Better utilization of crop residues and by-products in animal feeding: research guidelines

2. A practical manual for research workers

Prepared by
T.R. Preston
FAO Consultant

The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

M-23
ISBN 92-5-102422-7

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying or otherwise, without the prior permission of the copyright owner. Applications for such permission, with a statement of the purpose and extent of the reproduction, should be addressed to the Director, Publications Division, Food and Agriculture Organization of the United Nations, Via delle Terme di Caracalla, 00100 Rome, Italy.

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS Rome, 1986
© FAO

Hyperlinks to non-FAO Internet sites do not imply any official endorsement of or responsibility for the opinions, ideas, data or products presented at these locations, or guarantee the validity of the information provided. The sole purpose of links to non-FAO sites is to indicate further information available on related topics.
Better utilization of crop residues and by-products in animal feeding: ... http://www.fao.org/DOCREP/003/X6554E/X6554E00.htm#TOC

CONTENTS

Preface

1: EXTRACTION RATES: CEREAL AND GRAIN LEGUMES

2: GUIDELINES FOR ESTABLISHING FEEDING SYSTEMS FOR RUMINANTS

2.1 GENERAL CONSIDERATIONS

2.1.1 Introduction

2.1.2 Limitations to “conventional” feeding standards

2.1.3 An alternative approach

2.1.4 Animal response to non-conventional feed resources

2.1.5 Nutritive value

2.2 RELATING NUTRIENT SUPPLY TO PRODUCTIVE STATE

2.2.1 Introduction

2.2.2 Work

2.2.3 Maintenance

2.2.4 Growth

2.2.5 Reproduction

2.2.6 Milk production

2.2.7 Wool or hair production

2.2.8 Carry-over effects of balancing nutrients in early life

2.3 PRINCIPLES OF SUPPLEMENTATION

2.3.1 Select the basal carbohydrate-rich resource

2.3.2 Fermentable N

2.3.3 Highly digestible forage

2.3.4 Bypass protein

2.3.5 Long-chain fatty acids (LCFA)?

2.4 CATEGORIZATION OF FEED RESOURCES

2.4.1 Fermentable carbohydrate

2.4.2 Fermentable nitrogen

2.4.3 Supplements which contribute to an efficient rumen ecosystem

2.4.4 Bypass protein

2.4.5 Bypass starch and glucogenic precursors

2.4.6 Long chain fatty acids

2.4.7 Feeds and other materials with a capacity to manipulate the rumen microbial biomass

2.5 ALTERNATIVE SOURCES OF SUPPLEMENTS

2.5.1 Livestock excreta

2.5.2 Legume forages and foliages from food crops

2.5.3 Attributes of legumes as supplements

3: METHODOLOGY FOR THE EVALUATION OF FEED RESOURCES FOR RUMINANTS

3.1 INTRODUCTION

3.2 DEFINITION OF CROP RESIDUES AND AGROINDUSTRIAL BYPRODUCTS

3.3 CATEGORIES OF BYPRODUCTS

3.4 ASSESSING NUTRITIVE VALUE

3.4.1 To determine the rate of degradation in the rumen? (Stage 1)
Better utilization of crop residues and by-products in animal feeding: ...

3.4.2 Chemical analyses (Stage 2)
3.4.3 Test the feed with animals (Stage 3)
3.4.4 Parameters of rumen function (Stage 4)
3.4.5 Animal feeding trials (Stage 5)
3.4.6 Production trials (Stage 6)

3.5 HOW TO MEASURE IMPROVEMENT IN NUTRITIVE VALUE CAUSED BY CHEMICAL, PHYSICAL OR BIOLOGICAL TREATMENTS

4: GUIDELINES FOR THE UTILIZATION OF BYPRODUCTS BY PIGS AND POULTRY

4.1 INTRODUCTION
4.2 ELABORATION OF AN INVENTORY OF BYPRODUCTS USABLE BY MONOGASTRIC SPECIES
4.2.1 Byproducts of animal origin
4.2.2 Byproducts of plant origin
4.2.3 Unconventional feed resources

4.3 THE ECONOMIC AND PRACTICAL FEASIBILITY OF UTILIZING BYPRODUCTS IN PIG AND POULTRY PRODUCTION
4.4 DETERMINATION OF TOXIC AND HARMFUL SUBSTANCES IN BYPRODUCTS
4.5 PROPOSED METHODS FOR TREATMENT OF BYPRODUCTS CONTAMINATED WITH TOXIC OR HARMFUL SUBSTANCES

5: EXPERIMENTAL EVALUATION OF A BYPRODUCT FOR PIGS AND POULTRY

5.1 PRELIMINARY EVALUATION
5.1.1 Chemical analysis
5.1.2 Palatability and toxicity trials
5.1.3 Determination of the optimum range of inclusion
5.1.4 Feeding trials using target animals

5.2 PRECISE TECHNIQUES FOR EVALUATION OF A BYPRODUCT
5.2.1 Metabolizable energy for poultry
5.2.2 Digestible energy for pigs
5.2.3 Amino acids
5.2.4 Remarks

5.3 FEEDING TRIALS AND APPLICATION
5.4 PRIORITIES ON TESTS AND INVESTMENTS

6: ANALYTICAL METHODS FOR CHARACTERIZING FEED RESOURCES FOR RUMINANTS

6.1 INTRODUCTION
6.2 FACILITIES
6.2.1 Individual pens
6.2.2 Other facilities

6.3 RUMEN FISTULATION
6.3.1 Background
6.3.2 Principle of the method
6.3.3 Facilities and equipment
6.3.4 Preparation of the animal

6.3.5 The surgery
Better utilization of crop residues and by-products in animal feeding:

6.4 MANUFACTURE OF RUMEN CANNULAS FROM LOCALLY AVAILABLE MATERIALS
6.4.1 Available materials
6.4.2 Construction of cannulas from radiator tubing
6.4.3 PVC cannulas

6.5 RUMEN INCUBATIONS WITH NYLON BAGS
6.5.1 Characteristics of the bag
6.5.2 Sample size
6.5.3 Preparation of samples for incubation
6.5.4 Position of bags in the rumen
6.5.5 Incubation times of bags in the rumen
6.5.6 Replication of measurements
6.5.7 Use of sheep or cattle
6.5.8 Interpretation
6.5.9 Characterizing the rumen ecosystem

6.6 THE USE OF RUMEN AMMONIA CONCENTRATION TO DETERMINE WHEN UREA SUPPLEMENTATION IS NECESSARY
6.6.1 Introduction
6.6.2 Estimation of rumen concentration - field method
6.6.3 Laboratory techniques for estimation of rumen ammonia

6.7 GAS LIQUID CHROMATOGRAPHY OF VOLATILE FATTY ACIDS IN RUMINAL FLUID
6.7.1 Column packing
6.7.2 Method
6.7.3 Operating procedures
6.7.4 Preparation of rumen fluid for GLC with an internal-standard
6.7.5 Sample preparation
6.7.6 Calculation of total VFA concentration and VFA proportions using the internal standard method

6.8 ACETATE CLEARANCE AS AN INDICATOR OF THE BALANCE OF ABSORBED NUTRIENTS
6.8.1 Background
6.8.2 Hypothesis
6.8.3 Method
6.8.4 Injection solution
6.8.5 Blood samples
6.8.6 Chemical analysis
6.8.7 Gas-liquid chromatograph
6.8.8 Column
6.8.9 Calculations

6.9 ASSAY FOR BYPASS PROTEIN IN A SUPPLEMENT
6.9.1 Validation
6.9.2 Preparation of formaldehyde treated casein as a standard for the wool growth assay

6.10 CHEMICAL ANALYSIS OF FEED AND FAECES
6.10.1 Preparation of samples
6.10.2 Moisture
6.10.3 Ash
6.10.4 Kjeldahl Nitrogen determination

6.11 COLLECTION OF RUMINAL FLUID BY OESOPHAGEAL TUBE

6.12 TREATMENT OF STRAW AND OTHER FIBROUS ROUGHAGES TO INCREASE THE POTENTIAL NUTRITIVE VALUE
6.12.1 The principle
6.12.2 Wet ensiling with urea
6.12.3 The use of animal urine to ammoniate straw
6.12.4 Ammoniation of straw with gaseous ammonia
6.12.5 Ammoniation of straw with aqueous ammonia
6.12.6 Ammoniation with application of heat
6.12.7 Ammoniation with dry chemicals

7: VILLAGE/FARM SURVEYS AND ON-FARM TRIALS
7.1 INTRODUCTION
7.2 ATTITUDES
7.3 METHODOLOGY
7.3.1 The village survey on feed supply
7.3.2 Animal production systems
7.3.3 Introduction of innovations
7.4 CONCLUSIONS

8: REFERENCES

PREFACE

The purpose of this Manual is to assist researchers in developing countries, especially those in the tropics, to develop livestock feeding systems based on the available resources which are mainly crop residues, dry and/or mature pastures and agroindustrial byproducts.

The need for an alternative to the traditional methods of feed analysis was first raised at an Expert Consultation on New Feed Resources held in FAO Headquarters, Rome in November 1976. At that meeting data were presented to show that the conventional feeding standards, derived from research with feeds of temperate country origin, were of limited value when applied to the crop residues, dry pastures and sugar-rich agroindustrial byproducts which made up the feed inventory in most tropical countries.

As a follow-up to this meeting a small network involving institutions from Cameroon, Nigeria and Senegal was set up by FAO to promote research on several locally available crop residues and agroindustrial byproducts.

An FAO Seminar was organized in collaboration with the International Livestock Centre for Africa (ILCA), and held in Dakar, Senegal in September 1981. At this meeting, which addressed specifically the problems of utilizing feed resources in Africa, the first results of the Network were presented. During this discussion it became apparent that apart from the conceptual difficulties of applying in Africa the animal nutrition knowledge gained in Europe and North America, there were other serious limitations of lack of infrastructure, especially laboratory equipment and the means of servicing, coupled with irregularities in electricity supplies. Communication among researchers working with tropical feed resources was found to be another limiting factor. It was resolved to extend the activities of the original Network to other countries in Africa and to join forces with the recently formed African Research Network on Agroindustrial Byproducts (ARNAB). It was proposed that the International Livestock Centre for Africa, with its comprehensive documentation and laboratory analytical facilities, should provide the coordinating role.
The conclusions and recommendations from the Dakar meeting were that there was a need to develop more appropriate procedures for evaluating crop residues and by-products, taking into account the limited laboratory facilities of most institutions in Africa; and the nature of the livestock production systems, where multipurpose traits such as draught power, ability to survive extended dry seasons and rural (transhumant) milk supply were of greater relevance than the technologies from industrialized countries which emphasize specialized meat and milk production.

The third meeting of the series was also organized jointly by FAO and ILCA at Addis Ababa in March 1984 and addressed the specific issue of methodologies both for feed evaluation and research on livestock feeding systems. The advantages of promoting communication among different tropical regions was emphasized by drawing on participants from Latin America, Asia and Africa to share their experiences with each other and with colleagues from Europe and North America, which have specific expertise to offer in the subject area.

The Consultation was charged with producing two documents: the Proceedings dealing with the State of the Art of research into crop residues and by-products; and a practical manual to serve as a guide for field workers, especially those operating with minimum facilities in terms of laboratory and literature support.

Ruminants have received more attention than monogastrics. This is because, in tropical countries, they are generally the more important species from both the numerical and socio-economic viewpoints. Furthermore, their physiological adaptations enable them to harvest and digest feeds, which are not available to the monogastric species, and which ipso facto are not competitive with humans for their food supply.

The basis outline of the Manual was established by the participants of the Addis Ababa Consultation. Material for Chapters 3, 4 and 5 was provided by the Working Groups on Ruminants and Monogastrics, under the guidance respectively of Drs E.R. Orskov and N. Jayasuriya (ruminants) and M. Picard and M. Cuca (Monogastrics). Professor Frands Dolberg, although not a participant, contributed his wealth of experience in India and Bangladesh to Chapter 7 on Village and Farm Surveys and Innovations. Chapters 2 and 6 are based on material from a book “Matching Livestock Systems with Available Feed Resources” to be published by ILCA under the joint authorship of Professor R.A. Leng and the Technical Editor. Mark Powell, of the ILCA Sub-humid Programme in Kaduna, Nigeria provided the material for harvest indices. René Sansoucy, Animal Production Officer (Feed Resources), FAO, HQ made a critical review of the manuscript and his comments have been incorporated.
Chapter 1: EXTRACTION RATES: CEREAL AND GRAIN LEGUMES

The first step in estimating the availability of crop residues for animal feed is to determine the crops grown and the proportions of the land area that are devoted to the predominant crops. Information on cropping patterns on a national and/or regional basis can be obtained from FAO, Ministries of Agriculture, National and International Crop Research Institutes and the scientific literature.

Selected surveys at the farm level for major cropping patterns are required to assess the current use of the crop residues either as animal feed or for alternative purposes (eg: fuel and construction) and the potential quality of the residue when it becomes available for animals. For example, maize is widely cultivated in the tropics but is often inter-cropped, and allowed to dry completely before harvesting, so the residue (stover) is of low feeding value when it becomes available for grazing.

To estimate the quantity of residue produced it is possible to use the harvest index of a crop (ratio of grain: vegetative matter)(dry matter basis) so that grain yield becomes an indirect measure of the vegetative DM yield per crop. The harvest index figures may be obtained from crop research institutes dealing with the specified crops. When such data cannot be obtained, or a more direct measure is desired, grain and vegetative DM yields may be determined in situ.

When direct measurements are used, care must be taken in crop residue sampling so as to give the proportions and moisture content of plant part (leaves, stems etc.).

Relationships between grain and vegetative DM were determined under experimental and farmer conditions in central Nigeria (Table 1.1). Although the measurements were taken from various single crop and intercrop enterprises, the harvest index of the crops remained constant for the different cropping patterns (ICRISAT 1981, 1982).

However, factors such as low rainfall, planting date and densities can affect grain and DM relationships. It is therefore necessary to be cautious when using grain:vegetative DM ratios derived during years of normal rainfall distributions and timely plantings.

Table 1.1

<table>
<thead>
<tr>
<th>Crop</th>
<th>Plots(i) (n)</th>
<th>DM component</th>
<th>Regression relationship (Y=DM,X=grain in kg/ha)</th>
<th>r²</th>
<th>Total DM: grain ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorghum</td>
<td>18</td>
<td>Leaf</td>
<td>(Y=453 + 0.52X)</td>
<td>.88</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stalk</td>
<td>(Y=1040 + 2.2X)</td>
<td>.81</td>
<td>3.7</td>
</tr>
<tr>
<td>Millet</td>
<td>23</td>
<td>Leaf</td>
<td>(Y=78 + 0.92X)</td>
<td>.58</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stalk</td>
<td>(Y=178 + 3.3X)</td>
<td>.51</td>
<td>4.5</td>
</tr>
<tr>
<td>Maize</td>
<td>9</td>
<td>Leaf</td>
<td>(Y=431 + 0.28X)</td>
<td>.98</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stalk</td>
<td>(Y=699 + 0.70X)</td>
<td>.95</td>
<td>1.6</td>
</tr>
<tr>
<td>Groundnuts</td>
<td>17</td>
<td>Total</td>
<td>(Y=300 + 0.83X)</td>
<td>.91</td>
<td>1.2</td>
</tr>
</tbody>
</table>

(i) Number of 50 m² plots from which all grain and residue was harvested; 11 sorghum and 13 millet plots were 100 m² in farmers’ fields

Table 1.2

Mean values (\( \bar{x} \)) and standard deviation (s) for percentage composition(i) of sorghum, millet, maize and groundnut residue in Central Nigeria (Powell 1985)

<table>
<thead>
<tr>
<th>Component (i)</th>
<th>Sorghum</th>
<th>Millet</th>
<th>Maize</th>
<th>Groundnut</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \bar{x} )</td>
<td>s</td>
<td>( \bar{x} )</td>
<td>s</td>
</tr>
<tr>
<td>Panicles</td>
<td>1 .5</td>
<td>2 .5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Upper leaves</td>
<td>9 3</td>
<td>9 3</td>
<td>14 2</td>
<td>-</td>
</tr>
<tr>
<td>Lower leaves</td>
<td>13 1</td>
<td>12 3</td>
<td>20 3</td>
<td>-</td>
</tr>
<tr>
<td>Upper stalk</td>
<td>24 5</td>
<td>29 3</td>
<td>18 2</td>
<td>-</td>
</tr>
<tr>
<td>Lower stalk</td>
<td>53 7</td>
<td>48 3</td>
<td>48 3</td>
<td>-</td>
</tr>
</tbody>
</table>

All leaves 38 3
Entire stem 35 5
Roots 27 4

(i) 8 to 9 plots (50m²) from which the residue was fractionated into morphological components. For groundnut, 10 plants were selected at random from each plot and fractionated

(ii) As percentage of total stover dry matter

Because plant parts vary in their relative nutrient content and digestibility, residue components may be divided into upper and lower plant parts (Table 1.2). Such a separation may be desirable for predicting the relative contribution of each plant part in the total crop residue diet.
2. GUIDELINES FOR ESTABLISHING FEEDING SYSTEMS FOR RUMINANTS

2.1 GENERAL CONSIDERATIONS

2.1.1 Introduction

In order to develop feeding systems it is necessary to relate information on the nutritional characteristics of feed resources with the requirements for nutrients according to the purpose and rate of productivity of the animals in question. In the industrialized countries, this information has been incorporated in tables of “Feeding standards” which interpret chemical analyses of feed resources in terms of their capacity to supply the energy, amino acids, vitamins and minerals required for the particular productive purpose. These standards are steadily becoming more sophisticated with the aim of improving their effectiveness in predicting rates of performance of intensively-fed livestock and to derive least cost formulations.

2.1.2 Limitations to “conventional” feeding standards

The relevance of feeding standards for developing countries, particularly those in the tropics, has been questioned from the socio-economic (Jackson 1980) and technical (Graham 1983; Preston 1983) viewpoints. It has been apparent for many years that feeding standards based on assigned nutritive values (eg: net energy) are misleading when unconventional feed resources are used (eg: Preston 1972; Leng and Preston 1976; Gaya et al 1981), since the levels of production achieved may be considerably less than the level predicted. More importantly, this often led to the rejection of many available feed resources which apparently were too low in digestible energy to supply the energy needed for production. It also encouraged researchers to copy feeding systems used in temperate countries which are relatively “predictable”, but which require feed resources that are unavailable and/or inappropriate on socio-economic grounds, in most developing countries.

2.1.3 An alternative approach

The justification for a new approach to the development of feeding systems for ruminants, not based on conventional “feeding standards”, is that:

- The efficiency of the rumen ecosystem cannot be characterized by any form of feed analysis
- Feed intake on some diets bears no relationship to digestibility and is much more influenced by supplementation
- Availability of amino acids cannot be inferred from the crude protein content of the diet
- The energy value of a diet, and the efficiency of its utilization, are largely determined by the relative balances of glucogenic energy, long chain fatty acids and essential amino acids absorbed by the animal
In the early 1960s, Professor Max Kleiber had expressed a similar concern for these issues and stated (as quoted by Kronfeld 1982) “...metabolizable energy is not a homogeneous entity; instead it represents an assembly of nutrients or metabolites each of which is used with a specific efficiency for a particular purpose”. To this could be added that the availability of these nutrients, and their interactions, affect the efficiency of energy utilization.

The misconceptions inherent in any system based primarily on feed analysis are that it is almost impossible to predict:

- Whether the feed can support efficient rumen function
- The nature, amounts and the proportions of the end products of fermentation digestion
- The potential for rumen escape of nutrients and their digestibility in the small intestine.

For these technical reasons, and also because of differing socio-economic circumstances, it has been proposed that a more appropriate objective, especially for developing countries, is to “match livestock production systems with the resources available” (Preston and Leng 1986).

This chapter sets out the guidelines for applying these concepts to the development of feeding systems which aim to optimize the utilization of locally available feed resources and to build on traditional practices. Farming systems in developing countries are notoriously difficult to change and innovation must be introduced gradually without inducing excessive risk which may, in the poor conditions of small farmers, directly affect the well-being of the family.

2.1.4 Animal response to non-conventional feed resources

It is relevant to point out that the doubts concerning the usefulness of feeding standards for ruminants in tropical countries surfaced during development work in Cuba (Preston and Willis 1974) in the 1970's when livestock production systems were being established on non-conventional feed resources (ie: molasses-based diets). In these cases, although nutrient requirements were satisfied, according to traditional feeding standards, the responses of the animals did not correspond to the predicted levels of performance.

This research demonstrated that small inputs of bypass protein (Peruvian fishmeal) increased dramatically growth rate and feed efficiency of cattle (Figure 2.1). In contrast, this feeding system was not able to support high levels of milk production (Figure 2.2), because of the greater demands of lactation for glucogenic compounds and the relative deficiencies of these in the digestion end-products on molasses-based diets because of the low-propionate, high-butyrate fermentation (Marty and Preston 1970).

The high potential yield of animal products from a hectare of sugar cane stimulated the subsequent research in Mexico, Mauritius and the Dominican Republic that attempted to establish cattle production systems applying the principles developed for feeding molasses (both feed resources had similar concentrations of soluble sugars) (see Preston and Leng 1978a,b).

Research on the feeding value of derinded (Donefer, E. and James, L. cited by Pigden 1972) and chopped (Preston et al 1976) sugar cane demonstrated that:

- Feed intake was low even though digestibility was high (60–70%)
- The animals on this feed apparently needed glucose or glucose precursors because all the sugars are fermented, rumen propionate levels are no higher than observed on high-fibre diets, and the presence of a dense population of ciliate protozoa (Valdez et al 1977) reduces the availability of microbial protein to the animal (Bird and Leng 1985).

The implication of these two findings is that rumen function did not provide the required balance of nutrients for productive purposes (see Leng and Preston 1976).
Better utilization of crop residues and by-products in animal feeding: ...

Figure 2.1

Addition of fishmeal to a basal diet of ad libitum molasses/urea and restricted forage dramatically improves growth rate and feed conversion of cattle in Cuba (from Preston and Willis 1974)

Figure 2.2

Effect of replacing maize with molasses on the pattern of rumen fermentation and milk yield in Holstein cows. As dietary molasses increased propionic acid decreased and there was a concomitant fall in milk yield (Clark et al 1972)

Recognition of the role of fermentable N and bypass protein in low-N diets led to research aimed at increasing productivity of cattle and sheep on a range of fibre- and sugar-rich low-N feeds (Leng et al 1977; Preston and Leng 1984). Prior to this work, these feed resources were considered to have little value other than to support maintenance and were universally referred to as ‘low quality’ fibrous feeds. This led to attempts to improve the digestibility of fibrous feeds by, in particular, alkali treatment (Jackson 1977, 1978). However, the value of alkali treatment was partially obscured by the failure to recognize that the first limitation was not digestibility but the imbalance of nutrients at the level of both the rumen and the whole animal (Leng 1982; Preston and Leng 1984).

Combining alkali treatment and appropriate supplementation has led to practical rice straw-based feeding systems being applied on farms in Bangladesh (Dolberg et al 1981a; Davis et al 1983) and Sri Lanka (Perdok et al 1982; Jayasuriya 1984).

The significance of these developments is not so much the use of molasses or of straw in animal feeding, since both these feeds have been incorporated into diets of ruminants in industrialized countries for many years. The issue is the magnitude of the contribution of molasses and straw to the total dietary dry matter. In industrialized countries their contribution rarely exceeds 10–15% of the diet in the case of molasses, and 20 to 40% for straw, the rest of the ratio being cereal grains, highly fertilized grasses and legumes and oil seed cakes. In contrast, in developing countries the feeding regimes aim to incorporate these feeds as the principal component of the diet because these are the locally available resources; and there are restrictions on the use of grain for livestock feeding for financial, political and socio-economic reasons.

