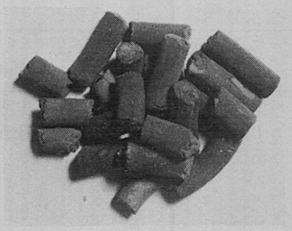

Figure 6. Fly ash in "green" condition.

temperatures in excess of 1100 °C. The small pellets (Figure 6) literally explode into coral hard, porous structures, similar in shape to popcorn. Use of this material as a concrete aggregate should reduce the steel required in high rise structures, improve the traction of road surfaces, and permit the use of light weight concrete blocks.

(4) Use of this binder, in combination with hydraulic portland cement, permits the extrusion of a wide variety of high strength products such as thin-walled pipe and tile, brick slabs, and blocks.

SUMMARY

From the diversity of the product application and the number and size of the affected industries, an insight can be gained into magnitude of the development programs that must be continued or undertaken if, in fact, a large-scale use of whey and lactose is to be developed. Further, not only must details of the processes and products be delineated, but the economics of each must be closely examined to establish market feasibility.

For these reasons work was concentrated in the iron/steel applications as the savings in energy and resource recovery were perceived to be appreciable. Continued and expanded support is being sought from interested companies and industry associations to further and accelerate these efforts.

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Nutritional Aspects of Refeeding Cattle Manure to Ruminants

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Cattle excrete manure dry matter at a daily rate of about 1% of body weight. In intensive confinement management systems proper manure disposal may be a major cost item; recovery of residual utility is therefore desirable if it can be done economically. Evidence that cattle manure does have residual nutritional value and that refeeding can be safe and economical is reviewed in this paper. Factors which influence the energy and protein value of manure or its derived products are discussed, including the influence of the ration originally fed to animals from which manure is collected and the type of processing which the manure may undergo. Other considerations for the formulation of rations with manure or manure products are palatability, the nutrient requirements of the recipient animals, disease and parasite transmission, presence of undesirable residues, performance of recipient animals, quality and consumer acceptance of the meat or milk produced, the cost of recycled nutrients compared to conventional feed sources, and the legal status of manure-derived feedstuffs.

The biological phenomenon of coprophagy is a normal act of many mammalian species. Scavenging is an even more broadly observed biological feature; in fact, until very recently in the United States, and even today in many other regions of the world, domesticated food-producing animals have received part of their nourishment by scavenging from partially digested fecal residues of other species.

Within the past decade there has been considerable research activity on the refeeding of animal and poultry excreta. Much of the impetus for such research has come from environmental concerns, which have forced the modification of certain pollution-causing traditional waste disposal methods. The influx of nonagricultural population into rural areas, the concentration of more animal units into feedlots or confined housing, the reduction of a surrounding land base for waste disposal, and higher labor and energy costs for handling animal wastes are other reasons why there is now a greater economic incentive for the maximum utilization of animal wastes.

Adult cattle excrete one-third to one-half of the dry matter (DM) which they consume. On a daily basis the average cow excretes a quantity of DM equivalent to about 1% of her body weight. For dairy cattle, this means that about 1 kg of fecal DM is excreted for every 3 kg of milk produced, which amounts to about 1125 metric ton of wet manure per 100 cows per year. In a feedlot for finishing beef cattle, about 2 kg of fecal DM will be produced for

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Table I. Chemical Composition of Feedlot Manure (Colorado) as Reported by Ward and Muscato (1976)(Dry Basis)

chemical component	percent
kjeldahl nitrogen	2.3
true protein nitrogen	1.4
ammonia nitrogen	0.3
neutral-detergent fiber	45.9
cellulose	9.6
lignin	5.3
ash	37.1
phosphorus	0.5
potassium	1.4
calcium	1.9
sodium	0.5

every kilogram of carcass yield, which adds up to around 250 metric ton of wet feces per 100 steers over a 6-month feeding period.

The traditional utilization for livestock and poultry manure has been as a fertilizer. The economic and environmental pressures outlined above have caused many other uses to be examined. Among various alternative uses, feeding to ruminant livestock is already gaining commercial acceptance, although the Food and Drug Administration still has not officially sanctioned the use of animal excreta or its derivatives as feedstuffs.

