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By-Product Utilization for Animal Production

Proceedings of a workshop on applied research held in Nairobi, Kenya, 26-30 September 1982

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BY-PRODUCT UTILIZATION FOR ANIMAL PRODUCTION

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Editors: Berhane Kiflewahid, Gordon R. Potts, and Robert M. Drysdale

Résumé[1]

L'utilisation de sous-produits agricoles pour la production animale a fait l'objet d'un grand intérêt de la part des spécialistes de l'alimentation du bétail et à cet égard, le Centre de recherches pour le développement international (CRDI) a subventionné un certain nombre de projets de recherche sur l'alimentation du bétail faisant appel aux sous-produits agricoles et à de nouveaux aliments au cours des neuf dernières années.

Cette monographie est le compte rendu des travaux et délibérations d'un atelier tenu à Nairobi, au Kenya, du 26 au 30 septembre 1982, pour examiner les résultats de recherches prometteuses, qui semblent sur le plan technique et économique être applicables aux systèmes d'alimentation des animaux, pour discuter et recommander les méthodes de recherche appropriées à l'évaluation des sous-produits spécifiques destinés aux systèmes de production animale identifiés ainsi que la normalisation des méthodes d'analyse pour la description de la valeur alimentaire des sous-produits et des aliments nouveaux.

On y trouvera une description des résultats de recherches sur les sous-produits effectuées en Égypte, au Soudan, en Indonésie, en Tanzanie, au Pakistan et au Kenya, suivie d'un résumé des débats sur les avantages et inconvénients de l'approche et des méthodes utilisées dans les essais de composition et de rations de ces sous-produits. Y figurent également des rapports sur les essais de bilan de la valeur nutritive des aliments, l'évaluation des expériences sur les animaux, et les aspects économiques dont il est nécessaire de tenir compte en matière de recherches sur l'utilisation de sous-produits pour l'alimentation du bétail. Et en dernier lieu, cette monographie traite des essais réalisés dans des exploitations agricoles, dans les conditions réelles d'emploi.

[1] Chaque communication du présent compte rendu des travaux et délibérations est accompagnée d'un résumé en anglais, en français et en espagnol.

Resumen[1]

El empleo de subproductos agrícolas para la producción pecuaria es un tema que ha recibido la atención de los especialistas en nutrición animal. El Centro Internacional de Investigaciones para el Desarrollo (CIID) ha apoyado durante los últimos nueve años un buen número de proyectos de investigación sobre alimentación de ganado con subproductos agrícolas y otros alimentos no convencionales.

Este libro contiene los trabajos presentados en un taller celebrado en Nairobi, Kenia, del 26 al 30 de septiembre de 1982 con el objeto de revisar los avances investigativos que se consideran técnica y económicamente factibles de aplicar en sistemas de alimentación animal, de discutir y recomendar metodologías de investigación que permitan evaluar subproductos específicos con destino a sistemas definidos de producción animal, y de discutir la normalización de los métodos analíticos empleados en la descripción del valor nutritivo de los subproductos y las raciones no convencionales.

Los resultados de las investigaciones sobre subproductos en Egipto, Sudán, Indonesia, Tanzania, Paquistán y Kenia, van seguidos de un recuento de las discusiones sostenidas sobre la validez o debilidad de los enfoques investigativos aplicados en la modificación y administración de los subproductos. También se presentan los trabajos sobre medición de la calidad nutricional de los alimentos, su evaluación en pruebas de alimentación y los aspectos económicos que deben tenerse en cuenta en este tipo de investigaciones. Finalmente, se describen y discuten ensayos en finca de los subproductos como alimento animal.

[1] Cada trabajo va accompañado de un resumen en español, francés e inglés.

Contents

Foreword

The subject of this monograph has received much attention from animal nutritionists. Reports on by-products such as straw, coffee pulp, or animal wastes abound. These provide valuable information on processes used to modify by-products and their effects on the nutritional quality of by-products. They also report increases in the utilization of crop residues by animals and effects on animal performance.

For the past 9 years, the International Development Research Centre (IDRC) has been supporting a number of research projects involving the feeding of agricultural by-products and nonconventional feeds to livestock. A technical review of these projects, conducted in 1981, showed that a considerable range of research methodologies was being used to identify which by-products are suitable for animal feed and to evaluate their availability, nutritional characteristics, and potential for improvement through modification. Differences were also apparent in the methods used to determine the level at which by-products should be incorporated into feeding regimes and in methods used to evaluate the appropriateness of these regimes. This review also showed that, despite important breakthroughs in terms of improving the nutritive value of by-products, practical application of research results in existing animal-feeding systems has been limited.

This monograph contains papers and discussion summaries from a workshop held in Nairobi, Kenya, 26–30 September 1982. The objectives of the workshop were to review promising research achievements that are technically and economically feasible for practical application in animal-feeding systems, discuss and recommend research methodologies appropriate to evaluate specific by-products for identified animal-production systems, and discuss standardization of analytical methods for describing the nutritive value of by-products and nonconventional feeds.

The first three sessions contain a review from selected projects of results of by-products research, research methodologies used in these projects, and the potential for the practical application of the results in animal-feeding systems. These papers are followed by discussion summaries of the strengths and weaknesses of the research approaches and methods used for modifying and feeding by-products. These papers and discussion summaries describe the difficulties encountered in introducing high-cost or complex by-product modifications and the dangers associated with research oriented toward specific types of equipment or modification processes. The fourth session contains three papers dealing with measurement of the nutritional quality of feedstuffs, their evaluation in animal-feeding trials, and the economic aspects to be considered in research on utilization of by-products for animal feed. This session led to a stimulating discussion among participants, the summary of which contains several important considerations for future research. It was evident that an orderly sequence of descriptive, analytical, and experimental activities can be followed by the formulation of by-product based feeding systems. It was found that a wide range of approaches should be considered for increasing the nutritional benefits that animals derive from low-quality roughages. In addition to by-product modification, other approaches include mineral and leguminous forage supplementation and feed storage alternatives. The final session contains three papers on on-farm testing of by-product use for animal feeding. The discussion summary of the session offers considerable insight into factors that are important to the design and operation of on-farm testing. It also emphasizes that new feeding systems must be evaluated by means of careful comparison with methods currently being used by farmers.

Throughout the workshop, participants stressed the importance of clearly identifying the beneficiary of by-product research. The type of farm and animal-production enterprise that comprise this target group should be clearly defined. Researchers often set out to demonstrate that partial substitution of a well-balanced feed ration by by-products does not reduce maximum animal performance. This approach leads to high-cost rations that are unacceptable to farmers, and was found to mask the effects of cheap, low-quality by-products and any modification technique being tested. The discussion sessions highlighted that on-farm research was required to identify farmers' goals and their production constraints and to ensure that the farmers' opinions were reflected in the formulation of by-product based feeding systems and in the criteria used for their evaluation. The study of existing production methods was considered necessary to define what changes in levels of animal performance should be aimed for, what increases in input requirements farmers can tolerate, and what the cost of production should be. This information would serve as a guide to the treatment levels to be used in feeding trials.

The papers and discussion summaries present a convincing case for the great contribution to animal production that can be made by better use of by-products. This is particularly so for small mixed farms on which agricultural by-products are produced that can be incorporated into a year-round feeding system. On these farms, the impact of by-products will most likely come about by initially raising animal productivities from often exceedingly low levels to intermediate levels, rather than from attempts to provide the nutritional requirements for high animal productivity.

All of the participants are indebted to the editorial committee, and to A.N. Said and M. Gomez of the University of Nairobi and R. Bruce Scott of IDRC's East Africa Regional Office, who cohosted this workshop.

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RESEARCH RESULTS

Use of By-Products in Animal-Feeding Systems in the Delta of Egypt

M.A. Naga and K. El-Shazly[1]

The gap between available and required amounts of animal feeds in Egypt was calculated to be 9 million tons per year. Almost two-thirds of this gap can be fulfilled by: redistributing consumption of presently consumed feeds over the entire year to provide animals with a well-balanced ration during both winter and summer; supplementing the poor-quality ingredients with urea, molasses, and minerals; chopping the lignocellulosic materials and treating them with some alkali to delignify them (ammonia treatment through the application of urea is recommended as the best treatment); and trying to transfer this knowledge to the small farmer. Due to the weakness of agricultural extension services in Egypt, however, it is thought that the introduction of the new knowledge might be more successful if feed mills of reasonable capacity (e.g., 10 t/hour) could be established. A prefeasibility study for such a plant was presented and the price of the manufactured product was adjusted within the feed efficiency of local animals and prevailing feed and meat prices in the Egyptian market.

En Égypte, la différence entre les besoins en alimentation du bétail et la quantité de produits disponibles a été évaluée à 9 millions de tonnes par an. Environ deux tiers de cette quantité pourraient être obtenus comme suit : en répartissant la consommation actuelle sur toute l'année, afin que les animaux puissent recevoir des rations équilibrées, autant en hiver qu'en été ; en ajoutant de l'urée, de la mélasse et des minéraux aux rations carencées ; en hachant la lignocellulose et en la traitant aux alcalis qui la décomposent par fusion (le traitement à l'ammoniac, par application d'urée, est considéré le plus satisfaisant) ; et en transmettant ces connaissances aux petits fermiers. Cependant, vue l'insuffisance des services de vulgarisation agricole en Égypte, il semble que l'introduction de ces nouvelles connaissances pourrait mieux se faire par l'établissement d'usines de fabrication d'aliments pour le bétail, d'une capacité appropriée (de 10 t/h par exemple). Une étude préliminaire a été effectuée sur la faisabilité d'une industrie de ce type et le prix de ces produits a été fixé en fonction de leur aptitude à satisfaire les besoins du bétail local et des prix de la viande et des aliments pour animaux sur le marché égyptien.

En Egipto, la diferencia entre la cantidad disponible y la cantidad requerida de alimento animal se ha calculado en nueve millones de toneladas por año. Casi dos terceras partes de esta diferencia podrían ser cubiertas si se redistribuyera el consumo de los alimentos que actualmente se ingieren durante todo el año, con el fin de suministrar a los animales una ración bien balanceada tanto en invierno como en verano; si se suplementaran los ingredientes pobres con úrea, melazas y minerales; si se picaran los materiales lignocelulosos y se trataran con algún álcali para deslignificarlos (se recomienda el amoníaco mediante aplicación de úrea) y si se transfiriera de este conocimiento al pequeño agricultor. Como los servicios de extensión agrícola de Egipto son insuficientes, se piensa que la divulgación de los nuevos conocimientos podría tener más éxito instalando moledoras de alimento de una capacidad razonable (por ej. 10 t/hora). Se presentó un estudio de pre-factibilidad para tal planta y se ajustó el precio del

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producto manufacturado entre la eficiencia alimenticia del ganado local y el alimento animal, y los precios de carne prevalecientes en el mercado egipcio.

The gap between available and required amounts of animal feed in Egypt is estimated to be about 9 million tons, of which 4 million tons are concentrates and the remainder roughage. Annual production of animal feed in Egypt meets no more than about 60% of the calculated requirements of the existing animal population. This low nutritional level is reflected in the productivity of Egyptian animals, with local production of animal protein meeting only one-third of the minimum needs of the Egyptian people. The Egyptian government is trying to solve the problem by importing poultry, eggs, milk and milk products, and red meat (beef and lamb). Imports of red meat reached 90 000 tons in 1981. This amount of meat costs about US$170 000, which places a strain on the balance of foreign exchange within the country. Moreover, the government sells this meat at a subsidized price (50%) to the public.

Under such conditions, the utilization of nontraditionally consumed field by-products becomes an obligation. There are about 6 million tons of corn stalks, rice straw, vegetable wastes, and cotton stalks, in addition to another 2 million tons of bagasse and other agroindustrial by-products, that could be introduced as animal feed. There are two limitations to such a trend, however: (1) the incompetent use of these materials, e.g., farmers using them as fuel; and (2) a lack of knowledge of the proper way to include these materials in the animals' diet.

For about 6 years, a group of animal nutritionists in the Department of Animal Production at the University of Alexandria, in cooperation with the International Development Research Centre, has been involved in a project to evaluate methods of improving the nutritive value of poor-quality roughage. The highlights of the information obtained from this project are summarized in this paper.

Present Situation

Currently, two animal-feeding patterns are followed in Egypt: (1) berseem (Egyptian clover), for the most part by itself, is fed to animals between December and May; and (2) wheat or barley straws with some concentrates are fed to animals throughout the remainder of the year. This system has the following disadvantages, in addition to the basic problem of a shortage of feed: about half of the protein content of berseem (20% on a dry-matter basis) is wasted; there is no source of carotene during the summer period; the animals suffer from heat stress during the summer due to the hot weather and high specific dynamic action of the feed straws; and the irregularity of the feed levels and feeding pattern results in depressing animal productivity.

Recommended Use of Available Feed

Berseem, which is practically the sole green forage crop available to the animals and contains (on a dry-matter basis) almost double the amount of protein required, should be fed to animals at half the rate that is presently being used during the winter season. The other half of the berseem crop should be preserved in the form of silage with half of the wheat and barley straw crops and some molasses. This silage would provide the animals with a succulent, balanced, and palatable diet during the summer season. At the same time, the remainder of the wheat and barley straws should be fed to the animals during the winter season along with berseem. This would bring about a better nutrient balance to the winter diet.

Acceptance of this proposal by farmers would have two benefits: (1) The animals would receive a balanced diet of constant composition over the whole year, thus avoiding a seasonal disturbance in production. (2) The nutritive value, i.e., total digestible nutrient (TDN) percentage, of wheat and barley straws would be improved by not less than 50%. (About 2.5 million tons of wheat and barley straws are produced annually, all of which is used for animal feed. The TDN content of these straws averages 42%. It was found repeatedly that feeding straws combined with berseem resulted in no change in berseem's nutritive value as long as the straw ratio in the diet (on a dry-matter basis) did not exceed 50%. This means that the TDN content of the straws fed with berseem would be increased from 42 to 65%. This 54.7% improvement in the nutritive value of the straws is equivalent to a gain of about 1.36 million tons of straws).

Availability of Nontraditional Agricultural By-Products for Animal Feed

It has been determined that some agricultural by-products that have been used traditionally as fuel or are left in the soil as fertilizers can also be used in animal feed. Such materials and their annual production rates (million tons) include corn stalks and cobs, 2.9; sorghum stalks, 1.1; rice straw and hulls, 2.0; bagasse and pith, 1.2; molasses, 0.4; and cotton stalks, 2.4.

A precise survey would be required to estimate the current uses of these materials and the amounts available for use in animal feed, but current estimates indicate that about one-third of the rice straw is used in paper factories; all of the sorghum stalks produced at upper Egypt are used as fuel for burning (hardening) mud bricks; the majority of corn stalks and cobs, as well as cotton stalks, are used by farmers as fuel for cooking and baking; and about one-quarter to one-third of the bagasse is used as fuel in sugarcane refineries, the remainder of the bagasse not being used at all. The following amounts (million tons/year), therefore, are available for use in animal feed: corn stalks and cobs, 0.5; rice straw and hulls, 1.3; bagasse, 0.8; and molasses, 0.4. To this can be added an unestimated amount of vegetable wastes.

Recommended Treatment for Improving the Nutritive Value of Low-Quality By-Products

Field by-products, generally, have low nutritive value because of their relatively high content of lignocellulose and low content of protein and perhaps some other nutrients. Improving the nutritive value of these materials can be achieved by adding the deficient nutrients, correcting the nutrient imbalance, and solubilizing or cracking the lignin layers coating the cells to enable enzymes of microorganisms or the digestive tract of the animal to digest the cell contents.

Urea Supplementation

Supplementation with urea, at levels between 0.5 and 2%, improves digestibility of the nutrients contained in the supplemented material. The TDN content of artichoke crown leaves was progressively improved by increasing levels of urea supplementation. TDN content of corn stalks or bagasse increased from 44 and 45% to 56 and 54%, respectively, due to urea supplementation (Borhami et al. 1975; Mohamed et al. 1971). The nutritive value of low-quality by-products is improved further if the contents of true protein and nitrogen-free extract are reasonable (about 5 and 25% respectively) (Coombe et al. 1971; Mulholland et al. 1976; Clanton 1977; Burroughs et al. 1950 a,b,c). When urea–nitrogen in the diet exceeds 30%, potassium losses in urine may increase, resulting in exhaustion of the animal's body potassium (Juhaz et al. 1975). In the early stages of this phenomenon, bacteria in the rumen begin to suffer from potassium deficiency. The potassium requirements of the plant kingdom (including bacteria) are much higher than those of members of the animal kingdom. The first symptom of the disorder, caused by feeding high concentrations of urea for long periods of time, is depressed bacterial growth and activity in the rumen. Consequently, synthesis of the B-vitamins in the rumen decreases, with a resultant loss of appetite and the development of cerebrocortical nicrosis (Naga et al. 1978).

Mineral Supplementation

Burroughs et al. (1950 a,b,c) pointed out the beneficial effect of alfalfa ash on fibre digestion of poor-quality roughages. They also reported a positive relationship between the digestibility of dry matter and its mineral content. Six sheep were fed a rice straw + concentrate (1:1) diet. The TDN content of this diet and ash balance of these animals were 37% and −21.8 g/head/day respectively. Of the 10 minerals studied, only phosphorus and sulfur balances were positive, the rest being negative. When the deficient minerals were supplemented in amounts sufficient to correct the imbalance, the TDN percentage and ash balance became 57.5% and 11.2 g/head/day respectively. Adjusting the ash balance by the addition of the proper mineral supplements to the diet of calves resulted in the improvements shown in Table 1.

Combined with Good-Quality Ingredient(s)

A low-quality by-product diet could be improved by the addition of protein or energy-rich supplements, or by being combined with good-quality ingredient(s). Supplements are not supposed to exceed 25% of the diet's dry matter otherwise they become a substitute (Crabtree and Williams 1971). Farid and Hassan (1976) concluded that a well-balanced supplement is better for improving low-quality roughage than a supplement rich in only protein or energy. It seems that feeding low- and high-quality ingredients together, at the ratio of 1:1, is more economical. Table 2 shows the results of four combinations of concentrates and by-products fed to growing lambs.

Feeding combinations of ingredients provides the so-called associative effect, i.e., the TDN combination exceeds that calculated by adding the TDN contents of the ingredients (Table 3).

Ensiling with Good-Quality Roughage

Ensiling of rice straw with berseem (1:1 on a dry-matter basis) was compared with feeding rice straw treated with 5% sodium hydroxide and offered with berseem silage (Table 4). Simple ensiling of raw rice straw and berseem proved to be more effective and economic than the other three combinations.

Recommended Alkali Treatments

Sodium Hydroxide

The Beckman NaOH-treatment method appears to be superior to other techniques. Raw rice straw or treated with NaOH according to different methods was included in a complete diet with concentrate mixture and fed to sheep (Table 5).

Ammonium Hydroxide from Urea

Due to the lack of skilled labour in Egypt, it is safer to deal with urea as an indirect source of ammonia than with gaseous or liquid ammonia. It is also cheaper in the Egyptian market. The by-product is sprayed with an equal weight of water, which contains a urea equivalent of 5% of the material's dry-matter weight. The heap is then covered completely with a plastic sheet to prevent exposure to the air. Ammonia

Table 1. Improvement of calves' performance through proper mineral supplementation.

	Mineral supplementation		Percentage improvement
	Without	With	
Feed intake (g/head/day)	1528	2700	76.7
Dry-matter digestibility (%)	64	79.2	23.8
TDN content of the diet (%)	51.3	63.6	24.0
Digestible protein (DP) content of the diet (%)	12.9	17.9	38.8
Daily body-weight gain (g/head)	345	470	36.2

Table 2. Effect of the ratio of high- and low-quality ingredients in the diet of growing lambs.

	Percentage of concentrates[a]/by-products[b]		
	100/0	70/30	50/50
Number of lambs	12	11	11
Daily feed intake (g/head)	1.67	1.76	1.77
Daily body-weight gain (g/head)	188	206	188
Feed efficiency (feed/gain)	8.88	8.54	9.41
Dry-matter digestibility (%)	69.3	67.1	66.9

[a] Concentrates (%): cottonseed cake, 20; rice bran, 5; wheat bran, 36; corn, 29; urea, 2; molasses, 5; and salts, 3.
[b] By-products (%): grape wastes, 32; date seeds, 29.3; orange peel, 19; pea pods, 16; urea, 2; and salts, 1.7.

Table 3. Associative effect gained when different ingredients were fed in combinations.

Combination	Parts of each ingredient	TDN percentage of each component	Calculated sum of TDN percentages	Actual TDN percentage	Percentage improvement
Rice straw	1	42			
Dried berseem	1	63	55.3	75.7	37
Concentrate mix	1	61			
Corn stalks	1	44	50.0	66.5	33
Dried berseem	1	63			
Wheat straw	1	40	55.0	62.0	13
Rice gluten	2	63			
Rice straw	1	41	50.5	65.0	29
Dried berseem	1	60			
Wheat straw	1	42	50.0	59.0	18
Dried berseem	1	58			

Table 4. Results of feeding different combinations of rice straw, offered with berseem silage, to sheep.

Combination	Estimated TDN percentage using sheep
Berseem silage + raw rice straw	69
Berseem silage + 5% NaOH-treated rice straw	74
Ensiled raw rice straw with berseem	75
Ensiled 5% NaOH-treated rice straw with berseem	68

Table 5. Comparison of the effect of different NaOH treatments on the nutritive value of rice straw.

NaOH-treatment method	TDN percentage: Of the whole diet	TDN percentage: Of rice straw alone (calculated by difference)
Control	59	46
Beckman[a]	72	69
Boliden[b]	69	62
Jackson[c]	55	44
Pigden[d]	58	44

[a] Soaked in 1.25% NaOH followed by two water soakings.
[b] Sprayed with 4% NaOH + 2% $Ca(OH)_2$ followed by neutralization with H_3PO_4.
[c] Mixed with equal volume of 5% NaOH.
[d] Sprayed with 40% NaOH to provide 5% NaOH on the straw.

evolves within 12–24 hours from the urea as a result of microbes contaminating the surface of the material. After 3–4 weeks during the summer or 5–6 weeks during the winter, the treatment is complete. The heap can then be uncovered to enable the removal of the ammonia that was released.

Improvement in nutritive value in response to the application of urea by the above method was greater than through supplementation of the material with urea. Table 6 compares the nutritive value of corn stalks under various conditions. The treatment resulted in a considerable improvement in both the voluntary intake and TDN content of the material. More important is the improvement in the initial mineral balance. The treatment converted the mineral content to a more readily available form.

Use of By-Products on an Industrial Scale

Along the edges of the delta, about 324 000 ha have recently been reclaimed. The population in this area is very limited due to its location inside the delta. There is a surplus of by-product materials, therefore, that can be manufactured on an industrial scale to produce complete animal feed or improved roughage. These two types of manufactured animal feeds are unfamiliar to Egypt. Recently, the Egyptian Ministry of Agriculture agreed to the licencing of feed mills to produce complete animal diets. Efforts are now under way to obtain the ministry's approval for producing manufactured roughage. In this way, the use of

Table 6. Comparison of the effect of using urea to treat corn stalks or as a supplement.

	Type of corn stalks		
	Raw	Urea-supplemented	Urea-treated
Intake (g/head/day)	694	957	1279
TDN content (%)	50.8	61.0	65.0
Digestible protein content (%)	2.0	3.1	3.9
Nitrogen balance (g/head/day)	0.0	0.8	0.8
Ash balance (g/head/day)	−40	−28	39

by-products will be under government control, which will help in the government's efforts to direct agricultural activities in Egypt.

Operational Characteristics of the Feed Mill

About 35 km south of Alexandria is a large agricultural company cropping about 12 000 ha. This company, Mariut Co., is a model in the newly reclaimed area. The resources available to the company at the site and the amounts required annually are presented in Table 7. The average price (EG£) per ton of air-dried mixtures of these ingredients is 7.8. At a rate of 300 working days/year, 2 shifts/day, 7 hours/shift, and a mill capacity of 48 000 tons, the hourly capacity of the mill is 11.4 tons/hour.

Costs

The capital cost to the mill of collecting and transporting raw materials to the mill amounts to EG£28 000.

It is beneficial for animals to receive a constant diet over the whole year in order to avoid a decrease in production due to shifting from one diet to another. Therefore, about half of the ingredients produced during a season will be stored for another season. It is estimated that 19 000 tons need to be stored. The average density of these materials is about 0.4. The area required for storage, therefore, would be 47 000 m^3. If this amount is stored as bales in blocks 3 m high and covering an area of 6 m × 12 m, with 2 m roads between each block, the area required for storage would amount to 2 ha. To rent an area of this size would cost EG£1000/year or EG£0.05/ton, which might reach EG£0.2/ton after adding in the cost of labour.

Treatment with urea (5%) is the recommended method for delignifying and enriching the mixture of these materials with nitrogen. Treatment of 80−100 tons takes place in a ditch coated with asphalt, the material being heaped to a height of about 1 m above the ground. During the heaping process, it is sprayed with urea solution. The heap is then covered with plastic or jute sheets coated with mud. The cost per ton of the final product is EG£7.3.

The treated materials should then be dried before they are ground. This is accomplished using a negative pressure jet-flow forage dryer, heated with oil, with a capacity of 20 tons/hour. The cost of the drying process is EG£6.56/ton.

A conveyer belt then receives the dried material and feeds it to the hammer mill. The material is conveyed to a mixer where minerals are added, a conditioner where molasses is added, a press for pelleting, a cooler, and then the bagging unit. The cost of this process is estimated to be EG£19.99/ton.

If a lorry of 10 tons capacity is used for transporting the feed bags to clients in Alexandria (about 30 km distance), the

Table 7. Requirements of the Mariut Co.

	Thousand tons/year	Price (EG£)	
		Per ton	Total
Sorghum (green)[a]	89	6	534000
Corn stalks (dry)	9	15	135000
Berseem and alfalfa (green)[b]	65	9	585000
Vegetable wastes[c]	9	10	90000
Total	172[d]		1344000

[a] Equivalent to 24 000 tons air-dried material.
[b] Equivalent to 11 000 tons air-dried material.
[c] Equivalent to 4 000 tons air-dried material.
[d] Equivalent to 48 000 tons air-dried material.

transportation cost per ton will be EG£2.50/ton.

The total cost/ton of the manufactured by-products, therefore, comes to EG£45.265/ton.

Marketing

If the final product is sold for EG£55.35, the profit (22.2%) will be encouraging enough for investors to provide the required capital. A price of EG£55.35 is very low in comparison with the prices of wheat straw or berseem hay in the Egyptian market. Moreover, the TDN and digestible protein contents of the product (65 and 10% respectively) are considerably higher than those contained in the hay or straw. This price is within the limits of the farmer. The governmentally fixed price for 1 kg live weight of animals is EG£1.08. Assuming that 20% of this price is profit for the producer (farmer), then the cost of producing 1 kg live body weight would be EG£0.864. It is well known that feed costs account for 65% of the total cost of production. The feed costs to produce 1 kg of body live weight, therefore, would be EG£0.562. Because the feed efficiency of Egyptian cattle averages 10 units of feed to 1 unit of body weight, the EG£0.562 should be the price of 10 kg of feed. This means that any feed that could be purchased at EG£56.5/ton would be consistent with prices currently prevailing in the Egyptian market.

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Potential of Agroindustrial By-Products as Feed for Ruminants in the Sudan

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Two feeding and two digestibility trials were conducted to evaluate three rations containing 30% low-quality agroindustrial by-products. The by-products tested, i.e., dura straw, groundnut hulls, and bagasse, were included in rations that also contained wheat bran (29.5%), cottonseed cake (29.5%), molasses (10%), and common salt (1%). In trial 1, dura straw (ration A) and groundnut hulls (ration B) were tested, whereas trial 2 tested dura straw (control, ration A) and bagasse (ration C). Each feeding trial employed 20 intact Western Baggara bulls of about 2.0–2.5 years of age and averaging 120 kg in weight. The trial lasted for 120 days.

No significant difference ($P>0.05$) was found among the three rations with respect to feed intake, daily gain, and feed efficiency. The daily dry-matter intake was 7.5, 7.3, 7.8, and 7.4 kg; daily gain, 1.2, 1.1, 1.2, and 1.0 kg; and feed efficiency, 6.5, 7.2, 7.3, and 8.5 for rations A, B, A, and C respectively.

The digestibility trials, which were carried out with sheep, indicated that ration A dry matter was significantly ($P<0.05$) higher in digestibility than that of rations B and C. The energy content, expressed in terms of total digestible nutrients and starch equivalent, was also observed to be significantly ($P<0.05$) higher in ration A than in rations B and C. The digestible crude protein, however, was higher in ration B than in the other two rations, although not to a significant ($P>0.05$) level. Economic evaluation of the results indicated that all of the rations used were profitable, providing a profit of at least SD 0.49/animal/day.

It was concluded that agroindustrial by-products could be used quite satisfactorily for fattening cattle in the Sudan.

Deux essais d'alimentation des animaux et deux de digestibilité des aliments ont été effectués afin d'évaluer trois rations contenant 30 % de sous-produits agro-industriels de qualité inférieure. Ces sous-produits — tiges de sorgho, coques d'arachides et bagasse — ont été incorporés à des rations qui contenaient aussi du son de blé (29,5 %), des tourteaux de semences de coton (29,5 %), de la mélasse (10 %) et du sel ordinaire (1 %). Les tiges de sorgho (ration A) et les coques d'arachides (ration B) furent testées au cours de l'essai 1, les tiges de sorgho (ration de contrôle A) et la bagasse, au cours de l'essai 2. Chaque expérience portait sur l'alimentation, pendant 120 jours, de 20 taureaux de Bouggara Ouest de 2 à 2,5 ans, pesant en moyenne 120 kg.

Aucune différence significative ($P>0,05$) n'a été enregistrée entre ces trois rations, en ce qui concerne la consommation de fourrage, l'augmentation de poids quotidienne et l'indice de transformation. L'ingestion quotidienne de matières sèches fut de 7,5, 7,3, 7,8 et 7,4 kg ; l'augmentation de poids quotidienne de 1,2, 1,1, 1,2 et 1,0 kg et l'indice de transformation pour les rations A, B, A, et C fut respectivement 6,5, 7,2, 7,3 et 8,5.

Les essais sur la digestibilité des aliments effectués sur des moutons, indiquèrent que le taux de digestibilité des matières sèches de la ration A était bien supérieur ($P<0,05$) à celui des rations B et C. Le contenu énergétique de la ration A, calculé selon les éléments digestibles totaux et l'équivalent amidon, s'avéra également bien supérieur ($P<0,05$) à celui des rations B et C. La quantité de protéines brutes digestibles était un peu plus élevée dans la ration B que dans les deux autres, soit $P>0,05$. L'évaluation sur le plan économique des résultats de cette expérience permit de conclure que toutes les rations

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utilisées présentaient des avantages, qu'elles permettent de réaliser un profit d'au moins 0,49 SOU par animal et par jour.

Il a donc été conclu que les sous-produits agro-industriels pourraient être utilisés d'une manière toute satisfaisante pour l'engraissement du bétail au Soudan.

Para evaluar tres raciones que llevaban 30% de subproductos agroindustriales de baja calidad se realizaron dos pruebas de alimentación y dos de digestibilidad. Los subproductos ensayados — paja dura, cáscara de maní y bagazo — hacían parte de raciones que contenían además salvado de trigo (29,5%), torta de semilla de algodón (29,5%), melazas (10%) y sal común (1%). En el primer ensayo se probó la paja dura (ración A) y la cáscara de maní (ración B); en el segundo, la paja dura (ración A, control) y el bagazo (ración C). Para cada prueba de alimentación se emplearon 20 toros Western Buggara enteros, de 2,0–2,5 años de edad y un peso aproximado de 120 kg. El ensayo duró 120 días.

No se encontró diferencia significativa ($P>0,05$) entre las tres raciones con relación con la ingestión de alimento, la ganancia diaria y la eficiencia alimenticia. La ingestión diaria de materia seca fue de 7,5, 7,3, 7,8 y 7,4 kg, la ganancia diaria fue de 1,2, 1,1, 1,2 y 1,0 kg, y la eficiencia alimenticia de 6,5, 7,2, 7,3 y 8,5 para les raciones A, B, A, y C respectivamente.

Las pruebas de digestibilidad, realizadas con ovejas, indicaron que la materia seca de la ración A era significativamente mayor ($P<0,05$) en digestibilidad que la de las raciones B y C. También se observó que el contenido de energía, expresado en términos del total de nutrientes digeribles y equivalente de almidón, era significativamente más alto ($P<0,05$) en la ración A que en las raciones B y C. La proteína cruda digerible, sin embargo, fue más alta en la ración B que en las otras dos, aunque no a un nivel significativo ($P>0,05$). La evaluación económica de los resultados señaló que todas las raciones utilizadas eran rentables ofreciendo una ganancia mínima de SD £0,49 animal/dia.

Se concluyó que los subproductos agroindustriales podían ser usados satisfactoriamente para el engorde de ganado en Sudán.

Livestock in the Sudan has customarily been maintained on feedstuffs that come from three main sources: natural rangeland grazing, grown fodder crops, and cereal grains. Unfortunately, there is considerable evidence to indicate that the productivity of feedstuffs from these sources is declining rather than increasing to match the steadily increasing livestock population. Large grazing areas have lost their plant cover as a result of desertification that swept the country during the drought years of the early 1970s. Land suitable for arable farming is used for cash and food crops rather than for forage crops because cash and food crops have priority over feed production. The other source of animal feed, cereal grains, which in the Sudan consist almost entirely of sorghum, can no longer be relied upon because of their increased consumption by humans. Eventually, it will be too expensive to feed sorghum to animals.

Fortunately, however, there are huge quantities of agroindustrial by-products that can replace, to a great extent, these traditional sources of feeds. This is not surprising in a country like the Sudan, which is primarily dependant upon agriculture for its livelihood and on an industry that is almost completely based on agricultural products. Estimates of the amount of by-products available from agricultural crops and the different industries are of the order of about 9 million metric tons annually and it is envisaged that this quantity will double by the year 2000 (Arab Organisation for Agricultural Development 1981).

These by-products, which include cereal straws, groundnut haulms and hulls, sugarcane tops, bagasse, molasses, sesame and cotton residues, etc., are highly underutilized at present, being left, for the most part, to rot or to be burned. It is inevitable, however, that the Sudan will soon have to resort to agroindustrial by-products to meet the feed requirements of its livestock. To achieve efficient utilization of these by-products, it is essential to have knowledge of their nutritive value and about the response of animals to their use. With this in mind, the current investigation has been undertaken to assess the value of some of the most abundant by-products, namely dura straw, groundnut hulls, and bagasse, as ingredients in cattle rations.

Materials and Methods

Feeding Trials

Diets

Two separate feeding trials were carried out. In the first trial, referred to as trial 1, dura straw (ration A) and groundnut hulls (ration B) made up 30% of the rations, respectively, that otherwise were of identical composition (Table 1). In the 2nd trial (trial 2), ration A of trial 1 was again fed (control) to one group of animals. The other group of animals was fed ration C, which was similar in content to ration A, except that the dura straw was replaced by bagasse.

Animals

The 20 head of cattle involved in each trial were intact males (uncastrated) ranging in age between 1.5 and 2.5 years. They were born and raised in the Ghazala Gawazat range livestock centre in Southern Darfur. Prior to their shipment to the site of the trials, at Kuku, the animals were vaccinated against the most common contagious diseases in the Sudan, i.e., black leg, anthrax, and haemorrhagic septicemia. Upon arrival at Kuku, they were sprayed with Gammatox and drenched with Mansonil to control external and internal parasites, respectively, and fed on straw.

Design and Procedure

Before starting the feeding trials, the animals were given a period of 14 days to rest and get used to their new surroundings. During that period, the animals were ear-tagged and weighed. According to their live weights, they were then divided into two groups of 10 animals each and introduced gradually to one of the two rations fed in each trial. Each experimental group was housed in a separate pen with an area of 20 m × 20 m and partly shaded by bamboo poles. The pens had feed bunks running their full length and water troughs equipped with automatic float valves that provided a continuous supply of drinking water.

The ration was provided in a mash form and offered twice daily, 7:00 and 16:00 hours, at a level that would ensure ad libitum intake. A daily record of the total feed intake of each group was recorded. Animals were weighed biweekly during the experimental period following an overnight fast. From these weighings, the average daily gain and feed efficiency were calculated. Each trial continued for 124 days.

Table 1. Formulation of the rations on an as-fed basis.

	Ration		
Feedstuff	A	B	C
Sorghum straw "Abu 70"	30	—	—
Groundnut hulls	—	30	—
Sugarcane bagasse	—	—	30
Wheat bran	29.5	29.5	29.5
Cottonseed cake	29.5	29.5	29.5
Molasses	10	10	10
Common salt	1	1	1

Digestibility Trials

Two digestibility trials were conducted, one for the two rations fed in trial 1 (rations A and B) and the other for the rations fed in trial 2 (rations A and C). Six sheep, Sudan desert type, ranging in age between 1.5 and 2.0 years and weighing approximately 40 kg were used in each digestibility trial. The design of the experiments was such that three sheep were selected at random and fed one of the two rations used in each feeding trial in a triplicated 2 × 2 Latin square. The procedure for measuring the digestibility of the diets is described in El Hag (1976).

Results

The chemical composition of the rations fed in the two trials is presented in Table 2. The results demonstrated that the control (ration A) had the same composition in the two trials, with a constant crude protein content of 13.1% and a crude fibre content of 22.1 and 21% in trials 1 and 2 respectively.

Comparing ration A with the other two rations (B and C), the crude protein content of the control ration was lower than that of ration B but higher than that of ration C. The crude fibre content was greatest in ration C, less in ration B, and lowest in ration A. The calcium:phosphorous ratio was nearly 2:1 in ration A and 3:1 in ration B. In ration C, the amount of phosphorus was greater than that of calcium.

Table 3 presents the digestibility coeffi-

Table 2. Chemical composition (%) of the ingredients and the rations on a dry-matter basis.

Feedstuff	Dry matter	Crude protein	Crude fibre	Ether extract	Ash	Nitrogen-free extract	Minerals (%)		
							Ca	PO_4	Mg
Abu 70	97.1	5.4	33.2	2.4	9.8	49.3	0.4	0.1	—
Sugarcane bagasse	98.2	1.3	42.0	1.0	2.0	53.7	—	—	—
Groundnut hulls	94.8	5.5	32.0	1.1	8.1	53.4	0.1	—	—
Wheat bran	93.3	15.6	10.8	5.4	4.7	63.7	0.5	0.7	—
Cottonseed cake	96.1	22.3	24.7	7.9	3.8	41.4	0.3	0.5	—
Sugarcane molasses	75.2	2.4	—	0.2	8.5	88.9	1.4	—	—
Ration A (trial 1)	88.7	13.1	22.1	5.8	8.4	50.6	1.0	0.5	0.3
Ration B	93.0	14.3	23.3	5.8	7.5	49.1	1.1	0.4	0.3
Ration A (trial 2)	91.4	13.1	21.0	5.8	8.4	51.7	1.1	0.5	0.3
Ration C	95.4	12.6	29.6	3.7	6.5	47.6	0.3	0.4	0.2

Table 3. Mean digestibility coefficients (%) for the components of the rations (± standard error).

	Dry matter	Organic matter	Crude protein	Crude fibre	Ether extract	Nitrogen-free extract
Ration A (trial 1)	63.9±3.9[a]	65.9±3.7	69.8±4.6	54.1±6.4	89.4±1.1	65.5±3.6[a]
Ration B	51.0±1.2	51.9±1.4	70.2±3.2	35.1±3.4	88.6±0.2	50.4±1.9
Ration A (trial 2)	63.2±2.1[a]	64.2±1.1	69.5±2.7	48.7±2.0	89.9±0.3[a]	65.9±1.1
Ration C	56.3±0.7	59.3±0.8	62.4±1.2	48.3±1.7	77.0±1.2	63.3±0.7

[a] Significant at $P<0.05$.

cients of the nutrients in the rations. With the exception of the crude fibre fraction, all other nutrients in ration A showed similar digestibility in the two trials conducted. The results also showed better digestibility for the nutrients in ration A than those in rations B and C. This difference in digestibility was statistically significant ($P<0.05$) with regard to dry matter, organic matter, and nitrogen-free extract for the rations used in trial 1 (A and B), whereas in trial 2 only the dry matter and ether extract showed a significant ($P<0.05$) difference. Ration C was superior to ration B in the digestibility of dry matter, organic matter, crude fibre, and nitrogen-free extract, whereas the reverse was true with respect to the digestibility of crude protein and ether extract.

Table 4 presents data on the nutritive value of the rations in terms of total digestible nutrients (TDN), starch equivalent (SE), and digestible crude protein (DCP). The energy content of the straw ration (A), whether expressed in the form of TDN or SE, was higher than that of the bagasse (C) and groundnut hull (B) rations. The difference in energy content between A and B in trial 1 and A and C in trial 2 was significant at $P<0.05$. Considering rations B and C, the latter was richer in energy with respect to TDN and SE. Digestible crude protein was greatest in ration B, followed by ration A and then ration C.

The average daily feed consumption (Table 5) indicated a negligible difference between the different treatments. In particu-

Table 4. Nutritive value of the rations (± standard error).

	Total digestible nutrients	Starch equivalent	Digestible crude protein
Ration A (trial 1)	58.8±4.1	50.1±2.3[a]	9.1±0.6
Ration B	48.1±1.2	38.6±1.2	10.0±0.4
Ration A (trial 2)	58.7±1.1[a]	50.6±1.2[a]	9.1±0.4
Ration C	55.0±0.6	39.9±0.6	7.8±0.1

[a] Significant at $P<0.05$.

Table 5. Intake, growth, and efficiency of feed utilization (± standard error).

	Trial 1		Trial 2	
	Ration A	Ration B	Ration A	Ration B
Number of animals	10	10	10	10
Initial live weight (kg)	116.5	116.5	124.0	125.5
Duration of test (days)	124	124	124	124
Final live weight (kg)	272.5	256.5	265.0	253.5
Total gain (kg)	156.0	140.5	141.0	128.0
Daily gain (kg)	1.2±0.06	1.1±0.11	1.2±0.10	1.0±0.06
Daily dry-matter intake	7.5±0.3	7.3±0.3	7.8±0.3	7.4±0.1
kg feed/kg gain	6.5±0.6	7.2±0.9	7.3±0.8	8.5±1.3
Total TDN consumed (kg)	545.6	434.0	558.0	508.4
kg TDN/kg gain	3.5	3.1	3.9	4.0

lar, when intake was related to the animals' live weight, it was found to be almost identical for all rations and amounted to 3.7% of the live weight.

In terms of the daily gain, none of the rations resulted in a daily gain of less than 1 kg, with ration A producing the greatest gain. The average daily gain of animals on ration A in trial 1 was greater by 115 g than those on ration B, whereas the difference in daily gain between ration A in trial 2 and ration C was 168 g. It should be noted that the difference in initial live weight between animals was small and insignificant ($P>0.05$).

The efficiency of feed conversion, i.e., feed consumed per kilogram live-weight gain (feed/gain ratio), expressed in terms of dry matter and TDN, is also shown in Table 5. Feed conversion was significantly ($P<0.05$) better for rations fed in trial 1 than those fed in trial 2. Even for ration A, efficiency of energy conversion was 11% higher in trial 1 than in trial 2. Ration A was superior to ration B in terms of being converted into body-weight gain, although not to a significant ($P>0.05$) level, whereas the difference in feed conversion between rations A and C was more pronounced ($P<0.05$) in favour of ration A.

Table 6 shows the costs of the rations. There was little difference between the rations, given the assumed prices. It should be noted that wheat bran and cottonseed cake were the most expensive ingredients in the rations and their costs accounted for 90% of the total.

The economic evaluation of fattening on rations containing 30% agroindustrial by-products is presented in Table 7. The data demonstrated that all rations used were profitable, providing a gross profit of at least SD 0.49/animal/day. Ration C, which incorporates bagasse, is the least profitable

Table 6. Cost of rations used.

	Unit price (SD£/t)	Ration A		Ration B		Ration C	
		kg	SD£	kg	SD£	kg	SD£
Sorghum stalks	17[a] – 23[b]	300	6.90				
Groundnut hulls	30 – 35			300	10.50		
Bagasse	12 – 23					300	6.90
Wheat bran	48 – 130	295	38.35	295	38.35	295	38.35
Cottonseed cake	80 – 150	295	44.25	295	44.25	295	44.25
Molasses	8 – 10	100	1.00	100	1.00	100	1.00
Salt	45	10	0.45	10	0.45	10	0.45
Subtotal			90.95		94.55		90.95
Grinding, mixing			5.00		5.00		5.00
Administration, profit (10%)			7.70		7.70		7.70
Total			103.65		107.25		103.65

[a] Fixed government price.
[b] Free-market price.

Table 7. Economic evaluation of meat production from by-product rations.

	Trial 1		Trial 2	
	Ration A	Ration B	Ration A	Ration C
Initial live weight (kg)	116.5	116.5	124.0	125.5
Final live weight (kg)	272.5	256.5	265.0	253.5
Live-weight gain (kg)	156.0	140.0	141.0	128.0
Daily live-weight gain (kg)	1.26	1.13	1.14	1.03
Value of daily gain (SD£)	1.58	1.41	1.43	1.29
Feed costs (SD£)	0.88	0.84	0.88	0.80
Economic efficiency	1.80	1.68	1.62	1.61
Gross profit/day/animal (SD£)	0.70	0.57	0.55	0.49
Feed cost per kg live-weight gain (SD£)	0.70	0.74	0.77	0.78

ration based on all of the factors considered, i.e., economic efficiency, gross profit, and feed costs per kilogram live-weight gain.

Discussion

The three fibrous by-products used in this study represent the most available agricultural by-products found in the Sudan. They are not only present in great quantities but are also widely distributed among the different regions of the country. It is evident from the nutrient content of these by-products that they could not be used on their own to sustain an animal or support any kind of production. Therefore, the successful utilization of these by-products for fattening cattle requires an understanding of their limited nutritional value and, hence, the need for specific supplements. Accordingly, the low-protein content of these by-products was ameliorated by using cottonseed cake and their high crude fibre content and low palatability were enhanced by using molasses.

Feeding these supplementary ingredients together with wheat bran, salt, and the tested fibrous by-products resulted in diets suitable for fattening cattle as recommended by NRC (1970), especially with regard to the crude protein content, which was found to be 13.1, 14.3, and 12.6% in rations A, B, and C respectively. The crude fibre percentage seemed to be a bit higher than that usually encountered in fattening rations.

The difference in the digestibility of the rations can be attributed mainly to the quantity and quality of their crude fibre. According to McDonald et al. (1973), the crude fibre fraction of a diet has the greatest influence on its digestibility and both the quantity and quality are important as determining factors. The results of the present investigation substantiate the importance of the crude fibre quality because ration C, with its higher crude fibre content, was digested to a greater extent than ration B.

The dry-matter intake of the animals in these trials was higher than that reported by NRC (1970), which gave the intake of fattening cattle as between 1.4 and 2.7% of their live weight. The intake from the rations used in the present study was nearly identical for all three rations and averaged 3.7% of the live weight. This higher intake is of great economic importance, especially from such inexpensive diets because, generally, animals that consume more will produce more and thus improve their efficiency. The lack of a difference in intake between the three diets might be attributed to molasses, which is known to improve palatability and, in effect, mask the difference in consumption.

The most interesting finding from this study was that of live-weight gain. The rate of growth that took place in these animals, considering that the experimental rations included nothing but agroindustrial by-products and salt, was really surprising. The response shown by these animals was quite similar to that reported by El Shafie and Mcleroy (1964), who employed Western Baggara bulls but utilized a ration that included sorghum grains. This fast rate of growth could be attributed mainly to the optimum composition of the rations, in terms of meeting the needs of the animals. In addition to that, however, it is reasonable to suggest that these animals should have also shown some compensatory growth because it is normal for them to experience a period of undernutrition on the range. It is known that animals of all species that have been subjected to a period of undernutrition subsequently exhibit compensatory growth during the period of realimentation (Wilson and Osbourn 1960). This phenomenon is characterized by faster than average growth when liberal feed supplies become available. The belief that the experimental animals had passed through periods of underfeeding could also be confirmed from their high feed intake because animals previously undernourished are found to have greater feed intake during a period of realimentation (Sheeny and Senior 1942; Winchester and Howe 1955).

El Shafie and Mcleroy (1964) ascribed the high rate of growth of Western Baggara cattle in feedlots to the fact that such cattle are bred and raised in an environment that necessitates the rapid buildup of body reserves during the relatively short lush season in order to have enough of these reserves to carry them through the much more extended dry months of the year.

The decline in weight gain after the 98th day of the trial implied that the animals had reached their full muscular growth and the extra live-weight increase was containing a higher proportion of fat to muscle. Because fat synthesis requires nearly double the energy needed for muscular growth, the efficiency of conversion should be expected to fall after this period. Zebu cattle seem to attain their maximum growth rate at a lower weight than the temperate breeds of cattle and, therefore, have to be marketed at a lower weight as well. A fattening period of about 3 months is thus recommended for animals of this age and coming from the range to a feedlot.

The efficiency of feed conversion compared favourably with rations containing 20% dura grain (El Shafie and Mcleroy 1964) and ration A gave the same conversion ratio (6.5). The conclusion that could be reached from this study is that using agroindustrial by-products to fatten cattle is not only technically feasible but also economically profitable, as shown in Table 7. These results will no doubt help toward increasing the use of agroindustrial by-products in feeds for ruminants in the Sudan. The increase in the proportion of these by-products in rations will reduce the cost of feeds even further.