One characteristic of diets based on crop residues, sugar-rich agroindustrial byproducts and/or mature grasses is the magnitude of the animal response when these feed resources are supplemented with small quantities of bypass protein. These responses to bypass protein are much greater than are observed when a diet is based on cereal grain (Table 2.1).

A second feature of these diets for ruminant production is that even when they are supplemented with bypass protein, the efficiency of utilization of digestible energy is generally poorer than on diets with similar digestibility but with a large part of that energy contributed by cereal grain (see Pigden 1972; Creek et al 1976). The inefficiency of energy utilization appears to be most pronounced when the host animal has a high demand for amino acids and glucose precursors (eg: the lactating cow) (Clark et al 1972; Chopping et al 1976; Perdok et al 1982).

Table 2.1

<table>
<thead>
<tr>
<th>Species</th>
<th>Bypass protein source</th>
<th>Basal diet</th>
<th>Growth rate (g/d)</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>-BP</td>
<td>+BP</td>
</tr>
<tr>
<td>Sheep</td>
<td>Fishmeal</td>
<td>Barley grain</td>
<td>230</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>Fishmeal</td>
<td>Sugar/chaff</td>
<td>0</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>Pellet*</td>
<td>Barley straw</td>
<td>24</td>
<td>100</td>
</tr>
<tr>
<td>Cattle</td>
<td>Fishmeal</td>
<td>Molasses</td>
<td>370</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>Fishmeal</td>
<td>Cane juice</td>
<td>800</td>
<td>960</td>
</tr>
<tr>
<td></td>
<td>Fishmeal</td>
<td>Straw/concen.</td>
<td>180</td>
<td>650</td>
</tr>
<tr>
<td></td>
<td>Fishmeal</td>
<td>Ammoniated rice straw</td>
<td>100</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>Cottonseed</td>
<td>Pasture</td>
<td>-320</td>
<td>+220</td>
</tr>
</tbody>
</table>

* Contained formaldehyde-treated cottonseed meal, meat meal and fishmeal


There are many reasons why molasses and straw, when fed as the main component of a diet, perform differently than when fed as relatively minor components. Some of these differences can be explained on the basis of interactions and associated effects among nutrients, and between nutrients and the site of digestion.

In order that responses in animal productivity to supplements can be predicted accurately on a particular diet, it is necessary to take account of the constraints to metabolism. These relate specifically to the relative amounts of amino acids, glucogenic energy, VFA energy and long chain fatty acid energy in the end products of fermentative and intestinal digestion, since this is what determines the animal's productivity.

Productivity of ruminants is influenced primarily by feed intake which in turn is determined by feed digestibility and the capacity of the diet to supply the correct balance of nutrients required by animals in different productive states. Therefore the two major variables that need to be considered are:

- The amounts and balance of nutrients required
- The quantitative availability of nutrients from the diet

The balance of nutrients required depends upon:

- The amounts of dietary components unchanged by rumen fermentation that are absorbed (amino acids, glucose and long chain fatty acids)
- The rates of production of the end products of fermentative digestion (which can be highly variable)
- Productive functions (pregnancy, lactation, growth, work, maintenance, depletion or repletion of bodyweight)
- Environmental factors (disease, parasitism, temperature and humidity, and other sources of stress)

The availability of nutrients from a diet is highly dependent on:

- The microbial ecosystem in the rumen which influences the availability of microbial protein, VFA energy and glucogenic energy
- The chemical composition and physical form of the diet which influence the amounts of protein, starch and long chain fatty acids which escape the rumen fermentation.

At the present time, it is not possible to predict the nutrients required by ruminant livestock and to match these with nutrients available from digestion, because of the many interactions among the animal, its rumen microbial ecosystem and the diet.
The most widely available low-cost feeds for ruminants in the majority of developing countries are usually native pastures, crop residues and to a lesser extent agroindustrial by-products. The expensive, and often unavailable (or exported), feeds are the protein meals, derived from oilseed residues and the processing of animals, fish and cereal grains.

Generally, energy (the basic feed resource) and fermentable nitrogen (urea) are relatively inexpensive ingredients, while the sources of amino acids and glucogenic compounds (the protein meals, cereal grains and cereal by-products) are very expensive. Since it is fermentation of carbohydrate which provides the energy for microbial growth, and as the feed is often low in digestibility, it is generally desirable to supply fermentable energy on and ad libitum basis. It is therefore contra-indicated to restrict the basal diet.

As a rule of thumb, 3 g of fermentable N per 100 g of fermentable organic matter are required to meet the needs for efficient microbial growth. It is not always necessary to provide this amount since some feed protein will be fermented to ammonia and some urea-N may enter the rumen in saliva. These processes reduce the amount of non-protein nitrogen needed. In addition there is evidence that the rumen microbes need small amounts of amino acids and other nutrients for efficient microbial growth.

The potential of the diet to satisfy the requirements of the animal for amino acids, glucogenic precursors and long chain fatty acids, depends on the pattern of fermentation and on the dietary protein, lipids (or their constituent fatty acids) and starch that escape fermentation and are digested in the intestines.

The extent to which the protein in a supplement escapes the rumen is partly a function of its rate of degradation (solubility) in the rumen. It is likely to be influenced greatly by the rate of flow of fluid and small particles out of the rumen. This latter characteristic will be influenced by processing of the feed (by physical or chemical means), the presence of some green forage, the amount of protein reaching the duodenum and external factors such as temperature and exercise/work.

The same factors will influence the supply of glucose and glucogenic precursors in terms of the likely bypass of starch to the duodenum. However, the nature of rumen fermentation will have a major influence in terms of the supply of propionic acid for glucose synthesis.

### 2.2 RELATING NUTRIENT SUPPLY TO PRODUCTIVE STATE

#### 2.2.1 Introduction

There is insufficient information available to permit the precise quantification of the proportions of the different nutrients required for different productive states. Nevertheless, an approximation of the needs of animals can be attempted. The suggested scheme attaches relative priorities to the groups of nutrients according to the physiological and biochemical processes underlying the expression of the particular productive state (see Table 2.2).
The groups of nutrients to be varied for different productive states are:

- VFA energy
- Glucogenic energy
- Amino acids
- Long chain fatty acids (LCFA)

### Table 2.2
Relative priorities attached to the requirements for oxidation (VFA) energy (E), glucogenic energy (G/E) and amino acids (P/E) according to the productive function of the animal (from Preston and Leng 1986)

<table>
<thead>
<tr>
<th>Function</th>
<th>Oxidation energy (C₂)</th>
<th>Synthesis energy (c₃:C₆)</th>
<th>Amino acids (1A)</th>
<th>Long chain fatty acid LCFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work</td>
<td>xxxxxx</td>
<td>x</td>
<td>x</td>
<td>xxx</td>
</tr>
<tr>
<td>Maintenance</td>
<td>xxxxxx</td>
<td>x</td>
<td>x</td>
<td>-</td>
</tr>
<tr>
<td>Late growth and gestation</td>
<td>xxxxxx</td>
<td>x</td>
<td>xx</td>
<td>xx</td>
</tr>
<tr>
<td>Early growth</td>
<td>xxxxxx</td>
<td>xx</td>
<td>xxx</td>
<td>xxx</td>
</tr>
<tr>
<td>High milk</td>
<td>xxxxxx</td>
<td>xxx</td>
<td>xxx</td>
<td>xxxxx</td>
</tr>
<tr>
<td>Medium milk</td>
<td>xxxxxx</td>
<td>xx</td>
<td>xxx</td>
<td>xxx</td>
</tr>
<tr>
<td>Low milk</td>
<td>xxxxxx</td>
<td>x</td>
<td>xx</td>
<td>xx</td>
</tr>
</tbody>
</table>

VFA energy arises from the rumen fermentation of all types of organic matter principally carbohydrates. The principal way of increasing VFA energy in a particular feed is to increase intake and/or the rumen degradability by supplementing with bypass protein and/or alkali treatment (mainly ammoniation).

Manipulation of the rumen to provide extra protein and glucogenic precursors is still at the experimental stage. Dietary supplementation is the most obvious way of manipulating the supply of absorbed amino acids, glucose and glucose precursors.

Most supplements are expensive and their use in ruminant nutrition competes with monogastric animal and human nutrition. If the primary feed resource is a product of low nutritive value, which would have been wasted if it were not fed to ruminants, it can be argued that the ruminant uses these concentrate supplements more efficiently than monogastric animals. For this reason the term “catalytic” supplement has been used to describe these effects (Preston and Leng 1980). Suckled milk, given in small amounts (<2 litres daily) as a supplement for calves given a straw or molasses based diet, is a good example of a “catalytic” supplement.

It is mandatory that research should produce response relationships to distinguish economic from biological optima. As a rule of thumb, the role of the supplement ceases to be “catalytic” when it exceeds about 30% of the diet dry matter. Beyond this point it assumes a major role and substitution occurs.

The productive functions and the need for supplementary nutrients are discussed in order of the least to the most demanding.

#### 2.2.2 Work

Work requires ATP (adenosine triphosphate) generated from the oxidation of long chain fatty acids, with obligatory requirements for glucogenic compounds and for amino acids (to repair the wear and tear of tissues and replace protein secretions) (see Leng 1985).

The working animal can often obtain sufficient nutrients from a nitrogen-deficient diet so long as it
balances the protein to energy ratio needed for tissue turnover by “burning” off acetate which is in excess of requirements. However, bodyweight loss may restrict the period of work. If the work period is to be prolonged and weight loss is to be minimized, then the nutrients available must be balanced so as to satisfy the needs of the working animal. The digestibility and the intake of the basal diet may also have to be increased by supplementing with urea to correct a deficiency of fermentable nitrogen in the rumen. This may be the only manipulation necessary but supplements rich in fat and bypass protein could be beneficial particularly where the animal is in a productive state (e.g., pregnant or lactating). If weight loss continues because work is prolonged, it may be necessary to increase the degradability of the basal diet, for instance by ammoniation (urea ensiling).

The mature, unproductive ruminant does not appear to require nutrients over and above those provided by an efficient fermentative digestion.

Since the heavily working animal uses largely long chain fatty acids and glucose (Pethick and Lindsay 1982a; Leng 1985), the supplements used should contain or provide these substrates. This is particularly important in the case of long chain fatty acids, since their absorption and use for fat deposition, mobilization and use for work, will be much more efficient and will require less glucose oxidation than fat synthesis from acetate and subsequent utilization in muscle metabolism.

### 2.2.3 Maintenance

Maintenance alone obviously requires less energy expenditure than work so there is a proportionately higher demand for amino acids (relative to energy) than in the working animal. This will always be provided by a rumen system which is adequate in fermentable nitrogen. Animals in negative energy balance for an extended period on low-nitrogen roughage-based diets extract more digestible energy from the basal diet when this is supplemented with fermentable nitrogen (see Table 2.3).

### 2.2.4 Growth

Growing animals have a very high requirement for amino acids for tissue synthesis and glucose for oxidation in specific tissues (e.g., brain). In addition considerable amounts of glucose must be oxidized to provide the NADPH (reduced nicotinamide-adenine dinucleotide phosphate) required to synthesize fat from acetate.

It is imperative to recognize that high growth rates cannot be supported on the products of fermentative digestion and that bypass protein supplements are essential to take advantage of the VFA energy absorbed.

![Table 2.3](https://www.fao.org/docrep/003/X6554E/X6554E02.htm)

<table>
<thead>
<tr>
<th>Diet</th>
<th>Hay intake (kg DM/d)</th>
<th>Liveweight change (kg/d)</th>
<th>Calf birth weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spear grass</td>
<td>4.2</td>
<td>-0.81</td>
<td>22</td>
</tr>
<tr>
<td>Spear grass + US*</td>
<td>6.2</td>
<td>-0.31</td>
<td>31</td>
</tr>
<tr>
<td>Spear grass + US + PP**</td>
<td>8.1</td>
<td>+0.75</td>
<td>32</td>
</tr>
</tbody>
</table>

* US supplied 55 g/d N;

** PP supplied 1 kg/d of a protein pellet containing 80% cottonseed meal, 10% fishmeal and 10% meat meal (protected with formaldehyde)
Many factors influence the level of protein supplementation to be used. Response relationships must be established which relate protein supply to animal productivity for each basal (carbohydrate) resource and for the available protein meals. The response pattern will vary according to the nature of the basal diet and the particular protein supplement.

Data taken from Bangladesh and Cuba demonstrate this rationale. Cattle on ammoniated (urea-ensiled) rice straw, when supplemented with only 50 g/d fishmeal, increased their liveweight gain threefold (Figure 2.3). On a molasses-based diet of higher energetic potential, 450 g/d of fishmeal were needed to raise liveweight gain from 300 to 900 g/day (Figure 2.1).

2.2.5 Reproduction

Improvements in fertility brought about through nutrition are usually attributed to increased energy intake. There is, however, information to show that the supply of glucogenic precursors relative to total energy is an important feature of the improved energy status which results in increased fertility.

2.2.5.1 Conception and puberty

Recent studies have demonstrated that even when the protein supply is adequate, the “quality” of the energy can also be a limiting factor. At the same metabolizable energy intake (the basal diet was low-N Coastal Bermuda grass pasture), puberty was reached at lower liveweights when glucose availability in the animal was enhanced (Table 2.4).

The effects of bypass protein on conception rates of cows grazing sub-tropical pasture during the dry season are shown in Table 2.5. A supplement providing fermentable energy (molasses) was much less effective confirming the report of Moseley et al (1982) that it is the “quality” of the energy (ie: energy in the form of glucogenic compounds) which is the critical issue.

2.2.5.2 Growth of the foetus

The growth of the conceptus has little effect on the protein and energy demand of ruminants until the last third of gestation when most of the foetal tissues are deposited. Because of the time course of growth of the conceptus which increases the daily need for nutrient to only a small extent, it appears that rumen function even on diets of low digestibility can support the birth of a viable offspring of normal weight. This was shown in studies in which urea was included in the drinking water of ewes on nitrogen deficient pasture (Table 2.6).
Figure 2.3

A small supplement of fishmeal dramatically increases growth in live and carcass weight in young cattle fed a basal diet of ammoniated (urea-ensiling) rice straw in Bangladesh (from Saadullah, M. personal communication)

Table 2.4

Feeding monensin to growing heifers on a basal diet of Bermuda grass hay and concentrates increased propionate and decreased butyrate proportions in the rumen VFA. Puberty was accelerated as evidenced by the greater proportion of heifers cycling by the end of the test period (from Moseley et al 1982)

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Monensin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liveweight (kg)</td>
<td>219</td>
<td>219</td>
</tr>
<tr>
<td>Initial</td>
<td>219</td>
<td>219</td>
</tr>
<tr>
<td>Final</td>
<td>313</td>
<td>319</td>
</tr>
<tr>
<td>Feed intake (kg)</td>
<td>8.0</td>
<td>7.7</td>
</tr>
<tr>
<td>Rumen VFA (% molar)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetic</td>
<td>74</td>
<td>69</td>
</tr>
<tr>
<td>Propionic</td>
<td>19</td>
<td>26</td>
</tr>
<tr>
<td>Butyric</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Total VFA (in M/litre)</td>
<td>65</td>
<td>67</td>
</tr>
<tr>
<td>Fertility</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cycling (%)</td>
<td>58</td>
<td>92</td>
</tr>
</tbody>
</table>
Table 2.5 Liveweight and conception rates of lactating beef cows (with first calf at foot) grazing native pasture and supplemented with 1.86 kg of an energy concentrate (molasses 85, cottonseed meal 12, urea 17 and monoammonium phosphate 1) or 1.5 kg of a bypass protein meal (cottonseed meal) during periods when only dry pasture was available. There were 12 cows per group (Hennessy, 1986)

<table>
<thead>
<tr>
<th>Supplement</th>
<th>Liveweight (kg)</th>
<th>Pregnancy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nil</td>
<td>302</td>
<td>10</td>
</tr>
<tr>
<td>Energy</td>
<td>332</td>
<td>20</td>
</tr>
<tr>
<td>Bypass protein</td>
<td>343</td>
<td>60</td>
</tr>
</tbody>
</table>

Increases in calf birth weight were recorded when pregnant cattle, given a basal diet of hay of low digestibility (45%), were supplemented with urea. However, to prevent bodyweight loss and/or promote weight gain of the dam through pregnancy, it was necessary to provide additional bypass protein (Table 2.3).

It appears that urea supplementation enhances milk production to a level that ensures survival of the offspring by the strategy of giving urea. But to allow the young animal to grow, milk yield must be further stimulated by feeding a bypass protein meal.

2.2.5.3 Male reproduction

Male reproduction has been enhanced under grazing conditions by supplementary feeding. Lindsay et al (1982) showed that bulls could be maintained in good condition on poorly digestible, low-nitrogen spear grass pasture by providing 1 kg daily of a protein supplement (Table 2.7) More importantly the circumference of the scrotum decreased considerably when no supplement was fed; and it is known that a bull with a lower scrotal circumference is less fertile and has a lower libido (Blockey 1980). This shows quite clearly that protein nutrition influences male fertility.

As with female fertility there appears to be evidence for beneficial responses to manipulating propionate production in the rumen. At the same feed intake, bulls reached puberty earlier and at puberty had a greater scrotal circumference and larger testicles (Table 2.8).

2.2.6 Milk production

The major constraint to milk production on diets based on crop residues and agroindustrial byproducts appears to be the availability of glucogenic compounds to provide the glucose for lactose synthesis and for oxidation to provide the NADPH for synthesis of fatty acids.

There is good evidence that in large ruminants about 50% of the fatty acids of milk arise from dietary fat. A dietary source of lipid can thus reduce considerably any imbalance caused by relative deficiencies of glucogenic energy and amino acids in the end products of rumen digestion. For many feeding systems in the tropics the level of fat in the diet could be a primary constraint to milk production. This could be particularly important in diets based on molasses or sugar cane.
### Table 2.6
Birth weight and growth rate of lambs; and feed and nitrogen intake, yield and liveweight loss of ewes grazing low-protein dry pasture (Stephenson et al 1981)

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Flinders grass</th>
<th>Flinders grass + urea (2.2 g urea/litre)</th>
<th>Flinders grass + urea (1% w/w of grass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ewes lambed</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Feed intake (g/d)</td>
<td>900</td>
<td>1,190</td>
<td>1,250</td>
</tr>
<tr>
<td>Nitrogen intake (g/d)</td>
<td>8</td>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td>Ewe liveweight loss (kg)</td>
<td>12</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Ewes milked</td>
<td>11</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>Milk yield (ml/4 hr)*</td>
<td>60</td>
<td>ND**</td>
<td>94</td>
</tr>
<tr>
<td>Lamb survivors</td>
<td>12</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Lamb birth weight (kg)</td>
<td>2.9</td>
<td>3.2</td>
<td>3.2</td>
</tr>
<tr>
<td>Lamb growth rate (g/d)</td>
<td>35</td>
<td>81</td>
<td>84</td>
</tr>
</tbody>
</table>

* Mean yields measured on days 1, 11 and 21
** Not determined

### Table 2.7
The effects of supplementation with 1 kg/d protected protein (80% formaldehyde-treated cottonseed meal, 10% meat meal, 10% fishmeal) on the liveweight change, feed intake and scrotal circumference of bulls fed spear grass pasture hay (Heteropogon contortus) containing 0.4% N (Lindsay et al 1982)

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Bypass protein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial weight (kg)</td>
<td>433</td>
<td>433</td>
</tr>
<tr>
<td>Liveweight change (kg)</td>
<td>-40</td>
<td>+14</td>
</tr>
<tr>
<td>Roughage</td>
<td>5.55</td>
<td>7.74</td>
</tr>
<tr>
<td>Total</td>
<td>5.55</td>
<td>8.65</td>
</tr>
<tr>
<td>Change in scrotal circumference (mm)</td>
<td>20.0</td>
<td>0.7</td>
</tr>
</tbody>
</table>

### Table 2.8
Higher proportions of propionic acid in the rumen VFA of growing bulls as a result of feeding the rumen manipulator “Lasalocid” are associated with greater testicular development and reduced age and liveweight at puberty (Neuedorff et al 1982)

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Lasalocid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rumen VFA (% molar)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetate</td>
<td>65</td>
<td>60</td>
</tr>
<tr>
<td>Propionate</td>
<td>21</td>
<td>32</td>
</tr>
<tr>
<td>Butyrate</td>
<td>15</td>
<td>7</td>
</tr>
<tr>
<td>Total VFA (mM/litre)</td>
<td>87</td>
<td>83</td>
</tr>
<tr>
<td>Increase in scrotal circumference (cm)*</td>
<td>3.1</td>
<td>5.3</td>
</tr>
<tr>
<td>Testicular volume (cm$^3$)</td>
<td>57</td>
<td>91</td>
</tr>
<tr>
<td>Age at puberty (d)</td>
<td>471</td>
<td>437</td>
</tr>
<tr>
<td>Weight at puberty (kg)</td>
<td>379</td>
<td>366</td>
</tr>
</tbody>
</table>

* from 29 to 175 days

Supplementation of lactating animals, particularly on diets based on tropical pastures, crop residues and sugar-rich agro-industrial byproducts, should aim to correct the imbalances of
nutrients for milk production. Bypass protein usually increases feed intake and as a consequence promotes milk production. But to balance energy quality, fat must be mobilized and glucose diverted from oxidation and tissue synthesis to lactose production. In these circumstances animals tend to lose body weight (Ørskov et al 1977). Dietary fat may reduce this effect. Adding a source of bypass starch in such a diet balances the ratio of glucogenic precursors to protein and energy and will tend to prevent body fat mobilization.

The points to be stressed are that:

- Bypass protein because of its effects on feed intake almost always stimulates milk production and depending on the imbalance in nutrients (fermentation pattern) may cause animals to mobilize body reserves. This may be prevented by the use of high-fat, high-protein meals that supply both protein and long chain fatty acids for digestion post ruminally.

- Bypass starch or manipulation of the rumen to give higher propionate production (eg: by supplementation with monensin), because it balances nutrients for milk production, may prevent mobilization of body reserves without large effects on feed intake and therefore on milk production. But because it balances the nutrients for milk production, efficiency of energy utilization is increased and bodyweight is often increased.

### 2.2.7 Wool or hair production

The effect of nutrition on wool production appears to be dependent almost entirely on the quantity, and quality, of the balance of amino acids absorbed. Therefore, feed intake is the primary limitation to wool or fibre growth although at any one feed intake, wool growth can be stimulated by altering the balance of protein relative to energy in the products of fermentative digestion (eg: removing protozoa from the rumen).

Thus on diets that require fermentative digestion, including those based on sugars or fibre, a bypass protein supplement will increase wool growth (Table 2.9).

### 2.2.8 Carry-over effects of balancing nutrients in early life

Under pastoral conditions with wet/dry seasons, young stock post-weaning are subjected almost invariably to a deficiency of protein relative to energy in the absorbed nutrients from the digestive tract. This results in reduced feed intake and energy deficiency.

In societies that depend on milk as a dietary staple, the young calf and people compete for the available milk supply. The reduced amount of milk available for the calves can be highly detrimental, particularly when the herd is grazing dry pastures or is being fed on crop residues. The cows will yield less at this time due to the imbalanced feed available. Thus the calf suffers on both counts (an imbalanced basal diet together with a reduction in the supply of bypass nutrients from milk).

The male stock, because they are less valuable and not usually given supplements, may die from inanition resulting from protein deficiency. This is manifested as a low intake of the available feed, usually straw or grass, which is low in fermentable nitrogen and lacks bypass nutrients. The calf normally obtains the latter from suckled milk, but this is highly restricted because it is used preferentially by the family.

In countries such as India, female offspring are more prized and are often given supplements of young grass and sometimes byproducts such as cottonseed meal. Their survival rate is much higher than the males.