Apart from the legal issue, a livestock producer needs to be convinced that manure refeeding is both safe and economical before he will adopt the practice. Review papers by Smith et al. (1971a) and Battacharya and Taylor (1975) have discussed these and other general issues pertaining to the use of livestock and poultry manures as feedstuffs. The purpose of the present paper is to focus specifically on the refeeding of cattle manure to cattle, with emphasis on its nutritional value. Results of our experiments on the feeding value of "screened manure solids" are summarized, along with a review of recent literature, especially that published since the Battacharya and Taylor paper.

NUTRIENT COMPOSITION OF CATTLE MANURE

The concentration of utilizable nutrients in cattle manure is influenced by the original ration fed to the animals producing the manure, as well as the length of time and conditions of storage of the manure between its time of production and time of use. Table I shows the average chemical composition of 139 samples of feedlot manure as reported by Ward and Muscato (1976). The same authors have shown how the composition is influenced by the original ration, principally the ratio of roughage to concentrate. As shown in Table II, a predominantly roughage ration will result in manure that is lower in crude protein and nitrogen-free extract concentrations and higher in percent crude fiber and percent ash than manure from cattle whose ration is 75 to 80% cereal grain or high-energy supplement. The same data indicate that whether the manure was collected from lactating dairy cows or from steers of a beef breed made little difference on the concentration of crude protein, ether extract, ash, or total carbohydrate (crude fiber plus nitrogen-free extract).

The data of Tables I and II indicate a crude protein content of 13 to 19%. This is not as high as normally found in poultry excreta, but high enough to indicate a potential use of cattle manure as a nitrogen source for ruminants. Table I shows about 40% of the crude protein equivalent to be derived from nonprotein nitrogen. Other estimates have indicated an even higher proportion of cattle manure nitrogen to be of a nonprotein nature (Day et al., 1977).

Table II. Proximate Composition of Feces from Dairy Cows or Beef Steers, as Influenced by the Original Ration (Ward and Muscato, 1976)(Dry Basis)

	source of feces[a]			
	lactating Holstein cows		Hereford steers	
proximate fraction	R	C	R	C
crude protein, %	13	19	13	17
ether extract, %	3	3	1	5
crude fiber, %	41	26	20	13
nitrogen-free extract, %	25	45	44	56
ash, %	20	7	21	9

[a] R = high roughage diet; C = high concentrate diet. Diets for Holstein cows were 83/17 or 25/75 parts alfalfa hay/corn grain. Diets for Hereford steers were ~95/5 or 20/80 corn silage/high energy, high-protein supplement.

Table III. Dietary Roughage Influence on Fecal Fiber Components (Smith et al., 1970)(Dry Basis)

	original ration	
component	alfalfa hay	Sudax silage
neutral-detergent fiber, %	66	68
hemicellulose, %	12	21
cellulose, %	26	28
lignin, %	26	20

The concentrations of cellulose, lignin, and total cell-wall constituents (neutral detergent fiber or NDF) shown in Table I are lower than those reported from our own laboratory (Johnson et al., 1974). Our data were derived from analysis of manure from lactating Jersey cows whose original diet was 31 or 43% concentrate and 69 or 57% corn or small grain silage. The fiber components on a dry matter basis were neutral-detergent fiber, 56%; hemicellulose, 26%; cellulose, 20%; lignin (by permanganate extraction), 7%; and the kjeldahl nitrogen content was 2.8%. When incubated with rumen microorganisms according to the in vitro method of Van Soest et al. (1966), the mean "digestibility" or true dry matter disappearance of samples of the same manure was 42%, which indicates a relatively low availability of the fiber fraction when compared with standard high quality roughages.

Smith et al. (1970) reported that the fiber components of cattle feces can vary according to the fiber source in all-roughage diets. These differences, shown in Table III, partly reflect the differences in proportions of lignin to cellulose or hemicellulose in the original forage. The same authors state that 40 to 60% of the original dietary cellulose and hemicellulose will be excreted in the feces, figures which agree very closely with our own data (Rodriguez and Johnson, 1976).

The length of time that manure is allowed to accumulate before collection can affect its chemical composition, particularly if it is subjected to leaching by rainfall. Day et al. (1977) reported that 15, 20, and 6% of the original nitrogen of feedlot manure was lost during the first, second, and third weeks of accumulation in the feedlot.

PROCESSING MANURE FOR REFEEDING

Many forms of processing of cattle manure have been tried experimentally or commercially in attempts to improve its nutritional value, safety, and storage characteristics, or to optimize the utilization of various separable fractions.