It is envisaged that the best way to utilize these by-products in feeds is to incorporate them into balanced rations and give these rations to animals after they leave the range. Because most animals coming from the range are quite lean, keeping them on by-product rations for some time (45 and 90 days for sheep and cattle respectively) will improve both the quantity and quality of their meat and enhance the profits associated with raising livestock. Feeding by-product rations to livestock while they are still on the range will be quite difficult to achieve because their owners are nomadic, and carrying loads of feed from one place to another is impossible.

We wish to express our gratitude to G.R. Potts, IDRC, Ottawa, Canada, for his help with the economic analysis of the data.

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Session I Discussion: Research Results

The high growth rates (>1.0 kg/day) of cattle in Prof. ElHag's experiment generated much discussion. The author suggested that it may have been due to a combination of compensatory growth and an "optimum" diet, but he was questioned on how he could separate the two. The participants agreed that care was needed when interpreting compensatory gains in cattle as they frequently showed very high gains (>3.0 kg/day) during the initial stages of realimentation, but then the gains frequently tapered off. High initial gains are largely due to increased gut-fill. In the experiment, initial growth rates were higher than the averages quoted in the paper but even at the end of the fairly long (124 days) trial growth rates were in excess of 0.5 kg/day. Other reasons for the high growth rates, such as rehydration and the fact that the animals were males and perhaps near puberty, were suggested. However, it was finally observed that the diet fed (63–65% total digestible nutrients in diet dry matter) was of such a high-energy density that growth rates of this order would be expected.

Prof. ElHag was questioned on why he chose only 30% inclusion of the residue test-materials in his diets. He explained that the experiment was the first of a series and 30% was chosen as a level unlikely to impair growth rates in what was essentially a cattle-finishing system. A participant criticized the experiment for not having a negative-control in its design and felt that resources would have been better utilized if the trial had confined itself to one residue included at several levels. Prof. ElHag indicated that a range of levels (up to 50%) was currently being investigated. He further pointed out that at the time of the experiment a "high" control (0% inclusion) treatment had been contemplated but dropped because of the excessive price of cereals at the time. A participant commented that the Abu 70 sorghum straw used in the experiment is normally regarded as a fodder feed and it should, therefore, not have been treated as a "costless" residue. The high cost of transporting residues such as straw was noted, especially in the Sudan, where crop production and animal production are geographically separated.

In answer to the question of who would be the beneficiaries of his research, Prof. ElHag replied that the nomadic cattle-keepers would not be interested. About 90% of the cattle in the Sudan are range-reared by nomads who sell them to cattle finishers located in periurban areas. The latter are used because of their proximity to the sources of high-grade by-products (flour and oil milling). In view of the high growth rates required, the scope for using substantial levels (>30%) of fibrous by-products in Sudan "feedlot" diets may be limited. In answer to another question, Prof. ElHag said that, having researched and developed rations incorporating fibrous by-products, it was anticipated that the government would set up the animal feed mills in periurban areas. This would mean that transport costs would be largely limited to the collection of fibrous residues.

Prof. ElHag was asked why molasses had not been used at higher levels. He replied that molasses was largely wasted (some was dumped into the Nile) because its transport was difficult. One participant indicated that research in Colombia has shown that it is possible to mix molasses and bagasse (1:1) to facilitate its transportation as a solid. It was noted that if more than 8% molasses was used, pelleting such diets (if contemplated) would not be possible. It was suggested that feedlots should, perhaps, be set up near sugar mills.

The merits and demerits of pelleting were then discussed. Transport costs and wastage were greatly reduced by pelleting. The extensive research into grinding and pelleting roughages, undertaken in North America and Europe, was noted. (It should be added that considerable controversy still exists about the nutritional benefits of these procedures. Although it is agreed that intake of poor-quality roughages is increased by about 30% following grinding, pelleting is not considered important except in reducing the amount of dust.) The high cost of fine grinding of roughage was raised, but it was pointed out that fine grinding (screen size <6 mm) is necessary to increase intake in cattle. The problem of low milk-fat due to feeding finely ground roughages was raised and the issue of milk-fat levels was discussed. The problems encountered by Dr Naga in developing grinding and pelleting machinery for alkali-treated roughages were also discussed and the special requirement for optimum die-design noted. The point was raised that machinery had been developed in the United Kingdom and Denmark to grind and pellet NaOH-treated straw under feed-mill conditions.

The question of mineral nutrition in relation to roughage utilization, in Dr Naga's paper, promoted much discussion. He suggested that the particular responses to mineral supplementation may have been partly due to soil mineral deficiencies caused by the alleviation of Nile-flooding since the construction of the Aswan dam. However, he felt, and the participants agreed, that the subject of mineral supplementation merited further research. It was also noted that there was a need to have an optimum balance of minerals, e.g., N:S ratio, for maximum use of nonprotein nitrogen. Water buffalo appear to need a higher mineral intake than cattle; more research is clearly needed in view of the importance of the buffalo in many developing countries. The apparent interference with potassium metabolism, caused by high rumen-ammonia levels (e.g., in high nonprotein nitrogen diets), was discussed. One participant felt that this was only a problem at very high rumen-ammonia levels, which rarely occured in practice. He conceded, however, that it was a potential problem for animals fed high levels of ammonia- or urea-treated roughages, and that it seemed to be an aspect not published to date.

The complex economics of the animal-feed industry in Egypt were noted, but Dr Naga felt that treatment with sodium hydroxide was currently too expensive. This was the reason why the research had centred on urea (as a source of ammonia) over the past few years.

When asked how he saw the development of greater usage of treated straw in Egypt by small farmers, Dr Naga intimated that the problem was complex. Small farmers were suspicious of developments that appeared to come from the government as they were thought to be concerned with tax collection, etc. Farmers were familiar with purchasing animal feeds from mills. He felt, therefore, that the plan to set up a mill to produce urea-treated straw was appropriate, at least initially. (One participant noted the "psychological" effect of pelleting, which allowed for the sale of even poor-quality feeds in pelleted form.) Once small farmers accepted the idea of using centrally-treated straws (even unpopular rice and bean straws), they would more readily accept the idea of on-farm treatments, which Dr Naga felt should be the long-term aim. Another approach was to get the idea accepted by the larger, more influential farmers who are less suspicious of new developments. These farmers frequently send their sons to Alexandria University to study agriculture. The university is currently teaching a course on low-quality roughage utilization. This is another means to promote the acceptance of the new philosophy.

Use of By-Products to Feed Bali Cattle

I.M. Nitis[1]

Two feeding experiments have been carried out in a mixed-farming village to study the effect of replacing 30% of the green roughage with readily available agroindustrial by-products (copra meal, rice bran, hen manure, and cassava chips) on the performance of Bali steers with an average initial live weight of 101–114 kg. The completely randomized block design arrangement consisted of five treatments (one diet with 100% green roughage and four diets of 70% green roughage + 30% various concentrate mixtures) and four replications, with two cattle in each replication. Sixteen cattle were raised using traditional methods for comparison. In experiment 1, the concentrate-supplemented diet was formulated to meet the requirements for the 100–200, 200–300, and 300–400 kg live-weight ranges. In experiment 2, the best diet in experiment 1 was compared with the cheapest concentrate-supplemented diet. The duration of experiments 1 and 2 was 200 and 68 weeks respectively.

Cattle supplemented with various concentrate mixtures gained 2.7–3.9 times more weight ($P<0.05$) and were 50.5–67.7% more efficient in utilizing the feed than those fed on green roughage alone. Among the concentrate-supplemented groups, the response varied according to the growth stages. Cattle supplemented with concentrate mixtures required 2.25 years to reach 375 kg (market weight), whereas those fed green roughage were expected to take 2–3 times longer to attain a weight of 375 kg.

Simple benefit–cost analysis showed that the gross profit from cattle receiving concentrate mixtures was 55.5% more than those receiving only green roughage. The greatest live-weight gain (average 349 g/day) occurred in cattle supplemented with 10% copra meal + 10% rice bran + 10% cassava chips, whereas the highest gross profit (IDRp53.45/day) resulted from cattle supplemented with 20% rice bran + 10% hen manure. The constraint was not on the concentrate but on the availability and cost of the green roughage.

Government extension officers, government cattle-breeding projects, small credit investment units, and some farmers are keen to implement the research results in their respective undertakings.

Deux expériences d'alimentation du bétail ont été effectuées dans un village où la polyculture était pratiquée, afin d'étudier les effets du remplacement de 30 % du fourrage vert par les sous-produits agro-industriels disponibles (farine de coprah, son de riz, fumier de poule et chips de manioc) sur la croissance de boeufs de Bali, dont le poids vif initial allait de 101 à 114 kg. L'expérience, réalisée selon le plan de répartition des blocs au hasard, comprenait cinq régimes alimentaires (un de 100 % de fourrage vert et quatre de 70 % de fourrage vert + 30 % de divers mélanges concentrés), répétés quatre fois sur deux animaux chaque fois. Un groupe témoin de seize animaux a été nourri de la manière traditionnelle. Dans le cas de l'expérience 1, la ration complémentaire de concentrés avait été calculée en fonction des besoins de bêtes ayant un poids vif entre 100 et 200 kg, 200 et 300 kg puis 300 et 400 kg. Au cours de l'expérience 2, le meilleur régime établi durant l'expérience 1 fut comparé à la ration complémentaire de concentrés les moins coûteux. La durée des expériences 1 et 2 fut de 200 et 68 semaines respectivement.

Les animaux ayant été soumis à des régimes comprenant des suppléments de divers mélanges et concentrés gagnèrent de 2,7 à 3,9 fois plus de poids ($P<0,05$) et leur taux

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d'utilisation des aliments était de 50,5 à 67,7 % supérieur à celui des animaux nourris uniquement au fourrage vert. Parmi les groupes d'animaux dont le régime comprenait des suppléments, les résultats varièrent aux différentes étapes de leur croissance. Les animaux dont le régime comprenait des concentrés prirent 2,25 années pour atteindre le poids marchand de 375 kg ; les animaux nourris au fourrage vert seulement auraient pris de 2 à 3 fois plus de temps pour atteindre ce poids. Une simple analyse des coûts et bénéfices indiqua que les animaux recevant des suppléments nutritifs permettaient de réaliser 55,5 % de plus de bénéfices bruts que ceux auxquels on ne donnait que du fourrage vert. On observa le taux le plus élevé de gain de poids vif parmi les animaux dont le régime comprenait les suppléments suivants : 10 % de farine de coprah + 10 % de son de riz + 10 % de chips de manioc, tandis que les animaux dont le régime comprenait 20 % de son de riz + 10 % de fumier de poule permirent de réaliser les bénéfices bruts les plus élevés (53,45 NRPH/jour). Les problèmes auxquels il fallut faire face au cours de cette expérience ne tenaient pas tant aux divers concentrés utilisés qu'à la disponibilité et au coût du fourrage vert.

Des agents de vulgarisation agricole du gouvernement, certains éleveurs, des directeurs de projets d'élevage gouvernementaux et plusieurs petits établissements de crédit d'investissement sont intéressés à appliquer les résultats de ces recherches à leurs entreprises respectives.

Se describen dos experimentos realizados para observar el efecto que sobre el desempeño de novillos Bali con un peso vivo inicial promedio de 101 a 114 kg, producía el reemplazo de 30% de forraje verde por subproductos agroindustriales fácilmente obtenibles (harina de copra, salvado de arroz, gallinaza y trozos de yuca). El diseño en bloques, totalmente al azar, consistió en cinco tratamientos (una dieta con 100% de forraje verde y cuatro dietas con 70% de este forraje + 30% de varias mezclas concentradas) y cuatro réplicas con dos animales cada una. Para efectos de comparación, se levantaron 16 novillos con los métodos tradicionales. En el primer experimento, la dieta suplementada con concentrados fue formulada para hacer frente a las necesidades de los pesos vivos de 100–200, 200–300 y 300–400 kg. En el segundo experimento, la mejor dieta del primer experimento fue comparada con la dieta suplementada con el concentrado más barato. La duración de las dos pruebas fue de 200 y 68 semanas respectivamente.

El ganado que recibió suplemento de mezclas concentradas ganó de 2,7 a 3,9 veces más peso ($P<0,05$) y fue de 50,5 a 67,7% más eficiente en la utilización del alimento que aquellos alimentados solo con forraje verde. Entre los grupos con suplemento de concentrados, la respuesta varió según las etapas de crecimiento. El ganado que recibió suplemento de mezclas concentradas requirió 2,25 años para alcanzar 375 kg (peso comercial); se esperaba que los alimentados con forraje verde tomarían el doble o triple de tiempo para lleger a los 375 kg.

Análisis sencillos de costo-beneficio mostraron que la ganancia bruta obtenida con el ganado que recibía mezclas concentradas era 55,5% más que la de los alimentados con forraje verde solamente. La mayor ganancia de peso vivo (un promedio de 349 g/día) se observó en el ganado que recibió como suplemento 10% de harina de copra + 10% de salvado de arroz + 10% de yuca picada. El más alto beneficio bruto (IDRp53,45/día) se presentó entre el ganado que recibió como suplemento 20% de salvado de arroz + 10% de gallinaza. La limitación no estuvo en el concentrado sino en la disponibilidad y costo del forraje verde.

Los funcionarios oficiales de extensión, los proyectos nacionales de producción pecuaria, las unidades de inversión en pequeños créditos y algunos agricultores están interesados en aplicar los resultados dela investigación en sus respectivos trabajos.

Traditionally, cattle are raised in Bali mainly for draft purposes. Animal feed consists predominantly of grass, tree leaves, stems, and the foliage of herbaceous broad-leaved species (Nitis 1967; Sudana et al. 1979).

In the Indonesian government's integrated small farm animal production system (Soehadji and Hutasoit 1976), concentrate supplement is one of the prerequisites. Experiments have shown (Supardjata et al. 1972; Mika et al. 1973) that commercial concentrate supplement improved the live-weight gain of Bali cattle but became uneconomic when used continuously.

This paper discusses the effect of readily available agroindustrial by-product feed supplements on the performance of Bali cattle, on the cost–benefit ratio, and the interest of government extension officers and farmers in using the research results.

Feeding Trials

Materials and Methods

Feeding experiments were carried out at Petang at an elevation of 450 m above sea level. The average annual rainfall of 2249 mm occurred mainly during the November to March rainy season. Temperatures ranged from 16–29°C, with 79–99% relative humidity.

In this intensive mixed-farming system, the farmer grows cassava and pulses in dry areas, rice in wet areas, and coconut trees and other fruit trees along the edge of fields. Petang is one of the better areas in Bali where cattle can be fattened.

Each experiment was arranged in a completely randomized block design consisting of five feeding regimes (diets) and four blocks (replications) with two cattle in each replication. Another eight local cattle were raised for comparison using traditional methods. The yearling Bali steers were arranged so that the average initial live weight of the cattle in each treatment at the beginning of the experiment was similar.

Green roughage consisted of 77% natural grasses (dominated by *Polytrias* and *Paspalum*) and 23% broad-leaved species (dominated by *Ageratum* and *Nephrolepis*). The broad-leaved species component increases during the dry season (up to 37%), whereas during the wet season the grass component can be as high as 85%. Due to a shortage of natural grass during the dry period, elephant grass (*Pennisetum purpureum*) was grown as a reserve.

The concentrate copra meal, rice bran, and cassava chips was bought in bulk. Hen manure was collected daily from hens fed commercial rations. The concentrate was mixed with water (1:1 ratio by weight) before feeding. Chemical analysis of the green roughage was carried out monthly and of the concentrate every 2–3 months.

There are two types of copra meal produced in Bali: that produced using the expeller process and copra meal produced by traditional methods. Rice bran is produced in factories as well as by traditional means, whereas cassava chips are produced solely by traditional methods. With the development of "Bimas Ayam" (a government small credit investment unit), a lot of poultry manures are produced. Because all of these feed ingredients are produced on the farm or nearby, they are easily accessible to the farmer.

At present, copra meal and rice bran are fed mainly to pigs and poultry and are also exported (quota basis). Cassava chips are fed to pigs and are used as ingredients to make snacking cake. Poultry manure is used as fertilizer to a small extent.

The diets consisted of 100% green roughage (diet A) and 70% green roughage supplemented with 30% various concentrate mixtures (dry-matter basis). Diet A contained nutrients below the standard requirements set forth by the National Research Council (NRC 1970).

In experiment 1, diets B_1, B_2, and B_3 met the standard requirements for the 100–200, 200–300, and 300–400 kg live-weight ranges respectively; whereas diets C, D, and E met only the requirements for the 300–400 kg live-weight range. The difference between diets B_3, C, D, and E was the ratios between the concentrate components.

In experiment 2, the best diet from experiment 1 (diet D) was compared with the other cheaper concentrate-supplemented diets. Diet D and H contained similar metabolizable energy (ME) and crude protein (CP), but differed in the composition of the concentrate mixture. Diet F contained higher ME but lower CP; whereas diet G contained lower ME but higher CP. Diet G contained CP according to the NRC standard for the 100–300 kg live-weight range, whereas diets A and F contained CP in accordance with the 300–400 kg live-weight range. The composition and chemical constituents of each of the diets are presented in Tables 1 and 2.

Local cattle, raised by traditional methods, were fed whatever green feed was available on the farm, i.e., grass, herbaceous broad-leaved species, stems, or shrub or tree leaves. The grasses were cut from the edge of the fields under the cash crop plants and land not used for cultivation. The shrub and tree leaves were cut from the shrubs and fruit trees grown along the edge of the fields and on land not suited for agriculture. The fruit of some trees was included in the feed on occasion.

Table 1. Percentage composition and determined chemical constituents of the diets used in experiment 1.

	Diet[a]						
	A	B_1	B_2	B_3	C	D	E
Natural grasses	100	70	70	70	70	70	70
Copra meal	—	25	20	15	15	10	5
Cassava chips	—	5	10	15	15	10	10
Rice bran	—	—	—	—	—	10	15
Crude protein (%)	9.15	11.63	10.38	10.09	9.84	10.04	9.58
Metabolizable energy (kcal/kg)	185	250	268	276	259	253	257
Crude fibre (%)	26.67	21.14	20.83	20.74	20.60	21.69	22.01
Ether extract (%)	1.47	4.40	3.85	2.80	2.88	2.21	2.85

[a] B_1 = 100–200 kg live weight; B_2 = 200–300 kg live weight; B_3 = 300–375 kg live weight; A, C, D, E = 100–375 kg live weight.

Table 2. Percentage composition and determined chemical constituents of the diets used in experiment 2.

	Diet				
	A	D	H	F	G
Roughage	100	70	70	70	70
Copra meal	—	10	—	—	—
Rice bran	—	10	30	—	20
Cassava chips	—	10	—	30	—
Hen manure	—	—	—	—	10
Crude protein (%)	9.70	10.65	10.88	7.68	12.79
Metabolizable energy (kcal/kg)	2510	2600	2562	2619	2496
Total digestible nutrients (%)	69.40	71.93	70.85	72.40	69.03

Observations

The roughage, concentrate, and water consumed and refused were recorded daily. Live weight was measured every 4 weeks. Daily feeding and care were carried out by the farmers (each farmer was responsible for five cattle). Experiment 1 was carried out for 200 weeks (24 July 1978 – 24 May 1982) and experiment 2 for 68 weeks (2 February 1981 – 24 May 1982).

The live weight of cattle raised by traditional methods was measured every 4 weeks. Of the feed given to each farmer, 5 kg was collected, all samples were mixed thoroughly, and 10-kg subsamples were taken to determine botanical and chemical composition.

An analysis of variance was conducted and when the differences among the treatments were significant ($P<0.05$) they were subjected to Duncan's multiple range test (Steel and Torrie 1960). The standard error of the treatment means (SEM) was tabulated. The responses of cattle on the farm were not included in the analysis. It should be noted that the standard deviation (SD) of the live weight of the cattle on the farm was quite large (±19 to ±21 at the beginning and ±54 to ±64 at the end of the experiments). This was due to the fact that these cattle included extremely light or heavy farm animals that were not used in the experiment.

Results

Live-Weight Gain

Up to 116 weeks, in experiment 1, cattle supplemented with various concentrate mixtures (diets B, C, D, and E) gained 2.7 times ($P<0.05$) more weight than those fed on grass alone (diet A) (Table 3). At this time, cattle that had reached 375 kg were slaughtered for carcass appraisal. From 116–200 weeks, cattle on diet A gained 0.117 kg/day. Therefore, it would require 2188 days to reach 375 kg (market weight).

Table 3. Performance of the cattle in experiment 1 from 0–116 weeks.

	Diet					SEM	Local cattle
	A	B	C	D	E		
Initial live weight (kg)	101.6	102.7	101.9	101.1	100.5		98.6
Live weight at 116 weeks (kg)	200.6	360.4	358.7	362	355.3		255
Live-weight gain (kg/day)	0.12a	0.32b	0.32b	0.32b	0.32b	0.01	0.19
Feed consumption (kg dry matter per day)							
Roughage	3.46a	3.15a	2.88a	2.89a	3.05a	0.34	
Concentrate	—	1.58a	1.66a	1.74a	1.70a	0.34	
Roughage/concentrate ratio							
Offered	100/0	70/30	70/30	70/30	70/30		
Consumed	100/0	67/33	64/36	63/37	64/36		
Feed conversion ratio (feed/gain)	30.34a	14.80a	14.06b	14.48b	15.02b	0.72	
Water consumption (L/day)	2.77a	5.49b	5.00b	4.57b	5.23b	0.33	

NOTE: Values followed by the same letter were not statistically significant ($P>0.05$).

Within the concentrate-supplemented group, the live-weight gain was similar (0.32 kg/day). In the live-weight range 100–200 kg, cattle fed on diets B and C gained more weight than those fed on diets D or E. From 200–300 kg, cattle fed on diet E gained the most weight (0.41 kg/day) and cattle fed on diet B the least (0.33 kg/day). From 300 kg onward, cattle fed on diets D or E gained more weight than cattle fed on diets B or C. On the whole, cattle fed on diet B grew the fastest up to a weight of 250 kg. After this point, however, cattle fed on diet C grew faster than those on diet B. Cattle fed on diets D and E, on the other hand, caught up to cattle fed on diet B after reaching 325 kg.

In experiment 2, cattle supplemented with concentrate (cattle fed on diets D, F, G, and H) gained weight 1.7–3.6 times faster ($P<0.05$) than cattle fed on diet A (Table 4). Within the concentrate-supplemented group, cattle fed on diet D gained weight quickly, whereas cattle fed on diet F gained weight slowly.

In both experiments, local cattle raised by

Table 4. Performance of cattle in experiment 2.

	Diet					SEM	Local cattle
	A	D	H	F	G		
Initial live weight (kg)	113.5	113.5	113.4	113.6	113.5	—	108.8
Live weight at 68 weeks (kg)	163.1	294.0	251.8	190.0	277.1	—	235.3
Live-weight gain (kg/day)	0.104a	0.379b	0.291c	0.161d	0.344b	0.03	0.266
Feed consumption (kg dry matter per day)							
Roughage	3.44a	2.44b	2.63b	2.78b	3.13a	0.11	—
Concentrate	—	2.02a	1.69b	0.89c	1.98a	0.17	—
Roughage/concentrate ratio	100/0	55/45	61/39	76/24	61/39	—	—
Feed conversion ratio (feed/gain)	33.08a	11.77b	14.85c	20.73d	14.85c	1.12	—
Water consumption (L/day)	10.13	10.31	10.26	7.26	8.26	—	—

NOTE: Values followed by the same letter were not statistically significant ($P>0.05$).

traditional methods gained 0.03–0.14 kg/day more than cattle fed on diet A, but 0.13 kg/day less than the best supplemented diet.

Feed and Water Consumption

In each experiment, cattle receiving diets supplemented with concentrate consumed more feed than those fed on grass alone. The higher feed consumption was due to the concentrate component, because the grass component was lower.

In experiment 1, cattle fed on diet B consumed more grass, whereas cattle fed on diets D and E consumed more concentrate. In experiment 2, cattle fed on diet D consumed more concentrate and less grass. Water consumption followed a similar pattern.

The green feed given to cattle in the project consisted of 78% grasses and 22% broad-leaved species during the dry season and 84% grasses and 16% broad-leaved species during the wet season, with *Pennisetum* and *Ageratum* dominating the grass and broad-leaved genera respectively. For the local cattle, the green feed consisted of 43% (dry season) – 52% (wet season) grasses, 28–29% broad-leaved species, 6–7% shrub leaves, 8–13% tree leaves, and 5–9% stems, with *Imperata* and *Paspalum*, *Nephrolepis* and *Ageratum*, *Manihot* and *Musa*, and *Erythrina* and *Artocarpus* leaves being the dominant genera. The CP content of the green feed given to cattle in the project varied not only from season to season but was also 9–28% lower than the CP content of the green feed given to local farm cattle (Tables 5, 6).

Efficiency of Feed Utilization

In both experiments, cattle receiving feed supplemented with concentrate were 37–64% more efficient in utilizing the feed than those fed on grass alone.

In experiment 1, between 100 and 200 kg, cattle fed on diet C utilized the feed most efficiently, whereas cattle fed on diet E were the least efficient in their utilization of the feed. Between 200 and 300 kg, on the other hand, cattle fed on diet E utilized the feed most efficiently and cattle fed on diet B the least. From 300 kg onward, the situation was the reverse of that between 100 and 200 kg. In experiment 2, cattle fed on diet D were the most efficient in the utilization of their feed and those fed on diet F the least.

Cost and Return Analysis

Steers are usually sold for meat as soon as they reach a weight of 375 kg live weight (market weight). Steers below 375 kg live weight are considered unsuitable for slaughter and the price per kilogram live weight becomes lower. Cattle exporters will buy such steers and fatten them to 375 kg.

Table 5. Seasonal variation in the chemical composition of the roughage fed to cattle in the project.

Season	Period	Dry matter (%)	Percentage dry matter: Crude protein	Percentage dry matter: Crude fibre	Gross energy (kcal/kg)
1978–1979					
Dry	July–September	21.30	11.11	25.46	4239
Wet	October–April	19.42	8.78	26.19	4218
1979–1980					
Dry	May–September	19.28	10.73	26.15	3938
Wet	October–April	22.27	8.17	28.66	4078
1980–1981					
Dry	May–September	24.95	8.58	27.50	3985
Wet	October–April	20.43	8.23	29.58	4196
1981					
Dry	May–September	18.40	10.24	28.78	3943
Wet	October–December	21.27	7.85	29.04	3934
Average					
Dry		20.98	10.17	26.97	4026
Wet		20.85	8.26	28.37	4106

Table 6. Seasonal variation in the chemical composition of the roughage fed to local cattle.

Season	Period	Dry matter (%)	Percentage dry matter: Crude protein	Crude fibre	Gross energy (kcal/kg)
1978–1979					
Dry	July–September	21.99	10.96	25.68	4210
Wet	October–April	20.75	11.67	26.26	4298
1979–1980					
Dry	May–September	21.79	11.00	24.82	4160
Wet	October–April	21.55	11.28	26.76	4059
1980–1981					
Dry	May–September	20.59	11.25	26.18	4062
Wet	October–April	18.52	11.33	28.12	4179
1981					
Dry	May–September	19.99	11.73	28.47	3956
Average					
Dry		21.09	11.23	26.29	4097
Wet		20.27	11.43	27.05	4179

During the 1980–1981 period (experiment 1), the cattle price per kilogram live weight varied from IDRp400 for the 200–300 kg range to IDRp611 for the 350–400 kg live-weight range. The price of grass, copra meal, rice bran, and cassava chips was IDRp2.15, 89.29, 66.37, and 65.22 per kg fresh weight respectively. During the 1981–1982 period (experiment 2) the cattle price increased (IDRp550 for the 150–200 kg and IDRp680 for the 250–300 kg live-weight ranges). The price of green roughage doubled (IDRp5), whereas the price of the concentrates increased only slightly (copra meal, IDRp105; rice bran, IDRp65; cassava chips, IDRp88; and hen manure, IDRp20).

In this report, the cost and return analysis was based either on similar live weight (375 kg) or on a similar time period (68 or 116 weeks).

On a similar live weight basis, the highest return in experiment 1 was from cattle fed on diet D and the lowest from cattle fed on grass alone (Table 7). Similarly, the total feed cost was highest for diet D and lowest for diet A. The gross profit was highest for diet E and lowest for diet B.

Based on a similar time period, the highest return up to 116 weeks in experiment 1 was from cattle fed on diet D and the lowest from cattle fed on diet A (Table 8). The total feed cost was highest for diet C and lowest for diet A. Conversely, the gross profit was highest for diet A and lowest for diet C.

In experiment 2, up to 68 weeks, the highest return was from cattle fed on diet D and the lowest from cattle fed on diet A, with the reverse being true for feed costs (Table 9). The gross profit was highest for diet G and lowest for diet D, with diets A and F showing a deficit.

Discussion

Cattle Performance

Better growth response and feed utilization of the concentrate-supplemented cattle, in comparison with those fed on grass alone, was due to the nutrients being readily available. Grass alone could not meet the nutrient requirements of the cattle, whereas tree leaves, shrub leaves, and stems could alleviate the deficiency to varying degrees because tree leaves contain more nutrients than natural grasses (Nitis et al. 1980).

Poor growth response was experienced by cattle supplemented with cassava chips only, presumably due to protein deficiency and an imbalance in the protein/energy ratio (high energy and low protein). The improved growth response exhibited by cattle supplemented with copra meal, rice bran, and cassava chips (diet D) in comparison with those supplemented with rice bran and hen manure (diet G) is due to the energy deficiency and imbalance in the energy/protein ratio (more protein and less energy) of diet G. The higher green roughage consumption of cattle fed on diet G might be an attempt to obtain more energy from the grasses.

Table 7. Cost and return analysis of experiment 1, based on similar live weight.

	Diet									
	A		B		C		D		E	
	kg/head	IDRp	kg/head	IDRp	kg/head	IDRp	kg/head	IDRp	kg/head	IDRp
Return from cattle										
Initial live weight	101.6		102.7		101.9		101.1		100.5	
Final live weight	375		375		375		375		375	
Live-weight gain (kg/day)	0.125		0.335		0.335		0.339		0.334	
Value of daily gain		76.38		204.69		204.69		207.13		204.07
Feed cost[a]										
Grass	24.71	53.13	15.49	33.30	14.22	30.57	14.15	30.42	14.53	31.24
Copra meal	—	—	1.24	110.72	1.00	89.29	0.71	63.40	0.35	31.25
Rice bran	—	—	—	—	—	—	0.72	47.79	0.71	47.12
Cassava chips	—	—	0.69	45.00	1.03	67.18	0.73	47.61	1.07	69.79
Feed cost per kg gain		425.04		564.24		558.33		558.17		537.13
Profit (IDRp/day)		23.25		15.67		17.65		17.91		24.67

[a] Calculated using dry matter content of grass = 21.44, copra meal = 89.47, rice bran = 88.61, and cassava chips = 87.11%.

Table 8. Cost and return analysis of experiment 1, based on a similar time period (116 weeks).

	Diet									
	A		B		C		D		E	
	kg/head	IDRp	kg/head	IDRp	kg/head	IDRp	kg/head	IDRp	kg/head	IDRp
Return from cattle										
Initial live weight	101.6		102.7		101.9		101.1		100.5	
Live weight at 116 weeks	200.6		360.4		358.7		362		355.3	
Live-weight gain (kg/day)	0.122		0.317		0.316		0.321		0.314	
Value of daily gain		48.80		193.69		193.08		196.13		191.85
Feed cost[a]										
Grass	17.02	36.59	15.49	33.30	14.22	30.57	14.16	30.44	14.50	31.18
Copra meal	—		1.25	111.61	1.02	91.08	0.71	63.40	0.35	31.25
Rice bran	—		—	—	—	—	0.72	47.79	0.72	47.79
Cassava chips	—		0.69	45.00	1.05	68.48	0.73	47.61	1.07	69.79
Feed cost per kg gain		304.92		593.47		594.28		591.38		562.53
Profit (IDRp/day)		12.21		3.78		2.91		6.89		11.84

[a] Calculated from Table 3, with dry matter content of grass = 21.44, copra meal = 89.47, rice bran = 88.61, and cassava chips = 87.11%.

Table 9. Cost and return analysis of experiment 2, based on a similar time period (68 weeks).

	Diet									
	A		D		H		F		G	
	kg/head	IDRp	kg/head	IDRp	kg/head	IDRp	kg/head	IDRp	kg/head	IDRp
Return from cattle										
Initial live weight	113.5		113.5		113.4		113.6		113.5	
Live weight at 68 weeks	163.1		294.0		251.8		198.0		277.8	
Live-weight gain (kg/day)	0.104		0.379		0.291		0.177		0.344	
Value of daily gain		57.20		257.72		197.88		97.35		233.92
Feed cost[a]										
Grass	17.04	85.20	12.11	60.55	13.02	65.10	13.81	69.05	15.49	77.45
Copra meal	—		0.73	76.65	—	—	—	—	—	—
Rice bran	—		0.73	47.45	1.88	122.20	—	—	1.17	76.05
Cassava chips	—		0.75	66.00	—	—	1.02	89.76	—	—
Hen manure	—		—	—	—	—	—	—	1.37	27.40
Feed cost per kg gain		819.23		661.64		643.64		897.23		525.87
Profit (IDRp/day)		−28.00		7.10		10.58		−61.46		53.02

[a] Calculated from Table 4, with dry matter content of the grass = 20.24, copra meal = 89.47, rice bran = 89.57, cassava chips = 87.07, and hen manure = 55.04%.

Cost and Return

Based on similar live weight (375 kg), the daily profit from concentrate supplements was IDRp4.27 more than from grass alone. It should be noted that concentrate-supplemented cattle grew 2.7 times faster than those fed on grass alone, so that farmers using concentrate supplements will sell their cattle sooner than farmers whose cattle are only being fed grass. In terms of cumulative profit, therefore, the daily profit from cattle supplemented with concentrate will be IDRp24.20 more than that from cattle fed on grass alone.

The higher the cost of grass, the more profit obtained from the concentrate-supplemented cattle, with the reverse being true for cattle fed solely on grass. The cost and availability of green roughage becomes an important factor in governing the profitability of concentrate supplementation. Attempts to increase the quantity and quality of green roughage are being studied through "companion cropping systems" (Nitis 1978) and the "three strata system" (Nitis 1979). It should be noted that cattle raised locally obtained green feed by following the "three strata system" (i.e., the cattle were fed on grass during the wet season, shrubs from the end of the wet season to early in the dry season, and tree leaves from the middle to the end of the dry season). With green-feed costs similar to grass costs, the feed cost per live-weight gain will be lower than that for cattle in the project. Due to a shortage of land on which to grow shrubs and trees, this intensive mixed-farming system may not be practicable, in which case the "companion cropping system" may be an alternative.

Applicability

Eleven farmers were directly involved in feeding and caring for the cattle and another 16 farmers followed the progress of the project on a monthly basis. It is hoped that each of these farmers will become a nucleus within the region, from which the idea of profitable concentrate supplementation can be disseminated.

The Extension Division of the Department of Animal Husbandry, Province of Bali, has incorporated 27 farmers to study the response of farmers to the idea of concentrate supplementation. In a completely guided trial (12 farmers were asked to care for cattle raised in a common shed), farmers responded well, and when the trial terminated some of the farmers continued to supplement their cattle with concentrate (Anonymous 1982a). In an observation trial (15 farmers were given concentrate to feed to the cattle raised in their own shed), it was found that the farmers were only willing to supplement their cattle's feed when the price of cattle was high; when the price of cattle decreased, however, the concentrate was fed to pigs (Anonymous 1982b). It should be noted that in both of these trials the cattle used were calves (sucklings) and calves just about to be weaned. These trials showed that the response of the cattle to the concentrate supplement improved as the cattle grew (Table 10). These trials and data from experiment 1 indicated the importance of proper timing in supplementing certain concentrates to increase growth and minimize feed cost.

The small credit investment unit of the Indonesian Bank is in the process of drafting a proposal to give credit (loans) to

Table 10. Effect of concentrate supplement on the live-weight gain (kg/day) of Bali cattle.

	Male		Female		Combined	
Live-weight range (kg)	Without concentrate	With concentrate	Without concentrate	With concentrate	Without concentrate	With concentrate
20–30	—	—	0.23	0.28	0.23	0.28
40–55	0.19	0.25	0.15	0.19	0.17	0.22
50–65	0.18	0.31	—	—	0.18	0.31
70–80	0.28	0.32	0.24	0.22	0.26	0.27
90–100	—	0.38	0.26	—	0.26	0.38
100–115	—	—	0.15	0.34	0.15	0.34

Source: Anonymous (1982a).

farmers to raise cattle using concentrate supplements starting at live weights of 240 kg and continuing until the market weight of 375 kg is attained. The interest rate on these loans would be 12% per year.

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Utilization of Low-Quality Roughages With or Without NaOH Treatment

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In Tanzania, crop residues play an important part, as livestock feed during the dry season, in the crop/livestock production systems that have evolved. A series of experiments were carried out to test the technology of alkali treatment of maize cobs, maize stover, and other low-quality roughages using NaOH. In the development of technology for farm-scale alkali treatment, optimal conditions were determined. For large-scale farms, a conventional flail forage harvester fitted with a boom sprayer was satisfactory for simultaneous cutting and alkali treatment.

The experience gained was used in production experiments involving heifers and steers and it was demonstrated that NaOH treatment brought about improved animal performance and improved feed conversion. Although it was economically feasible to fatten animals on roughage-based diets, the cost of NaOH and value of the carcasses produced were the main constraints. It appears that it is more economical to feed roughage-based diets in conjunction with traditional grazing than feeding them as complete diets.

En Tanzanie, au cours des saisons sèches, les déchets de récoltes représentent une part importante de l'alimentation du bétail, au sein des systèmes de production animale et agricole qui se sont développés dans ce pays. Une série d'expériences ont été effectuées pour mettre à l'essai les techniques de traitement des épis et tiges de maïs à l'aide d'alcalis et d'autres fourrages grossiers au NaOH. Les conditions optimales ont été établies pour appliquer la technique de traitement aux alcalis au niveau des exploitations agricoles. Et pour les grandes exploitations, l'usage d'une moissonneuse de fourrage à fléau ordinaire, à laquelle un pulvérisateur à rampe a été adapté, a permis d'effectuer simultanément, d'une manière satisfaisante, la coupe et le traitement aux alcalis.

Les connaissances acquises grâce à ces expériences ont été appliquées à des expériences portant sur l'élevage de génisses et de bouvillons et il a été démontré que le traitement du fourrage au NaOH permet d'améliorer l'assimilation des fourrages et la production animale. Malgré le faible coût des rations de fourrages grossiers, leur emploi dans l'élevage est limité par le coût du NaOH et la valeur des carcasses. Il semble donc plus avantageux d'associer ce régime de fourrages grossiers au pâturage courant plutôt que d'en faire l'unique produit alimentaire des rations.

En los sistemas de producción agropecuaria desarrollados en Tanzania, los residuos agrícolas desempeñan un importance papel como alimento del ganado en la estación seca. Por esta razón se experimentó el tratamiento alcalino de los sobrantes del maíz y otros forrajes verdes pobres con NaOH. Al desarrollar la tecnología para aplicar este tratamiento a nivel de finca, se determinaron las condiciones óptimas. Se encontró que para fincas grandes la labor simultánea de corte y tratamiento alcalino podía ser realizada satisfactoriamente por un cosechador convencional adicionado con un rociador.

La experiencia obtenida fue applicada en experimentos de producción con novillas y novillos, demostrándose que el tratamiento con NaOH lograba un mejor desempeño animal y una mejor conversión alimenticia. Aunque resultó económicamente factible engordar animales con dietas basadas en forraje verde, et costo del NaOH y el valor de las

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reses producidas fueron las principales limitaciones. Parece más económico suministrar el forraje verde en combinación con pasturas tradicionales que como dieta completa.

In developing countries, present crop/livestock production systems are complex due to the wide variety of objectives (food production, cash, manure, traction, social values) and stages of development or stability (traditional self-sustaining, cash crop, e.g., growing coffee in spite of declining food production per capita, increasing numbers of ruminants but decreasing grazing area).

In livestock production, it is generally agreed that poor or inadequate nutrition is the major limiting factor. Ruminants (kept in large numbers in developing countries) derive their feed from grazing on nonarable and arable but uncultivated lands, grazing on fallow lands, crop residues (grazed or stall-fed), and by-products of food processing (brans and oil meals). With the exception of the transhumance (nomadic) system, ruminants depend upon fallow land and crop residues from the villages. Estimates on the quantities of crop residues produced can be made from yields (Table 1). It is likely that crop-residue production will increase in developing countries as the need for increasing food production, by increasing acreage and technological inputs, increases. Thus, grazing acreage under fallow and uncultivated land is likely to decrease.

Table 1. Estimated quantities of field-crop residues in Tanzania based on grain-production estimates (based on straw:grain ratio of 2:1 for maize, sorghum, and millet and 1:1 for rice and wheat).

Crop	Production (1973) Grain (tons)	Field-crop residues (tons)
Maize	603196	1206392
Rice	204085	204085
Wheat	77375	77735
Sorghum	247624	495248
Millet	171410	342820

The significance of crop residues as a livestock feed can be assessed from the quantities produced, but it is even more desirable to know the proportion that is actually available and eaten by livestock. However, such information is not yet available in most developing countries. Notwithstanding this drawback, crop residues are important feeds during the dry season, e.g., stall-feeding of dairy cows on stover is common in Tanzania, as is grazing in situ. A similar situation exists in other developing countries. Some of the limiting factors associated with using crop residues as animal feeds include: procurement, storage, poor feed intake, low digestibility, and low nutrient contents and subsequent low animal performance (Ely et al. 1953; Forbes et al. 1969; Slyter and Kamastra 1974). According to recommendations of the National Research Council (1976) for beef cattle, when metabolizable energy (ME) content in the diet is below 2.0 Mcal/kg dry matter (DM), the energy is unlikely to meet maintenance requirements. From Table 2, it is apparent that among the common residues, maize and sorghum stover have adequate available energy for maintenance purposes but rice and wheat straw and maize cobs have small proportions of physiologically available energy. Variations in digestibility of local residues have been confirmed (Kiangi et al. 1981) through in vitro organic matter (OM) digestibility coefficients of 51.7, 48.0, and 44.9 for maize stover, wheat straw, and rice straw respectively.

Table 2. Metabolizable energy (ME) content of field-crop residues in relation to nutrient requirements for maintenance of beef cattle (NRC 1976).

Crop	ME content (Mcal/kg DM)	Estimated intake of a 300-kg steer (kg)	ME intake (Mcal)	ME required for maintenance (Mcal)
Maize stover	2.13	4.7	10.01	9.4
Sorghum stover	2.06	4.7	9.68	9.4
Rice straw	1.70	4.7	7.99	9.4
Wheat straw	1.74	4.7	8.18	9.4
Maize cobs	1.70	4.7	7.99	9.4

Because crop residues are of low nutritive value, efforts have been directed toward increasing the availability of energy, mainly by chemical processing. Research of this nature has been conducted in Kenya (Said 1981; Tubei and Said 1981), Bangladesh (Saadullah et al. 1981), India (Singh and Jackson 1971; Jackson 1978) and Tanzania (Urio 1977; Kategile 1979; Kategile and Frederiksen 1979; Kiangi et al. 1981; Kategile et al. 1981; Edelsten and Lijongwa 1981). This paper will discuss some of the studies conducted at the University of Dar es Salaam involving the collection of baseline data and the application of applied research involving NaOH treatment of low-quality roughages.

Collection of Baseline Data

It is known that the effects of NaOH treatment of low-quality roughages are influenced by: rate of treatment, volume of solution, temperature, pressure, time of treatment, supplement, and type of roughage. Because energy and high-technology inputs are required to increase temperature and pressure, these two factors were not varied in experiments conducted at the University of Dar es Salaam.

Three methods of NaOH treatment have been adapted for this study: dry, soaking (wet), and simultaneous mechanical harvesting and treatment.

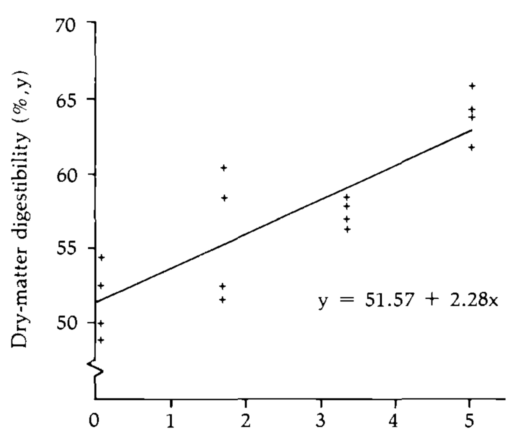

Fig. 1. Experiment 1A: Correlation between NaOH application and dry-matter digestibility of maize cob based rations (Kategile and Frederiksen 1979).

Dry Method

The objectives of the experiments were to determine the optimum NaOH treatment rates and volumes of NaOH solution for treating coarsely ground maize cobs. Maize cobs were chosen as test materials because they are produced locally, thereby eliminating collection and transportation costs. The maize cobs were passed through a hammer mill where they were ground to a coarse texture. They were then mixed with the NaOH solution on a concrete floor and allowed to react for 24 hours. The treated maize cobs were then sun-dried over a period of several days. The dried maize cobs were then mixed with molasses, plant proteins, and a mineral/vitamin mixture to form a complete diet, which was fed to test rams to determine the nutritive value of the diets.

In the first experiment (1A), maize cobs were treated at rates of 0, 1.67, 3.33, and 5.0 kg NaOH/100 kg DM and formed 52% of the diets on an air-dried basis. There was a significant correlation between DM digestibility and the NaOH treatment rate, expressed by the equation $y = 51.57 + 2.28x$ (Fig. 1). A response of 2.28 digestibility

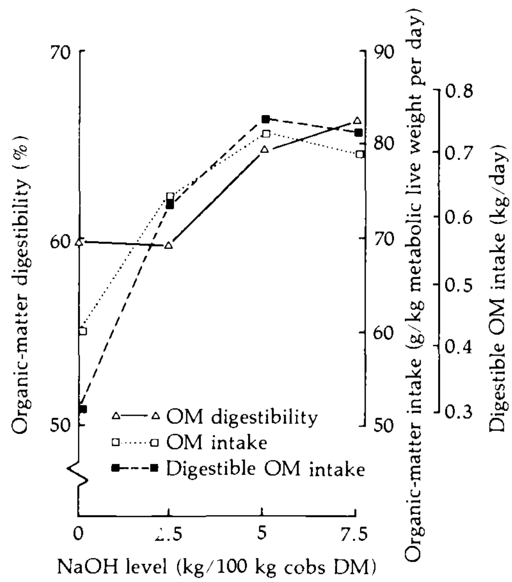

Fig. 2. Experiment 1C: Organic-matter digestibility, total organic matter digested, and organic matter voluntary intake for sleep fed on diets based on maize cobs treated with graded levels of sodium hydroxide (Kategile and Frederiksen 1979).

units for the whole diet was made up of approximately 4.5 digestibility units for maize cobs alone per 1 kg NaOH. Furthermore, the results indicated that maximal digestibility had not been attained. In experiment 1B, maize cobs treated at rates of 2.5, 5.0, 7.5, and 10.0 kg NaOH/100 kg DM formed 67% of the ration. Digestibility of DM, organic matter (OM), cell-wall constituents (CWC), and crude fibre (CF) was

Table 3. Experiment 1B: Chemical composition and digestibility of dry matter (DM), cell-wall constituents (CWC), organic matter (OM), crude fibre (CF), and nitrogen of rations based on maize cobs (Kategile and Frederiksen 1979).

	Treatment (kg NaOH/100 kg cobs DM)				Standard error of means and significance of differences
	2.5	5.0	7.5	10.0	
Chemical composition (% DM)					
DM	75.2	78.7	71.0	66.3	—
OM	92.9	91.9	91.6	89.9	—
CWC	65.1	66.9	65.3	71.7	—
CF	25.7	26.4	25.9	26.0	—
Nitrogen	2.35	2.41	2.39	2.40	—
Digestibility coefficients					
DM	43.1[a]	55.4[b]	54.2[b]	56.6[b]	3.5*
OM	43.8[a]	53.8[b]	52.6[b]	54.4[b]	3.0*
CWC	47.7[a]	59.2[b]	57.2[b]	57.2[b]	3.0*
CF	27.9[a]	62.2[b]	62.8[b]	63.4[b]	

NOTE: Means within a row followed by different superscripts are significantly different.
* = $P < 0.05$.

Table 4. Experiment 1C: Chemical composition of rations, voluntary feed intake, and digestibility (Kategile and Frederiksen 1979).

