Nutritional value of mixed diets in cattle

A thesis

submitted in partial fulfilment

of the requirements for the degree

of

Master of Agricultural Science

in the

University of Canterbury

by

Frederick Nii Ako Odoi

Lincoln College

1985

Abstract of a thesis submitted in partial fulfilment of the requirements for the degree of Master of Agricultural Science.

The nutritional value of mixed diets in cattle

by

F.N.A. Odoi

Field trials suggest that the nutritive value of high quality, high moisture feeds may be improved by the addition of a small quantity of roughage.

The nutritional value to steers of two high quality, high moisture feeds, fresh cut pasture and pressed beet pulp silage (PBPS), with and without various levels of straw was investigated. The general effects of straw substitution on the two diets and possible associative effect on DMD and MRT of DM, PEG and Cr-mordanted straw in the reticulo-rumen were measured in steers.

Barley straw was fed with pasture at 0, 20, 50 and 100% of DMI in a 4x4 Latin Square design over an 80 day period, and with PBPS at 0, 50 and 100% of DMI in a 3x3 Latin Square design over 60 days to rumen fistulated steers. On two selected days, a single meal was offered to steers and from 0 to 12 hours after feeding total rumen contents were baled and weighed on four occasions. At 0 hr, PEG and Cr-mordanted fibre as liquid and solid phase markers were mixed with rumen contents. Rumen digesta was sub-sampled for DM, PEG and Cr analysis at each baling session. In vivo DM and OM digestibilities were measured from day 10 to 20.

The general effect of adding 10% straw to pasture and PBPS was to reduce DMD by 2% units and 1.8% units respectively. MRT of DM, PEG and Cr in the rumen increased by 1.6, 0.5 and 1.2% for pasture, and by 1.0, -1.2 and 1.0% for PBPS respectively for every 10% increase in straw

level in diet.

There was little associative effect on DMD of feeding barley straw with PBPS, but an increase of 1.8% units and 3.1% units over predicted values were measured with 20% and 50% straw DM fed with pasture.

MRT for DM was 1.0 and 10.0% shorter at 20% and 50% straw with pasture respectively, and 6.5% shorter at 50% straw level with PBPS than would have been predicted from results of the diets fed separately. Similarly, shorter retention times for PEG, and Cr were observed when straw was fed with pasture or PBPS. A possible explanation for the positive associative effect on DMD of feeding straw with pasture is that pasture and/or straw digestibility was improved. Because straw DMD was likely to be close to its potential, it was calculated that pasture had to improve by 2.3% units on 20% straw and by 6.2% units on 50% straw fed with pasture to give the DMD values attained on the mixed diets. Had the improvement in digestibility of the mixed diets been due to an improvement in DMD of straw only, the DMD of straw would have to improve 9% units with the 20%, and 6.2% units with the 50% straw supplemented diets.

Total OM mass of the rumen was higher at all times on the straw supplemented diets compared with the 100% pasture diet. This potential source of slow releasing energy in the rumen may allow better utilization of the high levels of ammonia in rumen fluid from pasture degradation. The trend towards shorter retention times of digesta in the rumen when straw is fed with pasture or PBPS is likely to pass soluble carbohydrates and N into the small intestines, possibly improving ME utilization, and voluntary intake of the diets.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

Ruminants grazing high quality, high moisture pastures often grow at rates below that which would be predicted from feeds of such high nutritive value (Gibb and Treacher,1972; MacRae and Ulyatt,1974). Similar observations have been reported with certain forage crops such as swedes and turnips offered at high feed allowances (Drew, 1967; 1968).

Farmer opinion is that when ruminants on such diets are given access to some roughage (even low quality hay or straw), their performance in terms of growth rate appears to improve.

Experimental results have shown improved growth rate of both sheep and cattle when such high moisture feeds have been offered with some amount of roughage (Drew, 1967; 1968; Johnson, Arnold, Ellis, Smith, Lippke and Greene, 1983). The exact role of this small quantity of roughage in the utilization of these feeds is not clear. There have been suggestions that such low quality roughages, even at low intakes, might improve the nutritive value of high quality, high moisture feeds with which they are fed. If this was experimentally verified and explained, it would extend the use for such by-products which are at present under-utilized as a feed resource, and more importantly ensure a better utilization of such high quality feeds.

The areas identified for investigation were:

(i) Associative digestibility effects of a high and low digestibility feed fed in combination that may exist.

(ii) A change in metabolizable energy utilization, possibly as a result of a shift in the sites of digestion of one or more component of the two feeds that may take place.

(iii) A possible inefficient utilization of dietary protein of pasture may occur because of a high rate of protein degradation in the rumen, which is not matched by an adequate source of energy in young, succulent pastures but might be available with addition of the roughage.

(iv) A high level of ammonia in rumen fluid from degradation of pasture protein may correct the N deficiency in roughage, and improve its rate and extent of digestion.

The experiments which form the basis of this thesis were undertaken to identify some of the causes of the observed effects of supplementing succulent, high quality feeds with small amounts of roughage.

CHAPTER TWO

LITERATURE REVIEW

The nutritive value of a feed and its components is commonly expressed as apparent digestibility. For a mixed ration, this is usually considered as the weighted average of the apparent digestibilities of the individual feed components of the ration. This approach is supported by trials that have shown apparent digestibility coefficients equal to the weighted means of the individual feed constituents making up the ration (Fenner and Barnes, 1966; Wainmann, Smith and Dewey, 1979; Byers, Johnson and Preston, 1982). For example, the work of Wainmann et al (1979) with steers fed at 1.5 times maintainance on mixtures of maize silage and barley showed, through complete energy balance trials, that ME values of the dietary components were additive.

The implication has been therefore, that there is usually little influence of one feed component on the digestibility of others with which it is combined, and thus values for the dietary components are additive, with no evidence of large associative effects.

2.1. Associative effects of feeds fed in combination

Evidence from other trials (Schneider and Flatt, 1975; Byers, Johnson and Matsushima, 1976; Orskov, 1977) however, have shown that two feeds offered together are not necessarily additive in value, and the digestibility coefficient of the ration is not necessary a weighted average of values of the individual constituents determined separately or indirectly. One or more of the feed constituents can influence the digestibility of the others in the mixture. The effects of combining feeds may be either a direct enhancement or depression in digestibility, or indirect effects resulting from the correction of a dietary inbalance or from nutritive supplementation of one feed component by another (Schneider and Flatt, 1975).

The occurance of associative effects between two feeds appear difficult to predict. A review of work on combined feeds of similar type to those used in the trials for this thesis shows the following

results.

(1) Effect of a readily available carbohydrate source on roughage digestion.

The rate of digestion of the cellulose portion of a roughage when it is fed with a grain based diet is reduced, and the roughage source is then poorly digested (Kane, Jacobson and Damewood, 1959; Colucci, Chase and van Soest, 1982). The nutrient most affected is the crude fibre fraction, often with little decrease in digestibility of the other chemical constituents (Horton, 1979; Church and Santos, 1981). The reduced crude fibre digestion is due to a depression in cellulolytic bacterial activity. There is some indication however that crude fibre digestibility increases with rising level of straw (Forbes et al, 1969; White et al, 1975).

In fattening steers on mixed rations of whole maize and maize silage, Byers et al (1976) reported that ME values for both items fed in combination were depressed when compared with either component fed on its own, indicating a negative associative effect on combination. With moderate levels of a soluble carbohydrate source however, the intake of roughage, as well as total dry and organic matter may increase which can, in terms of DE intake, compensate for the decrease in digestibility (Kane et al, 1959; Church, 1976).

In an attempt to compensate for the dilution of ration energy with straw, animals tend to consume more feed (O'Donovan and Ghadaki, 1973). As the straw level is further increased (above about 30% of DMI), some data indicate that feed intake is reduced, and digestibilities of dry and organic matter, as well as energy are suppressed (Forbes, Raven and Irwin, 1969; White, Hembry and Reynolds, 1975). With a straw inclusion level of about 30% therefore, the higher total feed intake approximately compensates for any reduction in digestibility to give similar organic matter and digestible energy intakes as achieved with the 100% concentrate diet. Above 20-30% level however, digestible energy intake is depressed.

(2) Roughage supplementation of pasture

Ruminants grazing lush pastures (high crude protein, and low structural fibre content) did not attain growth rates obtained with concentrate diets of similar digestibility (Nicol and McLean, 1970; Gibb and Treacher, 1972; MacRae and Ulyatt, 1974). Recent work in New Zealand with sheep on diets of fresh rye-grass and white clover (Ulyatt, MacRae, Clarke and Pearce, 1975), has shown that approximately 70% of the dietary protein is degraded by micro-organisms in the reticulo-rumen. The quantity of protein-N arriving at the duodenum was much less than the protein intake, with the difference (net N loss across the rumen) getting larger as dietary-N intake increased.

Williams and Gordon (1983) demonstrated the presence of high levels of urea in the urine of sheep on such pastures and on high protein feeds such as lucerne hay. They showed that as much as 50% of the dietary-N intake on such diets was lost in the absence of a non-nitrogen source of energy for microbial use. MacRae and Reeds (1980) presented this graphically in FIGURE 1.

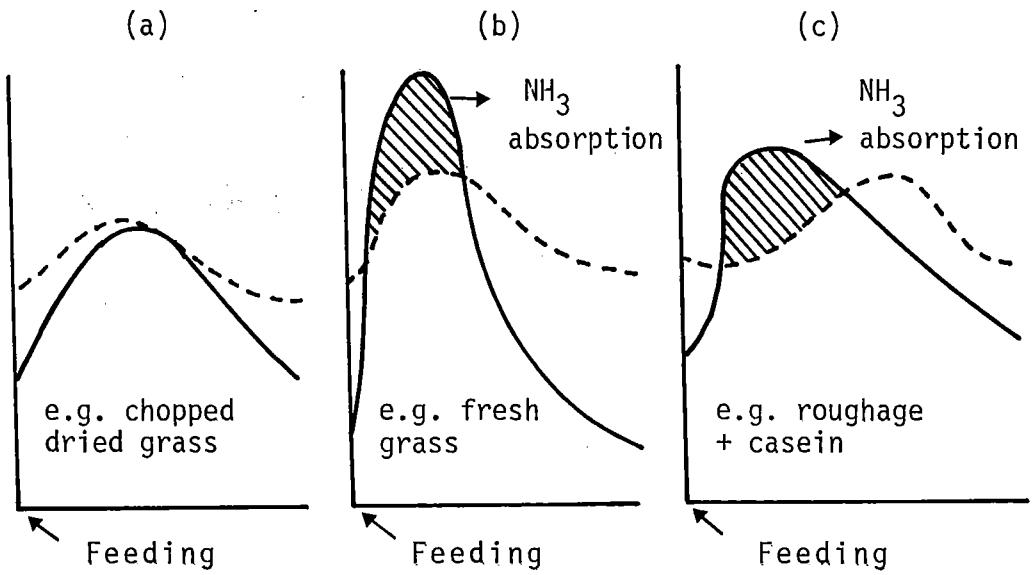
The loss of ammonia-N to the animal in situation (b) in Figure 1, can be as high as 25% of the apparently digested-N of a feed such as fresh ryegrass (MacRae and Reeds, 1980). This raises the question of whether many fresh forages are being inefficiently utilized because of their high degradability in the rumen (TABLE 1). Poor microbial utilization of soluble plant protein should therefore be improved if enough easily digestible carbohydrates were made available.

In a grazing trial where sheep were supplemented with barley grain, Joyce (1971) reported no effect of the barley on rumen ammonia and VFA concentrations. However, he obtained reduced liveweight gains in proportion to the decrease in digestible-N intake following successive additions of barley. Some other results using roughages as the energy supplement have been more encouraging.

Hildebrandt (1958) proposed that ruminants on succulent pastures had problems in regulating rumen pH, and may therefore not be able to fully adapt to the diet until the content of structural fibre in the pasture increased with further vegetative development. Supplementing such pasture with a low protein roughage such as straw or mature hay, might improve the efficiency of utilization of such high quality

FIGURE 1: A stylized representation of ways in which the release of NH_3-N and energy during fermentation can alter the efficiency of microbial utilization of 'degraded dietary protein'.

** (Source: MacRae and Reeds 1980)



(a) Where the release of NH_3-N matches available energy supplies, and micro-organisms are able to utilize most of it.

(b) Where there is rapid release of NH_3-N, and large amounts get absorbed directly from the rumen and is lost to the micro-organisms.

(c) Where rapid release of NH_3-N occurs in the presence of a basal roughage diet.

TABLE 1 Solubility of dietary nitrogen in some ruminant feeds

** Source : MacRae (1976)

mg/g DM

	Total N	Total Soluble N	% Solubility
Fresh rye-grass	34	13	38
Fresh clover	48	17	35
Freeze stored clover	48	10	21
Dried grass	17	2	12
Barley	18	2	12

TABLE 2 Approximate chemical composition (% DM) and energy value of pasture at different stages of growth

** Source : Scott et al. (1980)

Stage of growth	DM	CP	CF	Ash	OMD	DOM/100KgDM	ME(MJ/KgDM)
Short leafy	15	27	17	11	80	74	11.7
Mixed length leafy	18	21	21	11	75	67	10.7
Pre-flowering	21	17	26	10	70	63	10.0
Flowering	25	12	30	9	65	59	9.4
Dry, stalky	30	10	33	9	55	51	8.1

pastures probably through prevention of a low rumen pH.