Chemical treatment is a proven technique for improving the nutritive value of high fiber feedstuffs. The manures shown in Table III were treated with six chemicals to test

Table IV. Improvement of Nutritional Value of Fecal Fiber Residues by Chemical Treatment (Smith et al., 1970)

	hemicellulose	cellulose	lignin	in vitro cell wall disappearance, %
chemical				
sodium hydroxide	77	12	40	43
calcium hydroxide	62	3	39	43
sodium peroxide	85	21	49	40
acetyl peroxide	2	5	19	25
calcium hypochlorite	9	1	6	19
sodium chlorite	6	0	34	43
control (no treatment)				11
dietary fiber source				
alfalfa hay	37	10	24	19
Sudax	43	4	39	46

their delignifying or hydrolyzing effect on the polysaccharide–lignin complex. Results are summarized in Table IV. The alkalies, as can be seen, were more effective than the oxidants in total fiber degradation. Sodium hydroxide was suggested to be the most economical choice of chemicals, which coincides with recommendations for treatment of other high-fiber materials. The fiber of manure from a ration of Sudax, a hybrid of sudangrass and forage sorghum germplasm, was degraded to a greater extent than the fecal fiber residue from alfalfa hay, a legume. Unpublished data from our own laboratory suggests that alfalfa fiber is more completely utilized during the first pass through the bovine digestive tract than is fiber from the corn plant, leaving a lower quality fecal residue.

Lucas et al. (1975a) and Lamm et al. (1977) have also found that the nutritional value of manure can be improved by sodium hydroxide treatments.

PROCESSING MANURE TO DESTROY PATHOGENS

From the published reports on refeeding cattle manure, there is no indication that the practice can lead to any abnormal health problems. Nevertheless, there have been several studies directed toward the reduction of pathogenic organisms. McCasky and Anthony (1977) have reviewed these efforts, concluding that anaerobic fermentation (ensiling) is one of the most effective and economical means of reducing *Salmonella* and *Coliform* bacteria. Broiler waste, they report, can be completely sterilized by heating to 150 °C for 3 h. Pasteurizing (150 °C for 20 min) is undesirable because pathogen-limiting organisms are destroyed. Aerobic fermentation is not a satisfactory procedure for pathogen destruction. Certain chemicals, notably paraformaldehyde and ethylene oxide, are reasonably effective.

The incidence of internal parasites was found not to be related to manure refeeding in a study by Johnson et al. (1975a), in which cattle waste comprised 10–15% of the experimental rations.

PROCESSING TO FACILITATE STORAGE

Usually, in the practical situation, manure destined for refeeding will need to be stored for a period of time in order to even out discontinuities of supply in relation to need. Various processing methods will facilitate storage without serious deterioration of feeding value (Day et al., 1977). Dehydration, for example, will permit indefinite storage but is prohibitively expensive if heat must be applied. The addition of chemical preservatives such as formalin (Runkle and Hatfield, 1975) is also effective but also likely to be expensive. The most inexpensive method if facilities are available is likely to be ensiling. If conditions are adequate for anaerobic fermentation to take place, the resulting product will be quite satisfactory. Optimum conditions include moisture level at about 40%, water-soluble carbohydrates at 6 to 8%, and temperature held at about 30–32 °C. Under these conditions the pH will quickly drop to a point within the range of 3.9 to 4.8, and lactic acid will come to comprise 5% or more of the total DM.

Knight et al. (1977) ensiled manure from beef steers, blended with a basal ration at 20, 40, and 60%, and reported no survival of *Salmonellae* organisms after 3 days. All *Coliform* bacteria were apparently destroyed by 10 days. The desirable lactic acid fermentation was facilitated by *Streptococcus faecalis*, a normal fecal microorganism, during the first few days of storage while the pH was dropping through the range of 6.5 to 5.0. After 10 days the predominant acid-producing organism was identified as *Lactobacillus plantarum*.

PROCESSING TO OPTIMIZE UTILIZATION

The separation of manure into various fractions with different optimum uses has been accomplished experimentally and commercially. The "Cereco" process has reached commercial application in Colorado; the products of separation are (1) a high-fiber fermented feed, (2) a high-protein dry feed, and (3) a nonfeed product high in ash (Ward et al., 1974).