	Treatment (kg NaOH/100 kg cobs DM)				Standard error of means and significance of difference
	0	2.5	5.0	7.5	
Daily feed intake					
DM (kg)	0.841[a]	1.189[b]	1.314[b]	1.263[bc]	0.041*
DM ($g/kg_W{}^{0.75}$)	60.5[a]	83.3[b]	95.5[c]	96.0[c]	5.29*
OM (kg)	0.721[a]	1.105[b]	1.131[b]	1.068[b]	0.067**
OM ($g/kg_W{}^{0.75}$)	51.9[a]	73.9[b]	82.4[b]	81.3[b]	5.43**
Digestibility coefficients					
DM	61.3[a]	59.6[a]	65.4[b]	67.3[b]	1.46**
OM	59.9[a]	59.7[a]	64.6[b]	66.0[b]	1.51**
CF	70.2	64.1	69.7	70.7	2.66
Energy	61.5[b]	57.6[a]	64.4[c]	70.0[d]	1.75*
Quantities of digested fractions (kg/day)					
DM	0.517[a]	0.708[b]	0.857[c]	0.849[c]	0.064*
OM	0.4329	0.628[b]	0.729[b]	0.705[b]	0.065*
CF	0.183[a]	0.204[a]	0.253[b]	0.222[b]	0.012*
Energy (Mcal/day)	2.14[a]	2.73[b]	3.38[c]	3.57[c]	0.156*
Calculated energy (Mcal/kg diet DM)					
Digestible energy	2.55	2.32	2.57	2.84	—
Metabolizable energy	2.07	1.86	2.09	2.34	—
Chemical composition on DM basis (%)					
OM	85.7	88.7	86.1	84.6	—
CF	27.5	24.6	24.4	22.9	—
Nitrogen	2.17	1.97	1.94	1.97	—

NOTE: Means within a row followed by different superscripts are significantly different.
* = $P < 0.05$; ** = $P < 0.01$.

markedly increased as a result of NaOH treatments of 2.5 and 5.0 kg NaOH, with no further response thereafter (Table 3). This was confirmed in experiment 1C, in which maximal DM, OM, CF, and energy digestibility coefficients were reached at a treatment rate of more than 5.0 kg NaOH (Table 4). Responses of voluntary feed intake based upon NaOH treatment rate were measured in experiment 1C and the trends were parallel to the digestibility responses (Table 4, Fig. 2). The optimum NaOH treatment rates of about 5.0 kg NaOH/100 kg DM roughage for digestibility are similar

Table 5. Chemical composition and digestibility of rations based on maize cobs treated with 5 kg NaOH/100 kg DM in various volumes of solution (Kategile and Frederiksen 1979).

	Volume of solution per 100 kg DM of maize cobs								Standard error of means and significance of differences
	25	37.5	50	75	100	150	200	0	
Experiment 2A									
Chemical composition (% DM)									
DM (%)	—	—	87.5	—	86.4	86.6	87.8	—	—
OM	—	—	89.2	—	90.1	89.9	90.0	—	—
CWC	—	—	59.9	—	60.4	61.7	63.3	—	—
CF	—	—	42.7	—	45.3	44.4	45.2	—	—
Nitrogen	—	—	2.41	—	2.34	2.44	2.45	—	—
Digestibility coefficients									
DM	—	—	71.5^{a}	—	70.1^{a}	70.1^{a}	71.3^{a}	—	0.99
OM	—	—	71.8^{a}	—	70.5^{a}	70.4^{a}	72.4^{a}	—	0.97
CWC	—	—	69.4^{a}	—	67.4^{a}	67.9^{a}	69.7^{a}	—	0.96
CF	—	—	62.6^{a}	—	67.4^{ab}	63.0^{a}	71.4^{ab}	—	3.70*
Experiment 2B									
Chemical composition (% DM)									
DM (%)	—	—	85.5	84.7	81.5	—	—	—	—
OM	—	—	95.5	94.5	94.1	—	—	—	—
CWC	—	—	61.8	63.5	65.2	—	—	—	—
Nitrogen	—	—	2.26	1.91	1.88	—	—	—	—
Digestibility coefficients									
DM	—	—	70.6^{a}	72.3^{a}	70.1^{a}	—	—	—	0.98
OM	—	—	70.4^{a}	73.4^{b}	70.9^{a}	—	—	—	0.93*
CWC	—	—	71.2^{a}	72.6^{a}	70.6^{a}	—	—	—	2.50
Experiment 2C									
Chemical composition (% DM)									
DM (%)	85.4	—	83.5	—	84.5	—	—	—	—
OM	92.9	—	91.9	—	92.7	—	—	—	—
CWC	64.2	—	63.2	—	62.6	—	—	—	—
Nitrogen	1.86	—	1.64	—	2.18	—	—	—	—
Digestibility coefficients									
DM	65.9^{a}	—	67.5^{ab}	—	69.6^{b}	—	—	—	1.20*
OM	65.7^{a}	—	67.0^{ab}	—	69.3^{b}	—	—	—	1.07*
CWC	63.2^{a}	—	63.9^{a}	—	68.8^{b}	—	—	—	2.08*
Experiment 2D									
Chemical composition (% DM)									
DM (%)	85.7	87.2	86.0	—	—	—	—	89.8	—
OM	89.2	88.0	88.8	—	—	—	—	92.7	—
CWC	59.2	60.9	64.2	—	—	—	—	70.7	—
Nitrogen	2.30	2.22	2.03	—	—	—	—	2.26	—
Digestibility coefficients									
DM	68.5^{b}	69.0^{b}	68.4^{b}	—	—	—	—	61.1^{a}	1.44**
OM	68.8^{b}	69.3^{b}	69.3^{b}	—	—	—	—	62.6	1.58*
CWC	63.3^{b}	66.2^{c}	66.7^{c}	—	—	—	—	52.9	1.35*

NOTE: Means within a row followed by different superscripts are significantly different.
* = $P < 0.05$; ** = $P < 0.01$.

to those reported by Singh and Jackson (1971), Klopfenstein et al. (1972), Jayasuriya and Owen (1975), and Ololade and Mowat (1975). With respect to improving voluntary feed intake, the NaOH treatment rate of 5.0 kg NaOH/100 kg DM was again found to be the optimal rate and was comparable with observations made by Saxena et al. (1971) and Jayasuriya and Owen (1975).

In experiment 2, variation in the volume of the NaOH solution between 25 and 200 L/100 kg DM of cobs did not affect digestibility of DM, OM, and CWC, the only exception being for volumes less than 50 L (experiments 2C and 2D) (Table 5). Jayasuriya and Owen (1975) reported lowered digestibility with NaOH solution volumes of 30 L per 100 kg straw. Donefer et al. (1969) and Phoenix et al. (1974) demonstrated the same effects. Freshly treated maize cobs were moist without effluent. For ease of hand mixing of maize cobs with NaOH solution and drying of the roughage, a volume of 75–100 L/100 kg maize cobs was found to be optimum. The advantage of drying the treated maize cobs was demonstrated in one study in which treated maize cobs were fed after NaOH treatment in either the wet or dried form and it was apparent that drying improved voluntary feed intake (Table 6).

Table 6. Voluntary intake and digestibility of wet and dried NaOH-treated maize cob diets (Kategile 1979).

	Dried	Wet	Standard error of means and significance of differences
Chemical composition of maize cobs			
DM (%)	86.7	50	—
OM (% DM)	90.2	89.9	—
CWC (% DM)	74.7	77.2	—
Nitrogen (% DM)	0.50	0.50	—
Nitrogen (% of soybean meal)	6.32	6.32	—
Daily DM intake			
Soybean meal (g)	46	46	—
Maize cobs (kg)	0.502	0.416	0.025**
Maize cobs ($g/kg_W^{0.75}$)	47.1	37.2	2.23**
Digestibility coefficients (%)			
DM	58.7	56.5	6.8
OM	58.0	56.1	7.0
CWC	53.3	51.7	8.1

** = $P < 0.01$.

Soaking Method

In spite of recent research and development of industrial alkali treatments (Rexen et al. 1975; Wilson 1974), ammonia treatment of hay stacks (Sundstøl et al. 1978), and large-scale farm machines, these technologies cannot be used directly in developing countries because of socioeconomic factors. Simpler methods, such as soaking (Beckmann 1922) and Torgrimsby's (Jackson 1978) modification, might be of practical application in developing countries. Experiments were carried out to modify the procedures of Beckman and Torgrimsby by reducing the amount of NaOH used, water consumption and pollution by the effluent, and the amount of work involved on a small scale. The roughage was packed in steel-mesh baskets and soaked for 18 hours in an alkali solution, after which it was washed with a minimal amount of water. Treated roughages were evaluated in vitro and in vivo. For the in vivo evaluations, the roughages were fed to sheep together with concentrates. Optimal rates of alkali treatment were determined in three experiments (Tables 7, 8, and 9). In two of these experiments, $Ca(OH)_2$ and NaOH were compared. From these experiments, the optimal NaOH treatment rate (i.e., initial treatment rate) was found to be 100 kg/ton DM, with significant improvements in DM, OM, and CWC digestibility coefficients up to that level and no further response beyond this rate. Because the method involved reuse of the solution, the uptake of NaOH by the roughage is more accurate in measuring the treatment rate. The NaOH solutions were reused at least 20 times before developing an undesirable smell. The amount of NaOH needed for replenishment was found to be 40–60 kg/ton DM roughage, coinciding with the optimum treatment rates of the spraying/dry method (Rexen et al. 1975; Kategile and Frederiksen 1979), and less than the amount of NaOH used in the traditional Beckmann (1922) method, i.e., 150 kg NaOH/ton. $Ca(OH)_2$ was found to be ineffective and there were even cases when

Table 7. Digestibility of dry matter (DM), organic matter (OM), and cell-wall constituents (CWC), and voluntary feed intake of diets based on NaOH-treated *Cynodon* hay (Kategile et al. 1981).

	NaOH treatment (kg/ton DM)			Standard error of differences and level of significance
	0	50	100	
Restricted feeding				
DM intake (kg/day)	0.515	0.572	0.561	
Digestibility (%)				
DM	53.8[a]	49.0[a]	59.6[b]	1.63**
OM	55.8[a]	54.1[a]	63.6[b]	1.42**
CWC	46.2[a]	44.6[a]	55.8[b]	2.29**
Feeding ad libitum				
Daily intake				
DM (kg)	0.607[a]	0.835[b]	0.896[b]	0.0212**
OM (kg)	0.555[a]	0.751[b]	0.806[b]	0.0193**
DM ($g/kg_W^{0.75}$)	41.4[a]	58.6[b]	58.8[b]	3.46**
OM ($g/kg_W^{0.75}$)	37.9[a]	52.7[b]	52.9[b]	3.02**
Digestible intake				
DM (kg)	0.304[a]	0.447[b]	0.484[b]	0.0613*
OM (kg)	0.301[a]	0.413[b]	0.453[b]	0.0410*
Digestibility (%)				
DM	50.1	53.3	53.1	1.79
OM	54.4	56.6	56.2	3.62

NOTE: Means within a row followed by different superscripts are significantly different.
* = $P < 0.05$; ** = $P < 0.01$.

Table 8. The effects of NaOH and $Ca(OH)_2$ treatments of maize stover on DM and OM digestibility in vitro (Kategile et al. 1981).

	$Ca(OH)_2$-treatment rates (kg/ton DM)	NaOH-treatment rates (kg/ton DM)				Standard error of differences and level of significance
		0	50	100	150	
DM digestibility (%)	0	40.5	63.0	76.7	76.0	
	50	56.4	70.0	73.8	81.6	
	100	53.2	59.8	71.7	72.0	
	150	60.7	63.9	70.6	75.5	3.64**
OM digestibility (%)	0	42.4	63.4	76.0	76.2	
	50	56.9	71.2	74.8	82.6	
	100	52.6	57.7	70.9	70.6	
	150	58.0	59.8	67.7	73.3	3.41**

** = $P < 0.01$.

it depressed digestibility coefficients.

The optimal volume of solution used was determined to be the minimum volume to allow for total immersion of the roughages and was found to be a ratio of 1:15 weight/volume (roughage:solution). The method is described in detail in Kategile et al. (1981). The essential features include: the use of simple equipment such as a used oil drum, steel-mesh basket, and a watering can; soaking in alkali solution overnight; washing off excess alkali with a minimum amount of water, which is drained back into the treatment container; successive reuse of effluent NaOH solution after replenishment; and minimization of pollution. The method is simple and can be used at the small-scale farming level. The treated roughages are of superior nutritive value, with improvements of about 15 digestibility units being comparable with those obtained with the Beckmann method (Godden 1920; Randel 1972; Fernandez Carmona and Greenhalgh 1972).

Table 9. Chemical composition of maize stover and digestibility of DM, OM, and CWC in diets based on maize stover (Kategile et al. 1981).

Treatment number	Treatment (kg/ton DM)		Daily intake of stover (kg DM)	Digestibility (%)			Chemical composition of stover		
	$Ca(OH)_2$	NaOH		DM	OM	CWC	DM (%)	OM (% DM)	CWC (% DM)
1	0	0	0.497	53.2[a]	57.2[a]	52.6[a]	85.0	90.9	73.9
2	0	100	0.681	68.2[d]	71.8[c]	71.5[c]	22.7	88.4	68.4
3	0	150	0.651	70.3[d]	75.1[c]	72.1[c]	21.6	84.2	63.3
4	25	100	0.563	60.9[b]	65.1[b]	62.7[c]	21.6	84.5	63.9
5	25	150	0.524	64.6[c]	69.5[c]	68.3[c]	20.2	85.8	59.1
6	50	100	0.569	61.0[b]	65.5[b]	65.6[bc]	21.7	84.1	58.9
7	50	150	0.526	60.1[b]	65.8[b]	63.0[b]	19.1	85.9	62.3
Standard error of differences and level of significance				1.46**	1.52**	2.01**	—	—	—

NOTE: Means within a column followed by different superscripts are significantly different.
** = $P < 0.01$.

Simultaneous Cutting and Alkali Treatment

Presently, there are relatively large on-farm Taarup and Farm Hand machines for alkali treatments but because they are expensive and in many cases too large for even the large farms they have not been used widely. The concept of modifying the common flail forage harvester for alkali treatment was borne in an attempt to find an adaptable method that farmers already familiar with the forage harvester and silage-making operations could adapt. Such machinery could be used in cutting or collecting straws after harvesting. The objective was to adapt the flail forage harvester for simultaneous cutting and treating standing *Hyparrhenia* hay (Kategile 1981).

A Taarup flail forage harvester was modified by fitting a Lindinger boom sprayer whose six nozzles were connected to spray into the chopping chamber (Kjus 1978). An Albin RB3-010F1 pump was connected to the tractor propeller takeoff by a shaft and pulleys and this pump delivered the liquid into the chopping chamber at variable speeds. Batches of 400 L of 8% weight/volume NaOH solution were poured into the 440 L capacity boom sprayer tank. The flow rate was adjusted to pump NaOH solution at 250 L of solution/ton of cut forage. At this rate, the NaOH treatment rate was 40 kg NaOH/ton DM roughage and the moisture content of the roughage was raised by 10%. The material was then ensiled in a trench silo and allowed to react for 60 days. The material was fed to sheep together with simsim as a protein source and this was compared with the roughage that was cut by the same machine at the same time but sun-dried.

The *Hyparrhenia* silage was characteristically of golden colour without a typical silage smell. The digestibility of DM, OM, and CWC of the *Hyparrhenia*-based diets was improved significantly with NaOH treatment (Table 10). Furthermore, voluntary feed intake was improved with alkali treatment. The product is characteristically of improved nutritive value and similar to that produced by industrial NaOH-treatment methods (Wilson 1974; Rexen et al. 1975). The results of this study suggest that it is possible to harvest and treat low-quality roughages with a modified forage harvester.

Table 10. Chemical composition, in vivo digestibility, and voluntary feed intake of *Hyparrhenia* hay and NaOH-treated *Hyparrhenia* silage-based diets (Kategile 1981).

	Hyparrhenia hay	NaOH-treated *Hyparrhenia* silage	Standard error of differences between means and significant difference
Chemical composition (%)			
DM	91.3	61.9	—
OM	82.8	76.3	—
Neutral detergent fibre (NDF)	79.7	75.1	—
Digestibility coefficients during restricted feeding			
DM	46.4	53.9	1.74**
OM	49.3	61.5	2.95**
NDF	48.61	58.9	2.56**
Digestibility coefficients during ad libitum feeding			
DM	43.2	50.8	2.37**
OM	50.9	57.2	2.21**
NDF	44.4	55.7	3.35**
Quantities of digested fractions during ad libitum feeding (kg/day)			
DM	0.331	0.509	0.106**
OM	0.333	0.455	0.034**
NDF	0.225	0.368	0.018**
Daily roughage intake during ad libitum feeding			
DM (kg)	0.582	0.822	0.034**
DM ($g/kg_W^{0.75}$)	35.6	47.7	1.37**
OM (kg)	0.482	0.627	0.027**
OM ($g/kg_W^{0.75}$)	29.4	36.5	1.08**

** = Means different at $P < 0.01$.

Practical and Economic Aspects

The knowledge and experience gained in the experiments involving NaOH treatment of maize cobs were used in two experiments involving growing heifers and fattening steers. The objectives were to demonstrate the applicability of the method and the economic implications (Kategile 1979; Mangazeni, unpublished data).

Heifer Experiment

Twelve 9–15 month old dairy cattle heifers were allocated to two experimental groups according to breed, age, and weight. The cattle were tied in stalls and fed individually on complete untreated and NaOH-treated maize-cob diets containing approximately 61% maize cobs, 17.0% sunflower meal, 19.0% molasses, 1.0% urea, 2.0% bone meal, and 0.2% salt (for the control group only). The maize cobs were treated at rates of 5 kg NaOH/100 kg cobs in a 500 L NaOH solution in a 2000 L capacity steel tank. The material was left to react for 24 hours, then turned over to allow the cobs on the top to be in close contact with the NaOH solution and then a further 24 hours was allowed for the reaction to take place. Moistened maize cobs were ground in a hammer mill. The ground maize cobs were dried and mixed with other ingredients. Animals were fed ad libitum for 63 days, after an initial adjustment period of 21 days.

The daily feed DM intake and DM intake per kg metabolic body weight of the heifers were improved significantly by NaOH treatment of maize cobs (Table 11). Daily weight gains were similarly improved. The amount of feed DM consumed per kg gain decreased as a result of alkali treatment. The economic returns were evaluated (Edelsten and Lijongwa 1981) assuming that the animals were slaughtered for sale and, apparently, it was found to be uneconomic at the time (Table 11). The same data were reevaluated in late 1981. It was found at that time that it was economically beneficial to treat maize cobs because the value of the meat had doubled from TZSh12 to TZSh20 per kg carcass weight. The margins of profit were TZSh99 and TZSh62 for the untreated

Table 11. Voluntary feed intake, daily gains, feed conversion, and net benefits from feeding heifers (Kategile 1979; Edelsten and Lijongwa 1981).

	Diet		
	Untreated maize cobs	NaOH-treated maize cobs	Difference
Initial weight (kg)	170.1	196.0	
Final weight (kg)	195.3	232.8	
Daily DM intake (kg)	5.13	6.62	
Daily DM intake ($g/kg_W^{0.75}$)	104	119	
Daily gain (kg)	0.412	0.585	
Calculated gain over 100 days (kg)	41.2	58.5	17.3
Revenue from gain @TZSh6/kg[a]	247	351	104
DM intake over 100 days (kg)	513	262	149
Cost of grinding feed:			
80% of ration @TZSh0.15/kg[b]	0.12	0.12	
Cost of NaOH treatment:			
61% of ration @TZSh0.30/kg[c]	—	0.18	
Cost of remainder of ration	0.49	0.49	
Total cost of feed (TZSh/kg)	0.61	0.79	
Total cost of feed over 100 days	313	523	223
Margin over feed (TZSh)	−66	−172	−106

[a] Based on TZSh12 per kg carcass weight and 50% carcass composition of the gain.
[b] 5 kg NaOH/100 kg cobs DM @TZSh1700 per 340-kg drum, plus TZSh0.05 per kg cobs for depreciation of equipment.
[c] 17% sunflower @TZSh2.3 per kg, 1% urea @TZSh4 per kg, 2% bone meal @TZSh2 per kg, and 19% molasses @TZSh0.19 per kg.

Table 12. Net benefits per steer of feeding treated or untreated maize cob based diets together with urea or cottonseed cake to fattening steers (Mangazeni, unpublished data).

	Untreated maize cobs		NaOH-treated maize cobs	
	Urea	Cottonseed cake	Urea	Cottonseed cake
DM supplemented (kg/day)	3.42	3.46	3.48	3.49
Feed for 90 days (kg)	310.80	307.44	314.16	313.32
Gain over 90 days (kg)	49.0	48.3	53.2	51.6
Daily gain (kg)	0.511	0.537	0.593	0.573
Supplementary feed consumed per gain (kg/kg)	6.63	6.45	5.79	6.07
Expected revenue from gain (TZSh)[a]	621.00	652.05	718.20	696.60
Costs of grinding (TZSh/kg)				
45.5% of ration @0.2	0.09	—	0.09	—
36% of ration @0.2	—	0.072	—	0.072
Costs of NaOH treatment[b] (TZSh/kg)				
45.5% of ration @0.3	—	—	0.14	—
36% of ration @0.3	—	—	—	0.108
Cost of remainder of ration[c]	0.62	0.766	0.62	0.766
Cost per kg ration	0.71	0.84	0.85	0.95
Cost over 90 days	218.54	261.58	266.22	398.40
Margin over costs	402.46	390.47	451.98	298.20
Margin over control	11.99	0	61.51	−92.27

[a] Based on National Ranching Co. (NARCO) 1979/1980 price of TZSh13.5 per kg live weight.
[b] 5 kg NaOH per 100 kg DM @TZSh5 per kg plus TZSh0.05 per kg for depreciation of equipment.
[c] Based on Morogoro prices of TZSh2.5 per kg urea and per kg bone meal, TZSh1.7 per kg cassava meal, TZSh1.55 per kg cottonseed cake, TZSh0.3 per kg of molasses, and TZSh1 per kg salt.

and treated groups, respectively, indicating that the price of NaOH was a determining factor.

Steer-Fattening Experiment

Forty 2.5–3.0 year old Boran steers, weighing approximately 251±31 kg, were allocated to four treatment groups according to weight. All were allowed 8 hours of rough grazing (deficient in both energy and protein), simulating limited grazing during the dry season. After grazing they were fed on maize cob based supplementary diets at restricted levels of about 3.48 kg DM/day for an experimental period of 90 days, after an initial adjustment period of 14 days. NaOH treatment was carried out as in the heifer experiment, with rations containing 37.5% and 45% maize cobs, with either cottonseed cake or urea respectively. Daily weight gains were higher in the NaOH-treated groups than in the control group (Table 12). The source of protein had no influence on weight gains, except that NaOH treatment combined well with urea to produce gains in weight. In spite of the improvement in weight gain brought about by NaOH treatment, it was less pronounced when fed with cottonseed cake. Steers fed on NaOH-treated diets dressed higher, yielded heavier carcasses, and had higher fat content than those fed on untreated maize-cob supplements. Urea supplementation was the most beneficial in terms of economic returns and the largest margins were obtained when fed together with NaOH-treated maize cobs (Table 12). A combination of NaOH treatment and high levels of cottonseed cake was the least lucrative in terms of economic benefits.

From these two studies it is evident that it is economically feasible to feed maize cobs in the raw form or after NaOH treatment in the form of complete diets or supplementary diets. Although NaOH treatment improves animal performance, the current price of TZSh5 per kg is a limiting factor for its usage. Nevertheless, it is apparent that a combination of urea and NaOH treatment of maize cobs gives the highest comparison to plant proteins. The price of the product is also another determinant with respect to the economics of feeding maize cobs. Furthermore, the feeding of maize cob based diets as a supplementary feed rather than a complete meal reduced direct feed costs.

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Feeding Animal Wastes to Ruminants

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This paper describes the utilization of animal wastes in ruminant rations, including the background, trend, and approach toward the use of unconventional feed resources in general. It focuses on typical examples of least-cost rations based on poultry litter, poultry manure, and cattle wastes. The utilization of these resources offers a significant reduction in feed cost (as much as 40% or more) and also minimizes the requirements for expensive protein feeds and other competitive feed resources, such as cereal grains and milling by-products. In addition, animal wastes can be used as a total or partial substitute for forages. This in itself has considerable significance for developing countries because in many arid areas of the world the output of forage from rangeland is often minimal and even zero during certain seasons of the year.

Examples of typical feeding and least-cost computer rations for dairy, beef, replacement cattle, and fat lambs are presented on a dry matter and as-fed basis, together with feeding instructions for various live-weight categories or other parameters relating to performance. Indicative cost of rations is also incorporated using average international market prices for individual ingredients. In addition, systems of adaptation using a specific premix to overcome any initial problems associated with voluntary feed intake are presented. Finally, processing of poultry and cattle wastes at the farm level is described in considerable detail.

Le présent exposé décrit l'utilisation de produits d'origine animale dans les rations des ruminants et comprend aussi des informations de base et une description des réalisations et méthodes relatives à l'emploi de nouveaux produits alimentaires pour le bétail. Il met l'accent sur certains exemples typiques de rations peu coûteuses, à partir de litières et de fumier de volailles et de déjections du bétail. L'utilisation de telles ressources permet de considérablement abaisser les coûts des aliments pour animaux (40 % et plus d'économies peuvent être ainsi réalisées) et de minimiser le recours à des aliments coûteux à base de protéines ou autres, telles que les graines de céréales et les sous-produits de meunerie. De plus, les déchets d'origine animale peuvent servir de substitut partiel ou total du fourrage. Ceci est très important pour les pays en développement, car, dans beaucoup de régions arides du monde, la production de fourrage dans les pâturages est souvent minime ou même nulle au cours de certaines saisons.

Des exemples illustrant ce type d'alimentation et des rations — exprimées en matière sèche non traitée — à coût réduit, établies par ordinateur, pour les boeufs, les vaches laitières, le bétail de remplacement et les agneaux gras, sont décrits dans cette communication ainsi que des instructions relatives à l'alimentation pour diverses catégories de poids vif ou autres paramètres de croissance. Y figurent aussi, à titre indicatif, le coût des rations calculé d'après les moyennes du marché international de chaque élément. Ce document donne, en outre, des techniques pour faciliter l'adaptation des animaux à leur nouveau régime tel que certains mélanges, préparés à l'avance. Et enfin, le traitement sur la ferme même des déjections de volailles et de bétail y est décrit d'une manière très détaillée.

Este trabajo describe la utilización de desechos animales en raciones para rumiantes, incluye información sobre antecedentes, enfoque y tendencias generales en el uso de recursos alimenticios no convencionales, y ofrece ejemplos comunes de raciones de menor costo basadas en estiércol y desechos de aves de corral y de ganado. La utilización

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de estos recursos rebaja significativamente el costo dell alimento (40% o más) y reduce los requerimientos de proteínas costosas y otros recursos competitivos, como los cereales en grano y los subproductos de la molienda. Además, los desechos animales pueden ser usados como substituto total o parcial de los forrajes. Esto es de enorme importancia para los países en desarrollo porque en muchas zonas áridas del mundo la producción de forraje en tierras de pastoreo es a menudo mínima e incluso nula durante ciertas épocas del año.

Los ejemplos de alimentación típica y de raciones de menor costo, diseñadas por computador, para ganado lechero, ganado de carne, ganado de reemplazo y para corderos gordos se presentan con base en la materia seca y la forma de suministro, junto con instrucciones de alimentación para varias categorías de peso vivo u otros parámetros de desempeño. Se incluye tabién el costo indicativo de las raciones, usando los precios promedio del mercado internacional para ingredientes individuales. Además, se presentan sistemas de adaptación para superar los problemas iniciales asociados con la ingestión alimenticia voluntaria. Finalmente, se describe en detalle el procesamiento de los desechos de aves y ganado a nivel de finca.

The high population density of Pakistan is associated with the most intensely tilled land in the world. Because the rural scene is dominated by small farmers, the technological level of agriculture is still very low. Their economic status determines how much and, even more important, what they eat in terms of plant and animal produce. This reflects in the allocation of land for plants for direct human consumption and for consumption by animals. Whenever there is pressure on land, livestock suffers. Only about 13% of arable land is allocated to fodder production and a substantial portion of the best forage produced is consumed by draft animals. The number of large and small ruminants in relation to available feed resources is too large to maintain them. Unfortunately, livestock owners are more concerned with the number of animals rather than their productivity. This, of course, greatly affects the structure of the national herd and introduction of better management practices, adequate nutrition in particular. Where nutrition is poor, disease becomes a dominant constraint. Government funds are, thus, inevitably poured into veterinary services rather than into the improvement of animal husbandry.

This dilemma is further accentuated by the low input of science and technology into livestock production, specifically nutritional science and feed biotechnology. Another missing link is the complete absence of research activities backed by an integrated field development program from which scientific data and research results can be fed into a network of commercially oriented agrorelated industries and feed mills.

A change will take place, however, as the level of income increases demand, and prices for animal products follow.

Trends

It is estimated that 50 million tonnes of unconventional feed resources are currently available in Pakistan. They are either left behind on fields (crop residues), on farms (manure), elsewhere in agroindustries (sugar mills), or utilized inefficiently. The cost of these resources is usually low and they can be readily collected because they are concentrated on farms (manures), in sugar factories (bagasse, pith), or, in some instances (monocultures), on fields. These potential feeds represent a vast reservoir of cheap nutrients that can be converted into milk and meat. Maximum utilization of these resources requires the application of new principles of livestock nutrition and feeding management. This necessitates advanced knowledge of feed processing/treatment and nutrition, augmented with appropriate feeding management within a nontraditional farming system.

Since 1977/1978, the development of new feed resources and improved knowledge of modern livestock nutrition and the application of modern feeding systems — normally seriously neglected disciplines in Pakistan — have gained momentum. New systems are being devised for large-scale application in agrorelated industry and small-scale rural technology to meet the needs of small farmers and landless livestock owners.

Approaches

It is recognized that conventional protein and energy feeds such as oil cakes, legumes, and grains are too expensive for ruminants. The cheapest and most effective substitute for protein is urea; for energy, molasses; and for forage, treated crop residues. This paper focuses on the impact of animal wastes when fed to ruminants, both large and small.

The potential of poultry-litter feeding can be clearly demonstrated from Table 1, in which three nutritionally equivalent dairy rations utilizing either traditional or unconventional feed resources are compared.

Least-Cost Ruminant Rations Utilizing Poultry Waste

The feeding of poultry waste to ruminants is a well established practice that is applied worldwide (Muller 1980; Shah et al. 1981; Shah and Muller 1982).

The rations presented here are designed for large and small ruminants at a medium production level. They are based on standard nutrient requirements.

The choice of ingredients depends upon their availability and cost. In this regard, poultry waste as a source of protein is the most strategic ingredient of this unconventional feeding system. Poultry wastes are available in most countries either at a low cost or free of charge. They can, in general, supply 30–90% of the protein requirement of ruminants. This, however, depends upon the level of nutrition required, production intensity, and, naturally, the quality and content of the protein preserved in the poultry waste.

For computing rations, three different poultry wastes were chosen (broiler litter (26% CP), replacement bird litter (20% CP), and dry cage layer manure (25% CP)). Some examples of poultry waste based rations for large and small ruminants are given in Tables 2–4.

Some important points concerning the feeding of poultry waste to ruminants need to be stressed:

(1) Prior to feeding, poultry waste should be treated either by ensiling, stacking, chemicals, or dehydration or other suitable processes to reduce the microbial count and totally eliminate pathogens.

(2) Poultry waste can be fed to high-yielding dairy animals with levels of up to 80% DM in the ration, i.e., 4–6 kg DM/head/day; higher levels (up to 45%) are possible for brief periods when feeds are scarce or when a low or medium level of nutrition is to be maintained. It can also be fed to beef cattle with an optimal level for broiler and replacement bird litter of up to 40% (DM), but it may be higher at lower levels of nutrition. Layer manure, however, imposes a serious limitation due to its high content of inorganic matter. Normally, no more than 30% (on a DM basis) is recommended. When fed to fat lambs, the conditions are similar to those for beef cattle but the copper content of the poultry waste may limit the level of poultry waste incorporated into the feed to less than 30%.

(3) High-energy feed ingredients (molasses, root crops, grain, etc.) must be incorporated into the ration to balance energy requirements. The feeding of larger quantities (above 25% DM) of poultry waste requires ingredients containing soluble carbohydrates to obtain maximum utilization of the nonprotein nitrogen (NPN) fraction of the waste.

(4) Problems with palatability of poultry waste are best overcome by ensiling or chemical treatment. Molasses has a significant impact on palatability and intake of the waste. A dust-free ration prevents irritation of the eyes and respiratory system.

Table 1. Impact of unconventional feeds on economic and resource crises.

	Traditional ration (untreated straw)	Unconventional ration based on	
		Molasses + urea (straw)	Molasses + poultry litter + straw
Cost of ration (DM) (PKRs/t)	1141.7	760.0	607.2
Crude protein (CP) (%)	13.0	13.0	15.4
Total digestible nutrients (%)	63.5	63.0	63.0
Requirements for critical ingredients			
Protein feeds (%)	19.4	Nil	Nil
Cereal grain (%)	16.8	4.7	1.3

Table 2. Examples of least-cost rations containing optimal levels of broiler litter.

Ingredients (%)	Dairy cattle[a]		Finishing cattle[b]		Young growing cattle[c]		Fat lambs[d]	
	% DM	% as fed	% DM	% as fed	% DM	% as fed	% DM	% as fed
Broiler litter (26% CP)[e]	30.0	30.3	40.0	40.0	40.0	40.3	40.0	39.8
Nonlegume hay[f]	35.0	33.4	—	—	40.0	38.1	—	—
Cereal grain[g]	18.0	17.4	29.4	28.7	4.9	4.9	29.3	28.7
Milling by-products[h]	—	—	15.3	14.7	—	—	15.4	14.8
Molasses, cane (78% DM)	16.7	18.6	15.0	16.3	14.8	16.4	15.0	16.4
Salt	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Nutrients (% DM)								
Crude protein	14.0	—	16.4	—	15.5	—	16.4	—
Crude fibre	20.5	—	12.6	—	24.4	—	12.6	—
Calcium	0.70	—	0.71	—	0.82	—	0.71	—
Phosphorus	0.44	—	0.61	—	0.51	—	0.65	—
TDN	65.0	—	70.0	—	62.0	—	70.0	—
Cost (US$/tonne/DM)	87.40	75.89	104.80	90.00	64.4	56.00	104.70	89.92

[a] Medium production level lactating animals (300–600 kg live weight, 6–14 L of milk, 4% butter fat).
[b] Medium production intensity for live weight gain above 600 g/head/day.
[c] Replacement herd, from 6 months or 12 months onward.
[d] An intensive fattening ration for finishing lambs, from 15 kg live weight onward.
[e] Containing, on a dry-matter basis, not less than 26% crude protein and no more than 20% ash.
[f] Medium-quality hay containing not less than 10% crude protein and not more than 38% crude fibre.
[g] Maize, broken rice, barley, oats or dried root crops (provided crude protein is balanced), or other starchy ingredients.
[h] Wheat bran, rice polishing, or good-quality rice bran (not contaminated with rice husks (hulls)).
Source: Muller (1982).

Table 3. Examples of dairy rations containing replacement bird litter.

Ingredients (%)	Dairy cattle		Finishing cattle		Young growing cattle		Fat lambs	
	% DM	% as fed	% DM	% as fed	% DM	% as fed	% DM	% as fed
Broiler litter (26% CP)	20.0	22.0	38.0	40.2	30.0	32.4	30.0	32.0
Nonlegume hay	30.0	28.1	—	—	42.2	39.1	—	—
Cereal grain	26.2	25.4	46.9	43.9	12.5	12.0	36.0	34.2
Milling by-products	—	—	—	—	—	—	18.7	17.5
Molasses, cane (78% DM)	15.0	16.0	14.8	15.6	15.0	16.2	15.0	16.0
Protein concentrate[a]	8.5	8.2	—	—	—	—	—	—
Salt	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Nutrients (% DM)								
Crude protein	14.0	—	12.9	—	12.1	—	13.2	—
Crude fibre	17.0	—	11.0	—	22.9	—	10.6	—
Calcium	0.90	—	1.27	—	1.20	—	1.00	—
Phosphorus	0.60	—	0.83	—	0.72	—	0.80	—
TDN	69.0	—	70.0	—	60.0	—	70.0	—
Cost (US$/tonne/DM)	123.44	105.66	120.40	99.63	77.0	65.30	117.0	98.30

[a] Soybean meal, groundnut meal, cottonseed meal, fish meal, meat and bone meal, etc., and other protein feeds containing more than 44% crude protein.
Source: Muller (1982).

Table 4. Examples of dairy rations containing dry layer manure.

Ingredients (%)	Dairy cattle		Finishing cattle		Young growing cattle		Fat lambs	
	% DM	% as fed	% DM	% as fed	% DM	% as fed	% DM	% as fed
Layer manure (25% CP)	15.0	17.1	25.0	27.9	25.0	28.2	25.0	27.6
Nonlegume hay	38.9	36.4	18.4	16.9	47.7	44.3	—	—
Cereal grain	23.0	22.4	44.8	42.6	17.0	16.4	34.5	32.6
Milling by-products	—	—	—	—	—	—	25.2	23.6
Molasses, cane	15.0	16.4	11.5	12.3	10.0	10.8	15.0	15.9
Protein concentrate	7.8	7.4	—	—	—	—	—	—
Monosodium phosphate	0.3	0.3	0.3	0.3	—	—	—	—
Salt	—	—	—	—	0.3	0.3	0.3	0.3
Nutrients (% DM)								
Crude protein	14.0	—	13.0	—	13.3	—	14.3	—
Crude fibre	17.0	—	11.0	—	20.1	—	6.8	—
Calcium	1.07	—	1.40	—	1.50	—	1.50	—
Phosphorus	0.70	—	0.80	—	0.81	—	1.0	—
TDN	67.00	—	70.60	—	61.00	—	70.00	—
Cost (US$/tonne/DM)	121.71	104.50	127.80	107.60	53.00	45.34	122.14	102.00

Source: Muller (1982).

(5) The adaptation period for voluntary intake of poultry waste varies among animals, with most adapting within 3–5 days. It is necessary, therefore, to introduce waste-based rations gradually (see recommended premix in Table 5).

(6) In the case of dairy animals, it is of paramount importance to ensure that a sufficient amount of "long fibre" is made available; otherwise, the fat level in milk may be affected and metabolic disorders may occur.

(7) Poultry waste fed at levels of 20% or greater usually supplies all the calcium and phosphorus required but in the case of layer manure the addition of phosphorus may be necessary to obtain a satisfactory Ca:P ratio.

(8) The critical constituent of poultry waste is ash, because it reduces the level of organic matter in the complete ration and adds to the total indigestibles.

(9) Poultry wastes containing high levels of antibiotics and other antimicrobials and chemotherapeutics should be avoided.

Table 5. Premix for adaptation period.

Substance	(%)
Sodium sulphadimidin (technical grade)	0.40
Tetracycline (technical grade)	0.40
Acetylsalicylic acid (technical grade)	1.30
Sodium bicarbonate (technical grade)	97.85
Vitamin A/D_3 (A:500000 IU/kg; D_3:100000 IU/kg)	0.05

NOTE: This premix can be incorporated into a complete ration at the 1% level. It may, however, be necessary (whenever voluntary feed intake is low) to administer the premix via feed in accordance with the live weight. The premix is recommended to be applied for at least 5 or a maximum 10 days at the time of introduction of a new feed.

Least-Cost Rations Using Cattle Manure

The nutritional value of cattle manure varies with the level of nutrition and class of cattle, composition of the ration, and handling of the manure. Feeding cattle manure to livestock is not as common as feeding poultry wastes because it has lower nutritional value than poultry litter or poultry manure. Although experiments with feeding cattle manure to cattle and other livestock species have been going on for more than 100 years, practical application of the technique is only recently receiving more interest.

Cattle manure derived from a high source of nutrition (dairy and beef feedlots) is most suitable for feeding because its nutritional value is much higher than that of manure from cattle fed on high-fibre rations. The level fed to poultry, however, is limited by fibre content. Nevertheless, small quantities of cattle manure, up to 10% of the dry matter in the ration, have significant effects on productivity and particularly on reproductive performance. Levels greater than 10% can be used for low levels of nutrition (poultry developers).

Dried cattle manure can be collected from concrete aprons and yards or from other paved areas. In dry climates, the manure dries quickly, often within 1 day. Mechanical drying of manure is not envisaged because it is too expensive for practical application. It is possible, however, to speed up drying of cattle manure using solar dryers, similar to greenhouses with a plastic covering. Cattle manure should be treated with formalin (0.5–0.7% DM) to remove pathogens and maintain quality.

Examples of rations containing dry cattle manure for various species or classes of ruminants are presented in Table 6 and for poultry in Table 7.

Feeding conventional protein and energy feeds, such as oil cakes, legumes, and grains, to ruminants in Pakistan is too expensive because these resources can be better utilized by monogastric animals, and in the case of legumes and grains they are competing with human consumption.

Poultry wastes are the cheapest and most effective substitute for protein feeds in urban areas of Pakistan but in rural areas these wastes are not available. Thus, urea remains the only potential substitute for protein. Molasses offers the most economic replacement for grains. A serious scarcity of forage grown on cultivable land upgrades crop residues to an important forage substitute. When these are chemically treated they can help, to a large extent, in solving the deficiency of bulk feed in ruminant rations.

This paper has presented a series of typical least-cost rations for various species and classes of ruminants. These nutritionally equivalent rations are designed to contain different levels of poultry wastes of

Table 6. Examples of least-cost ruminant rations containing dry cattle manure.

Ingredients (% DM)	Dairy cattle		Beef finishing		Young growing cattle		Fat lambs	
	% DM	% as fed	% DM	% as fed	% DM	% as fed	% DM	% as fed
Cattle manure (dry)	10.0	9.3	15.0	14.0	20.0	18.8	15.0	13.8
Nonlegume hay	45.4	44.1	30.0	29.0	57.6	56.8	12.2	11.7
Cereal grain	16.3	16.4	30.7	30.8	5.0	5.1	27.3	27.4
Milling by-products	—	—	—	—	—	—	29.4	29.1
Molasses (78% DM)	15.0	17.1	15.0	17.0	12.6	14.5	15.0	17.0
Protein concentrate (45% CP)	12.7	12.5	8.7	8.6	4.5	4.5	—	—
Limestone	0.3	0.3	0.3	0.3	—	—	0.8	0.7
Salt	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Nutrients (% DM)								
Crude protein	14.0	—	13.0	—	12.0	—	12.0	—
Crude fibre	21.0	—	17.6	—	28.0	—	14.0	—
Calcium	0.50	—	0.50	—	0.43	—	0.60	—
Phosphorus	0.40	—	0.34	—	0.35	—	0.50	—
TDN	67.0	—	70.0	—	60.0	—	70.0	—
Cost (US$/tonne/DM)	125.50	111.60	132.40	117.40	83.10	74.80	117.50	103.00

Source: Muller (1982).

various origins (broiler litter, replacement bird litter, layer manure) and urea, molasses, and low levels of traditional feeds. These rations are formulated to substitute most of the protein, energy, and forage by using unconventional feeds and to demonstrate the maximum scope and extent of their utilization. The formulated diets indicate that the use of these nontraditional feeds is closely interconnected.

Least-cost rations based on nontraditional feed resources meet 60–80% of the feed requirements of semi-intensively fed ruminants (dairy cattle, beef cattle, and lamb finishing) and up to 95% of extensively reared ruminants (growing, dry animals). This reduces feed costs by 40% or more, compared with the cost of nutritionally equivalent rations utilizing traditional feeds.

Processing of Animal Wastes at the Farm Level

Many technologies have been developed during the past two decades for processing animal wastes and converting them into a stable product. On the farm, however, only simple systems can be applied to make use of animal wastes available to a wide farming community. The systems that are most suitable include: ensiling of animal wastes together with forages; stacking of dry animal wastes for a period of 6–8 weeks; chemical treatment with formalin; and "in-house" drying of poultry manure from cages and batteries.

Without processing, the nutritional value of animal wastes deteriorates rapidly. Poultry waste, when stored in the open air, and particularly when exposed to rain, rapidly loses its nitrogen due to high proteolytic activity. This also accelerates the mineralization process, resulting in a considerable increase in ash content. These changes, marked by the abatement of organic matter and increase in mineral matter, are typical features of the composting process that converts organic material into fertilizer.

Drying of Animal Wastes

Because energy has become expensive, dehydration processes have become prohibitively costly. In addition to the operating costs, it implies a substantial capital investment. Although the performance of

Table 7. Examples of poultry rations containing dry cattle manure.

Ingredients (% as fed)	Chicken: Starter	Chicken: Grower	Chicken: Developer	Chicken: Layer	Chicken: Broiler starter	Chicken: Broiler finishing	Duck: Grower	Duck: Breeder
Cattle manure (dry)	4.0	12.0	15.0	10.0	3.0	4.0	10.0	10.0
Maize, grain (ground)	61.0	68.3	65.0	50.0	56.0	58.0	53.1	46.0
Soybean meal	24.8	13.7	6.9	20.0	32.6	28.6	22.6	24.0
Fish meal	4.8	3.0	3.0	3.0	3.0	3.0	4.0	6.0
Wheat bran	—	—	7.0	—	—	—	7.0	—
Fat	2.0	—	—	6.0	2.0	3.0	—	4.0
Mineral supplement (see below)	2.4	2.0	2.1	10.0	2.4	2.4	2.3	9.0
Microingredients (see below)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
% DM	89.2	88.9	89.1	90.2	89.4	89.4	89.3	90.1

Nutrients (%)	Starter DM	Starter As fed	Grower DM	Grower As fed	Developer DM	Developer As fed	Layer DM	Layer As fed	Broiler starter DM	Broiler starter As fed	Broiler finishing DM	Broiler finishing As fed	Duck Grower DM	Duck Grower As fed	Duck Breeder DM	Duck Breeder As fed
Crude protein	21.5	19.2	17.7	15.7	15.8	14.1	18.2	16.4	23.0	20.6	22.0	19.7	21.2	18.9	21.0	18.9
Crude fibre	4.5	4.0	7.1	6.3	8.0	7.1	6.0	5.4	4.0	3.6	4.5	4.0	7.0	6.2	6.2	5.6
Calcium	1.1	1.0	1.1	0.98	1.1	0.98	4.0	3.6	1.1	1.0	1.1	1.0	1.2	1.0	3.6	3.2
Phosphorus	0.8	0.7	0.7	0.6	0.8	0.7	0.7	0.6	0.8	0.7	0.8	0.7	0.7	0.6	0.7	0.6
Ash	5.9	5.3	6.1	5.4	7.3	6.5	14.0	12.6	5.7	5.1	6.2	5.4	7.5	6.7	13.2	11.9
ME (Mcal/kg)	3.13	2.85	3.12	2.85	3.18	2.80	3.18	2.80	3.03	2.95	3.03	2.95	3.19	2.80	3.22	2.80

	Chicken: Starter	Chicken: Grower	Chicken: Developer	Chicken: Layer	Chicken: Broiler starter	Chicken: Broiler finishing	Duck: Grower	Duck: Breeder
Mineral supplement (%)								
Limestone	41.3	59.0	59.0	64.9	—	—	57.8	63.8
Tricalcium phosphate	46.3	28.0	28.0	30.0	83.7	83.7	28.0	22.0
$MnSO_4$	0.4	0.4	0.4	0.5	0.6	0.6	0.5	0.5
$ZnSO_4$	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7
Iodized salt	11.4	12.0	12.0	4.0	15.0	15.0	13.0	13.0
Microingredients[a] (per tonne of feed as fed)								
Vitamin A ('000 IU)	8000	6000	6000	8000	8000	8000	8000	8000
Vitamin D_3 ('000 IU)	800	700	700	1000	800	800	800	800
Vitamin K_3 (g)	1	1	—	—	—	—	—	—
Riboflavin (g)	2.5	2	2	4	2.5	2.5	2.5	4
Niacin (g)	5	—	—	5	10	10	5	5
Pantothenic acid (g)	3	3	—	4	5	5	3	3
Coccidiostatic agent (g)	+[b]	+	+	—	+	+	—	—
Antibiotic (g)	+	+	+	—	+	+	—	—
Antioxidant	125	125	125	125	125	125	125	125
Vitamin B_{12} (mg)	—	—	10	8	—	—	—	—
DL methionine (g)	1500	750	1200	400	2500	2500	1000	—

[a] Soybean meal is the carrier.
[b] + = trace amounts.
Source: Muller (1982).

different mechanical dryers varies considerably because of a wide margin in their relevant efficiency, they cannot be recommended for farmers at present unless the farmer has access to a cheap source of fuel or other energy for drying.

"In-house" drying of poultry manure by incorporating slats below the cages is now practiced widely in many countries. Droppings fall directly onto timber slats and remain there until the time of cleaning. The framed slats are pivoted on posts under the cages or supported from the catwalks by metal straps or ropes. The reduction of moisture depends upon the widths of the slats. This system produces dry manure and, in addition, it greatly improves the poultry house environment by reducing ammonia levels; odour, especially at low ventilation rates; and the fly population. The results obtained from manure samples collected after 2, 4, and 6 months, comparing different widths of slats with traditional pit systems, are self-explanatory (Table 8).

Table 8. Effect of time on moisture content (%) of poultry manure on slats.

	Slat width (mm)			
Drying period (months)	76	100	150	Pit
2	26.0	34.4	42.5	70.9
4	15.1	18.0	29.0	65.0
6	13.4	12.7	15.4	65.0

Source: Agricultural Development and Advisory Service of the Ministry of Agriculture, Fisheries and Food (Elson, undated), cited by Muller (1980).

Chemical Treatment

The prime objective of chemically treating poultry waste is to reduce its bacterial count, preserve nutrients, reduce protein solubility, improve the nutritive value of the waste, and increase the feed intake of the ration.