Cattle grazing wheat pastures, and given access to sorghum stubble were reported by Johnson et al (1983) to have higher average daily weight gain compared to other cattle with no access to roughage. They explained that stubble provided additional energy allowing for increased utilization of the high level of dietary-N available in the wheat pasture, and also prevented the likelihood of dietary-N being inefficiently utilized as a source of energy.

Other work by Barry (1981), and Cruickshank, Poppi and Sykes (1985) has highlighted the large amounts of N lost across the rumen, and suggested that protein supply to the small intestines was limiting lamb growth rates on pasture. Barry (1981) for example, obtained increased growth rates on infusing amino acid supplements into the abomasum of sheep, showing that ruminants fed fresh herbages of high digestibility and protein content, may nevertheless suffer from a deficiency in one or more essential amino acid absorbed from the small intestines.

(3) Roughage supplementation of forage crops and green feed cereals

Drew (1967; 1968) fed hoggets on swedes in two trials, and reported weight gains nearly 50% higher for animals allowed a small quantity of hay (350g/head/day) as supplement, compared with others on swedes only. This was in spite of the fact that the supplemented group consumed only 5% more digestible energy than the all swede group. The quality of hay fed did not appear very important, as results were similar for average and high quality hay. Differences observed between groups were attributed to a possible change in the different proportions of VFA's produced. Results obtained showed a similar trend in both indoor and outdoor work.

Bines and Davey (1978) using pelleted diets, concluded that 20% chopped straw in the ration yielded the highest blood concentration of acetate, propionate and β-hydroxybutyrate, nearly twice the amounts recorded in the absence of the roughage. They suggested that an inhibition of acetate absorption from the rumen on an all concentrate diet may lead to excessive accumulation at this site leading to an unusually low voluntary intake. However, the results obtained in Drew's work (1967; 1968) where digestible energy intakes were similar with

both roughage supplemented and unsupplemented groups, would question a low voluntary intake (resulting from acetate accumulation) and thus differences in VFA proportions, as the sole reason for the better growth performance recorded by the supplemented group. Another explanation for differences between the groups was that the extra heat of fermentation generated by the roughage reduced the energy cost to the hoggets of warming the ingested feed in winter, though this appears improbable in the light of similar results obtained indoors.

Summary of Section 2.1

Results from several trials in which two or more feeds have been fed in combination suggest little effect of one on the digestibility and utilization of another. Other trials however, provide definite evidence for the existence of associative effects (both positive and negative) between two or more feeds. The reasons suggested in explanation of the complimentary effects include :

(i) The different proportions of VFA's produced with two or more feeds offered together improves the efficiency of nutrient utilization.

(ii) One feed supplies a nutrient that may be deficient in the other.

(iii) A supplemented roughage serves as an additional source of energy, and thus improves the ability of the microbial population to utilize soluble dietary-N, and therefore reduces losses of ammonia-N across the rumen.

(iv) The additional heat of fermentation generated, particularly with roughages, has an energy sparing effect in the maintenance of body temperature under cold conditions.

2.2. Effect of site of digestion on Metabolizable Energy utilization

Some of the possible explanations for complimentarity between feeds involve a change in site of digestion.

The digestive system of the ruminant is unique in its combination of exogenous with endogenous enymatic hydrolysis. Microbial fermentation in the rumen provides microbial enzymes for hydrolysing β-glucose polymers (or fibre) and uronic acid esters, for which the host lacks metabolic pathways and, in the absence of which, these feed components are poorly utilized (Putnam and Davis, 1965). The end products of this fermentation are available for metabolism by the ruminant.

Passage of digesta out of the rumen results in the "flushing" out of micro-organisms and rumen indigestible material to the abomasum and small intestines (Owens and Isaacson, 1977), where the microbes are exposed to hydrolytic processes and provide essential amino acids for use by the host animal (Loosli, Williams, Thomas, Ferris and Maynard 1949).

Most solids that leave the rumen are poorly digested in the intestines of ruminants. For those nutrients that can be digested enzymatically in the small intestines, ruminal fermentation is an inefficient process (Bull, Rumpler, Sweeney and Zinn, 1979). The site of feed digestion is therefore important in the efficiency of feed utilization. Some control over the site of feed digestion is provided by rate at which digesta disappears from the reticulo-rumen.

(1) Disappearance of digesta from the reticulo-rumen

Ingested feed leaves the reticulo-rumen basically by two routes:

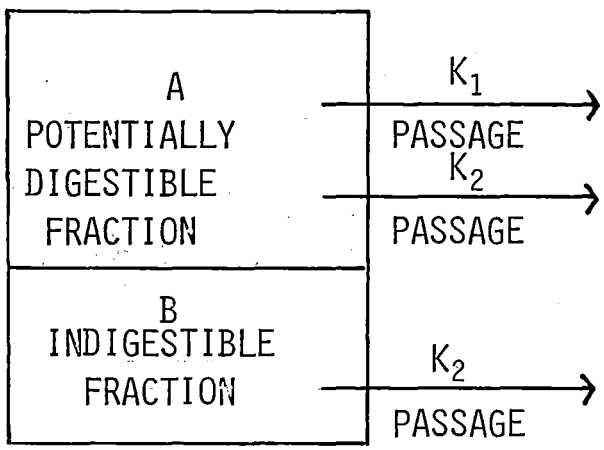
(i) By digestion and absorption, and

(ii) By feed particles being broken down to a size small enough to pass through the reticulo-omasal orifice (Balch and Campling 1962).

Waldo and Smith (1972) proposed a model for fibre disappearance from the reticulo-rumen based on what they termed 'potentially digestible and indigestible fractions' of the feed (FIGURE 2.). Wilkins (1969) described potential digestibility as 'the maximum digestibility attainable when the conditions and the duration of fermentation are not limiting factors'.

FIGURE 2: Model for disappearance of digesta from the reticulo-rumen.

** Source: Waldo and Smith (1972)



(A) An indigestible fraction which disappears by passage only.

(B) A potentially digestible fraction which disappears both by passage and digestion.

K_1 = rate of digestion

K_2 = rate of passage

Model for fibre disappearance from the rumen.

The proposal of Waldo and Smith (1972) is that not all fibre present in feed of ruminants is potentially digestible, and that the digestion of lignified fibre proceeds as if the cellulose component is of two definable fractions:

(A) an indigestible fraction which disappears from the reticulo-rumen by passage only (through the reticulo-omasal orifice), and

(B) a potentially digestible fraction which disappears by both passage and digestion.

The proportion of the potentially digestible fraction actually digested in the reticulo-rumen is represented by the ratio K1 / K1 + K2, where

K1 = digestion rate, and

K2 = passage rate

Anything that affects digesta disappearance from the reticulo-rumen will therefore invariably influence the site of feed digestion.

(2) Factors that affect the disappearance of digesta from the rumen.

Several factors are involved in the disappearance of particulate matter from the reticulo-rumen. Most of these exert their influence through altering the length of time feed is retained in the rumen, and hence influence digestibility and intake (Balch and Campling, 1965). Of major importance are:

(i) Level of feeding

Tyrell and Moe (1975) stated that the amount of a ration consumed has a large influence on digestibility, and there is usually a depression in apparent digestibility with increasing level of feeding (Andersen, Reid, Andersen and Stroud, 1959; Lindgren, 1981; Colucci et al, 1982). The greatest reduction in retention time in the rumen is likely to be because of an increased feed consumption (Thornton and Minson, 1973), as digestibility of the microbial dependent fraction is likely to be reduced. disadvantage digestibility of the microbial dependent fractions.

(ii) Feed processing

Processing methods such as grinding and pelleting usually cause a depression in digestibility (Balch, 1960; Minson, 1963), and an increase in intake and rate of passage from the rumen (Campling, Freer and Balch, 1963; Campling and Freer, 1966), provided adequate protein is present. Processing affects physical form, particle size and specific gravity, and thus the inherent rate of digestion (Campling and Freer,1960; Cole, Johnson, Owens and Males, 1976; Prange, Stern, Rode, Santos, Jorgenson and Satter, 1979).

(iii) Rate of flow of water

Since water is the medium in which dry matter in the rumen is dispersed, factors that affect the flow of water through the rumen will influence flow of dry matter from the rumen. Sutherland (1975) concluded that the flow of water depended on the level of intake, rumen tactile stimulation, rumen motility, salivary flow and negative feedback from the rest of the digestive tract. Because 80-85% of fresh herbage is water, the retention times of water and organic matter in the rumen on such diets are low compared with other diets of similar digestibility (Ulyatt and MacRae, 1974).

(iv) Dietary factors and rumen fill

Stemmy material is retained longer than leafy material, and on the whole legumes have a shorter retention time when compared with grasses (Poppi, 1981).

Cell contents are rapidly digested, and are generally absent from the rumen within six hours of ingestion (Hungate, 1966). Cell wall components on the other hand, often show a time lag before the onset of a slow fermentation and feed breakdown, and normally remain in the rumen for at least 24 hours (Mertens, 1977).

Gut fill on any one diet is relatively constant under ad lib feeding conditions (Minson, 1966). If rumen fill is increased with no corresponding increase in digesta disappearance, then intake will not change, but retention time and digestive efficiency will increase. It is usual however, for an increase in the passage component to be associated with an increase in gut fill (Tulloh, 1966).

(v) Physiological state

Various physiological conditions of the animal may change the level of fill, rate of rumen digesta disappearance and intake. These include lactation, compensatory gain and cold exposure which increase rumen motility and thus the rate of passage, and depress digestibility (Tulloh, 1966; Kennedy, Christopherson and Milligan, 1976).

(vi) Microbial growth

Some chemical factors in the feed may affect bacterial growth, and the microbial species present. Low rumen ammonia levels (Nolan, 1974), and deficiencies of sulphur (Bray and Till, 1974) reduce microbial growth, and the resultant rate of digestion may be less than is possible given the chemical moiety of the cell wall and its physical structure.

From this review of the sites of feed digestion in the ruminant, and the factors that have an influence on it, it would appear that retention time in the rumen of soluble, high moisture feeds will be relatively short. Adding a roughage to such diets should lengthen the time digesta is retained in the rumen. This may have an effect on digestibility and voluntary intake.

(3) Measurement of retention time of digesta in the reticulo-rumen.

From the above discussion, the concept of retention time of feed in the reticulo-rumen is important as it can give an indication of the likely major site(s) of digestion, and thus the efficiency with which the feed can be utilized by the host animal.

Retention time in the rumen has been defined as 'the average time digesta stays in the rumen' (Minson, 1966), or as 'the time required for the input of a component to equal that in the rumen' (Bull et al 1979; Minson, 1966).

Mathematical relationships in retention time measurements

Because of the differential rates of digestion of various components of the feed, measurements of feed retention time can be done either for whole digesta eg. dry matter, or for specific components such as the liquid and particulate phases.

Retention time is related mathematically to some of the other parameters used in marker dilution studies. Several of these mathematical relationships were originally proposed by Hyden (1961). Variations of them have been used by Ulyatt (1964), Reid (1965) and Faichney (1975). For example,

Retention time (hours) = 1 / K = 0.693 / $T^{0.5}$ where,

K (refered to in the literature severally as, dilution rate or rate constant) is the fractional outflow rate, the proportion of rumen pool passing out in unit time. K is derived from the slope of the semi-log plot of the amount of material remaining in the rumen, against time.

$T^{0.5}$ is the the half life, or the time taken for half the pool size to disappear, and 0.693 is a constant.

Other parameters like rumen volume, flow rate, and rate constant can be calculated from the above relationship (Hyden, 1961; Ulyatt, 1964).

Retention time measurements refer to disappearance by both passage and digestion. Owing to the flow of saliva into the rumen and the passage of feed components across the rumen wall, estimates of retention time are apparent and not absolute values for the feed involved, except for fibre (Minson, 1966).

(4) Techniques for measuring retention time of digesta in the rumen

The techniques commonly used in retention time measurements on digesta in the reticulo-rumen are:

(i) Serial emptying (Reid, 1965) : A single meal is fed each day, and the rumen is emptied at pre-determined time intervals over a 24 hour period. The inverse of the slope of the semi-log plot of the amount of any component remaining in the rumen against time, gives retention time for that component.
The disadvantages of the technique are that a single meal may be abnormal, compared with the normal eating pattern and rumen physical functions may be impaired. Also the rumen is emptied several times in a 24 hour period, which might disturb anaerobic rumen function.

(ii) Steady state (Minson, 1966) : With this procedure, the animal is fed at hourly intervals, and the rumen is emptied only once, midway between two feeds.

This approaches a more normal feeding pattern, and the rumen need only be emptied once. It is therefore probably the better of the two techniques, although the serial emptying method also gives good results where steady state conditions cannot be imposed.

Because water soluble constituents of the digesta pass out of the rumen more quickly than the insoluble material both during and after feeding, the breakdown of the latter will be incomplete before the ingestion of the next meal. There will therefore be in the rumen at any one time, the residues of several meals at various stages of digestion.