Various screen-separation processes have been described (Ngoddy et al., 1971; Graves and Clayton, 1972; Johnson et al., 1974). The vibrating screen technique described by Johnson et al. yields a high-fiber product called "screened manure solids", about 80% neutral-detergent fiber on a dry matter basis, which has been the subject of refeeding research at our university; and a liquid fraction which retains most of the fertilizer value of the original manure and which can be economically applied to the field through an overhead irrigation unit.

DIGESTIBILITY OF NUTRIENTS FROM CATTLE MANURE

Several research groups have investigated the digestibility of manure or manure-containing rations. McClure et al. (1973) collected cattle manure which was mixed with corn stover bedding. To this material was added 10% corn grain. The resulting feed was compared with corn silage and found to be higher in digestibility of cellulose and crude protein but slightly lower in total organic matter digestibility (Table V).

Smith et al. (1971b) collected manure from dairy cows that had received a 33% concentrate diet and fed it as the sole ration for sheep in a digestibility trial. Resultant coefficients of digestibility were 27, 22, and 31% for dry matter, neutral-detergent fiber, and nitrogen, respectively.

Rodriguez and Johnson (1976) estimated the digestibility of screened manure solids (SMS) by linear extrapolation, using data derived from rations which incorporated SMS at five different levels. The results are shown in Table VI. The digestibility estimates represented reductions of 8, 12,

Table V. Composition and Digestibility of Manure plus Corn Stover Bedding, with 10% Ground Corn (McClure et al., 1973)

nutritive criteria	ensiled manure	corn silage
dry matter, %	33.5	33.6
dry basis		
crude protein, %	15.6	7.3
ash, %	19.6	4.6
cellulose, %	25.2	19.0
digestibility, %		
organic matter	61	72
cellulose	67	60
crude protein	67	61

Table VI. Feeding Value of Screened Manure Solids from Dairy Cows (Rodriguez and Johnson, 1976)

fraction	percent of DM	estimated digestibility, %
dry matter		33
crude protein	6.9	64
neutral-detergent fiber	83.6	26
hemicellulose	31.1	49
cellulose	34.7	54
lignin	13.9	15

and 15% in the digestibilities of cellulose, hemicellulose, and lignin, respectively, when compared to the original corn silage based ration.

The ingredients of the original diet can affect the digestibility of the resultant manure, as demonstrated by Braman (1975) and Braman and Abe (1977). These investigators fed rations of 100% Coastal Bermuda grass hay or 20% hay plus 80% concentrate. The manures from cattle fed these rations were 13 and 16% crude protein, 72 and 41% neutral-detergent fiber, and 25 and 18% crude fiber, respectively. The estimated digestibility of organic matter was only 36% in the Bermuda grass manure, compared with 77% in the high concentrate manure.

Lucas et al. (1975b) found very low digestibilities of dry matter (17%) and crude protein (24%) in fecal waste from steers fed a high (50%) roughage finishing ration.

CATTLE RATIONS INCORPORATING CATTLE MANURE

Among the various considerations when making the decision whether to include cattle manure in rations for commercial cattle production are ration palatability, animal performance, ease of handling, quality of product, economic return, and consumer acceptance. Data for product quality and consumer acceptance are insufficient for definitive recommendations, except to say that no serious problems have yet been encountered on either score. As for the economics of manure refeeding, this will very largely depend on the particular circumstances of the individual feeder and the prevailing prices of the moment when the decision is to be made.

Ease of handling is largely an engineering and organizational problem. If manure refeeding is deemed profitable, most farmers could work out a practicable system for their own circumstances.

Palatability may be a problem if levels are not carefully controlled and other management items such as proper storage and careful mixing are not followed. However, in the studies reported below the palatability of the rations studied was sufficient to achieve desirable performance levels.

W. B. Anthony of Auburn University has been a pioneer in the formulation of practical systems of manure refeeding. He has developed a product called "wastelage" which is simply an ensiled mixture of fresh manure from finishing steers and ground grass hay (usually Coastal Bermuda grass), combined in the proportion of 57% manure to 43% hay.

In trial with 12 steers per treatment, Anthony (1969) fed 40% wastelage and 60% whole corn to one group and a control ration with 75% ground corn to a second group. Average daily gains were 1.2 and 1.1 kg; dry matter/gain ratios were 9.3 and 7.4, respectively.