Male stock that survive are often reared as replacement oxen, and their ultimate body size is important since in countries where feed resources are scarce, using a single ox for work (instead of the traditional pair) is an obvious advantage in conserving valuable feed resources. However, as body size is related to work capacity, a large animal is needed if the move to a single ox is to be successful.
There are indications that permanent stunting of cattle occurs if they are underfed in the pre- and post-weaning period. The stunting is probably due to depressed feed intake particularly during dry seasons when the level of both fermentable nitrogen and bypass protein limits feed intake of the available feeds (pasture and straw). Two sets of information support this thesis.

### Table 2.9

Goats and sheep on “high quality” carbohydrate feeds do not produce without supplements of bypass protein. Bypass starch appeared also to increase productivity. The animals were given a basal diet (Basal which was readily fermented in the rumen (i.e. 35% oaten chaff, 25% maize flour, 15% molasses, 15% sucrose, 125% barley grain, 4.5% urea, 0.5% complete mineral/vitamin mixture); and the basal diet supplemented with protected casein (formaldehyde-treated) (Bypass protein) or 5% protected casein and 10% cracked rice (Bypass protein and starch) (Throckmorton et al 1982).

<table>
<thead>
<tr>
<th></th>
<th>Basal</th>
<th>Bypass protein</th>
<th>Starch + Bypass protein</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Goats</td>
<td>Sheep</td>
<td>Goats</td>
</tr>
<tr>
<td>Daily gain (g)</td>
<td>32</td>
<td>45</td>
<td>68</td>
</tr>
<tr>
<td>Patch weight at 105 days (mg/cm²/d) *</td>
<td>0.54</td>
<td>0.74</td>
<td>0.82</td>
</tr>
<tr>
<td>Feed intake (g/d)</td>
<td>465</td>
<td>538</td>
<td>604</td>
</tr>
<tr>
<td>Feed conversion (g DM/g gain)</td>
<td>14.8</td>
<td>11.9</td>
<td>8.9</td>
</tr>
<tr>
<td>Rumen fluid half life (hr)</td>
<td>16.1</td>
<td>14.1</td>
<td>8.6</td>
</tr>
</tbody>
</table>

* Wool or hair clipped from a 10 cm square mid-side batch

- Studies by Hennessy (1984) with Hereford cattle grazing native pastures which were low in N in the dry season showed that, if a protein supplement was given during early life, the adult body size was increased by 60 kg compared with animals that were unsupplemented (Table 2.10).

- Surveys of cattle bodyweight in traditional grazing systems as compared to ranching in Africa indicated that mature bodyweight was greater in cattle on the ranches. Calf birth weights, weaning weight and live weight at two years of age were also higher in the animals under ranching conditions (Leng and Brumby 1985). The competition between calves and humans for milk is apparent throughout Africa. The low birth weight of cattle is also indicative of nitrogen or protein deficiency and/or low feed availability to the dam.

The two sets of data strongly suggest that inadequate protein nutrition and/or low feed availability at critical periods may lead to permanent stunting of cattle. The small size of cattle in traditional systems may be partly the result of inadequate nutrition in early life.

### 2.3 PRINCIPLES OF SUPPLEMENTATION

The proposed scheme (Figure 2.4) is empirical but is considered to be appropriate for the conditions of most developing countries.

#### 2.3.1 Select the basal carbohydrate-rich resource

The first step is to select the basal carbohydrate resource according to availability, potential fermentability and price. Supplementary nutrients should then be provided in accordance with their relative priorities and costs.

#### 2.3.2 Fermentable N

The first supplement to be considered should be a source of fermentable nitrogen (usually urea or ammonia) to ensure the level of rumen ammonia is above 150 mg/litre of rumen fluid. The generally recommended minimum level of rumen ammonia to support efficient use of fermentable carbohydrate for microbial growth is 50 mg/litre. However, this appears to be too low to optimize
the rate of degradation of fibrous substrate, since the disappearance rate of cellulose and fibre from nylon bags in the rumen was increased when the concentration of ammonia was raised to 200 mg/litre (see Figure 2.5).

Table 2.10
Effect of bypass protein supplements on mean liveweight of cows during a nine week mating period (November to January) 1978–82 (Hennessy 1984)

<table>
<thead>
<tr>
<th>Year</th>
<th>Native pasture year round kg</th>
<th>Native pasture supplemented in the dry season with bypass protein</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group 1 kg</td>
<td>Group 2 kg</td>
</tr>
<tr>
<td>1978</td>
<td>197</td>
<td>259</td>
</tr>
<tr>
<td>1979</td>
<td>263</td>
<td>292</td>
</tr>
<tr>
<td>1980</td>
<td>259</td>
<td>322</td>
</tr>
<tr>
<td>1981</td>
<td>329</td>
<td>378</td>
</tr>
<tr>
<td>1982</td>
<td>320</td>
<td>382</td>
</tr>
</tbody>
</table>

* This group was not mated in 1978

Figure 2.4
Principles of supplementation

- Select the basal carbohydrate-rich resource
- Provide fermentable nitrogen (urea or ammonia)
- Provide a highly digestible forage (young grass, a legume or beet pulp)
- Provide a source of bypass protein (oilseed meal, fishmeal, cereal bran, tannin-containing legume)
- Provide a source of long chain fatty acids (more research is needed before strong recommendations can be made about this)

When the substrate was alkali-treated maize cobs (Alvarez et al 1983), rate of dry matter loss from nylon bags in the rumen increased linearly as rumen ammonia concentration was raised from 30 to 120 mg/litre of rumen fluid. Similarly, the optimum level of rumen ammonia for maximum rate of fermentation on starch-based diets, was above 200 mg/litre (Mehrez et al 1977). However, it must be stressed that the rate of breakdown of starch in the rumen is probably never a constraint for the utilization of grain-based diets. On the contrary, it may well be an advantage on such diets to have a lower than optimal rumen ammonia level to slow down the fermentation rate.

In contrast, rate of degradation is of paramount importance when the diet is based on crop residues; because it is the rate of degradation of fibre which eventually limits feed intake and therefore animal productivity.

When rumen ammonia levels are lower than 150 mg/litre it is recommended that the effects of adding urea should be monitored under the prevailing field/farm situation. As a general rule, if a deficiency is suspected, urea should be added at the rate of about 1–2% of the organic matter in the diet. It is desirable that supplementation ensures an almost continuous supply of ammonia-nitrogen in the rumen and the use of molasses/urea blocks or high-urea (10%) liquid mixtures with molasses is a convenient way of ensuring this. Ammoniation using ammonia gas, or through ensiling with urea, are other ways of providing a continuous supply of rumen ammonia with the associated advantage of upgrading the carbohydrate component. A recent development is the generation of ammonia from mixtures of dry chemicals (eg: ammoniate sulphate and quicklime) when these are mixed with water (Mason et al 1985).
2.3.3 Highly digestible forage

The second supplement should be a source of highly digestible forage, preferably legume (or beet pulp) given at about 10–20% of the diet (Juul-Nielsen 1981; Gutierrez and Elliott 1984; Silva and Ørskov 1985). The exact action of this type of supplement on rumen function is not fully understood. In some way it helps to ensure a more efficient rumen environment for the digestion of cell wall carbohydrate perhaps by providing micro-nutrients (eg: peptides, amino acids, minerals, vitamins) which increase fungal biomass and/or the rate of bacterial colonization of the fibre.

Figure 2.5

The effects of rumen ammonia levels on the rate of degradability of the insoluble components of cotton wool and oaten chaff (fibre) as measured by the nylon bag technique. The sheep were given a diet of oaten chaff and had access to molasses/urea blocks containing 10, 15 or 20% urea. The data show that the rumen ammonia level should exceed 150 mg/litre of rumen fluid in order to maximize the rate of fermentation of cellulose or fibre (Krebs and Leng 1984)

2.3.4 Bypass protein

The third supplement should be an oilseed meal, cereal bran or an animal by-product meal (supplying protein and fat) and should be given in amounts not to exceed 30% of the total diet dry matter. The 30% limit is to prevent depression/substitution of the digestible energy of the basal diet. Lesser amounts may be more economical, and it is imperative that feeding trials be carried out to define response relationships. In this way the amount of supplement can be related to the rate of animal productivity. The optimum level (in economic rather than biological terms) and the degree of response to the supplement, will depend upon the fermentability of the basal diet.

2.3.5 Long-chain fatty acids (LCFA)?

Supplementation with a source of long-chain fatty acids (LCFA) is a strategy that promises to be of considerable benefit, especially on diets with a low content of lipids (eg: crop residues and molasses). However, more research is needed before making recommendations.
2.4 CATEGORIZATION OF FEED RESOURCES

The principles underlying the development of feeding systems are based on:

- Identifying the locally available dietary resources which deserve better attention
- Understanding the nutritional constraints associated with their efficient utilization by ruminants
- Formulating supplements with the objective of optimizing the nutrient supply to the animal given the basal carbohydrate resource

In some instances it may be justified to use imported materials especially where small amounts have dramatic (catalytic) effects. Urea and fishmeal (or cottonseed meal) are good examples when they are used as supplements in diets based on molasses or cereal straws.

2.4.1 Fermentable carbohydrate

Many naturally occurring materials can be fed to ruminants but relatively few of these are available in sufficient quantity to permit them to be selected as the "principal source of fermentable carbohydrate". The main feed resources that fall into this category include:

- Pastures (a distinction should be made between pastures during the dry and wet seasons)
- Crop residues (e.g: straws from rice, millet, sorghum, maize and wheat)
- Cut forages and high-biomass crops (e.g: sugar cane, elephant grass and other grasses)
- Agroindustrial byproducts of which molasses is the most important. Other byproducts include pulps from the citrus, pineapple and the sisal industries, and reject fruit and waste from bananas

2.4.2 Fermentable nitrogen

A source of fermentable nitrogen must be added when the basal diet does not give rise to sufficiently high levels of rumen ammonia. The most important source is urea; animal excreta also fall in this category. The protein of some high protein forages (e.g: sweet potato foliage) is rapidly degraded in the rumen to ammonia. However, this process implies a destruction of protein which should be avoided wherever possible (e.g: it may be better to use this forage in the feeding of monogastric animals).

It is emphasized that fermentation (deamination) of protein is not only wasteful of protein but it is energetically inefficient. A kilogramme of protein yields only about 30–60g of microbial protein compared with about 200g microbial protein from the same amount of carbohydrate. Because the protein is converted to VFA and ammonia, feeding a highly soluble protein as a basal fermentable organic matter source can actually imbalance the protein to energy ratio in the end products absorbed, if none of the protein escapes degradation in the rumen.

2.4.3 Supplements which contribute to an efficient rumen ecosystem

The characteristics of a feed that contribute to an efficient rumen ecosystem are:

- Physical factors which influence the motility of the rumen wall, the amount of digesta held in the rumen and its flow to the lower digestive tract. The data in Table 2.11 show that intake decreases (and rumen liquid volume decreases) as the physical nature of the forage supplement in a molasses-based diet becomes less stimulatory (due to being ground too finely) or is removed completely.

- Nutrients, other than ammonia, which stimulate microbial growth in the rumen (e.g: peptides, amino acids, branched-chain acids). On fibrous diets, these critical nutrients may
help to stimulate the size of the pool of colonizing microbes, free floating in rumen fluid. These nutrients may also promote fungal growth.

Many of the above factors appear to be present in green forage (see Figure 2.6). Leguminous plants are probably better than grasses in this respect since they provide in addition a source of bypass protein. Normally it is sufficient to have 20% dry matter of a diet in the form of green forage to avoid any deficiency of the type mentioned. However, even smaller amounts have given beneficial effects on animal performance.

### 2.4.4 Bypass protein

Once the supply of fermentable nitrogen is assured and a small supplement of green forage has been included in a diet, then the next limitation to rate of productivity will be the availability of amino acids at the level of the intestine. For many of the feed resources that will be used in tropical countries, the value of bypass protein lies mostly in its effect in stimulating voluntary intake. It is thought this comes about through the improvement in the balance of nutrients in the digestion end products, and hence their more rapid metabolism. This is in addition to the role of bypass protein in complementing the amino acids supplied by microbial protein. Slowly degradable protein, in addition to providing bypass protein, may also supply amino acids and peptides for microbial growth.

<table>
<thead>
<tr>
<th>Forage treatment</th>
<th>Fresh</th>
<th>Dehydrated and ground</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter intake (kg/d)</td>
<td>2.4</td>
<td>2.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Rumen contents (kg DM)</td>
<td>4.3</td>
<td>5.9</td>
<td>8.3</td>
</tr>
</tbody>
</table>

Figure 2.6

Supplementing a diet of sisal pulp (included urea and minerals) for sheep with freshly harvested African Star grass improved the rumen ecosystem as evidenced by the 50% increase in the rate of cellulose digestion (in nylon bags in the rumen). This in turn led to an 80% increase in feed intake (Gutierrez and Elliott 1984)

### 2.4.5 Bypass starch and glucogenic precursors
Absorption of glucose usually leads to an increase in the glucogenic energy ratio. In addition, energy losses associated with glucose synthesis in the animal and also fermentative losses in the rumen are avoided. Supplements which increase propionic acid relative to the other VFA increase glucogenic energy and also have lower fermentative losses (less heat and methane are produced). The important role of these nutrients is to improve the efficiency with which metabolizable energy is utilized for productive purposes.

Starch which bypasses the rumen contributes glucose directly through gastric digestion in the intestine (see Elliott et al 1978; Ferreiro et al 1979). Although all sources of starch are fermented completely with time in the rumen, there are marked differences among them in their rates of degradation. Starches from maize, rice, banana and to a lesser extent sorghum, appear to have characteristics which permit them to escape partially the rumen fermentation; in contrast the starch present in cassava (and probably also in sweet potato roots) is fermented in the rumen rapidly (see Figure 2.7).

### 2.4.6 Long chain fatty acids

Supplementation with long chain fatty acids appears to have two opposing effects. Increasing the long chain fatty acid component of a diet, low in fat, will increase the efficiency of feed utilization especially for milk production. But on high-fibre diets (such as crop residues) lipid added above 5% of the diet will depress fibre digestion. However, recent work with protected fats and soaps has shown that addition of long chain fatty acids in these forms will increase substantially feed utilization for milk production (see Palmquist 1984).

Available sources of fatty acids include the oilseed residues (particularly pressure extracted cakes) and milling offals or brans and in some countries animal byproducts such as tallow. The effectiveness of any lipid source will be enhanced by protection (formaldehyde/protein complexes - Ferguson 1975) or by saponification with calcium salts (Palmquist and Jenkins 1982).

### 2.4.7 Feeds and other materials with a capacity to manipulate the rumen microbial biomass

Manipulation of rumen fermentation with natural feeds is becoming more feasible as knowledge of the processes of rumen digestion develops. In general manipulation aims at enhancing the proportions of propionate and of amino acids in absorbed nutrients; and in increasing digestibility.
Figure 2.7

The rate of degradation of the dry matter in nylon bags in the rumen of maize and rice grains is slower than of cassava root meal. The host cattle were fed on chopped sugar cane supplemented with urea and minerals (from Santana and Hovell, 1979).

Propionate enhancement has been associated primarily with the use of the chemical additive monensin in grain-rich fattening diets in cattle in Europe and North America. On molasses-based diets, poultry litter appears to perform a similar role (Fernandez and Hughes-Jones 1981; Marrufo 1984).

2.5 ALTERNATIVE SOURCES OF SUPPLEMENTS

The primary limiting nutrients for production on most tropical feed resources are fermentable nitrogen, glucogenic precursors and bypass protein and dietary long chain fatty acids. Urea, oilseed cakes, cereal milling byproducts and animal byproduct meals are the logical supplements when available. However, there are many situations where farmers do not have access to these supplements either because they are not locally available or are too expensive. In addition, there is often a reluctance to use urea because of the fear of toxicity.

2.5.1 Livestock excreta

Excreta from all types of livestock have been used in livestock rations. It is obvious that excreta in general must be a poor source of fermentable carbohydrate and protein. However long chain
Fatty acids may build up in litter as small amounts will be present in faeces and they are only slowly degraded by micro-organisms in the litter. Microbial growth in the litter will therefore tend to concentrate these fatty acids. Excreta from ruminant animals are high in refractory cell wall carbohydrate with smaller amounts of microbial cells (from the caecum) and some urea if the urine is incorporated with the faeces. The monogastric species produce the most valuable excreta; and especially in the case of poultry, there may be considerable contamination with wasted feed grains. Excreta from poultry are rich in nitrogen mostly as uric acid which is hydrolyzed to ammonia by rumen microorganisms.

Excreta (often depathogenized with formalin or by ensiling) have been used widely in the developed countries as a component of cereal grain-based diets in which their main contribution is as a source of non-protein nitrogen and minerals.

In developing countries, only poultry litter has found ready acceptance as a component of livestock feeds. It appears to play a particularly appropriate role in high-molasses diets, where it complements the readily fermentable sugars and the low levels of fermentable N and of phosphorus. The apparent beneficial effect of poultry litter on rumen propionate production in cattle fed a molasses-based diet has already been mentioned; and it is well documented that this is reflected in higher levels of animal performance (Meyreles and Preston 1982; Meyreles et al 1982).

The data in Table 2.12 show that poultry litter is less effective than fishmeal or an oil cake meal for supplementing cattle given a molasses- or a pasture-based diet, from which it can be inferred that it provides little or no bypass protein. This is to be expected in view of its chemical characteristics.

### 2.5.2 Legume forages and foliages from food crops

An alternative resource which can serve as a source of fermentable N and of bypass protein is a forage crop grown on the farm, or produced as a byproduct or residue from a food crop. A legume crop has a further advantage because of its capacity to fix atmospheric nitrogen and thus spare the need for fertilizer N. Based on the premise of using protein economically, then the intake of these forages should be restricted and therefore it is preferable to grow the legume as a pure sward.

The amount of bypass protein in a legume (green or dry and used as a supplement) has not been estimated. It may be beneficial to grow tannin-rich legumes where these are grown as supplements to crop residues. Whereas if they are to provide a high proportion of the diet, the low tannin legumes may be more appropriate (eg: feeding leucaena with molasses/urea) (Hulman et al 1978).

The tree legumes such as *Gliricidia*, *Erythrina* and *Leucaena* have very great potential because they are high yielding and perennial. They are also deep-rooted and may have access to water and nutrients (eg: phosphorus) unavailable to smaller plants. In the tropics, tree legumes have a special role, since they can also be used for shade (eg: in coffee plantations), as "live" fences and as sources of fuel. Some of them (eg: *Gliricidia* and *Erythrina*) can be established easily from cuttings hence their use as "live" posts.

On low-nitrogen diets supplemented with legumes, there is still a need to ensure that ammonia concentrations in the rumen are adequate by supplying fermentable nitrogen usually as urea. It is also important that the protein source, which is usually in short supply, should be partitioned between as many animals as possible.
Table 2.12 Comparison of sunflower cake with poultry litter as supplements for grazing cattle (Delgado et al 1979)

<table>
<thead>
<tr>
<th>Amount of supplement (kg/day):</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Poultry litter</td>
<td>1.3</td>
<td>1.0</td>
<td>0.64</td>
</tr>
<tr>
<td>Sunflower cake</td>
<td>0.0</td>
<td>0.12</td>
<td>0.31</td>
</tr>
<tr>
<td>Liveweight gain (g/day)</td>
<td>480</td>
<td>580</td>
<td>680</td>
</tr>
</tbody>
</table>

Pasture was pangola grass and the cattle were also fed 1.5 kg/day of molasses containing 2.5% urea.

The other valuable forages are from cassava and sweet potatoes and, to a lesser extent, bananas. Some results from using these materials as supplements in molasses-based diets are described by Ffoulkes and Preston (1978) and Rowe and Preston (1978).

In temperate countries legumes have long been used as an alternative to nitrogenous fertilizers to increase pasture biomass production per hectare. It has also been recognized that they are superior in nutritive value compared with grasses, apparently because of their higher protein content. The metabolizable energy in legumes is also used more efficiently for productive purposes as compared with grasses of the same digestibility (Walco et al 1982).

Tropical grasses support lower levels of animal production compared with temperate grasses, mainly because they are lower in nitrogen and are less digestible (see Minson 1982). Low productivity from tropical pastures has stimulated considerable research aimed at developing grass-legume associations for tropical conditions. Presence of legumes in the sward has led to increase in animal production, but mainly in terms of productivity per unit area rather than per animal (see Mannateje 1982). But maintaining grass-legume associations in a pasture requires very careful management.

The present discussion is restricted to the role of legumes as supplements in feeding systems based on low-nitrogen crop residues and byproducts.

2.5.3 Attributes of legumes as supplements

In developing countries where competition for land to grow crops or grazing is high, the area likely to be sown to fodder legumes will be almost always a small proportion of the total. It follows therefore that the role of a legume must be to increase the efficiency of utilization of the basal diet (ie: a low-N pasture or a crop residue) at low levels of supplementation (usually less than 20%) and used “catalytically”.

As a priority, the legume should have a high protein content to supply both fermentable and bypass protein; there will be additional benefits if the legume contains other critical nutrients (eg: lipids, minerals, vitamins and other plant compounds) which enhance the rumen ecosystem so as to increase microbial growth, rate of fibre digestion, propionate production and escape of dietary protein (eg: contains tannins).

There are two sets of data which indicate the suitability of legumes as sources of fermentable nitrogen and bypass protein: comparative studies with grasses (almost entirely for temperate species) and animal response trials.

The data in Table 2.13 show that, compared with ryegrass, white clover contains more nitrogen and provides more protein that is available for intestinal digestion in sheep. This almost certainly indicates that a proportion of the legume protein escapes rumen fermentation. The fact that the efficiency of utilization of metabolizable energy is higher for a legume as compared with a grass, is further evidence that the digestion of legumes provides a better balance of nutrients for productive purposes than is the case with grasses. However, protein from white clover only appears to escape rumen fermentation at high intakes of the clover. Therefore when it is used as a supplement to a fibrous feed it may only provide fermentable N. Clover also provides highly digestible carbohydrate which will stimulate digestibility of the basal diet. It also provides lipids which may help to spare glucose oxidation for adipose tissue or milk fat synthesis.
It is likely that legume forages rich in tannins will be superior as sources of bypass protein since tannins link with proteins during mastication, and appear to reduce microbial degradation of plant proteins (Reid et al 1974). The high levels of tannins in Lotus pedunculatus, whilst protecting protein from degradation, reduce digestibility of fibre by inhibiting the activity of bacteria (Chesson et al 1982) and fungi (Akin and Rigsby 1985). Barry (1985) considered that the ideal concentration of condensed-tannins was 20–40 g/kg diet dry matter; and that higher levels (76–90 g/kg) were detrimental. He also found that sheep could adapt to high tannin levels. Provided that tannin-rich plants are only used as supplements (eg: less than 25% of the diet dry matters), there is unlikely to be a serious problem and their presence in the diet may well be beneficial (Barry and Manley 1984). Examples of tropical legumes which are known to contain tannins are: Leucaena, Gliricidia and Sesbania.

Recent research in New Zealand (Figure 2.8), comparing the utilization by sheep of mature and immature ryegrass and white clover, demonstrates three points:

- At low total feed intake virtually no protein bypassed the rumen on any of the herbages. As intake increased protein bypass also increased.
- There appeared to be no difference in the bypass characteristics of young ryegrass and white clover (at close to ad libitum intake about 25% of the protein appeared to escape the rumen) whereas on the mature ryegrass virtually none of the protein escaped.
- The efficiency of microbial growth was similar on all herbages and was apparently not affected by the level of intake.