Other problems that might be encountered with retention time measurements are :

(i) Changes in concentration of a metabolite can be a result of differences in rates of production, absorption and passage, as well as in the volume of material in which the metabolite is dispersed (Reid, 1965).

(ii) A layering of particle dry matter in the rumen may lead to an uneven distribution of feed components, making it difficult to obtain truly representative samples in vivo, particularly with cattle (Bryant, 1964).

Markers used to follow the flow of individual fractions of the digesta, and total emptying of rumen contents prior to sampling, have helped overcome some of these problems.

(5) Use of markers to measure passage of different fractions of digesta.

A solution to the differential turnover rates of various fractions of the digesta has been the use of two markers to label the liquid and particulate phases separately.
To be of value, the selected marker should be:

(i) Strictly not absorbed in the gastro-intestinal tract

(ii) Unaffected by conditions in the tract, and in turn not affect the microbial population

(iii) Physically similar to, and associated intimately with the fraction it is to label

(iv) Capable of accurate estimation in digesta samples, and not interfere with other chemical analysis (Faichney, 1975).

It should be noted however, that no one marker is likely to fully satisfy every one of the above requirements.

Liquid phase markers.

Liquid phase markers are diluted and pass out in the flow of water and other fluids continuously leaving the rumen. They give an indication of how quickly soluble feed material not absorbed from the rumen, and the portion of the digesta dry matter which has been reduced to a small enough particle size, leave the rumen.

Some of the more commonly used liquid phase markers are polyethylene glycol (PEG), and chromium ethylenediamine tetraacetate (Cr-EDTA).

PEG as a liquid phase marker.

PEG (MW 3350) appears to satisfy most of the criteria required of a good water soluble marker in the gastro-intestinal tract. Its distribution volume has been shown (Uden, Colucci and van Soest, 1980) to be about 95% of total rumen water, although under some circumstances it has been known to associate with digesta dry matter to a small extent. Czerkowski and Brackenbridge (1969) showed it to be excluded from a small proportion of the water in beet pulp, and it is precipitated when given with feeds rich in tannin (Kay, 1969).

It can be accurately estimated turbidimetrically, if care is taken with clarifying rumen liquor (Ulyatt, 1964; Malawer and Powell, 1967).

Particulate phase markers.

Insoluble or particulate phase markers have a disappearance rate which depends on the specific gravity and particle size of the fraction they mark (King and Moore, 1957; Balch, Campling and Freer, 1961). They remain in the rumen until the solid fraction is reduced to fragments small enough to pass out through the reticulo-omasal orifice.

These particulate markers can be :

(i) Indigestible feed substances such as lignin and silica .

(ii) Chemical elements firmly bound to fibre by mordanting eg. chromium, cobalt and cerium.

(iii) Loosely attached material to the digesta eg. chromic oxide, stained feed particles or even plastics (Kotb and Luckey, 1972; Church, 1975; Uden et al (1980).

Chromium mordanted straw fibre as a particulate marker

Metal complexes with plant fibre should be good markers provided the bonding can withstand conditions in the gastro-intestinal tract, and the metal element is easily recovered from the fibre matrix to which it is bound.

Chromium has been shown to form a stable complex with straw fibre (Uden et al, 1980), making it suitable for use in retention time studies (Pienaar, Roux and van Zyl, 1983). The mordanting process is described in Appendix Method 1.

Both liquid and particulate phase markers can be used with steady state and serial emptying techniques.

Summary of section 2.2.

Retention time of ingested feed in the digestive tract is important in ruminants because of the role of the exogenous microbial population in rumen fermentation. Feeds, particularly those high in fibre if retained for long periods in the rumen allow time for maximum microbial breakdown, and the potential digestibility of the feed is more likely to be attained. On the other hand, feeds capable of being digested in the small intestines would benefit from a short retention time in the rumen so that extent of rumen degradation is reduced, and the efficiency of utilization increased by more digestion in the small

intestines.

Factors such as the level of feeding, the fibre content of the diet, and the animal's physiological state influence retention time of digesta in the gastro-intestinal tract, and are therefore important in efficient feed utilization.

Because of observed differences in turnover rates of various fractions of the digesta, two or more markers are often used to measure retention times of different fractions. Markers have been used with either the serial emptying, or steady state technique. The latter may more closely resemble normal conditions in the grazing animal. Where facilities preclude the use of steady state methods, serial emptying has been shown to give satisfactory results.

2.3 Feeds

Two high moisture feeds were selected for feeding with roughage for digestibility and retention time studies. These were:

(i) High quality succulent pasture (mainly ryegrass-white clover swards), which form the basis of grazing in New Zealand and many other temperate countries.

(ii) Silage made from pressed sugar beet pulp (PBPS), a high energy by-product feed for livestock.

(iii) Barley straw was selected as a readily available cheap roughage source to be fed with the high moisture feeds.

(1) Pasture

The dominant species in the swards used for the trial were rye-grass (*Lolium* spp.) and white clover (*Trifolium* spp.).

Composition and nutritive value

Table 2 shows the range in nutritive quality of pasture swards over the year. Young succulent pasture has a high crude protein (20-35%) and soluble carbohydrates (10-20% of DM)content, but is low in structural carbohydrates (15-30% of DM). It has an organic matter digestibility of between 75-85% (MacRae, 1976).

The extent of microbial degradation of the dietary protein of pasture in the rumen is high with fresh young pasture (Table 1). Ammonia levels in rumen fluid will therefore usually exceed the capacity of micro-organisms to utilize ammonia for synthesis, and excess ammonia is absorbed across the rumen wall and excreted as urea in urine. The amount of N passing out of the rumen will therefore be considerably less than that ingested, limiting amino acid absorption in the ruminant (Barry 1981). The main determinants of the ability of micro-organisms to utilize dietary N are how degradable the protein is, and the availability of a source of energy in the rumen at the time of the release of ammonia. Given most diets, about 30g of microbial protein can be synthesized per kg OM fermented (ARC 1980). Beyond this, ammonia-N of any origin is nutritionally useless to the ruminant.

Roughage supplementation of pasture

Because of the low level of structural carbohydrates in young pasture, a source of energy required by the rumen micro-organisms in order to be able to effectively utilize the high level of ammonia-N released can be limiting. It is suggested that the feeding of a roughage such as barley straw with pasture may provide additional slow release energy and therefore may be beneficial to the ruminant on such diets (MacRae and Reeds, 1980; Johnson et al, 1983).

(2) Pressed Beet Pulp Silage.

In the manufacture of sugar or methanol from beet, the residue after extraction of the product is refered to as beet pulp. It is often pressed by rollers to remove excess water, leaving a by-product of about 20% DM. Because of the high moisture content, pressed beet pulp goes mouldy on exposure to air and loses its palatability and acceptance to livestock. It is therefore often preserved by ensiling in air-tight containers (Fairburn 1974; ADAS 1976), and refered to as pressed beet pulp silage (PBPS).

Composition and nutritive value.

When well preserved PBPS has a nutritive value comparable to the fresh material (Harland 1981).
Table 3 compares the chemical composition of the fresh and the ensiled product.

TABLE 3 A comparison of the chemical composition of pressed beet pulp silage (PBPS) on a % Dry Matter basis

** Source : Kelly 1983

Constituent	PBP	PBPS
Dry Matter	18.8	17.7
Crude Protein	10.3	11.2
Crude Fibre	19.6	20.9
Ether Extract	0.6	0.9
Ash	6.5	7.4
Nitrogen free extractive (NFE)	63.1	59.6
Neutral Detergent Fibre (NDF)	55.8	47.7
Acid Detergent Fibre (ADF)	28.3	28.8
Acid Detergent Lignin (ADL)	2.8	3.4
Cellulose	22.1	22.8
Gross Energy (MJ/KgDM)	17.1	-
Metabolizable Energy (MJ/KgDM)	12.1	-
Water soluble carbohydrates	4.0	-
Phosphorus	0.11	-
Calcium	0.95	-
Magnesium	0.19	-
Sodium	0.51	-
Potassium	0.78	-

TABLE 4 Coefficients of digestibility (%) of constituents in Pressed Beet Pulp

(** Source : Sheehan and Quirke 1982)

Constituent	% Digestibility
Dry Matter	81.1
Organic matter	85.2
Crude Protein	65.5
Crude Fibre	90.8
Ether extract	73.7
Acid detergent fibre (ADF)	81.8
Neutral detergent fibre (NDF)	79.9
Lignin	69.2

Pressed beet pulp has a high ME value of between 12.0-12.5 MJ/KgDM, comparable to a high energy grain such as barley (Harland, 1981; Kelly, 1983). The high value of pressed beet pulp as a feedstuff lies mainly in its high energy content, derived largely from a high fibre fraction made up mainly of cellulose and hemicellulose easily digested by ruminants. Because of its small particle size and non-rigid physical form it produces lower rumination times (78 minutes) compared with good quality hay (516 minutes) during a 24 hour period (Welch and Smith, 1971).

It is not a good source of protein, containing only between 60 and 70g DCP per kgDM. It has been suggested however that this protein might be largely undegraded in the rumen, due to heat treatment during the sugar extraction process. This protection could enhance the feeding value of the dietary protein of pressed beet pulp or silage made from it (ADAS 1976).

PBPS is low in phosphorus, and some form of dietary mineral supplement is usually required if it forms a considerable portion of the ration for any length of time.

TABLE 4 shows digestibility coefficients for the chemical constituents of beet pulp. The high digestibility of the fibre fraction, and results from production trials (Sheehan and Quirke, 1982) suggest that the ME value quoted for PBPS may be an underestimation of its true feeding value.

Roughage supplementation of PBPS

PBPS like young pasture has a high moisture content and is highly digestible. Unlike pasture however, it is high in structural carbohydrates although this is mostly digestible material. Its small particle size and high moisture content should promote a fast rate of passage through the digestive tract, and reduce overall digestibility of DM. Addition of barley straw to PBPS it is proposed would slow the rate of passage, and allow a high level of the potential digestibility of the fibre fraction to be attained.

Rumen pH on feeds high in soluble carbohydrates.

The end products of carbohydrate metabolism in the rumen are VFA's, which although continuously absorbed require the buffering effect of alkaline saliva to prevent a marked fall in rumen pH (Church 1975). Due to the high content of readily soluble carbohydrates in both fresh pasture and PBPS, there is the possibility of lactic acid accumulation leading to an acidic rumen environment (Briggs, Hogan and Reid, 1957). This will be detrimental to cellulolysis, which is inhibited below pH 6.1 (Mould, Orskov and Mann, 1983). Many of the other extracellular rumen micro-organisms function within fairly narrow pH ranges (Church 1975).

On adding straw to such feeds, there is usually a depression in DMD. This is due both to the lowered rumen pH and an increase in the rate of solubilization of the more readily degradable substrates. This latter effect cannot be corrected by pH manipulation as for the former because of the preferential attack by micro-organisms on the readily fermentable substrates rather than the relatively complex fibre fraction. More frequent feeding of the ration helps stabilize rumen pH at peak value associated with that feeding regime (Kaufmann, Hagemeister and Dirksen, 1980).

(3) Barley straw.

Barley straw together with other cereal straws represent a vast potential feed resource world wide.

Composition and nutritive value.

Crude protein (1-5% of DM) and phosphorus have been identified by Anderson (1978) as the nutrients most usually deficient in straws. Their content of other minerals like Ca, Zn, Mg, Mn and Se may limit animal productivity when straw is fed as the sole diet for an extended period (Mathison, Hardin and Beck, 1981).

Straws are however high in structural carbohydrates and cell wall fraction may often account for 70-80% of plant DM (Jackson 1977). The cellulose and hemicellulose fractions are digestible to a large extent but their digestibilities are often reduced through lignification and interference from the silica fraction.

The slow rate of breakdown of straw increases appreciably its retention time in the rumen. This leads to low voluntary intakes (1-2% of liveweight) and therefore inadequate energy consumption (Balch and Campling, 1962; O'Donovan 1983). The main cause of the low voluntary intakes on straw is that CP levels are inadequate to promote efficient microbial growth. It is usually below the 8.5% threshold level quoted by Blaxter and Wilson (1963) as being necessary to prevent the inhibition of cellulolysis. Thus although potentially a good source of energy, DMD of most straws are only about 40% (Jackson 1977; O'Donovan 1983), which limit its use as a feed.

Increased rate of passage and intake of straws has been achieved through supplementation, with large responses to extra protein reported by O'Donovan, Silva and Euclides, (1983). Energy supplements are less effective in the absence of protein.

Feeding straw with pasture

The effects of feeding straw with pasture should be mutually beneficial. The high level of ammonia-N released into the rumen from pasture should help to partially make up the N deficiency in straw. Straw on the other hand, would provide an extra source of energy for microbial growth and synthesis, allowing for the more efficient utilization of ammonia-N in the rumen.

An optimum inclusion level of about 20% in mixed rations has been suggested from growth rate studies by Davendra (1975), and Davendra and Raghavan, (1978).

Summary of literature review

When two or more feeds are fed together, several results from the literature suggest little effect of one feed on the digestibility and utilization of the others. There is however evidence for the occurance of both positive and negative associative effects in some experiments where mixed diets have been fed to ruminants.