Apart from formalin's main function as a feed preservative and protection of proteins, it also acts as a fly larvicide, bactericide, and fungicide, rapidly reducing the microbial count to a minimum. It effectively kills important pathogens and greatly reduces fecal coliforms to zero. An example of treatment of dry animal waste by formalin is as follows: 0.8–1.0% formalin (on DM of animal waste) is, if necessary, dissolved in water (to make up 80% of the moisture in the waste). The liquid is then sprinkled on poultry waste and thoroughly mixed. Mixing can also be achieved by shoveling the waste already moisturized with formalin solution into plastic bags. The longer the formalin reacts the better; usually, a few hours before feeding is sufficient to achieve the effect. The addition of water is necessary to enable more intimate contact between the formalin and microorganisms in the wastes to take place. When wastes contain 30% moisture or more, the addition of water is not necessary and formalin is mixed as is. Treatment with formalin can also be performed at the time of litter collection and filling into bags.

Treatment of Poultry Litter or Other Dry Animal Wastes by Stacking

Poultry litter is stacked to a height of 1.5 m under a roof and left to rest for a period of 6–8 weeks. This system is suitable for litter when the moisture content does not exceed 35%. In practice, this is rarely the case, as the usual moisture content in litter varies between 12 and 25%. After a 6-week period, the litter is fairly sterile. Fecal coliforms, *Salmonella* and *Shiquella*, as well as other undesirable microorganisms are effectively eliminated. Whenever possible, it is, however, suggested to treat animal waste after stacking with formalin to ensure that the bacteriological capacity of the waste is reduced to a minimum. Adherence to the principle and good management practices are of paramount importance to ensure maximum performance, provided the composition of rations remains reasonably constant.

Muller, Z.O. 1980. Feed from animal waste: State of knowledge. FAO Animal Production and Health Paper No. 18. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

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Shah, S.I. and Muller, Z.O. 1982. The economic impact of feeding poultry litter to lactating cows and buffaloes. Pakistan Journal of Agricultural Research (PJAR), in press.

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Session II Discussion: Research Results

Dr Nitis reported on the feasibility of utilizing by-product supplements, such as copra meal, rice bran, cassava chips, and poultry waste, in complete rations based on widely available natural grass. The experimental results demonstrated that the ration containing 70% natural grasses supplemented with 15% rice bran, 10% cassava chips, and 5% copra meal was the most profitable compared with three other supplemented rations and the control (100% natural grass).

During the discussion period, the major issues focused on the practical applicability and economics of the research approaches. It was indicated that small-scale farmers were involved as a nucleus for the dissemination and implementation of the research results. This was also adopted by the extension service of the Ministry of Agriculture. Furthermore, small credit support for such a scheme was established. In addition, intercropping of legumes under cash crops for intensive farming and a three strata system, grass–shrub–trees, were suggested as possible improvements.

Dr Kategile focused on the use of untreated and treated crop residues, such as maize cobs and stover, for livestock feeding during the dry season. The main constraints for the practical application of NaOH treatments were the cost of the alkali and the relatively low price of the fattened cattle.

During the discussion, a suggestion was made to use cheaper alternative chemicals, such as Magadi soda and wood ash, which is locally available, as a substitute for the more expensive NaOH. The results with Magadi soda, however, were not very encouraging and further study is required to elucidate the use of this alternative alkali treatment. In subsequent discussions, the use of urea supplementation as a replacement for protein feeds appeared to be most promising in terms of performance and economics.

The paper by Drs Shah and Muller demonstrated the potential use of poultry and cattle wastes in complete rations for large and small ruminants as well as poultry. It focused on typical examples of least-cost rations based on poultry litter, poultry manure, and dried cattle manure. In addition, it described processing methods of animal wastes at the farm level (ensiling, stacking, formalin treatment, and "in-house" drying of caged manure). The results indicated that poultry waste at the 25–40% level can substitute most of the protein and mineral requirements.

During the discussion, the major issues raised were the problems of contaminant transfer into milk and, in the case of layer manure, the presence of high ash levels, Ca in particular. With respect to the transfer of contaminants, such as arsenic and drugs, into milk via the feed, it is felt that the risk involved is minimal because of the metabolic capacity of the liver to remove and partly or fully destroy most of the currently used drugs. In terms of applicability, it was indicated that the diets based on poultry waste could be used in urban centres, where most of the intensive livestock production takes place. The use of formalin for treatment of animal wastes, as well as for protecting protein and enhancing its utilization by ruminants, was highlighted by several participants.

Use of By-Products for Ruminant Feeding in Kenya

A.N. Said,[1] F. Sundstøl,[2] S.K. Tubei,[1] N.K.R. Musimba,[3] and F.C. Ndegwa[1]

An estimated 6.9 million tonnes of arable farm by-products, excluding maize cobs, were produced in Kenya in 1978. Accelerated agricultural development in the field of cereal production will result in increases in available by-products far exceeding the estimated 6.9 million tonnes. Currently, very little of the by-products is used for livestock feeding by large-scale farmers. Most small-scale farmers, however, use maize stover to feed dairy cattle.

Chemical treatment of the by-products, using sodium hydroxide, ammonia, and a natural salt deposit called "Magadi," have shown that it is possible to improve the nutritive value and intake levels of ruminant livestock; confirming the already established positive effects of treatments discussed in the literature. Some of the experiments undertaken have shown that treated by-products equal the nutritive value of the medium-quality *Chloris gayana* hay farmed by large-scale farmers in Kenya and that the by-products are promising silage extenders. They could, therefore, spare forage and pasture land for arable crops to meet the ever-increasing national demand for cereals and other agricultural products.

The constraints to using by-products in Kenya are mainly the high costs of chemicals and transportation if the by-products are to be used away from the production sites. It is advocated that economic assessments of treatments be carried out that take into consideration the overall impact on both the agricultural and animal-production sectors. It is probable that large-scale treatments would be a practical and economic proposition to large-scale cereal-growing farmers or proprietary feed compounders located within the cereal-production sites.

Due to escalating feed prices and the scarcity of good-quality forage as a result of population pressure on premium farmland, chemical treatment of on-plot produced by-products might be an economical proposition to small-scale farmers.

It is suggested that government involvement in evaluating economic studies on by-product treatments and utilization would be desirable and should be included in national development projects.

En 1978, environ 6,9 millions de tonnes de sous-produits agricoles, épis de maïs non inclus, ont été produits au Kenya. Et l'accélération du développement de l'agriculture au niveau de la production céréalière, entraînera une augmentation du volume des déchets fermiers. Actuellement, les grands éleveurs n'utilisent que très peu de ces sous-produits pour l'alimentation du bétail mais la plupart des petits éleveurs se servent des tiges de maïs pour nourrir les vaches laitières.

Le traitement chimique de ces sous-produits, à l'hydroxyde de sodium, à l'ammoniac et à l'aide de dépôts de sels naturels appelés « Magadi », a prouvé qu'il est possible d'améliorer la consommation et la valeur nutritive des aliments chez les ruminants. Ceci ne fait que confirmer encore une fois les aspects positifs de ces traitements, déjà largement publiés. Certaines expériences ont démontré que la valeur nutritive de sous-produits soumis à ce genre de traitements est égale à celle du foin *Chloris gayana* de qualité moyenne produit par les grands exploitants du Kenya et que ces sous-produits

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laissent entrevoir la possibilité d'accroître les réserves de fourrage ensilé, ce qui permettrait d'utiliser moins de terres pour la culture du fourrage et la pâture, et de les réserver à la production de céréales et autres produits agricoles, pour répondre à l'augmentation de la demande nationale.

Les facteurs limitants de l'emploi des sous-produits agricoles au Kenya sont principalement le coût élevé des produits chimiques et du transport, si ces sous-produits doivent être utilisés loin du lieu de production. Il a été recommandé que des évaluations économiques des traitements de ces sous-produits soient effectuées en tenant compte de leur impact global sur les secteurs agricoles et de la production animale. Il est probable que le traitement à grande échelle de ces sous-produits représenterait une solution pratique et économique pour les grands producteurs céréaliers ou les producteurs d'aliments pour animaux, situés sur les lieux de production des céréales.

En raison de la montée en flèche des prix des aliments pour le bétail et du manque de fourrage de bonne qualité, s'expliquant par la pression démographique qui monopolise les terres arables de première qualité, le traitement chimique sur place des sous-produits pourrait constituer une option avantageuse pour les petits exploitants agricoles.

Il a donc été suggéré que la participation du gouvernement à l'évaluation d'études économiques sur le traitement des sous-produits agricoles et leur utilisation serait souhaitable et qu'une telle participation devrait être intégrée au plan de développement national.

En 1978 Kenia produjo una cantidad calculada de 6,9 millones de toneladas de subproductos agrícolas, sin contar los zuros o tusas, del maíz. El rápido desarrollo de la producción cereal aumentará en mucho más la cantidad de subproductos disponibles. Actualmente, los grandes agricultores emplean muy pocos subproductos para la alimentación animal. La mayor parte de los pequeños agricultores, sin embargo, emplea la hojarasca del maíz para alimentar el ganado lechero.

El tratamiento químico de los subproductos con hidróxido de sodio, amoníaco y un depósito de sal natural llamado "Magadi," has mostrado que es posible mejorar el valor nutritivo y los niveles de ingestión del ganado rumiante, confirmando lo que dice la literatura respectiva. Algunos de los experimentos realizados han mostrado que los subproductos tratados igualan el valor nutritivo del heno *Chloris gayana* de mediana calidad, cultivado por los grandes agricultores de Kenia, y que los subproductos resultan una ampliación promisoria de los ensilados. Por tanto, se podría dedicar la tierra de forrajes y pasturas a cultivos que satisfagan la creciente demanda nacional de cereales y otros productos.

La limitación para el uso de los subproductos en Kenia radica, ante todo, en el alto costo de los químicos y del transporte si los subproductos van a ser usados lejos de los sitios de producción. Se recomienda realizar evaluaciones económicas de los tratamientos, tomando en cuenta el impacto general tanto en el sector agrícola como en el de producción pecuaria. Es probable que los tratamientos a gran escala representen una proposición práctica y económica para los grandes cultivadores de cereal o para las mezcladoras de raciones animales ubicadas dentro de los lugares de producción cerealera.

En vista del creciente costo del alimento animal y la escasez de forraje de buena calidad resultantes de la presión poblacional sobre la mejor tierra de cultivo, el tratamiento químico de los subproductos en el terreno podría ser una propuesta económica para los pequeños agricultores.

Se sugiere la participación del gobierno en los estudios de evaluación económica del tratamiento y utilización de los subproductos y su inclusión en el proyecto nacional de desarrollo.

This paper will give a brief review of treatment methods tried in Kenya aimed at utilizing by-products in animal-feeding systems. The scope for utilization will be discussed in terms of the availability of by-products and the economics of treating some of the highly lignified arable farm by-product residues. No attempt will be made to discuss conventionally used by-products, such as oilseed cakes, or industrial by-products, such as wheat bran, maize bran, and maize germ meal. These by-products are widely used by commercial feed compounders. Individual farmers use them either as straight supplements or for homemade feed mixtures. Their utilization has enabled the dairy, pig, and poultry industries in Kenya to attain their present levels of productivity, albeit below national targets.

Availability of Highly Lignified Farm By-Products in Kenya and Their Present Utilization

Table 1 gives the estimated quantities of wheat, rice and barley straws, maize stover, maize cobs, sugarcane tops, bagasse, millet, and sorghum stovers produced in Kenya. Under Kenyan farming conditions, only a small percentage of some of these by-products are utilized for livestock feeding by the agrarian communities.

Maize stover, which is the most abundant of the crop residues, is used almost entirely for livestock feeding, untreated, by small-scale peasant farmers within high-potential areas. Within the large-scale maize growing areas, the residue is almost totally unused for livestock feeding. It is either plowed back into the soil or used for making contours (ridges).

Peasant farmers use maize cobs from their subsistence crops as a source of firewood. Cobs from large-scale farmers are either discarded or sold to a furfural-extraction plant, centrally situated within the large-scale maize-production areas. A small percentage of ground maize cobs is used as a constituent of homemade feed mixtures by some livestock farmers.

Rice straw is not used for livestock feeding. Some of the straw is baled and sold to neighbouring coffee farmers as mulch. The remaining unbaled straw is burned and remnant stubble is plowed back into the soil during preparation of the paddy fields for the next crop. An attempt was made to make partition boards but the enterprise was not found to be economical and was discontinued.

Table 1. Estimated availability of some highly lignified arable farm by-products in Kenya, 1978.

Crop residue	Estimated yield[a] (1000 metric tons)
Maize stover	5000
Wheat straw	187
Barley straw	49
Rice straw	39
Sorghum/millet stovers	676
Sugarcane tops	400
Bagasse	500

[a] Assume crop residue to grain of 1:1 for wheat, barley, and paddy rice; 2:1 for maize, sorghum, and millet; 1:4 for sugarcane tops to cane; and 1:5 for bagasse to cane (Owen 1976).

It is difficult to give a percentage breakdown of the utilization of wheat and barley straws due to a lack of statistics. However, it is fair to state that some of the wheat and barley straw is baled and used for livestock bedding under mixed-farming conditions. Some is sold as bedding outside the farms to the few horse stables in the country. Baled wheat and barley straws are also used by the glass industry for packaging but the percentage utilization for this purpose is also difficult to estimate. During the dry season and post-cropping period, farmers that also keep sheep and cattle (mixed-farming system) feed their animals untreated straws and the common practice is to allow the animals to go into the fields to feed on the remaining unbaled straw and stubble prior to field preparations for the next crop. Some of the straw is plowed back into the soil. Few farmers throw baled straw onto the fields for animals to feed on during the dry season.

Very little, if any, sugarcane tops are used for livestock feeding by the "outgrowers" in sugarcane growing areas. None of the sugarcane tops from sugar plantations are used for livestock feeding. Bagasse produced on plantations and at local small-scale jaggeries is used as a source of fuel in the process of sugar production.

Other types of crop residues, such as millet and sorghum stover, are hardly used for livestock feeding.

The common practice under Kenyan conditions, except in a few cases with maize cobs when these crop residues are used for livestock feeding, is to feed them untreated in the long dry form. Due to their poor palatability and digestibility, however, intake is low when they are fed as the only roughage. At best, the animals can hardly obtain subsistence energy from them. Their utilization as animal feed is also limited by their bulk and transport costs.

Treatment Methods and Scope for Practical Application

Since the beginning of the 19th century, attempts have been made to improve the digestibility and nutritive value of cereal straws for livestock feeding. A major breakthrough in the studies has been chemical treatments involving alkalis to remove encrusting substances (cellulose, hemicellulose, and lignin). Chemicals such as sodium hydroxide, sodium hypochlorite, calcium hydroxide, metallic acids, and, recently, ammonia in both its anhydrous and aqueous forms have been tried. Microbial and steam and pressure treatments have also been used.

It has now been established that intake and utilization of these high lignocellulosic cell-wall materials can be increased by supplementary feeding and by various pretreatment methods. Recent literature on the subject can be found in Jackson (1977), Klopfenstein (1978), Owen (1979), Sundstøl et al. (1979), Greenhalgh (1980), and Kategile et al. (1981). The consensus is that amongst the various chemicals used sodium hydroxide and ammonia have proven to be the most successful. Recent work in Kenya, Tanzania, and Bangladesh has shown that "Magadi" soda (a natural alkali salt deposit) and urea are also effective in improving digestibility and intake of straws (Musimba 1980; Kategile et al. 1981; Saadullah and Haque 1981).

Within the developed countries, commercial and on-farm utilization of treated straws is common in Western Europe, especially in Scandinavian countries; United Kingdom; United States; and Canada. The technology, commercial infrastructure of livestock industries, and other related factors make it economical for those countries to utilize treated, high-lignocellulosic crop residues for livestock feeding.

Within the developing countries, research undertaken in India (Jackson 1977), Bangladesh (Saadullah et al. 1981), Egypt (El-Shazly and Naga 1981), Tanzania (Kategile 1981), and Kenya (Said 1981; Musimba 1980; Tubei 1982; Nangole 1982) has shown that chemical treatments of highly lignified crop residues resulted in improved digestibilities and intake levels. However, the economics of the scale of operation and application need to be studied.

Treatment Methods Tried in Kenya

A detailed description of the methodologies of treatments will not be covered in this presentation. These have been discussed in some of the literature referred to earlier. Instead, only those methods that show promise of being sold to small- and large-scale farmers and to feed compounders, provided that the economics of the treatment methods are justifiable, will be described.

Sodium Hydroxide (NaOH)

Sodium hydroxide can be used in the form of a dip treatment by small-scale farmers. Maize stover, which is available to the small-scale subsistence farmer, could be treated in this way. Small-scale farmers near wheat- and barley-growing farms could use this method to treat wheat or barley straw. The steps in a dip-treatment method are described in Sundstøl (1981). Small-scale farmers can use a 200-L drum that has been cut in half. Chopped maize stover or other cereal straws can be bundled in an ordinary nylon net that can be purchased commercially or is homemade. The bundle can be lifted up for dripping prior to storage for ripening. The latter method was tried on three small-scale farms in Kenya. The average daily intake of treated wheat straw over 20 days by each cow was 18 kg wet straw, which provided about 7.5 kg of dry matter per day, in addition to variable concentrates of about 2 kg in the form of proprietary dairy meal or pollard and variable quantities of Napier grass (*Pennisetum purpureum*), green chop, sweet potato vines (*Ipomea batatas*), or some other home offals.

In an experiment conducted on a beef feedlot, NaOH-treated (27 g NaOH/kg DM straw) and untreated wheat straws were fed together with maize silage (60%), maize bran and germ meal (20%), and a proprietary mixture of molasses, urea, and minerals compounded as ration 3 (67% roughage and 33% concentrates). The straw was fed unchopped and treatment was by sprinkling the NaOH solution at a rate of 800 mL/kg DM. Table 2 gives the performance of the three treatment groups.

Alternatively, small-scale farmers can sprinkle sodium hydroxide on chopped by-products at a rate of 33 g NaOH per kg dry matter of chopped stover/straw. A sprinkling rate of 800 mL/kg chopped stover/straw, left to ripen overnight, was comparable in nutritive value to that of medium-quality *Chloris gayana* hay (Said 1981).

Table 2. Effect of feeding NaOH-treated and untreated wheat straw to beef feedlot cattle together with maize silage.

	Group		
	A	B	C
Number of steers	10	10	10
Initial live weight (kg)	264	263	264
Final live weight (kg)	333.5	329.0	328.0
Daily gain (130 days) (g)	534.6	507.7	492.3
Intake of ration 3 (kg)	12.7	12.7	12.7
Intake of ration 3 (kg DM)	5.9	5.9	5.9
Intake of treated straw (kg)	2.1	—	—
Intake of treated straw (kg DM)	1.90	—	—
Intake of untreated straw (kg)	—	2.09	—
Intake of untreated straw (kg DM)	—	1.88	—

In a laboratory experiment, maize stover, rice straw, and wheat straw were treated with NaOH by soaking chopped materials in plastic laboratory silos for 8 hours at the rates indicated in Table 3. One kilogram of the material was soaked in 4 L of the solution. In vitro dry matter and organic matter digestibilities are shown in Table 3.

Magadi

Magadi is a natural salt deposit that occurs at Lake Magadi in the Rift Valley passing through Kenya. The lake is situated about 120 km southwest of Nairobi. The salt deposit, or trona, is a result of the high evaporation rate of water from the lake. It is in the form of crystals of sodium sesquicarbonate ($Na_2CO_3NaHCO_32H_2O$). Magadi is processed into a commercial product, soda ash (sodium carbonate).

Laboratory experiments were conducted to test the effect of Magadi treatment on in vitro digestibility of some arable farm by-products (Table 4). The solutions, 800 mL/kg roughage, were sprayed on and left to ripen for 3 hours. Treated materials were then oven-dried and milled for analysis. Table 4 indicates positive treatment effects. A treatment rate of 4.9% of dry matter of the by-product was found to be the optimal rate under the conditions of the experiment.

In another laboratory experiment (Table 5), eight levels of Magadi were used to soak chopped maize stover, rice straw, and wheat straw for 8 hours in 800 mL of the solutions per kilogram of roughage. The treated roughages were then washed with

Table 3. Percentage in vitro dry matter digestibility (IDMD) and in vitro organic matter digestibility (IOMD) of wheat straw and maize stover treated with NaOH.

Percentage NaOH on DM basis	Maize stover		Rice straw		Wheat straw	
	IDMD	IOMD	IDMD	IOMD	IDMD	IOMD
Untreated	50.25^a	48.76^a	50.24^a	49.35^a	39.41^a	47.66^a
2.5	55.11^a	49.37^b	49.43^a	55.06^a	43.25^a	50.27^a
5.0	61.37^b	67.95^c	57.41^b	64.97^b	53.55^b	58.76^b
6.5	69.04^c	67.78^c	64.50^c	75.02^c	60.43^c	66.08^c
8.0	68.77^c	70.55^c	65.04^c	76.21^c	59.40^c	63.80^{bc}

NOTE: Means within treatments followed by a common superscript were not significantly different ($P<0.05$).

Table 4. Effect of Magadi on IDMD (%) and IOMD (%) of wheat and rice straws, rice husks, and maize stover using a spraying technique.

Magadi used (% of DM of by-products)	Maize stover		Rice straw		Wheat straw		Rice husks		Sugarcane tops	
	IDMD	IOMD	IDMD	IOMD	IDMD	IOMD	IDMD	IOMD	IDMD	IOMD
0	61.5	64.0	51.3	55.0	46.0	41.0	5.2	4.4	59.5	59.6
3.3	66.3	67.8	59.1	64.0	55.8	55.5	7.6	4.8	63.3	62.9
4.9	67.4	68.5	59.8	64.9	61.0	60.1	9.8	6.6	64.8	64.4
6.6	70.6	60.3	61.0	65.2	60.7	59.0	10.7	6.2	63.8	62.7

Table 5. Effects of Magadi on IDMD (%) and IOMD (%) of maize stover, rice straw, and wheat straw using a soaking method.

Percentage Magadi on DM basis	Maize stover		Rice straw		Wheat straw	
	IDMD	IOMD	IDMD	IOMD	IDMD	IOMD
2.5	52.57[a]	55.34[a]	55.51[a]	60.29[ab]	36.59[a]	42.66[b]
5.0	52.08[a]	57.66[a]	53.30[a]	61.68[ab]	39.59[b]	46.46[c]
6.5	52.89[a]	62.41[b]	59.96[b]	60.40[ab]	34.88[a]	39.38[a]
8.0	55.72[ab]	56.91[a]	53.96[a]	59.23[a]	41.80[b]	46.30[c]
10.0	56.84[b]	61.58[b]	54.65[a]	62.04[b]	46.49[cd]	49.87[de]
12.0	63.51[c]	68.48[c]	53.3[a]	59.69[a]	41.29[b]	44.89[cd]
15.0	76.76[d]	78.22[d]	59.67[b]	61.10[ab]	47.22[d]	52.18[c]
18.0	78.72[d]	80.33[d]	64.74[c]	74.37[c]	44.21[c]	47.47[d]

NOTE: Means within treatments followed by a common superscript were not significantly different ($P<0.05$).

water and dried for in vitro analysis. Up to 8% Magadi treatment gave lower DMD and OMD than treatment with 8% NaOH (Table 3). Maize stover and rice straw showed increased digestibility, for the most part, with increasing treatment levels up to 18%. Wheat straw IOMD increased only five percentage units at 18% Magadi. It is probable that the differences in treatment effects by Magadi in Tables 4 and 5 are due to differences between the spraying and soaking methods used or the fact that in the experiment utilizing the soaking method the roughages were washed with water prior to drying, milling, and laboratory digestion.

Ammonia (NH_3)

Both laboratory and feeding experiments were carried out using anhydrous NH_3. In the laboratory experiment, NH_3 was used on chopped maize stover and rice straw at two levels of moisture content and NH_3 levels as indicated in Table 6. There were increased digestibilities with NH_3 treatments but elevated moisture content had little effect on digestibility.

Table 6. Effect of varying levels of moisture and NH_3 on in vitro organic matter digestibility (IOMD) of maize stover and rice straw.

	Moisture content in the straw (%)	IOMD (%)	
		Maize stover	Rice straw
Untreated	8.5	43.9	50.0
3% NH_3	8.5	48.2	57.9
3% NH_3	25	51.1	58.2
6% NH_3	8.5	49.2	59.6
6% NH_3	25	52.6	62.1

In a feeding trial with Dopper sheep, ground maize cobs (MC) and chopped maize stover (MS) were treated with 4% anhydrous NH_3 on a dry-matter basis for 6 weeks at ambient temperature, as per the method described by Sundstøl et al. (1978). In addition to the ad libitum treated roughages offered, each sheep in a group of 10 was given 400 g of a proprietary concentrate mixture (16% DM crude protein and 7.7% DM crude fibre), estimated to be a maintenance ration. Table 7 gives the results of the experiment.

In another feeding trial involving Boran beef feedlot steers, NH_3-treated maize stover (35 kg NH_3/tonne DM) and untreated *Chloris gayana* hay were used as a supplement with sorghum silage, as described by Said (1981), on a 26% DM silage replacement basis. Table 8 gives the composition of the diets and Table 9 the performance of the steers on the three rations. The NH_3-treated maize stover tended to be superior in nutritive value to *Chloris gayana* hay but at a replacement level of 26% DM it was slightly inferior to the sorghum silage ration alone.

Treatment Methods Tried in Other Developing Countries

Experiments to improve nutritive value and utilize highly lignified crop residues have been tried in many other developing countries. Some recently published results can be found in Kategile et al. (1981). Almost consistently, NaOH, $Ca(OH)_2$, urea,

Table 7. Roughage dry matter and organic matter intake, digestibilities, and live-weight gain of Dopper sheep fed on untreated and NH_3-treated maize cobs (MC) and maize stover (MS).

	Untreated MC	NH_3-treated MC	Untreated MS	NH_3-treated MS
DM intake (g/day)	359.0[a]	634.0[b]	338.0[c]	434[d]
OM intake (g/day)	329.0[b]	585.0[a]	320[b]	414[ab]
DM intake ($g/kg_W^{0.75}$)	25.2[b]	41.5[a]	23.5[b]	28.4[b]
OM intake ($g/kg_W^{0.75}$)	23.1	49.3	22.4	27.0
DM intake (kg/100 kg body weight)	1.03	1.65	0.96	1.12
Average daily gains (g/day)	79.4[b]	129.9[a]	61.8[b]	88.7[ab]
In vivo digestibility (%)				
DM	55.01	61.24	56.12	58.93
OM	56.20	62.49	56.13	60.96
Neutral detergent fibre (NDF)	60.19	62.02	63.23	69.90

NOTE: Means followed by different superscripts are significantly different at $P<0.01$.

Table 8. Chemical composition (% DM basis) of sorghum silage, NH_3-treated maize stover, and *Chloris gayana* hay fed to Boran steers.

	DM	Crude protein	Ether extract	Crude fibre	Ashes	Nitrogen free extract
Sorghum silage	38–45	6.75	2.21	32.58	10.25	48.21
NH_3-treated maize stover	89.0	8.06	1.50	35.84	7.20	47.40
Chloris gayana hay	94.15	6.03	2.07	41.62	11.62	38.60

Table 9. Performance of Boran steers (mean figures per steer) (Said 1981).

	Group		
	A	B	C
Number of steers	10	10	10
Initial live weight (kg)	250	250.8	251.2
Live weight after 133 days (kg)	302.8	301.8	296.2
Total live-weight gain (kg)	52.8	51.0	45.2
Daily live-weight gain (g)	394	383	340
Intake of silage (kg DM/day)	3.31	2.89	2.83
Intake of maize grain (kg DM/day)	1.91	1.83	1.81
Intake of molasses, urea, and mineral mixture (kg DM/day)	0.60	0.58	0.57
Intake of maize stover (kg DM/day)	—	0.75	—
Intake of *Chloris gayana* (kg DM/day)	—	—	0.74
Total DM intake/day	5.82	6.05	5.95

and NH_3, both in the anhydrous and aqueous forms, have indicated improved but variable intake levels and digestibilities of roughages. Soaking, spraying, ensiling, and stacking techniques have also shown variable levels of improvements, as indicated in the literature referred to earlier.

Scope for Utilizing Highly Lignified Arable Farm By-Products in Kenya

The most profitable areas for utilizing highly lignified arable by-products include dairy production, on both large- and small-scale farms, and beef production under intensive systems. Lately, it has been established that maize and millet stovers and sugarcane tops could provide potential roughage supplements in the planned goats' milk production program, part of the Republic of Kenya's small ruminant collaborative research support program (1980–1981) implemented by the Ministry of Livestock Development (1980). Depending upon production and opportunity costs, commercial feed compounders might find it profitable to market pelleted treated straws.

In 1977, Said and Sundstøl assessed the potential and scope for utilizing rice straw in dairy cattle rations at the Mwea Rice Irrigation Scheme in Kenya. It was estimated at that time that the annual production of rice straw and rice bran meal at the scheme was 12 000–15 000 and 2600 tonnes, respectively, from the 5648 ha under paddy rice. It was assumed that milking dairy cows would need a ration of 3 kg maize silage, 6.2 kg treated rice straw, and rice bran meal according to yield; dry cows (180 days) would need 7.5 kg treated rice straw and 1 kg molasses. Thus, 2000 dairy cows, each producing about 10 kg of milk per day over 6 months, would need the following amounts of feed per year: treated rice straw, 5000 tonnes; maize silage, 1080 tonnes; rice bran meal, 1920 tonnes; and molasses, 360 tonnes.

This meant that there would have been 7000–10 000 tonnes of rice straw and 700 tonnes of rice bran meal remaining for raising other forms of livestock. The rice husks from the on-site factory could be used for bedding and the considerable amount of manure from the animals mixed with the bedding could be utilized as a cheap source of humus and fertilizer for the rice fields.

The 1980 countrywide hectarage under paddy rice, as calculated from Table 10, is 8560 ha; this does not include conventional paddy rice grown by peasant farmers on seasonal swamps. Within the next 5–10 years, there will be a substantial increase in rice production resulting from the planned study at the Lower Tana River Basin (12 000 ha), implemented by the Tana River Development Authority, and in Nyanza, under the proposed Lake Basin Development Authority.

Between 1978 and 1980, economic feasibility studies were undertaken by B. Eidsvig (personal communication) of the Kenya Industrial Estates, a government parastatal body, to evaluate the feasibility of NH_3 and NaOH treatment of rice straw at the Mwea Rice Irrigation Scheme. At the prices of machinery, materials, and chemicals prevailing at that time, it was concluded that utilization of treated rice straw was an economic possibility. It is doubtful whether the escalating costs of treatments would still make production of treated straws and stovers a profitable venture for commercial firms. On-farm treatments by both large-scale farmers and, even more so, small-scale farmers needs further assessment.

According to the Ministry of Economic Planning and Development (1981), in 1980 the area on large-scale farms under wheat, barley, maize, and sugarcane was 79 378, 9006, 70 677, and 37 397 ha, respectively, generating a substantial tonnage of straws, stover, sugarcane tops, and bagasse that could be used for livestock production. It could be a means of boosting returns from mixed-farming systems. The hectarage under cereals is likely to increase with the implementation of the current World Bank study on the Narok Agricultural Development Project.

The greatest scope for utilizing maize stover and sugarcane tops is by small-scale farmers in high- and medium-potential areas and by outgrowers around the sugarcane estates. Over the last 19 years, Kenya has been moving toward small-holder production systems within almost all of the highly populated high-potential farming areas. This trend is definitely going to increase with the population growth currently estimated at 4% per annum, and also for reasons of political pacification. At present and estimated land availability (Table 11), there will be pressure on food- or cash-crop activities. Livestock may have to be fed on residues from the land as prices of concentrates and commercial forages escalate continuously. Currently, almost all dairy cattle within small-scale farming areas are undernourished. An average figure per lactation is likely to be of the order of 646 kg

Table 10. Irrigated paddy rice in Kenya, 1980.

Location	Area (ha)
Mwea	5771
Ahero	1348
Bunyala	213
West Kano	1228

Table 11. Per capita land availability in high- and medium-potential areas of Kenya (Said 1980).

Year	Population (× 1000)	Land availability (ha)
1948	5406	1.83
1962	8636	1.15
1969	10943	0.90
1979	15332	0.64
1985	19310	C.51
1990	23302	0.43
1995	28213	0.35
2000	34286	0.29

Table 12. Development of the dairy-cattle population by size of farm operation (× 1000) (Said 1980).

Type of farm	1977	1978	1979
Small holding	784.5	842.4	900.4
Large-scale holding	286.3	283.3	280.1

(Stotz 1979). The luxury of extensive livestock production on pastures will almost certainly disappear from the Kenyan agricultural scene within high-potential areas as indicated in Table 12.

There is and will continue to be an increasing demand for maximizing the feeding and management of the livestock of small-scale farmers. A number of strategies are possible depending upon the economics and opportunity costs. As a prerequisite to increased intensification of livestock farming, there must be, among other things, increased improvement in crop and forage production so that greater quantities of land or, better yet, crop residues and irrigated fodder are available for livestock. Regrettably, capital, technology, and treatment costs for crop residues are prohibitive factors.

Constraints to Practical Utilization of Treated Crop Residues for Livestock Feeding

The major constraints are transport costs of the residues if they are to be used away from production areas, the cost of chemicals, and, if used on commercial and industrial scales, the cost of machinery.

Crop residues are very bulky. The cost of rail transport is based upon both weight and volume. The cost of transportation by road is based on the hiring charges per truck, e.g., the mean current cost of transporting a bale of wheat or barley straw or maize stover from farms near Nakuru area in the Rift Valley, Kenya, to Nairobi warehouses, a distance of 160–180 km, ranges from KESh5–KESh7. Because of escalating costs of machinery, the selling price, at the farm, of wheat straw ranged from KESh4–KESh5 per bale. The current selling price of wheat straw in Nairobi is KESh14 per bale when taken from the warehouse and sold. *Chloris gayana* hay sells at KESh17.50 per bale.

Table 13. Prices of NaOH, NH_3, Magadi, and urea in KESh (KESh10.86=US$1).

Chemicals	Price per kg 1976 1980	1982
NaOH	3.80–8.50	40.00
NH_3	9.00–14.80	36.00
Magadi	0.27–0.50	1.60
Urea	—	3.15

Table 13 shows the trend of increasing prices for chemicals from the end of 1976 to 1980. Current prices are also indicated. The cost of chemically treating 15 kg of crop residues is given in Table 14. The costings need more careful economic assessment to evaluate the advantages of treatment methods. Apart from the cost of treatments, the effect of increased intake of residues by animals and the practicability of treatment methods are important parameters to consider.

Conclusions

There is no doubt that treatment of the crop residues discussed increased both the nutritive value of the residue and intake levels by the ruminant livestock. There is a need to undertake a more comprehensive economic study to evaluate the merits of these increases. The practicability of the methods, especially for small-scale farmers, also needs further study.

The most likely practical and economical ways of utilizing the by-products would probably be on the site of production to save on transport costs. The treated by-products could be used either for beef production by large-scale arable farmers or for dairy production by small-scale farmers. Alternatively, commercial firms could be established for the large-scale cereal-production farms to utilize treated by-products in compounded concentrate feeds. Another alternative is to use a high-pressure press to reduce bulk, thereby reducing transport costs as well. The roughages could be treated at the sites of production and compressed or they could be treated at the location where they will be utilized.

There should also be further studies to evaluate the effect of plain ensiling of crop residues with either maize, Napier, or sorghum silages. Straightforward physical

Table 14. Comparative costings[a] of treating wheat straw or maize stover; inclusive of the cost of the crop residues and the resultant nutritive value.

Chemical	Residual/Product	Cost (KESh/15 kg/DM)	Nutritive value
NaOH[b]	Maize stover	30.20	0.31 SE[g]
NH_3[c]	Maize stover	18.90	0.31 SE
Magadi[d]	Maize stover/wheat and rice straws	1.18	IOMD from 68.5–60.1
Urea[e]	Rice straw	2.36	In vivo OMD increased to 52–54% from 40% for untreated straw
No treatment	*Chloris gayana* hay	17.50	0.31 SE
No treatment	Dairy cubes[f]	20.00	0.42 SE

[a] Estimated from costs of chemicals and residues only.
[b] Spray treatment, 27 g/kg DM (Said 1981).
[c] 3.5 kg/100 kg DM.
[d] Rate used in Table 4.
[e] Saadullah and Haque (1981).
[f] Proprietary concentrate (16% DM CP and 7.7% DM CF).
[g] SE = starch equivalent (0.70 SE = 1 feed unit = 4620 kcal = 1.05 TDN).

treatment, such as chopping up and feeding the residues with protein and energy feeds, could be still another alternative use. Some additional comprehensive recommendations and conclusions can be found in Kategile et al. (1981).

The utilization of such vast quantities of arable farm by-products should not be left entirely to private entrepreneurs. There is a need for a national policy in this important field, which in the final analysis embraces the various facets of national development. The estimated 6.9 million tonnes of highly lignified arable farm by-products (Table 1), if treated to a starch equivalent of 0.3, would result in close to 2.07 million tonnes of starch equivalent, which is equivalent to 2.96 million tonnes feed unit or 2.96 million tonnes of barley.

The questions that arise include: What will be the cost and level of technology to attain the proposed objectives? For how many more years will Kenya be self-sufficient in milk and beef supplies? What will be the cost in terms of foreign exchange that would have to be spent to meet the national requirements for these products? These are not simple questions to answer. In time and with further research, however, answers to some of these questions may be found.

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Nutritional Characteristics of Some Selected Nonconventional Feedstuffs: Their Acceptability, Improvement, and Potential Use in Poultry Feeds

M. Gomez[1]

With a view toward developing nonconventional feedstuffs (NCFs) for use in poultry feeds, a number of NCFs were screened and collected from a selected location. They were initially subjected to a proximate analysis. Some of the promising NCFs, such as bulrush millet (*Pennisetum typhoides*), finger millet (*Eleusine coracana*), pigeon peas (*Cajanus cajan*), and cocoyam (*Colocasia esculenta*), were further evaluated.

A scheme was developed whereby the promising NCFs were tested in acceptability trials followed by identification of antinutritional and restrictive factors. Processing methods to overcome antinutritional and restrictive factors were tested. The protein NCFs received amino-acid supplementation to improve utilization value. Finally, they were evaluated for their replacement value in practical feeds.

The bulrush millet and finger millet were acceptable as energy sources at levels up to 60%. The bulrush millet appeared to be more beneficial due to its higher protein contribution and was improved further with lysine supplementation. Raw pigeon peas were a suitable source at levels up to 15% and were improved with autoclaving and methionine and L tryptophan supplementation. Bulrush millet and pigeon peas combined were able to effectively replace up to 40% of the conventional energy and protein sources in practical diets. Cocoyam meal has substantial potential to be developed as an energy source; however, processing techniques need to be improved to increase energy utilization.

Dans le but de produire des aliments non conventionnels (ANC) pouvant être incorporés à l'alimentation de la volaille, un certain nombre de nouveaux aliments ont été sélectionnés et recueillis dans un endroit donné. Ces aliments furent d'abord soumis à une étude préliminaire approximative et on a approfondi l'analyse des plus intéressants, notamment le mil perlé (*Pennisetum typhoides*), le fonio (*Eleusine coracana*), le pois d'Angole (*Cajanus cajan*) et le taro (*Colocasia esculenta*).

Un plan fut établi, selon lequel les ANC prometteurs devaient être soumis à des tests d'acceptabilité, suivis de l'identification de leurs facteurs nutritifs et de ceux limitant leur utilisation. Des méthodes de traitement de ces aliments destinées à surmonter ces facteurs furent également essayées. Des acides aminés furent ajoutés aux ANC ayant une haute teneur en protéines afin d'améliorer leur potentiel alimentaire. Ces aliments furent, en dernier lieu, évalués sur le plan pratique, en tant qu'éventuels substituts dans l'alimentation du bétail.

L'apport d'énergie du mil perlé et du fonio s'est révélé acceptable, le niveau pouvant aller jusqu'à 60 %. Le mil perlé semblait cependant plus avantageux, en raison de sa haute teneur protéique et put être encore amélioré par addition de lysine. Les pois d'Angole à l'état brut représentaient une bonne source de protéines (à un pourcentage pouvant s'élever jusqu'à 15 %) et leur valeur nutritive fut améliorée par cuisson à l'autoclave et addition de méthionine et de tryptophane. Le mélange de mil perlé et de pois d'Angole permit de remplacer d'une manière satisfaisante jusqu'à 40 % des sources d'énergie et de protéines conventionnelles dans l'alimentation du bétail. La farine de taro pourrait constituer une autre source d'énergie mais les techniques de traitement de cet

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aliment doivent encore être améliorées pour pouvoir en augmenter le potentiel alimentaire.

Con miras a desarrollar raciones no convencionales para las aves de corral, se seleccionaron y recogieron materiales en un sitio identificado para este propósito y se sometieron inicialmente a un análisis próximo. Algunos de los materiales promisorios, como los mijos *Pennisetum typhoides* y *Eleusine coracana*, el guandul (*Cajanus cajan*) y el cocoñame (*Colocasia esculenta*) fueron sometidos a evaluaciones posteriores.

Se preparó un plan de pruebas de aceptación de las raciones no convencionales y de identificación de los factores antinutricionales y restrictivos. Se ensayaron métodos de procesamiento para superar estos factores y las raciones recibieron suplementación de aminoácidos para mejorar su valor de utilización. Finalmente, se evaluaron como reemplazo en raciones prácticas.

Los dos tipos de mijo se desempeñaron bien como fuentes de energía a niveles hasta del 60%. El *Pennisetum typhoides* hizo la más alta contribución de proteína y mejoró aun más con suplementación de lisina. El guandul crudo fue una fuente adecuada de proteína a niveles hasta dell 15% y mejoró con autoclave y suplementación de metionina y triptofano. El *Pennisetum typhoides* y el guandul combinados reemplazaron efectivamente hasta un 40% de las fuentes convencionales de energía y proteína en dietas prácticas. La harina de cocoñame exhibe alto potential para ser desarrollada como fuente de energía, sin embargo las técnicas de procesamiento necesitan ser mejoradas para aumentar la utilización de esta energía.

The development of the small-scale poultry producer in the rural sector and the improvement of the poultry industry in general has been receiving a great deal of attention in all national agricultural-development programs. Unfortunately, the major input in poultry-production programs, the supply of quality feedstuffs and feeds, has lagged behind the rapid and enthusiastic growth of the industry in both the rural and commercial sectors. The increasing demand for energy and protein feedstuffs and the prospect of spiraling costs, particularly sources of protein, is already having its effect on the supply and, even more importantly, on the quality of finished compounded feeds. In addition, it should be noted that a substantial proportion of the protein feedstuffs, being unavailable locally, have to be imported. As a result of these circumstances, an urgent need to initiate investigations on ways of meeting the increasing deficit of feedstuffs and feeds, if the rate of growth of the industry is to be maintained and promoted, has arisen.

An approach that seemed worthy of pursuing was the screening, evaluation, and development of locally produced and available feedstuff alternatives. As expected, there is inadequate, or very little, information on the compositional or nutritional characteristics of this hitherto unexplored and underexploited pool of local resources. This neglect is understandable and has been largely due to dependence upon conventional feedstuffs in the formulation of conventional compounded feeds. This dependence upon conventional feedstuffs, however, has obvious limitations when applied under local conditions.

In an attempt to study the potential of feedstuff alternatives, the objective was to screen, analyze for composition, and test the nutritional value of a variety of agricultural products, field by-products, and agroindustrial by-products that have not been used before in conventional or traditional feed formulations by the commercial feed miller or the small-scale farmer. The agricultural products selected have to be of relatively low fibre content because the feedstuffs are to be used in monogastric feeds. The search was for materials that showed potential for inclusion in nutritionally acceptable and usable feedstuffs. The term nonconventional feedstuffs (NCF) was thus adopted for this category of potential feedstuffs. It was strongly felt that this was an untapped resource that showed promise of possibly meeting at least some of the feedstuff deficits currently facing the expanding poultry and poultry-feed industry. The development of NCFs, therefore, can play a major role in filling the widening gap between the increasing demand for and shrinking supply of feedstuffs. The development of NCFs would also result in a range of other benefits, such as upgrading nutritional and utilization value and enhancing economic value while providing incentives for increased production of new feedstuffs. In the case of agricultural by-products, further benefits would include upgrading a waste product or overcoming a disposal problem. Although the present study was limited to the feasibility of utilizing NCFs in poultry feeds, the nutritional findings indicate that some of the NCFs may have some application as feedstuffs for other farm-animal species as well as in human nutrition.

Research Approach: General Scheme for the Development of NCFs

The systematic approach used to study and identify promising agricultural products that could eventually be acceptable as NCFs is presented in Fig. 1.

Procurement of Samples

Samples of agricultural products and by-products were procured from a variety of sources: the field, farms, rural produce markets, agroindustries, and food processors. Collection of these products was based on the following criteria: availability, reasonable quantities available, potential use as a feedstuff, potential for increased production, market value, fibre content, subsidiary importance as a human food source, and not used as a conventional

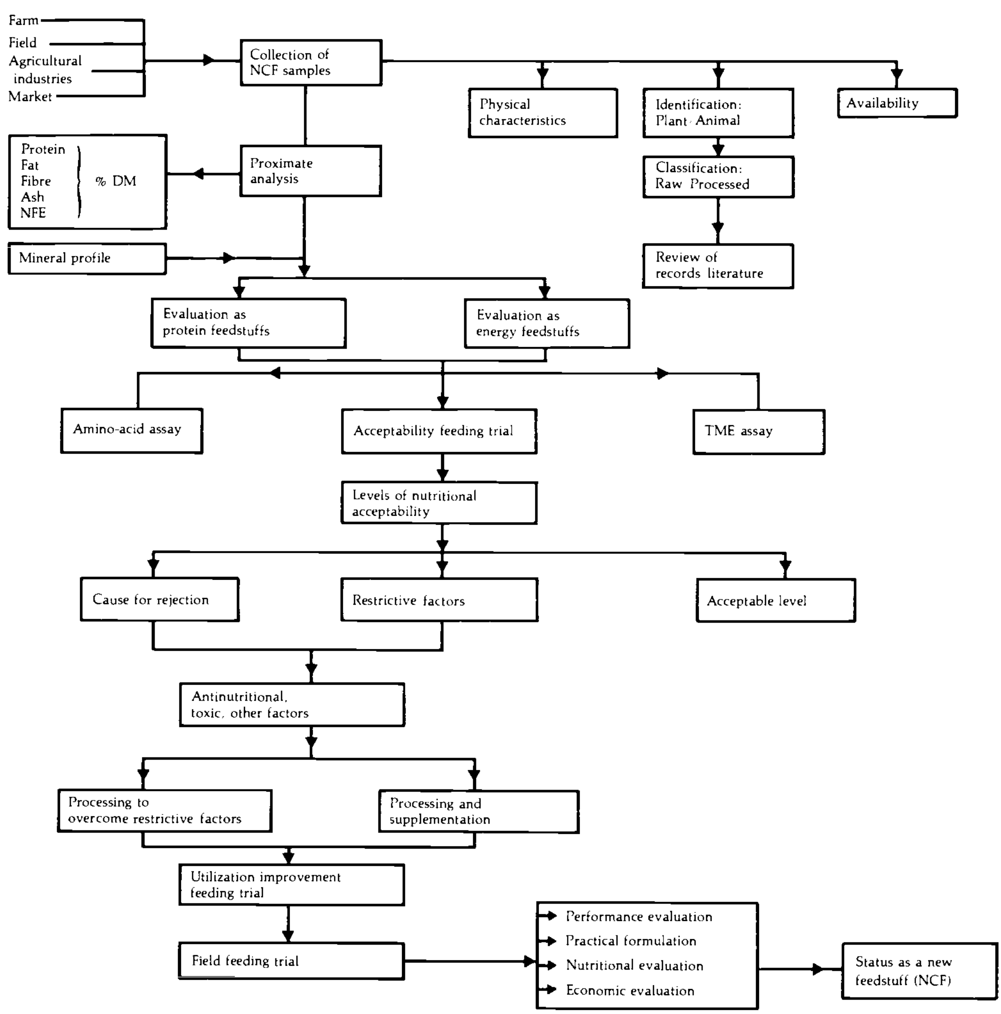

Fig. 1. Scheme for development and evaluation of NCFs.

feedstuff. The samples collected were classified and identified according to botanical nomenclature and their physical characteristics. Data on production and availability was collected when available and literature reviewed for any additional information.

Compositional Assays

In the development of NCFs, the feedstuffs have to be identified as principal feedstuffs or subsidiary feedstuffs. Principal feedstuffs would have to be major energy contributors (energy feedstuffs) or major protein contributors (protein feedstuffs), whereas subsidiary feedstuffs contribute both energy and protein but at a much lower or supplementary level, in addition to acting as a source of other micronutrients. During the screening process, the samples were subjected to a preliminary proximate analysis, followed by a true metabolizable energy (TME) assay for energy NCFs and, if possible, an amino-acid assay for protein NCFs.

It is understood that the proximate composition data is inadequate to evaluate the nutritional quality of a feedstuff and serves only as a guide to the actual potential nutritional value for comparative evaluation purposes.

Acceptability Trials

On the basis of information collected from the screening process, the more promising feedstuffs were selected for further testing in a series of feeding trials.

The feedstuffs were fed in their "as is" form (usually raw) at various levels as energy or protein substitutes or supplements in standard rations to test for levels of acceptability (or rejection). The acceptability trials to determine practical acceptable levels and reasons for rejection are monitored using parameters such as growth performance, feed intake, feed-conversion efficiency, morbidity, and mortality. Information related to adverse effects was obtained from autopsies, both during and at the termination of the experiments. From these data the feed value of the feedstuff, especially at the acceptable level, becomes apparent. Also at this stage, there is some indication of the restrictive factors, usually antinutritional or toxic factors, that limit the usable level of the feedstuff. Some indication of the nature and level of the restrictive factor in the feedstuff would also be detectable.

