and maturity of the plant when harvested. Carbohydrate content of several of our more important crops is listed in Table IV, along with that of lignin and protein. About 20% of the carbohydrate in plant tissue is composed of sugars other than glucose. These sugars will be released upon acid or enzymic hydrolysis and must be considered when developing products from agricultural residues.

The digestibility of the crop fibers by ruminants (Table IV) is a good indication of the availability of the carbohydrate to attack by free enzymes. To sustain acceptable growth rates in ruminants digestibility levels in the range of 75 to 80% are required. At the digestibility levels shown in Table IV, energy release is too slow to allow growth by ruminants. A mature animal can almost maintain its body weight when the residues are supplemented with sufficient nitrogen and minerals. A young animal will rapidly lose body weight. Improved digestibility either by ruminants or by enzymes requires reduction in fiber particle size and chemical pretreatment, or both.

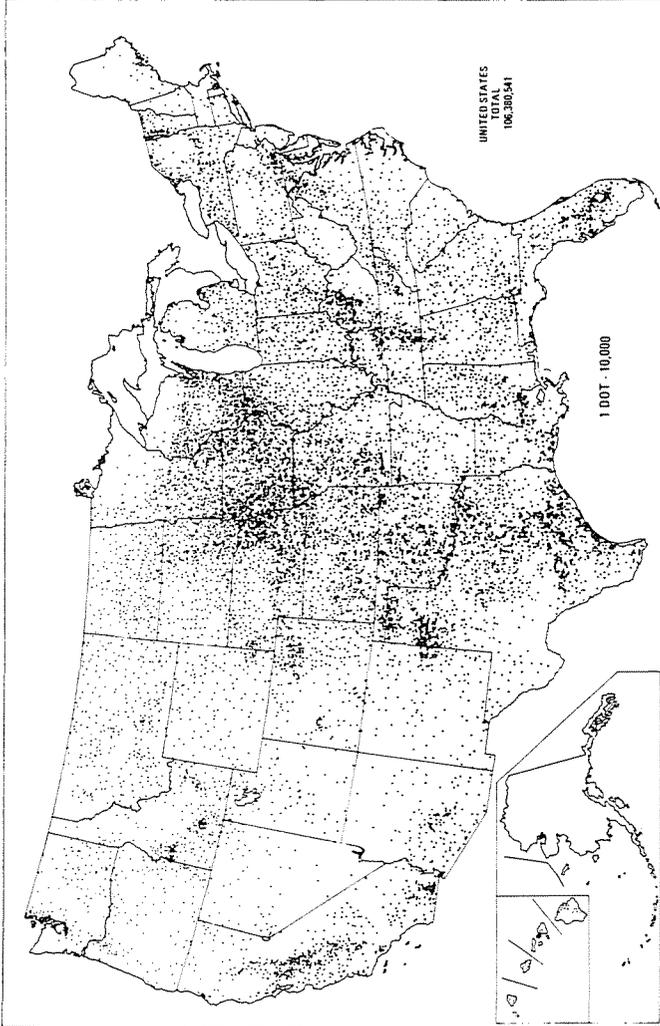


Fig. 6. Cattle and calves, 1969 [9].

TABLE IV
Composition of Agricultural Residues

Plant residue	Carbohydrate (%)						Cellulose	Lignin ¹⁰ (%)	Protein ¹⁰ (%)	TDN ^{10a} ruminant
	Arabinose	Xylose	Mannose	Galactose	Glucose	Total				
Cornstalks	1.9	15.5	0.6	1.1	37.7	56.8	29.3	3.1	5.5	60
Flax straw	2.1	10.6	1.3	2.2	34.7	50.9	34.5		7.2	41
Kenaf stalks	1.5	12.8	1.6	1.3	41.4	58.6	41.9	12.3	4.6	
Soybean straw	0.7	13.3	1.7	1.2	43.7	60.6	41.4		5.5	42
Sunflower stalks	1.4	19	1.35	0.05	39.4	43.8	35.1		2.1	45
Sweet clover hay	3.2	7.2	1.2	1.7	31.1	44.4	29.8		24.7	65
Wheat straw	6.2	21.0	0.3	0.6	41.1	69.2	40.0	13.6	3.6	48

^a TDN = Total digestible nutrients.

Kenaf (Table IV), a woody plant, has potential as a supplement in paper pulps [11]. Depending on soil fertility and cultural methods, it can produce up to 10 tons per acre per year of stem tissue. Because of its productivity, kenaf has also been considered as a renewable source of energy. However, to produce 5% of the energy needs for the United States, 50 million acres of kenaf would have to be grown on prime farm ground—a figure slightly less than that for corn. Kenaf can be utilized most efficiently by first producing paper and then secondly, converting the waste paper that is generated to some form of energy.

Animal wastes contain 25 to 30% carbohydrate derived from plant fibers and up to 20% crude protein, primarily in the form of microbial protein [12]. The fiber fraction containing 40–60% carbohydrate can be readily isolated by a simple screening process [12]. About 60% of this fiber is rapidly digested by the fungus, *Trichoderma viride*, at substrate concentrations above 16%. Neither alkali pretreatment nor particle reduction is required. The carbohydrates of whole waste are digested to the same degree, but fungal growth is inhibited at substrate concentrations greater than 2.5%.