Associative effects on digestibility of feeding mixed diets have been attributed to one feed correcting a nutrient deficiency in another with which it is fed, or the mixed diet providing a better balance of nitrogen and energy, so that ME utilization is improved. Associate

effects of feeding a mixed diet may also act by altering the rate of passage of ingested feed through the digestive tract. The time digesta is retained in the reticulo-rumen is important because feeds high in fibre are better digested in the rumen (through the action of extracellular microbial enzymes) and benefit from a long retention time. High quality feeds capable of being digested in the intestines by host enzymes on the other hand, are more efficiently utilized when retained for a short time in the rumen.

Ruminants grazing certain high quality feeds such as young pasture or forage crops grow at rates below what may be expected from the nutritive value of the feed. Feeding such diets with some roughage seem to improve growth rates. Reasons for this roughage effect have not been determined. This trial was undertaken therefore, to investigate any effects of feeding a high quality diet such as young pasture or beet pulp silage with some amount of straw on the digestibility, and retention time of digesta in the reticulo-rumen.

CHAPTER THREE

MATERIALS AND METHODS

The retention time of feed components, and *in vivo* digestibility coefficients were measured on the feeds under consideration, using four adult cross-bred steers fitted with a large permanent rumen fistula closed by a cannula and bung.

3.1 Feeds

Two experiments were conducted; the first over four, twenty day periods (80 days), and the second over three further twenty day periods (60 days).

The feeds used were :

(i) High quality, succulent mixed swards of rye-grass and white clover freshly cut each morning using a motorized 'Graveley' cutter. Herbage mass of swards were in excess of 4000 kg DM/ha, and contained from between 5-15% white clover on a DM basis. The DM content of pasture over the four twenty day periods was between 17 and 24%.

(ii) Pressed sugar beet pulp silage was prepared (in wool sacs lined with a double layer of polythene sheets) from pulp obtained as a by-product of a methanol extraction plant at the New Zealand Agricultural Engineering Institute (NZAEI), Lincoln College.

At the time of feeding out, the silage had been stored in a shed from between two and six months. With most sacs, the top 10cm had to be discarded because it had deteriorated or gone mouldy. The depth of this rejected mass increased with length of storage, though most of the contents of the sacs were in good condition.

(iii) Barley straw baled post-grain harvest, and stored in a shed was fed as the roughage supplement.

3.2 Experimental design and treatments

Pasture trial

Four steers were assigned to four feed treatments, in a 4 x 4 Latin Square design. Animals were individually penned in large, adjustable (for size) metabolism crates, with a mesh floor which was padded at selected spots for animal comfort. The crates were fitted with individual feed boxes, automatic drinkers and faecal collection trays.

The four feed treatments during the pasture trial were :

(i) 100% pasture

(ii) 80% pasture and 20% barley straw

(iii) 50% pasture and 50% barley straw

(iv) 100% barley straw.

Percentage formulation of diets were on a DMI basis. DMI was restricted to an approximate maintenance level, and was planned to be equal across treatments. To minimize the likelihood of diet selection with the combined feeds, the grass and straw were thoroughly mixed together, and offered twice daily at 07.30 and 13.00 hours. Steers were accustomed to crates, feeders and drinkers for some time before the trial begun.

Each experimental period consisted of a ten day preliminary period, during which the amount of feed offered was adjusted in response to the animal's feed consumption over the previous day. This was done until the daily feed intake for the animal stabilized. Over the ten day faecal collection period (for *in vivo* digestibility determination) therefore, refusals were less than 300g.

3.3 Measurements

(1)Apparent coefficient of digestibility determination

During the ten day faecal collection period the feed offered to each steer daily was weighed, thoroughly mixed, and a subsample of between 700 and 900g oven dried at 70°C for 24 hours for DM determination. Any feed refusals after 24 hours were similarly weighed,

mixed and subsampled for DM analysis. DM subsamples of both fresh feed and refusals were bulked for each steer over the ten day period, and stored at -8°C for chemical analysis.

Daily total faecal output from each steer was weighed, mixed, and between 400 and 500g (wet weight) subsampled and oven dried at 70°C for DM determination. Dry subsamples were again bulked over the collection period for each steer, and stored at -8°C for analysis.

(2) Retention time determination

On days 2 and 8 of the faecal collection period, steers were fed only the morning meal. This was in two hours. Any feed left at the end of the two hour period was withdrawn, weighed and subsampled for analysis as described ealier. Total reticulo-rumen contents were baled out and weighed over a 12 hour period at 4 hourly intervals from immediately post-feeding.

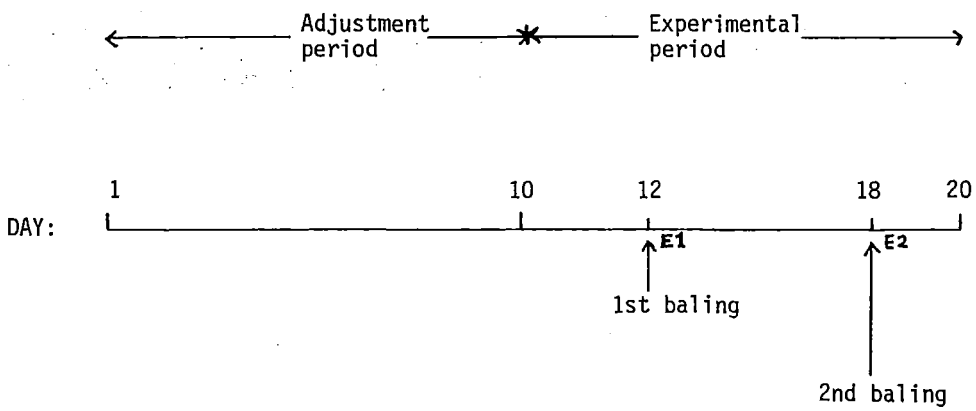
A schematic representation of an experimental period is shown in FIGURE 3.

Rumen baling procedure

Preparation of animals for baling was similar to that described by Reid (1965), although the actual emptying technique was modified.

At the end of two hour feeding period, steers were restrained by a halter tied to the crate. A plastic apron was draped around the cannula to conserve rumen contents. The rubber bung in the cannula was removed, and reticulo-rumen contents baled. The solid material in the rumen was removed by hand into a large plastic container in a water bath at a temperature of between 35-40°C. The semi-liquid fraction was then evacuated using a vacuum cleaner modified as a suction pump. The rumen wall was protected by keeping the operator's fingers between it and the end of the suction line at all times. The suction arrangement speeded up the baling process, and removed almost all the semi-liquid contents of the rumen.

FIGURE 3: Timetable of various operations in an experimental period.



pH measurement

Rumen contents were quickly and thoroughly mixed by hand and the pH read off a portable pH meter calibrated by a standard corrected for ambient temperature.

Weighing

Total rumen content in the tared plastic container was weighed to the nearest 100g.

Introduction of markers

During the second of the two days selected for rumen emptying, a solution of 100g PEG (MW 3350) in 2 litres of water, and 100g DM chromium mordanted straw fibre, were mixed into the rumen contents in the plastic container to serve as liquid and particulate phase markers respectively. This was done during the first baling session immediately after feeding (0hr).

Sampling

A sample of rumen liquor (about 150ml) was strained through a piece of muslin to remove solid plant material and immediately frozen at -8°C in a tightly stoppered honey pot for analysis.

Duplicate samples (about 200g wet weight) of solid material taken from various positions in the plastic containe were oven dried in flat aluminium trays at 70°C for 48 hours, to determine the DM of rumen contents.

Return of rumen contents

After weighing and sub-sampling, digesta contents were returned to the rumen. Solid material was pushed back by hand, while the semi-liquid fraction was run down a plastic gutter fashioned to fit the cannula opening. This speeded up the return process. The time period involved in the whole cycle (of baling, weighing, sampling and return of rumen contents), ranged from a maximum of 30 minutes per steer at the 0hr baling time, to about 12 minutes by the last sampling period 12 hours later. Baling was soon after feeding (0hr), and subsequently at 4, 8 and 12 hours.

At the end of each twenty day experimental period, steers were re-assigned to the next diet, until each had been on all four feed treatments.

The steers were let out of the crates after the first two periods for about four weeks for exercise, before going back for the last two periods.

Sugar Beet Silage trial

Three of the four steers used in the pasture trial were assigned to three feed treatments, in a 3 x 3 Latin Square design.

The feed treatments were :

(i) 100% Sugar beet pulp silage

(ii) 50% Beet silage and 50% barley straw

(iii) 100% Barley straw.

Percentage ration formulation were on a DMI basis.

The facilities used, and the experimental procedure followed were the same as described for the pasture trial.

Adjustment of steers to rations, determination of feeding levels, feeding times, digestibility and retention time measurements all followed a similar procedure to the first trial. Beet silage was fed out fresh each morning from the sealed sacs.

3.4 Laboratory Analytical Methods

(1) Determination of chromic oxide, PEG, ammonia-N and total N concentrations in rumen digesta

Chromic oxide concentrations in rumen DM were determined by atomic absorption spectrophotometry, following the method of Williams, David and Iismaa (1962).

PEG concentrations in rumen fluid were measured by the improved turbidimetric method described by Malawer and Powell (1967), after stabilizing the oil-in-water emulsion with gum arabic solution.

Rumen ammonia-N concentrations in rumen fluid were obtained through distillation, using the Kjeltec System 1002 Distilling Unit, after lowering pH by the addition of saturated sodium tetraborate (Savage, 1977).

The CP content of feed samples were determined as total N by the Kjeldahl method, using copper sulphate/potassium sulphate as a catalyst for digestion, followed by steam distillation with sodium hydroxide (Jacobs, 1965).

All the analytical procedures followed in the determinations of chromic oxide, PEG, ammonia-N and total N are fully outlined in Appendix Methods 2-5.

3.5 Statistical Analysis

DMI, coefficients of digestibility, mean retention times, rate constants etc., were statistically tested by analysis of variance and co-variance using the Genstat Package (Alvey, Galwey and Lane, 1982).

Linear and quadratic regressions were computed using Minitab (Ryan, Joiner and Ryan, 1981).

The significance of differences between means of feed treatments were determined by the 'F' test and Duncan's Multiple Range Test (Steel and Torrie, 1981).

CHAPTER FOUR

RESULTS

4.1 Chemical composition

The chemical composition of the feeds used is shown in Table 5. Pasture averaged 21.8 ±1.4% DM and 15.8 ±2.1% CP (of DM) over the four experimental periods.

The DM and CP contents of PBPS were on average 13.1 ±0.6% and 9.5 ±0.4% (of DM) respectively.

Barley straw had an average DM content of 88.1 ±0.9%. Its CP value was about 3-4% of DM.

4.2 Mean DMI and apparent digestibility coefficients

Mean DMI, apparent DMD and OMD for all treatments are shown in Table 6. Although it was planned to maintain constant DMI on all the feed treatments, there was a tendency for DMI/head/day to fall as the proportion of straw in the ration increased.

There was a highly significant ($P<0.001$) effect of the introduction of straw on the digestibility of pasture , with higher apparent DMD and OMD when no straw was included in the ration. The 20% straw supplemented ration had significantly higher digestibility coefficients (69%) than than the 50% straw ration (64%).

The mean of the linear regressions on a within animal basis of DMD and OMD on level of straw was significant ($P<0.05$), with a high coefficient of determination (R2) (Table 8). This was consistent in individual animals despite the slight differences in DMI (Appendix Table 1).

Despite these good linear relationships of % straw on DMD, there was a consistent trend towards curvilinearity (Figure 5), with the 20% and 50% straw rations having DMD and OMD values higher than that predicted from the two feeds fed separately (Table 7). The extent of the deviations (ie. observed values from predicted values) indicate a 2.5% (or 1.8% units) and 4.8% (or 3.1% units) positive associative

effect on DMD of feeding pasture with 20 and 50% straw respectively.

When digestibility values were regressed quadratically on level of straw in the diet a higher mean R2 value (98.2 versus 95.6) than for the linear regression was obtained, indicating that the relationship was more curvilinear than linear. Standard errors for estimates were also lower than for the linear regressions.

The inclusion of straw also led to a reduction in the overall DMD and OMD of PBPS. Values for means of DMD differed significantly between all feed treatments (Table 6).

Regression of DMD and OMD on level of straw in the ration were not significant, although the coefficients of the equation were similar to that observed for pasture (Table 8).

There was little deviation between observed and predicted values for DMD and OMD of the PBPS and straw ration (Figure 5). R2 values were not improved with the quadratic regression, implying no significant deviation from a linear relationship.

There was a relatively lower DMI of beet silage and straw which was significantly increased when 50% straw was fed.

4.3 Mean retention times

Table 10 shows mean retention time in the rumen (MRT) and flow rates for total digesta DM, PEG and Cr in the reticulo-rumen for all feed treatments.

MRT for DM and OM although tending to be longer with increasing level of straw in the ration were significantly different ($P<0.05$) only between the all barley straw diet and the other treatments.

Treatment means for MRT's of PEG and Cr did not differ significantly between treatment means ($P>0.05$).

Large differences were observed between individual steers in the retention of most fractions of the digesta even on the same feed treatment (Appendix Table 2).

The mean linear regressions of MRT's on level of straw in the ration for the different components of the digesta on a within animal basis are shown in Table 9. Mean R2 values were high for DM and OM (78 and 82%), moderate for PEG (41%) and low for Cr (18%) on the pasture diet.