Table 2.13

More protein reaches the intestine of sheep when the diet is composed of white clover rather than ryegrass. Total N in dry matter in both species was adequate to support an efficient rumen and the implication is that more protein in the clover escapes fermentation. The higher efficiency of utilization of the metabolizable energy in the clover, compared with grass, confirms work reported elsewhere (Waldo et al 1982) and implies that legumes are superior to grasses as sources of both protein and energy (Beever et al 1980; Ulyatt et al 1980)

<table>
<thead>
<tr>
<th></th>
<th>Lolium perenne</th>
<th>Trifolium repens</th>
</tr>
</thead>
<tbody>
<tr>
<td>N in DM, %</td>
<td>2.6</td>
<td>4.2</td>
</tr>
<tr>
<td>NAN, g/kg DMI (entering SI)</td>
<td>30</td>
<td>44</td>
</tr>
<tr>
<td>OM digest., %</td>
<td>82</td>
<td>74</td>
</tr>
<tr>
<td>ME in DM, MJ/kg</td>
<td>12.2</td>
<td>11.5</td>
</tr>
<tr>
<td>kf, %</td>
<td>0.33</td>
<td>0.51</td>
</tr>
</tbody>
</table>
Figure 2.8

Relationship between organic matter intake and flow of microbial protein (NAN= non-ammonia-N) and ruminally undergraded (bypass) N to abomasum in sheep fed early- (o) or late-cut (o) ryegrass or clover (o) (from D.W. Dellow and J.V. Nolan, cited by Preston and Leng 1986)

Thus, if temperate clovers and immature grasses are to be used as bypass protein supplements, their effectiveness will depend on the level of intake of the basal diet.

While a proportion of the protein in some legumes appears to be able to escape rumen fermentation, the greater part - at least in the fresh plant - is rapidly degraded by rumen microorganisms. This is well illustrated by the data in Table 2.14 which show that the quantity of amino acids flowing to the small intestine of sheep was highest when clover was dehydrated, was intermediate in frozen material and was lowest on the fresh herbage. Assuming a constant
Better utilization of crop residues and by-products in animal feeding: ...

microbial growth rate in the rumen on all diets, it can be estimated that less than one quarter of
the protein consumed escaped to the small intestine when the fresh material was fed (see
MacRae 1976).

In these trials, the legume was the only component of the diet. If fresh legume forages are given
as supplements (less than 20% of dietary DM intake) to a diet based on dry forages, its bypass
protein contribution may be very small. It must be considered therefore as mainly providing
fermentable nitrogen. Theoretically, including a high-protein legume at 20% of a straw-based diet
should provide most of the ammonia needed by the rumen microbes. However, if the legume is
given as a single feed, say early in the morning, the ammonia may be used wastefully and a
fermentable N deficiency might occur later in the day. There is therefore an urgent need to
examine what level of supplementation with fresh legume forage is necessary to raise rumen
ammonia levels consistently above the critical value (eg: 150 mg/litre); and how it should be
distributed (ie: how many feeds per day).

In situations where the fermentable N requirement can be met from other sources (eg: urea or
animal excreta) the need is to reduce the degradability of the legume protein so as to increase its
bypass characteristics. This has been shown to occur when a forage is artificially dried and more
so when pelleted (see Table 2.14).

Table 2.14
Preparation of clover when fed to sheep markedly affects the amounts of amino acids
flowing to the intestines. Freezing or artificial drying and pelleting both apparently
increase dietary protein bypassing rumen fermentation (MacRae and Ulyatt 1974, Beever
et al. 1971)

<table>
<thead>
<tr>
<th></th>
<th>Fresh</th>
<th>Frozen</th>
<th>Artificially dried and pelleted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amino acid intake (g/d)</td>
<td>127</td>
<td>127</td>
<td>124</td>
</tr>
<tr>
<td>Amino acid entering small intestine (g/d)</td>
<td>80</td>
<td>133</td>
<td>175</td>
</tr>
</tbody>
</table>

Rarely will it be economic to dehydrate or pellet legume forages and sun-drying is the only
feasible alternative. Nolan and Leng (1972) showed that some 60% of the protein in sun-dried
lucerne apparently escaped rumen fermentation when the legume was fed as the sole diet.

As discussed earlier, secondary plant compounds such as tannins are known to protect dietary
proteins against rumen microbial attack. Thus if a freshly harvested or grazed legume is to be
used as a bypass protein supplement then it should be selected for a relatively high content of
tannins.

This point is illustrated by the data in Table 2.15 which show that although the tannin-containing
legumes (trefoil and sanfoin) were less palatable than lucerne, nevertheless they supported
faster growth rates in heifers. The authors concluded that this was because more of the protein in
the legumes containing tannins escaped degradation in the rumen.

Tropical legumes generally are richer in tannins than are temperate legumes and therefore
should function better as sources of bypass protein. Evidence for this is provided by the results of
feeding trials with tropical tree legumes discussed earlier. It must be emphasized that when
legumes contain a high proportion of protected protein, then some other source of rumen
fermentable nitrogen will be required, usually urea.

Table 2.15
Effect of drying temperature on the solubility and digestibility of nitrogen in lambs fed
dried lucerne (Goering and Waldo 1974)

<table>
<thead>
<tr>
<th>Temperature of drying (°C)</th>
<th>Soluble N (%)</th>
<th>N digestibility (%)</th>
<th>N retention (g/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>65</td>
<td>43</td>
<td>49</td>
<td>6.0</td>
</tr>
<tr>
<td>130</td>
<td>40</td>
<td>68</td>
<td>7.4</td>
</tr>
<tr>
<td>160</td>
<td>40</td>
<td>66</td>
<td>6.9</td>
</tr>
<tr>
<td>180</td>
<td>34</td>
<td>52</td>
<td>3.9</td>
</tr>
</tbody>
</table>
Chapter 3: METHODOLOGY FOR THE EVALUATION OF FEED RESOURCES FOR RUMINANTS

3.1 INTRODUCTION

What is the minimum information required in order to identify and classify feed resources for the functions set out in Chapter 2?

It seems that the classical system of proximate analysis and even the more sophisticated methods for identifying the components of plant cell walls (ie: ADF and NDF) contribute little information for the development of feeding systems which aim to utilize tropical feed resources efficiently. The application of the Van Soest ADF and NDF analysis is in basic research to provide understanding of the dynamics of fibre fermentation in the rumen (Van Soest 1982).

3.2 DEFINITION OF CROP RESIDUES AND AGROINDUSTRIAL BYPRODUCTS

Crop residues are invariably fibrous, of low digestibility and low in nitrogen. They are produced on the farm and therefore widely spread geographically. On small farms in developing countries they form the principal feed of ruminant livestock during the dry seasons.

Agroindustrial byproducts result from the processing of crops such as oilseeds, sugar cane, sisal, citrus, pineapple and bananas; or the slaughter and processing of livestock and fish. They are geographically restricted to the factory sites, are usually marketed and frequently exported to earn foreign exchange. They are rich in protein (oilseeds and meals of animal origin) or sugar (molasses, citrus and pineapple pulps) and occasionally in starch (reject bananas, cassava peels) and usually low in fibre. Exceptions are sugar cane bagasse, palm-press fibre, coffee pulp and cocoa pods.

3.3 CATEGORIES OF BYPRODUCTS

It is convenient, when establishing principles for evaluating byproducts and crop residues for ruminants, to divide them into four categories:

Group 1: Feed resources high in fibre and low in nitrogen: this group includes the most important crop residues, namely cereal straws and stalks, legume haulms and straws and stovers of low digestibility and N content from other plants.

Group 2: Byproducts high in fibre and high in nitrogen: this group comprises in general animal excreta products and brewers' grains.

Group 3: Byproducts low in fibre and low in nitrogen: this group includes products from sugar processing (eg: molasses), citrus and pineapple pulps, reject bananas and other products from food processing plants.

Group 4: Byproducts low in fibre and high in nitrogen: this group comprises mostly oilseed cakes and meals and slaughter offal, etc.
3.4 ASSESSING NUTRITIVE VALUE

In discussing guidelines for research on byproducts and residues it is convenient to consider the different objectives relating to the use of these feed resources.

- What is the feed value of a relatively unknown byproduct or fibrous residue?
- How can an improvement in nutritive value caused by chemical, physical or biological treatment, be measured?
- How can the product be used best in feeding systems with other locally-produced feeds or byproducts/residues?
- How can rumen degradability be best measured within the context of a feeding system?
- How can responses to protein and other supplementary nutrients be measured in animals?
- How can crop residues and agroindustrial products be integrated into feeding systems for non-ruminant herbivores?

In order to establish evaluation procedures, it is deemed logical to make the approach in six stages as illustrated in Figures 3.1 to 3.6.

3.4.1 To determine the rate of degradation in the rumen? (Stage 1)

Let us consider a residue/byproduct about which relatively little is known (see Figure 3.1). The most appropriate first assessment of feeding value would be by incubating it in nylon bags in the rumen of fistulated animals given a standard diet well balanced in terms of availability of nutrients for efficient rumen function and the animal. Three to four animals should be used to ensure replication of each test (see Ørskov et al 1980). By efficient rumen function is meant a rumen ecosystem which produces a high rate of degradation of the carbohydrate and is not deficient in N or other nutrients.

Figure 3.1: STAGE 1 To determine the rate of degradation with standard diet

As a standard, incubate simultaneously with the unknown feed a product of known degradability which is easily reproducible (eg: leaves from leucaena or sweet potato). A detailed description of
the nylon bag technique is given in Chapter 6.

Having ascertained the rate of degradation in the nylon bag, it is then possible to assess first of all whether the extent of degradation is satisfactory. If the degradation after 48 hr or so is more than 40–50% then the product is worth more consideration, and evaluations can proceed directly to Stage 2 (see Figure 3.2). On the other hand if the degradation is low (say 10–30% after 48 hr of incubation) then the product is unsuitable for feeding directly to animals.

Two options are then available depending on the local importance of the byproduct (Figure 3.1). If it is of little importance, probably the project should not be pursued further. On the other hand, if large quantities of the by-product are available, it may be justified to attempt to increase its nutritive value by chemical treatments. These are described in Chapter 6.

Having ascertained that the potential rumen degradability of the residue/byproduct is satisfactory, or that there is a need to improve it by chemical or other means, evaluation can proceed to Stage 2.

3.4.2 Chemical analyses (Stage 2)

Some simple chemical analyses should be done (Figure 3.2). The most important are dry matter (DM), nitrogen (N), ash (to estimate organic matter [OM]) and lipids. Other analyses such as for cell wall constituents (Van Soest 1982) can be carried out if deemed necessary or appropriate. The most important information at this stage is simply DM, OM, lipids and N.

Figure 3.2

STAGE 2: To make essential chemical analysis

3.4.3 Test the feed with animals (Stage 3)

Animals which previously were fed on a standard nutritionally-adequate diet should now be adapted to eat the residue/byproduct under test. The adaptation may take two or three weeks.
Two options are possible at this point (Figure 3.3). Either the test material should be given as the only feed, or virtually the only feed (except for urea/minerals); or it should be included as one component in a mixed diet. If the product is classified in Groups 2 and 4, it may well be appropriate to use it only as a supplement at up to maybe 30% of the diet.

3.4.3.1 The byproduct as the sole feed

Intact or preferably fistulated animals can be used. Depending on the N and OM content and on the degradability of the feed resource, a mixture of urea and ammonium sulphate should be added to satisfy microbial requirements for N and S (usually in the ratio 10N:1S (eg: 5 parts urea and 1 part ammonium sulphate). Sodium sulphate can also be used as a source of S but ammonium sulphate is usually more readily available. It is worth emphasizing that fertilizer grade materials should be used in both cases.

It is best to spray the N:S mixture onto the diet in aqueous solution to ensure homogeneous distribution. The quantities can be estimated by assuming that the microbes require about 3 g degradable N/100 g fermentable OM. Trace minerals and vitamins should be added in order to ensure that the diet is not, as far as is known, deficient in any micronutrients. If there is a risk that the test material might contain some toxic element, then it should be sent to a laboratory equipped to investigate such problems.

If reasonable intakes of the diet containing the test material are obtained (at least 1.5 kg DM/100 kg liveweight/d), then the rumen degradability test should be repeated. It is often convenient, though not always possible, to use fistulated animals for the feed acceptability study, as this will save time otherwise needed to adapt new animals to the diet before the degradability test is done with the test feed providing the rumen environment (instead of the good quality feed used in the first test).

Figure 3.3: STAGE 3 To determine the degradation in diets including the byproduct

If the rate and extent of degradation are considerably less than was observed when the incubations were done in the rumen of animals receiving the standard diet, it may be necessary to supplement the test diet with up to 25% (DM basis) of an easily digestible forage (Preston and Leng 1984) or byproduct such as beet pulp (Juul-Nielsen 1981; Silva and Ørskov 1985).
3.4.3.2 The byproduct as a supplement

Byproducts used as supplements will normally be rich in fermentable N (eg: livestock excreta), or protein, oil and/or starch (eg: oilseed cakes, cereal milling offals and slaughter offal). Their role will then be to improve the rumen ecosystem, by providing nutrients/physical characteristics which will stimulate rumen microbial activity, or supply bypass nutrients. Knowledge of the origin of the byproduct, the processing it has received coupled with chemical analysis, will enable it to be categorised as either mainly a rumen activator (poultry litter) or source of bypass nutrients (eg: oilseed meals). Methods of designing trials to characterize the relative usefulness of the byproduct for these purposes are given in Stage 5.

3.4.4 Parameters of rumen function (Stage 4)

In Stage 3 it will have been ascertained if the test byproduct is consumed in adequate quantities and that its rumen degradability is similar to that which occurred when it was incubated in fistulated animals given a high quality diet.

The next step (Figure 3.4) is to measure if the fermentable N (usually urea) is sufficient or in excess of that required. This can be done by reducing the urea supplementation to the point where degradation rates begin to decrease. It is also possible to estimate whether trace minerals are required by removing those added in Stage 3 and finding out if this makes any difference to the degradation rate. It may still be necessary to add the trace minerals to sustain the host animal's requirement rather than the microbial requirement.

In Stage 4, it is desirable to measure some parameters of rumen fermentation and function. If the test byproduct has been classified as an energy resource (Groups 1 and 3) and it is to form the basis of the diet, then almost invariably the feeding will be ad libitum. Under these conditions new feed will be offered once daily in the morning in quantities slightly in excess of the normal daily intake.

Figure 3.4

STAGE 4 Trials on rumen function

Useful parameters, measured over a period beginning before the new feed is offered and
Better utilization of crop residues and by-products in animal feeding: ... http://www.fao.org/DOCREP/003/X6554E/X6554E03.htm

continuing for some 5 hr afterwards, are:

- Rumen ammonia
- Ratios of the volatile fatty acids (VFA) in rumen fluid
- Acetate clearance rate

The level of rumen ammonia will indicate immediately if there is a need to provide additional fermentable N in the diet. The proportion of propionate relative to the other VFA will provide an idea of the likely glucogenic status of the end products of fermentative digestion (2.4.7). The rate of clearance from blood of an injected dose of acetate appears to offer promise as a means of predicting the adequacy of the final balance of nutrients for a particular productive function (see Preston and Leng 1986).

3.4.5 Animal feeding trials (Stage 5)

Stage 5 should involve experiments with intact animals (minimum of 4, preferably 8) because now it is necessary to determine what will be the level of intake when feeding is ad libitum (Figure 3.5). If the intake in cattle is less than say 1.5 kg DM/100 kg liveweight/d (2 kg DM/100 kg in sheep), then either the palatability is very poor, or more likely the diet is deficient in an essential nutrient. This could be a source of highly digestible forage (for the rumen ecosystem) or of bypass nutrients (protein is the most important) which partially or wholly escapes being degraded in the rumen (see Chapter 2 for a more complete discussion of these inputs in relation to supplementation of residues/byproducts).

A factorial arrangement of treatments should be set up employing 8 individually housed/fed recently weaned animals. The main treatments will be presence or absence of a source of locally available highly digestible green forage (eg: leucaena - or similar legume - or the foliage of cassava or sweet potato); and presence or absence of a standard bypass protein meal (fishmeal or cottonseed meal, or other oilseed meal). The arrangement of treatments will be:

- The basic feed resource (residue or by-product) supplemented with urea and minerals and vitamins) (= basal diet).
- The basal diet plus the green forage usually at about 20% of the diet DM (0.5 kg DM/100 kg LW/d).
- The basal diet plus fishmeal (or oilseed meal) at about 5% of the diet DM.
- The basal diet plus the forage plus fishmeal.

Figure 3.5

STAGE 5 Feeding trials
The results for voluntary intake will indicate the relative importance of either or both of these two types of supplement for the feed resource being evaluated.

If the intake exceeds 2.0 kg DM/100 kg liveweight/d in cattle (4.0 kg DM/100 kg liveweight in sheep/goats) then one can proceed directly to response trials (Stage 6) to determine the most economic amount of supplement to give according to the productive function of the target animal.

### 3.4.6 Production trials (Stage 6)

In Stage 6, as depicted in Figure 3.6, it is time to move to the target animal. The target animals can be producing different products; they can be growing and/or fattening, lactating, reproducing or working or producing wool/hair (or combinations of these activities).

There should generally be at least eight animal observations per treatment (the replications can be less when factorial or latin square designs are used; or covariance analysis is employed); and the experimental period should usually be at least 84 days (may be less in milk production trials using covariance analysis).

If the supplementation trial indicates a response in feed intake to either the forage or bypass protein supplements (or to both) then the appropriate treatments should be included in the feeding trial, using graded amounts of the particular supplement and employing usually some form of regression analysis in order to describe the response surfaces to supplementation. The wool growth assay, as a means of comparing protein meals, is an example of this approach (6.9).

Figure 3.6: STAGE 6 Production trials - (high priority)
3.5 HOW TO MEASURE IMPROVEMENT IN NUTRITIVE VALUE CAUSED BY CHEMICAL, PHYSICAL OR BIOLOGICAL TREATMENTS

It is assumed that the final objective is to choose a treatment method (physical, biological or chemical) that is appropriate for the particular locality. The starting point should be the optimal treatment for the residue/by-product in question, taking into account the following:

- The availability of the reagent/treatment method
- The cost
- The risks
- The feasibility of using the method at farm level
- The availability of equipment required for the treatment
- The efficiency of the process

The first step is to measure the improvement in degradability brought about by the treatment. The untreated and treated material should be incubated in nylon bags in the same rumen-cannulated animal given a standard diet as described in Stage 1. The degradation rate is described. If there is a satisfactory improvement due to treatment, the decision may be taken to modify the treatment, for instance to use different concentrations of chemical, or different treatment times or methods of treatment (eg: whether the stacks of straw should be covered or not).

The results of each new treatment can be measured against the optimum one. Having ascertained the most appropriate treatment to use, it is time to proceed to the next stage, namely to determine the response to improved rumen environments and to supplementation. The appropriate steps are those described in Stages 2 and 3.
Chapter 4: GUIDELINES FOR THE UTILIZATION OF BYPRODUCTS BY PIGS AND POULTRY

4.1 INTRODUCTION

Monogastric animals are the most efficient transformers of raw ingredients, rich in starches/sugars and proteins, into meat and eggs. Only milk may be produced with a similar efficiency by ruminants.

However, the usual feeding techniques of monogastric animals require the utilization of cereals and costly protein meals as the basis of the diet. In many developing countries this usually leads to direct competition with human consumption and the expenditure of foreign currencies for importation of the raw materials.

On the other hand, poultry and pig meats and eggs can be intensively and rapidly produced and distributed in large and small cities and can improve quite strongly and dramatically the nutritional status of these populations. Therefore an effort to use locally produced byproducts through monogastric species has to be considered as a major priority, even at the expense of lower rates of individual animal productivity.

The following suggestions are a non-exhaustive list of proposals to help progressing in that direction.

4.2 ELABORATION OF AN INVENTORY OF BYPRODUCTS USABLE BY MONOGASTRIC SPECIES

Each country should prepare a rough inventory of all crop residues and agroindustrial byproducts that can be utilized by monogastric animals. The main objective of this inventory is to identify all the possible ingredients and the quantities available for use in poultry and pig diets.

The crop residues and byproducts usable by monogastrics can be divided into four main groups:

4.2.1 Byproducts of animal origin

These include all the products coming from the slaughter houses mainly in the big cities, from large animals and poultry. Typical products are meat, bone and blood meals. These may be as single products or they may be mixed (eg: meat and bone meal). Feather meal is sometimes produced at poultry slaughter plants. There are also hatchery byproducts elaborated from dead birds and eggs.

Fishmeal is produced in many countries. Usually it is produced from the byproducts of fish canning enterprises and other processing activities, in which case the ash content (from the bones) can be quite high. In some countries, like Peru, the fish meal originates from whole fish harvested specifically to make meal for animal feeding; these meals can have quite high oil contents.

4.2.2 Byproducts of plant origin
Many originate from the milling industry such as bran, rice polishings, wheat millings, maize gluten, sorghum gluten, etc.

Others are from the edible oil industry e.g.: the meals obtained after extraction of oil from the seeds of soybean, cotton, sunflower etc.

There are useful byproducts from the sugar industry, such as molasses and sugar beet pulp.

Byproducts from fruit processing include reject bananas, citrus and pineapple pulps, reject apples and some other fruits discarded as unsuitable for marketing for human consumption.

By-products from the fermentation industry are the yeasts from brewing and distilling. In some countries, yeasts are produced as a primary product for animal feeding (e.g: torula yeast from fermentation of molasses).

### 4.2.3 Unconventional feed resources

In this category can be grouped feed resources such as sugar cane juice; foliage from some legumes and food crops such as sweet potato and cassava; waste food from catering establishments in large institutions; larvae from the artificial breeding of flies; livestock excrement; earthworms reared artificially, and so on.

### 4.3 THE ECONOMIC AND PRACTICAL FEASIBILITY OF UTILIZING BYPRODUCTS IN PIG AND POULTRY PRODUCTION

When a byproduct is identified which is thought might be useful in monogastric feeding, some preliminary investigation should be carried out to ensure that it is practically possible to use the byproduct. This survey should precede any chemical or other analysis. Some of the points to take into account are:

#### 4.3.1 Amounts available

Is the byproduct available in sufficient quantities to make a worthwhile contribution to ration formulation? Gaps can exist between the theoretical availability based on extraction rates and the actual amounts of the material that are produced.

#### 4.3.2 Distribution

Is the by-product available within a reasonable distance from the site of production?

#### 4.3.3 Infrastructure

Is there infrastructure (roads, handling facilities, transport) already in place to deal with the byproduct or will this have to be developed?

#### 4.3.4 Level of technology

Will the byproduct have to undergo any preparatory treatment to make it suitable for inclusion in a ration? If so is the technology available locally to perform this treatment economically? Does it need equipment, investments? What is the cost of the treatment?

#### 4.3.5 Availability

Will the product be available on a year-round basis at a standard price? Beware of seasonal fluctuations which may cause prices to rise to uneconomic levels at certain times of the year; and breakdowns in the supply which may cause changes in the diet formulation.

#### 4.3.6 Toxic substances
Are there any toxic substances present in the product? (This can be determined by chemical analysis.) If so, is it necessary to remove these at the intended level of inclusion in the ration, and if it is, can this be done economically?

4.3.7 Quality

What is the likely nutritional value of the product? This can be determined by chemical analysis and by feeding trials. Will the nutritional quality vary during the year to a degree that might jeopardize its inclusion in a ration?

4.3.8 Alternative uses:

Are there alternative uses for the byproduct which may compete with its utilization as feed? What are the perspectives for such alternative uses?

4.3.9 Cost

In view of all the above points, is the product competitive economically with other available materials? In some cases, when one starts to buy what was previously a waste product, the producer may take advantage of the demand and raise the price to an uneconomic level.

**4.4 DETERMINATION OF TOXIC AND HARMFUL SUBSTANCES IN BYPRODUCTS**

4.4.1 Determination of toxicity (lethal dose)

Biological tests can be done with different animals (ducklings, chicken, egg embryos) to estimate amounts of contaminated byproducts which are safe to utilize as feed ingredients. This method can be applied to determine the efficacy of the detoxification process used for the contaminated produce.