COLLECTION

The equipment used for harvesting corn refuse, silage, and hay for animals can be readily used for collecting and hauling plant residues to a central location for processing. Large mechanical stackers, manufactured by several equipment companies, will pick up plant

refuse directly from the field and pack it into 3- to 6 ton stacks. These stacks can be stored outside with less than 5% spoilage. Spoilage is greater if the stacks are allowed to touch one another during storage. However, 12,000 to 20,000 tons, depending on stack size, can be stored on an acre of ground. Special trailers have been built to pick up and move the stacks from one location to another. Some direct costs in stacking and hauling hay or corn residues in the Corn Belt (Table V) would be applicable to plant refuse as well, however, the 9 to 12 dollars per ton stacked and delivered does not include a monetary incentive to the farmer for losses in mineral and soil organic matter. On the basis of current prices for straw in the field, such an incentive payment would cost a processor 15 to 25 dollars per ton.

Baling in large round bales compares in price with stacking equipment, but refuse has to be cut and raked into windrows before packaging. These operations would add another 3 to 4 dollars per ton. Like stacks, large round bales can be stored out in the weather. The small 60 lb bales are too labor-intensive to compete with the larger packaging devices.

Flail-type silage harvesters are available that will pick up, chop, and blow the refuse directly into a truck for transport. Storage of chopped material would be most efficiently done in a large trench silo. This facility has long side walls and silage or chopped refuse is packed on the ground or concrete between the walls. The silo is covered with plastic when full. As with the two previous methods, refuse will store better in the dry state. If collected wet and put into a silo, much

TABLE V
Harvesting Costs Per Type of Operation

Operation	Cost per dry ton (dollars)
Mechanical stacking, 3-6 ton	7.00
Baling, 1250 lb.	5.60
Baling, 60 lb.	8.00
Flail silage harvester	5.00
Hauling, 10-mile radius	4.00

spoilage can occur because it packs poorly and there are few free sugars to produce a lactic fermentation.

Time is a factor that enters into the collection of agricultural residues. In the Corn Belt only about one to one and one-half months remain after harvest when refuse can be collected. Fall work, fertilizing and plowing must be done before the ground freezes or becomes covered with snow. Even with wheat or oats, the straw must be collected as soon as possible or it will spoil in the summer rains. Except in arid regions, expensive collecting equipment would be used about two months out of the year.

Because collection time is so short, the investment in equipment and part-time labor will be large unless individual farmers can be induced to own the equipment and gather the refuse. For example, consider a 100 ton/day capacity plant with a 300 day operating year. This plant will require 30,000 tons of material gathered from 15,000–20,000 acres of corn and soybean ground—about 30 square miles. Since one stacker can form 10 to 11 3-ton stacks/day, 30 stacking machines would be needed for 30 days to collect refuse for year-round operation of the plant. At \$10,000 per stacker and \$20,000 for the proper sized tractor to pull it, capital outlay for the harvesting equipment alone is nearly 1 million dollars. Alternatively, farm ownership of equipment would be considerably less expensive, because the farmer can spread investment costs over a longer season. The tractor is needed in other field operations and the stacker can also be used both personally and for hire in stacking hay for animals.

Kenaf farming is more appealing from a collection standpoint because the tonnage per acre (5–10) is higher and because kenaf stalks can be left standing in fields up to four months before harvesting [11]. Agricultural production costs for growing kenaf averaged about \$26.00/ton in 1974 [13]. However, for kenaf to compete profitably with other crops, prices paid to the farmer would have to be 36 to 40 dollars per ton [13].

Animal waste produced on large feed lots has the advantage that it is concentrated in a small area. The number of cattle required to supply a 100 ton/day plant is 25,000 head. Animal wastes are an excellent substrate for production of cellulolytic enzymes by *T. viride* and are most efficiently fermented when fresh. Decomposition and sugar loss occur in the fiber after long standing on the feedlot deck. With the

increase in fertilizer prices since 1974, feedlot wastes have again become a valuable source of fertilizer containing from 5 to 6 dollars worth of nitrogen, phosphorus, and potassium. Fermentation of these wastes will, therefore, have to compete against their more traditional use.

So far, hauling only one way has been considered in any contemplated usage of agricultural residues. However, all three methods described earlier, hydrolysis, methanogenesis, or feeding will consume maximally about 70% of the solids. Between 30 to 50% will have to be disposed of by other means, such as landfill, feeding, or application as fertilizer. Also, at this stage of the process, wet residue (60 to 80% moisture) will be hauled back because of costs involved in drying a material of such low value. Consequently, the total tonnage of spent fibers hauled back will be greater than the tonnage of starting material.

RESIDUE REMOVAL AND SOIL PRODUCTIVITY

The function that crop residues perform in soil fertility is poorly understood. The author's own experience revealed that properly incorporated into the soil, they increase soil tilth and water sorption during rains; consequently soil erosion is reduced because the amount and rate of run-off are decreased. Sugars in the residues supply energy for the teeming microbial ecosystem that releases carbon dioxide, which accelerates chemical weathering of minerals. The refractory organic material remaining, humus, changes the soil pH, chelates heavy metal ions, and affects the physical condition and water-holding capacity of the soil. Also, according to Mortenson [14], the carbohydrates in such residues can be used by certain microorganisms for fixing nitrogen. Under laboratory conditions *Nocardia cellulans* and *Azotobacter vinlandii* fixed 12 and 20 mg of nitrogen, respectively, per gram of carbohydrate substrate. Between 20 and 40 lb of nitrogen would be fixed per ton of refuse. The maximum value represents about 25% of the nitrogen needed for an acre of corn.

The impact that continuous residue removal will have on soil fertility remains to be thoroughly examined. Certainly, this effect should be a major factor in the decision as to how we utilize our agricultural wastes. For example, any process based on microbial fer-

mentation or enzymolysis will leave 30 to 50% of the residue undigested. This refractory material, if returned to the land, may be sufficient to maintain tilth and organic matter in the soil.

Mr. M. O. Bagby provided residue samples and Miss M. K. Keel conducted the carbohydrate analyses.

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