The deviations between observed and values predicted for the combined diets for MRT's are shown in Table 12. Except for the MRT-PEG at the 20% straw level (8% longer), all observed values for MRT were shorter than predicted (from 1-32%), implying a negative associative effect of the combined feeds.

Despite the marked curvilinearity of these data (Figure 6), MRT regressed quadratically on level of straw were lower compared with those from the linear regressions (eg. 78 to 49% for DM; and 82 to 49% for OM).

As with pasture, MRT for DM and OM of PBPS showed an increasing trend with higher levels of straw (Table 10). Treatment means for MRT's of all components of the digesta and total DM were not significantly different ($P>0.05$).

With PBPS, regression of MRT on level of straw (Table 9), gave mean R2 values of 60% (DM and OM), 86% (PEG) and 22% (Cr) with PBPS. Improved R2 values were obtained with the quadratic regressions compared with the linear, for DM (80 and 60%) and OM (82 and 61%).

Deviations of observed from predicted values for MRT's (Table 12), show consistently negative values for DM, PEG and Cr implying shorter retention times of the different phases of digesta in the rumen with the addition of straw to PBPS. These are shown graphically in Figure 7.

4.4 Total DM, fluid volume and pH of rumen digesta

Total DM content (kg), fluid volume (l) and pH of rumen contents are shown in Table 14.

Rumen pH levels were fairly high (above 6.0) on all diets except for two individual sampling times on PBPS with one steer (5.8 and 5.9). Differences between treatments for pH on both pasture and PBPS were not significant ($P>0.05$).

Rumen volume varied widely among individual steers even on the same treatment (Appendix Table 3). Treatment means were however similar between the treaments on pasture and straw (Table 14). Although mean volume was lower on the 100% PBPS ration compared with that containing 50% straw, the difference was not significant ($P>0.05$).

Total DM content of rumen digesta increased as the level of straw in the ration rose (4 and 10% between 100% pasture and 20% and 50% straw, and 10 and 27% between those treatments soon after feeding and 12 hours later respectively). Differences between means were significant ($P<0.05$) among all treatments for both pasture and PBPS.

4.5 Concentration of ammonia, total PEG and Cr in rumen digesta

Mean ammonia concentrations in rumen fluid (mg/l) were above 220mg/l on pasture soon after feeding. This fell with time, so that by 12 hours levels were just over 90mg/l (Table 15). The all straw and PBPS diets had ammonia levels always below 50mg/l.

4.6 Total OM, ammonia and ammonia:OM ratio of rumen digesta

Total OM content of rumen digesta followed a similar trend to that observed with DM above. Differences in the total ammonia content of rumen fluid (gN) was significant between the mixed pasture and straw rations and the 100% pasture diet soon after feeding (0 hr). The differences between treatments became non-significant by 8 hours after feeding (Table 13). The ratio of total ammonia-N to OM in rumen digesta followed the trend shown with total ammonia content of rumen fluid.

TABLE 5 Chemical composition of feeds (%DM) during trial periods

Feed	Period	DM	OM	CP
(A) Pasture Trial				
Pasture	1	24.3	93.0	11.0
"	2	23.9	92.1	14.0
"	3	20.7	89.9	17.4
"	4	18.2	89.7	20.9
MEAN		21.8	91.2	15.8
±SEM		1.4	0.8	2.1
Barley Straw	1	89.2	95.0	3.6
"	2	86.6	96.0	3.4
"	3	86.8	95.3	3.2
"	4	85.9	95.1	3.5
MEAN		87.1	95.4	3.4
±SEM		0.7	0.2	0.1
(B) Beet Silage Trial				
Beet Silage	1	12.6	93.1	8.7
"	2	14.2	93.7	10.1
"	3	12.5	92.9	9.7
MEAN		13.1	93.2	9.5
±SEM		0.6	0.2	0.4
Barley Straw	1	91.6	95.7	3.7
"	2	88.3	95.4	3.2
"	3	88.5	95.4	3.3
MEAN		89.5	95.5	3.4
±SEM		1.1	0.1	0.2

TABLE 6 Mean dry matter intake (Kg/day) and mean coefficients of digestibility for dry and organic matter (%) of the rations

Level of straw in ration (%DMI)	DM	OM	DMI
(A) Pasture Trial			
0	71.1[a]	72.7[a]	5.0
20	68.9[ab]	70.8[ab]	4.8
50	64.2[c]	66.6[c]	4.6
100	51.1[d]	53.7[d]	3.4
±SEM	1.7	1.7	0.6
Difference	***	***	NS
(B) Beet Silage Trial			
0	70.6[a]	74.8[a]	3.1[a]
50	61.3[b]	63.2[b]	5.6[b]
100	52.6[c]	53.5[c]	4.9[b]
±SEM	2.3	1.7	0.3
Difference	*	*	*

[+] Means designated by same letter superscript not statistically different from each other.

* = Means significantly different at 5% level ($P < 0.05$)

*** = Means significantly different at 0.1% level ($P < 0.001$)

TABLE 7 Significance of associative effects on dry matter intake (Kg/day) and digestibilities of dry and organic matter (%) of rations supplemented with barley straw

	Pasture Trial		Beet Silage Trial
	Level of barley straw in ration (%DMI)		
	20%	50%	50%
(i) DMD			
Measured	68.9	64.2	61.3
*Predicted	67.1	61.1	61.6
Deviation (%)	+ 2.5	+ 4.8	- 0.5
(ii) OMD			
Measured	70.8	66.6	63.2
Predicted	68.9	63.2	64.2
Deviation (%)	+ 2.6	+ 5.0	- 1.4
(iii) DMI			
Measured	4.8	4.6	5.6
Predicted	4.7	4.2	4.0
Deviation (%)	+ 2.1	+ 8.7	+28.6

* Predicted from ratios of pasture/beet silage to straw assuming no associative effects.

Figure 5. The effect of level of straw (%DMI) on the mean apparent digestibility of dry matter (%) in the rumen of steers fed mixed diets of pasture/beet silage and barley straw.

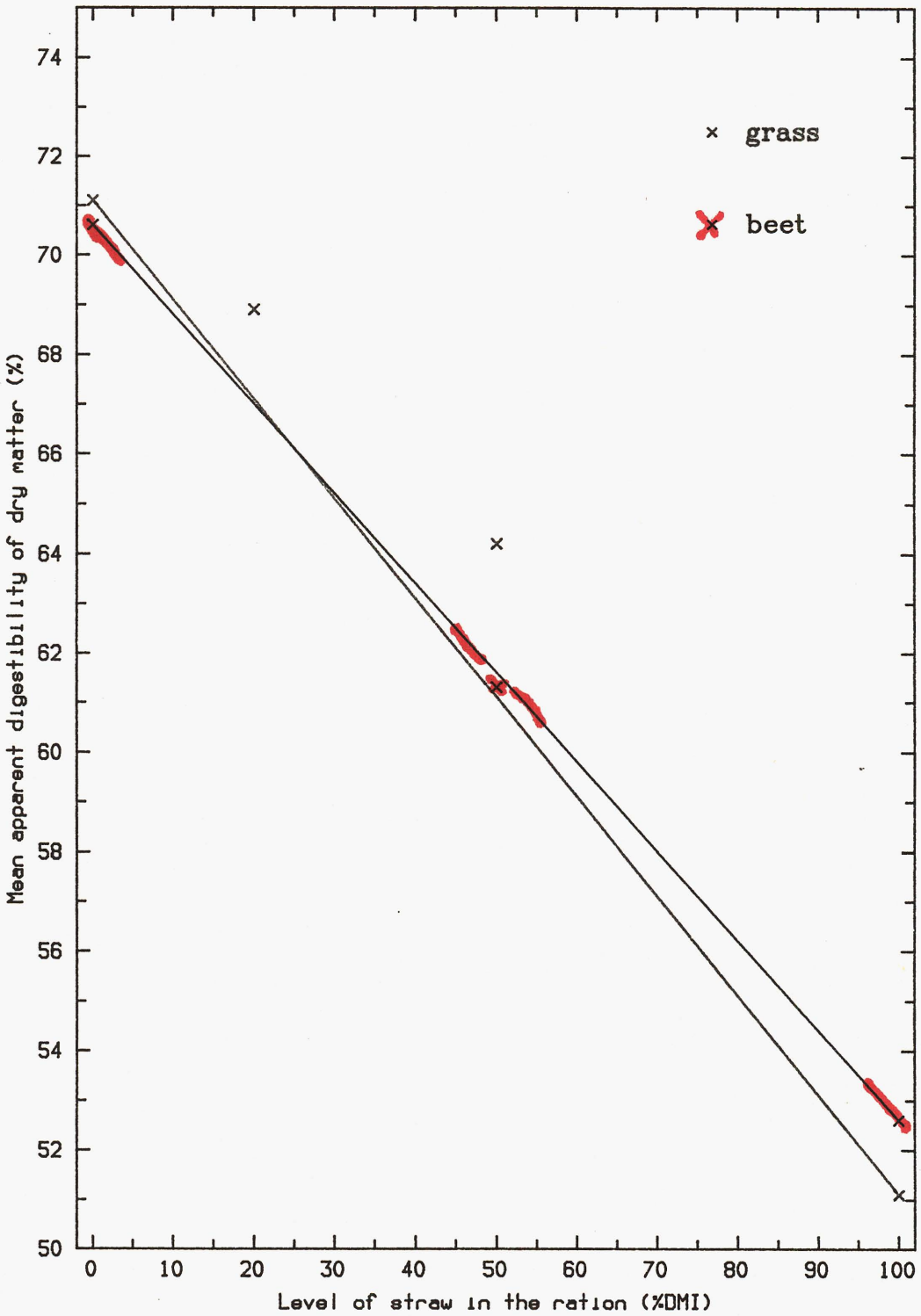


TABLE 8 Regression of mean dry and organic matter digestibilities (%) on level of barley straw (%DMI) in the ration.

Equation:	Y	=	a	+	b	X_1	R^2
(A) Pasture Trial							
(i)	DMD (Linear)	=	72.5	-	0.204*	% straw	95.6
	DMD (Quadratic)	=	71.1	-	0.080*	"	98.2
(ii)	OMD (Linear	=	74.2	-	0.193*	"	92.8
	OMD (Quadratic)	=	72.6	-	0.058*	"	96.2
(B) Beet Silage Trial							
(i)	DMD (Linear	=	70.5	-	0.180	"	96.3
	DMD (Quadratic)	=	70.6	-	0.191	"	-
(ii)	OMD (Linear)	=	74.5	-	0.212	"	93.7
	OMD (Quadratic)	=	74.8	-	0.250	"	-

* Coefficient significant at 5% level ($P < 0.05$)

TABLE 9 Regression of mean retention times (hours) of dry matter, PEG and chromium on level of barley straw (%DMI) in ration

Equation:	Y	=	a	+	b	X_1	R_2
(A) Pasture Trial							
(i)	DM (Linear)	=	19.9	+	0.161	% Straw	77.9
	DM (Quadratic)	=	16.2	+	0.201	"	49.3
(ii)	OM (Linear)	=	18.8	+	0.154	"	81.5
	OM (Quadratic)	=	15.3	+	0.223	"	48.6
(iii)	PEG (Linear)	=	8.8	+	0.051	"	41.1
(iv)	Cr (Linear)	=	41.5	+	0.118	"	17.5
(B) Beet Silage Trial							
(i)	DM (Linear)	=	23.6	+	0.100	"	60.3
	DM (Quadratic)	=	21.2	+	0.139	"	79.5
(ii)	OM (Linear)	=	21.4	+	0.109	"	60.9
	OM (Quadratic)	=	20.7	+	0.102	"	81.6
(iii)	PEG (Linear	=	13.4	-	0.121	"	86.1
(iv)	Cr (Linear)	=	36.9	+	0.103	"	21.7

TABLE 10 Mean retention time (hrs) and flow rate (%/hr) of digesta dry matter, PEG and chromium from the reticulo-rumen for the different ration treatments.

Level of straw in ration (%DMI)	Dry Matter		PEG		Chromium	
	MRT	MFR	MRT	MFR	MRT	MFR
(A) Pasture Trial						
0	20.5[a]	5.1[a]	8.6	13.5	49.4	2.2
20	23.7[a]	4.5[a]	10.5	11.3	40.0	4.0
50	25.8[a]	4.0[a]	10.7	10.4	36.4	3.1
100	37.0[b]	2.8[b]	14.1	7.3	57.1	2.0
±SEM	4.3	0.7	2.3	3.2	8.6	1.0
Difference	*	P<0.10	NS	NS	NS	NS
(B) Beet Silage Trial						
0	24.2	4.5	14.8	10.7	40.4	3.0
50	27.4	3.8	8.5	14.1	35.2	3.5
100	34.2	2.9	10.7	12.2	50.7	2.3
±SEM	5.6	0.9	6.8	6.4	8.8	0.9
Difference	NS	NS	NS	NS	NS	NS

[+] Means designated by the same letter superscript not significantly different from each other.