4.4.2 Detection and determination of:

- alkaloids
- glucosides
- goitrogenic substances

4.4.3 Determination of toxic metabolites produced by fungi (eg: Aspergillus and Penicillin)

- aflotoxins
- penicillic acid

4.4.4 Other tests for harmful substances

- Determination of potential toxicity of some mycotoxins produced by fungi. This information helps to establish the best method of preservation to prevent spoilage.
- Determination of fungicides and other chemical substances used in plant protection.
- Determination of nitrite and nitrate in green plants when large doses of N-fertilizer have been used.
- Determination of cyanogenic substances present in some green plants (alfalfa, clover, grasses).
- Determination of toxic metabolics produced by bacteria (salmonella strain) as well as presence of salmonella in some products of animal origin.
- Determination of some medicaments (eg: coccidiostats) in poultry litter or excrements which
Better utilization of crop residues and by-products in animal feeding:...

4.5 PROPOSED METHODS FOR TREATMENT OF BYPRODUCTS CONTAMINATED WITH TOXIC OR HARMFUL SUBSTANCES

4.5.1 Ensiling

Use of microbiological or chemical treatments is an effective method for destroying glucosides, alkaloids and some mycotoxins.

4.5.2 Ammonification

This is a very effective method for destruction of aflatoxins.

4.5.3 Use of high temperatures

Autoclaving or drying processes can be applied to animal byproducts and some oilseeds (eg: soybean, rapeseed).
Chapter 5: EXPERIMENTAL EVALUATION OF A BYPRODUCT FOR PIGS AND POULTRY

5.1 PRELIMINARY EVALUATION

To evaluate whether a byproduct is likely to be a suitable feed resource for monogastric animals, the following examination should be undertaken.

5.1.1 Chemical analysis

The byproduct should be analysed according to the AOAC's Official Methods of Analysis. Emphasis should be put on dry matter (DM), crude protein (CP), crude fibre (CF), ash, acid insoluble ash (AIA), calcium (Ca) and phosphorus (P). This is in order to classify the byproduct into one of INFIC's feedstuff classes. Macroscopic and/or microscopic appraisal of the by-product may be helpful.

The conventional feed ingredient(s) that will be potentially substituted by the byproduct should be identified. Comparing their chemical composition to that of the byproduct always helps in the initial estimation of the level of substitution in isonitrogenous-isocaloric diets for monogastric animal in which the byproduct is to be fed.

5.1.2 Palatability and toxicity trials

In order to evaluate the acceptability, palatability and/or toxicity of the byproduct in monogastric animals, a preliminary feeding trial should be carried out. A statistically sound design should be used with an adequate number (>4) of replication and sufficient numbers of animals in each experimental unit (>35 unsexed broilers, >12 layers or >2 pigs).

5.1.3 Determination of the optimum range of inclusion

Isonitrogenous-isocaloric experimental diets should be formulated including the byproduct to supply a key nutrient (primarily energy or protein) at 4 to 5 levels (eg: 0, 25, 50, 75 and 100%) of that supplied by the substituted ingredient. This is to enable the researcher to detect the optimum range of inclusion from the response curve (Figure 5.1).

5.1.4 Feeding trials using target animals

A feeding trial on broilers should be carried out through a normal production range (6–8 weeks); for layers it should be through the first half of the laying period (point of lay to 22 weeks). Pigs should be studied over the range 25 to 60 kg liveweight. This is to ensure that the observed responses are real and reliable.

Animal performance can be assessed from the response curve with appropriate statistical analyses of observed weekly records of feed intake and liveweight gain (or egg production).

A precise evaluation of the byproduct, in terms of optimum substitution level, nutrient supplementation/correction and method to improve its nutritive value, can be subsequently
5.2 PRECISE TECHNIQUES FOR EVALUATION OF A BYPRODUCT

Once a byproduct has been defined chemically and tested on animals to know its acceptability level (i.e., the maximum concentration in a feed which does not affect too much the health, feed intake or faeces consistency. A digestibility test may provide useful information of its feeding value.

Bio-available energy and amino acids account for over 90% of feed costs. Therefore a priority must be given to determine the digestibility of these nutrients. The following suggestions are proposed as guidelines for such a determination. A comprehensive discussion of the subject was given by Picard et al (1985).

5.2.1 Metabolizable energy for poultry

- Animals: Adult cockerels of light weight housed in cages with a collecting tray.
- Replicates: Minimum 6 birds per treatment.
- Preparation of the animals: No adaptation to the diet starvation 24 hr prior to the beginning of the test.
- Diets: The sample must be homogenized. If acceptability level (x) as determined in (5.3.1) is less than 100% a basal diet (e.g., maize grain) is prepared and mixed with the ingredient to reach the desired concentrations (e.g., 0, 0.5x, x and 2x% of the sample in the basal diet). Sampling of individual ingredients for laboratory analysis should be done at the same time as the weighing and mixing of the test diets.
- Feed distribution and faeces collection: The birds may be either force-fed (50 g) or fed ad libitum during 24 to 96 hr. The force-feeding will be followed by a 48 hr starvation period with excreta collection. The ad libitum test will be followed by a 24 hr starvation period with excreta collection. Care must be taken to avoid spillage of feed, to record accurately the feed consumption and any variation in moisture content of the feed. The excreta should be collected twice daily and stored at <4°C.
- Laboratory assays: DM (2 repetitions per sample), N (3 repetitions), GE (calorimeter) (5 replications). GE values should be made on the ingredients and on the basal diet, separately, and on the pooled excreta samples. Freeze drying of the excreta is recommended but classical methods may be used for drying.
- Interpretation: Measurement of the endogenous energy losses on either starved birds or birds fed a 100% absorbable diet (e.g., glucose) is highly useful to calculate the energy value with various units (e.g., apparent ME, true ME), corrected or not for a given N retention. This should be done for each concentration of the product and by regression to 100% if linearity of the response permits it.

5.2.2 Digestible energy for pigs

- Animals: Growing pigs (liveweight range 25–60 kg), the exact point depending on the type of ingredient being studied.
- Replicates: Minimum 4 pigs per treatment if the animal serves as its own control.
- Preparation of the animal: Anti-parasite treatment; 10 day adaptation to the cages; 7 day adaptation to the feed; no starvation.
- Diets: The sample must be homogeneous. Then all depends on the type of ingredient. Some may be fed pure (e.g., wheat bran); some are either high in humidity or difficult to mix;
they will be tested by addition to a balanced basal diet or previously tested alone on the same pigs. The level of addition must represent more than 30% of the ingested DM. Some are dry and easy to mix; they will be introduced by dilution as for poultry.

- Feed distribution and faeces collection: The digestibility test will last 7 days for each diet after a 7-day period of adaptation. The daily allowance should be given in two meals (morning and afternoon), and the feed should be given wet. The feeding level should be 80–90 g DM/kg (LW) {LW}^{0.75}/d.

Care must be taken in measuring feed refusals, and the moisture content and N content of the wet refusals. Faeces should be collected twice daily and stored at -18°C.

- Laboratory analyses: The same procedures recommended for poultry. Freeze drying is proposed as the best method for preparing samples for analysis. DM should be estimated in duplicate; N and GE in triplicate.

- Interpretation: Depending on the technique used; digestible energy of the ingredient is calculated either:
  - Directly (when fed as the sole ingredient) or;
  - By difference between the two periods (basal diet alone - basal and ingredient); or
  - For each dilution level and by regression to 100% if linearity permits it.

Metabolizable energy (ME) may be calculated using the following equation:

\[
\frac{\text{ME}}{\text{DE}} = 100 - 0.07 \cdot \frac{\text{DP}}{\text{DE}} - 1
\]

ME: metabolizable energy (Mcal/kg)
DE: digestible energy (Mcal/kg)
DP: digestible protein (g N × 6.25/kg)
(100 - 1) is the correction for DE lost as heat (1%)
0.07 = Coefficient assuming a 50% N retention and 9 Kcal/g of N in urine (measured).

5.2.3 Amino acids

For any monogastric animal a precise determination of the amino acid content of the ingredient is essential for feed formulation. However such measurements are costly and difficult. The best way is to send a sample to a specialized laboratory or to refer to a value taken from the literature. In fact, a given protein source shows a relative consistency of its amino acid composition. Therefore a standard value may be adjusted to the actual N content of the sample using the following equation:

Sample AA content = Table AA content (in g/16 g N) × Sample N × 6.25 content

For any new byproduct or, if the chemical analysis value of the sample (moisture, N, ash, lipids, fibre) differs too much from the literature reference values, an analysis of AA is recommended.

Digestibility of N can be worked out together with the energy measurement. It gives useful information to be compared with regular raw materials. For cockerels, a special treatment of the faeces is necessary in order to eliminate the uric acid prior to measurement of the excreted N (Terpstra and Dehart 1974).

Amino acid digestibility per se can be derived from N digestibility using the simplified procedure suggested by Picard et al (1985).
5.2.4 Remarks

- Simple digestibility tests give very useful information on the value of a byproduct if constant attention is given to precision while the test is carried out. Fluctuations in the DM content of the samples, of the diets and of the faeces between weighings and analyses are a major cause of error.

- Results must be discussed with regard to the methodology, the level of inclusion, the unit used in order to improve the procedures.

- Total collection has been favoured against the use of any indicator. If digestibility cages for pigs are not available, the use of acid insoluble ash is suggested (eg: McCarthy et al 1974, 1977).

5.3 FEEDING TRIALS AND APPLICATION

This is the last section in the guidelines on methodology for evaluating feeds for monogastric animals. All too often the researcher, having published the preliminary evaluation, is inclined to stop at this point. But the job is not finished!! The research findings must be applied to a practical situation. How can this be done?

Design a practical ration which includes the byproduct taking into account:

- nutritional balance of the feed
- simplicity of utilization
- economics (least cost formulation)
- social implication
- alternative animal species

Feeding trials should be run using the levels of introduction and the diets suggested above:

- At the research farm level: Large numbers of replicates are suggested using practical diets and preparations.

- At the commercial farm level: Depending on the target group, this kind of trial will be handled either by a large corporation or directly with small farmers.

Information about feeding trials is important. It should be disseminated in as many ways as possible (eg: local conferences, local publications, in schools and in technical training).

5.4 PRIORITIES ON TESTS AND INVESTMENTS

- Recommended minimum animal facilities:
  - 20 pens or cages for 3–5 growing chickens
  - 20 pens or cages for 2 pigs each
  - 20 pens or cages each for 1–2 layers

- Recommended minimum feed mixing facilities:
  - A shovel!!

- Recommended minimum laboratory equipment:
  - Oven
  - Kjeldahl furnace
  - Muffle furnace

- Fibre analysis apparatus
- Lipid extraction apparatus
- For exact laboratory evaluation:
  - Calorimeter
  - Digestibility cages
    - Minimum of 8 cages for pigs and 30 cages for cockerels
  - Large scale feeding trial units
    - 24 broiler pens each for 100 birds
    - 100 cages each for 3 laying hens
    - 16 pens each for 2 pigs

However, there was only 2% N in the diet dry matter and the diets were balanced for N by replacing a fermentable-N source (urea) with a protein which largely escapes rumen fermentation (fish meal) and no consideration was given to the level of rumen ammonia. It is equally valid to suggest that rumen ammonia was probably low on the fishmeal diet and that this led to a decrease in the rate of fermentation of the grain carbohydrate; as a result, rumen pH would stay high (see Mehrez et al 1977). The consequence of this is that the pelleted straw and the maize silage might be more fully digested in the rumen. On the urea diet rumen ammonia levels would be higher leading to a faster rate of grain fermentation (Mehrez et al 1977), a lower pH and therefore a reduced rate of cellulolysis (Mould et al 1983).
Chapter 6: ANALYTICAL METHODS FOR CHARACTERIZING FEED RESOURCES FOR RUMINANTS

6.1 INTRODUCTION

It is not intended to provide a comprehensive description of all analytical methods used in ruminant nutrition research. The aim is to identify those procedures considered to be more applicable and critical to the characterization of feed resources for incorporation into livestock feeding systems in developing countries. Emphasis is given to methods which are least demanding in terms of sophisticated facilities and equipment. Most of the techniques that are proposed can be established with a minimum of infrastructure in terms of laboratory facilities. The exception to this is the recommendation to estimate rumen volatile fatty acids with a gas-liquid chromatograph. However, such equipment is commonly available in at least one laboratory in many developing countries (eg: in a university, or research centre and often in factories); and it is enough to have access to such equipment as and when needed.

The laboratory measurements are the minimum needed to enable researchers to acquire the essential information for them to set up meaningful feeding trials. Observing and measuring animal response to dietary manipulation of the available feed resources are essential first steps in the development of feeding systems for application on farms. This is the correct order of priorities for allocation of resources aimed at development of animal feeding systems. Too often the research is “bogged down” in the laboratory without excursion into the field, which is a necessary prelude to any study of farmers' problems and of how possible solutions might fit into existing farming systems (see Chapter 7).

The approach is aimed at scientists working in National Institutions but the methods are also applicable to International Research Centres. Obviously there is a special role for the latter and they require many more tools in their research. Their task must be to examine, in depth, the problems that arise in the field and which are generated by the pragmatic “local” approach that is advocated. Such centres should support national institutions, and be engaged in the more sophisticated basic studies that such research requires.

The proposed research methods relate closely to the guidelines for feed resource classification and evaluation set out in Chapters 2 and 3.

6.2 FACILITIES

6.2.1 Individual pens

The first requirement is for individual pens to house both intact and fistulated animals. The pens can be simple, but, they must facilitate adequate care of the animals, especially feeding and cleaning. Floors which are slatted, allowing faeces and urine to fall through into a pit below, are more expensive but the investment is justified in the improved environment for the animals (they are always dry and clean) and elimination of unpleasant tasks for the attendants. The feed hoppers should be designed to avoid spillage and to facilitate the collection of residues. Clean water should always be available.
Pens should be in multiples of four and the minimum needed is 16 units. This gives flexibility for feeding trials with up to four treatments in factorial and latin square arrangements. Figure 6.1 gives the design and dimensions of suitable pens for cattle and sheep/goats.

Animals with rumen fistulas must be held individually; the walls of their pens may need to be solid to prevent them damaging the fistula.

6.2.2 Other facilities

Accurate balances are essential both for weighing animals and feeds. Spring balances should generally be avoided and simple scales which use weights hung from an arm are to be preferred. For cattle it is desirable to be able to weigh by intervals of 500 g and for sheep 200 g. Feed scales should weigh to 100 g.

6.3 RUMEN FISTULATION

6.3.1 Background

Animals with rumen cannulas are an indispensable feature of the feed evaluation strategy. Two procedures for cannulation have been used by researchers. In 1928, Schalk and Amadon described a one stage surgical technique. A two-step method was developed later by Jarrett (1948) mainly for use with sheep. Both methods have been used but for unknown reasons the Schalk and Amadon method seems to have been neglected except in Australia (Hecker 1974).

Figure 6.1. a

Plans of experimental pens for carrying out feeding trials with Cattle. Building is 19.0 m × 7.0 m
for 16 pens.

Figure 6.1 b: Cattle slats (in mm)

Figure 6.1 c: Cross-section of cattle pens (in cm)

Figure 6.1 d: Feed trough for cattle (in cm)

Fig. 6.1. e: Plans of experimental pens for carrying out feeding trials with sheep (in cm)

Figure 6.1. f: Cross-section (in cm)
The surgery associated with establishment of rumen fistulas by the two stage operation requires considerable skill, is laborious and can be stressful to the animal. The method is extremely difficult to carry out in laboratories that do not have the minimum facilities (e.g. an operating table). Furthermore, it was presumed that such surgery was the domain of the trained veterinarian. This resulted in “a mental block” for many young scientists, particularly those in developing countries.

One result of this has been an undue emphasis on feed analyses as a means of predicting nutritive value of feeds, to the neglect of studies on the live animal.

The most appropriate method for establishing rumen fistulas, especially in laboratories with limited surgical facilities, is the one-step Schalk and Amadon procedure. In the last 10 years in Australia, this technique has been considerably simplified allowing untrained but “aware” scientists to establish fistulas with a minimum of stress to the animal. For example in a course in Ethiopia for young African scientists from many backgrounds (all with the “mental block” concerning “surgery”), each was able to establish (under guidance) a rumen fistula in either cattle or sheep.

The animals that were surgically modified were in the preliminary phase of a feeding trial. Their feed intake was monitored both before and after surgery. The effects of the establishment of a fistula on feed intake of a 350 kg steer is shown in Figure 6.2. The animal ate less on the day of the operation but quickly regained its appetite. With the two stage surgical method animals go “off feed” often for several days.
The technique has been successfully applied to cattle, sheep, goats, buffalo and camels.

### 6.3.2 Principle of the method

A metal clamp is applied to a fold of the rumen wall exposed by an incision into the body cavity. The clamp holds the fold of rumen wall outside the body, occludes the blood supply and causes the damaged area below the fold to adhere to the body wall. In ten to fourteen days the clamped piece of rumen 'sloughs off' leaving a fistula through which a cannula can be readily introduced and secured.

Figure 6.2

Rumen cannulation of large ruminants can be accomplished without undue stress on the animal. The data in the figure are the feed intakes of a steer (350 kg) prior to and following fistulation carried out according to the procedure described above. The animal reduced its feed intake only during the day when the surgery was carried out, (Leng, R.A., unpublished data)

### 6.3.3 Facilities and equipment

Only minimum facilities are needed; a simple crush or some method of restraining the animal in a standing position (cattle only), a minimum of surgical equipment (scalpel, forceps etc.), a tranquillizer and local anaesthetic.

The clamp consists of two brass rods 11 cm long and 0.6 cm in diameter (for sheep) and about twice this size for cattle. Each brass rod has two holes 2.5 cm from either end of the rods. The holes in one rod are threaded to take a brass screw which is fitted through a hole in the other rod so that when the screws are turned the two rods draw together forming a clamp (Figure 6.3 and 6.4).

### 6.3.4 Preparation of the animal

It is not necessary to starve animals prior to surgery; in fact it is desirable to have the rumen relatively full. A tranquillizer given prior to the actual surgery is an advantage in the case of cattle.

The animals should be accustomed to handling by attendants and should be docile and easily led. The surgery is carried out with the fed animal standing in a crush or even restrained in the
corner of a yard by a moveable gate. The animal is tranquilized by intramuscular injection (e.g. with Rompun) but this is not absolutely necessary. A 350 kg cow requires about 0.5 ml of Rompun to be sufficiently sedated. Approximately 15 minutes after the injection of the tranquillizer, surgery may commence.

The area of incision should be closely clipped or shaved and cleansed with a mixture of alcohol or alcohol and iodine. The incision should be made high on the left side in the anterior dorsal abdomen. The site of the incision is identified by marking a triangle from the point of connection of the last rib with the spine and moving the same distance along the spine from the last rib. The area between the last rib and where it connects with the spine should be sufficiently large to take the external flange of the cannula. In general the closer to the spine on the flank the incision is made the better; but only experience will allow accurate placing and estimation of size of the incision. Before starting such operations cannulas of different sizes (5–12 cm internal diameter) should be on hand.

Analgesia of the incision area can be produced by paravertebral anaesthesia; however, this requires experience and skill. A more practical approach is to inject a local anaesthetic in a series of subcutaneous and intramuscular injections immediately above and along the site of the incision. Approximately 25 ml of Zylocain is injected into a steer of 250 kg and 15 ml into a sheep.

Figure 6.3:
Illustration of rumen fistula produced by the one-step method of Schalk and Amadon
6.3.5 The surgery

Once the site has been cleaned and disinfected, and the local anaesthetic injected, an incision about 5 cm for sheep and about 10 cm for cattle is made in the ventro-cordal direction through the skin, following the line identified previously (6.3.4).

In the original description of this method the underlying abdominal muscles and peritoneum are separated by blunt dissection to form an opening in the abdominal wall. This requires considerable physical strength with large animals such as buffaloes and the bold use of the scalpel to cut to the peritoneum is less traumatic to the animal.

On reaching the peritoneum, this is cut and the rumen wall which lies immediately below is drawn to the exterior to form a fold and held with two “Alice” forceps. The brass clamp is applied and the screws tightened (Figure 6.4). Sutures should be placed through the skin and under the clamp...
and are tied to the clamp at both ends. These sutures hold the clamp to the skin and also prevent accidents which can occur if the rods catch on the sides of the pen. Stitching the skin is one of the most difficult aspects of the operation, particularly with buffaloes, and a sharp cutting needle is needed.

In ten to fourteen days the rumen fold held by the clamps will slough off and can be removed quite easily. A flexible rubber cannula or rigid cannula prepared as described below is inserted and clamped into position.

6.4 MANUFACTURE OF RUMEN CANNULAS FROM LOCALLY AVAILABLE MATERIALS

The use of the one-step fistulation technique means that animals (cattle, buffalo, sheep or goats) can be prepared for use in almost any research laboratory.

The lack of availability of manufactured cannulas has often been the reason for not preparing fistulated animals. It is relatively simple to devise rumen cannulas for both cattle and sheep. The method described below is taken, in part, from a paper by Rowe (1979).

6.4.1 Available materials

In most countries PVC conduit is available with diameters from 13 to 300 mm and with a wall thickness of 3–5 mm. In the Dominican Republic, PVC tubing has been used for cannulas which were placed in the fistula of cattle which were under experimentation for more than two years without apparent problems.

Rubber tubing is also available in most countries (e.g., car radiator manifolds) and has been used to prepare cannulas. Car tyres or the protective band from inner tubes usually provide a suitable rigidity for retaining flanges for the cannula.

6.4.2 Construction of cannulas from radiator tubing

Flexible rubber cannulas are preferred since these can be easily compressed to introduce them into the oval fistula that results from the method of cannulation.

For sheep the components of the cannula can be constructed from a section of radiator hose and a round flat piece of rubber cut from a truck tyre. These two parts may be sewn together with nylon thread (as shown in Figure 6.5). Insertion of this cannula into sheep is facilitated by twisting a section of the retaining flange into the tube (see Figure 6.5). When the cannula is in position the retaining flange may be pushed out of the tube of the cannula to allow it to assume its normal shape but inside the rumen.

The cannula is held in position with a second rubber retaining flange and this is secured against the body of the sheep as shown. The retaining flange is kept in position by a radiator hose clamp. A suitable stopper for the cannula can be a plastic bottle inverted and inserted with the open end downwards into the tube of the cannula. This is extremely light and causes no problems to the animal.

6.4.3 PVC cannulas

The design of the PVC cannula is shown in Figure 6.6. The PVC tube is prepared with a flange by making cuts of up to 5 cm (for sheep) and 15 cm in length (for cattle) at four intervals around the circumference of the tube; when this is heated uniformly with a gas jet, the plastic becomes pliable and the flanges can be bent outwards at a right angle to the main tube. The flanges can be filed so that there are no rough edges and enclosed in rubber tubing.

(a) Cross-sectional view of cannula
Better utilization of crop residues and by-products in animal feeding: ...

Figure 6.5: Rumen cannula for cattle made from rubber components (Row 1979)
Better utilization of crop residues and by-products in animal feeding: ...

Figure 6.6: Diagram showing the construction of a rumen cannula from PVC tubes and rubber flanges (Rowe 1979)

To facilitate placing the cannula in the fistula, it is cut longitudinally in half and a small hole made in each half at the upper end of the flange to attach a length of string. The retaining flanges and the clamping arrangements are prepared as described for rubber cannulas. To hold the two halves of the cannula together, an outer split tube is prepared from the same diameter PVC tube but with only a single cut. The cannula is inserted by first putting the two halves (attached to a
length of string) into the rumen. The internal retaining flange is then passed around the string and into the rumen before pulling the two halves together and positioning them in the fistula.