In a second trial the wastelage was blended at 20, 40, and 60% levels with whole corn at 80, 60, and 40% (Anthony, 1969). Average daily gains for these three rations and a control treatment were 0.95, 0.97, 0.76, and 1.10 kg. Dry matter from corn, per kilogram of animal gain, was 7.3, 8.3, 7.2, and 11.4 kg, respectively, indicating a sparing effect of the wastelage on corn grain intake.

In yet another trial, the wastelage was fed as the sole ration ingredient for ten adult ewes. Ten control ewes consumed only Coastal Bermuda grass hay. The rations were fed continuously for 384 days or through two complete breeding cycles of the ewes. No performance differences were noted between the two treatment groups.

McClure et al. (1973) stored a manure–straw bedding mixture in steel drums, anaerobically, and later fed the silage to two steers for 60 days. Body weight was maintained when this material was the sole feed. In a subsequent trial the same authors stored manure plus corn stover bedding in a stack silo, then fed the silage to steers, with supplemental corn, for 80 days. Intake and average daily gains were equivalent to a control group consuming only corn silage.

Manure from cattle fed a high-concentrate diet was mixed at 60% with 35% peanut hulls and 5% ground corn, stored in an anaerobic silo, and later fed to Hereford heifers for 180 days with 2.7 kg of high-energy supplement. Daily gains were 8% lower than for a control group that received Coastal Bermuda grass hay plus 2.7 kg supplement, but feed cost per kilogram of gain was reduced by 16% (Braman and Abe, 1977).

A unique scheme for utilizing manure has been reported by Schake et al. (1977). These workers have used wet manure (16% DM) to reconstitute dried sorghum grain to 70–75% DM. After storage for 20–30 days, the product was fed to heifers, with satisfactory intake for normal growth; to steers, with a fiber source and protein supplement, achieving average gains of 1.25 kg/day; and to mature cows, with up to 69% of ration DM from high fiber screenings (similar to our SMS), achieving intakes satisfactory for maintenance of body weight.

The "screened manure solids" or SMS refeeding at North Carolina State University has been reported by Johnson et al. (1975b), Rakes et al. (1977), and Oliveira et al. (1977). Oliveira et al. have demonstrated normal growth, reproductive performance, and general health in Jersey replacement heifers that consumed SMS as 50% of their daily ration dry matter. Several trials (Johnson et al., 1975b; Oliveira et al., 1977) have demonstrated that Jersey steers can gain an average of 900 g/day when SMS is included as 30% of the ration dry matter. Rakes et al. (1977) reported milk yields averaging 8620 kg/305 days from adult Holstein cows that were fed rations containing SMS as up to 25% of total dry matter. In the heifer and steer trials, results were equally satisfactory if the SMS were fed fresh (immediately after collection) or after several weeks of anaerobic storage (ensiling). With no additives, the ensiled SMS reached pH levels of about 4.

Other reports of satisfactory gains by steers consuming rations containing recycled manure have been published by Hill et al. (1975), Vetter and Burroughs (1974), Westling and Brandenburg (1974), and Williams et al. (1974).

REGULATORY CONSIDERATIONS

The Food and Drug Administration has jurisdiction for sanctioning the use of feedstuffs which enter interstate commerce or which are fed to animals whose products enter interstate commerce. To date the FDA has not sanctioned any animal manure product as a feedstuff for animals. However, they have the matter under study and are currently seeking new information, via a Federal Register notice, which may pertain to the unresolved issues regarding the safety of animal manure refeeding (Taylor and Geyer, 1977).

In the meantime, ten individual states have promulgated specific regulations providing for animal waste feedstuffs to be used under certain controlled conditions, such as 15- or 30-day withdrawal times if the waste is from poultry or animals that had been fed drugs. These states are Alabama, California, Colorado, Florida, Georgia, Iowa, Mississippi, Oregon, Virginia, and Washington (Taylor and Geyer, 1977). In view of these actions, all within the past several years, and the burgeoning commercial interest in waste refeeding, it seems highly likely that the practice will soon achieve full legal sanction (subject to reasonable restrictions and controls).

CONCLUSIONS

The use of cattle manure as a feed ingredient in rations for various classes of ruminant livestock has been demonstrated as feasible from the point of view of nutritional value, palatability, animal health, product safety, and economic viability. The nutrient content and biological availability of nutrients is subject to considerable variability, however, depending on the original ration fed to animals from which the manure is collected, storage conditions, processing methods, and additives such as bedding materials. Potential users of manure-based feeds must also guard against the use of materials contaminated by drug residues or other harmful chemicals.

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