* = Means significantly different from each other at 5% level ($P < 0.05$)

NS = Means not significantly different from each other at 5% level ($P > 0.05$)

TABLE 11 A comparison of some mean retention time (hrs) results from a review of literature

Feed/s	Animal Specie	Mean Retention time of: DM	Liquid	Indigestible fraction	Reference / Comments
(1) Grain(G) and Hay(H)	Dairy Cows	22.7(G) 25.6(H)	12.4 -	- -	Hartnell and Satter (1979)
(2) Ground straws (NaOH treated and untreated)	Beef Cows	19.2-22.7	-	28.2-48.2	Coombe et al. (1979)
(3) High Concentrate (C) 50% C and 50% alfalfa High roughage (H)	Beef Cattle	22.2 17.0 -	18.9 12.8 19.2	- - 45.5	Owens et al. (1979)
(4) Perrenial rye-grass Short rotation rye-grass White clover	Sheep	10.4 8.7 6.3	- - -	- - -	Ulyatt (1971)
(5) Prairie Grass White clover	Sheep	12.8-13.9 9.6	10.3 7.7	- -	Cruickshank et al.(unpublished)
(6) Dried grass	Sheep	13.9-17.1	-	-	Egan and Doyle (1982)
(7) Dried grass	Sheep	16.2-24.3	-	-	Margan et al. (1982)
(8) LI/LF diet** HI/LF diet LI/HF diet HI/HF diet	Dairy Cattle	44.2 24.9 24.6 20.7			Colucci et al. (1982)
(9) Hay and Concentrate*	Sheep	60.0 62.0 66.0 48.0	20.0 23.0 18.0 20.0		100% Hay 30% hay Large heifers Small heifers Uden (1984b)

** LI, HI, LF; HF denote low intake, high intake, low fibre and high fibre respectively.

* Retention time values are for whole tract.

TABLE 12 Significance of associative effects on mean retention times (hrs) of dry matter, organic matter, PEG and chromium in the reticulo-rumen of rations supplemented with barley straw.

	Pasture Trial		Beet Silage Trial
	Level of barley straw in ration (%DMI)		
	20%	50%	50%
(i) DM			
Measured	23.7	25.9	27.4
*Predicted	23.8	28.8	29.2
Deviation (%)	-0.7	-10.2	-6.3
(ii) OM			
Measured	22.3	24.6	25.7
*Predicted	22.5	27.2	27.5
Deviation (%)	-0.8	-9.7	-6.7
(iii) PEG			
Measured	10.5	10.7	8.5
*Predicted	9.7	11.4	12.8
Deviation	+7.9	-6.0	-33.6
(iv) Cr			
Measured	40.0	36.4	35.2
*Predicted	50.9	53.3	45.5
Deviation (%)	-21.5	-31.8	-22.8

* Predicted from ratios of pasture/beet silage to barley straw assuming no associative effects.

Figure 6. The effect of level of straw in the ration (%DMI) on the mean retention time (hours) of digesta dry matter in the reticulo-rumen.

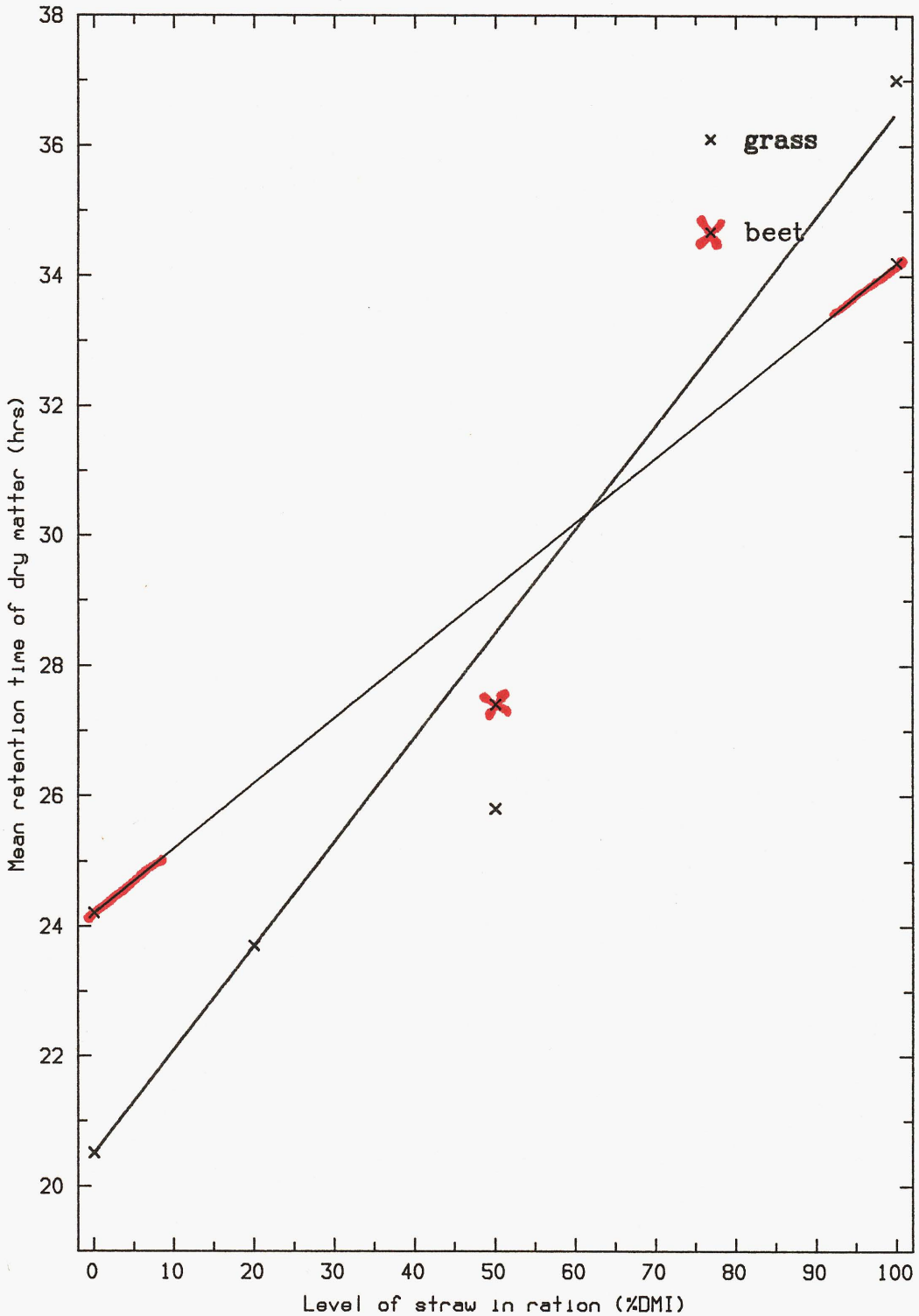


Figure 7. The effect of level of straw in the ration (%DMI) on the mean retention time (hours) of phases of digesta in the reticulo-rumen of steers fed mixed rations of pasture/beet silage and straw.

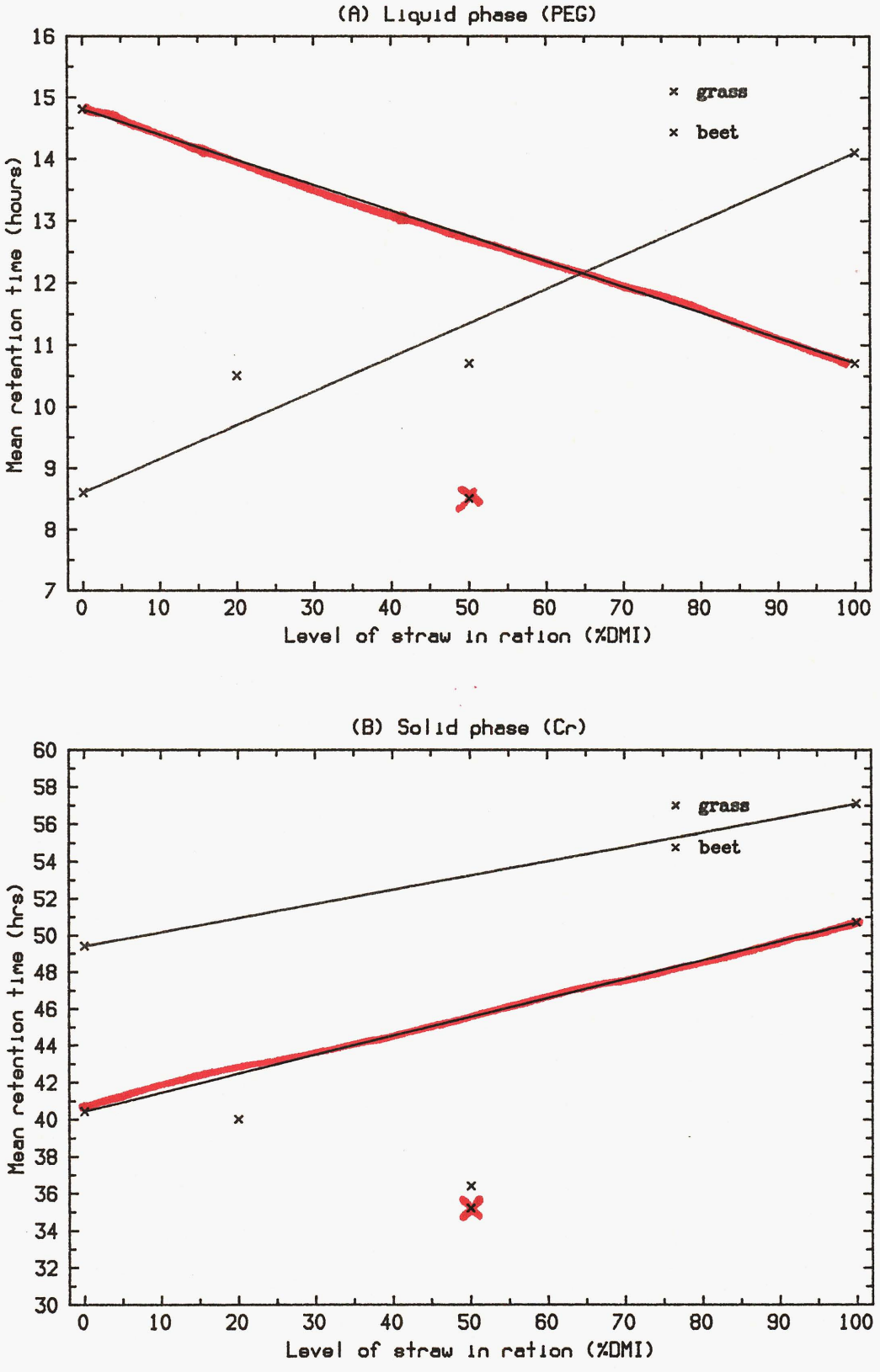


TABLE 13 Mean total organic matter (Kg), mean total NH_3-N (g) and NH_3:OM ratio (X 10^{-3}) of reticulo-rumen contents soon after feeding (0hr), and 4, 8 and 12 hours later.

Level of straw in ration (%DMI)	0hr			4hrs			8hrs			12hrs		
	OM	NH_3	NH_3/OM	OM	NH_3	NH_3/OM	OM	NH_3	NH_3/OM	OM	NH_3	NH_3/OM
(A) Pasture Trial												
0	4.5^a	9.7^a	2.3^a	3.5^a	5.4^a	1.7^a	2.8^a	3.3^a	1.2^a	2.4^a	3.2^a	1.4^a
20	4.7^a	7.3^b	1.7^b	3.6^b	4.7^a	1.2^a	2.9^a	3.3^a	1.1^a	2.6^a	3.2^a	1.1^a
50	5.4^b	7.4^b	1.4^b	4.5^c	3.4^b	0.7^b	3.8^b	2.3^a	0.6^b	3.3^a	2.7^a	0.8^a
100	6.1^c	0.6^c	0.1^c	5.3^d	0.4^c	0.1^c	4.8^c	0.2^b	0.1^c	4.2^b	0.3^b	0.1^b
±SEM	0.6	0.9	0.3	0.5	0.9	0.4	0.4	0.8	0.3	0.4	0.8	0.3
Difference	*	**	**	*	**	*	*	*	*	*	*	*
(B) Beet Silage Trial												
0	2.2^a	0.7	0.3	1.8^a	0.7	0.4	1.5^a	0.7	0.6	1.3^a	0.8	0.6
50	5.7^b	0.6	0.1	4.8^b	0.8	0.2	4.1^b	0.9	0.3	3.6^b	0.9	0.3
100	7.5^c	0.6	0.1	6.6^c	0.4	0.1	5.9^c	0.4	0.1	5.2^c	0.4	0.1
±SEM	0.6	0.0	0.1	0.5	0.2	0.1	0.5	0.3	0.2	0.5	0.2	0.2
Difference	*	NS	NS	*	NS	NS	*	NS	NS	*	NS	NS

** = Means significantly different at 1% level

* = Means significantly different at 5% level

NS = Means not significantly different at 5% level.

TABLE 14 Mean total dry matter (Kg), mean fluid volume (l) and pH of reticulo-rumen contents soon after feeding (0hr), and 4, 8 and 12 hours later.

