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THE UTILIZATION OF CROP RESIDUES AND ANIMAL WASTES BY RUMINANTS

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The oil crisis, together with a maintained accelarated population growth as well as increased standards of living, and that in a country with limited agricultural resources, has recently highlighted the need for rationalization of food production in South Africa. At the same time the frantic anti-pollution actions in the United States and Europe have brought about at least a pollution awareness in South Africa. Against this background the aim of this paper is to attempt to place into perspective the utilization of crop residues and animal wastes by ruminants.

Crop Residues

The structure and chemistry of straws

Most crop residues of practical importance can be classified as straws. Straws can be divided into 2 main categories, viz. grain- and legume-straws.

Grain straws are most resistant to breakdown, as can be evidenced from the use of straw as roofing material throughout the ages, in which capacity it has been known to have withstood the onslaughts of wind and rain for as long as 40 years. This resistance is derived from the fact that the fibrous elements are situated near to the periphery, thus forming a tube in which the vascular tissue and parenchyma are contained. The epidermal tissue is normally protected by a deposit of cutin and silica. The strength of the stem and its resistance to digestion are thus situated in this tube of lignified polisacchrides (Bacon, 1979).

The stem of legumes is less resistant to digestion due to the fact that the epidermis is not as highly lignified, and does not contain as much collenchyma as grain straws. Strength and rigidity are derived from fibre cells associated with the vascular bundles. This arragement makes provision for lateral thickening of the stem, but is at the same time obviously less resistant to digestion (Bacon, 1979).

Although both grain and straw consist mainly of carbohydrates, there are fairly large differences in chemical composition (Fig. 1).

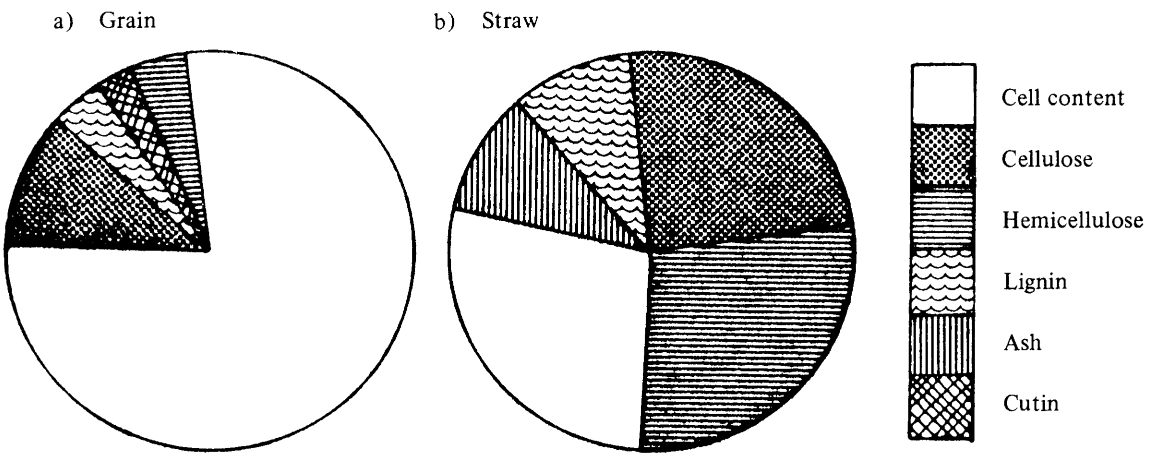

Fig. 1 Relative composition of barley grain and straw (Evans, 1979)

While grain consists mainly of cell contents such as starch granules and protein bodies, straw is characterised by a high cell-wall content. These cell walls are typically made up of cellulose, hemicellulose, and lignin as well as small amounts of resins, waxes and ash (Van Soest, 1974). Although the digestive tract of the ruminant has evolved primarily to facilitate the digestion of cellulose and hemicellulose, the fibre composition of straws still poses a problem even to these animals. The exact reason for this situation remains unknown (Evans, 1979). It is, however, general knowledge that lignin is virtually indigestible to the ruminant. Recent evidence points to the fact that lignin in straw is covalently bonded to the cellulose and hemicellulose fractions. The exact mechanism of the depressing influence of these bonds on digestion is not clearly understood, although it appears to be a chemical as well as physical effect which prevents enzymes from coming into contact with the cellulose and hemicellulose fractions (Evans, 1979). Recent work at the Rowett Research Institute has indicated the possibility that acetylated residues of the hemicellulose fraction occuring in grain straw may exert an even greater depressing effect on fermentation than the lignin fraction (Morris & Bacon, 1977).

The physical morphology of the cellulose fraction in straw must also be taken into account. For the purpose of this paper it is sufficient to say that this fraction consists of highly organised cellulose molecules predominantly in crystalline form which are laterally bonded in the microfibrils by hydrogen bonds. It is generally accepted that this crystalline form is less accessible to enzyme digestion (Evans, 1979).