The surface of the tube must be thoroughly dried before applying PVC cement and placing the outer split tube in position. The application of PVC cement is not necessary if the tube is clamped close to both the entry of the cannula into the rumen and at the top adjacent to the stopper. A lightweight plastic bottle makes the best seal for the entrance to the cannula. Any size cannula can be made in this way.

6.5 RUMEN INCUBATIONS WITH NYLON BAGS

This method is given first priority for researchers in developing countries, as the most appropriate tool for providing information on:

- The nutritive value of a feed for ruminants
- The efficacy of the rumen ecosystem

It generates useful information from the point of view of both the carbohydrate and protein status of a feed; and the degree to which it will be digested in the rumen or escape to the intestines. The method is described in detail for this reason.

6.5.1 Characteristics of the bag

The bags should be prepared from a nylon or other synthetic fibre material with a pore size of between 20 and 40 microns. The pore size is a compromise between minimal loss of small particles and making sure that microbes, including protozoa, can enter the bags uninhibited; and also that gas can escape from the bags. When gas does not escape the bags may float on top of the solid phase of the rumen and give very variable results. It is desirable that each research network (eg: ARNAB, Bangladesh, SW Asian group) uses the same material. Distribution of appropriate material would be a useful role for each coordinator.

The bags should be sewn with polyester or nylon thread with double seam and close stitching. Overall dimensions for cutting out should be 17 × 10 cm to give an effective length of about 12–14 cm. Smaller bags can be used if samples are smaller. It is not necessary to introduce a draw-string in the neck of the bag, as they can be closed with a separate length of nylon thread (eg: fishing line), and/or attached to a long nylon string (eg: baler twine) or a plastic rod (see 6.5.4). The bags can be reused as long as there are no holes in them; each time they should be checked for breakages.

6.5.2 Sample size

The sample size has to be adapted to the size of the bag. With the size of bag suggested, samples of between 3 and 5 g of DM are appropriate. For smaller bags, the quantity should be less, but with a minimum of 2 g. To avoid forming micro-environments in the bag the material has to be able to move freely within the bags. If larger samples are needed for analysis, larger bags must be used.

6.5.3 Preparation of samples for incubation

The preparation of samples must, as far as possible, represent materials as they would appear in the rumen after they have been consumed naturally by the animal. It is recommended that the materials are processed through a hammer mill with a screen size of 2.5 mm; the same screen size can also be used for forages and cereals. For green and succulent materials and silage, a mincer with a 5 mm screen is more appropriate. If the apparatus for grinding materials is not available this can be done by other means, but it is important to specify exactly what was done in the preparation process.

6.5.4 Position of bags in the rumen
If sheep are used, a 25 cm nylon cord is normally used to attach the bags to the cannula cap. The size of the animals might be considered. In many countries, where the sheep and goats are small, it is probably better to use cattle.

In cattle, depending on their size, the nylon cord should be about 40 cm. This allows the bag to move freely within the digesta, both in the liquid and solid phases. It is not usually necessary to anchor the string of bags with a weight. Inserting a glass marble, or a brass weight, in each bag sometimes helps to ensure that each bag is kept well within the digesta. Another method is to fix the bags to a nylon tube (Figure 6.7). This latter system simplifies withdrawal of the bags since bags with individual cords can become tangled and difficult to withdraw from the rumen.

Figure 6.7: Illustration of plastic tube and attachments of nylon bag for suspension in the rumen

6.5.5 Incubation times of bags in the rumen

Selection of the most appropriate times to withdraw bags from the rumen depends on the shape of the curve of degradation with time. It is not possible, therefore, to give absolute recommendations. Having tested one material, the test may have to be repeated with slightly different incubation times.

It is important to describe the most sensitive part of the degradation curve and also the asymptote. For straw and other fibrous materials, incubation intervals of 12, 24, 48 and 72 hr are usually suitable. For protein meals shorter incubation times should be used (eg: 2, 6, 12, 24 and 36 hr).

6.5.6 Replication of measurements

The important source of variation is between animals. There is little to be gained by repeating treatments within the rumens of the same animals. The number of animals needed will depend on the expected magnitude of the differences between treatments.

To measure degradabilities of proteins, at least three animals are needed per treatment; while to test the effect of chemical treatment of straw two repetitions (animals) will probably suffice.

6.5.7 Use of sheep or cattle

If the sheep weigh less than 40 or 50 kg, it is probably better to use cattle. Cattle are much easier to work with than very small sheep and goats; moreover, it is often convenient to be able to insert a hand directly through the cannula into the rumen so as to introduce, and later extract, the bags more easily.

6.5.8 Interpretation
6.5.8.1 Degradability of the substrate

Irrespective of whether the results are going to be used for estimation of degradability of protein or dry matter, the most appropriate method of describing the results is in the form of an equation. The expression

\[ D = a + b (1 - e^{-ct}) \]

is the most appropriate equation. In this equation \( D \) is the degradation which has taken place; "a" is the intercept; "b" is the amount which in time ("t") will be degraded; "c" is the degradation rate constant and "e" is the natural logarithm. If computers or scientific calculators are not available, the equation can be derived by eye.

The procedure is to fit the curve to the measurements obtained (Figure 6.8). It can be seen that the intercept "a" is "6"; the asymptote is "92" (ie: \( a + b = 92 \)) which means that "b" is "86" (ie: 92–6). Taking a value on the curve where degradation is occurring most rapidly (eg: \( t = 8 \)) the "D" = 48.

It is now possible to describe the equation as:

\[ e^{-ct} = (a + b - D)/b \]

Which means that:

\[ e^{-ct} = (6 + 86 - 48)/86 = 0.512 \]

By taking the natural logarithm on both sides of the equation, it is found that:

\[ c = 0.084 \]

All the constants in the equation are now known and they will be found to agree closely with those obtained more accurately with the computer.

6.5.8.2 Effect of outflow rate

Protein-rich meals, derived from oilseed cakes and byproducts from cereal processing and animal slaughter, contain quite a high proportion of small particles which can escape easily from the rumen. The effective rate of degradation of the protein will then depend on the solubility (a), the rate at which the "b" fraction is degraded (c) and the outflow rate of small particles (k) which can be measured by mordanting the protein supplement with chromium (Figure 6.9a shows a typical curve of outflow rate from which "k" is derived). The expression which combines these three factors is:

\[ p = a + bc/(c + k) \]
Figure 6.8:

Estimating degradabilities of feeds by the nylon bag technique; calculation of degradation rate (c) from disappearance curve fitted by eye

Figure 6.9: Examples of degradation patterns of three protein supplements (2a); and a typical excretion curve for a protein mordanted with Cr (from Ørskov 1985)
Figure 6.10: The effect of outflow rate on effective rumen degradability of fish meal, linseed meal and groundnut meal (from Ørskov 1985)

Figure 6.9b illustrates degradation patterns for three different protein supplements. Supplement “F” has a high solubility (a) and a low rate (c) and low potential degradability (a + b); this curve is typical of fishmeal. Supplement “G” is degraded rapidly and has a high potential degradability; supplement “L” is intermediate between the other two. It follows that supplement “F” will be very little influenced by outflow rate; and supplement “L” will be most affected (see Figure 6.10).

6.5.9 Characterizing the rumen ecosystem

The second major use for the nylon bag technique is to measure the adequacy of a diet for a particular purpose. Under these conditions a standard material is put in the bags and the rumen ecosystem varied by supplementation or other means.

For example, if the objective is to assess the adequacy of the rumen ecosystem to digest cell wall carbohydrate, then a fibrous substrate with a high potential fermentability (e.g. cotton wool) is put in the bags (see Figure 2.5 for the application of this method). The effect of supplementing the basal diet (e.g. with urea or highly digestible forage) can be investigated in terms of the relative loss of the cotton wool during a 48 hr incubation period.

The other important feature of the rumen ecosystem is the extent to which it permits dietary protein to escape to the intestines. There is some indication that high rumen ammonia levels (Preston, T.R. and Nuwayaka, M. unpublished data), and the feeding of high levels of sugar-rich feeds (Encarnación and Hughes-Jones, 1981) reduce the rate at which dietary protein is degraded in the rumen, thus facilitating its escape to the intestines. To assess this effect the test protein meals are incubated in nylon bags in the rumen of animals subjected to manipulation of the basal diet by, for example, adding urea or molasses. An example of the use of this procedure to assess degradability of a protein meal, subjected to different rumen environments, is shown in Figure 6.8.

6.6 THE USE OF RUMEN AMMONIA CONCENTRATION TO DETERMINE WHEN UREA SUPPLEMENTATION IS NECESSARY

6.6.1 Introduction

The level of rumen ammonia is critical for efficient microbial fermentation of feed (Chapter 2). Rumen ammonia concentration can therefore be used to diagnose a deficiency of fermentable N in a diet. This will indicate when urea supplements are required.

The critical ammonia level in the rumen for efficient microbial growth on different substrates is likely to vary according to the fermentability of the substrate. As a “rule of thumb”, rumen ammonia nitrogen should be at least 5 mg/100 ml rumen liquor. However, values as high as 15 –20 mg/100ml rumen liquor may be necessary for optimum fermentation of fibrous feeds (see Chapter 2).

Where rumen ammonia is to be used as a diagnostic tool then the times of sampling of rumen fluid are critical. It is necessary to synchronize the availability of ammonia with the fermentation of the carbohydrate. The ammonia level at 4 to 6 hours post feeding or following the commencement of grazing is the recommended time for sampling.

Ammonia concentrations in rumen fluid must be above the critical level for prolonged periods on fibrous diets which are only slowly digested in the rumen. For this reason the concentration immediately before feeding may also be an index of the need to supplement.

6.6.2 Estimation of rumen concentration - field method

There are two methods of measuring rumen ammonia which are relatively simple. One of these can be used under field conditions (i.e. the use of an indophenol-dye to produce a colour reaction

with ammonia). This method is used by extension officers in Queensland to predict when urea supplementation through drinking water is likely to be effective in increasing productivity of grazing ruminants McMeniman 1981). The method as modified by Leng (see Preston and Leng 1986) is as follows:

6.6.2.1 Rumen ammonia kit

- Collection tube
- Beaker
- 1 litre 0.2 hydrochloric acid
- Muslin
- 200 ml sodium salicylate reagent
- 200 ml dichloroisocyanuric acid reagent (DCL)
- Ammonia standards 0, 2.5, 5.0, 7.5, 10.0 mg NH3-/100 ml
  (These have already been diluted with HCl)
- Test tubes
- Test tube rack
- Syringes

6.6.2.2 Reagents

- Solution A (Salicylate): Dissolve 85 g of Na and 100 mg of Na nitroprusside in a litre of distilled water
- Solution B (DIC): Dissolve 5 g of sodium dichloroisocyanurate in a litre of 0.3M NaOH containing 5% commercial bleach (50 ml commercial bleach and 12 g NaOH in one litre of water)
- Solution C (Stock solution): Weigh 3.28 g NH4Cl (equivalent to 100 mg NH3-N/100 mg) and dissolve in one litre 0.1M HC1 (in distilled water)

6.6.2.3 Chemical principles

Ammonia reacts with free chlorine to form chloramine which then condenses with two phenol molecules to form an indophenol dye (strongly reducing compounds in rumen fluid are oxidized by the hypochlorite).

Since excessive amounts of both salicylate and hypochlorite are present, the amount of dye produced depends on the amount of ammonia present. The relatively high concentration of salicylate was chosen to “swamp” the effect of any phenolic compounds which may be present in the rumen fluid.

6.6.2.4 Obtaining a sample

- Using a stomach tube (see 6.11) obtain 20–30 ml of liquor from the sheep
- Strain the liquor through four layers of muslin into the beaker

6.6.2.5 Analysing the sample

- Using a syringe or pipette, measure 0.2 ml of the range of standards into labelled tubes, starting with the lowest concentrations taking care to blow out any fluid left in the syringe between standards
- Using a plastic syringe for rumen fluid measure 0.2 ml of strained rumen fluid into a second row of tubes already containing 0.2 ml of 0.1M HCl; blow out the syringe between samples
- Add 1 ml of the salicylate solution to each tube using a 5 ml syringe
- Add 1 ml of DIC solution to each tube using a 5 ml syringe; cap and shake to mix

- Allow 5 minutes for colour development, then add 0.2 ml rumen fluid to all standards; compare samples with standards. Do not allow samples to stand longer than 10 minutes as colour will over-develop.

6.6.2.6 Points to note in analysis

The reagents are relatively stable but they are unlikely to keep indefinitely. Attention is given to the following problems:

- If the zero standard is highly coloured then the standards have been contaminated and the salicylate needs renewing

- If the colour developed in the range of standards is the same, the DIC reagent needs renewing. Add 5–10 drops of commercial bleach to 100 ml of the DIC and repeat the test, before remaking the solution

The standards are in an acid solution and will absorb ammonia from the air, therefore the standards must be sealed at all times and where analysis appears unreliable this is the most likely site for investigation.

Sampling from 6–8 sheep in a grazing group gives a reliable estimate of the mean rumen ammonia concentration of the group of animals.

6.6.3 Laboratory techniques for estimation of rumen ammonia

6.6.3.1 Principle

The ammonia is separated from rumen fluid by steam distillation, collected in boric acid solution and determined by titration with standard acid.

\[ \text{NH}_4^+ + \text{OH}^- \rightarrow \text{NH}_3 + \text{H}_2\text{O} \]

\[ \text{NH}_3 + \text{H}_3\text{BO}_3 \rightarrow \text{NH}_4^+ + \text{H}_2\text{BO}_3 \]

6.6.3.2 Equipment

Standard steam distillation apparatus is used to isolate ammonia from rumen fluid.

6.6.3.3 Preparation and distillation of samples

Strained rumen fluid is centrifuged for 15 min (3000 rpm) and the supernatant frozen after being acidified with 2–3 drops of concentrated sulphuric acid.

Pipette 5 or 10 ml rumen fluid into a distillation flask, add a few drops of universal indicator solution; followed by a small drop of defoaming agent (if necessary) and 10 ml Natetraborate solution - distill immediately. Distill until 30–40 ml is collected (about 4 min), remove conical flask and titrate the distillate using 0.1 M HC1. A standard ammonium sulphate should also be titrated.

6.6.3.4 Reagents

- Ammonium sulphate - a standard solution is prepared from AR material and diluted for use.

- Working acid solutions
  - 0.05N H2SO
    
    50 ml N H2SO4 standard diluted to 1 litre with distilled H2O
  - 0.0075 N H2SO4; 7.5 ml standard 1, N H2SO4 IN is diluted to 1 litre with distilled water

- Boric acid solution (20%):
Dissolve 20 g AR boric acid in approximately 700 ml hot distilled water, cool and make 1 litre in a volumetric flask.

- Sodium tetraborate solution (5%) saturated: Dissolve 50 g AR sodium tetraborate (powder or crystals) in 1 litre distilled H2O

- Universal indicator solution (BDH Chemicals Ltd.) Range pH 4 - pH 11 product No. C21049.

- Silicone antifoaming agent (BDH Chemicals Ltd): An aqueous emulsion containing 30% silicon product no. 33151 - use discretely and in extremely small amounts to counter "greasiness" of glass ware.

6.6.3.5 Mixed indicator solution

- 0.1% ethyl red in 85–95% ethanol
- 0.1% Bromocresol green
- 40 ml 0.1% methyl red make to 2 litres
- 8 ml 0.1% bromocresol green with 2% boric acid solution

6.7 GAS LIQUID CHROMATOGRAPHY OF VOLATILE FATTY ACIDS IN RUMINAL FLUID

The total concentrations and individual proportions of the volatile fatty acids in the rumen are an indication of the animal status for glucogenic compounds. Fermentations giving high proportions of propionic acid (25–35%) are desirable since these fermentation patterns are most efficient energetically (less heat is lost as methane). The level of total VFA is also indicative of total fermentation rate. For these reasons a method for VFA analysis by gas-liquid chromatography (GLC) is given below.

6.7.1 Column packing

Inert support: chromosorb “W”, acid washed 50–80 mesh

Liquid phase:

a. phosphoric acid (1.5% by weight of the inert support)

b. polypropylene glycol sebacate (PPGS) (18% of the inert support)

6.7.2 Method

- 12 g of the chromosorb “W” are placed into an evaporating basin (12 cm diameter)
- 0.2 g of 88% phosphoric acid (H2PO4) in 70 ml of distilled water is then added and the mixture gently stirred until the chromosorb “W” is uniformly wetted.

  The mixture is then oven dried at 80°C.
- 2.1 g of PPGS is dissolved in 70 ml of methylene chloride and added to the chromosorb “W” - phosphoric acid mixture in the evaporating basin and then dried in an oven at 80°C.
- The column is packed using slight suction from a vacuum pump while vibrating the column. Acid washed glass wool is packed into the end of the column then attached to vacuum pump and suction applied. The free running packing is held in a funnel attached to the other end of the column. Vibration or tapping causes the mixture to run into the column.

6.7.3 Operating procedures
Operating conditions using FID (Flame Ionization Detector)

- Column temperature - 135°C
- Detector temperature - 180°C
- Injection port temperature - 200°C
- Nitrogen carrier gas flow - 60 ml/min
- Hydrogen flow to FID - 49 ml/min
- Air flow to FID - 400 ml/min

6.7.4 Preparation of rumen fluid for GLC with an internal standard

- Make a stock solution of the internal standard - 1.6% isocaproic acid in formic acid. Store at 4°C.
- Composition of standard VFA (standard A) solution for GLC

<table>
<thead>
<tr>
<th>Conc. (mM/litre)</th>
<th>Acetic acid</th>
<th>56</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Propionic acid</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Isobutyric acid</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Butyric acid</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Isovaleric acid</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Valeric acid</td>
<td>3</td>
</tr>
</tbody>
</table>

The concentration of each acid must be known accurately and can vary slightly from that indicated. The mixtures are prepared from AR grade acids and stored neutralized (because a variable loss of individual acids from frozen samples occurs). The formic acid/isocaproic acid, internal standard acidifies the samples prior to injection onto the column.

A solution of the internal standard for use (Standard B) over a few days is prepared weekly.

- 10 ml of stock internal standard solution (see Standard A) + 10 ml of 15% metaphosphoric acid (freshly prepared) + 30 ml of formic acid. Store at 4°C.

6.7.5 Sample preparation

- Ruminal fluid is centrifuged at 3000 rpm for 10 min
- 0.4 ml of the internal standard solution B is placed into a small (1.5 ml) disposable centrifuge tube followed by 0.7 ml of ruminal fluid. This is mixed and if necessary the sample is again centrifuged at 3000 rpm for 5 min. These samples can be stored for 1–2 days at 4°C.
- Standards: 0.4 ml of internal standard solution B plus 0.7 ml of mixed VFA standard. 1 to 4 microlitres of this mixture is injected into the column.

6.7.6 Calculation of total VFA concentration and VFA proportions using the internal standard method

- The relative response factor (representing the area under the peak of that acid) for each volatile fatty acid is calculated using the standard VFA mixture which is chromatographed in every group of 50 samples

\[ f_{Ac} = \frac{CAc \times \text{Std A (ic)}}{\text{Std.A (Ac)}} \]

where \( f_{Ac} \) = the relative response to acetate

\( CAc = \) concentration (uM/ml) of acetic acid in the VFA standard

\( \text{Std.A(ic)} = \) area under the isocaproic acid peak in the standard.
Better utilization of crop residues and by-products in animal feeding: ...

Std. A(Ac) = area of the acetic acid peak in the standard.

Factors are similarly calculated for the other VFAs.

- These factors are used to calculate the individual VFA concentration for each sample.
  
  eg: Acetic acid = fAc × sample A(Ac) × sample A(ic) where sample A(ic) = area of isocaproic acid peak in the sample,

  sample A(ic) = area of isocaproic acid peak in the sample.

- The sum of all the individual VFA concentrations for each sample is the total VFA concentration (in μM/ml of ruminal fluid).

- By taking the sum of all the individual VFA concentrations as 100% the molar percentage of each acid is calculated.

6.8 ACETATE CLEARANCE AS AN INDICATOR OF THE BALANCE OF ABSORBED NUTRIENTS

6.8.1 Background

Early studies in Australia, aimed at examining the role of glucose as a priming substrate for the TCA cycle (ie: providing oxaloacetate), used acetate clearance rate as a measure of glucose sufficiency. Acetate clearance was most rapid on those diets likely to have a high glucogenic capacity (ie: diets high in protein or maize; or where it could be expected that propionate would be a high proportion of the rumen VFA). The rate of clearance of injected acetate on the lucerne hay diet was highly correlated (r² = 0.98) with feed intake (Figure 4.20). The increasing level of intake could be expected to lead to greater escape of potentially glucogenic nutrients.

The suggestion from this work is that there is a close correlation between the ability of an animal to clear acetate and the availability of glucose. Ruminants must control blood acetate within physiological limits, and therefore feed intake and fermentation rate must match the animal's ability to utilize acetate which is dependent on the availability of glucose provided that the acetate is being used for fat synthesis. This hypothesis should be tested since acetate clearance rate is relatively easy to measure.

The other point arising from these considerations is that the intake of a particular feed will be maximized when nutrient availability is "balanced" with requirements. Therefore, the ability of the animal to clear acetate could be used as an index of the "balance" of the absorbed nutrients. This relationship could be especially useful in grazing studies to identify the effects of supplements.

6.8.2 Hypothesis

It is proposed that in cattle and sheep, acetate clearance rates reflect the balance of nutrients available for metabolism for a given productive state and that acetate clearance from blood will be directly related with feed intake (Weston 1966).

6.8.3 Method

Cattle (about 150 kg) are injected with about 2.5 mM sodium acetate per kg liveweight. The injection can be done via an in-dwelling cannula in the jugular vein or injected directly into the vein. The injection should be done slowly over about 4 minutes. Blood samples (10 ml) are taken at intervals post injection for analysis of acetate or total VFA.

6.8.4 Injection solution

Dissolve 30 g of sodium acetate in 300 ml sterile double-distilled water. Inject directly into the jugular vein.
6.8.5 Blood samples

When an in-dwelling cannula is used, this is normally filled with dilute heparin solution (100 units/ml of 0.9% saline) to prevent it being blocked with coagulated blood, and then sealed with a nail. Prior to taking samples, remove the heparin solution and 5 ml of blood from the cannula and discard. Take a further 20 ml of blood into a bottle containing two drops of heparin (3 000 units/ml). Flush the cannula with the dilute heparin solution and seal it. Take samples at 10, 20, 30 and 40 minutes post injection.

6.8.6 Chemical analysis

- Centrifuge blood at 3 500 rpm for 10 minutes
- Take off the plasma; store 5 ml; for analysis
  - Put into 50 ml centrifuge tubes the following:
    - 20 ml 0.2N H2SO4
    - 0.4 ml of isobutyric acid (1.75q/litre)
    - 5 ml 10% Na tungstate
  - Leave for 10 min at room temperature
  - Centrifuge at 3 000 rpm for 10 min
  - Put supernatant in conical flask and add 1 drop of phenolphthalein
  - Neutralize with about 0.5 ml of 3M NaOH (add a drop at a time until a pink colour persists)
  - Evaporate to about 1 ml by boiling the solution on a hot plate (add glass beads to prevent bumping)
  - Add 0.5–1.0 ml of metaphosphoric acid (36% HPO3)
  - Inject 1–2µl into GLC

6.8.7 Gas-liquid chromatograph

- H2 gas flow 30 ml/min
- Air flow 350 ml/min
- N2 carrier gas flow 40 ml/min

Range 10
Attenuator 128
10mv recorder

Injector temperature 210°C
Detector temperature 180°C
Column temperature 135°C

6.8.8 Column

- Column: 1.5 m × 4 mm ID glass column
- Inert support: Chromosorb “W” acid washed
- Column coating: 17.5% polypropylene glycol

6.8.9 Calculations

Divide the area of the acetate peak by the area of the isobutyrate peak to obtain the relative concentration of acetate in blood. Regress the relative concentration of acetate against time from injection and calculate the time for the concentration of acetate to fall to half the value following
injection.