Level of straw in ration (%DMI)	0hr			4hrs			8hrs			12hrs		
	DM	Vol.	pH	DM	Vol.	pH	DM	Vol.	pH	DM	Vol.	pH
(A) Pasture Trial												
0	5.1^{a}	42.6	6.9	4.0^{a}	37.5	7.0	3.2^{a}	35.2	7.2	2.7^{a}	33.4	7.3
20	5.3^{a}	45.6	6.9	4.1^{a}	42.5	7.0	3.4^{a}	41.9	7.1	3.0^{a}	37.6	7.2
50	6.0^{b}	48.6	6.9	5.1^{b}	44.9	7.1	4.4^{b}	42.9	7.2	3.7^{b}	40.9	7.3
100	6.7^{c}	50.0	7.1	5.8^{c}	46.8	7.2	5.3^{c}	44.7	7.3	4.7^{c}	42.4	7.3
$\pm$SEM	0.5	4.3	0.2	0.5	4.2	0.2	0.4	3.9	0.1	0.4	3.9	0.1
Difference	*	NS	NS	*	NS	NS	*	*	NS	*	*	NS
(B) Beet Silage Trial												
0	2.5^{a}	39.3	6.4	2.2^{a}	35.6	6.7	1.9^{a}	33.6	6.9	1.6^{a}	32.3	6.9
50	6.3^{b}	56.1	6.7	5.4^{b}	52.1	6.9	4.6^{b}	48.5	7.1	4.0^{b}	47.2	7.0
100	8.2^{c}	61.6	6.8	7.2^{c}	58.4	6.8	6.5^{c}	55.5	7.0	5.7^{c}	52.9	6.9
$\pm$SEM	0.6	5.0	0.2	0.5	4.5	0.2	0.5	4.7	0.4	0.5	4.8	0.2
Difference	*	NS	NS	*	NS	NS	*	NS	NS	*	NS	NS

* = Means significantly different from each other at 5% level ($P < 0.05$) if designated by different letter superscript.

NS = Not significant at 5% level ($P > 0.05$).

TABLE 15 Mean concentrations of NH_3-N (mg/l), total PEG (g) and total chromium (g) in reticulo-rumen contents soon after feeding (0hr), and 4, 8 and 12 hours later.

Level of straw in ration (%DMI)	0hr			4hrs			8hrs			12hrs		
	NH_3	PEG	Cr	NH_3	PEG	Cr	NH_3	PEG	Cr	NH_3	PEG	Cr
(A) Pasture Trial												
0	227[a]	68.3	4.6	143[a]	37.4	3.8	95[a]	21.6	3.3	94[a]	11.9	3.1
20	155[b]	78.3	3.6	103[a]	44.9	3.4	74[a]	30.0	3.2	78[a]	19.4	3.0
50	153[c]	85.6	4.9	77[b]	49.0	4.0	54[a]	33.0	3.5	66[a]	18.5	3.2
100	14[d]	73.3	4.3	8[c]	42.3	3.0	5[b]	28.8	2.8	7[b]	21.0	2.6
±SEM	44.5	14.8	1.7	28.4	10.0	1.1	19.2	9.0	1.0	19.0	6.8	1.0
Difference	***	NS	NS	***	NS	NS	**	NS	NS	**	NS	NS
(B) Beet Silage Trial												
0	13	69.9	3.9	18	34.0	3.4	22	24.0	2.7	23	17.7	2.5
50	11	61.6	3.2	16	33.2	3.3	20	24.0	3.0	20	12.1	2.6
100	9	71.8	3.7	7	41.9	3.3	6	27.4	2.9	7	14.1	2.8
±SEM	1.2	9.0	1.1	3.4	9.8	0.9	5.0	9.1	0.7	4.9	7.2	0.7
Difference	NS	NS	NS	NS	NS	NS	*	NS	NS	*	NS	NS

+ Means designated by same letter superscript and significantly different from each other.

* = Means significant at 5% level ($P < 0.05$)

** = Means significant at 1% level ($P < 0.01$)

*** = Means significant at 0.1% level ($P < 0.001$).

CHAPTER FIVE

DISCUSSION

5.1 Chemical composition of feeds

The chemical composition of the feeds used were within the range published by Scott, Lamont, Smeaton and Hudson (1980) for pasture, Kelly (1983) for PBPS and Anderson (1978) for barley straw. An exception was the lower DM content of PBPS (13%) compared with 18% reported by Kelly (1983). This is likely however to be due to differences in the degree to which water is extracted from the pulp, which varies between factories.

It appears from the chemical composition of the pasture used in this trial that it was similar in quality to a sward at pre-flowering stage (Scott et al, 1980), although the high digestibility values recorded (over 70%) suggest better quality material. It should be noted that feed samples were oven-dried for DM determination. Even at drying temperature of 70°C, slight losses of dietary N occur (Faichney and White, 1983), and CP values determined for both pasture and PBPS may have been higher than recorded.

The remaining discussion is in two sections :

(i) The general effects observed when straw is included with the two basal diets, and

(ii) The complimentary effects of the two feeds offered together.

5.2 General effects of including straw with the basal diet

(1) Digestibility of dry and organic matter

The overall effect of replacing a proportion of the basal high moisture diet with barley straw was to lower DMD by 2% units for pasture, and 1.8% units for PBPS for every 10% straw DM included (Table 8). Although the magnitude of the effect was similar for both feeds, only that with pasture was statistically significant.

This overall effect agreed closely with the theoretical effect of feeding 10% straw (51% DMD) with pasture (71.1% DMD) or PBPS (70.6% DMD).

(2) Mean retention time of dry matter (MRT-DM)

MRT-DM in the reticulo-rumen increased by about 1.6 hours and 1.0 hour for every 10% straw DM added to pasture and PBPS. The magnitude of the increase in retention time of DM agreed with the theoretical effect of feeding 10% straw with pasture or PBPS calculated from the MRT-DM of the two feeds fed separately.

Evans (1981b) in a review of the literature, observed no significant relationship between digesta retention time in the rumen and the level of roughage included in various forage and grain based diets, and generally values recorded for MRT-DM or other fractions of the digesta varied considerably between experiments. For example, Prange (1981) noted a small but inconsistent increase in MRT-DM with increasing level of lucerne hay, whilst consistently shorter values were recorded by Colucci et al (1982) and Campher, Roux and Meissner (1983) with maize and maize meal-based concentrate fed with increasing levels of straw. Other results summarized in Table 15 (Hartnell and Satter, 1979; Owens, et al, 1979) agree that addition of straw to a concentrate diet leads to shorter retention time of DM in the rumen. On theoretical grounds however, adding straw to a diet might be expected to lead to longer retention time of dry matter in the rumen because of the slower rate of breakdown of the fibrous material in straw by micro-organisms and rumination.

MRT-DM of pasture recorded in this work with cattle was on the whole 7-10 hours longer than that observed for sheep on perennial ryegrass (Ulyatt, 1971). This could be due to species differences and the effect of rumen size. Thomas and Campling (1977) suggested cattle digest low quality feeds better than sheep because digesta is retained longer in cattle which have a larger rumen/ body weight (Purser and Moir, 1966). This effect of rumen size is also seen in large heifers retaining digesta longer in the rumen than small heifers (Uden 1984b). The increasing MRT-DM values realized in this work with the addition of straw could partly be due to the lower DMI of the straw supplemented diets. Minson (1966) showed a 3-4% increase in the MRT-OM in the rumen

for every 10% decrease in intake. In this work MRT-DM increased by 2.8% for 10% change in DMI. This is less than Minson (1966), and therefore DMI is unlikely to explain the straw substitution effect on MRT-DM.

(3) Mean retention time of liquid phase of rumen digesta

Mean retention time of the liquid phase of rumen digesta (MRT-liquid), measured by reference to PEG, was similar to those reported by Hartnell and Satter (1979) with dairy cows on grain and hay diets, and with sheep on perennial rye-grass (Cruickshank et al, 1985). Values were 0.5 hour longer for pasture, but 1.2 hours shorter with PBPS for every 10% increase in straw DM added.
Owens and Isaacson (1977) have indicated an increased turnover of liquid, bacteria and small particles with increasing straw level in diet as observed with PEG in this work. Because of the higher water intake that invariably accompanies the ingestion of a high fibre feed, an increased passage of the liquid fraction (which carries with it the bacteria and small feed particles) might be expected.

Large differences in MRT-liquid (nearly twofold) were observed among individual steers in this trial, and in general, those with larger rumen fill retained all fractions of the digesta longer on all rations than those with smaller sized rumens.

(4) Mean retention time of solid phase of rumen digesta

Mean retention time of chromium mordanted fibre was longer by 1.2 and 1.0 hour for every 10% increase in straw DM added to pasture or PBPS respectively, but treatment differences were not significant.

In other trials where liquid and chromic oxide turnover rates were measured simultaneously, addition of roughage to a grain based diet generally increased MRT-solid (Owens et al, 1979; Wheeler, Dinius and Coombe, 1979). In a few other studies (van Soest, 1975) a shorter retention time of the solid phase was noted with increasing roughage, whilst yet in others roughage level had no effect on rumen turnover (Hartnell and Satter 1979). Theoretically, addition of straw to a high quality forage diet should increase MRT of the solid phase because of the slower rate of digestion and passage of straw. However, the opposite effect may be observed when roughage is added to a grain based diet because of the stimulating effect on rumination and rumen motility.

(5) Comparison of liquid and solid phase turnover in the reticulo-rumen

Changes in turnover of PEG paralleled those for Cr in this trial, with increasing MRT as the level of straw in the ration increased. MRT-liquid were about 2.5 times shorter than DM, and 4-5 times shorter than MRT-solid. This observation is consistent with the trend in the literature (Hartnell and Satter, 1979; Campher et al, 1983), and indicates the slower rate of disappearance of feed particles than liquid from the rumen.

(6) Limitations of markers used

The extent to which choise and use of markers have influenced retention time measurements for the liquid and solid phases of rumen digesta is difficult to assess.

Colucci et al, (1982) used three different solid phase markers to evaluate maize silage, lucerne and concentrates, while one common marker was used on all feeds in this work. The mordanted particles were small straw particles, and MRT-Cr represents the passage of common particles in all diets. They are thus different from MRT-DM and also may not represent the passage component of pasture or PBPS particles.

Chromium concentration in rumen digesta samples were low, and varied widely (50-350mg/100g DM) between batches of mordanted straw fibre due to problems with the mordanting technique. Measured concentrations of Cr in digesta soon after feeding (0 hr) were unreliable, and values for 0 hr time used in calculations were obtained by extrapolation of the marker concentration versus time regression line. The unreliable 0 hr time values were probably due to the difficulty involved in mixing 100g DM of marker material thoroughly enough into digesta masses often in excess of 60kg. Concentration values at 4, 8 and 12 hours were consistent with an exponential decline in marker concentration and it appeared that the marker was well mixed by this stage.

PEG recovery rates were calculated by multiplying marker concentration in rumen fluid at 0 hour by rumen fluid volume. They were high in the pasture experiment (over 85%) except for one period, but only moderate (about 68%) for PBPS, which was not unexpected because it

has been reported that a certain fraction of PEG is excluded from the fluid fraction of beet pulp (Czerkawski and Brackenbridge, 1969).

(7) Relationship between DMD and MRT-DM at different levels of straw included in the ration

In this trial, there was a linear relationship between DMD and MRT-DM (Figure 8), where DMD declined by 1.4% and 2% for every hour increase in MRT-DM for pasture and PBPS respectively at different straw levels. The coefficients of determination were 99 and 94% for pasture and PBPS respectively. Such a result occurs because of the longer retention time of straw and its lower potential digestibility.

(8) Total ammonia levels in rumen fluid

The pasture results suggest a rapid release of ammonia soon after the consumption of this high nitrogen feed. The high level of ammonia did not persist, and the ammonia was most likely absorbed, although some of it would have ended up in the small intestine. The literature suggests 50mg/l of rumen fluid as the minimum concentration of ammonia critical for optimal bacterial function (Satter and Slyter 1974). There does not appear to be a value for maximum rumen ammonia concentration that micro-organisms can effectively utilize for growth and synthesis. Most ammonia concentrations in rumen fluid of the steers on the 100% pasture treatment were low (about 280mg/l) compared with 700-800mg/l (Johns 1955) observed in grazing ruminants, but it was still well above the critical level. The lower level in this work may have been a function of the relatively low (maintenance) DMI.

On 100% straw and PBPS, ammonia concentrations in rumen fluid were always below the critical level of 50mg/l. It should be noted however that because of the low degradability of PBPS protein in the rumen (ADAS 1976), the low rumen concentration of ammonia-N was not unexpected, and sufficient amino acid N may still be getting to the small intestine to meet protein requirements of the host. The low ammonia concentration on the 100% straw and PBPS diets may have been limiting the rate of digestion of the diets.

Figure 8. The relationship between mean apparent digestibility (%) and mean retention time (hours) of feed dry matter in the reticulo-rumen of steers fed mixed diets of pasture/beet silage and barley straw.