Utilization Improvement Trials

Depending upon the nature of antinutritional or toxic factors detected, the feedstuff is subjected to various appropriate and simple processing techniques to overcome, in whole or in part, the restrictive factors and improve utilization of nutrients. The processed or treated feedstuff is fed at levels higher than the marginally acceptable level in a series of experimental diets to test the improvements in utilization value. The outcome of these experiments reveals whether the treatment methods are successful, need alteration or modification, or are unsuitable; the objective being to improve utilization and enhance acceptable levels. Because most of the NCFs are of plant or vegetable origin, the nutritional value of the protein supplements, in particular, could be considerably improved through adjustments to or supplementation with the limiting amino acids. Most plant protein NCFs invariably need amino-acid supplementation for improved utilization. The treated NCFs, therefore, are tested further in a series of trials involving appropriate amino-acid supplementation at various levels.

Field Feeding Trial

The foregoing phases of experimentation should now have cleared the prospective NCF as being ready for field testing in practical feed formulations under farm conditions. At this stage of evaluation, several practical adjustments or changes may be necessary, such as modification of treatment methods, levels, and supplementation procedures. Amino-acid supplementation, for instance, may be substituted by the incorporation of appropriate complementary feedstuffs that would provide the desired improvement in the amino-acid balance of the feed.

Studies on Selected NCFs

Research Location

Because these are pilot studies of a preliminary nature, they were initially confined to two selected locations based upon certain relevant criteria. Some of the considerations were that the location be in a medium to high potential agricultural area identified for a national program, includes a predominance of small-scale farms and farmers interested in poultry production, and be of relatively easy access. The locations selected were Machakos and Nakuru. Much of the initial studies reported here were carried out in the Machakos District.

The choice of Machakos as a project area was due primarily to the fact that one of the national integrated broiler projects is located in this district. This meant that support services would be available for the field investigations and on-farm tests. The Machakos District covers 14 000 km^2, with a population of approximately 700 000, and is one of the key and central districts of the large Eastern Province. It is within 100 km of Nairobi and is easily accessible. With a mean altitude of 1600 m and a bimodal rainfall pattern of 760–900 mm, the area is considered to have medium agricultural potential. The agricultural community is made up predominantly of small-scale farmers, with mixed-farm holdings of 2–4 ha each. A variety of food crops, principally maize, yams, and legumes, are grown. In addition, there is a fair distribution of cash crops, such as coffee, and a range of fruits and vegetables and other subsistence crops. Livestock farming is confined to cattle and poultry. Based upon these conditions, the location appeared ideally suited as a target area for the studies.

Initial Screening and Compositional Assays

The field survey and search for agricultural products with the potential to become NCFs were conducted with the assistance of the field extension staff of the District Agricultural Office of Machakos. Samples were collected from a variety of sources in the field over two production seasons and through several bimonthly visits.

A list of the samples collected and their botanical classification is given in Table 1. The samples were classified into a number of groups on the basis of certain common characteristics. The groups were cereals/cereal by-products, root crops, pulses, fruit seeds, and leaf meals.

Most of the samples collected were in dried form, except the root crops and field leaves. The root crops were sliced and dried in solar driers, whereas the leaves were air-dried under laboratory conditions. In cataloguing the samples, observations were made on physical characteristics; condition, i.e., raw or processed; seasonal availability; and locational notes on their use and nonuse.

For the compositional assay, the samples were subjected to a standard proximate analysis to determine moisture, crude protein, ether extract, crude fibre, and ash content. The nitrogen free extract (NFE) value was also calculated. There values are also given, on a dry-matter basis, in Table 1. From the proximate analysis, samples with protein levels >20% were broadly grouped as protein NCFs and those with NFE values >70% as energy NCFs. Because the objective was to develop protein or energy NCFs, samples from these categories were subjected to further scrutiny to select those samples warranting more detailed testing and study. The selection of these samples was based upon available research information on nutritional value and prospects for improving nutritional value by processing techniques, and nutritional supplementation or complementation.

Nutritional Characteristics of Selected NCFs

Energy NCFs

Of the energy NCFs showing promise for development, bulrush millet (BM), finger millet (FM), and cocoyam meal (CYM) were selected for further study of their nutritional properties and characteristics and adoption as NCFs.

French (1947), Ayyaluswami and Jaganathan (1967), Yeong and Ali (1976), and Singh and Barsaul (1977) have shown that millets can replace maize effectively at levels ranging from 20–40%. They observed, in general, that feed-conversion efficiency (FCE) was lower with the FM than with BM.

In the initial feeding trials, FM and BM were substituted at 0, 20, 40, and 60% for maize in starter feeds to ascertain acceptability levels as indicated by body-weight gain and FCE data. The experimental results showed that both FM and BM could par-

Table 1. Proximate composition of prospective NCFs from the Machakos District.

Common name	Botanical name	DM (%)	Dry-matter basis (%) Crude protein	Crude fibre	Ether extract	Ash	Nitrogen free extract
Cereals/cereal by-products							
Bulrush millet	*Pennisetum typhoides*	87.61	15.78	4.22	3.40	2.32	74.28
Finger millet	*Eleusine coracana*	89.82	9.30	6.45	2.59	4.86	76.80
Sorghum	*Sorghum vulgare*	90.74	12.45	4.15	5.97	1.78	75.65
Root crops							
Cassava meal	*Manihot esculenta*	96.52	3.00	0.70	3.28	2.52	90.50
Cocoyam meal	*Colocasia esculenta*	95.24	2.90	0.74	3.45	4.95	87.96
Yellow-yam meal	*Dioscorea cayenensis*	98.89	5.34	5.39	0.80	3.93	84.54
Pulses							
Pigeon peas	*Cajanus cajan*	88.40	26.35	8.30	1.44	3.00	60.91
Cowpeas	*Vigna unguiculata*	89.71	25.52	8.73	3.01	4.49	58.25
Chick-peas	*Cicer arietinum*	92.73	21.97	9.40	1.61	5.10	61.92
Field beans var. Canadian Wonder	*Phaseolus vulgaris*	88.59	27.47	11.69	1.57	4.47	54.80
Field beans var. Rose Coco	*Phaseolus vulgaris*	92.00	23.65	6.60	1.62	4.65	63.48
Field beans var. Mwezi Moja	*Phaseolus vulgaris*	91.95	23.62	6.28	2.04	5.23	62.83
Fruit-seed meals							
Orange-seed meal	*Citrus aurantium*	92.72	18.80	34.34	41.04	3.57	2.25
Lemon-seed meal	*Citrus aurentifolia*	93.96	20.46	31.78	39.35	2.65	5.76
Passion-seed meal	*Passiflora edulis*	92.30	11.61	55.54	22.26	2.12	8.47
Mango-seed meal	*Mangifera indica*	88.2	8.5	2.8	8.9	5.4	74.4
Gourd-seed meal	*Cucuroita* sp.	93.45	33.71	6.74	50.53	5.56	3.46
Green-banana meal	*Musa paradisiana*	92.90	5.42	4.16	2.60	7.65	80.17
Leaf meals							
Amaranthus meal	*Amaranthus* sp.		27.3	12.43	2.86	9.4	48.01
Cassava-leaf meal	*Manihot esculenta*		24.20	16.9	6.5	9.0	43.40
Cocoyam-leaf meal	*Colocasia esculenta*		23.22	13.16	8.14	11.21	44.27
Potato-leaf meal	*Solanum tuberosum*		17.23	9.60	5.91	9.86	57.40
Cowpea-leaf meal	*Vigna unguiculata*		31.84	15.28	7.32	12.18	33.38

tially or completely replace maize up to a level of 60% with no significant changes in weight gain or FCE values (Table 2).

From the assays to determine proximate composition of the BM varieties, it was found that BM had a protein content of nearly 16%, compared with 9.5% for FM. The consistently better growth responses recorded with BM feeds could very well be attributed to the higher protein contribution of the BM. Purseglove (1972) noted that BM protein was a good source of most essential amino acids, except lysine. In extending the nutritional evaluation of BM, experiments were conducted to assess the nutritional quality of BM protein and whether or not it would be possible to increase acceptability levels of BM to take advantage of the increased protein contribution, thus reducing the need for protein supplementation. Also, could BM be used as a protein supplement? The results of these experiments are shown in Table 3. At the 70% level, and supplemented with 0.3% lysine, BM could satisfactorily replace part of the protein supplement requirements, and thus was an excellent NCF to be developed, because it had not only high potential as an energy source but also the advantage of contributing protein.

Cocoyam meal (CYM) was the other energy NCF selected for further study and development. In studying the nutritional characteristics, it was found that this yam meal has many nutritional peculiarities, which posed many problems and still remain unresolved.

Raw CYM (sliced and dried) was unable

Table 2. Effects of substituting bulrush millet (BM), finger millet (FM), cocoyam meal (CYM), and cassava meal (CSM) for maize (MZ).

NCFs	Body-weight gain (g)	Feed-conversion efficiency
0–8 weeks		
60% MZ	1594	2.32
Finger millet		
20% FM	1593	2.42
40% FM	1566	2.41
60% FM	1585	2.51
Mean	1580	2.48
Bulrush millet		
20% BM	1595	2.36
40% BM	1674	2.37
60% BM	1677	2.31
Mean	1649	2.35
0–4 weeks		
Cocoyam meal		
60% MZ	560[a]	1.99[a]
29% CYM	388[c]	2.47[b]
58% CYM	261[d]	3.40[c]
Cassava meal		
29% CSM	520[ab]	2.09[ad]
58% CSM	481[bc]	2.37[ad]

NOTE: Values followed by the same superscript are not significantly different ($P<0.05$).

Table 3. Effects of supplementing bulrush millet (BM).

NCF supplement	Body-weight gain (fed 0–4 weeks) (g)	FCE
40% BM	619	2.04[ab]
55% BM	591	1.98[bc]
70% BM	569	2.10[a]
70% BM + 0.3% Lysine	610	1.94[cd]

NOTE: Mean values followed by the same superscript are not significantly different ($P<0.05$).

to support growth when partially or wholly replacing maize. Growth depression was severe, up to 31% and 53% when CYM replaced 50 and 100% of the energy from maize in starter feeds. Likewise, FCE values of 2.47 and 3.40 were recorded when CYM was partially or wholly substituted for maize, compared with a FCE of 1.99 for the maize control diet (Table 2). It was, however, interesting to note in comparable treatments that cassava meal at similar substitution levels showed acceptability when partially or wholly substituted for maize. The disappointing performance of CYM indicated that further investigation would be needed. Gohl (1975), Onwueme (1978), and Kay (1973) have shown that the needle-shaped raphides occurring in CYM are crystals of calcium oxalate and that the levels of oxalate could be as high as 0.4%. Gohl (1975) and Lyn et al. (1967) maintain that cooking reduces oxalate irritation and supplementary levels of calcium decrease the antinutritional effects of oxalates.

In attempts to improve the utilization value of CYM, experiments were conducted subjecting CYM to simple-peeling or wet-thermal processing techniques. Removal of the peel or wet-thermal processing at 100°C for 1 hour had no significant effect on utilization value of CYM fed at half substitution of maize in starter feeds (Table 4). In true metabolizable energy (TME) assays (procedure of Sibbald 1976) conducted with CYM, there were indications of considerable improvement up to 50% of the TME value when CYM was autoclaved at 121°C and 1.05 kg/cm^2 pressure for 15 min.

When raw CYM was supplemented with calcium carbonate at levels of 1.0–2.0%, there was an increased growth response by 30%, showing a positive response to calcium supplementation in overcoming the antinutritional effect of the high oxalate content of CYM. Higher levels (3–4%)

Table 4. (a) Effects of processing cocoyam meal (CYM).

NCF	Processing method	0–4 weeks BWG (g)	0–4 weeks FCE
29% CYM	Raw	606	1.74
29% CYM	Peeled	583	1.80
29% CYM	Wet thermal (100°C/1 hour)	580	1.74

(b) Effects of supplementing cocoyam meal (CYM).

NCF	Supplementation	BWG (g)	FCE
58% CYM	None	367[b]	2.57[b]
58% CYM	1% $CaCO_3$	479[c]	2.23[a]
58% CYM	2% $CaCO_3$	470[c]	2.17[a]
58% CYM	3% $CaCO_3$	441[c]	2.35[ac]
58% CYM	4% $CaCO_3$	387[b]	2.48[bc]

NOTE: Mean values followed by the same superscript are not significantly different ($P<0.05$).

of calcium-carbonate supplementation depressed growth (Table 4).

It is clear from the feeding trials that the major constraint in developing CYM as an energy NCF is that simple processing methods are not adequate to improve the digestibility of the CYM starch. Szylit et al. (1979), in a study of tuber meals, showed that the utilization value was directly related to the size of the starch granules. Of the tubers studied, cassava had the smallest starch granule (<1–2 μm) and was the most highly digestible. The low digestibility of the CYM starch is likely to be related to the large size of the CYM starch granules.

Protein NCFs

Of the protein NCFs that were selected for development, pigeon peas showed the most promise and, therefore, were studied in more detail. The pigeon peas tested had a crude protein content of 22%. According to Khan and Rachie (1972), the crude-protein content can range from 20–28%. Sohonie and Bhandarkar (1954) and Tawde (1961) were the first to report the presence of trypsin inhibitors in pigeon peas. However, the trypsin inhibitor content of pigeon peas is reported to be much less than in the other grain legumes (Leiner 1973).

In the initial acceptability trials, raw pigeon peas were fed at levels of 0, 10, 15, and 20% of the feed, as partial replacement of soybean meal in standard starter feeds. The results showed that raw pigeon peas appear to be tolerated up to levels of 15% in the diet without any adverse effect on weight gain or FCE. At levels greater than 20%, pancreatic hypertrophy by nearly 12% was evidenced (Table 5). Thus, raw pigeon peas were limited in use because of the trypsin inhibitor content, even though present at low levels.

Dako (1966) demonstrated with rats that cooking improved the nutritive value of pigeon peas and reduced hyperactivity of the pancreas. In another set of experiments, the effects of wet-thermal processing on improving acceptability levels of pigeon peas were studied. Pigeon peas autoclaved at 121°C and 1.05 kg/cm^2 pressure for 15 and 30 min or steam blanched were included at the 20% level in test feeds. Although processing by autoclaving or steaming had no significant effect on improving the utilization value, autoclaving of the pigeon peas for 15 min appeared to show some benefit (Table 5). The experimental data tend to agree with previous findings that the trypsin inhibitor in pigeon peas is resistant to heat inactivation (Tawde 1961).

Table 5. (a) Effects of substituting pigeon peas (PP) to test acceptability levels.

NCF	Fed 0–5 weeks: BWG (g)	FCE	Pancreas weight (mg/g)
10% PP (raw)	853^{ab}	1.96^{a}	2.87^{b}
15% PP (raw)	857^{ab}	2.00^{a}	2.95^{b}
20% PP (raw)	807^{b}	2.10^{b}	3.23^{c}
MZ/Soybean (control)	882^{a}	1.94^{a}	2.20^{a}

NOTE: Mean values followed by the same superscript are not significantly different ($P<0.05$).

(b) Effects of processing pigeon peas (PP) and fed over marginally acceptable levels.

NCF	Processing method	BWG (g)	FCE	Pancreas weight (mg/g)
20% PP	Raw	605	2.23	3.61
20% PP	Autoclaved (15 min)	638	2.06	3.43
20% PP	Autoclaved (30 min)	584	2.12	3.26
20% PP	Steamed	591	2.20	3.58

Mtenga and Sugiyama (1974) and Ahmad and Shah (1975) have shown that sulfur amino acids and L. tryptophan are the most limiting amino acids in pigeon peas. In addition, it has also been established that the methionine requirement increases due to methionine losses resulting from increased pancreatic secretion, known to be high in sulfur amino acids. Improvement in the nutritive value of pigeon peas was tested by supplementing the raw or processed pigeon pea diets with DL methionine at 0.2% or DL methionine at 0.2% and L tryptophan at 0.1%. The results (Table 6) showed that the autoclaved pigeon peas with DL methionine and L tryptophan supplementation improved weight gain by 17% over the unsupplemented form. Also, autoclaved pigeon peas unsupplemented or supplemented with DL methionine showed a slight improvement in weight gains over comparable treatments with raw pigeon

Table 6. Effects of processing or supplementing pigeon peas (PP).

NCF	Processing method	Amino-acid supplementation	0–4 weeks	
			BWG (g)	FCE
20% PP	Raw	None	531[a]	2.17[a]
20% PP	Raw	0.2% DL methionine	546[ab]	2.09[ab]
20% PP	Raw	0.2% DL methionine + 0.1% L tryptophan	558[ab]	2.08[ab]
20% PP	Autoclaved	None	589[bc]	2.21[a]
20% PP	Autoclaved	0.2% DL methionine	588[bc]	1.98[ab]
20% PP	Autoclaved	0.2% DL methionine +0.1% L tryptophan	621[c]	1.86[ab]

NOTE: Mean values followed by the same superscript are not significantly different ($P<0.05$).

peas. Thus, pigeon peas appear to be acceptable as a protein NCF at levels up to 15%. There is evidence of enhancement of nutritive value with autoclaving at 121°C and 1.05 kg/cm^2 pressure for 15 min or autoclaving and supplementation with DL methionine and L tryptophan. Supplementation levels could be waived or modified depending upon the complementary protein supplements available for inclusion in practical diets.

NCFs in Practical Feeds

Because most of the screening, analytical tests, acceptability trials, processing, and supplementation trials were conducted under controlled conditions and in standard test feeds, the final feasibility tests had to be carried out under field conditions. Promising NCFs were formulated into practical feeds and feeding trials were conducted in the environs of the small-scale farmer.

Selected NCFs were included in practical formulations in various feasible combinations, taking into account their nutritional constraints; the major objective being to maximize levels of both energy and protein NCFs to replace their conventional counterparts. The compositional levels of the NCFs used (BM, PP) in one of the experiments is given in Table 7. The BM was used to replace maize in part (nearly half) or in full. The protein NCF, pigeon peas, was included at a marginally acceptable level of 15% in the form of raw, processed, raw and supplemented, or processed and supplemented. The growth response showed that

Table 7. Performance of NCFs in practical broiler feeds in field feeding trials.

Feed composition (%)				Performance of NCF (0–4 weeks)	
Maize	Basal protein supplement[a]	Energy NCF (BM)	Protein NCF (PP)	BWG (g)	FCE
60	26	0	0	752[a]	1.75[a]
30	17	30	0	750[a]	1.87[ab]
0	15	60	0	766[a]	1.93[ab]
50	21	0	15 (raw)	722[a]	2.00[bc]
0	9	50	15 (raw)	660[b]	2.48[c]
25	15	25	15 (raw)	673[b]	1.93[b]
25	15	25	15 (processed)	694[a]	2.10[bc]
25	15	25	15 (raw) + (lysine (0.2%) + DL methionine (0.2%))	735[a]	1.83[ab]
25	15	25	15 (processed) + (lysine (0.2%) + DL methionine (0.2%))	795[a]	1.73[a]

NOTE: Mean values followed by the same superscript are not significantly different ($P<0.05$).
[a] Combination of soybean meal and cottonseed meal.

with 25–60% substitution of maize with BM and 15% substitution of pigeon peas supplemented with lysine and methionine, the NCFs provided generally satisfactory growth and FCE values, compared with the conventional maize/soybean meal control. The best responses, however, were obtained with BM substituted for maize at levels of 30 or 60% and in treatments supplemented with lysine and methionine.

Recommendations

From the studies described, the following recommendations emerge. Bulrush millet can very effectively replace maize, in whole or in part, in starter feeds. Some varieties of bulrush millet having a protein content of about 15% can be used at higher levels to partly replace protein supplements. The protein value of bulrush millet is greatly enhanced when supplemented with up to 0.3% lysine. Finger millets have also proven to be an efficient energy NCF in starter feeds and could serve as a feasible alternative to maize in marginal areas. With respect to cocoyam meal as an energy source, further investigations and studies have to be conducted to develop processing methods to improve the digestibility of the cocoyam starch. Calcium-carbonate supplementation is indicated to overcome the high oxalate content in these yams.

In the case of the protein NCFs studied, raw pigeon peas can be recommended for use in starter feeds as a protein supplement up to a level of 15%. Autoclaving the pigeon peas at 121°C and 1.05 kg/cm^2 for 15 min tends to improve nutritive value. Supplementing pigeon peas (particularly the autoclaved form) with 0.2% Dl methionine and 0.1 L. tryptophan greatly improved the protein quality of the pigeon peas.

In practical feeds, NCF combinations of 25% BM and 15% pigeon peas supplemented with 0.2% lysine and 0.2% DL methionine can effectively substitute for up to 40% of the conventional energy and protein sources. The prospect of increasing the NCF levels up to 60% appears promising.

The studies reported here covered a rather narrow aspect of the NCF possibilities in a selected region. There is a need for more intensive studies in the region itself and expansion of the project to more farming areas. The potential for development of NCFs appears to be unlimited.

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Research Experiences in the African Research Network on Agricultural By-Products (ARNAB)

A.K. Mosi and L.J. Lambourne[1]

Approximately 70% of the livestock in Africa depend on crop residues for part of their nutrition during the dry season and this dependency is expected to increase. Although zonally oriented, African researchers are intensively exploring the possibilities of improving the nutritional value of the coarse crop residues popularly cultivated in their zones.

The African Research Network on Agricultural By-Products (ARNAB) was formed to foster professional contacts, widen training opportunities, encourage the sharing of ideas, and promote standardized technical procedures and applications among scientists involved in studying the use of crop residues for livestock nutrition.

Research achievements and future goals of some ARNAB members have been cited to illustrate the diversity of investigations currently being pursued in Africa and the need to share the results with other researchers.

Environ 70 % du bétail de l'Afrique dépend des résidus de récoltes pour une partie de son alimentation au cours de la saison sèche et cette dépendance devrait encore s'accroître. Bien que leurs travaux soient limités à certaines zones, les chercheurs africains sont en train d'explorer intensivement les possibilités d'améliorer la valeur nutritive des résidus des récoltes bruts disponibles dans leurs régions.

Le Réseau africain de recherches sur les sous-produits agricoles (RARSA) fut formé dans le but d'accroître les possibilités de formation, d'encourager les contacts professionnels et les échanges d'idées et de promouvoir, parmi les hommes de science effectuant des études sur l'utilisation des résidus de récoltes pour l'alimentation du bétail, la standardisation des techniques et de leurs applications.

Les résultats de recherches, ainsi que les objectifs de certains membres du RARSA ont été cités afin de montrer la diversité des efforts de recherches actuellement poursuivies en Afrique et la nécessité de faire connaître les résultats de ces recherches à d'autres chercheurs.

Aproximadamente un 70% del ganado africano depende de los residuos agrícolas para parte de su alimentación durante la estación seca. Para el futuro se espera que esta dependencia aumente. Con una orientación hacia sus áreas respectivas, los investigadores africanos estudian asiduamente las posibilidades de mejorar el valor nutricional de los residuos agrícolas de cultivos comunes en estas zonas.

La Red Africana de Investigación en Subproductos Agrícolas (ARNAB) fue constituida para fomentar los contactos profesionales, ampliar las oportunidades de capacitación, estimular el intercambio de ideas y promover los procedimientos y aplicaciones técnicas normalizadas entre los científicos que estudian el uso de los residuos agrícolas en la alimentación del ganado.

Se mencionan los logros investigativos y las metas futuras de algunos miembros de ARNAB para ilustrar la variedad de las investigaciones en curso en Africa y la necesidad de compartir los resultados con otros investigadores.

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It has been estimated that there are about 140 million cattle in tropical Africa. For part of the year, approximately 70% depend upon crop residues and, with the extension of cereal production into even marginal grazing lands, this dependence is expected to increase. Although crop residues are nutritionally low in quality, they are the only feed resources available during the dry season, at which time the limited natural vegetation is of even lower quality. This is particularly true in emerging mixed-farming systems, e.g., Ethiopia, where about 80% of the total feed resource is provided by crop residues and stubble grazing.

Because this situation is important throughout Africa, the International Livestock Centre for Africa (ILCA) has accepted responsibility for maintaining an expanded information network on crop-residue improvement, covering a number of African countries with a wide variety of cropping and livestock-production systems. This paper highlights the objectives and research experiences of the African Research Network on Agricultural By-Products (ARNAB) and what, in the opinion of ILCA, appears to be an acceptable and practical approach to such studies for easy adoption by vast numbers of rural farmers.

Crop-Residue Research in Africa: A Brief Summary

Africa is a vast continent endowed with myriad climatic conditions suitable for the cultivation of almost all known crops. Emphasis in crop-residue research, therefore, varies from zone to zone, depending upon the crops grown and the livestock they are intended to feed.

The cattle industry in the East African highlands produces milk, meat, and power for animal traction. Under the traditional system (e.g., Ethiopia), available crop residues are sufficient to maintain one local cow and a pair of oxen per farming household. In order to fulfill the demand for increased milk production and traction, crossbred cattle have been introduced that can produce a minimum of 1800 L per lactation and work at least 4 hours. (Local cows produce about 200 L per lactation. A local mature ox weighs 250 kg compared with 400 kg for a Fresian–Borana crossbreed.) Concentrates or nonpasture supplements of higher nutritive value are not available in adequate quantities. As a result, it has been necessary to study the possibilities of improving the feed value of cereal straws and other by-products. At its headquarters in Addis Ababa, ILCA has established a research project on crop-residue improvement and utilization. Simple, adaptable, on-farm procedures involving slaked lime and fertilizer-grade urea are being devised as treatment alkalis for the degradation of lignocellulose fractions in cereal straws. Straw treatment with commercial-grade slaked lime is carried out in empty oil barrels containing the appropriate solutions for periods ranging from 24–72 hours. The treated straw (contained in wire-mesh baskets) is allowed to drain for about 90 min and is fed after 1-day's drying in the sun.

Urea solutions are dispensed by means of garden-watering cans. The appropriate solutions are sprayed on preweighed straw at a rate of 1 L/kg straw. Ensiling takes place in pits lined with plastic sheets.

These techniques require very simple inputs and are likely to be affordable to rural farmers owning one or two plow oxen, one dairy cow, and about five small ruminants.

The target group is, hence, the arable farmer who keeps oxen for plowing the farm, some dairy cattle to supply milk to the household, and some small ruminants for cash sales to meet emergency cash needs.

Biological treatments with lignin-degrading enzymes or fungi are also envisaged in the near future. The use of yeasts and fungi that can preferentially grow on lignin is a subject of intensive research in recent years. Although no definite breakthrough has yet been developed, techniques that entail simple inoculation of piles of straw for later use are likely to catch on with small-stock owners because labour inputs would likely be minimal. Preliminary results indicate that both the intake and digestibility of tef (*Eragrostis tef*) straw, oat straw, and mixed legume haulms are approximately doubled when such straws are ensiled for 3–6 weeks with 4% (weight/volume) fertilizer-grade urea. Sheep fed on the ensiled product gained 80 g/day during the 21-day experimental period. The improvement in nutritive value when local straws are sprayed with up to

4% urea and fed without ensiling is also being assessed.

Although less-startling results have been obtained when such products are soaked in 10% calcium hydroxide for 24 hours, the lignocellulose components appear to be digested better after the treatment. Similar research has been conducted elsewhere in Africa.

In 1975, a collaborative research project was established with the Universities of Norway, Nairobi, and Dar es Salaam. Available reports (Urio 1977; Kategile and Frederiksen 1979; Kategile 1980, 1981a,b; Kiangi 1981; Tubei and Said 1981; Sundstøl 1981) indicate that most of the cereal by-products and coarse grasses in Kenya and Tanzania are improved in nutritional quality when treated with sodium hydroxide, anhydrous ammonia, urea, or Magadi soda (a naturally occurring deposit of sodium sesquicarbonate salt). Some of the technologies evolved can be applied at the farm level (Kategile 1980).

In contrast, most of the studies conducted in West Africa have centred around the use of crop by-products such as cocoa pods and cassava peels (Adeyanju et al. 1975, 1976; Smith and Adegbola 1981), milling by-products (Dia N'dumbe 1981), and agroindustrial by-products (Adebowale 1980; Adebowale and Ademosun 1981; N'diaye et al. 1981). These studies were given a tremendous boost in 1978 when the Food and Agriculture Organization of the United Nations (FAO), in collaboration with several research centres in Cameroon, Nigeria, and Senegal, established a study network to explore methods of minimizing competition between humans and livestock for food.

At the national and institutional levels, various researchers in West Africa are experimenting with livestock rations based on crop processing by-products (Ouandaogo 1981; Diallo 1981; Soro Tiorna 1981; Pessinaba 1981; Kesse and Donkoh 1981).

The African Research Network on Agricultural By-Products (ARNAB)

Considering the diversity of crop-residue studies being pursued in Africa, there is a clear need to foster professional contacts and share information and technical procedures. At a workshop organized by ILCA and the Association for the Advancement of Agricultural Sciences in Africa (AAASA), held in Douala in 1979, 52 scientists recommended that ILCA form a network of scientists involved in research on the use of crop residues for feeding livestock. A similar request was tabled by the 68 scientists who convened in Arusha, Tanzania, in January 1981 to discuss the utilization of low-quality roughages in Africa. Finally, at a conference organized by FAO, in collaboration with ILCA, held in Dakar in September 1981, it was decided that ILCA, in collaboration with FAO, would extend the network to all African countries.

The priorities of network member countries include: organizing an inventory of primary agricultural by-products (based upon official statistics) and determining the dry-matter production based upon extraction percentages; tabulating the feed value of all residues studied; conducting research, based upon appropriate technology, to obtain additional data on the nutritive value of existing crop residues; investigating the seasonal availability of local crop residues and by-products; assessing the location of crop residues or by-products versus that of livestock-production schemes; determining alternate beneficial disposal avenues (e.g., biogas production, foreign-exchange earning capacity) in relation to existing and future livestock enterprises; and determining haulage costs.

The specific activities of the network include: identifying scientists engaged in research in these fields; encouraging interdisciplinary solutions to the problems associated with farming-systems development; encouraging information sharing through letters, a newsletter, biennial and bilingual workshops, and country visits by the network coordinator; and supplying minor pieces of equipment when necessary for specific studies.

Proposals for research approaches were discussed and it is hoped that FAO will organize a group of experts to establish guidelines for research.

Publication of the ARNAB newsletter began in July 1981. It is hoped that the financial difficulties under which the network is currently operating will be short-lived, enabling ARNAB to thrive and fulfill its objectives.

Other Approaches to Crop-Residue Use: ILCA's Current Views

Chemicals such as sodium hydroxide and anhydrous ammonia are not only dangerous poisons in inexperienced hands, but they can also be hazardous environmental pollutants. Available technologies involving these alkalis for crop-residue amelioration, although suitable for industrial plants in advanced countries, are not applicable to small farms in Africa.

With or without other treatment, some cereal straws improve tremendously in nutritive value when fed with green legumes (Coxworth and Keran 1981). It appears logical, therefore, to encourage intercropping of suitable legumes with cereal crops so that the post-harvest, standing straws can be grazed in situ along with the legumes. This would offer the advantage of improving soil fertility both through nitrogen fixation (by the legumes) and the animal droppings. Labour availability permitting, this approach is simple enough for immediate on-farm adoption, especially in monocultures such as sorghum, oats, maize, wheat, and barley. There are, however, some instances where intercropping with legumes may not be practicable, e.g., in tef stands or in some parts of West Africa where up to 52 crop combinations are found on the same farm (Charreau 1974). Here, it is suggested that some alternate provision be made to grow green feed separately and then feed it to animals with treated or untreated straws. Where residue treatment is envisaged, it would appear advisable to concentrate on the use of calcium hydroxide or fertilizer-grade urea.

Conclusions

To increase the number and quality of livestock to meet the ever-growing demand in Africa for more milk, meat, and livestock products, and to bridge the dry season feed gap for over 75% of African livestock, feed resources other than the dwindling area of unimproved grazing lands must be found. Zonally-oriented, intensive, continuing studies on the use of cereal straws, crop by-products, and agroindustrial by-products for livestock nutrition are being undertaken throughout Africa. These studies involve the use of alkalis in treating cereal straws (East Africa) or the incorporation of cash crop by-products (cocoa pods, groundnut shells, cassava peels) in complete livestock rations (West Africa). ARNAB was formed to foster professional contacts, widen training opportunities, and encourage the sharing of information on technical procedures and applications.

The scope of current studies on crop residues could be widened by the introduction of green legumes into existing farming systems (where applicable) for in situ grazing by livestock of both legumes and standing hay. This would not only extend the grazing period but would be easy to adopt and would improve the fertility of arable lands.

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Session III Discussion: Research Results

The discussion focused on a small number of specific themes that were felt to represent the main topics of the papers presented by Drs Said and Gomez.

In attempting to define nonconventional feedstuffs (NCFs), it became apparent that it is a difficult matter, and it was felt that a description is preferred, describing a NCF as one that is not normally used as a feed for a certain class of livestock in a particular locality. It was further agreed that in the description of NCFs consideration should be given to quantities produced and their alternative uses, especially as human feeds.

The relationship between level of inclusion of by-products in diets and level of productivity was another topic that was discussed. In view of the fact that the various by-products used as livestock feeds have specific limitations of low nutrient contents, imbalance of nutrients, low digestibility, and low voluntary feed intake, they naturally act as diluents when fed with concentrates. At low levels of incorporation, i.e., $<50\%$, they exert less influence on animal performance than at higher levels of inclusion. Furthermore, the benefits of processing, such as alkali treatment, are felt only when low-quality roughages are included at levels of $>60\%$. The negative influences of low-quality roughages can also be offset by the supply of limiting nutrients, e.g., minerals and vitamin A. It was also noted that when low-quality roughages are fed to ruminants the animals may not perform at their maximum level. It was, however, agreed that maximal production levels may not necessarily be optimum and thus the merits and demerits should be judged in the context of optimum resource use, objectives of the undertaking, and socioeconomic benefits.

With respect to the relationship between technological innovations and the user, it was felt that the motives of research activities varied a great deal, e.g., scientific inquiry, testing of technology established elsewhere, and research to solve specific production problems. It was noted that in the developing countries the need for applied research is eminent. Furthermore, for research activities to be appropriate, an understanding of the socioeconomic and technological levels of the farmer is a prerequisite for testing relevant technological innovations. It was also realized that there are organizational (structural) and functional problems that make it difficult for researchers to exchange information with users in order to become aware of their needs and gain their confidence.

To identify users of technological innovations and facilitate the planning of applied research, it was felt important to define the beneficiaries of technological innovations. The basis for identifying the users or target should include farm size, climate, soil type, nature of the enterprise, objectives, and resource base. Alternative resource uses should also be covered.

In evaluating research activities, information accumulated during the execution of the research can be used. Because ideas develop and socioeconomic aspects change with time, it was felt that researchers should evaluate their research activities and their objectives to suit an ever-changing situation, e.g., changes in prices of inputs such as NaOH may change the feasibility of alkali treatment of roughages, as pointed out in Dr Said's paper.

The study by Dr Gomez is geared toward the use of cereals, root crops, and pulses that are not normally included in Kenyan poultry feeds. These are produced by small-scale farmers and this work is relevant to the objective of commercialization of the small-scale farmers. Two important aspects came out of this work: identification of high-potential crops and optimization of their use in poultry rations.

ILCA and ARNAB

Some confusion was caused by the apparent contradiction between ILCA's research programs in several African countries and ILCA's support, through ARNAB, of research into locally important crop residues or by-products. It was made clear that ILCA's research was essentially system-based, and included several production systems where crop residues or by-products were grazed by pastoralists' cattle. ILCA was also investigating the introduction of legumes to improve the utilization of the crop residues or as a high-quality supplementary feed and to improve soil fertility by the nutrients returned through the cattle. In other production systems, ILCA was using legume introduction and intercropping with legumes, as well as chemical treatment of straws, and supplementary feeding with urea/molasses/minerals or cotton or peanut cake to improve cattle productivity on low-quality crop residues or pastures.

ILCA's support of ARNAB was a separate function and the training, workshops, and research proposed within ARNAB would cover the whole field of treatment and utilization of crop residues and by-products on a national basis. ILCA's overall plans for future research included, as a major theme, the close interdependence of cropping and livestock production systems. ILCA's interest in residue and by-product utilization would increase steadily over the next few years.

Examples were cited of the use of legumes in the tropics and a question was raised about leucaene feeding levels to avoid mimosine toxicity. Experiences in Australia under a variety of production conditions were mentioned along with experiences in Indonesia and Trinidad that showed no major problems, especially when other feed sources were available in adequate quantities. The well-known rule of thumb of not using more than one-third of the total dry matter from leucaene was also mentioned, although the possibility of utilizing higher levels was also raised because in Indonesia ruminants appear to have resistance to the toxic effects of mimosine.

Comment

The following comment was made by L.J. Lambourne on other approaches to crop-residue and by-product use.

Conclusions from Australian Experience

The chemical treatment of low quality by-products or pelleting of feeds seems to be uneconomical except under the semi-industrialized conditions of large-scale feedlots or feed mills or for special purposes such as feeding animals on sea voyages. There are no national or even regional schemes for long-term fodder reserves because most producers prefer to accept the risk of occasional bad years rather than to take expensive precautions.

Individual producers make extensive use of urea combined with molasses and minerals, using the cheap and safe roller-drum method of feeding. Under Australian conditions, the most successful approach has been the inclusion of legumes in pastures to provide a "concentrate" of high-protein high-mineral content.

ILCA's Future Research

In ILCA's country programs, various by-products have been tested, e.g., cottonseed meal and urea molasses have produced good production responses in milking cows. By ensuring that only milking cows receive the supplement, the economics of this procedure is improved further. Standing rice, millet, and sorghum crop residues are the mainstay of dry season feed in many of the agropastoral zones of the Sahel; however, high-quality supplements are not available to improve their utilization and value. The traditional use of cowpea as a quality forage can probably be extended by the introduction of varieties better suited to particular areas, and the introduction of some intercropping system may help increase the amount of nitrogen fixed by the cowpea that is made available for growth of the following cereal crop. Rice straw is grazed in situ or eaten from the heaps left after threshing, and concurrent grazing of the green regrowth of herbs, forbs, and legumes may play an important role in improving the weight gains of cows at this time. ILCA currently has a program involved in studying the alkali treatment of residues such as "tef" and other cereal or legume straws, and results from the use of urea in residue treatments are being compared with those using urea as a direct nonprotein-nitrogen supplement for animals receiving the untreated materials. Because urea is the limiting material in terms of availability and cost, it is important to seek the most efficient use of the urea nitrogen, which may not coincide with the most efficient use of the cheaper and more abundant cereal straws.

It has been found that, where the customary system of land use permits farmers/pastoralists in the subhumid zone of Nigeria to reserve an area of land for their own use, it is possible for them to grow a "special-purpose" crop of, for example, *Stylosanthes* as a "fodder bank" and to use this as the cheap home-grown protein concentrate, which is essential to ensure higher production from the improved dairy cows now being introduced.

This approach may have widespread applicability in the small-holder production systems of many African countries, combined with the use of browse plants such as *Leucaena* or *Gliricidia* where conditions are suitable, both to safeguard the structure and fertility of fragile soils and to initiate a more productive livestock component. This sort of procedure is not practicable in the common grazing of purely pastoral areas, except, for example, where the local practice allows a person to reserve an area for rearing calves.

Current ILCA studies of different forms of land tenure and occupancy make it possible to look forward to rangeland management methods involving pastoralist agreement to some control of grazing intensity. This could exploit the proven benefits of heavier grazing in the early wet season in some areas, which implies deferment of grazing in other areas and the possibility of introducing legumes into the latter areas by a cheap, large-scale method such as aerial sowing of pelleted inoculated seed.

Thus, ILCA is looking increasingly toward the possibilities of introducing appropriate legumes into many livestock- and crop-production systems. This is a proven technology, and there is now available a wider range of genetic material than ever before, with possibilities of further advances at least as great as those already made by plant breeders in the cereal-improvement programs of the past 20 years. We hope, therefore, to make this a major theme of ILCA's future research whenever livestock-production systems permit, and to make this a major part of our work in the utilization of crop residues and low-quality forages.

RESEARCH METHODOLOGY

An Overview of Research Methods Employed in the Evaluation of By-Products for Use in Animal Feed

Berhane Kiflewahid[1]

The nutritive value of low-quality agricultural and agroindustrial by-products can be improved by utilizing various processing methods involving physical, chemical, and microbiological treatments. This paper provides a review of various treatment approaches, analytical methodologies used, and results achieved in research projects in Bali, Egypt, Guatemala, and the Sudan. Several physical-treatment processes, such as grinding, chopping, pelleting, drying, soaking, percolation, extraction, and high pressure – high temperature steam, were used to increase digestibility and voluntary intake by ruminants. In these studies, physical treatments were used primarily as first-stage processes for subsequent chemical and microbiological treatments and in the preparation of complete by-product-based rations for ruminants. Chemicals used in these studies include sodium hydroxide (NaOH), calcium hydroxide ($Ca(OH)_2$), aqueous and anhydrous ammonia (NH_3), urea, and acids. Microbiological (ensilage) methods were also used in bioconversion and fermentation processes of reconstituted dry agricultural by-products, such as straws, stover, and groundnut hulls, and agroindustrial by-products, such as citrus waste, pea pods, coffee pulp, pith, and sugarcane bagasse, by blending with molasses and with or without alkali treatments. Proximate-analysis values and in vitro dry-matter digestibilities were determined for various treated and untreated by-products. In vivo dry-matter digestibility, voluntary feed intake, and performance values were available from feeding trials in which treated or untreated by-products were fed with either protein, nonprotein nitrogen, energy, or mineral supplements. Based on the feeding trial results, it was demonstrated that treated by-products can be used to replace a major portion of conventional concentrates in ruminant diets. The by-product utilization research results presented in this review were mainly from laboratory-scale studies and feeding trials on experimental research stations. The technical and economic feasibility for practical application at the farm level were not adequately considered in most of the projects. Methodological approaches suggested for improving the design of applied by-product utilization research include a survey of locally available by-products, identification of beneficiaries (small scale, large scale, feed mills) and existing farming systems, and selection of potentially practical treatment approaches for studies in collaboration with different beneficiaries at the farm level.

La valeur nutritive des sous-produits agricoles et agro-industriels de basse qualité peut être améliorée par diverses méthodes de traitements physiques, chimiques et microbiologiques. Ce document est une étude des divers traitements, des méthodes d'analyse utilisées et des résultats de projets de recherches de Bali, d'Égypte, du Guatemala et du Soudan. Plusieurs sortes de traitements physiques de ces sous-produits, tels que le broyage, le hachage, la réduction en granulés, le séchage, le trempage, la percolation, l'extraction et la cuisson à la vapeur, à haute pression et à hautes températures, furent utilisées afin d'en accroître la digestibilité et le taux de consommation volontaire par les ruminants. Dans le cas de ces études, le traitement physique des sous-produits

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constituait à l'origine une première étape, devant être suivie d'un traitement chimique et microbiologique et ultimement, de la préparation de rations complètes, à base de ces sous-produits, pour les ruminants. Ces expériences ont fait appel aux substances chimiques suivantes : de l'hydroxyde de sodium (NaOH), de l'hydroxyde de calcium ($Ca(OH)_2$), de l'ammoniac aqueux et anhydre (NH_3), de l'urée et des acides. Des méthodes de traitement microbiologique (ensilage) furent utilisées pour la bioconversion et la fermentation de sous-produits-agricoles secs reconstitués, notamment les pailles, tiges et coques d'arachides moulues, et de sous-produits agro-industriels, tels que déchets d'agrumes, cosses de pois, pulpe de café, moelle et bagasse ; ces derniers furent mélangés à de la mélasse et soumis à des traitements avec ou sans alcalis. Les valeurs d'analyses approximatives et le degré de digestibilité in vitro des matières sèches de divers sous-produits traités ou non traités furent déterminés. Le degré de digestibilité in vivo des matières sèches et de consommation volontaire des aliments et les qualités respectives de ces sous-produits ont été établis à partir d'essais d'alimentation, au cours desquels des sous-produits, traités ou non traités et additionnés de protéines, de composés azotés sans protéines et de suppléments énergétiques et minéraux ont été utilisés. Les résultats de ces essais d'alimentation ont permis de démontrer que les sous-produits traités peuvent avantageusement remplacer une part importante des produits faisant traditionnellement partie de l'alimentation des ruminants. Les résultats de recherches sur l'utilisation des sous-produits qui figurent dans cette étude sont basés principalement sur des recherches en laboratoire et des essais d'alimentation effectués dans des stations de recherche. Dans le cas de la plupart des projets, la faisabilité technique et économique de l'application pratique des résultats de ces recherches au niveau des exploitations agricoles n'a pas été considérée de manière adéquate. Les méthodes et approches suivantes ont été suggérées pour améliorer la recherche appliquée en matière d'utilisation des sous-produits : établissement d'un inventaire des sous-produits disponibles localement, identification des bénéficiaires (petites et grandes fabriques d'aliments du bétail) et des systèmes agricoles en usage, et choix de techniques de traitement pratiques pouvant être expérimentées, au niveau de la ferme, en collaboration avec les différents bénéficiaires.

El valor nutritivo de los subproductos agrícolas y agroindustriales de baja calidad puede ser mejorado con métodos de procesamiento que involucran tratamientos físicos, químicos y microbiológicos. Este trabajo ofrece una reseña de los varios tratamientos y metodologías analíticas usadas, así como de los resultados alcanzados, en proyectos de investigación en Bali, Egipto, Guatemala y Sudán. Se aplicaron varios tratamientos físicos — molido, tajado, granulado, secado, remojado, colado, extractado, vapor a presión y alta temperatura — para aumentar la digestibilidad y la ingestión voluntaria de los rumiantes. Estos tratamientos fueron un paso previo a la aplicación de otros tratamientos químicos y microbiológicos y se usaron también en la preparación de raciones completas para rumiantes a base de subproductos. Los químicos empleados incluyen hidróxido de sodio (NaOH), hidróxido de calcio ($Ca(OH)_2$), amoníaco acuoso y anhidro (NH_3), úrea y ácidos. También se emplearon métodos microbiológicos (ensilaje) en la bioconversión y la fermentación de subproductos agrícolas secos reconstituidos, como paja, hojarasca, cáscara de maní, y subproductos agroindustriales, como desechos de cítricos, vainas de arverja, pulpa de café, y bagazo de caña de azúcar, mezclándolos con melazas y traándolos con o sin álcalis. Se determinaron los vallores del análisis próximo y las digestibilidades de la materia seca in vitro para varios subproductos tratados y sin tratar. La información sobre digestibilidad in vivo de la materia seca, ingestión voluntaria y valores de desempeño se obtuvo de pruebas de alimentación en que se administraron subproductos tratados o sin tratar con diversos suplementos. La prueba de alimentación demostró que los subproductos tratados pueden reemplazar una parte importante de los concentrados convencionales en las dietas de rumiantes. Los resultados de estas investigaciones provienen en su mayoría de estudios de laboratorio y pruebas de alimentación en estaciones experimentales. La factibilidad técnica y económica para su aplicación práctica en la finca, no fue adecuadamente considerada en la mayoría de los proyectos. Los enfoques metodológicos sugeridos para mejorar el diseño de la investigación aplicada sobre utilización de subproductos incluyen un estudio de los productos disponibles a nivel local, identificación de los beneficiarios y de los sistemas agrícolas existentes, y selección de los tratamientos potencialmente prácticos con el fin de realizar estudios en finacas con la colaboración de los diferentes beneficiarios.

There are a large number and variety of agricultural and agroindustrial by-products potentially available for use in livestock feed in developing countries. In almost all agricultural activities, the quantity of farm residue dry matter is equal to or greater than the quantity of products used directly as human food. Many agroindustrial residues, such as oil cakes, fish meal, meat meal, bone meal, cereal-milling residues, molasses, and others from the fruit- and vegetable-processing industries, are used directly as protein, energy, and mineral supplements in livestock diets without costly processing. The major classes of by-products from agriculture, such as straws, stalks, bagasse, legume hulls, and leaves, are not utilized efficiently due to their low digestibility and voluntary intake by ruminants. The low digestibility and intake is due mainly to their highly lignified cell wall and low protein components. Although some proportion of these by-products is traditionally used in livestock feed, fuel, construction, bedding, or for industrial purposes, large quantities are wasted.

In developing countries, it has been recognized that supplementation of livestock diets with protein and energy concentrates would not be economically feasible, particularly under small-farmer production systems. Given such constraints, the relevance of by-product utilization research involving a strong applied component cannot be overemphasized. In recent years, there has been increased research interest to improve the nutritive value of low-quality farm by-products and residues from agroindustries by utilizing different processing approaches. Many processes involving physical, chemical, and microbiological treatments have been tried on low-quality by-products (Baret 1977; Loehr 1977; Jackson 1978). The most significant effect of these processes has been on increasing the rate and extent of cellulose and hemicellulose digestion and, consequently, increasing voluntary intake and live-weight gain by ruminants. Numerous studies have also established that feeding low-quality by-product based diets supplemented with protein, nonprotein nitrogen, and mineral sources result in increased digestibility, voluntary intake, and performance by ruminants.

The purpose of this paper is to provide an overview of research methods used in the evaluation of by-products for use in animal feed. Specifically, it is intended to (1) review various research methods, the results achieved, and the potential practical benefits in developing countries; (2) assess the major problems encountered, prospects of these research methods, and their biological and technical suitability for different beneficiaries (small scale, large scale, feed mills) and users of by-product technology; and (3) identify priority and promising methodological approaches for future by-product research in collaboration with potential beneficiaries engaged in different production systems.