6.9 ASSAY FOR BYPASS PROTEIN IN A SUPPLEMENT

Wool growth in sheep is highly dependent on the quality of amino acids absorbed from the intestines, in particular the sulphur amino acids. However, these amino acids are not absorbed other than from the protein (dietary and microbial origin) digested in the intestines. Increased wool growth rate in response to ingestion of a protein supplement is directly related with the content of bypass protein in the supplement.

6.9.1 Validation

Mixed sex cross-bred Merino/Border Leicester sheep (1 year old) were housed in individual pens and given a basal ration of 700 g/d of oaten hay chaff plus 3% mineral mixture and 1% urea (to ensure adequate fermentable-N in the rumen). Sheep were randomized to five treatments (11 animals per treatment). The treatments were 60 g/d untreated casein and 0, 20, 40, and 60 g/d of formaldehyde-treated casein (HCHO-casein) prepared as described later (formaldehyde treatment leads to almost complete protection of the casein from degradation in the rumen). Wool growth was estimated by clipping and weighing the wool from a 10 cm square patch on the flank of the sheep every three weeks (Leng et al 1984).

Preliminary studies indicated that the carryover effects of diet on wool growth were reduced to insignificant levels after 3 weeks. Trials therefore were carried out for a six week period and only the wool growth in the final three weeks was related to the amount of protein in the supplement.

In subsequent studies the sheep were re-randomized before being allocated to treatments. Each group was fed either the standard protein or a test protein-rich meal. Data for the response of wool growth to HCHO-casein three consecutive experiments are shown in Figure 6.11. The amounts of wool clipped from the patch were linearly related with the level of HCHO-casein added to the basal diet. When soluble casein was added to the diet, wool growth rate was only slightly increased over the control animals indicating that this protein had no bypass characteristics.

In subsequent experiments wool weight from the clipped patch in sheep fed 100 g/d protein meal (containing say 40 g protein) was related to the wool grown when HCHO-casein was fed.

Selected results from the use of this assay to evaluate a number of plant protein sources are given in Table 6.1. The wool growth represents the level of bypass protein relative to formaldehyde-casein. Meals that had received most heat treatment gave the highest wool growth and were therefore the best sources of bypass protein. Sunflower-seed meal was a poor source of bypass protein, especially when the oil had been extracted by the expeller system. The better bypass characteristics of the protein in meals produced by the solvent extraction process is because these meals are usually “toasted” at 120°C after the oil is extracted.
Better utilization of crop residues and by-products in animal feeding: ...

http://www.fao.org/DOCREP/003/X6554E/X6554E06.htm

Figure 6.11:

Wool growth rate in sheep given a standard basal diet (oaten chaff/ urea supplemented with casein protected with formaldehyde. The three experiments were each of six weeks duration and were run consecutively. Wool growth was measured during the last 21 days on a 10 cm² patch (Leng et al 1984)

Table 6.1

<table>
<thead>
<tr>
<th></th>
<th>Relative Wool Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSW Sunflower meal</td>
<td>5.5</td>
</tr>
<tr>
<td>Qld Sunflower meal</td>
<td>3.3</td>
</tr>
<tr>
<td>Ext. Soybean meal</td>
<td>4.5</td>
</tr>
<tr>
<td>Fishmeal (1)</td>
<td>7.5</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>5.9</td>
</tr>
<tr>
<td>Linseed meal</td>
<td>10.6</td>
</tr>
<tr>
<td>Rice Pollard</td>
<td>1.0</td>
</tr>
<tr>
<td>Casein</td>
<td>0.3</td>
</tr>
<tr>
<td>HCHO-Casein</td>
<td>10.0</td>
</tr>
<tr>
<td>Cotton Seed Meal</td>
<td>7.2</td>
</tr>
<tr>
<td>Pellets</td>
<td>5.8</td>
</tr>
<tr>
<td>Rapeseed</td>
<td>3.9</td>
</tr>
</tbody>
</table>

Feeding trials ranked the protein meals in the same order as indicated by the wool growth assay (Leng, R.A. unpublished data). In this case the criteria were feed intake and liveweight gain, both of which are good indicators of the bypass protein status of a supplement when added into a low-protein diet.

6.9.2 Preparation of formaldehyde treated casein as a standard for the wool
growth assay

- Place 5.08 kg of casein into a food mixer (a cement mixer is normally used).
- Put 140 ml of formalin (47% formaldehyde) and 240 ml water into a beaker using a measuring cylinder and transfer to a pump fitted with a fine spray.
- Cover with a sheet of plastic the opening in the mixer containing solid casein. The plastic cover has a hole to take the nozzle and add the formaldehyde whilst mixing.
- Put the formaldehyde-casein in plastic bags for a week prior to feeding.

6.10 CHEMICAL ANALYSIS OF FEED AND FACES

6.10.1 Preparation of samples

Samples of material to be analysed must be oven-dried at 65°C and then ground to pass through a 1 mm screen. Further drying to constant weight may be necessary to remove residual moisture.

Dried material may be stored at room temperature in sealed vessels or plastic bags, preferably under nitrogen gas.

6.10.2 Moisture

A sample containing the equivalent of about 2 g dry matter is dried to constant weight at 95–100°C over 24 hr. Use an aluminium dish or porcelain crucible. Calculate percentage moisture from the loss in weight (to first decimal place).

6.10.3 Ash

Weigh a 2 g sample into a weighed porcelain crucible and place in a temperature-controlled furnace preheated to 600°C. Take care to avoid loss of material by convection currents. Hold at this temperature for 4 hr. Transfer crucible directly to desiccator, cool and weigh immediately. Calculate percentage ash (to first decimal place).

6.10.4 Kjeldahl nitrogen determination

The Kjeldahl technique can be divided into three basic steps:

- Digestion of the sample in concentrated sulphuric acid during which all organic compounds are broken down, and organic N is converted to ammonia
- Over-neutralization of the solution with a caustic soda solution and distillation and collection of the ammonia
- Titration of the ammonia

6.10.4.1 Reagents

50% Sodium hydroxide: Dissolve 600 g of NaOH in distilled water and make up to a volume of 1 litre. When the pellets of sodium hydroxide are added to water, stir with a glass rod. This is necessary to prevent NaOH from fusing to the bottom of the beaker. Keep in a rubber- or plastic-stoppered bottle.

Digestion mixture: Mix 8 g selenium with 400 g potassium sulphate, and the mixture into 2 litres concentrated sulphuric acid and heat until all reagents are dissolved.

Note: When the chemicals are mixed the Se and potassium sulphate set solid so it is easier to put the chemicals into the digestion flask and then add the acid.
Alternatively, Se catalyst tablets can be purchased and concentrated sulphuric acid is used as the digestion mixture.

6.10.4.2 Sample size

Determination of sample size assumes some prior knowledge of the material under investigation. For maximum accuracy, a sample size should be taken which will require 10–20 ml of the standard acid. The amount of titrant can also be varied by changing the normality of the standard acid.

Some feeds may be low in protein, and it may be difficult with small samples to obtain truly representative samples. Consequently, a considerable amount of dry material must be digested.

Using 0.1 M acid as titrant for the ammonia that had been distilled, it is recommended that the following sample sizes are used:

- Dry feed samples 300 mg
- Milk, except colostrum 1 ml (or 1 g)
- Colostrum 300 mg
- Plasma and serum 0.5 ml
- Urine 0.2 ml

Very dilute samples (e.g.: rumen fluid) may require use of a 0.01M standard acid for titration.

Because of the sensitivity of the analysis, high accuracy cannot be obtained without thorough mixing of the material to be analysed prior to sampling. This is especially true with materials which have been frozen and allowed to thaw.

6.10.4.3 Digestion

To the 100 ml Kjeldahl digestion flask, add:

- Sample (approximately 150 mg DM);
- One glass bead to prevent bumping;
- 5 ml conc. H2SO;
- 1 se catalyst tablet.

Heat the mixture on the digestion rack in an area with air extraction. If foaming occurs, the early part of the digestion can be carried out at a lower temperature.

Silicone antifoam agents should never be used (contrary to several current texts). The silicone spray coats the sides of the digestion tube producing a non-wetting surface. Large water droplets collect, and when sufficiently large, drop into the superheated anhydrous digestion mixtures, with violent consequences.

Following removal of all the water, white sulphur dioxide fumes will be evolved. These fumes are irritating and toxic and must be exhausted in a hood with sufficient capacity to prevent transfer into the laboratory.

During the digestion, charred material can be washed down into the digestion mixture by swirling the digestion flask. If swirling does not flush all charred material into the digestion mixture, let the mixture cool completely, and wash the charred material down with a fine stream of water. Then redigest until the mixture clears.

After white fumes are no longer evolved and the boiling mixture is clear, allow the digestion to proceed for a further 30 minutes. Then allow the flasks to cool.

Add about 20 ml of deionized water, mix immediately to prevent crystallization of the sodium
sulphate.

6.10.4.4 Distillation

This is the same as for ammonia estimation.

Turn on the heater under the steam generator and increase the heat to boil the water steadily (not violently), and turn on water to condenser. Put the empty digestion flasks on the collector tubes, and with the alkali stopcocks closed and steam directed into the apparatus, run steam through the assembly and collect the condensates in 100 ml beakers for several minutes. This serves to warm up the apparatus, and flush out any residual alkali.

When the apparatus is preheated, open the alkali stopcocks and direct the steam into a water drain. Place samples in the distillation apparatus and place 100 ml flasks containing 20 ml 2% (w/v) boric acid (containing indicator) under the condenser stem. Be sure the tip of the condenser stems are below the surface of the boric acid solution.

Admit alkali solution through the alkali stopcocks (about 5 ml alkali for 1 ml of H2SO4 used in the original digestion) and close the alkali stopcocks. Then turn steam on through the apparatus and allow steam distillation to proceed for 6 min. Near the end of this period, lower the receiving beaker so that the distillate washes any remaining ammonia solution from the tip of the condensing units. When the distillation is completed, turn steam stopcock into the position which diverts the steam to sink waste and another opens the distillation flasks to atmospheric pressure. Remove distillation flasks and turn steam stopcock to the off position.

6.10.4.5 Quantification of the ammonia

Titrate the ammonia-boric acid solution to the pink end-point with standardized acid (0.1N HCl or 0.05N H2SO4). Appropriate blanks must be run and their values subtracted from the sample titration values.

6.10.4.6 Calculations

There is a direct mole-per-mole relationship between ammonia released, the acid needed to titrate that ammonia, and the total N originally present. The number of ml of acid multiplied by its molarity gives the millimoles of ammonia. Since the ‘average’ protein is 16% N, multiplication of percent N by the factor 6.25 gives percent crude protein (some factor other than 6.25 may be used for particular proteins).

6.10.4.7 Precautions

Care must be taken when working with hot concentrated acid and alkali. Take normal precautions: safety goggles must be worn when starting distillations. In each step where water is added to acid and alkali to acid, the solutions must be cool, otherwise the reactions can be quite violent.

6.11 COLLECTION OF RUMINAL FLUID BY OESOPHAGEAL TUBE

For sheep a plastic tube of 10 mm internal diameter and some 90 cm long is suitable. The rumen sampling tube should be moistened and the sheep's mouth opened by placing a thumb in the region without teeth. The tube is then passed over the back of the tongue and into the oesophagus. Test for its presence in the rumen by checking for the smell of rumen fluid, and the lack of respiratory air movements along the tube. A vacuum pump is used to apply suction to draw the rumen liquid into the sampling bottle.

With cattle, a larger tube is required (15 mm internal diameter and 150 cm long). The rumen fluid can be obtained by lowering the animal's head until fluid runs from the tube. Move the tube in and out a few centimetres in taking the samples.

Filter rumen fluid through gauze. Note that samples obtained in this way may be contaminated with variable amounts of saliva.
6.12 TREATMENT OF STRAW AND OTHER FIBROUS ROUGHAGES TO INCREASE THE POTENTIAL NUTRITIVE VALUE

Several methods to treat straw to increase digestibility are available. The methods use chemicals such as sodium hydroxide, ammonia and calcium oxide.

At the present time the only method recommended for practical application involves ammoniation either using gaseous ammonia or through wet ensiling of the material with urea. The effect of this treatment is to increase digestibility (often by 5–10% units), to increase the nitrogen content of the straw (to approximately 1% of the dry matter) and to increase acceptability and voluntary intake of the treated straw as compared to untreated straw (usually by 25–50%) when this is made available on a free choice basis.

Only a brief outline of the methods is given here and the reader is referred to recent reviews for more complete descriptions of the method (eg: Sundstol and Coxworth 1984).

6.12.1 The principle

Ammonia as gas or generated from urea (by bacterial and/or plant ureases in the ensiling process) hydrolyzes the chemical/physical bonds between lignin and the cellulose and hemicellulose in the plant cell walls. The hydrolysis of these bonds makes the cellulose and hemicellulose more accessible to microorganisms in the rumen and increases total fermentation and usually the rate of fermentation. Some chemical hydrolysis of hemicellulose also takes place resulting in an increase in the portion of soluble carbohydrate in the straw.

6.12.2 Wet ensiling with urea

Straw is mixed with an equal weight of water containing 4–5% urea. This mixing may be done in a pit, in a container such as a basket lined with mud or even on the floor. Occasionally it may be advantageous to add a meal containing urease (eg: from whole soybean or other legume beans or even livestock excreta which also contain urease). Additional urease may reduce the reaction time, especially if the fibrous resource appears relatively sterile such as for example, bagasse.

After mixing, the urea-treated straw is sealed with a plastic sheet and left for a period of between 10 and 30 days. The higher the ambient temperature the shorter the time needed for digestibility to be increased. It is always important to study reaction time under the local conditions where the straw is to be treated (for a more complete description see Jayasuriya 1984).

Evidence of the reaction taking place is a change in colour of the fibrous material usually to a bright yellow; there is also a strong smell of ammonia when the straw is uncovered. Dark yellow or even brown discoloration of straw may result if the stacks become hot.

Treated straw can be fed immediately following ammoniation. It must not be sun-dried as this results in a loss of gaseous ammonia. Another procedure is to use a hand or foot operated pump in order to aerate the straw and drive out the ammonia into a container of water so that it can be trapped for recycling. The ammoniated water fortified with some urea is used to ensile a second batch of straw.

6.12.3 The use of animal urine to ammoniate straw

Animal urine, provided that it comes from animals consuming diets adequate in nitrogen, can be used to provide the source of urea for ensiling with straw.

Initially in any system where treatment of straw with urine is to be an on-going technology, it is probably advisable to estimate the quantity of urea in urine and to fortify the urine in the first treatment. From then on the urine ought to contain sufficient urea, if the animals are fed on the ammoniated straw.

Urine is collected from animals or humans and the straw is ensiled with the urine in a similar way...
to that described above for the urea-ensiling method.

### 6.12.4 Ammoniation of straw with gaseous ammonia

Straw stacks are constructed of a size that can be readily covered by the black polythene sheeting available in most countries. On sandy soils a ground sheet is required. Where large stacks are to be ammoniated, the straw should be sampled and the dry matter content determined. Water should be added to the straw to raise the moisture content to at least 15%.

The ammonia-gas cylinder is connected to a long perforated metal pipe about 4 cm in diameter which is inserted into the stack through a hole in the plastic about the middle of one end and pushed into the stack (the bales are always stacked so as to facilitate its entry).

The plastic sheet is tied around the tube and sealed along the bottom edges of the stack with earth. A weighed amount of ammonia is then added to give 3 kg of ammonia/100 kg of straw. It is always better to inject liquid ammonia and not gaseous ammonia and this is one by inverting the cylinder. The ammonia is rapidly absorbed into water and although the plastic sheet billows it is not likely to rupture. As ammonia inhalation is deleterious to health, it is beneficial to force air through the stacks and trap the excess ammonia prior to opening the stack.

### 6.12.5 Ammoniation of straw with aqueous ammonia

The same procedures, as used for urea ensiling, can be applied to aqueous ammonia. 12.5 kg of aqueous ammonia (18% ammonia) are added to 75 kg of straw. The ammonia solution is added to each level of the stack as the stack is constructed in a pit or above ground. The stack is sealed with plastic as described above.

All these methods require from 10 days (tropical countries) or up to six weeks (temperate countries) for digestibility to be optimized.

A combination of gaseous ammonia and aqueous ammonia is applicable on large farms where numerous batches of straw are to be treated. The loss of gaseous ammonia on opening the stacks is wasteful and often makes the whole procedure uneconomic. However, the gaseous ammonia from one stack can be blown to adjacent stacks using a compressor.

### 6.12.6 Ammoniation with application of heat

Ammoniation of straws with gaseous ammonia is improved by raising the temperature to 90°C. In Europe, ovens have been developed which take several tonnes of straw and enable the treatment time to be reduced to less than 24 hours. The treatment of straw at these temperatures can give rise to toxic compounds which cause “bovine hysteria” and since these compounds are transmitted via milk, it becomes hazardous (to calf or human health) to feed these feeds to dairy cows (see Perdok and Leng 1985). The method is not recommended for developing countries.

### 6.12.7 Ammoniation with dry chemicals

A recent development in ammoniation is the use of dry chemicals which when mixed together generate ammonia gas (Mason et al 1985). For one tonne of straw, 132 kg ammonium sulphate and 70 kg quicklime (CaO) are mixed in a metal trough placed adjacent to the stack of straw which is then covered with plastic sheet using the same procedure as for ammoniation with ammonia gas. 120 kg water are then added to the chemicals in the trough using a plastic hosepipe inserted through the plastic cover. These quantities of chemicals are needed to generate 34 kg ammonia. The reaction proceeds rapidly because of the heat developed when the quicklime reacts with the water.

The method appears to be more effective than urea-ensiling, at least under European conditions where the lower ambient temperatures slow down the rate of urea hydrolysis. The disadvantage is the amount and therefore the cost of the chemicals; 132 kg of ammonium sulphate and 70 kg of quicklime compared with 50 kg of urea required for urea-ensiling.
Chapter 7: VILLAGE/FARM SURVEYS AND ON-FARM TRIALS - HOW TO INTRODUCE INNOVATIONS TO EXISTING FEEDING PRACTICES ON FARMS

7.1 INTRODUCTION

Two major issues are discussed in this chapter. The first concerns the existing village parameters relating to feeding and feed supply; and the second to the introduction of innovations on farms. The critical role of village/farm surveys will be discussed in relation to both issues.

For unknown reasons, livestock workers have been slower, apparently than workers in other fields such as agronomy, to realize the value of village/farm surveys and on-farm trials. However, there is now a growing understanding throughout the tropical world that for research to be contributing to local development, it needs to be more specifically geared to the particular situation prevailing in a local environment. Earlier, the justification for research attention to animal production has mainly been seen in situations where increasing incomes would lead to greater demands for milk and meat - or increasing incomes have been one of the major underlying premises justifying research objectives.

It is now clear that the spectrum is broader. Particularly, that there are a number of countries where economic growth is stagnating or negative and that in these situations the correct approach will be to maintain and support the traditional systems, which have the merit that they are operating under the existing conditions and on the basis of existing management skills.

There are two more reasons. Numerous attempts have been made to make shortcuts to increased animal production by introduction of the very intensive Western types of animal production, particularly through importation of temperate breeds of animals without due consideration to the nutritional and managerial aspects. It is now clear that no breed can substitute for adequate nutrition and management. And that these problems must be tackled first, if progress is to be expected on the basis of local resources.

Furthermore, with the energy crisis the role of the working animal as a source of renewable energy, independent of oil and spare-parts imports is being increasingly appreciated.

As another reason, it may be mentioned that livestock are seen now as also having a contributing role to play in connection with fuel supply to rural households, either by supplying dung for burning or biogas production or as converters of residues produced in connection with energy production from crops or trees into useful products.

Much of the current thinking may be summarized in the following statement by Kjaerby (1983): “The basic premise is that it is easier and potentially more productive to adapt technology to peasant farming than it is to transform peasant farming to inappropriate technology”.

It is on this background that the growing interest in village/farm surveys and on-farm trials should be seen. The approach should be based on the following sequence of priorities:

- Identify the problem/constraints at the farmer level
- Consider possible solutions based on previous experience and knowledge
• Carry out applied research to verify the hypotheses

• Undertake basic research when needed for specific problems in support of the applied programme

The following observations are strongly influenced by practical experiences from Bangladesh and to a lesser extent India. However, it is hoped that the underlying principles can be useful in other countries.

7.2 ATTITUDES

Although there is a growing appreciation of the traditional animal production systems, it needs to be stressed that there is a long way from understanding the need for village and farm based survey and trial work till this becomes a regular feature of the time schedule of the animal nutrition worker. Some of the reasons are that most people in developing countries, who have received education to an extent that enables them to consider village-oriented animal nutrition work, come from a social background which is different to the background of the core of the livestock keepers. They are often impractical and their knowledge of local agriculture is poor. This makes rapport and communication with the farmer difficult in the same way as it makes it difficult for the aspiring young research officer to gain the confidence and understanding from his/her superiors. Experienced guidance will be still more difficult to obtain.

On the other hand, expatriate advisers working in developing countries may have a more practical farming background with them from their own country, but the conditions are different and they do not know the local language and customs. Even in the best case it will take time to learn both. Finally, village based work cannot be conducted with the same experimental rigour as laboratory or experiment station work. For scientists giving high priority to such rigour, village based work will not be easy.

Nevertheless, there are examples of successful survey and on-farm trial work being reported (Agarwal and Verma 1983; Breinholt 1982; de Lasson 1981; Dolberg et al 1981a; Jabbar and Green 1983; Helmrich 1983; Ibrahim et al 1984; Sere and Vaccaro 1984) indicating that the problems can be overcome. In this connection there is no doubt that more could be done to make such work professionally rewarding by - for instance - instituting rewards for successful application of scientific principles under practical farm and village conditions. Promotions might also be based on successful conduct of such work.

7.3 METHODOLOGY

7.3.1 The village survey on feed supply

This might also be termed the aggregate survey or the survey setting the framework (context) for animal production. Some key variables are discussed below.

7.3.1.1 Quantity

Most feed grows on land although the water hyacinth is important in some areas together with other water plants. Land can usefully be classified as agricultural, common and homestead land. Each component will typically contribute to livestock feeding. Roadside and embankments are included under the term common land. Figures on size of the areas and the cropping patterns/most common vegetation will help identify the relative quantities and qualities of the feeds available. Based on Helmrich (1983) the following schematic outline can be given;

| Table 7.1: Village fodder potential: origin, type and quantity |
When presenting the information gathered on quantity, the supply situation will be put into a useful perspective, if figures are given not only in the aggregate, but also as amounts per head of livestock, separated according to different categories (eg: basal feed resource and supplements), to give perspective and relevance to research work in this area.

7.3.1.2 Quality

When information has been obtained on the quantity and origin of the feed, the next question to answer will be about quality. The most important indicator will be the potential rate and extent of digestion (see Chapters 2 and 3). If reasonable values cannot be obtained for these two parameters, voluntary intake will be too low and the material will be unfit as a feed, unless it is upgraded by adequate supplementation and/or chemical treatment.

If there are no facilities to measure rate and extent of fermentation, the nitrogen content may also be used as an indicator of nutritive value. However, this can be misleading as N deficiencies are easy to correct; and a simple analysis for nitrogen does not differentiate between fermentable N for the rumen microorganisms and protein that is likely to escape the rumen fermentation (bypass protein) and contribute directly to the needs of the animal.

7.3.1.3 Seasonality

By establishing seasonality in feed supply, the survey may immediately point at storage and preservation as important research topics. This may not only be with the objective of matching energy and protein supplying feeds. It is possible attention to the seasonality factor also has revealed a need for measures to avoid losses of feeds due to climatic factors such as rain.