In addition, it is also well known that straw is particularly low in protein and minerals.

There are, however, methods which can be employed to improve straw utilization by ruminants:

Supplementation with minerals, nitrogen and readily available carbohydrates

There are strong indications that fibre digestion may be enhanced by supplementation of readily digestible carbohydrates, nitrogen and minerals (Mackie, Gilchrist, Robberts, Hannah & Schwartz, 1978; Stewart, Dinsdale, Chang & Panoagua, 1979). It should also be pointed out that there are indications that the protein fraction contained in straw is not fully available to the ruminant digestive tract (Smith & Broster, 1977). Consequently the crude protein content of diets containing straw should possibly be made higher than for high concentrate diets.

Chopping, grinding and pelleting of straw

The effect of physical treatment of straw is well known (Basson, 1970; Smith & Broster, 1977) and is extensively applied in practice. The grinding of straw enlarges the surface exposed to microbial attack and accelerates the rate of flow of digesta through the gastro-intestinal tract. This results in a higher intake of up to 30% (Kay, 1972). Swan & Clarke (1974) have indicated that the optimum particle size is in the region of 0,6 cm. For all practical purposes a maximum of not more than 30% ground straw in production rations can be accepted (Lamming, Swan & Clarke, 1966); higher inclusion rates cause the efficiency of utilization of the grain component to be lowered (Elliot, 1970).

Assuming then that up to 30% straw can be included in ruminant diets one might reach the conclusion that livestock production in this country could be greatly increased. There are, however, serious problems:

a. In the predominantly grain producing areas there exists an abundance of surplus straw. In order to utilize this surplus, livestock numbers would have to be drastically increased, together with an increase in either good quality grazing or grain for livestock production. Both these alternatives seem unlikely.

b. In certain areas livestock numbers are such that the utilization of straw would seem feasible, but
   i) these areas are far removed from areas of surplus straw and
   ii) are also characterized by an abundance of roughage in the form of natural grazing.

   These factors may render the utilization of surplus straw impractical and uneconomical in these areas.

It is obvious that the scope for greater utilization of straw for ruminant production is rather limited if purely physical methods are employed to improve it.

Chemical treatment of straw

Over the years many researchers, in South Africa as in the rest of the world, have investigated the improvement of straw by chemical treatment. Treatment with NaOH, Ca $(OH)_2$, NH_3 and other techniques have been reviewed by Hofmeyr & Jansen (1976), and Jackson (1977). Since the development of the Beckmann method in 1921, major advances have been made in practical processing techniques, making the application of these techniques on farm- and industrial scale possible. Although much attention is currently being given to ammonia treatment, the caustic soda method remains at present the most practical method. The action of NaOH on straw can be summarized as follows:

a. The bonds between lignin and the cellulose and hemicellulose fractions are broken. This leads to improved digestibility via

i) increased solubility of the hemicellulose fraction;
ii) increased availability of cellulose and hemicellulose.

b. Evidence exists to indicate that acetyl esters are hydrolyzed by NaOH resulting in increased digestibility of the fibre fraction.

c. Swelling of microfibriallae results in disruption of the crystalline structure of cellulose. This probably gives rise to increased digestibility as well as increased rate of digestion (Evans, 1979).

A resultant *in vivo* digestibility of up to between 60 and 65% can be expected under normal circumstances. It can therefore be used for overwintering and drought-feeding of livestock, in dairy rations and up to 70% in growth and finishing rations (Hofmeyr & Jansen, unpublished). In spite of these advantages, the chemical treatment of straws has not as yet gained wide-spread acceptance in South Africa. Several reasons for this may be given:

a. Economic considerations. The price of caustic soda, ammonia, and treatment machinery are such that the treated product does not necessarily compete favourably with maize or good quality roughage, which are fairly freely available in livestock production areas.

b. In the grain-producing areas, where straw is in abundance, farmers are not always equipped for large scale livestock production and neither will it become a proposition in those areas unless it's economic viability is a certainty, which is not necessarily the case at present.

c. The handling, distribution and application of chemicals demands a certain amount of skill and time. The South African farmer, it would appear, is reluctant to expend much effort on the treatment of a waste product to which he attaches little value.

d. The possibility of erecting straw processing plants at central points (as is the practice in certain overseas countries) has been investigated. The bulkiness of straw together with the large distances between farms in South Africa make this practice uneconomical.

Although the chemical treatment of straw is an area of challenging propects for the scientist, there are still problems to be overcome if this practice is to gain widespread acceptance.