The Data Base

The data base for this review comes from unpublished progress reports submitted to the International Development Research Centre (IDRC) by research institutions in Bali, Egypt, Guatemala, and the Sudan. It is believed that the research approaches used by these institutions are representative of the general trend in by-product utilization research in developing countries. It should be noted that the selected projects are still in progress in most of these countries and the results, therefore, cannot be taken as conclusive.

The by-product research selected from the Sudan involved the replacement of conventional concentrates by 30% sorghum stalks, sugarcane bagasse, or groundnut hulls in diets intended for fattening steers. Some microbiological treatment studies were also conducted. In Bali, the studies focused on the replacement of natural grass by 30% by-product supplement (i.e., different levels of copra meal, cassava chips, rice bran, and hen manure). In Egypt, research has been conducted on the effect of chemical (NaOH, NH_3, urea) and microbiological (ensilage) treatments on by-product utilization and the incorporation of different levels of untreated and treated by-products into complete rations for ruminants. In Guatemala, the research was based on the detoxification of coffee pulp through physical, chemical, and ensilage methods and incorporation into complete cattle, poultry, and swine diets.

Research Methods and Results

Several treatment approaches have been tried to improve the nutritive value of low-quality by-products. A summary of the analytical methodology, by-products used, and results achieved is provided in Tables 1, 2, 3, and 4.

The chemical composition and in vitro or in vivo digestibility results in all research institutions demonstrated that agricultural and agroindustrial by-products in their "as is" form contained sufficient levels of nutrients and can, potentially, be used in ruminant and monogastric diets. Based on the various research approaches involving physical, chemical, and microbiological treatments, and by-product based complete formula feeds, the following general observations can be made.

Physical Treatments

The effect of physical treatments such as grinding, drying, soaking, pelleting, high pressure – high temperature steam, and percolation on various by-products; analytical methodology used to assess nutritive value; and results achieved are summarized in Table 1.

Grinding

The major purpose of grinding in the by-product utilization studies reviewed for this report was for preparing dry by-products, such as sorghum stalks, in chemical-treatment experiments using NaOH, NH_3, $Ca(OH)_2$, etc.; ensiling with or without additives; pelleting of by-product based ration mixtures; or incorporation into complete formula feeds in the loosely ground form. The effect of grinding on the nutritive value compared with the "as is" form has not, therefore, been studied for any of the by-products. In other studies involving grinding of low-quality roughages, it has been established that the major result of grinding was increasing voluntary intake and live-weight gain. There was, however, no effect on digestibility and in some cases a decrease was observed. In a review paper, Donefer (1977) reported that a decrease in the digestibility of ground low-quality by-products could be attributed to the increase in the rate of passage without any effect on delignification. The increased live-weight gain observed from feeding ground by-products, such as straw, may also be due to the increase in net energy value resulting from the more efficient utilization of digested nutrients by the animal (Jackson 1978) and the increase in total digestible energy intake (Donefer 1973, 1977).

High Pressure – High Temperature Steam

The effect of a high pressure – high temperature (20 PSI) steam treatment on the in vitro digestibility and total digestible nutrient (TDN) content of rice straw, corn stalks, bagasse, and pith was studied in Egypt. It was reported that the steam treatment increased dry-matter digestibility and TDN (10–30%) in all by-products studied. These findings are consistent with results reported in the literature, e.g., Donefer (1977) reviewed studies that indicate that high pressure – high temperature steam improved the in vitro and in vivo organic-matter digestibility of various low-quality by-products such as sugarcane bagasse.

Pelleting

Pelleted, complete diets containing rice straw with or without 4–5% NaOH treatment; various levels of concentrates; and other by-products, such as grape waste, date stone, pea pod, orange peel, molasses, and fat, were prepared for a digestibility and feeding experiment using sheep. The study is still in progress and, therefore, no performance data are available.

Although pelleting may not result in significant advantages in terms of increasing the nutritive value of by-products, it is preferable over the loosely ground form because it makes feed easier to handle and reduces feed losses during the feeding process.

Drying

A comparative feeding trial between an air-dried (60°C) and ensiled orange waste – pea pod mixture resulted in no significant difference in milk yield, although dry-matter intake was higher when fed in the dried form to sheep and dairy cattle. In Guatemala, it was reported that solar de-

Table 1. Physical treatments.

		Analytical methodology								
		Chemical analysis		Digestibility		Feeding trial				
								Performance		
Treatment	By-product	Proximate	Other	In vitro	In vivo	Species	Voluntary feed intake	Off farm	On farm	Results
Grinding	Sorghum stalks[a] Groundnut hulls Bagasse	X	Ca, P, Mg	X	X	Beef	X	X		Preparation for beef rations at 30% level
	Cotton stalks[b] NaOH Urea Concentrate	X			X	Sheep				NaOH and urea treatment increased digestible crude protein
Steam (20 PSI)	Rice straw[b] Bagasse Corn cobs Cotton stalks Pith	X	Volatile fatty acids	X						Increased total digestible nutrients (10 – 30%) and dry-matter digestibility
Drying (solar or mechanical)	Pea pod[b] Orange waste	X		X	X	Sheep, dairy	X	X		Compared to ensiled form, increased dry-matter intake
	Coffee pulp[c]	X	Cell-wall constituents	X	X	Beef, dairy Swine	X	X	X	Preparation for beef, dairy, and swine rations
Soaking (H_2O)	Sorghum stalks[a] Groundnut hulls Bagasse		pH Lactic acid NH_3N							Reconstitution of dry by-products for ensiling
	Molasses Sugarcane tops		Dry-matter loss							

(continued)

Table 1 concluded.

		Analytical methodology								
		Chemical analysis		Digestibility		Feeding trial				
								Performance		
Treatment	By-product	Proximate	Other	In vitro	In vivo	Species	Voluntary feed intake	Off farm	On farm	Results
Pelleting Urea (1.5%) NaOH (4–5%) $Ca(OH)_2$ (2%)	Rice straw[b] Concentrate Molasses Grape waste Date stone Pea pod Orange peel Cottonseed meal Fat	X			X	Sheep				Preparation for sheep rations
Percolation	Coffee pulp[c]	X	Cell-wall constituents Caffeine Tannin	X	X	Swine Poultry	X	X		Removed 90% caffeine
Extraction (mechanical)	Berseem leaves[b] Hyacinth	X								Produced protein precipitate for poultry and calf feed and residue for ruminants

[a] Source: Sudan by-product utilization research.
[b] Source: Egypt by-product utilization research.
[c] Source: Guatemala by-product utilization research.

hydrated or ensiled coffee pulp could be used for up to 20 and 16% of ruminant and swine diets, respectively, without causing adverse effects in terms of dry-matter and crude-protein digestibility.

Soaking (Water)

Water was added to reconstitute dry by-products, such as sorghum stalks, groundnut hulls, bagasse, and sugarcane tops, for ensiling. The laboratory study on ensilage properties (pH, organic acids) indicated that reconstituted by-products could be ensiled when blended with additives such as molasses.

Percolation

It was reported that decaffeination using water percolation removed 90% of the caffeine present in coffee pulp. In these studies, caffeine was found to be both toxic and diuretic, and caused increases in protein requirement by inducing a negative nitrogen balance when fed to monogastric animals. Ensiling coffee pulp with 6% sugarcane molasses, however, was shown to be the most appropriate method for using coffee pulp in ruminant diets.

Extraction

In Egypt, berseem (clover) and water hyacinth leaves were mechanically pressed to produce a protein precipitate that is used in poultry and calf rations. Amino acids, lysine, and methionine were added to make the protein cake a complete protein supplement. The study demonstrated that it was possible to produce 35 and 20 kg of protein cake and 100 and 80 kg dry residue from 1000 kg of berseem and water hyacinth leaves respectively. The residue remaining after extraction was dried and used in ruminant rations.

These are the major physical treatment approaches tried in the selected project countries. In all cases, physical treatments have been utilized as first-stage treatment processes, in conjunction with chemical and microbiological treatment, in the preparation of complete by-product based formula rations for ruminants. Grinding, for example, which is the major by-product physical-treatment process, was used mainly to reduce particle size for subsequent chemical treatment experiments, facilitate homogeneous ration mixing with supplements by reducing bulk, and prepare pelleted complete formula feeds for ruminants.

Chemical Treatments

The different types of chemicals used and their effect on the nutritive value of various by-products are shown in Table 2. In Egypt, several sodium hydroxide (NaOH) treatment approaches, using the original Beckman method, modified Beckman method, dry methods, and the J.F. Danish farm machine for bulk treatment, were tested. The effect of alkali level and duration of treatment on the nutritive value of by-products was also studied. Other major chemicals used in these studies included aqueous and anhydrous ammonia, calcium hydroxide, urea, and acids.

Sodium and Calcium Hydroxide ($NaOH$ and $Ca(OH)_2$)

In Egypt, several experiments on the effect of various levels of NaOH treatments on the digestibility of wheat straw, corn stover, cotton stalks, rice straw, bagasse, and corn cobs with or without urea supplementation using lactating cows, sheep, and calves were conducted. Increasing levels of NaOH (ranging from 3–12%) treatment increased in vitro dry-matter digestibility, by 28–108%, and dry- and organic-matter intake by sheep. NaOH treatment caused a decrease in crude protein, ether extract, and crude fibre but increased ash content in all by-products. No effects were observed due to treatment duration (10–25 days). In other studies with sheep, a comparison of different methods of straw treatment with NaOH and $Ca(OH)_2$ and NaOH alone supplemented with 5% molasses and 2% urea indicated that the best results were obtained with 4% NaOH and 2% $Ca(OH)_2$. Similar studies comparing 5% NaOH treated cotton stalks and wood pulp with urea-supplemented cotton stalks and wood pulp showed that the NaOH-treated diet was superior to diets supplemented with urea alone or a combination of both urea and NaOH.

In the Sudan, the in vitro dry-matter digestibility of untreated and 5% NaOH treated by-products was determined. Di-

Table 2. Chemical treatments.

		Analytical methodology								
		Chemical analysis		Digestibility		Feeding trial				
								Performance		
Treatment	By-product	Proximate	Other	In vitro	In vivo	Species	Voluntary feed intake	Off farm	On farm	Results
NaOH (5%)	Sorghum stalks[a] Groundnut hulls Bagasse			X						Increased digestibility of various by-products (3–82%)
NaOH (3,6, and 12%)	Wheat straw[b] Corn stover Cotton stalks Rice straw Bagasse Corn cobs	X	Volatile fatty acids	X						Dry-matter digestibility increased by 28, 63, and 108% at 3, 6, and 12% NaOH treatments respectively. No effect due to treatment duration. Increased ash and crude fibre were observed
NaOH (5%)	Rice straw[b] Corn stover Bagasse Pith	X	Nitrogen balance	X		Sheep	X			Increased dry-matter digestibility (4–41%). Decreased crude protein and ether extract
NaOH	Coffee pulp[c]	X	Caffeine Tannin	X						No improvement in nutritive value. No effect on caffeine content. Increased percentage ash
NH_3 liquid (3%)	Corn stover[b] Rice straw		Volatile fatty acids		X	Sheep	X	X		Increased total digestible nutrients (22%), dry-matter intake (84%), and dry-matter digestibility (45%)

Urea (2%) + NaOH (5%)	Cotton stalks[b] Wood pulp Molasses (5%)	X X	Nitrogen balance Nitrogen balance	X	Sheep	X	Increased crude protein, dry-matter intake, and organic-matter intake. Compared with urea treatment, NaOH caused higher increase in dry-matter and organic-matter digestibility and nutritive value in cotton stalks and wood pulp
Urea (1–2%)	Orange waste[b] Molasses (5%) Cattle excreta (10–40%) Bagasse (20%)		pH NH_3N Lactic acid				Good-quality silage produced based on pH, acidity, NH_3N, and volatile fatty acids
Urea (5%)	Corn stover[b]		Volatile fatty acids	X	Sheep	X	84% increase in intake and 45% in digestibility
NaOH (4%) $Ca(OH)_2$	Rice straw[b] Molasses (5%) Urea (2%)	X		X	Sheep	X	Based on dry-matter and organic-matter intake and nitrogen balance, superior to other treatment methods
$Ca(OH)_2$	Coffee pulp[c]	X	Caffeine Tannin				No improvement in nutritive value. No effect on caffeine content. Increased percentage ash
Rumen contents + NaOH (12%) in artificial rumen	Cotton stalks[b]	X			Poultry Sheep	X	Percentage protein in fibrous residue and supernatant fluid determined

(continued)

Table 2 concluded.

Treatment	By-product	Analytical methodology: Chemical analysis: Proximate	Chemical analysis: Other	Digestibility: In vitro	Digestibility: In vivo	Feeding trial: Species	Feeding trial: Voluntary feed intake	Feeding trial: Performance: Off farm	Feeding trial: Performance: On farm	Results
HCl	Rice hull[b] Rice straw Corn stover Wheat straw Bagasse Cattle excreta		pH NH_3N Lactic acid Volatile fatty acids							Good-quality silage produced with 6–10% addition of HCl-acidified molasses
Na metabisulfite (1.5%)	Coffee pulp[c]	X	Caffeine Tannin			Poultry	X	X		Improved performance in broilers
H_3PO_4	Coffee pulp[c]	X	Cell-wall constituents	X						Treated and ensiled to study effect on caffeine, tannins
$FeSO_4$	Coffee pulp[c]	X	Cell-wall constituents	X						Treated and ensiled to study effect on caffeine, tannins
Formic acid (1.5%)	Rice straw[b] Berseem Silage									Laboratory-scale treatment
Formalin (2%)	Rice straw[b] Berseem Silage									Laboratory-scale treatment
Acetic acid (1%)	Rice straw[b] Berseem Silage									Laboratory-scale treatment

[a] Sudan by-product utilization research.
[b] Egypt by-product utilization research.
[c] Guatemala by-product utilization research.

gestibilities of the dry matter ranged from a low of 25.4 to a high of 72.2% in banana leaves and tobacco residues respectively. Treatment with 5% NaOH increased digestibility of the dry matter in all by-products except groundnut hulls. The percentage increase in in vitro dry-matter digestibility ranged from 3.4 in tobacco dust to 82.1 in banana leaves. NaOH treatment showed the highest digestibility increase in by-products with low pretreatment digestibility values. NaOH treatment of low-quality by-products, such as straw, and the results achieved were similar to those presented in reports and review papers by Jackson (1978), Homb et al. (1977), Kristensen (1981), Kategile and Fredrickson (1979), Berger et al. (1980), Arndt et al. (1980), and Klopfenstein (1981).

Ammonia (NH_3)

In the Egyptian experiments, treatment of corn stover and rice straw with 3% (dry-matter basis) liquid ammonia increased dry-matter digestibility, dry-matter intake, and TDN by 45, 84, and 22% respectively. In other studies, fertilizer-grade urea (5% on a dry-matter basis) dissolved in an equal weight of water was sprayed over fibrous by-products such as corn stover. The results from feeding trials showed that ammonia released from urea caused increased digestibility (45–60%) and voluntary feed intake (60%). Increased dry-matter digestibility, voluntary feed intake, and nitrogen content of ammonia-treated low-quality roughages has also been reported (Homb et al. 1977; Jackson 1978; Sundstøl et al. 1978; Oji and Mowat 1979; Berger et al. 1980; Morris and Mowat 1980; Klopfenstein 1981).

Microbiological Treatments

Ensilage

Several studies on ensilage of dry by-products (e.g., straws and stovers) and agroindustrial by-products (e.g., citrus waste, sugarcane bagasse, and coffee pulp blended with molasses), with or without alkali treatments, have been reported. The methods used and results obtained are summarized in Table 3.

In the Sudan, laboratory-scale ensilage studies demonstrated that a mixture of reconstituted groundnut hulls and sorghum straw with 5 and 10% molasses, bagasse, and sugarcane tops could be ensiled in polyethylene bags. Based on the characteristics used to measure silage quality (i.e., pH, lactic acid, ammonia nitrogen, dry-matter loss, smell, etc.), the best-quality silage was obtained by using reconstituted groundnut hulls blended with 5% bagasse.

In Egypt, good-quality silage (pH 3.8) was produced from an orange waste, 5% molasses, 1% urea, 20% bagasse, and 10–40% cattle excreta mixture. Similar studies on wet by-products, such as citrus waste, pea pods, and artichoke leaves mixed with 5–10% molasses, demonstrated that ensiling increased in vitro dry-matter digestibility. Supplementation with 1% urea at feeding also increased dry-matter intake by sheep. Other studies on silage-making involving orange waste; rice straw; date stones; grape waste; pea pod; sugarcane bagasse; pith; 10–40% cattle excreta; berseem using 5–10% molasses, 5–10% NaOH, and 1–2% urea indicated that good silage was produced based on acidity, ammonia nitrogen levels, digestibility, and feeding trials. The results also showed that NaOH treatment followed by ensiling caused increased voluntary intake and dry-matter digestibility in sheep. A comparative study of rice straw ensiled with berseem and rice straw treated with 5% NaOH resulted in a similar performance by dairy cattle. Better results were obtained, however, from berseem-ensiled rice straw when used to fatten lambs.

In Guatemala, dehydrated coffee pulp was ensiled by blending it with 3–6% sugarcane molasses. Ensiled coffee pulp reduced toxicity due to caffeine and other nutritional inhibitors and was recommended as the best method for use in cattle diets.

Formula Feeds

The results of digestion and feeding experiments with diets containing various levels of treated or untreated low-quality by-products and concentrate supplements are presented in Table 4.

In the Sudan, complete diets containing 30% sorghum stalks, 30% groundnut hulls, and 30% sugarcane bagasse were compared in digestion and feeding experiments. The by-products were mixed with the same basal supplement (29.5, 29.5, 10, and 1% wheat bran, cottonseed cake, molasses, and salt respectively). Sheep were used in the digestion trials and cattle (Baggara bulls) in the feeding experiments. There was no appreciable difference in chemical composition between the sorghum, groundnut, and bagasse diets. The feeding experiment (124 days), using 10 bulls per treatment, indicated that voluntary feed intake, daily gain, and efficiency of feed conversion were similar for all treatments. Average dry-matter intake and live-weight gain were 7.40 and 1.14 kg/day respectively. The apparent digestibility coefficients for nutrient components, using sheep, were lower for the groundnut hull bagasse diet than the sorghum straw diet. The dry-matter digestibility value for the groundnut hull diet was 51.0%, compared with 63.9% in the sorghum stalk diet and 56.3% in the bagasse diet.

In Bali, Indonesia, a feeding trial (27 months duration) involving four different diets, based on 70% natural grass and 30% by-products (composed of various levels of copra meal, cassava chips, and rice bran with or without hen manure), and a control diet (natural pasture composed mainly of broad-leaf and grass species) was conducted. There were no significant differences in either feed intake or weight gain among the experimental diets. Average daily dry-matter intake and average live-weight gain for the 30% by-products diet were 4.66 kg and 0.32 kg/day, respectively, compared with 3.46 kg and 0.12 kg/day for the control diet. These values are significantly different.

In Egypt, several diet combinations that involved replacing the conventional commercial concentrate mix with cheaper by-products (30% date stone, 15% orange waste, 15% pea pods, 25% grape waste, 5% artichoke leaves, 5% molasses) supplemented with urea and minerals ($CaCO_3$, NaCl, mineral mix) were compared in diets fed to sheep and lactating cows. The results demonstrated that there were no differences in either voluntary intake or milk production. Similar results were obtained when rations composed of various levels of rice straw, concentrate supplement, by-product mix, and silage (orange waste – pea pod) were compared. In other studies incorporating ground rice hulls, results showed that animals performed well at a level of 20–40% when supplemented with urea. It was also shown that when diets containing 5% by-product mix (molasses, garlic waste, rice hulls) were supplemented with urea they could be used to maintain animals during periods of feed shortages. When rations containing NaOH-treated sugarcane bagasse were compared with untreated diets, it was found that the treatment increased digestibility and live-weight gain in sheep.

In Guatemala, studies demonstrated that dehydrated and ensiled coffee pulp (with 3–6% molasses) can replace 20% (DM basis) of the conventional ruminant ration and 16% of the conventional swine ration. It was demonstrated that this was the practical approach to its utilization at the farm level.

This review is based on the research results achieved from laboratory-scale studies and feeding trials. Therefore, although various ration combinations were tested, the by-product level for optimal utilization and the technical and economic feasibility for practical application were not investigated.

It can be concluded, however, that based on the results of the feeding trials using various physical, chemical, and microbiological (ensilage) treatment methods, by-products can be used to replace a portion of the expensive conventional concentrates in ruminant diets, when supplemented with protein, nonprotein nitrogen (NPN), energy, and mineral sources.

Analytical Methodology

Proximate-analysis components and in vitro dry-matter digestibility were determined for most of the by-products subjected to the various physical-treatment methods. In vivo digestibility and voluntary feed intake values were also obtained from feeding trials involving rations in which chemically treated or untreated by-products were mixed and fed with either protein, nonprotein nitrogen, or energy and mineral supplements. In studies in which chemically treated by-products were ensiled, other criteria, such as pH, ammonia nitrogen, organic acids, and dry-matter loss, were determined.

Table 3. Microbiological (ensilage) treatments.

	Analytical methodology								
	Chemical analysis		Digestibility		Feeding trial				
							Performance		
By-product	Proximate	Other	In vitro	In vivo	Species	Voluntary feed intake	Off farm	On farm	Results
Groundnut hulls[b] Sorghum straw Bagasse Sugarcane tops Molasses (5–10%) Berseem		pH Lactic acid Ammonia nitrogen Dry-matter loss							Best-quality silage (laboratory scale in polyethylene bags) obtained by using reconstituted groundnut hulls blended with bagasse
Citrus waste[b] Pea pods Artichoke leaves Molasses (5%)	X	pH Lactic acid Volatile fatty acids NH_3N	X		Sheep	X	X		Good silage (citrus waste and pea pods) produced. Addition of 1% urea at feeding increased dry-matter intake
Corn stover[b] (5%) Wheat straw (20%) Rice straw (30%) Cotton stalks (20%) Cattle excreta (10–40%) Molasses (5%) NaOH (3, 6, and 12%)	X	pH Lactic acid Volatile fatty acids NH_3N	X	X	Sheep	X	X		Nutritive value (total digestible nutrients and dry-matter digestibility) increased with increased NaOH-treated silage
Orange waste[b] Molasses (5%) Urea Cattle excreta (10–40%) Pea pods	X	pH Lactic acid Volatile fatty acids NH_3N	X						Good silage produced based on pH (3.6), NH_3N, and organic acids. Digestibility increased due to addition of urea

(continued)

Table 3 continued.

By-product	Analytical methodology: Chemical analysis: Proximate	Chemical analysis: Other	Digestibility: In vitro	Digestibility: In vivo	Feeding trial: Species	Feeding trial: Voluntary feed intake	Feeding trial: Performance: Off farm	Feeding trial: Performance: On farm	Results
Bagasse[b] (20%) Molasses (5%) Urea Cattle excreta (75%) Rice straw	X	pH Lactic acid Volatile fatty acids NH_3N		X	Sheep	X	X		Good silage produced based on pH (3.6), NH_3N, and organic acids. Digestibility increased due to addition of urea
Pea pod[b] Artichoke leaves Urea (1–2%)	X	Nitrogen balance Volatile fatty acids NH_3N		X	Sheep				Good silage produced based on pH (3.6), NH_3N, and organic acids. Digestibility increased due to addition of urea
Bagasse[b] NaOH (5–10%) Molasses (10%) Cattle excreta	X	Nitrogen balance		X	Sheep	X			Increased pH (7.4 average), NH_3N, and organic acids due to NaOH treatment. NaOH did not cause any change in chemical composition or total digestible nutrients but caused increased dry-matter intake by sheep
Pith[b] NaOH (5–10%) Molasses (10%) Cattle excreta	X	Nitrogen balance		X	Sheep	X			Increased pH (7.4 average), NH_3N, and organic acids due to NaOH treatment. NaOH did not cause any change in chemical composition or total digestible nutrients but caused increased dry-matter intake by sheep

Bagasse[b] H_2O Molasses (10%) Cattle excreta	X	Nitrogen balance	X	Sheep	X		Increased pH (7.4 average), NH_3N, and organic acids due to NaOH treatment. NaOH did not cause any change in chemical composition or total digestible nutrients but caused increased dry-matter intake by sheep
Pith[b] H_2O Molasses (10%) Cattle excreta	X	Nitrogen balance	X	Sheep	X		Increased pH (7.4 average), NH_3N, and organic acids due to NaOH treatment. NaOH did not cause any change in chemical composition or total digestible nutrients but caused increased dry-matter intake by sheep
Rice straw[b] Molasses (10%) Urea (5%) NaOH (5%)	X		X	Sheep	X		No significant effect in chemical composition or intake
Rice straw[b] (20–30%) Cattle excreta (70%) Molasses NaOH		Nitrogen balance	X	Sheep	X		Ensiling increased total digestible nutrients, digestible crude fibre, nitrogen balance, and feed efficiency
Dehydrated coffee pulp[c] Molasses (3–6%) 1.5% Na metabisulfite	X	Caffeine Tannin		Dairy, swine	X	X	Ensiled coffee pulp at 20% of the ration (dry-matter basis) was as good as grass control diet (7 kg milk/day for both)
							Ensilage recommended as the best approach to crude-protein utilization

[a] Sudan by-product utilization project.
[b] Egypt by-product utilization project.
[c] Guatemala by-product utilization project.

Table 4. Formula feeds.

		Analytical methodology								
		Chemical analysis		Digestibility		Feeding trial				
							Voluntary feed intake	Performance		
Treatment	By-product	Proximate	Other	In vitro	In vivo	Species		Off farm	On farm	Results
"As is" Ground	Sorghum stalks[a] (30%) Groundnut hulls (30%) Bagasse (30%) Concentrate (70%) Wheat bran (29.5%) Cottonseed meal (29.5%) Molasses (10%) Salt (1%)	X				Beef Sheep	X	X		Three diets based on 30% by-product and 70% concentrate did not show any significant differences in intake, gain, or carcass characteristics. Average dry-matter intake, 7.4 kg/day, and 1.14 kg/day gain were satisfactory
"As is"	Natural grass[b] (70%) Copra (5–25%) Cassava (5–15%) Rice bran (0–15%)	X		X	X	Beef	X	X		Four diet combinations (B, C, D, E) compared with natural grass (0.12 kg/day) alone caused significant weight increases. No significant difference in performance (0.32 kg/day) among steers fed experimental diet
"As is"	Natural grass[b] (70%) Copra (0–10%) Cassava (0–30%)	X			X	Sheep	X	X		Four diet combinations (D, H, F, G) compared with natural grass alone showed significant intake

	Rice bran (0–30%) Hen manure (0–10%)							and gain (0.26 kg/day) for 10% copra (D) and 10% hen manure (G) based diets. No gain for 30% cassava diet (F), 0.18 kg/day for 30% rice bran (H)
Silage + concentrate	Wastage[c] (52–74%) Molasses (17–20%) Cottonseed meal (0–25%) Urea (2.4–2.8%) $CaCO_3$ (1–2%) NaCl (1%) Mineral mixture (0.5%)	X	Nitrogen balance NH_3N Volatile fatty acids	X	Sheep	X		Four diet combinations tested. Intake and nitrogen balance favoured 52% wastage
Silage + concentrate	Wastage[c] (1–15%) By-product mix (0–5%) Concentrate (0–6%) Rice straw (7%)	X	Milk constituents	X	Dairy	X	X	Six diet combinations involving wastage and by-product mix indicated no significant difference in milk production
"As is" ground	Rice hulls[c] (35–70%) Concentrate (30–65%)		Volatile fatty acids	X	Sheep			Total digestible nutrient percentage increased with increasing rice hulls at 40% of diet for productive functions and 60% for maintenance of sheep

(continued)

Table 4 continued.

Treatment	By-product	Analytical methodology: Chemical analysis: Proximate	Chemical analysis: Other	Digestibility: In vitro	Digestibility: In vivo	Feeding trial: Species	Voluntary feed intake	Performance: Off farm	Performance: On farm	Results
Silage concentrate	Wastage[c] (pea pod – orange waste) Concentrate					Dairy Buffalo	X			Various levels of silage to concentrate produced no differences in milk production
	Pea pods[c] Orange waste Urea (1–2%)	X			X	Sheep Dairy	X	X		Comparison between dried (60°C) and ensiled pea pod – orange waste did not cause differences in digestibility or milk yield by dairy cattle. Intake by sheep and dairy cattle favoured dry form significantly. Efficiency of milk production was higher for cattle fed ensiled form
Silage concentrate	Wastage[c] (0–75%) By-product mix (0–100%) Concentrate (0–100%) Rice straw	X	Milk constituents		X	Dairy	X	X		Six diet combinations composed of different levels of pea pod – orange waste silage, by-product mix, and concentrate caused no significant difference in intake, milk yield, or milk constituents. Performance was as good as when cattle were fed concentrate alone
"As is"	Rice straw[c] concentrate	X			X	Sheep	X			Improved total digestible nutrient value for rice straw when fed with concentrate (1:1)
"As is"	Rice straw[c] concentrate Urea (1–1.5%)		Milk constituents			Dairy	X	X		No significant difference in milk yield or intake due to addition of urea

"As is"	Corn stover[c] Urea				X	Sheep	X			Comparison of moistened and urea-treated corn stover showed increased intake and digestibility by sheep for urea-treated corn stover
	Bagasse[c] (NaOH) (20–55%) Molasses (20–55%) Cottonseed meal mineral (25%) Concentrate (0–100%)				X	Sheep	X			Increased digestibility with NaOH-treated bagasse in diet. Dairy gains were also higher for treated bagasse based diet
Silage	Coffee pulp[d] (20–30%) Molasses Bagasse Cottonseed meal Hen manure Bone meal	X	pH Cell-wall constituents	X	X	Swine Beef Dairy	X	X	X	Comparative feeding trials demonstrated that dried or ensiled coffee pulp can replace 20% of ruminant and 16% of swine diets. Studies conducted on poultry and rats indicated similar results
										Concluded that, based on cost and yield, ensiling was the best approach to coffee-pulp utilization in livestock rations
Silage	Coffee pulp[d] silage Sorghum silage Concentrate Grass Sorghum grain	X				Beef Dairy	X	X	X	Concluded that, based on cost and yield, ensiling was the best approach to coffee-pulp utilization in livestock rations

[a] Sudan by-product utilization research.
[b] Bali by-product utilization research.
[c] Egypt by-product utilization research.
[d] Guatemala by-product utilization research.

Methodological Approaches for Applied By-Product Research

It has been demonstrated that many of the by-product research experiments and results conducted to date were based on limited feeding trials carried out at experimental research stations. Considerable literature discussing the effects on and performance of animals fed physically and chemically (alkali) treated agricultural and agroindustrial by-products has been produced over the last few years. However, if treatments are to be used in these studies, the cost of the treatments, treatment methods, and technical and economic aspects for on-farm application need to be tested.

As shown in this review, the applied aspect of the research has not been considered in many of the projects. A priori identification of beneficiaries is critical for determining the type of by-products and experimental approaches used in the selection of research sites (off-farm or on-farm), as well as for the final success of the projects. In addition, the economic aspects of by-product utilization were not well integrated with the biological and technical research, although this is an important component for the ultimate success of utilizing these resources.

In view of these findings, the following recommendations are suggested for improving the design and approach of by-product utilization research for animal feeding.

Survey

A complete survey of the type, quantity, availability, alternative uses, and relative cost of agricultural and agroindustrial by-products is needed. The survey should also include collection of representative samples for initial routine chemical analysis and in vitro dry-matter digestibility determination. An in-depth study can then be conducted on a few but widely available by-products by using suitable biological experimentation methods in addition to cost–benefit analysis at the user level. The survey will thus provide justification for the continuation of studies of by-products that may be widely available and accessible to the beneficiary. In the studies reviewed, although some estimates of overall quantity have been reported for some by-products, there appears to be little information on the location, cost, and availability of by-products for economic incorporation in livestock feed.

Beneficiary

The ultimate success of by-product utilization depends upon the development and application of appropriate technologies for local livestock-production systems. It is, therefore, essential to initiate and develop contacts with possible beneficiaries (small-scale farmers, large-scale farmers, or feed mills) for the purpose of demonstrating the technical and economic feasibility of by-product utilization. This will encourage initial interaction between researchers and producers and allow for rapid identification of the benefits and constraints of the research methodologies designed. Researchers could also learn more effectively from their own experience by testing the applicability of these approaches in on-farm trials.

Approach

After estimating the availability and nature of specific by-products from surveys and identifying the possible beneficiary, relevant experimental approaches need to be initiated to maximize the use of these resources in cooperation with potential users.

The approach selected has to be worthwhile to the target group, in terms of its applicability and economic benefits. If the intention is to increase productivity of animals owned by small-scale farmers, for example, it would be appropriate to design experiments that are likely to be adopted by these farmers. The design should consider components such as the technical know-how of the farmer; number and species of animals involved; labour involved and equipment required; and, most importantly, socioeconomic factors and type of agricultural-production system practiced locally.

Physical Treatments

Various physical treatments, such as chopping, grinding, pelleting, and high-pressure steam, have shown beneficial results in terms of increasing voluntary intake and performance by ruminants and monogastric animals fed on by-products.

There are limitations, however, depending upon the ultimate beneficiary of these approaches.

Chopping is potentially useful on small-scale farms for by-products such as sorghum stalks and corn stover if its advantages, compared with the "as is" form, can be demonstrated at the farm level. Chopping involves cost, however, in terms of labour, equipment, and time. The effectiveness of such an approach, therefore, needs to be studied in on-farm trials. The viability of supplementing by-product fed cattle with inexpensive energy–protein sources, such as molasses–urea, can also be investigated.

Grinding and pelleting have greater practical value for feedlot operators or feed-processing plants. This approach will produce limited direct practical value for small-scale farmers.

Steam treatment of dry by-products and percolation of coffee pulp may not be the practical approach at this stage due to the high energy and high volume of water required. These approaches, therefore, do not warrant further investigation in view of the high cost of treatment, particularly for small-scale farmers.

Chemical Treatments

It has been demonstrated that there was a substantial increase in the performance of animals fed chemically treated by-products in comparison with those fed untreated materials. Further investigation, therefore, is warranted.

NaOH, NH_3, or other chemical treatments are likely to be adopted by feedlot operators and feed-processing plants. Feeding trials, therefore, should be initiated to confirm laboratory results through large-scale comparative performance and cost–benefit studies, using a large number of animals and longer feeding duration.

Urea supplementation during ensiling, at feeding of alkali-treated by-products, or in the production of complete pelleted rations can be recommended for practical use by feedlot or feed-processing plants. A molasses–urea–mineral mixture can be recommended for supplementation of diets on small-scale beef or dairy farms, but this also requires careful cost–benefit analysis.

On-farm chemical treatment of by-products is not a practical method for small-scale farmers due to possible health and pollution hazards, transport and storage problems, and the large volume of water used during treatment.

Therefore, the economic and technical feasibility of chemically treating by-products need to be studied on the farm in collaboration with the potential beneficiaries. If chemical treatments do not result in increased livestock production to offset the cost of the treatment, the technology developed may be unusable by the farmers.

Microbiological Treatments

A large number of by-products were successfully ensiled using 5–10% molasses and with or without alkali treatments. The best practical silage combination based on availability, handling, and relative cost of ensiling needs to be studied.

Ensiling is recommended as the preferred method for preserving and utilizing wet by-products from the fruit and vegetable industry, e.g., studies with coffee pulp, in Guatemala, have demonstrated that ensiling is the best approach to its utilization in animal feed.

Because there is not much gain (in terms of digestibility, voluntary intake, and performance) realized from ensiling dry by-products (sorghum stalks, straws, groundnut hulls), such studies can only be recommended if these dry by-products are used as dry-matter additives for ensiling wet by-products in fresh green forages.

Ensilage of wet by-products can have practical value only to feedlot operators in view of the expense associated with permanent silos and problems of handling and preparation. Ensiling these by-products involves processes such as chopping, pressing, and mixing with materials such as sugarcane molasses, alkalis, or acids for proper fermentation or preservation of nutrients. These operations are difficult for a small-scale farmer.

Formula Feeds

Feeding trials involving sheep, beef cattle, dairy cattle, and swine have demonstrated that by-products, treated or untreated, can be incorporated into livestock-feeding systems. The dietary ratios of by-product to concentrate that allow optimal utilization of by-products, in terms of economy and performance, need to be considered in collaboration with the potential user. High feed intake and live-weight gains from diets based on 30% sorghum stalks, sugarcane bagasse, or groundnut hulls in the Sudan, for example, indicate the possibility of increasing the levels of these by-products in profitable feeding systems. The intention of the experiments was to maximize the use of the relatively cheaper and available by-products by proportionally reducing the more expensive concentrates, thus showing a relative increase in farm income production.

Conclusions

The nutritive value of agricultural and agroindustrial by-products can be increased using various processing methods involving physical, chemical, and microbiological treatments. For optimal performance by cattle, treated or untreated by-product based diets need to be supplemented with protein, nonprotein nitrogen, energy, and mineral sources. Some methodological problems, in terms of the suitability and technical applicability of the research methods used, have been identified. Based on the findings, attempts have been made to isolate the criteria required for selecting methodological approaches for applied by-product research.

It is recognized that the relevance of by-product utilization research in developing countries rests primarily in its applicability and potential to address the needs of small-scale farmers, who are the major livestock producers. The few large-scale farmers and feed-processing industries may also benefit from the research results. Much of the research work to date, however, has produced only limited concrete recommendations for incorporating by-products in livestock rations.

In view of such findings, this paper has recommended an overall methodological approach that involves a complete survey of locally available by-products, identification of beneficiaries, and description of existing farming systems prior to the selection of potentially useful and practical by-product treatment methods. The treatment methods used for upgrading the quality of by-products and the research approach need to consider the potentiality of adoption by the producer. Whereas preliminary basic off-farm station experimentation is essential for testing the feasibility of utilizing these approaches, the ultimate testing of these methodologies has to be conducted on the farm at the users' level. The design and implementation of appropriate on-farm research, in collaboration with different users and particularly the small-scale farmer, has to be developed. Participation of economists and extension agents during the research is also highly desirable.

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Application of Research Results on By-Product Utilization: Economic Aspects to be Considered

Gordon R. Potts[1]

Economic evaluation in a by-product research program is often considered as an activity to be conducted when the technical results have been achieved. This paper suggests that a consideration of economic aspects early in the research program provides the by-product researcher with one additional criterion with which to assess the suitability of each by-product alternative. This offers potential savings to researchers in their use of resources, both human and financial.

Four economic considerations are presented. A primary consideration deals with the costs attributed to by-products that are potentially available for the research program. Market prices, whether government-controlled or free market, are the most appropriate cost. Several methods of determining the costs of apparently "free" by-products, including the use of opportunity cost, are presented.

A costs and returns analysis of a by-product modification process, such as the ammonia treatment of straw, is presented as a means of assessing the economic feasibility of the process. This ex ante evaluation is beneficial, especially in situations where research into the modification process will be expensive to conduct.

Feeding trials provide information on the potential profitability of feed rations fed to a particular animal-production system. Using discounting and partial cash flow budget, an estimation of the investment potential of different feed rations can be determined, especially where time is a factor in the utilization of the by-product alternatives.

Lastly, consideration of the least-cost approach of feed-ration formulation provides the researcher with an indication of which ration is least expensive for the specified animal-performance level.

L'évaluation économique dans un programme de recherches sur les sous-produits est souvent vue comme une activité dont il faut s'occuper une fois les résultats techniques obtenus. Il est suggéré dans le présent rapport, que de tenir compte des aspects économiques dès le début des travaux fournit au chercheur dans ce domaine un critère supplémentaire d'évaluation de l'option et des possibilités offertes par chaque sous-produit. Ceci devrait éventuellement, permettre aux chercheurs de réaliser des économies de ressources, tant humaines que financières.

Ce rapport fait l'exposé de quatre considérations d'ordre économique. Il se penche d'abord sur la question des coûts des sous-produits éventuellement disponibles pour le programme de recherches. Les prix en vigueur sur le marché, libre ou contrôlé par l'État, constituent la base la plus appropriée de détermination des coûts de ces produits. Ce document décrit plusieurs méthodes de détermination des coûts, y compris l'utilisation des coûts d'options, de sous-produits qui pourraient sembler « gratuits ».

Une analyse des coûts et bénéfices d'une technique de transformation d'un sous-produit, tel que le traitement de la paille à l'ammoniac, est présentée dans ce document en tant que moyen d'évaluation de sa faisabilité économique. Une telle évaluation préliminaire est utile, particulièrement pour les cas où les recherches sur le processus de transformation seraient coûteuses.

Les essais d'alimentation fournissent des informations sur l'éventuelle rentabilité de certaines rations dans un système particulier de production animale. Établir un budget d'actualisation et un plan d'auto-financement partiel permet de déterminer les potentiels

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d'investissements pour différentes sortes de rations, particulièrement lorsque le facteur temps entre en jeu dans l'utilisation de sous-produits nouveaux.

En dernier lieu, une description de l'approche la moins coûteuse pour l'établissement des rations alimentaires indique au chercheur quelle est la ration la plus économique pour le niveau de performances spécifié des animaux.

A menudo se considera que la evaluación económica en un programa de investigación sobre subproductos es una actividad que debe realizarse cuando se obtienen resultados técnicos. Este trabajo sugiere que una temprana consideración de los aspestos económicos ofrece al investigador un criterio adicional para sopesar la adecuación de cada subproducto alternativo. Además, ofrece un ahorro potencial tanto en el uso de recursos humanos como financieros.

Se presentan cuatro consideraciones económicas. La primera se refiere a los costos atribuidos a los subproductos potencialmente disponibles para el programa de investigación. Para esto, los precios del mercado, ya sean controlados oficialmente o de mercado libre, son los más adecuados. Se presentan varios métodos para determinar los costos de subproductos aparentemente "libres," incluyendo el uso del costo de oportunidad.

Se ofrece un análisis de costos y beneficios de un proceso de modificación de un subproducto — el tratamiento de la paja con amoníaco — como medio para evaluar la factibilidad económica del mismo. Esta evalución previa es benéfica, especialmente cuando la investigación sobre el proceso es costosa de realizar.

Las pruebas de alimentación proporcionan información sobre la rentabilidad potencial de las raciones animales empleadas en un determinado proceso de producción pecuaria. Al emplear un presupuesto de descuento y flujo parcial de caja, se puede calcular el potencial de inversión de diferentes raciones, especialmente cuando el tiempo es un factor en la utilización de las alternativas de subproductos.

Finalmente, la consideración del menor costo para la formulación de las raciones ofrece al investigador una indicación de cuál ración es menos costosa para el nivel especificado de desempeño animal.

In assessing the role of economics and the agricultural economist in by-product research, one must first describe the framework within which economic discussions will be required. By-product research is concerned with the application of technical processes (physical, chemical, microbiological) to selected agricultural by-products to improve their utilization in animal-feeding systems. Ultimately, it will be a farm-level animal-feeding system that will utilize the research results, even though the initial recipient of some of the research on by-product utilization may be a feed-mill operator. Figure 1 outlines a suggested framework for research on by-product utilization. The by-product researcher investigates the availability of feedstuffs for animal feed. By-products from crop enterprises, farm-processing industries, or farm agroindustrial sources are identified and their availability over time is established. Available by-products then undergo nutritional evaluation. Changes in nutritive value (proximate analysis, digestibility, volatile fatty acid content) and performance (voluntary feed intake, milk or meat production) are used as nutritional criteria for evaluating nutrient availability over time. Promising by-products and modification processes are then combined to design feeding systems with the desired protein and energy requirements for satisfactory animal production.

This implies that scientists, both technical and social, need to have a clear picture of the existing animal-feeding system that will be modified by the most appropriate results of by-product research. Feeding systems that appear suitable must then be integrated into the total farm system, taking into consideration the interactions of the animal enterprises with crop enterprises and other farm activities.

At all stages of this framework, there are economic aspects that, when taken into consideration, can assist the researcher in evaluating the results of by-product research. Often, economic considerations have been considered only after the completion of technical research. This paper, however, will consider four general aspects of economics that can assist technical scientists in establishing a more efficient screening of research results. Many of these economic aspects can be applied during the

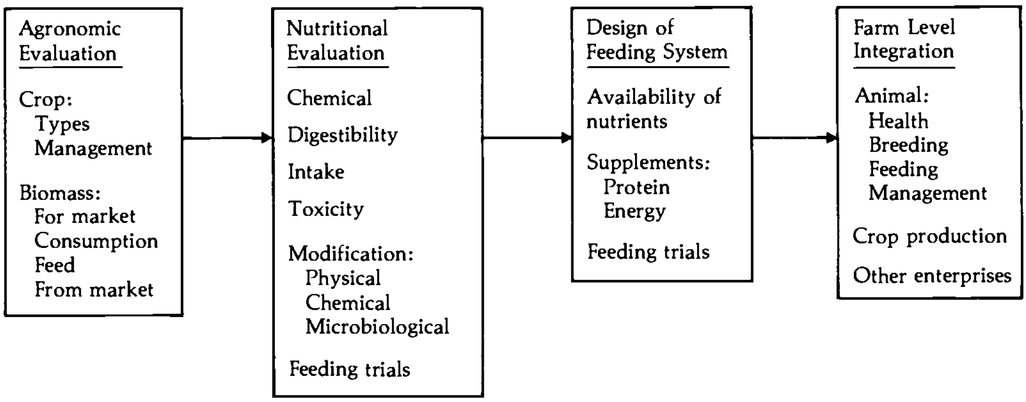

Fig. 1. Framework for by-product utilization research for animal-production systems.

research process such that an economic evaluation provides the researcher with one additional criterion with which to evaluate the suitability of a by-product alternative at the time the research is being conducted. This offers potential savings to researchers in the use of their resources, both human and financial.

Animal-Feeding Systems of Small Farmers

Research results on by-product utilization appear to be applicable to three types of animal-feeding systems: (1) feed mills involved in the formulation of partial or complete rations for selected animal producers; (2) large-scale producers, whether private feedlot operations or goverment state farms; and (3) small-scale producers, often subsistence farmers but also including small commercial producers. To narrow the scope of this paper, attention will be focused on small-scale producers and their animal-feeding systems, although references to other beneficiaries will be made.

An understanding of the animal-feeding system, in this case that of the small farmer, is needed to focus the by-product research more precisely. Animal production constitutes only one aspect of the small farmer's total farming system, which also includes crop production and perhaps other small on-farm or off-farm activities (food processing, skilled trade). Traditionally, the small farmer has limited resources in terms of: (1) animals: fewer than 10 animals, usually comprised of a mixture of beef cattle, milking cows, goats, and sheep; (2) accessible by-products: consisting of on-farm crop residues (maize stalks), agricultural by-products from on-farm processing (root-crop peels), or locally available agricultural by-products (cottonseed meal); (3) land: <5 ha, of which most is used for crop production; (4) labour: generally family labour with occasional hired labour; (5) capital: few cash expenditures, especially in the animal-production enterprise; and (6) goals and objectives of the farm enterprise: survival of animals during the dry season rather than maximum animal performance.

These farmers must make decisions pertaining to the organization of their farms in terms of the combination of resources to be used in crop, animal, and off-farm enterprises. They make these decisions on the basis of tradition, i.e., growing crops and raising cattle as they have always done and their fathers did before them. These traditional methods, developed over a period of generations, are suited to local conditions and their very survival, even at a subsistence level, is indicative of the value of traditional methods.

Animal scientists generally approach the question of decision-making from a technical point of view. Technical solutions are developed to meet the physical conditions of soils, climate, and vegetation. Often, the technical optimum, e.g., weight gain or milk production per day, is chosen as the factor for evaluating technical solutions. These solutions provide farmers with a range of alternatives from which they choose the most appropriate to achieve their objectives.

Social scientists, in this paper agricultural economists, attempt to evaluate these alternatives by measuring the costs and benefits incurred. Cost is used in its broadest sense to mean not only expenditure of money but also the sacrifice of leisure, food for seed, or anything that is valued by farmers and their families. This is based on the assumption that farmers grow crops and keep livestock for the satisfaction of their personal wants and implies that farmers are capable of evaluating the satisfaction they get from the various alternatives or, at least, that they can identify priorities within the alternatives (Upton 1973). Often, profit maximization is selected as the factor for evaluating farmer satisfaction, although there are some very important wants, such as those of respect and security, that cannot be measured objectively in monetary terms.

Technical and social scientists must, therefore, focus their research efforts on the animal-production system, which provides many methodological problems in terms of the research process. Combined efforts are needed to ensure that the results of by-product research have a practical application for a particular animal-production system. Ultimately, the research results must satisfy the user.

In this paper, specific examples have been drawn from unpublished progress reports submitted to the International Development Research Centre by research institutions in Egypt, Indonesia, Kenya, and the Sudan. Although these ongoing research projects are constantly changing, it is anticipated that these examples are relevant to the discussion.

Cost of By-Products

Numerous by-products are potentially available for the researcher to investigate. At the agronomic evaluation stage, the scientist identifies the availability of by-products, i.e., crop residues, on-farm processing wastes, or agroindustrial wastes. This information identifies which by-products are potentially available for use in animal-feeding systems. One of the first economic concerns in by-product research relates to the cost associated with each by-product to be used in the animal feed. The most obvious mechanism for costing a by-product is to use the price associated with the market value of the by-product as an animal feed. In Bali, in 1980, rice bran cost IDRp60/kg (as-is basis) (US$0.10/kg). This represents an appropriate pricing of the by-product, except in markets where an official government price for a by-product is artificially in effect, and often considerably lower than the "free-market" price. In Egypt, in 1980, cottonseed meal was officially priced at EG£10.00/tonne, even though the free-market price was two to three times higher. In this instance, the by-product should be given the market price that is most appropriate to the particular user. If the small farmer has little opportunity of obtaining cottonseed meal at official government prices, then the free-market price is more appropriate.