7.3.1.4 Ownership/user rights and feed market

Ownership/user rights are other important variables to consider in connection with a survey on feed supply. In the situations where the agricultural land is privately owned, it should not always be taken for granted that feed from such land is only for the owner. There are areas of the world, where crop residues are a part of labour wages or the owners find it too expensive to transport them home and leave it on the field for anybody to pick up. Similarly, it is also seen that livestock graze stubble over all agricultural land after harvest, irrespective of ownership. Or, crop residues may be burned or ploughed into the soil to improve fertility.

With regard to village common land, it will be important to determine who controls it not only in formal but, more importantly, in real terms. It is insufficient to accept a statement that it is - for instance - government land. It is more important to establish whether and from where any opposition may be expected in case any improvement schemes are taken up. Only then, it will be possible to make realistic proposals about how such land can be used better.

The market for feed is linked with the questions of origin and ownership of feed resources. Information on whether the farmer and/or village is a net importer or exporter of feed will also be
important.

7.3.1.5 Competition between feed and fuel

The use of dried cow dung as fuel is well known. That this phenomenon is only one step on a road, which ultimately may lead to a competition between feed and fuel, is perhaps, less well understood. Taking the example presented in Figure 7.1 from Bangladesh (Helmrich 1983), it is seen that during phase I until about 1960, wood or wood products were the single most important source of fuel. Thereafter the importance of wood starts to decline and its use becomes insignificant from 1990, as none is available. From 1960, cow dung plays a significant role but agricultural residues, having no use as feed, are more important and from about 1980 agricultural byproducts, which could as well be used as feed, assume an increasing importance.

From 1990 onwards, the use of agricultural byproducts for fuel affects feed supply so markedly that the cattle population starts to decline, which in turn has an influence on dung supply. The underlying cause is the growing human population which leads to an increase in demand for fuel. These issues must be brought to the attention of animal nutritionists so that they can make realistic projections and establish priorities for research.

7.3.1.6 Governments' role

Governments assist in livestock production in various ways by providing veterinary and other services. Governments also decide on the training and allocation of manpower. The scope and intensity of such assistance need to be assessed. For example, Government subsidies for imported feeds affect the use of local feeds.

7.3.2 Animal production systems

The notion that livestock are an integrated part of the total farming system in developing countries is not always correct. This has been illustrated in Bangladesh with data on land ownership and livestock keeping (Table 7.2). Only 23% of the households owning draught animals were in the category of having from zero to 0.20 ha of land. Relatively speaking it is clear that the draught animals belong to the holdings with land. The situation for the other categories of livestock is different. Of the households owning milking cows, 44% had between zero and 0.20 ha of arable land. For young stock, goats and poultry, the figures were 50%, 49% and 57%, respectively.

Fig. 7.1 RELATIONSHIP BETWEEN POPULATION GROWTH, ENERGY SUPPLY AND CATTLE POPULATION

Source: Helmrich (1983)
Table 7.2 Relationship between total arable land ownership and livestock keeping

<table>
<thead>
<tr>
<th>land, ha</th>
<th>Draught cattle</th>
<th>Milk cows</th>
<th>Young stock</th>
<th>Goats</th>
<th>Poultry</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>House-holds</td>
<td>Animals</td>
<td>House-holds</td>
<td>Animals</td>
<td>House-holds</td>
</tr>
<tr>
<td>0</td>
<td>(342)</td>
<td></td>
<td>13</td>
<td>24</td>
<td>20</td>
</tr>
<tr>
<td>0–0.2</td>
<td>13 (288)</td>
<td>27</td>
<td>49</td>
<td>50</td>
<td>55</td>
</tr>
<tr>
<td>0.2–1.6</td>
<td>63 (200)</td>
<td>52</td>
<td>32</td>
<td>38</td>
<td>55</td>
</tr>
<tr>
<td>0.6–1.6</td>
<td>58 (125)</td>
<td>46</td>
<td>39</td>
<td>53</td>
<td>46</td>
</tr>
<tr>
<td>Above 1.6</td>
<td>14 (38)</td>
<td>16</td>
<td>39</td>
<td>29</td>
<td>14</td>
</tr>
<tr>
<td>Total</td>
<td>993</td>
<td>339</td>
<td>159</td>
<td>196</td>
<td>210</td>
</tr>
<tr>
<td>Chi square</td>
<td>230.40</td>
<td>124.73</td>
<td>98.55</td>
<td>41.03</td>
<td>171.22</td>
</tr>
<tr>
<td>Pearson's R</td>
<td>0.39</td>
<td>0.28</td>
<td>0.26</td>
<td>0.12</td>
<td>0.33</td>
</tr>
</tbody>
</table>

1 Number of households in this size group

Source: de Lasson (1981)

It is clear that a substantial part of the livestock, even among the households with draught animals, is kept by households with insufficient home-produced feed. From that point of view, it may be safe to assume that about 50% of the livestock in this case is not integrated into the farming system as such livestock have to rely on common land for feed supply. Such information is important as it can be used to identify the existing animal production systems.

It is clear that at least two systems exist: one that is integrated with farming and one which is not. To devise useful strategies for the section of livestock owners not having sufficient land, organizational issues (cooperatives, credit and marketing), including control and increased productivity of common land, may be the first constraint to increased animal production.

Feed can also come from private land, owned by individual landowners or it may be imported. For any of these sources to be exploited by livestock keepers who have no land, an organization needs to be formed, which will ensure the transfer of feed to the livestock keepers.

Transfer of feed to livestock keepers without land can be done through the established technology of feed mills. However, for this to be economical, it often presupposes large animal units and productivity per animal usually has to be at a high level.

There are traditions for extensive grazing of stubble after harvest across fields, irrespective of animal or land ownership. Productivity per animal is low in these systems. There is also the tradition of common land grazing with low productivity per animal. It is quite possible that a more intensive exploitation of village common land is a way by which the landless livestock keepers could derive more benefits from animal production. However, the organizational and technological issues have hardly been touched, although this approach might represent an alternative to the high-technology feed mills and their dependence on imported feeds.

### 7.3.3 Introduction of innovations

#### 7.3.3.1 Dealing with farmers

To be able to evaluate the impact of an innovation, it is useful to start by collecting some base-line data. There is now sufficient evidence to postulate that farmers can be found all over the developing world, who are willing to collaborate with researchers. A successful outcome depends on the researcher.
An introductory survey is a useful tool to identify collaborating farmers for on-farm testing of innovations. In selecting such farmers it is important to appreciate that whereas it may be possible to maintain statistical rigidity, when selecting farmers for the base-line survey, this may not be the case for on-farm trials. It is not all farmers, who are interested in hosting an innovation trial. The pragmatic procedure is to include only motivated farmers.

The foremost condition for successful work is to establish a good relationship with the farmer. It is imperative that the farmer be regarded as a collaborator, who has specialized knowledge and who can be helpful in establishing research priorities. The farmer must not be treated as an object, and a farm survey/trial should not be considered in the same way as a controlled experiment station trial, where the researcher decides when a variable has to be changed. It is quite possible that farmers will agree to be grouped into various treatments. It is also possible to arrange with them that animals are weighed on particular weekdays at times suiting the farmer, although this may mean odd working hours for the researchers such as early morning or late evening. Agreements can also be reached about feeds kept aside in separate heaps for weighing till the recorder reaches the village, when due respect is given to feeding times.

If during the course of the survey an extraordinary situation arises, which causes the farmer to deviate from the agreed procedure, this will have to be accepted by the researcher. Such situations may be caused by a daughter’s marriage and suddenly the researcher may find that supplements are not being fed any more or - even worse - the animals are being sold.

Natural calamities, such as cyclones and droughts, can also interfere. The farmer may face a shortage of feed and accept emergency feed distributed by the Government or start to buy feed. Although such deviations may defeat the purpose of the survey, it cannot help if the researchers start to argue with the farmer.

The farmer and his family have to live from farming and have no permanent salary and they have to exist within the social structure of the village. Instead of criticizing the farmer, it is more useful for the researcher to reflect on his/her own reactions to social pressure and salary cuts.

It must be understood from the initial stage that the trial must in no case be detrimental to the income of the farmer. Firm guarantees should be given before undertaking any trial and compensation be paid should any difficulties be encountered.

7.3.3.2 Size of sample

The size of the sample may be determined in consultation with a statistician. However in many situations such ideal requirements cannot be met for want of money, qualified manpower, transport, etc. In this situation, it may be useful for the researcher to recall that the human brain is the most important research tool after all and that it is important not to allow the lack of conventional research gear to stifle one's determination to get into the villages and be exposed to the environment.

Even with one farmer important observations can be made. Thus the first observation on the high level of straw intake by the native cattle of Bangladesh (Mould et al 1982) was made on a village farm.

There have been numerous research reports discussing the possibility of using rice straw for animal feeding, often concluding that the high silica content is a major limitation. In this connection it is sobering to get into the villages and realize that irrespective of the composition of rice straw, it is the staple feed of millions of animals and it has been so for years and probably centuries.

Agarwal and Verma (1983) have described an on-farm trial carried out by Jackson in the hills of Uttar Pradesh in India in a cluster of 4–5 villages. Twenty-seven calves, a mixture of males and females, and cattle and buffaloes, were used and allocated in blocks to treatments of untreated rice straw and a small supplement of grass (control); the control plus 30 g/d of a commercial mineral mixture; or rice straw ensiled with urea according to the procedure described by Dolberg et al (1981a). Liveweight gains (Table 7.3) were derived as the differences between initial and

There were no statistically significant differences between the treatments when the former method of calculating liveweight gain was used; whereas use of regression analysis revealed an obvious advantage for the animals fed the urea-ensiled straw.

Table 7.3 On-farm trials involving the feeding of urea-treated straw

<table>
<thead>
<tr>
<th>Diets</th>
<th>Farm diet</th>
<th>Farm diet + mineral mixture</th>
<th>Farm diet of urea-treated straw + mineral mixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM digestibility of straw (%)</td>
<td>32</td>
<td>32</td>
<td>57</td>
</tr>
<tr>
<td>Nitrogen content of straw</td>
<td>0.5</td>
<td>0.5</td>
<td>1.3</td>
</tr>
<tr>
<td>Ca content of straw</td>
<td>0.5</td>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Average daily weight gain (kg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>By difference</td>
<td>0.12&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.17&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.26&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>By regression analysis</td>
<td>0.13&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.17&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.26&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Source: Jackson, M.G(personal communication) NOTE: Values followed by different superscripts are significant at P< 0.05.

It is important that the research worker undertaking village work is alert to such phenomena and uses the correct analytical methods.

It is likely that village-oriented work will throw up a number of issues requiring the use of appropriate research tools. As stated earlier, the correct approach is not to stay out of the village for want of tools, but rather look to other disciplines for techniques which will overcome the problems.

7.3.3.3 Time scale

It is difficult to give firm rules about the correct time scale. The objective of the particular research work will obviously be one important determinant. For measurements of feed intake, 3 weeks may be enough; whereas the effect of a particular supplement on reproductive parameters such as age at puberty or calving intervals will have to be studied over several years.

In general, the view taken here is that while the specific research objectives may vary, village surveys and on-farm trials should become a permanent feature of animal production work.

In most developing countries, relatively large livestock farms are found belonging to universities, research stations and Government department farms. All too often, applied research is confined to such farms and researchers rarely move outside them. This is in spite of the fact that only a small fraction of the national livestock production will ever take place on farms in this category.

Most of the livestock production takes place in private livestock units, small and large, and will continue to do so. Measured on any product (milk, meat or draught power) the private units account for the major part (usually over 90%) of total national production. As the funds, which go into training of livestock research workers are spent with the objective of increasing national production, national questions must be addressed. As nobody plans to stop research work in animal nutrition, it is only logical that village based work becomes a permanent feature of such work and not only a brief interlude. This is also the only way dynamics over time can be established.

7.3.3.4 The control group

The question to be discussed in this section is, how to measure the effects of innovations? Participating farmers may be allocated to control and experimental treatments, but after a short time the control farmers may also want to switch to the experimental treatment. There may be two reasons for this. One may be a positive effect on the animals; another is that the treatment input is provided free of cost, and the control farmers want their share as well. In this case, some indication of real impact may be obtained by returning to the village some months after the trial is

over and making a survey on whether the farmers still continue with the new practice.

In situations where all participating farmers have at least two animals of the same category, the problem of the control group may be overcome by putting one animal into the control group and one into the treatment group. This will also minimize the management factor. A third way is to use the base-line data collected through the introductory survey (7.3.3.1). If this has been done for a sufficiently long period, the researcher will have a good foundation for judging when performance is good due to the treatment and when it is poor.

7.3.3.5 What can be measured?

A number of parameters can be measured, although it may be useful to start with only a few. Some of them are feed intake, growth rates, working hours, age at calving or work, calving intervals and lactation length.

Feed samples can be collected and taken to experimental stations for determinations of in vitro or nylon bag digestibilities. Content of nitrogen and other nutrients can also be measured. An assessment of draught power can be made in villages by recording the nature of the work and the time spent in the activity; and as the objective is usually to compare one treatment against another, absolute figures are rarely required.

7.3.3.6 Equipment

The required equipment will vary with the objective. Patience, common sense and endurance are important qualities in the researcher. A small pocket balance with a capacity of 25 kg may be all that is needed, if the objective is to weigh new-born and young sheep and goats. In many areas this will also be sufficient for new-born calves. Feed can also be weighed with such a balance. A piece of rope and a basket or a bag on which to place the animal or feed during weighing can be found in most villages or their markets.

Growth of larger animals can be measured in terms of increments of chest girth, measured by a tape. It is not necessary to transform these into weights, as the objective is simply to have comparative data; and in any event, the girth: weight relationship differs according to breed.

In Bangladesh a cycle rickshaw was remodelled and used to carry a weighing scale from village to village. Transport facilities in the form of bicycles, bus tickets, motorbikes or cars will be needed.

7.3.3.7 Manpower and cost

There are many examples of investigator assistants with from 5–10 years of school education, recruited from within the village, who have done an excellent job. People with higher education can also be used and it is possible to identify a number of problems for graduate student projects within this type of work.

The first point, which needs appreciation in considering cost is that by spending money on getting into the villages, the researcher is saving on other accounts. Money is not needed for experimental animals, buildings, pens, offices, machinery and feed. Management of the animals is also free of cost. These points are very important for the research worker, who is short of funds.

There may be good reasons to conduct animal trials simultaneously on farms and in research stations; one need not exclude the other. However, if the arguments advanced in support of village-based work (7.3.3) are accepted, it seems logical to ask the question as to whether it would not be correct to allocate funds for this type of work, and to give this higher priority than the work to be carried out on large livestock farms (university, research station and Government farms), which almost all as a rule operate at a loss without contributing much to increasing national livestock production.

It is though-provoking that in situations where this applies, the only positive function left for these units is a social welfare function, which they serve by providing employment and some produce
(eg: eggs, milk and meat) for the surrounding community.

7.4 CONCLUSIONS

It is concluded that a number of factors have to be considered for successful execution of village surveys and on-farm trials. However, the most important is the attitude of the researcher. There are sufficient examples from developing countries to demonstrate how such surveys can be conducted and that farmer participation is not a problem.

Finally, such research conducted on the farm is the best guarantee that the objectives are sound, and that the findings will be of interest to the farmer. This also facilitates the success of the extension.

There is no doubt that more could be done to stimulate such work by Governments and other high level authorities. Surveys and on-farm trials must, ideally, be viewed as tools to establish two-way communication with livestock keepers. New ideas can be tested and new research objectives identified. They should therefore become permanent features of animal nutrition work.
Chapter 8: REFERENCES


Better utilization of crop residues and by-products in animal feeding: ...


de Lasson, A. 1981 Socio-economic aspects of livestock keeping in Noahali District, Bangladesh. In: Maximum livestock production from minimum land (Editors: M.G. Jackson, F.Dolberg, C.H. Davis, M. Haque and M. Saadullah). Bangladesh Agricultural University, Mymensingh


Dolberg, F. 1982 Livestock strategies in India. University of Arhus, Institute of Political Science, Arhus, Denmark


Fernandez, A. and Hughes-Jones, M. 1981 Rumen fermentation and rumen function in bulls receiving a basic diet of molasses/urea supplemented with poultry litter, sweet potato forage or wheat bran. Tropical Animal Production, 6:360


Gutiérrez, E. and Elliott, R. 1984 Interacción digestiva de la pulpa de henequén (Agave fourcroydes) y el pasto estrella de Africa (Cynodon plectostachyus). In: Alternativas y valor
nutritivo de algunos recursos alimenticios destinados a producción animal. Informe provisional No. 16. Fundación Internacional para la Ciencia, Stockholm, pp 229–246


Henry, Y.M. and Perez, J.M. 1982 Les systèmes d'évaluation de l'énergie dans l'alimentation du porc. Les dossiers de l'élevage, 5 (1) and (2)


ICRISAT 1981 Proceedings International Workshop on Intercropping. ICRISAT, Patancheru, India

ICRISAT 1982 Sorghum in the eighties. Proceedings of the International Symposium on Sorghum. ICRISAT, Patancheru, India

Jabbar, M.A. and Green, D.A.G. 1983 The status and potential of livestock within the context of agricultural development policy in Bangladesh Department of Agricultural Economics. The University of Wales, Aberystwyth, UK


Jackson, M.G. 1978 FAO Animal Production and Health Paper No: 10, FAO, Rome


Kjaerby, F. 1983 Problems and contradictions in the development of ox-cultivation in Tanzania

Centre for Development Research. Copenhagen Research Report No. 66


Leng, R.A. and Brumby, P.B. 1985 Cattle production in the tropics. 13th International Congress of Nutrition, Brighton (In press)


Marrufo, D. La 1984 Leucaena leucocephala: su productividad en la zona henequenera de Yucatan y su uso como suplemento en dietas a base de melaza/urea. Tesis de Maestria, Universidad de Yucatan


McMeniman, N.P. 1981 The use of rumen ammonia estimations to determine when urea supplementation is necessary. Queensland Journal of Primary Industries No. R/ Jun 81


Meyreles, L., Pound, B. and Preston, T.R. 1982 The use of Leucaena leucocephala or sugar cane tops as sources of forage in cattle diets based on molasses/urea, supplemented with chicken litter and/or wheat bran, Tropical Animal Production, 7: 92–97


minimum land (Editors: T.R. Preston, C. Davis, F. Dolberg, M. Haque and M. Saadullah),
Bangladesh Agricultural University and BARC, Dacca


Pigden, W.J. 1972 Sugar cane as livestock feed. Report to Caribbean Development Bank, Barbados


Preston, T.R. 1972 Molasses as an energy source for cattle. World Review of Nutrition and Dietetics, 17: 280–311


Preston, T.R. 1983 Feeding standards can be misleading. In: Recent advances in animal nutrition in Australia (Editors: D.J. Farrell and Pran Vohra). University of New England Publishing Unit, Armidale


Rowe, J.B. 1979 Homemade gastro-intestinal cannulae. Tropical Animal Production, 4: 127–133


Sere, C. and Vaccaro L. 1984 de Milk production from dual purpose systems in tropical Latin America. Paper presented at the International conference on milk production in developing countries, Edinburgh


Throckmorton, J.C., Ffoulkes, D, Leng, R.A. and Evans, J.V. 1982 Response to bypass protein and starch in merino sheep and angora goats. Animal Production in Australia, 14: 661


FAO TECHNICAL PAPERS

FAO ANIMAL PRODUCTION AND HEALTH PAPERS:

1. Animal breeding: selected articles from World Animal Review, 1977 (C* E* F* S*)
2. Eradication of hog cholera and African swine fever, 1976 (E* F* S*)
3. Insecticides and application equipment for tsetse control, 1977 (E* F*)
4. New feed resources, 1977 (E/F/S*)
5. Bibliography of the criollo cattle of the Americas, 1977 (E/S*)
6. Mediterranean cattle and sheep in crossbreeding, 1977 (E* F*)
7. Environmental impact of tsetse chemical control, 1977 (E* F*)
Better utilization of crop residues and by-products in animal feeding: ... 

7 Rev. Environmental impact of tsetse chemical control, 1980 (E* F*)
8. Declining breeds of Mediterranean sheep, 1978 (E* F*)
9. Slaughterhouse and slaughterslab design and construction, 1978 (E* F* S*)
10. Treating straw for animal feeding, 1978 (C* E* F* S*)
11. Packaging, storage and distribution of processed milk, 1978 (E*)
12. Ruminant nutrition: selected articles from World Animal Review, 1978 (C* E* F* S*)
13. Buffalo reproduction and artificial insemination, 1979 (E**)
14. The African trypanosomiases, 1979 (E* F*)
15. Establishment of dairy training centres, 1979 (E*)
16. Open yard housing for young cattle, 1981 (E* F* S*)
17. Prolific tropical sheep, 1980 (E*)
18. Feed from animal wastes: state of knowledge, 1980 (E*)
19. East Coast fever and related tick-borne diseases, 1980 (E*)
20/1. Trypanotolerant livestock in West and Central Africa, 1980
   Vol. 1 - General study (E* F*)
20/2. Trypanotolerant livestock in West and Central Africa, 1980
   Vol. 2 - Country studies (E* F*)
22. Recursos genéticos animales en América, Latina, 1981 (S*)
23. Disease control in semen and embryos (E* F* S*)
25. Reproductive efficiency in cattle, 1982 (E*)
26. Camels and camel milk, 1982 (E*)
27. Deer farming, 1982 (E*)
28. Feed from animal wastes: feeding manual, 1982 (E*)
30. Sheep and goat breeds of India, 1982 (E*)
31. Hormones in animal production, 1982 (E*)
32. Crop residues and agro-industrial by-products in animal feeding, 1982 (E/F*)
33. Haemorrhagic septicaemia, 1982 (E* F*)
34. Breeding plans for ruminant livestock in the tropics, 1982 (E* S*)
35. Off-tastes in raw and reconstituted milk, 1983 (E* F* S*)
36. Ticks and tick-borne diseases: selected articles from World Animal Review, 1983 (E* F* S*)
38. Diagnosis and vaccination for the control of brucellosis in the Near East, 1983 (E*)
39. Solar energy in small-scale milk collection and processing, 1983 (E*)
40. Intensive sheep production in the Near East, 1983 (E*)
41. Integrating crops and livestock in West Africa, 1983 (E*)
42. Animal energy in agriculture in Africa and Asia, 1983 (E/F*)
43. Olive by-products for animal feed, 1982 (E* F* S* Ar*)
44/1. Animal genetic resources conservation by management, data banks and training, 1984 (E*)
44/2. Animal genetic resources cryogenic storage of germplasm and molecular engineering, 1984 (E*)
45. Maintenance systems for the dairy plant, 1984 (E*)
46. Livestock breeds of China, 1985 (E*)
Better utilization of crop residues and by-products in animal feeding: research guidelines 
- 1. State of knowledge, 1985 (E*)
50/2. Better utilization of crop residues and by-products in animal feeding: research guidelines
- 2. A practical manual for research workers, 1986 (E*)
51. Dried salted meats: charque and carne-de-sol, 1985 (E*)
52. Small-scale sausage production, 1985 (E*)
53. Slaughterhouse, cleaning and sanitation, 1985 (E*)
54. Small ruminants in the Near East: Vol I (E***)
   Selected papers presented at Tunis Expert Consultation
55. Small ruminants in the Near East: Vol II (E***)
   Selected papers from World Animal Review
56. Sheep and goats in Pakistan, 1985 (E*)
57. Awassi sheep, 1985 (E*)
58. Small ruminant production in the developing countries, 1986 (E*)

Ar - Arabic
C - Chinese
E - English
F - French
S - Spanish
* Available
** Out of print
*** In preparation
Availability: June 1986

The FAO Technical papers are available through the authorized FAO Sales Agents or directly from Distribution and Sales Section, FAO, Via delle Terme di Caracalla, 00100 Rome, Italy