Microbiological Techniques

Microbiological techniques probably offer the most promising method of increasing the availability of the energy contained in straw. It would appear that a process of anaerobic fermentation, as is the case with the ruminant, would be less effective than a combined aerobic/anaerobic fermentation. It also seems unlikely that the process of anerobic fermentation, which has been perfected in the rumens of billions of cattle over the ages could be improved upon to any appreciable extent.

The potential of microbiological treatment methods lies in the possibility of releasing hitherto unavailable sources of energy through enzymatic action. The advantages of such a process are the low energy input and the fact that the process can be applied at farm level. Mushroom production is an example of the biological utilization of straw. After a certain amount of 'composting' (bacterial decomposition) has taken place, the straw is innoculated with mushroom spores. The well known mushroom, *Agaricus bisporus* is known to degrade lignin, cellulose, xylan, β-glucane, proteins, and phosphate esters by enzymatic action (Wood, 1976). There are numerous other edible fungi that possess similar qualities (Zadrazil, 1979). The possibility exists, therefore, that fungus species can be selected so as to provide a source of human nourishment, while at the same time improving and enriching the straw growth-medium for use by ruminants. The requirements of such fungi are as follows:

a. It should colonise the straw rapidly.

b. It should be able to digest lignin to a meaningful extent.

c. It should be able to produce edible nutrients with maximum efficiency.

(Zadrazil, 1979)

A problem that has been encountered is the fact that any advantages gained by delignification are cancelled out by the utilization of cellulose and hemicellulose by the organism itself. In addition, considerable problems have been encountered with toxicity. There is, however, a definite possibility of eliminating these drawbacks through genetic selection. Indeed, several species of fungi are known that are capable of increasing the *in vitro* digestibility of straw by 40 to 80% (Zadrazil, 1979). Burrows, Seal & Eggins (1979) have experimented with *Coprinus cenereus* which shows exceptional tolerance for NH_3. The mixing of animal manure, a source of NH_3, with straw would promote the growth of *C. cenereus*, while depressing that of various other micro-organisms. This process could play an important role in animal waste recycling systems. The results of the experiments of Burroughs *et al* (1979) show that the *in vitro* digestibility of straw was increased to 60%. No signs of toxicity were discerned, even after 2 years of rat growth experiments. These workers visualise the on-farm implementation of such a process as follows:

a. Straw is stored in a loose stack in a sheltered location.

b. It is ammoniated by inclusion of manure.

c. The straw is innoculated with the fungi and covered with black polythene material.

d. After completion of the degradation process, the material is stored and subsequently fed.

Encouraging results have been obtained by Ramasamay & Verachtert (1979) with a process based on bacterial fermentation alone. Straw was fermented with a *Pseudomonas* culture obtained from activated sludge. It is calculated that a dry matter loss of 34% was obtained after 96 hours and that the resulting fermented material consisted of 38% protein. The implications of this are that a gain of 20 g protein per 100 g straw is achieved with a loss of only 34 g, consisting mainly of cellulose.

Although work in this field is still in the early experimental stage, it must be regarded as an important field perhaps deserving of more attention in South Africa.

Animal Wastes

Cattle Manure

Although ruminants, being non coprophagous, show a positive aversion for their own excrement, there are indications that cattle manure can be recycled to a certain extent (Harper & Seckler, 1975). Apart from alleviating the waste disposal problem, the aim of such recycling is to utlilize nitrogenous and mineral fractions contained in the faeces. Any process designed for this purpose must fulfil certain basic requirements (Harper & Seckler, 1975):

a. Manure contains residues of heavy metals, antibiotics, insecticides, as well as indigestible fractions of the diet such as lignin. Recycling will lead to an accumulation of these undesirable elements. Two practical alternatives have been proposed which can be employed to regulate this build-up.

   i) A diluting effect can be obtained by recycling only a portion of the manure.

   ii) Distribution of the manure product to animals other than those that produced it. The intimate association of an intensive - with a non-intensive phase would necessitate considerable restructuring of the industry.

b. Pathogens must be destroyed.

c. The product must be palatible and possess a long 'shelf life'.

d. As the animals on the farm will not be able to consume all the processed manure, it is important that the product be marketable and easily transported. Here, the large variation in compostion of the raw material becomes an important consideration (Table 1).

Various processing methods have been devised in answer to these criteria:

a. *Drying Techniques*

   In the light of the rising costs of energy, artificial drying techniques are rapidly becoming uneconomical. Air drying provides no guarantee of pathogen destruction.

b. *Ensilage*

   The Wastelage system entails ensiling fresh manure in the ratio of 57% manure to 43% hay or hay and grain (Ward & Muscato, 1976). This process results in a typical lactic acid type fermentation which depresses pathogen growth. Excellent results have been achieved with the feeding of this product to cattle. Only 25% of the total amount of manure can be recycled in this manner.