Many low-quality by-products, such as maize stalks, bagasse, and groundnut hulls, are often thought of as "free" because, as waste material, there is no apparent market price for them. For their utilization in animal-feeding systems, however, there is often a cost that can be calculated using one of several approaches:

(1) Opportunity cost: This is the amount of money given up by choosing one alternative over another. Many agricultural by-products have alternative uses, e.g., fuel, brick-making, export, etc., with a readily recognizable price associated with each use. If the alternative-cost is higher than the animal-feed cost, this higher price should be used as the cost of the by-product. In a controlled economy such as Egypt, the opportunity cost of a by-product, even if very high, may still not preclude its use in animal feeds because there is often a severe shortage of feed alternatives at certain times of the year. Wheat straw, during the summer season of 1981, soared to a price of about EG£100.00/tonne, more than the grain price, due to a shortage of this by-product, which has several strongly-competing alternative uses.

(2) Cost determination: For a "free" good, accessible to the farmer, a price for the by-product can be established by considering the likely costs associated with obtaining the by-product at the location where it is needed and in the form that it will be used in the animal-feeding system. For the farmer to use maize stalks lying in the field as animal feed, a costing of the stalks, including labour costs for collecting and transporting them, must be made. If a

feed-mill operation is purchasing these stalks for inclusion in a ration, some cost for grinding should be added. This would represent a minimal cost because a profit for the middleman has not been included. Seldom will a by-product have no cost associated with its use.

(3) Nutritional/energy equivalent pricing: A by-product price can be derived, by extrapolation, from the price of a recognized standard on the basis of nutritional content (total digestible nutrients (TDN), starch equivalent (SE), crude protein (CP), or energy content (calories)). For example, in the Sudan, groundnut hulls are compressed into bricks and sold to bakeries as fuel. If these bricks replace kerosene as a fuel source, a price for groundnut hulls can be determined based on their respective energy contents. If kerosene, with a heating value of 46.0 MJ/kg, costs about SD£0.10/kg, then groundnut hulls, which have a heating value of 20.6 MJ/kg (dry-matter basis), would cost about SD£0.04/kg or approximately SD£40/tonne. This cost does not include the labour involved in making the bricks. This approach has several weaknesses, which makes it less than satisfactory in its application. Little new information is likely to be gained by pricing according to nutritional or energy content because most by-products have been evaluated previously on a nutritional basis and the results would tend to be identical. The most serious disadvantage of using these equivalents is that they do not take into account the effect of scarcity. Pricing on the basis of energy equivalence (joules) may have a place if there is a direct substitution of the by-product (maize stalks) by the energy source (kerosene). This would imply the need to consider the farmers' satisfaction with this approach, e.g., the conversion of an energy supply from locally available maize stalks to purchased kerosene and the requisite changes in cooking methods.

Technology Costing

A great deal of by-product research is oriented toward the application of a particular modification process to selected by-products and the evaluation of the qualitative and quantitative changes in nutritive values. This nutritional evaluation is particularly relevant to by-product research involving chemical processes. Several chemicals, notably NaOH and $Ca(OH)_2$, have been studied extensively due to their effect on the delignification of low-quality roughages. In addition, nonprotein nitrogen, in the form of urea or ammonia (anhydrous or aqueous), has been added to low-quality roughages as a supplement to facilitate microorganism activity on the by-product in the rumen.

An economic evaluation of a particular modification process can assist scientists in assessing the economic feasibility of the process itself and the likely cost of the treated by-product. Information needed to make such an economic evaluation includes: (1) Input–output data: In physical terms, data are needed on the resources used (quantities of the by-product, chemicals, plastic covers, etc.) and physical product obtained (quantity of treated by-product) measured over a specific period of time. (2) Value placed on inputs and outputs: Generally, market prices are used as a means of evaluating inputs and outputs. The prices should be those most likely to be applicable to the immediate beneficiary (small farmer, feed-mill operator) of the process. (3) Economic and social constraints: Actual physical constraints on specific resources (e.g., labour may be in short supply at the time that the mechanical process is most applicable) should be identified. Social constraints, based on local customs or user preferences (e.g., maize stalks might not be sold in marketable quantities but could be given to others in the village who are in need of a fuel source) should be detailed.

Technical experiments involving a particular process under controlled conditions can provide much of the input–output data required. The value placed on inputs and outputs, in terms of market prices, may be sufficient to decide on the feasibility of the technical process. Even where expensive machinery is involved in the process, an initial economic evaluation of the resources used and products obtained may be sufficient to determine the long-range potential of the process. Work with NaOH treatment of roughages in Egypt was temporarily suspended because the cost of NaOH (approximately EG£400/tonne) made the process prohibitively expensive, based on the costs of ingredients, namely NaOH, alone.

In this case, further consideration of fixed costs associated with the machinery involved in NaOH application was not warranted.

Urea or ammonia as a source of nitrogen supplementation of low-quality roughages offers a relatively low-management technical process for the chemical treatment of by-products. Using data from the Norwegian "stack" method (Sundstøl et al. 1978), whereby straw is ammoniated in stacks covered with plastic, Table 1 was developed to estimate the cost associated with this process for conditions in Canada (because prices are available). This economic evaluation suggests that the minimum cost of 1 tonne of treated wheat straw is CA$73.25. Without the results of a feeding trial to assess the added production to be obtained from treated wheat straw, it is difficult to assess the profitability of this process.

Initially, the scientist can compare directly the two alternatives (untreated versus ammonia-treated by-product) to determine experimentally the increased nutritional value from the process. Then, through interaction with the beneficiary, the scientist can determine if the improved nutritional value and calculated costs of the treated by-product are within acceptable limits for use by the beneficiary. For a modification process that, at this point, appears to have potential, further research could be focused on fine-tuning the modification process (using feeding trials) so that a feeding system incorporating the treated by-product could be designed.

Feeding-Trial Evaluation

As part of the nutritional evaluation, feeding trials, using treated and untreated by-products, form an integral part of by-product research. The scientist is interested in assessing the increased production (milk, meat, eggs) that can be achieved through feeding the by-product to a particular type of animal. Only those by-products that, through earlier agronomic and nutritional evaluations, appear to have sufficient potential are tested in feeding trials. Proximate analysis, digestibility, and voluntary feed intake factors tend to suggest that specific by-products have potential as animal feed and feeding trials provide a quantitative measure of that potential. The technical scientist assesses the production (kg liveweight gain/day) and feed intake (kg dry matter/day) and calculates several nutritional criteria, such as the feed conversion ratio (kg feed/kg production). The scientist can then evaluate the various feeding sys-

Table 1. Cost of ammonia-treated wheat straw in Canada (1981).[a]

Inputs	Description	Unit cost (CA$)	Treatment cost (CA$)
Wheat straw	3 tonnes baled	35/tonne	105.00
Anhydrous ammonia	90 kg	0.52/kg	46.80
Plastic sheets	136 m^2, 0.25-mm thickness	0.50/m^2	68.00
22 sandbags[b]			
4 poles[b]	4 m each		
Injection pipe[b]	Perforated, 2.5 m long		
Total cost			219.80

Outputs

Three tonnes of wheat straw with a doubled nitrogen content, slightly improved organic matter digestibility, but sometimes having a slight decrease in palatability.

Cost

One tonne of treated wheat straw costs CA$73.60.

Socioeconomic constraints

(1) Established distribution system for ammonia needed
(2) Shortage of polyethylene
(3) Two-thirds of ammonia lost to atmosphere when stack is opened
(4) Turnaround time for each pile is 7–30 days for 15–30°C temperatures
(5) Air containing 15–28% NH_3 is potentially explosive

[a] Three tonnes of wheat straw were piled in 4.6 m × 4.6 m × 2.5 m stacks using a plastic groundsheet (6 m × 6 m) and a plastic cover (10 m × 10 m). A 3% anhydrous ammonia solution was injected and the stack was sealed.

[b] Costs associated with these reusable locally available goods are likely to be negligible per tonne of treated by-product.

tems to determine which one can provide the desired production most efficiently. The economist can provide additional criteria that indicate the most suitable feeding trial based on the availability and costs of feed ingredients. These costs, in this instance of by-products, may reflect market costs, government-regulated prices, or opportunity costs of alternative uses, depending upon the situation.

The primary concern in an economic evaluation of a feeding trial is to determine if the value of the increased production (milk, meat), known as marginal revenue, is greater than the cost of the feed ingredients fed to the animals (marginal costs). Data from the by-products (Bali) project, presented in Table 2, illustrate the type of information that can be obtained to assist in the economic evaluation of feeding trials. In this case, eight animals were fed selected rations for a period of 116 weeks. Table 3 presents a costs and returns analysis of the data. It has been assumed that the prices presented (IDRp/kg of feed in the dry-matter state) have been converted from "as is" market prices. To reduce confusion, it is suggested that "as is" feed consumption data be used, in conjunction with "as is" prices, to carry out the economic evaluation.

Table 2 indicates that diets B, C, D, and E provided the same daily live-weight gain and comparable feed conversion ratios. Several conclusions based on the economic evaluation in Table 3 can be drawn: (1) All diets are profitable, ranging in gross profit from IDRp19–IDRp39 per day. (2) Although producing the lowest daily live-weight gain, the daily feed costs of diet A are approximately 20% of those of the other diets. Similarly, the feed costs per kilogram live-weight gain for diet A are at least 40% lower than the feed costs of the other diets. (3) Diet A (grass only) and diet E (5% copra, 10% cassava chips, and 15% rice bran) provide approximately the same marginal return (IDRp38/day). (4) Because the price of grass (a "free" good) is difficult to verify, a break-even price for grass, based on the known costs of the other feed ingredients, can be calculated. This break-even price for grass indicates that diets A and E could afford to pay up to IDRp21/kg dry matter for grass and still have sufficient live-weight gain to meet feed costs. (5) The price of grass needs careful investigation. The stated cost of IDRp10/kg dry matter is equivalent to about IDRp2200/tonne (US$3.5/tonne) of fresh forage, an extremely low cost for green forage.

To determine which economic conclusion should be most influential, the scientist needs to reexamine the conclusions (both

Table 2. Performance of the cattle from 0–136 weeks.

	Diet						
	A	B	C	D	E	SEM	Local cattle
Performance from 0–116 weeks (24 July 1978 – 13 November 1980)							
Initial live weight (kg)	101.6	102.7	101.9	101.1	100.5		98.6
Live weight to 116 weeks (kg)	200.6	360.4	358.7	362	355.3		255
Live-weight gain (kg/day)	0.12[a]	0.32[b]	0.32[b]	0.32[b]	0.32[b]	0.01	0.19
Feed consumption (kg dry matter/day)							
Roughage	3.46[a]	3.15[a]	2.88[a]	2.89[a]	3.05[a]	0.34	
Concentrate	—	1.58[a]	1.66[a]	1.74[a]	1.70[a]	0.04	
Roughage/concentrate ratio							
Offered	100/0	70/30	70/30	70/30	70/30		
Consumed	100/0	67/33	64/36	63/37	64/36		
Feed conversion ratio (feed/gain)	30.34[a]	14.80[b]	14.06[b]	14.48[a]	15.02[b]	0.72	
Water consumption (L/day)	2.77[a]	5.49[b]	5.00[b]	4.57[b]	5.23[b]	0.33	
Performance from 116–136 weeks (13 November 1980 – 2 March 1981)							
Live weight at 116 weeks (kg)	200.6	360.4	358.7	362	355		255
Live weight at 136 weeks (kg)	200	—*	—*	—*	—*		
Live-weight gain (kg/day)	0.14	—	—	—	—		0.33

NOTE: Values followed by the same superscript were not statistically significant ($P>0.05$).
* Cattle receiving this diet had already attained a weight of 375 kg.

Table 3. Costs and returns analysis of experiment 1 using Bali cattle.

	Diet									
	A		B		C		D		E	
	kg/head	IDRp	kg/head	IDRp	kg/head	IDRp	kg/head	IDRp	kg/head	IDRp
Returns										
Initial live weight	101.6		102.7		101.9		101.1		100.5	
Final live weight	200.6		360.4		358.7		362.0		355.3	
Live-weight gain	99.0		257.7		256.8		260.9		254.8	
Daily live-weight gain	0.12		0.32		0.32		0.32		0.31	
Value of daily gain		73.20		195.20		195.2		195.2		189.1
Daily feed costs (dry-matter basis)										
Grass	3.46	34.6	3.15	31.50	3.88	28.8	2.89	28.9	3.05	30.5
Copra			1.04	104.0	0.83	83.0	0.58	58.0	0.28	28.0
Cassava chips			0.54	40.5	0.83	62.3	0.58	43.5	0.56	42.0
Rice bran							0.58	34.8	0.86	51.6
Total costs		34.6		176		174.1		165.2		152.1
Gross profit per day		38.6		19.2		21.1		30.0		37.0
Feed cost per kg live-weight gain		288.3		550.0		544.1		516.25		490.8
Break-even price for grass (kg dry-matter)		21.2		16.1		17.3		20.4		22.1

NOTE: Prices used in calculations (IDRp/kg): live-weight price = 610; roughage = 10; copra = 100; cassava chips = 75; and rice bran = 60. Duration of experiment was 116 weeks (812 days), involving two animals per diet.

nutritional and economic) in light of the objectives of the research and the needs of the potential beneficiary. For the farmer with very limited available capital, diet A may be the most suitable due to the low daily feed costs. For farmers having sufficient capital and wanting to maximize daily live-weight gain, diet E would tend to be the most suitable for their animal enterprises.

One obvious concern in comparing diets A and E is the time factor. Bali has an export market for cattle having a minimum live weight of 375 kg. The by-product concentrate in diet E enables the producer to achieve this optimum live weight in 2.4 years, starting with 100-kg animals. Diet A, by extrapolation, requires about 6.2 years. This delay between the investment of capital (purchase of 100-kg animals and yearly purchases of feed ingredients) and the receipt of capital from the sale of fattened cattle must be considered to estimate the return on capital. By using the discounting technique and a partial cash flow budget (Dillon and Hardaker 1980), the net present value of feeding diets A or E can be calculated to assess the cost of waiting for returns to capital invested for a given period of time. For simplicity, let us assume a 5-year time frame in which diet A, with some farm-based supplements (banana leaves, peelings), can achieve the 375 kg live weight (as indicated by the diet given to local cattle in Table 2). Diet E will provide the opportunity to have two complete fattening cycles of 2.4 years each. Tables 4 and 5 present a partial cash flow budget for each of diets A and E.

Several conclusions can be drawn that have implications for the research program. Both rations are profitable, as indicated by the positive net present values. Over the 5-year time frame, under the assumptions given, diet A is more profitable due to the low annual feed costs (23% of diet E feed costs). The most appropriate ration would be that meeting the needs of the farmers. If the farmer is interested in maximizing animal live-weight gain, using purchased by-product concentrates, diet E may be suitable. For the farmer presently using diet A (grass alone), it may be difficult to convince this farmer to replace the diet with a by-product concentrate diet, especially if financial resources are limited.

One limitation in the experiment and the economic analysis relates to the assumption that animals fed grass only (diet A) would attain the marketable live weight of 375 kg in 5 years. In connection with this slow growth, profitability and diet choice would be greatly influenced should there be a price premium for meat quality. Market conditions and expectations should be investigated and, if a premium for quality is available, the profitability and resultant selection of diet may be modified.

A feeding trial with the farmer is likely needed to provide a direct comparison of meat production from each of the two diets. Other factors, such as cattle management,

Table 4. Partial cash flow budget for diet A (IDRp).

	Year					
	0	1	2	3	4	5
Losses						
100-kg animal	41678	—	—	—	—	—
Grass	—	12629	12629	12629	12629	12629
Total annual losses	41678	12629	12629	12629	12629	12629
Gains						
375-kg animal	—	—	—	—	—	228949
Total annual gains	—	—	—	—	—	228949
Extra net cash flow	−41678	−12629	−12629	−12629	−12629	216320
Discount factor[a]	1.000	0.8929	0.7972	0.7118	0.6355	0.5674
Present value	−41678	−11276	−10068	−8989	−8026	122740
Net present value (NPV)[b]		+42703				

[a] Discount factor: the value by which a future cash flow must be multiplied to calculate the present value. This value usually represents the cost of capital or the interest rate, assumed to be 12% in this instance.

[b] Net present value: the net total of the discounted values of all future payments and receipts associated with a given project or farm plan.

Table 5. Partial cash flow budget for diet E (IDRp).

	Year					
	0	1	2	3	4	5
Losses						
100-kg animal	41678	—	—	41678	—	—
Grass	—	11132	11132	10019	11132	10019
Concentrate	—	44384	44384	39946	44384	39946
Total annual losses	41678	55516	55516	91643	55516	49965
Gains						
375-kg animal	—	—	—	228949	—	228949
Total annual gains	—	—	—	228949	—	228949
Net cash flow	−41678	−55516	−55516	137306	−55516	178984
Discount factor[a]	1.000	0.8929	0.7972	0.7118	0.6355	0.5674
Present value	−41678	−49570	−44257	97734	−35280	101555
Net present value (NPV)		+28504				

[a] Assuming an annual interest rate of 12%.

occasional supplementary feeding, or availability of by-product concentrates would also influence the decisions of farmers in their evaluation of the two diets.

Least-Cost Ration

By-products that, after agronomic and nutritional evaluation, appear promising for animal production are then incorporated into a feeding system appropriate to the beneficiary. In the design of this feeding system, a major initial concern is the cost of the feed ingredients required to achieve a satisfactory performance level. At the design stage, attention should be given to determining the least-cost system from the proposed alternatives that appear nutritionally promising. Linear programing has been developed to assist scientists in determining a minimum-cost feed ration for livestock that will provide the necessary dietary requirements. The computer combines data on the nutritional values of by-products, their costs, and animal-performance information to select those combinations of by-products that provide the desired animal production for the least cost. For the scientist involved in by-product research, this approach may be unnecessarily complex, complex, or simply unavailable. In the design of feed rations using by-products, a simple costing of the rations, used in conjunction with a sensitivity analysis, will provide the scientist with a clearer understanding of the economic feasibility of a particular ration. This would be particularly appropriate when several rations, using various by-products, are being considered for nutritional evaluation by the scientist or will be utilized in feeding trials under scientist or farmer management.

Data from two experiments involving three rations in the by-products project in the Sudan provide the basis for a least-cost approach to economically evaluating the rations. Table 6 presents the costing of three rations, incorporating 30% by-products, that were used in feeding trials in the Sudan. Each of these rations provided approximately the same daily live-weight gain (1.1 kg). The prices associated with the by-products are critical to the costing process. When designing a feeding system for a particular beneficiary, the prices of the by-products should be those prices most likely to be accessible to that beneficiary. If the farmer is unable to obtain cottonseed meal at government prices, due to accessibility limitations, then the free-market price for this feed ingredient is more suitable. These low-quality by-products are occasionally sold in the Khartoum area as fodder and the prices reflect estimated collection and transport costs (sorghum stalks, bagasse) or opportunity cost (compressed groundnut hulls are sold as fuel bricks to bakeries). The highest cost for each feed ingredient was used in the calculations, although it would be more desirable to use specific by-product prices associated with an identified beneficiary in the Sudan.

Several conclusions may be drawn from Table 6. No single ration is noticeably lower

Table 6. Costing of selected rations in the Sudan.

	Unit price	Ration A		Ration B		Ration C	
	(SD£/tonne)	kg	SD£	kg	SD£	kg	SD£
Sorghum stalks	17–23	300	6.90				
Groundnut hulls	30–35			300	10.50		
Bagasse	12–23					300	6.90
Wheat bran	48–130	295	38.35	295	38.35	295	38.35
Cottonseed cake	80–150	295	44.25	295	44.25	295	44.25
Molasses	8–10	100	1.00	100	1.00	100	1.00
Salt	45	10	0.45	10	0.45	10	0.45
Total cost (SD£/tonne)		90.95		94.55		90.95	

Table 7. Costing of selected rations in the Sudan.

	Unit price	Ration A		Ration B		Ration C	
	(SD£/tonne)	kg	SD£	kg	SD£	kg	SD£
Sorghum stalks	34–46	300	13.80				
Groundnut hulls	60–70			300	21.00		
Bagasse	24–46					300	13.80
Wheat bran	48–130	295	38.35	295	38.35	295	38.25
Cottonseed cake	80–150	295	44.25	295	44.25	295	44.25
Molasses	8–10	100	1.00	100	1.00	100	1.00
Salt	45	10	0.45	10	0.45	10	0.45
Total cost (SD£/tonne)		97.85		105.05		97.85	

in cost for the daily live-weight gain of 1.0–1.1 kg. The high-quality by-products account for 87–91% of the feed costs in the rations, whereas the low-quality by-products account for 7–11%. If it is considered that the price of low-quality by-products is uncertain or prone to error, a sensitivity analysis can be used to vary the prices of a particular by-product and determine the effect on the ration costs. Because the prices of the low-quality by-products are uncertain, the researcher may choose to double the prices and determine the new costs of the rations. Table 7 presents the costs of the rations under this assumption. The low-quality by-products now account for 14–20% of the total costs of the rations. Clearly, substantial increases in the prices of the low-quality by-products will not greatly influence the selection of a minimum-cost ration. Cottonseed and wheat bran, on the other hand, are more influential in determining the costs of the rations. To obtain a least-cost ration: (1) cheaper sources of cottonseed meal or maize bran are needed; (2) cheaper alternatives to cottonseed meal or maize bran should be researched; or (3) alternative rations should be formulated and tested, maximizing the use of low-quality by-products while still achieving an acceptable level of performance, although less than that found in the present experiments.

Summary

Economic aspects related to the prices of by-products, costing of by-product modification processes, evaluation of feeding trials, and determination of least-cost rations are important factors in the nutritional evaluation of by-products and in the design of animal-feeding systems incorporating by-products. These economic considerations provide additional criteria upon which the researcher can make decisions concerning the suitability of using by-products in animal-feeding systems. As such, these economic considerations should be made as early as possible in the research process to identify by-products, modification processes, or rations that are not economically feasible. This will enable the researcher to more precisely focus the by-product research program on by-products and modifi-

cation processes that are both technically and economically appropriate to the beneficiary. This more efficient screening process will enhance the efforts of the by-product researcher in identifying suitable research results for practical application in an identified animal-feeding system.

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Standardization of Analytical Methods for Evaluating the Nutritive Value of By-Products

E. Donefer[1]

Sampling and detailed identification of material can often be the most important and limiting aspect of a by-product research program. Samples of specific materials should be representative of different geographic areas, crop varieties, and harvesting conditions. Variability of chemical and nutritional criteria within a named material should always be identified through multiple sampling, because it has been demonstrated that the effect of processing on improving the nutitive value of by-products is closely related and varies according to the original unprocessed material. To define the most appropriate analytical procedures, the most meaningful criteria of nutritive value must first be clearly established. Research institutions in developed countries tend to use sophisticated laboratory procedures that are often replicated in areas where limited resources must be used with the utmost efficiency. With respect to chemical procedures, the detergent fibre analysis scheme represents the most important method of characterizing by-products. Regarding the use of in vitro fermentation techniques, they should specifically identify the effect of treatments on the plant fibre fraction so that the more complex 2-stage systems are not necessary. Nylon-bag digestibility offers a procedure more closely related to the ruminant environment, although still requiring rumen-fistulated animals. Whatever in vitro system is used, it is important to establish the relationship with in vivo criteria, particularly with measures of animal performance. Data indicate that in vitro – in vivo relationships change according to the level of by-product feed incorporated in the ration, e.g., at high levels there is a reduced in vitro – in vivo correlation. The relationship between analytical results and animal performance must always be emphasized, with a well-integrated research program containing a balance of laboratory and animal measurements. Facilities for accurate measurement of feed intake, digestibility, and weight gain may actually be simpler to establish and maintain than complex laboratory techniques, as only dry-matter determination may be required in the former case. A well equipped and managed feed evaluation laboratory can also serve a relatively large region, contributing to standardization of results and minimizing expenditures.

L'échantillonnage et l'identification détaillée des matières peuvent fréquemment constituer les aspects les plus importants et les limites d'un programme de recherches sur les sous-produits. Les échantillons de certaines matières devraient être représentatives des différentes zones géographiques, des variétés de cultures et des conditions dans lesquelles les moissons sont effectuées. La variabilité des critères chimiques et nutritifs d'une matière donnée devrait toujours être identifiée par de nombreux échantillonnages, car il a été démontré que les effets du traitement visant à améliorer la valeur nutritive des sous-produits sont étroitement liés et varient selon la nature de la matière brute. Afin de pouvoir établir les modes d'analyse les plus appropriés, il faut d'abord établir clairement quels sont les critères les plus importants en matière de valeur nutritive. Les instituts de recherches des pays en développement utilisent généralement de complexes techniques de laboratoires, souvent reproduites dans des régions où il faut tirer le meilleur parti de ressources limitées. En ce qui concerne les méthodes chimiques, le dosage de la cellulose au détergent représente la méthode la plus importante d'établissement des caractéristiques des sous-produits. Les techniques de fermentation in vitro devraient spécifique-

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ment permettre d'identifier l'effet des traitements sur les différentes parties des fibres des plantes, de manière à ce que les systèmes complexes d'analyse en deux temps ne soient pas nécessaires. Et les tests d'évaluation de la digestibilité à l'aide de sachets de nylon dans lesquels la nourriture est placée en présence d'acide gastrique sont une procédure particulièrement appropriée à l'environnement des ruminants bien qu'ils requièrent la pose de fistules dans le rumen des animaux. Quel que soit le système d'analyse in vitro utilisé, il est toujours important de relier les critères de ce mode d'analyse à ceux de l'analyse in vivo, particulièrement en ce qui concerne les mesures des performances des animaux. Les données existantes indiquent que la correspondance entre les observations in vitro et in vivo varie selon les quantités de sous-produits incorporées aux rations ; c'est un fait par exemple, que plus ces quantités sont élevées, le moins de relations il y a entre les observations in vitro et in vivo. Il faut toujours mettre l'accent sur la relation entre les résultats des analyses et les réactions des animaux, avoir un programme de recherche bien construit, qui permet de réaliser un équilibre entre les mesures effectuées en laboratoire et sur les animaux. Les locaux et l'équipement nécessaires à la mesure précise de l'ingestion des aliments et de leur digestibilité et de l'augmentation du poids des animaux peuvent, en fait, être plus faciles à mettre en place que de complexes techniques en laboratoire ; il pourrait, pour les premiers, être seulement nécessaire de déterminer la proportion de matières sèches. Un laboratoire bien équipé et géré efficacement, pour l'évaluation des aliments du bétail, peut aussi desservir une région assez étendue et contribuer à l'uniformisation des résultats et à minimiser les dépenses.

El muestreo y la identificación detallada del material puede ser el aspecto más importante, a la vez que el más limitante, de un programa de investigación en subproductos. Las muestras de materiales específicos deben ser representativas de las diversas áreas geográficas, variedades de cultivo y condiciones de consecha. Hay que encontrar la variabilidad química y nutricional dentro de un material dado, mediante el muestreo múltiple, porque se ha demostrado que el efecto del procesamiento sobre el valor nutritivo de los subproductos se relaciona íntimamente con el material original. Antes de definir los procedimientos analíticos más apropiados, hay que establecer los criterios de valor nutritivo. Las instituciones de investigación en los países en desarrollo tienden a usar complejos procedimientos de laboratorio, olvidando que estos tienen que ser a menudo replicados en ŕeas donde los escasos recursos deben ser usados con la mayor eficiencia. En cuanto a los procedimientos químicos, el análisis de fibra por detergente representa el método más importante para caracterizar los subproductos. En cuanto al uso de las técnicas de fermentación in vitro, estas deben identificar específicamente el efecto de los tratamientos sobre la fracción de fibra vegetal, para evitar los complejos sistemas de la segunda etapa. La digestibilidad de las bolsas de nylon se acerca más al medio rumiante, pero todavía requiere animales con el rumen fistulado. Cualquiera que sea el sistema in vitro empleado, es importante establecer relación con criterios in vivo, particularmente con las mediciones del desempeño animal. La información indica que las relaciones invitro – in vivo cambian según el nivel de subproducto incorporado en la ración. Por ejemplo, a niveles altos esta correlación se reduce. La relación entre los resultados analíticos y el desempeño animal debe ser siempre subrayada con un programa de investigación bien integrado que incluya un balance de las mediciones de laboratorio y de los animales. Las instalaciones para una medición fidedigna de la ingestión de alimento, la digestibilidad y la ganancia de peso pueden ser más sencillas que las complejas técnicas de laboratorio, requeridas solo para la determinación de la materia seca. Un solo laboratorio de evaluación de alimentos animales bien equipado y administrado puede servir a una región relativamente grande, contribuyendo a la normalización de resultados y a la reducción de los gastos.

Description of Feeds and Processes

International System of Feed Nomenclature

Detailed laboratory-evaluation and animal-feeding trials might very well produce results of limited usefulness to other researchers or for practical application if the materials and methods under investigation are not accurately described. Feed description is complicated by the use of local or regional names, as well as the use of different languages.

The past 20-year period has seen a

pioneering effort to standardize feed terminology as a first step in the collection and compilation of the results of laboratory analyses and animal-digestibility trials. The concepts and efforts of various researchers have resulted in the organization of the International Network of Feed Information Centers (INFIC), which in its latest publication (Harris et al. 1980) outlines in detail a comprehensive system of feed nomenclature. A prerequisite of any research program involving the utilization of agricultural by-products, therefore, is the use of the INFIC system to describe feeds and processes.

The INFIC system is computer-based, thus greatly facilitating storage of feed-information data collected internationally and enabling these data to be summarized and reproduced for use by nutritionists in teaching, research, and government applications. The potential of this system is tempered by the problems that can and have arisen and are characteristic of processing large amounts of information (often without careful screening of the raw data). A special obligation thus exists to verify the technical accuracy of information going into the system, as the dissemination of questionable information can be greatly accelerated by the use of computer technology.

As an example, a recent study related to sugarcane-derived feeds (Donefer and Latrille 1980) compared chemical composition and energy content data obtained from United States National Research Council (NRC) sources (upon which the INFIC system is based). Many inaccuracies and inconsistencies were found, which would limit the practical application of this data base. To cite one example, of the six sources of data (published between 1971 and 1978) for sugarcane bagasse, the metabolizable energy (ME) content varied from 0.80–1.79 Mcal/kg dry matter (DM), a more than twofold difference.

The dissemination of erroneous data on agricultural by-products can have a negative effect on its application to animal-production systems, particularly in less-developed countries where facilities for verification or availability of local information may be limited. Because the development of international systems of feed nomenclature and nutritional descriptions plays an important role in improving worldwide livestock-production programs, it is essential that those involved in producing nutritional information on agricultural by-products be actively involved in the application of the INFIC system and the prepublication editing of its summaries of data.

Use of the INFIC System

The major characteristic of the INFIC system is its use of an International Feed Name and Number (Harris et al. 1980). Feeds are assigned to one of eight feed classes according to their physical and chemical characteristics, with the class number also appearing as the first digit in the six-digit International Feed Number. Of the eight feed classes, only the first three contain the high fibre agricultural by-products (straws, hulls, bagasse, etc.), with a smaller number of by-products falling under the energy feed (e.g., molasses) or protein supplement (e.g., cottonseed or coconut meal) classifications. The INFIC class numbers and their components are given in Table 1.

The International Feed Name can consist of up to six categories or "facets" of description, although as little as two might be used if more detailed information is not available. From the list of facets given in Table 2, it is apparent that the first three are the most important in naming agricultural by-products.

Table 3 lists the International Feed Names and Numbers of some common agricultural by-products. Because most cellulosic by-products can be characterized as low-quality roughages, due to their lignified nature, an important part of the feed name is the process or treatment (facet 3) used to

Table 1. Feed classes of the INFIC International Feed Name System.

Class no.	Feed class
1	Dry forages and roughages (>35% neutral detergent fibre)
2	Pasture, range plants, or forages fed fresh
3	Silages
4	Energy feeds (<35% neutral detergent fibre; >20% crude protein)
5	Protein supplements (>20% crude protein)
6	Mineral supplements
7	Vitamin supplements
8	Additives

Table 2. Categories (facets) of the INFIC International Feed Name System.

Facet	Description
1	Original material or origin (plant, animal, other basic material)
2	Parts of the material used as feed as affected by processes
3	Processes or treatments to which the material has been subjected
4	Stage of maturity
5	Cutting or crop (for plants only)
6	Grade (quality)

improve nutritive value. Some of these "process descriptions" relate to feed particle size (coarse or fine ground), whereas others relate to treatments (ammoniated, steamed, treated with sodium hydroxide, etc.). Facet 6, quality or grade, can also be used to describe the ratio of different feeds that might be combined as part of the process (e.g., a 70:30 mixture of barley straw and alfalfa aerial parts). The examples in Table 3 also indicate a limitation of the International Feed Name system, in that it accurately identifies the *general* aspects of the feed but is not designed to give the detailed information on feed processing that is necessary to accurately describe agricultural by-product feeds.

Detailed Description of Processes

Because certain processing conditions or treatment levels are more effective in improving feed value, some even having a negative effect, it is necessary to develop a more detailed system of describing processes or treatments that can be used as an auxiliary to the International Feed Name.

Examples of this need can be seen with respect to the use of both physical and chemical treatments. Reduction in particle size can be an effective and inexpensive method for improving low-quality roughages, but in addition to a description of whether the particles are coarse or fine ground it would be important to measure the actual average particle size (mm) and ideally the percentage distribution of different particle sizes contained in the feed as determined by a sieve or screening device.

In a review of the use of high pressure–temperature steam treatments in treating roughages, it became apparent that an accurate description of the exact pressure or temperature was necessary to determine the effectiveness of the treatments (Donefer 1977). It was only when steam temperatures were in excess of 160°C (requiring a pressure of 6 kg/cm^2) that digestibility was effectively increased. When temperatures of 232°C (28 kg/cm^2) were used, negative effects on intake were observed due to production of undesirable phenolic compounds. Thus, a process description of "steam treatment" without information on treatment temperature–pressure and time does not allow other researchers to properly interpret the results presented.

This same type of example can be made with respect to chemical treatments such as sodium hydroxide. Additional information required includes the level of alkali (kg/100 kg feed), strength and amount of solution, treatment temperature, length of treatment, and post-treatment processing, if any (e.g., dehydration).

Table 3. Examples of International Feed Names for some agricultural by-products.

Common name(s)	International Feed Name[a]	International Feed Number
(Sugarcane) bagasse	Sugarcane, bagasse, wet	2-09-909
Rice hulls	Rice, hulls, ammoniated	1-05-698
Cottonseed hulls	Cotton, hulls	1-01-599
Aspen wood	Aspen, aerial part, ground	1-12-241
Straws		
Barley	Barley straw treated with sodium hydroxide, dehydrated	1-27-548
Oat	Oat straw, ensiled, ammoniated	3-26-647
Rice	Rice straw	1-03-925
Maize (corn stover)	Maize, aerial part, without ears, without husks, sun-cured, mature	1-12-179

[a] With examples of some processes.

Variation Within Agricultural By-Products

A description of the specific agricultural by-products available can help to determine their potential feed value, either untreated or treated. It can be generalized that cereal straws are higher in quality than sugarcane bagasse, which, in turn, is better than wood. This type of generalization overlooks the large variation that exists within a particular feed, which can often be greater than the variation between different feeds.

In comparing the dry-matter digestibility of corn stalks (stover) and corncobs, as reported from many sources, Klopfenstein (1981) presents the same average value of 55% for each feed. The range of values for the stalks is 38–65%, compared with 48–58% for the cobs, making any general statement about the similarity of these feeds meaningless.

In another example, a detailed laboratory study was conducted with 14 samples of sugarcane bagasse that had been obtained from four countries in the Caribbean area (Pathirana 1976). In vitro cellulose digestion was measured for the untreated samples and after treatment with alkali (4 kg NaOH/100 kg straw) or steam (170°C at 8.1 kg/cm^2). The results are summarized in Table 4, together with the average content of the cell-wall constituents. Although the variation in acid detergent fibre (ADF) values is not large (coefficient of variation=8.1%), considering the diversity of the samples, the difference in ADF values is highly correlated to the in vitro cellulose digestion (IVCD) of the untreated samples ($r=-0.91$). This observation indicates that determining the ADF content of untreated samples of the same agricultural by-product may provide a good indication of its potential for improvement through treatment.

Comparing the IVCD of the untreated and treated samples indicates (as has often been reported) that the better the quality of the initial sample the higher its potential feed value after treatment. This would suggest the importance of screening batches of materials to select those that will have the highest feed value after treatment, thus having the best economic return, because the processing cost would be the same for all samples. It is of interest to note that the two bagasse samples with the highest initial (untreated) IVDC values were actually digested better than six of the other samples *after* treatment.

Chemical Analyses

Detergent-Fibre Analyses

The use of the traditional Weende Proximate Analysis scheme for feedstuff analysis has, in part, been displaced by the general adoption, in recent years, of the Van Soest Detergent Analysis system. Nutrition laboratories should no longer be using crude fibre or nitrogen free extract analyses for feed evaluation purposes; instead, neutral and acid detergent fibre fractions should be measured.

The reliability of detergent-analysis data for estimating the feed value of agricultural

Table 4. Cell-wall constituents and in vitro cellulose digestion of sugarcane bagasse samples.

	Percentage dry matter	± SD	Coefficient of variation (%)	Correlation with untreated in vitro cellulose digestion (r)
Cell-wall constitutents (untreated samples)				
Neutral detergent fibre	88.0	4.1	4.7	−0.34
Acid detergent fibre	58.2	4.7	8.1	−0.91**
Acid detergent lignin	10.5	2.4	22.9	−0.87**
Cellulose	47.8	2.4	5.0	−0.50
Hemicellulose	28.9	4.7	16.3	+0.61
In vitro cellulose digestion				
Untreated	24.6	10.4	42.3	—
4% NaOH	39.9	8.2	20.6	+0.61*
170°C steam	42.0	8.0	19.1	+0.91**

* = $P<0.05$.
** = $P<0.01$.

by-products is illustrated in Table 4 (Pathirana 1976), where analysis results from 14 samples of sugarcane bagasse obtained from four countries are presented. ADF and acid detergent lignin (ADL) were the best indicators of feed value, as measured by in vitro cellulose digestion, with correlation coefficients of −0.91 and −0.87 respectively. Ohlde and Becker (1982) compared the chemical analysis of 24 tropical and subtropical by-products with in vitro organic matter (OM) digestibility and obtained correlation coefficients of −0.86 and −0.69 for ADF and lignin respectively. Thus, there is a marked similarity between the two studies with regard to the superiority of the ADF analysis.

Although detergent fibre analysis is a valuable tool for evaluating the potential feed value of untreated agricultural by-products, it does not provide a good estimate of the effect of a treatment on improving the feed value of low-quality roughages. Data from Rexen and Thomsen (1976) illustrate (Fig. 1) that increasing levels of NaOH treatment had no effect on ADF or lignin content of straw, but did result in a constant decrease in neutral detergent fibre (NDF) content. The latter observation illustrates the effect of alkali treatment on solubilizing the hemicellulose fraction of the straw, which is defined as the difference between NDF and ADF.

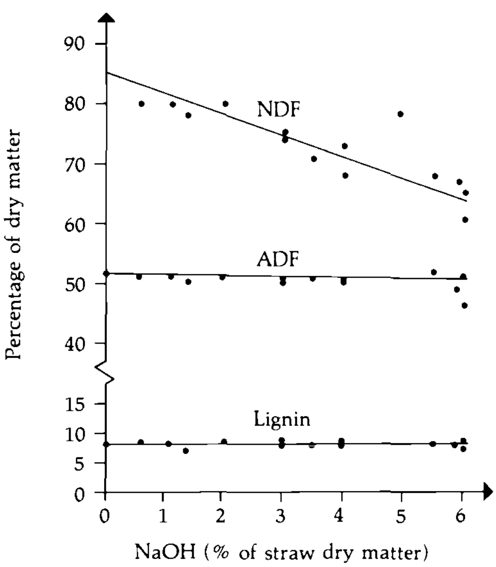

Fig. 1. Effect of NaOH treatment on ADF, lignin, and NDF content of straw (reproduced, with permission, from Rexen and Thomsen (1976)).

Other types of chemical analysis may be of limited value in studies with agricultural by-products because these feeds are generally low in protein, fat, and minerals. It may only be necessary to conduct such analyses in special cases, e.g., measuring crude protein increase when ammoniation treatment is used with roughages.

An extremely simple but apparently effective method for predicting the digestibility of treated low-quality roughages has been described by Cuban workers (Cabello et al. 1981). Hot-water solubility, determined by boiling 1 g of sample in 100 mL of water for 10 min, was found to have a correlation of 0.99 when compared with in vitro dry-matter digestibility of samples of the gas pith and straw from sugarcane that had been treated with varying levels of NaOH. It would be of great interest to determine if this method is applicable to the evaluation of other treated by-product feeds.

In Vitro Digestibility Methods

In Vitro Rumen Fermentation Procedures

The development over the past 20 years of in vitro digestion procedures for forage evaluation purposes has provided an excellent tool for studying agricultural by-products. In the Department of Animal Science, McGill University, the "1-stage" cellulose digestion procedure is still used in studies involving low-quality roughages. This is based on the fact that treatments to improve roughage quality effect the lignocellulose structure, thus increasing cellulose digestion. Because cellulose is not soluble in the in vitro medium, any disappearance with fermentation time can only be due to digestion by cellulolytic bacteria.

In another study from McGill University on the effect of increasing steam−pressure treatment time on in vitro digestion, the DM, OM, and cellulose fractions were measured. Blanks (no bacteria inoculum) were run for DM and OM determination to correct for the effect of solubilization of these fractions. The results presented in Fig. 2 indicate the greater sensitivity of cellulose digestion to the treatment process.

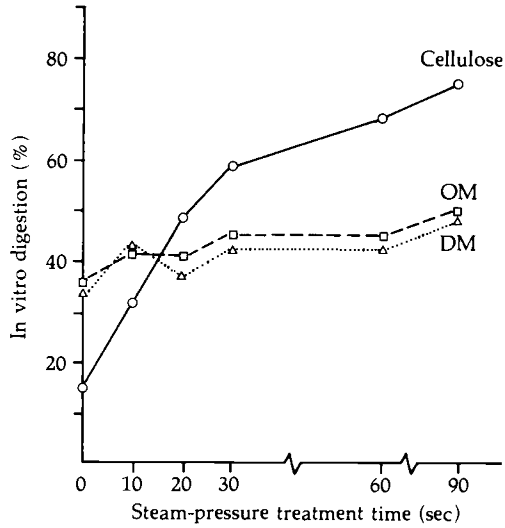

Fig. 2. Effect of increasing steam–pressure treatment time on in vitro digestion.

In this case, the in vitro procedure is being used to screen treatment levels or it can be used to survey different substrates, so the exact relationship of the results to in vivo data is not a factor.

Many laboratories have reported using the 2-stage in vitro procedure in by-product studies. Because the second stage (pepsin treatment) was developed for use with normal forages containing higher levels of protein, there is no need to use both stages with low-protein roughages because it doubles the time required for analysis without increasing the accuracy of the results.

Enzymatic Procedures

Some laboratories cannot sustain operation of an in vitro rumen fermentation system due to the requirement for rumen-fistulated sheep or cattle and highly trained technicians. An alternative and simpler in vitro system makes use of the cellulase enzyme. Such a procedure has been reported by Rexen (1977) in evaluations of alkali-treated straw. When enzyme digestion and standard in vitro digestion were compared in 46 samples of straw treated with different quantities of NaOH, a very high correlation (r=0.91) was found between the methods, although the numerical results of the in vitro procedure were considerably higher than those obtained with the enzyme.

Nylon-Bag Procedure

The nylon-bag digestion procedure has also been used for evaluating treatment of by-products (Chesson 1981). A disadvantage of this procedure for some laboratories is the requirement for rumen-fistulated animals in order to insert the nylon bags.

In Vitro Versus In Vivo Results

The basis and justification for using in vitro laboratory procedures is a high correlation of results when compared with digestibility data obtained in vivo. Most often, this correlation is assumed and in vitro – in vivo comparisons have not been made. A problem in making such comparisons is the fact that whereas the in vitro test is generally based on the by-product as the sole substrate, the in vivo digestion trial uses a ration in which the level of the by-product may vary considerably. This suggests that the actual ration fed should also be used as the substrate in the in vitro measurement.

In general, good agreement between in vitro and in vivo results has been reported. Data presented by Homb et al. (1977) indicate that the difference between in vitro and in vivo data widens at higher levels of NaOH treatment. The lower in vivo digestibility can be attributed to the negative effect of higher Na levels on the animal.

In a study by Klopfenstein (1981), Fig. 3, NaOH-treated corn (maize) cobs were used to replace alfalfa hay in a lamb ration. In vitro and in vivo results were closely related up to 50% corncob substitution, but the in vivo results decreased with higher corncob levels, whereas the in vitro response remained linear. The author suggests that the depressed in vivo values are due to the Na load on the rate of passage and fibre digestion.

The results of in vitro – in vivo comparisons indicate the usefulness of in vitro procedures as screening devices for by-product feeds and treatment but also imply that caution must be used in relating in vitro results to in vivo conditions. The simplest possible laboratory procedures that are good estimates of the in vivo parameters of interest should be used because it is possible that developing and maintaining more complicated techniques and equipment may not only be unnecessary but would also

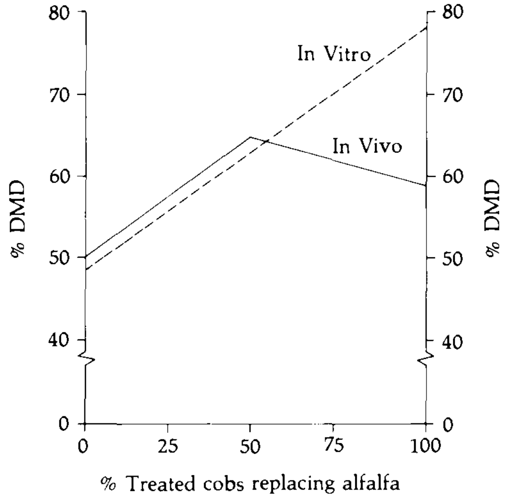

Fig. 3. Influence of percentage of NaOH-treated corncob ration replacing alfalfa hay on dry matter digestibility (DMD) (reproduced, with permission, from Paterson, J.A., Klopfenstein, T.J., and Britton, R.A. 1978. Journal of Animal Science, 47, Supplement 1, 340).

result in completely diverting major efforts and interests from the problems to be solved to that of methodology.

In Vivo Digestion Trials

If the amount of by-product feed available is not limiting, the use of small ruminant (sheep, goats) digestibility trials may actually be simpler to conduct and may produce more applicable data than in vitro laboratory procedures. Digestibility cages can be constructed easily, particularly if urine is not collected, and total feces collection can be made quantitatively. The use of dry-matter determinations means that the only laboratory equipment necessary includes scales or balances for weighing the feed and feces and an oven for drying to constant weight (or the use of sun drying).

Another advantage of in vivo trials is that they measure the actual response of the animal to the feed tested at different ration levels and indicate the presence of negative substances by the animals acceptance of the ration (e.g., the presence of phenolic compounds due to overprocessing with steam pressure).

A major advantage of in vivo trials is their measurement of the voluntary intake of the ration as well as digestibility. A major shortcoming of many in vivo digestion trials is that digestibility is measured at a restricted feed intake and voluntary intake is either not measured accurately or not reported.

The problem related to restricted intake during the digestibility determination is that digestibility values are generally higher compared with those measured under conditions of ad libitum consumption. This can be a particularly serious handicap because the feed by-products are designed to be used in free-choice rations in practical applications. The advantage of controlling experimental error by means of restricted feeding may thus be offset by the reduced reliability of the results.

In another study in the Department of Animal Science, McGill University, involving varying ration levels of steam processed aspen wood (Table 5), the difference between DM digestibility measured under restricted and ad libitum intake varied according to the level of processed wood in the ration. At the 50 and 65% wood levels, there is a marked difference in DM digestibility, with the values obtained during restricted feeding perhaps being unrealistically high.

Another reason for measuring voluntary intake as part of the digestibility trials is the demonstration that the effect of treatment of low-quality roughages may be just as important and sometimes greater in increasing intake than digestibility. If, for instance, treatment consists of reducing particle size (i.e., grinding), there may actually be depressed digestibility accompanied by marked increases in voluntary intake.

An intake and digestibility trial (Donefer et al. 1969) determined the effect of urea supplementation on untreated or NaOH-treated oat straw (Table 6), with straw and urea being the only ration ingredients. Although marked increases in digestibility

Table 5. Effect of ration level on the apparent dry-matter digestibility measurement.

	Ration level of processed aspen wood (% DM)			
Feed intake	50	55	60	65
Restricted	63.4	56.2	56.4	53.1
Ad libitum	55.3	48.5	53.2	51.2
Increased due to restriction (%)	8.1	7.7	3.2	1.9

Table 6. The effect of NaOH treatment and urea supplementation on the nutritive value of oat straw.