Table 1

The composition of cattle manure (Van Soest & Robertson, 1976)

Type of manure	True dry matter digestibility	Crude protien (%)
Beef Cattle	79,2	25,0
Dairy Cattle	60,8	16,9
Cow faeces - Orchardgrass diet	46,1	-
Cow faeces - Lucerne diet	35,0	-
Cow faeces - Maize hay diet	47,1	13,2

c. *Fractionation with partial recovery*

These systems entail washing of the manure and recycling of a particular fraction of the manure.

d. *Fractionation with full recovery*

The manure may be separated into several potentially usefull fractions:

i) A high-fibre product.

ii) A high-protein product.

iii) A non-feed product containing large quantities of ash (Johnson, 1979).

In addition, there are several screen-separation procedures which result in a high fibre-and a liquid fraction. The high fibre fraction has been successfully used as bedding material for cattle (Lombard, personal communication).

Although fractionation may possibly play a role in the future, it would appear that ensilage is the only system which could be applied in practice with any measure of success in South Africa at present. It should be noted however, that this would entail modification of existing feedlots in order to facilitate manure collection. In addition, it must be emphasised that only 25% of the total manure produced can be recycled in this way.

In conclusion, it would therefore appear that the recycling of cattle manure offers only a restricted solution to either the food shortage problem or the waste disposal problem. In the light of this, it is felt that cattle manure could be put to more effective use in methane production systems. Rapid advances have recently been made in the development of such systems (McCarty, 1964; Smith, Hein & Greiner, 1979) and at present on-farm implementation is dependant only on the development of suitable fermentation units (Mackie, personal communication).

Poultry Waste

As a ruminant feed, poultry waste is the most promising of all animal waste products. Large quantities of poultry waste are available in South Africa (Cloete, 1981). Poultry waste can be divided into two categories, viz. laying hen manure, and chicken litter. As is evident from Table 2, poultry waste may be regarded as a source of protein and nitrogen with an energy content comparable to that of hay.

Table 2

Average composition of poultry waste (Battacharya & Taylor, 1975)

Component	Broiler litter (D.M. Basis)	Laying hen manure (D.M. Basis)
Crude Protein (%)	30	30
Crude Fibre (%)	15	12
Digestible Energy (MJ/kg)	10,2	8,37
Ca (%)	2,37	8,8
P (%)	1,8	2,5

Numerous reports dealing with the nutritional value of poultry waste under South African conditions have been published (Van der Westhuizen & Hugo, 1972a & 1972b; Bosman, 1973; Van der Merwe, Pretorius & Du Toit, 1975; Kargaard & Van Niekerk, 1977, 1978; Van Ryssen, Channon & Stielau, 1977; Harwin, 1979; Van Ryssen, 1979). Poultry waste has been utilized for some time in South Africa in over-wintering licks and feedlot rations. As in the case of cattle waste, there are certain problems associated with the feeding of poultry waste:

a. The fact that poultry waste is not registered as a feedstuff is due mainly to the possibility of pathogen contamination and feed additive residues such as antibiotics and arsenicals. Sterilization by heat treatment is not always economical. At present, ensilage promises to be the most viable alternative.

b. The variable composition of poultry waste presents a problem for the prospective buyer (Table 3).

The protein content may vary as much as five-fold and the ash content seven-fold. This variation may be the result of several factors; the composition and physical form of the poultry diet, level of feeding, age of poultry, amount and nature of litter, storage and processing

Table 3

Variation in the composition of poultry manure (Pearce, 1979)

	Caged Poultry Manure	Poultry litter
Crude Protein (%)	9,4 - 53,0	7,5 - 41,9
Ash (%)	13 - 49	9 - 68
Gross energy (KJ/g)	11 - 17	-
In vivo D.M. digestibility (ruminants)	39 - 73	38 - 66

methods, being the main factors. For example, results (Bhattacharya & Taylor, 1975) have shown the crude protein concentration of layer manure to decrease from 30,3% after 7 days of storage to 18,3% after 98 days.

Statutory control of the composition of poultry waste offered for sale is obviously impractical. An alternative would be the integration of poulty and beef units in a production system in which the fact that poultry waste forms part of the ruminant diet is taken into account with poultry ration formulation. This would obviously necessitate a large scale change in the structure of the livestock industry, which might enhance economical utilization of poultry waste but not necessarily the interests of the farming community.

In conclusion, certain products are designated as waste products by virtue of a specific system. 'Waste products' can become 'products' only if the system *per se* is altered. A particular system may be altered by a changed system of values or through innovative technology. It is hoped that the present system of values be maintained in that high quality animal products are considered an essential part of the human diet. To maintain the *status quo* will require a concious effort on the part of researchers to develop technologies whereby ruminants are enabled to utilize every possible fibre and N source to the limit, without seriously polluting our environment to the detriment of human existence.

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