	Untreated		NaOH-treated	
	No supplement	2.5% urea supplementation	No supplement	2.5% urea supplementation
Digestion coefficients (%)				
Cellulose	54.3[a]	52.4[a]	66.4[b]	69.6[b]
Dry matter	46.0[d]	44.2[d]	59.5[e]	62.5[e]
Gross Energy	44.2[a]	41.6[a]	53.8[b]	58.5[b]
Relative Intake (%)	54.0[b]	60.8[b]	30.4[a]	99.9[c]
Nutritive Value Index	24.3[d]	25.4[d]	16.4[d]	58.1[e]
Digestible Energy Intake (kcal $Wt_{kg}^{0.75}$)	83.9[d]	89.5[d]	52.7[d]	188.0[e]

NOTE: Means in the same row followed by different superscripts differ significantly ([a,b,c] = $P<0.05$; [d,e] = $P<0.01$).

were observed as a result of NaOH treatment (8 kg NaOH/100 kg straw), the largest increase was the almost doubling in Relative (voluntary) Intake due to NaOH treatment and urea addition. The most important criteria measured was digestible energy (DE) intake (kcal DE/$Wt_{kg}^{0.75}$), because it takes into consideration both the observed digestibility and voluntary intake, and should be closely related to the productive potential of the ration.

A logical sequence in feed evaluation experimentation is to follow in vitro screening trials and in vivo intake and digestibility studies with animal trials measuring productivity. Feeding rations containing agricultural by-products to lambs or kids for periods of at least 40–60 days allows for the measurement of growth rate, which is one of the prime criteria that can be used in an economic evaluation of a proposed feeding system.

Recommendations

(1) The international system of feed nomenclature developed by INFIC should be used to identify all feeds used in by-product evaluation studies.

(2) Data on feed composition and feed value going into and coming out of the INFIC data bank should be carefully edited to determine its accuracy and erroneous data should not be included in published summaries or tables.

(3) In addition to the International Feed Name, a detailed description of the treatment procedures used to improve by-product feeds must be included with reports of data so that the treatments can be accurately duplicated by other workers.

(4) In laboratory evaluations of a by-product feed, samples from different locations or time periods should be included to obtain a measure of the variability, both before and after treatment.

(5) The detergent fibre analysis scheme is most valuable for analyzing by-product feeds, particularly the use of acid detergent fibre.

(6) As simple as possible in vitro or in vivo procedures should be used so that the need for complex methodology does not become a limiting aspect of research.

(7) In vivo determinations of voluntary intake and dry-matter digestibility should be followed by measurements of productivity (growth rate) so that the economic potential of by-product feeds and their treatments can be evaluated.

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Session IV Discussion: Research Methodology

During the discussion of the three papers presented in this session, several points were raised. It was noted, for instance, that the clear identification of the beneficiary of the technology is a necessary step to orient research program activities.

There was a short discussion on the advantages and disadvantages of conducting biological versus multidisciplinary systems oriented research. It was concluded that multidisciplinary research makes more efficient use of research resources and probably more efficiently reaches the small farmer, who is in the majority in developing countries.

Concerns were expressed on the need to analyze research results on both micro- and macroeconomic levels to decide on recommendations for farmers. Also, the related topic of whether the recommendations should be based on farmer's priorities or national priorities was discussed.

It was mentioned that both micro- and macroeconomic analyses should be carried out. Cost-benefit and partial cash flow budget analyses are important tools for deciding on the best research results to be recommended. However, they are not the only criteria upon which to base the decision. Other considerations also have to be taken into account, such as availability of inputs, price changes, market considerations, credit availability, simplicity of alternatives, and farmer's acceptability.

In relation to which priorities to follow, i.e., farmer's or national, the consensus was to consider both. Basing research and development activities solely on national priorities or decisions was not advised. Therefore, both priorities should be satisfied.

The importance of surveys as a step in the research process was also addressed. Such surveys can provide valuable information on many factors endogenous and exogenous to the farming system that could orient the type of research to be carried out and the evaluation and verification of research results. However, precautions should be taken to avoid diagnostic studies that are extremely lengthy and difficult to analyze, unreliable, or are an objective in themselves. Field surveys provide a solid base for calculating the actual availability of by-products in an area instead of enormous desk studies using statistical data.

More consideration should be given to on-farm activities as a means of identifying constraints to production systems (whether on small, medium, or large farms), adapting or validating new technology, and facilitating its application.

From the project review, it was evident that some simple technological alternatives that could have an important impact have not been tested, e.g., feeding chopped by-products (without any further treatment), supplementing the animals on poor pasture or utilizing low-quality by-products with a preparation of molasses, urea, and minerals.

Questions were raised in relation to the role of INFIC and the utility of its information, considering the large number of factors that cause variability in the composition and nutritive value of feedstuffs. It was mentioned that researchers would have the primary responsibility of trying to identify and quantitatively describe the factors that affect the specific feeds. The exact mechanism for summarizing this detailed data should be determined in consultation with INFIC staff.

There still remains the need, however, to have specific knowledge about the nutritional characteristics of feedstuffs, in addition to data on their chemical composition and nutritive value. Associative effects (synergistic or detrimental) among ingredients and nutrients, toxic effects, and other characteristics should also be considered.

In relation to the analyses to be used in the evaluation of by-products, it was recognized that they should be simple, reliable, and of ample diffusion. In this regard, the Van Soest method of determining fibre and in vivo and in vitro digestibility is a useful tool. However, in many cases the limitation of resources or difficulties in obtaining chemicals might make it impossible to carry out these tests. The evaluation of feed intake and animal performance has to be carried out under specific production systems to arrive at a recommendation for their utilization. In the case of utilizing equations to predict nutritive value or performance of by-products, care should be taken to use data that reflect local conditions.

In the case of by-product evaluation in Africa, ARNAB has to play an important role in helping national institutions to standardize evaluation methods and collect information coming from national institutions. In this way, it will provide support for strengthening national research programs.

Experiences in On-Farm Research and Application of By-Product Use for Animal Feeding in Asia

I.S. Agarwal and M.L. Verma[1]

There is a great need to conduct research on farm animals to determine the response of improved methods of utilizing agricultural by-products in physical and economic terms. An on-farm testing program on urea treatment of straw to improve its nutritive value was started in two clusters of 4–5 villages each in the hills and *tarai* tract of Uttar Pradesh, India. Similar on-farm trials were carried out in Bangladesh and Sri Lanka. The results of these on-farm studies have clearly demonstrated that feeding of urea-ensiled straw offers great promise for better feeding of dairy cattle and buffaloes. However, a more simplified method of stacking and a better system of feeding the treated straw should be developed for village conditions. More and more farmers should be involved in such on-farm testing programs to evaluate the economic benefits of straw treatment under diverse situations.

Il y a un grand besoin d'effectuer des recherches sur le bétail afin d'évaluer, sur le plan physique et économique, les résultats de l'amélioration des méthodes d'utilisation des sous-produits agricoles. Un programme d'essais sur la ferme même, du traitement de la paille à l'urée, pour améliorer sa valeur nutritive, a commencé dans deux groupes de quatre ou cinq villages situés dans les collines et la zone *tarai* d'Uttar Pradesh, aux Indes. Des essais similaires furent effectués dans des fermes du Blangladesh et de Sri Lanka. Les résultats de ces études ont clairement démontré que les rations de paille enrichie d'urée et ensilée sont très prometteuses pour l'amélioration de l'alimentation des vaches laitières et des buffles. Il est cependant nécessaire d'adapter certains aspects aux conditions villageoises : de simplifier la méthode de mise en meules de la paille et d'améliorer le mode d'alimentation. Un plus grand nombre de fermiers devraient participer à ces programmes d'essais au niveau des fermes, afin de pouvoir évaluer les avantages économiques du traitement de la paille dans diverses conditions.

Hay necesidad de realizar investigaciones sobre los animales de finca para determinar la respuesta de los métodos mejorados de utilización de los subproductos agrícolas en términos económicos y físicos. En dos grupos de 4 a 5 aldeas hindúes se inició un programa de pruebas en fincas de un tratamiento para mejorar el valor nutritivo de la paja con úrea. En Bangladesh y Sri Lanka se realizaron pruebas similares. Los resultados de estos estudios en finca han demostrado claramente que la paja ensilada con úrea ofrece buenas perspectivas para una mejor alimentación del ganado de leche y los búfalos. Sin embargo, se requiere un método más sencillo de apilamiento y un mejor sistema de administración de la paja tratada para las condiciones de las aldeas. Hay que involucrar más agricultores en tales programas de pruebas para poder evaluar los beneficios económicos del tratamiento de la paja bajo diferentes situaciones.

A number of new techniques have been developed that increase efficiency of utilization of crop residues (Jackson 1977). These have been tested predominantly on animals maintained on research stations in controlled experiments. These techniques, however, need to be tested on farmers' animals under village conditions to find out whether or not they maintain their effec-

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tiveness under the village environment. If not, it is desirable to continue the work until all constraints for its adoption by farmers have been fully identified and removed. The conditions under which village animals live, grow, and produce cannot be simulated on the experimental stations in general, and in the countries of Southeast Asia in particular. It is also essential that the economic usefulness of a new technology be assessed within the system into which it is to be eventually used. Furthermore, on-farm research provides exposure to research scientists of the problems of feeding farm animals under village conditions and an insight into the conditions of the rural people. Considering the importance of on-farm testing programs, a proposal for a coordinated field-testing and demonstration project, similar to the field-testing program now beginning with crops (Izuno 1977), was submitted to the Food and Agriculture Organization of the United Nations (FAO) by one of its consultants (Jackson 1978). In brief, the main objectives of an on-farm testing program should be to generate a technology suitable to the farmer's conditions, ascertain the constraints that limit animal production, and fix research priorities.

In this paper, the methodology and results of new on-farm trials on treatment of crop residues and the experiences of the participating farmers are discussed.

Review articles by Jackson (1977) and Sundstøl et al. (1978) showed ammonia as a possible alternative to sodium hydroxide, with an added advantage that it supplies nonprotein nitrogen. Urea as a source of ammonia has been used recently in several areas. It has been reported that the treatment of wheat straw with urea (4.0 kg urea/100 kg straw) solution to produce a moisture content of 45–55%, followed by putting it into a silo or stacking it for more than 4 weeks, produced wheat straw comparable in nutritive value to that obtained after treatment with sodium hydroxide spray (Verma 1981; Saadullah et al. 1982; Jayasuriya and Perera 1982). In view of the ready availability; low price; ease of handling, with known yield-promoter qualities for crops; and versatility of its use in ruminant feeding; urea was chosen for treating straw for the on-farm trials.

Materials and Methods

The first on-farm trial was carried out in the hills district of Uttar Pradesh in a cluster of 4–5 villages. Twenty-seven calves of 1.5–2.0 years of age were selected and grouped in such a way that three calves from each group were almost similar in age and body weight. Nine such blocks were made. An animal from each block was allotted to one of three treatments/diets. The calves on the first diet were fed untreated rice straw and a small supplement of grass. The second diet was identical to the first, except that the calves in this group were given a daily supplement of 30 g commercial mineral mixture. The third diet was identical to second, except that the untreated straw was replaced with urea-treated straw. All of the animals were fed on a free-choice basis. The experiment lasted for 4 months and was then discontinued due to a lack of treated straw. Body measurements were taken to calculate the body-weight gains of calves.

Method of Treatment

Rice straw was treated by spraying it with 5% urea solution (1L/kg straw). The straw was spread in a 15–20 cm thick layer in a high place where it was to be stacked. It was moistened thoroughly with urea solution, using a garden sprinkler, and simultaneously pressed by the persons spraying the solution. A second layer of rice straw was spread over the first layer and the same procedure was carried out. This process was continued until a conical structure of about 2.5 m in height was formed. The stack was kept for a 4-week period to complete the reaction with the ammonia produced from the urea. The treated straw stack was subsequently opened, the straw was sun-dried, and then restacked. This helped prevent the growth of moulds. Sun-drying of treated straw is, however, not essential if chaffed straw is used instead of long straw.

The second on-farm study was conducted in *tarai* tract of Uttar Pradesh in a cluster of 4–5 villages. The object of this study was to allow the farmers to continue using their normal feeds and enrich them with a urea supplement when nonleguminous forages and straw were fed. A mineral mixture was provided to all of the animals. Urea was supplemented at 1.0 kg/100 kg of dried

Table 1. Quantities of feeds fed to dairy cattle in India.

Category	Type of animal	Quantity fed daily[a] (kg/day)		
		Dry fodder	Green fodder	Concentrate
Milch	Cows	3.5	4.4	0.3
	Buffaloes	5.9	6.8	0.8
Dry	Cows	2.8	2.8	0.1
	Buffaloes	4.0	4.3	0.1
Adult male	Cows	5.7	5.0	0.3
	Buffaloes	5.4	6.5	0.2
Young	Cows	1.5	1.6	Nil
	Buffaloes	1.7	1.6	Nil

Source: Amble et al. (1965).
[a] The quantities do not include the amount grazed.

straw and 0.2 kg/100 kg green sorghum, sugarcane tops, and other nonleguminous forages. In order to avoid miscalculations, farmers were supplied with suitable containers to measure the quantity of urea required for each basket (a measure) full of feed. Simultaneously, a group of farmers was selected who were not feeding urea-supplemented roughages. The advantages of using urea for the treatment of straw were explained to the farmers by nutrition specialists at a number of group meetings conducted during late-evening and early-morning hours. A village-level worker was also posted to train all the members of the farmer's family on the method of urea supplementation. Body measurements of all the animals were recorded at monthly intervals and used to predict body-weight changes.

Results and Discussion

In India, crop residues such as wheat *bhusa*, rice straw, sorghum, *bajra*, and maize stovers are the staple livestock feeds. These roughages are fed to livestock either alone or supplemented with a small amount of green forage with or without concentrates (Table 1). The future holds no hope of increasing the availability of concentrates for the majority of livestock. The situation is not much different in Bangladesh, Sri Lanka, and a few other countries of Southeast Asia. The straws and stovers will occupy an even more important place in the feeding of farm animals in years to come. Concerted efforts must be continued to work out economical and practical methods of improving the feed value of crop residues. Such methods should always be tested under village conditions. Urea as a source of ammonia has been tried recently in laboratory experiments and farm trials in India and elsewhere, and it appears to be a promising method (Tables 2, 3).

The on-farm study carried out in the hills of Uttar Pradesh clearly demonstrated that calves on treated-straw diets gained an average of 260 g/day (Table 4), which was significantly ($P<0.05$) higher than the untreated-straw group. Even a small supplement of mineral mixture improved the weight gains by nearly 50 g/day. This is in agreement with the findings of Walker et al. (1976) who reported a comparable figure of 89 g for untreated straw and 138 g for rice straw treated with 5% aqueous NH_4OH and then pelleted. Sundstøl and Matre (1980) also observed similar differences. This was primarily due to increased consumption and higher digestibility of treated straw. The consumption of straw could not be measured in the study because the animals

Table 2. Comparative feed value of NaOH and ammonia (through urea) treated wheat straw.

	NaOH-treated	Ammonia-treated
Dry-matter intake ($g/kg_W^{0.75}$)	86.0	89.3
Dry-matter digestibility (%)	55	49
Digestible dry-matter intake ($g/kg_W^{0.75}$)	47	43
Average daily gain (g)	158	181

Source: Verma (1981).

Table 3. Mean live-weight change and ration digestibility of calves fed with differently treated rice straw.

	Treatment				
	A	B	C	D	E
Initial live weight (kg)	54	58	58	57	56
Final live weight (kg)	57	65	67	65	66
Daily gain (g)	35[a]	75[b]	110[cd]	99[c]	120[d]
Apparent digestibility					
Dry matter	40[a]	46[b]	51[c]	48[bc]	62[d]
Crude fibre	58[a]	63[b]	65[b]	65[b]	74[c]
Crude protein	—	54[a]	58[b]	50[a]	65[c]
Total dry-matter intake (kg)	1.8	1.8	2.0	1.7	1.7

Source: Saadullah et al. (1982).

NOTE: A = untreated; B = urea-supplemented; C = 5% urea-treated; D = 4% lime-treated; E = 3% NaOH + 1% lime-treated. Values followed by different superscripts are significant at $P<0.05$.

Table 4. On-farm trials involving the feeding of urea-treated straw.

	Diets		
	Farm diet	Farm diet + mineral mixture	Farm diet of urea-treated straw + mineral mixture
DM digestibility of straw (%) (nylon bag)	32	32	57
Nitrogen content of straw	0.5	0.5	1.3
Ca content	0.5	0.5	0.6
Average daily weight gain (kg)			
By difference	0.12[a]	0.17[ab]	0.26[b]
By regression analysis	0.13[a]	0.17[a]	0.26[b]

Source: M.G. Jackson (personal communication).

NOTE: Values followed by different superscripts are significant at $P<0.05$.

Table 5. Regression equations for body-weight change in village cows and buffaloes given urea-supplemented roughage diets ($Y = a + bx$).

Weight group	August–December	December–April	April–July	Full year
<100 kg	74.6+4.83x(161)	90.8+7.48x(249)	124.9+8.01x(267)	69.2+6.82x(227)
100–200 kg	150.1+6.08x(203)	184.3+10.85x(362)	214.3+12.02x(401)	140.8+0.32x(344)
201–300 kg	236.7+7.65x(255)	260.8+11.71x(390)	314.1+11.81x(394)	228.8+10.34x(345)
> 300 kg	362.7+8.19x(273)	388.5+12.72x(424)	442.4+9.09x(303)	357.5+10.08x(336)
Overall average	(211)	(335)	(311)	(290)

NOTE: Figures given in parentheses are the average daily weight gain (g).

were not fed in mangers and the residues were used as bedding material. Farmers, however, observed that the animals were eating more straw and the palatability had improved.

The result of a second study carried out in *tarai* tract of Uttar Pradesh showed that the rate of growth was at a maximum in rabi (winter) season (335 g/day), when berseem fodder was available. The rate of growth during the rest of the period ranged between 211 and 311 g/day (Table 5), which is good considering that there is little or no concentrate feeding in these villages. On the basis of an evaluation carried out through a questionnaire, 62, 10, and 20% of the farmers stated that the animals on a urea-supplemented diet (Table 6) grew at a faster, reduced, and normal rate respectively. Results of the same on-farm trial in

Table 6. Effect of urea supplementation on the performance of village cattle and buffaloes (based upon answers to a questionnaire).

Parameter	Percentage distribution of answers			
	Increased	Decreased	No change	Not observed
Feed consumption	85.0	5.0	5.0	5.0
Feed refusals	9.0	71.5	9.5	10.0
Growth rate	62.0	9.5	18.5	10.0
Milk production	81.0	0.0	14.0	5.0
General health	Improved (95)	Deteriorated (0.0)	No change (5.0)	

NOTE: Values in parentheses are percentages of respondents.

Table 7. Change in body weight of calves on untreated and urea-treated straw in *tarai* tract of Uttar Pradesh.

Duration of test (days)	Farm ration of untreated straw + mineral mixture		Farm ration of treated straw + mineral mixture	
	Total weight gain (kg)	Daily gain (kg)	Total weight gain (kg)	Daily gain (kg)
337	131.61	0.390	203.15	0.605
337	121.12	0.359	131.13	0.389
306	109	0.326	148.13	0.484
233	76.28	0.301	75.97	0.300
213	101.76	0.478	51.99	0.244
Average		0.371 NS		0.404 NS

NOTE: NS = nonsignificant.

Table 8. Age, weight, and working hours of bullocks.

	Estimated age (year)	Weight (kg)			Working time (hours)
		Initial	Final	Change	
Treated straw	5.3 ± 1.6	171 ± 32	168 ± 30	−3 ± 3.8	30 ± 23
Untreated straw	6.0 ± 1.5	193 ± 47	188 ± 39	−5 ± 9.4	33 ± 21
Significance		NS	NS	NS	NS

Source: Dolberg et al. (1981).
NOTE: NS = nonsignificant.

another village showed that animals on urea-supplemented rations gained an average of 404 g/day, which was not significantly higher than the 371 g/day gained by those animals on an untreated straw and mineral mixture diet (Table 7). The high growth rate in the unsupplemented group and the nonsignificant increase in liveweight gain as a result of urea supplementation could be due to a better feeding schedule in this particular village compared with other villages. Both studies clearly established that urea treatment and urea supplementation of straws and stovers increases the growth rate of calves.

A similar on-farm study was carried out by Dolberg et al. (1981) involving seven pairs of bullocks averaging 3–8 years of age in a village in Noakhali district, Bangladesh. They reported that the bullocks fed on treated straw lost 3 kg and on untreated straw lost 5.0 kg body weight (Table 8). They concluded that the village cattle could be fed on treated straw alone for maintenance of both energy and protein. A lack of minerals and internal parasites might be the factors responsible for the observed decrease in body weight. Dolberg et al. reported that the urea treatment of straw increased dry-matter intake (Table 9) and found that the intake of treated straw was as high as 4.14% of the body weight. Perdok et al. (1982) carried out a few on-farm trials in Sri Lanka using urea-ensiled straw and

Table 9. Daily intake of straw by bullocks.

	Daily straw dry-matter intake	
	% of body weight	$g/kg_W^{0.75}$
Treated straw	3.4 ± 0.5	121 ± 17
Untreated straw	2.5 ± 0.5	90 ± 12
Significance	$P<0.05$	$P<0.05$

Source: Dolberg et al. (1981).

Table 10. Gain, feed conversion, calculated metabolizable energy (ME) of straw, and straw dry-matter intake of Sahiwal heifers fed untreated (US) and urea-treated (TS) straw diets.

	US	TS	Difference
No. of heifers	17	17	—
Initial weight (kg)	165.2	166.9	1.7[NS]
Final weight (kg)	170.3	191.1	20.8**
Gain in 70 days (kg)	5.1	24.2	19.1**
Daily gain (g)	73	346	273**
Feed conversion ratio (kg DM/kg gain)	52.7	13.3	39.4**
Calculated ME value of straw (MJ/kg DM)	6.0	7.6	
Straw dry-matter intake (% live weight)	1.3	1.6	
Total dry-matter intake (% live weight)	2.31	2.58	

Source: Perdok et al. (1982).
** = $P<0.01$; NS = nonsignificant.

Table 11. Milk yield, milk-fat yield, milk-fat percentage, cows milked, live-weight change of cows and their calves, milk intake of calves, and straw dry-matter intake of Gir cows fed untreated (US) or urea-treated (TS) straw diets.

	US	TS	Difference
No. of cows	17	17	—
Overall period (days)	175	175	—
Milk yield (kg/day)	2.42	3.41	0.99**
Milk fat (g/day)	111	168	57**
Milk fat (%)	4.6	4.9	0.3
Live-weight change over 63-day period (g/day)	−266	93	359
Calf live-weight gain (g/day)	181	257	76**
Calf milk intake (kg)	1.35	1.88	0.53**
Straw dry-matter intake (% live weight)	2.0	2.9	

Source: Perdok et al. (1982).
** = $P<0.01$.

observed that the heifers fed on treated straw gained weight at a daily rate of 346 g, which was about five times the rate of the untreated-straw group (Table 10). However, in another experiment involving 60 draft bulls, Perdok et al. found unexpectedly low body-weight gains of 107 and 89 g on untreated and treated straw rations respectively. One of the reasons for the low weight gain might be that the animals were of a slightly higher age group. They also conducted a trial on 34 lactating Gir cows and reported that the daily milk yield in Gir cows increased significantly ($P<0.01$) by 41% and milk fat by 51% on a treated-straw ration (Table 11). On the basis of the results reported, it may be concluded that feeding of urea-ensiled straw offers great scope for cattle owners to increase the productivity of their cattle and buffaloes.

The treatment of straws with urea also suffers from the following limitations:

(1) Nonavailability of a water source near the homestead could be a serious constraint in the hills and some other areas.

(2) The use of unchaffed straw for treatment creates two major problems. Firstly, due to incomplete compaction the treated straw has to be dried and restacked, which makes the process laborious and risky, particularly during bad weather. Secondly, due to substantial wastage on unchaffed straw, the economics of using treated straw may become questionable.

(3) The major effect of treated straw is a substantially higher intake. It is presupposed, however, that the availability of straw is not limited and, hence, in places where the availability of straw is limited the usefulness of this technique becomes doubtful. As such, determination of optimum levels of feeding urea-treated straw to various categories of livestock for increasing the efficiency of utilization becomes a high priority for future research.

The authors realized that farmers who obtain a major source of their income from the sale of milk and other animal products may adopt new technology faster than those whose dairy cattle are kept primarily for providing draft and dung, with milk and meat being by-products.

Farmers' Experiences with Urea-Treated Straw

The owner of a model cooperative farm

Table 12. Feeding schedule for milch animals.

Month	Type of roughage[a]	Amount of milk produced for ad libitum intake of roughage (L/day)[b] 1980–1981	1981–1982
October	Hybrid napier grass	1.5	3.0
November	Hybrid napier grass + wheat *bhusa* (3:1)	1.0	4.0
December	Berseem + wheat *bhusa* (1:1)	4.0	5.0
January	Berseem + wheat *bhusa* (3:1)	6.0	6.0

Source: Dhillon (1982).

[a] In 1981–1982, urea-enriched hybrid napier grass and urea-treated stacked wheat *bhusa* replaced plain hybrid napier grass and wheat *bhusa* respectively.

[b] Concentrate allowance for individual cows was calculated at a rate of 1 kg concentrate for every 2.5 L of additional milk.

Table 13. Feed costs and milk production on untreated and urea-treated straw rations.

Ration	Ingredient	Quality (lb)	Costs	Milk production (lb)
Untreated Straw	Straw	8.0	1.60	1154
	Oil cake	0.5	0.62	
	Soybean gruel	0.5	0.15	
	Pulse bran	0.5	0.75	
Urea-treated straw	Straw	12	3.60	1572
	Oil cake	0.25	0.31	
	Soybean gruel	0.25	0.07	

Source: D'Silva, A.U., Derek (1981).

with 80 crossbred cows having a yield potential ranging from 3500–3600 L/lactation fed urea-supplemented nonleguminous green forages and urea-treated straw to the high producing cattle. Not only was an increase of 2–3 L of milk per head per day obtained but also a saving of 1 kg of concentrate/head/day, in addition to replacing 10% of the costly groundnut cake by cheaper feeds such as brans (Table 12; Fig. 1). The owner proposed the possibility of partially replacing the area under nonleguminous kharif fodders with cereal crops such as rice and using the treated and stacked straw in place of sorghum or hybrid napier grass. D'Silva, A.U., Derek (1981) also reported an increased production of 418 lb of milk in a lactation on a treated-straw diet even after a saving of costly and scarce concentrates (Table 13).

From the foregoing discussion, it is evident that urea supplementation and urea treatment of straws both offer excellent opportunities for cattle owners to increase animal production, and it may become an economical alternate feeding practice in the near future. There is, however, a need for further simplification of treatment procedures and stacking. There is a need to develop a method of treatment that can be used at threshing time so that additional labour is not required. There is also a need to develop suitable structures for stacking treated straw based on locally available material, so that wastage of the straw can be minimized. It is felt that some feeding system should be developed that requires

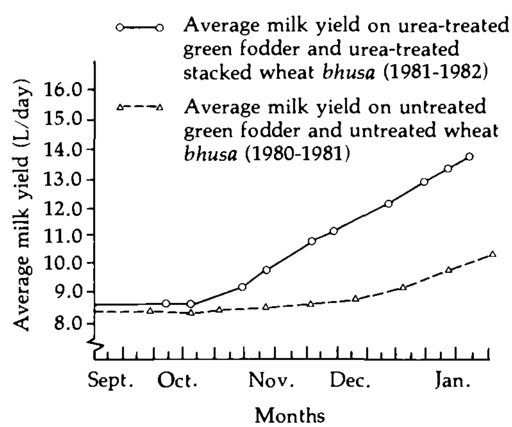

Fig. 1. Effect of urea treatment of green fodder and wheat bhusa *on average milk yield.*

only small quantities of protein supplements (preferably having bypass protein quality) and large quantities of treated straw. Efforts should also be made to minimize losses of ammonia by recycling it. More and more farmers should be involved to work out the economic benefits of straw treatment under diversified situations. This will not only educate them but also their relatives, friends, and neighbours.

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Farm Surveys as a Tool for Conditioning Applied Research on By-Product Utilization for Animal Feed[1]

Kamal Sultan[2]

A farm survey can provide the by-product researcher with the means to more clearly identify the resources available, particularly crop residues and by-products, to a specific animal-production system. This will facilitate the decision-making process in by-product research with respect to the emphasis of the research program, the by-products and modification processes to be used, and the constraints that influence by-product utilization.

This paper outlines a farm survey, conducted in the Beheria governorate in Egypt during the 1980/1981 summer season, to assess the availability and alternate uses of crop by-products. From a sample of 300 farmers, the survey indicated that maize and cotton stalks are used almost exclusively for fuel. Wheat and faba bean straw are used as animal feed. By-product research, to improve the utilization of these by-products, would appear to have potential for improving the animal-production systems in the Beheria governorate.

Des études au niveau des fermes peuvent permettre aux scientifiques effectuant des recherches sur les sous-produits de mieux déterminer quelles ressources sont disponibles, particulièrement en ce qui concerne les résidus de récoltes et les sous-produits, au sein d'un système spécifique d'élevage. Elles faciliteront la prise de décisions lors de recherches sur les sous-produits, pour ce qui a trait au principal objectif du programme de recherches, aux sous-produits et aux processus de transformation devant être utilisés et les facteurs limitants de leur utilisation.

Ce document décrit une étude effectuée dans des fermes du gouvernorat de Beheria, en Égypte, au cours de l'été 1980–1981, pour évaluer la disponibilité et les possibilités d'utilisation des sous-produits des récoltes. Après étude des exploitations de 300 fermiers, ces recherches indiquèrent que les tiges de maïs et de coton sont utilisées presque exclusivement comme combustible et que la paille de blé et de féveroles sert à l'alimentation des animaux. Il semble que la recherche sur les sous-produits, pour améliorer leur utilisation, permettrait d'améliorer la production animale du gouvernorat de Beheria.

Un estudio de finca puede ayudar a que el investigador en subproductos identifique màs claramente los recursos disponibles para un sistema específico de producción animal, particularmente residuos y subproductos agrícolas. Esto facilitarà la decisión sobre el ènfasis del programa de investigación, los subproductos y procesos de modificación que seràn usados y las limitaciones que influyen en el uso de los subproductos.

Este trabajo describe un estudio de finca, realizado en la gobernación de Beheria en Egipto durante el verano de 1980/1981, con el fin de evaluar la disponibilidad y alternancia en el uso de los subproductos agrícolas. A partir de una muestra de 300 agricultores, la encuesta señaló que las cañas de maíz y algodón eran usadas casi

[1] Summarized for publication and presented at workshop in Dr Sultan's absence by Dr M.A. Naga and G.R. Potts.

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exclusivamente como combustible, mientras la paja del trigo y el haba se usaba como alimento animal. La investigación para mejorar la utilización de estos subproductos parece tener el potencial de mejorar los sistemas de producción animal en Beheira.

In 1978, animal production in Egypt accounted for about 26% of the total value of agricultural output. In rural areas, animals provide a substantial part of the labour required for farming, particularly land preparation, pumping of irrigation water, threshing, and transportation.

The major constraint to the livestock sector in Egypt is a lack of feedstuffs, in terms of quantity and quality, especially during the summer season. From June to November, available green forage consists of small amounts of darawa (densely planted maize) and the lower leaves stripped from maize and sorghum plants. Limited amounts of wheat straw and commercial concentrates are also fed to livestock during the summer season.

To more clearly focus research efforts on appropriate by-products, it is of great importance to recognize the extent of the availability of by-products for the purpose of animal feeding. In many instances, alternative uses of many by-products preclude their utilization in animal-feeding systems. A farm survey was conducted during the 1980/1981 summer season in the Beheria governorate to assess the availability and alternate uses of crop by-products.

Sampling and Data Collection

The Beheria governorate was chosen for the survey because the animal population in Beheria represents about 12.4% of the total animal population of Egypt. The Damnhour district in the Beheria governorate was selected for the farm survey because it contains the largest number of fattening (about 15 000) and milking (about 6000) animals of all of the 15 districts in the governorate. A stratified random-sampling technique was used to obtain a sample of 300 farmers, representing about 1.4% of the total landholders in the surveyed area. Frequent meetings were held with district agricultural officers, who conducted the interviews, so that they would be familiar with the objectives of the survey. The distribution of farmers in the sample, based on numbers of animal units, is presented in Table 1.

A questionnaire was designed to collect information on the number of animals owned, area of green forage produced on the farm, amount of concentrate purchased, types and amounts of by-products used, amounts of by-products purchased or sold, and age and education level of the farmer.

Results

Table 2 presents the structure of the animal population in the Damnhour dis-

Table 1. Size of animal-production units in the Damnhour district sample (1980).

Class	Number of animal units[a]	Number in sample
Small	<15	170
Medium	15–29	100
Large	≥30	30

[a] Animal units were calculated as follows: cattle, 1.00; buffalo, bulls, 1.25; sheep, 0.07; goats, 0.10; mules, 0.75; donkeys, 0.50; camels, 0.75; horses, 1.00; small calf, 0.25; and small buffalo calf, 0.30.

Table 2. Distribution of animal population in the Damnhour district sample.

		Equivalent animal unit[a]	
	Number of animals	Number	Percentage of total
Cattle			
Above 2 years	540	540	
Under 2 years	2700	675	42
Bulls	218	273	
Buffalo			
Above 2 years	771	964	
Under 2 years	2462	739	49
Bulls	29	36	
Donkeys	518	259	7
Sheep	47	3	
Goats	171	17	
Mules	2	2	2
Camels	48	36	
Horses	6	6	
Total	7512	3550	

[a] Animal units calculated as in Table 1.

Table 3. Area cropped and production of major crops in Damnhour district.

Crop	Area (ha)	Main output (t/ha)	By-product production (t/ha)
Wheat	272	2218	3353
Faba bean	77	547	631
Rice	234	1461	1873
Cotton	257	495	1730
Maize	196	1752	1649

trict. Buffalo and cattle represent 49 and 42%, respectively, of the total animal units in the district. These animals provide milk, meat, power, and manure for the farming system.

Wheat and berseem are the dominant winter crops, whereas cotton, rice, and maize are the major crop enterprises during the summer season. Table 3 indicates the area cropped and production of these crops in the sample.

Crop by-products are used primarily on the farm but some are marketed as shown in Table 4. Farmers in the survey sold about 15% of their rice straw, cotton stalks, and maize stalks. Wheat straw was the major by-product purchased by farmers, amounting to about 44% of the farm production of wheat straw.

Table 5 indicates the utilization of the crop by-products on the farms in the survey. All crop by-products are presently fully utilized for one purpose or another. Maize and cotton stalks are used almost exclusively for fuel. Wheat, and to a large extent faba bean straw, are presently used for animal feeding. Other alternative uses for the by-products include bedding and making mud bricks.

Conclusions

The survey found that the major crop by-products are fully utilized on the farms. With the strong preference for cotton and maize stalks as fuel sources, it appears unlikely that these by-products could be considered for use in animal-feeding systems. Should they be used for animal feeding, however, alternative energy sources for home use would need to be provided. Improving the utilization of wheat, faba bean straw, and rice straw, through by-product research, would appear to have potential for improving the animal-production system because these by-products are already being used for animal feeding.

Table 4. Net availability (tonnes) of selected crop by-products in Damnhour district.

	Wheat straw	Faba bean straw	Rice straw	Cotton stalks	Maize stalks
Farm production	1409	265	787	727	693
Purchased	625	12	35	5	21
Sold	21	59	107	115	112
Net availability	2013	218	715	617	602

Table 5. Utilization of crop by-products in Damnhour district.

	Wheat straw	Faba bean straw	Rice straw	Cotton stalks	Maize stalks
Availability	2013	218	715	617	602
Utilization (%)					
Bedding	1	3	60	1	—
Animal feeding	98	71	—	—	—
Fuel	1	5	40	99	100
Brick making	—	21	—	—	—

Discussion of the Role of Farm Systems in By-Product Research

Gordon R. Potts[1]

Several considerations of farm surveys are highlighted. An aggregate survey, using secondary data based on national production statistics, provides some indication of the potential availability and geographical distribution of by-products. A localized farm survey is used, however, to determine the actual availability of by-products to a specific animal-production system. By identifying several major characteristics of farmers in a particular animal-production system, a sample of 30 farmers is deliberately selected for the survey. The survey questionnaire should focus on the critical information needed by the researcher to implement an applied research program, including the animal enterprise, feeding system, crop production, and farm resources. Throughout the survey, collaboration between researcher and farmer should be encouraged, through the use of repeated visits, open-ended questions, and technical assistance, to obtain the maximum benefit of the farmer's specialized knowledge of by-product utilization.

Ce document met l'accent sur plusieurs points à inclure dans les enquêtes administrées dans les exploitations agricoles. Une étude globale, faite à partir de données secondaires tirées des statistiques de production nationale, fournit des indications sur l'éventuelle disponibilité de sous-produits et leur répartition géographique. Une enquête locale, au niveau des fermes est cependant en train d'être effectuée pour déterminer quels sous-produits sont réellement disponibles pour le système d'élevage en usage. Trente fermiers ont été choisis d'une manière précise pour cette étude, c'est-à-dire après avoir déterminé un certain nombre de caractéristiques propres aux exploitants agricoles d'un système de production animale particulier. Le questionnaire utilisé visera à obtenir des informations importantes, dont le chercheur a besoin pour mettre sur pied un programme de recherche appliquée ; les questions porteront sur les exploitations d'élevage, le système d'alimentation des bêtes, les types de cultures et les ressources agricoles. Tout au long de cette étude, la collaboration entre le chercheur et le fermier devrait être encouragée, par des séries de visites, des questions posées sans idées préconçues et de l'assistance technique, afin de tirer le maximum de profit des connaissances spécialisées du fermier en utilisation des sous-produits.

Se destacan varias consideraciones en relación con los estudios de fincas. Un estudio agregado, que emplea información secundaria basada en las estadísticas de producción nacional, ofrece indicios sobre la disponibilidad potencial y la distribución geográfica de los subproductos. Sin embargo, se emplea un estudio localizado de finca con el fin de determinar la disponibilidad real de los subproductos para un sistema específico de producción pecuaria. Al identificar varias de las principales características de los agricultores de un sistema particular de producción pecuaria, se selecciona deliberadamente del estudio una muestra de 30 agricultores. El cuestionario del estudio debe centrarse en la información crítica que el investigador necesita para poner en práctica un programa de investigación aplicada, incluyendo la empresa pecuaria, el sistema de alimentación, la producción de cultivos y los recursos agrícolas. A lo largo del estudio, debe estimularse la colaboración entre el investigador y los agricultores, mediante el uso de visitas repetidas, preguntas abiertas y asistencia técnica, con el fin de obtener el máximo beneficio del conocimiento especializado de agricultor sobre la utilización de los subproductos.

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For a farm survey to be an appropriate tool for conditioning the scope and direction of the by-product research program, it is imperative that it be designed to provide the critical types of information required by the by-product researcher to establish research priorities. This implies that the by-product researcher and agricultural economist, who traditionally conducts the farm survey, must interact effectively to develop a questionnaire that focuses on the key issues related to utilization of by-products in an animal-feeding system. The need for more detailed and comprehensive surveys on particular areas of the animal-production system may be identified as a result of the initial farm survey, and these can be conducted as the research program proceeds. Initially, however, the farm survey should involve a relatively brief investigation of the animal-feeding system and the role of by-products in that system to provide the researcher with sufficient information to set priorities in the research program.

In this paper, for simplicity of presentation, the beneficiary of by-product research is the farmer. Other appropriate beneficiaries, however, might include feedlot and feed-mill operators.

Aggregate Survey

The survey most often encountered in by-product research consists of aggregate data that indicate the amount of by-products *potentially* available on a regional or national basis. The information is usually calculated using crop-production data in which a predetermined percentage of the crop is assumed to be crop by-product. This information, often from secondary data sources, can be supplemented by contacts with knowledgable agricultural officials and farmers to provide an indication of what geographical area or type of animal-production enterprise would benefit most from applied research oriented to by-product utilization for animal feed. A second type of by-product survey involves primary-data collection using a randomized stratified sample, representative of the total population through selection of a sufficiently large sample. This type of survey does provide some indication of the *potential* availability and geographical distribution of by-products. A greater degree of specificity is needed, however, to enable the researcher to develop an applied research program. This includes a definition of which animal-production system will use the results, what by-products are actually available to this particular animal-production system, and what resource constraints limit the utilization of by-products in animal feeds.

Localized Survey

To provide specific information for the by-product researcher, a farm survey that is focused on particular animal-production systems is suggested. This more precise focusing of research is necessary because the best type of by-products, their collection, modification, handling, and incorporation into a feeding regime will be different for different animal-production systems. To maximize the utility of the information to the researcher, while minimizing costs of data collection, in terms of time and manpower, the researcher must make conscious, deliberate choices to narrow the scope of the survey. Using available secondary information and the expertise and experience of the researcher, one or two specific animal-production systems should be identified that represent substantial numbers of farmers.

The selection of specific production systems by the researcher is based on several criteria: (1) Selected animal-production systems should represent a major proportion of animal producers in the area, e.g., in the methodology used for cropping-systems research in Asia, it is suggested (as a rule of thumb) that 3–4 identified land types (comparable to animal-production systems in this paper) represent 70–80% of the farms of the area (Zandstra et al. 1981). (2) There must be some potential for improving the animal-production system using by-products. (3) The study area must be accessible for survey purposes and, later, research activities. The differentiation of a particular animal-production system (e.g., goat's-milk production) into two or more related enterprises (e.g., by-product or grazing based) is only justified if the enterprises are sufficiently different to expect that different feeding regimes will be recommended for each enterprise.

Using these criteria and the expertise of the researchers, several major characteristics of the production systems (e.g., herd size, farm size, land quality, major cropping system) should be identified to enable the selection of farmers that are representative of each production system. The researcher then selects about 30 farmers as the sample for each animal-production system, e.g., small-farm dairy producers in Egypt may be characterized as having farms of less than 2 ha, fewer than five animals, and primarily buffalo-milk animals. To facilitate the decision-making required in this process, the researcher may visit (for less than 1 week) the target area to carry out an informal survey with colleagues or local extension staff. Through discussions and observations, the researcher gains a more precise understanding of the production systems, farmer characteristics, and possible survey questions.

Survey Questionnaire

Survey questionnaires have traditionally been used to collect data, often without careful examination of the information needed or the ultimate use of the results. The by-product researcher needs to clarify and specify the critical types of information required to make decisions about the applied research program to be implemented. This is particularly important if the by-product researcher is not directly involved in the data-collection process. To ensure that the proper data are collected, the by-product researcher must provide considerable input into the design of the questionnaire to counteract the tendency to collect too much information that cannot be analyzed easily or quickly.

The specific information required from a farm survey is a function of the animal-production systems under investigation. If purchased feeds are not important in the systems, minimize the questions on this aspect in the survey. The following represent major categories of information that can be collected using a farm-survey questionnaire.

(1) Animals on farm: types and numbers only; data on ages are not usually considered to be critical information.

(2) Feeding system: feed ingredients (forages, concentrates, protein or energy sources); quantities fed; quantities purchased; and cost of feed ingredients.

(3) Animal-production system: description of system, i.e., housing, cut and carry/grazing, management (when fed, use for labour, performance), and major diseases; priority given to animal production; cash expenditures for animal production; and farmers' objectives in animal production (cash, traction, food, herd replacement).

(4) Crop production: as it relates to by-products in terms of quantities available (by month or quarter), alternative uses, costs, and quantities purchased/sold.

(5) Farm resources: farm size and fragmentation; labour, i.e., family/hired, cost; cash availability (willingness to spend cash for animal feeding or care); technical knowledge (use of fertilizers, chemicals, and other farm innovations); and power availability, i.e., animal, mechanical, hired or owned.

(6) Open-ended questions: This category looks at questions such as: What improvements would the farmer suggest for the animal-production system and with regard to which animals? What is the farmer's response to suggested alternative solutions involving by-products? These open-ended questions provide the researcher with an important opportunity to probe the thinking of the farmers, confirm or refute hypotheses about possible by-product research, and gain the confidence of the farmers.

Farmer Participation

To realize the full potential of a farm survey, it is imperative that the farmer be regarded as a collaborator, i.e., one who has specialized knowledge of available resources and who can assist the researcher in setting research priorities. The emphasis on collaboration must permeate all aspects of farmer–researcher interaction and should begin with the survey. Collaboration is enhanced by conducting the survey over several visits. Repeat visits not only establish credibility and build rapport but also enhance the reliability of recall information because the time elapsed between visits is minimized. Later in the research process, opportunities for on-farm testing of technologies are more readily identified, using interested farmers from the survey.

The researcher, if personally involved in the survey, is in a position to identify key informants who have been particularly candid and thoughtful in responding to the survey questions. These farmers can be very helpful sources of informal, detailed information concerning the place of by-products in the animal-production system.

Collaboration between researcher and farmer, to be fully effective, implies that both individuals must benefit from the interaction. The more immediate the benefit, the greater the interest in and commitment to collaboration. The researcher immediately benefits from the survey due to the information gained. The farmer, on the other hand, often receives little direct benefit from answering the survey questions. To encourage farmer interest and participation, the researcher should attempt to provide some concrete assistance to the farming system. This may take the form of supplying a simple improvement technique, known as the best-bet idea, for the animal-production system, e.g., simple molasses supplementation may be possible. Immediate assistance to the farmer will reinforce the interest of the researcher in the total farming activity and not just the responses to survey questions.

Conclusions

The farm system can be very beneficial to the researcher in planning the activities of by-product research. To realize this benefit, the researcher must carefully specify the critical information required to set research priorities. This will tend to minimize the time spent on data collection and the cost of conducting the farm survey. Throughout, the researcher, in interacting with farmers, needs to emphasize the collaborative nature of the relationship to fully utilize the valuable knowledge of the farmers in using by-products in animal feeds.

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Session V Discussion: On-Farm Research (OFR) Techniques

The paper by Drs Agarwal and Verma provides a clear demonstration of the importance of on-farm testing of feeding systems based on by-products. This research provides the only valid means of evaluating the performance of improved animal feeding methods and their suitability for a given production system. During the discussion of this paper, the value of OFR was emphasized for identifying heretofore unrecognized constraints faced by farmers in the use of by-products. The effects of a limited water supply and the absence of straw chopping equipment were highlighted.

An important side effect of using urea-treated straw, in northern India and Bangladesh, is the increased animal consumption of the straw in communities where insufficient straw is available to satisfy present demands of animals. This points to the importance of separately understanding the relative contribution to animal performance derived from improved nutritional value as opposed to increased intake. Where straw availability is limiting, it was felt that further research is needed to determine the most appropriate level of urea-treated straw to be fed to animals. Finally, it was stressed that the increased voluntary intake will make straw shortages more acute and may lead to a sharp increase in straw prices.

Several participants commented on the difficulties related to the design and execution of on-farm research and on the limits the farm setting places on measurement techniques. The use of blocking of treatments to remove effects of animal size or influences of farm family of village on treatments, although considered desirable to remove these sources of variation, was thought to be difficult because of the small number of animals that can be included in these studies if research costs are to be kept low.

Farmers were found apt to interfere with the management of untreated (check) animals where treatment differences are substantial. Researchers, therefore, found that they had to assure close supervision of on-farm trials. Others decided to separate (e.g., in different villages) animal groups that receive different treatments. This, however, was felt to lead to the possibility of confounding treatment effects with village characteristics.

The heart-girth technique for estimating live-weight gain was considered to be an effective tool for on-farm research. Relationships between the heart-girth measurement and weight should be developed for each animal type (breed) and care should be taken to qualify the measurements with a statement on the animal's condition, particularly for animals with very low or very high body weights.

Most participants agreed that the nylon (Dacron) bag technique for estimating digestibility of low-quality roughages was very useful as a backup procedure at the research station. The method, however, requires a well-trained technician and fistulated animals. Participants also felt that caution was needed when extrapolating digestibility results obtained from a well-conditioned animal to animals on a different diet and management regime.

The effect of regional, village, and farm-level constraints on the performance of by-product based feeding systems, so clearly demonstrated in the paper by Drs Agarwal and Verma, shows the importance of a detailed study of the production system in which researchers seek to incorporate the feeding of by-products. The joint presentation of Dr Naga and G. Potts of the survey work described by Dr Sultan provided insight into survey methodology and the role and contribution of surveys in by-product research.

Considerable emphasis was placed on limiting the scope of surveys to avoid unmanageable data loads and to provide a focus for analyses. Particularly important in this respect is a clear identification of the targeted production system(s), a small sample size (about 30) for each system, and careful screening of information to be collected.

Discussants emphasized that the relevant questions to be asked would depend upon the type of production system considered. For this reason, it was felt that these questions should be identified by the animal scientist and economist and should consider the research objectives and characteristics of the target system.

The need for more precise national inventories of by-product availability and demand was raised. It was stressed that these macrosurveys could often be prepared from existing production statistics. It was felt that such inventories should also take into account the effects of seasonality and regional differences in the agricultural production of a country on by-product availability and costs.

Although national inventories can provide insight into the potential for using by-products in animal production, the concern among participants was that they do not provide sufficient insight into the factors that control by-product use at the farm level. It was felt that detailed studies within one or a few well-defined production systems were required to assure relevance and applicability of research on the use of by-products to the farmer.

Several participants agreed with the observation by the speakers on important spin-offs obtained from on-farm surveys. The farm community became more aware of by-product research results and was partly prepared for participating in on-farm testing. Extension staff involved in the surveys also became more aware of the potential of by-product research and were better prepared to contribute to future on-farm evaluation of research results.

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