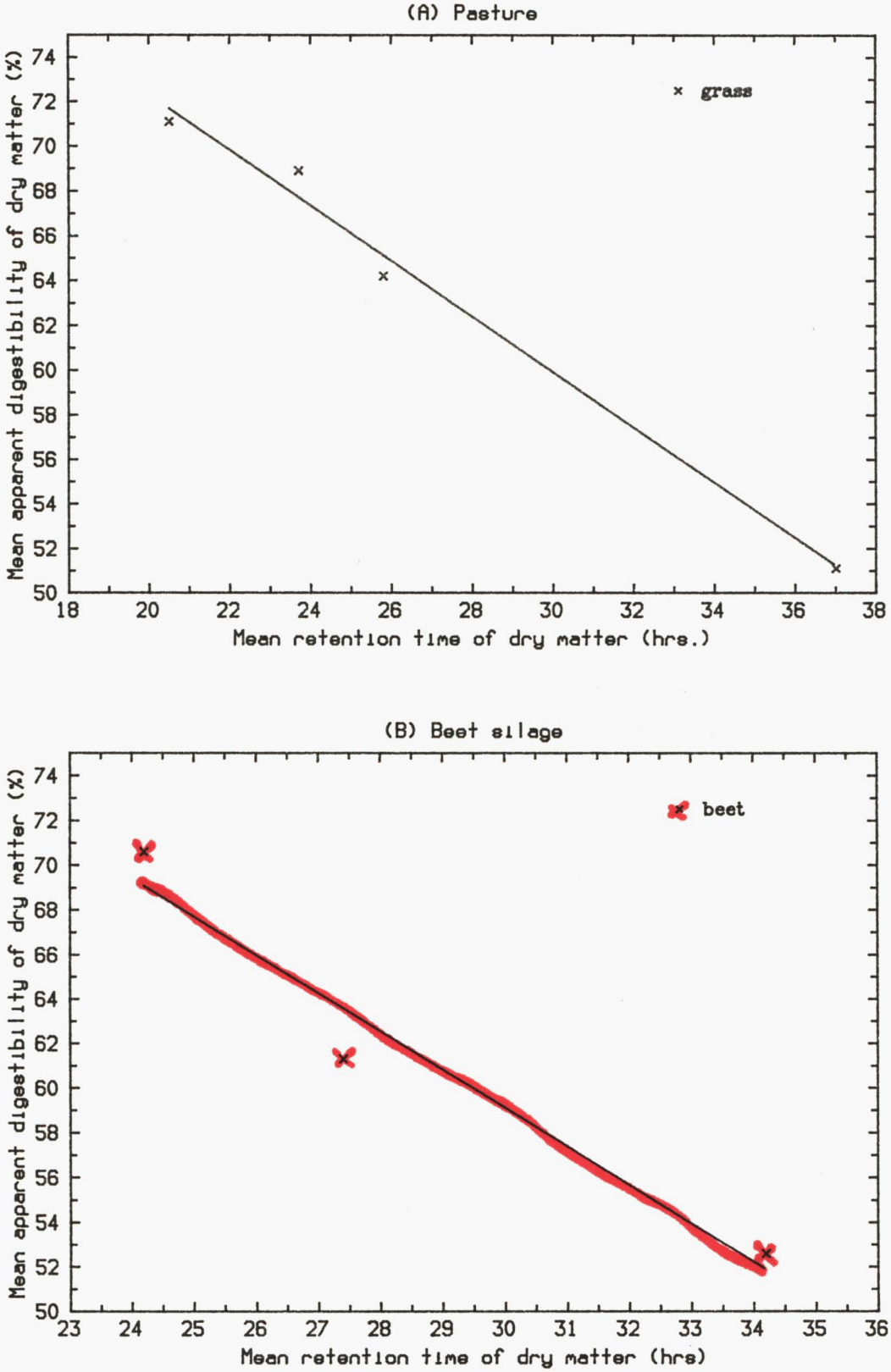
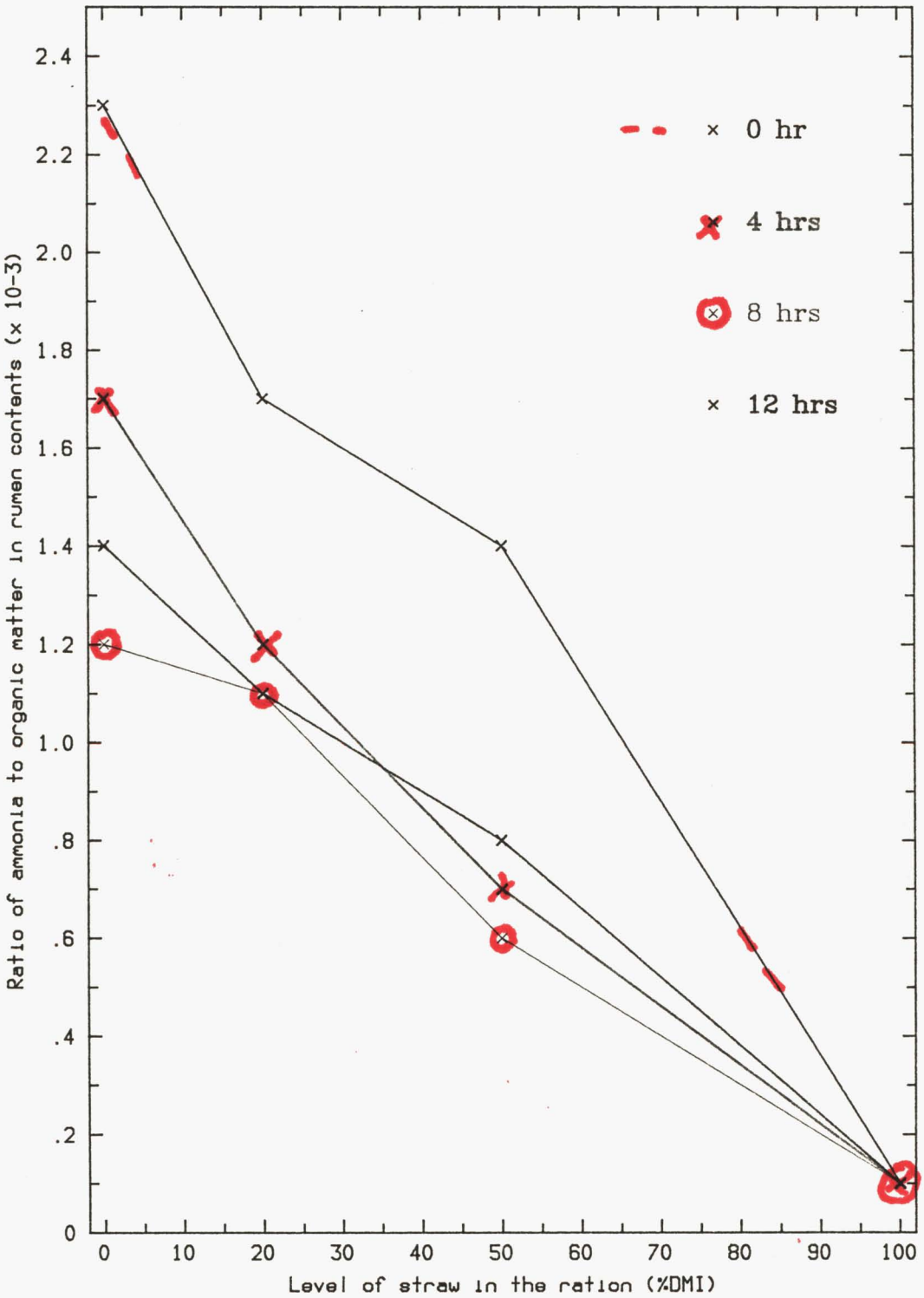


Figure 9. The effect of level of straw in the ration (%DMI) on the ratio of total ammonia N (g) to total organic matter (kg) in the reticulo-rumen contents of steers fed a mixed diet of pasture and barley straw soon after feeding (0 hr), and after 4, 8 and 12 hours.



5.3 Complimentarity between the feeds offered together

Complimentarity is defined as the extent to which the results for the mixed diets deviate from that which would be predicted from the two diets fed separately. Some of the results from this work indicate complimentarity between two feeds offered together.

The complimentary (or associative) effects observed in feeding barley straw with pasture and PBPS were :

(1) Digestibility

A positive associative effect was indicated by a significant curvilinear relationship between DMD and the level of straw in the ration, with pasture, but not with PBPS. DMD and OMD were 2.5 and 5.0% (or 1.8 and 3.1% units) higher for 20 and 50% straw with pasture than would have been predicted from the two feeds fed separately. Results with PBPS confirm other literature findings, which show no, or negative associative digestibility effects when straw is fed with a high quality feed. Williams, MacDearmid, Innes and Brewer (1983) noted a 5-6% depression in fibre digestibility and DMD with straw and turnips, while a 28% depression in DE of maize fed with 20% rice straw was recorded by White et al (1975) when the ration was deficient in protein and some minerals. With a protein and mineral supplement however, the depression was only 1% (White, Hembry and Reynolds, 1972). The depression in DMD in these mixed diets is the result of the preferential attack by rumen micro-organisms on the more readily fermentable portions of the feed at the expense of the complex fibre matrix (Mould et al, 1983). The opposite effect was found with the pasture in this work.

Possible explanations for this contrary result with pasture and straw diets include :

(i) Dry matter intake

DMD is known to increase as DMI decreases (Thornton and Minson, 1973; Grovum and Williams, 1977). DMI on the straw supplemented rations were 7.3 and 3.3% above the mean daily DMI for all the feed treatments when 20 and 50% straw were fed with pasture respectively. The increase in DMI was 19.1% above the mean daily DMI with PBPS and 50% straw. Correction for this variation in DMI could not be made due to the experimental design used, but the slightly higher DMI of the mixed diets would tend to mask a positive complimentarity on DMD rather than

enhance it. Therefore variation in DMI cannot explain the positive associative effect.

(ii) Rumen N and microbial activity causing an improvement in straw digestibility

The large amount of N released in the rumen from pasture could serve as a N source for enhanced digestion by cellulolytic micro-organisms, of the N deficient straw (Schwartz, Schoeman and Faber, 1964). For example, it can be calculated that, if the digestibility of pasture was unaffected by feeding in the mixed diet, then the digestibility of straw DM must have been 60.1% (or 9% units higher) with the 20% straw supplement, and 57.3% (or 6.2% units higher) with 50% straw fed with pasture, than barley straw fed on its own. Given that the rumen digestibility of a low digestibility feed is usually within 2-5% of its potential, it is unlikely that N supplementation of straw in this way could account for such a large improvement in DMD of straw.

(iii) Improvement in pasture digestibility

If the digestibility of the straw fraction is held constant, it can be calculated that digestibility of pasture DM must have been 73.4% (or 2.3% units higher) with 20% straw, and 77.3% (or 6.2% units higher) with 50% straw level in the mixed diet compared with pasture fed on its own. Pasture has a potential digestibility above the levels attained in this trial, and was more likely to be improved in digestibility through the possible increase in microbial activity resulting from the energy source from the straw.

(2) Mean retention time

MRT for both DM and OM were 1% and 10% shorter for 20 and 50% straw with pasture, and 6% shorter for 50% straw with PBPS (Table 12) than would have been predicted from the MRT-DM and OM of the two diets fed separately. This suggests a negative associative effect on MRT-DM when straw is fed with the high moisture feeds. Similar negative associative but much larger effects were recorded for MRT of PEG and Cr.

The implications of these relatively shorter retention times of dietary components in the mixed diets in the rumen are :

(i) Extent of rumen digestion

Straw fed with pasture or PBPS was retained for a shorter period of time in the rumen than when fed on its own. This is likely to reduce the degree of microbial degradation and fermentation in the rumen for the straw and thus decrease, not increase its digestibility, unless the rate of fermentation of the straw also increased. A higher rate of fermentation of the straw due to the availability of soluble carbohydrates or ammonia-N from pasture is a possibility. Although MRT-Cr only measured MRT of straw indigestible material, if it is assumed that this was also representative of pasture indigestible material, then the possible shorter retention time of pasture on the mixed diets could "flush" more soluble carbohydrates of the high quality feed to the small intestine to be more efficiently utilized by the host and raise Kf.

(ii) OM:ammonia-N ratio in the rumen

The total OM mass of rumen content at any time on mixed diets was higher than on 100% pasture (4 and 17% higher after feeding, and 7.7 and 27% higher 12 hours after, on 20% and 50% straw diets respectively). This means that potentially, more energy is available for microbial synthesis when the next rapid build up of ammonia occured in the rumen after feeding pasture (MacRae and Reeds, 1980). If such an improved "capture" of rumen N occured, and this was reflected in a higher ratio of N:OM in digesta reaching the small intestine, an improvement in the utilization of ME for growth (Kf) might be anticipated (Barry 1981). It can be calculated that Kf would only have to increase by 0.02 units for the net energy (NE) value for growth of the 100% pasture and 20% straw with pasture diets to be equal.

In summary therefore, feeding straw with pasture and PBPS resulted in :

(i) Shorter retention times for all phases of rumen digesta compared with the feeds offered separately, suggesting negative associative effects on feed retention in the reticulo-rumen

(ii) DMD significantly higher than would be expected from predicted values for those proportions of straw and pasture in the mixed diet. No associative effect on DMD was observed when PBPS was fed with

barley straw.

It is suggested that the improvement in DMD observed might be due to pasture supplying a source of N and energy for the digestion of straw. In addition, the straw component of the mixed diets might provide a slow release of energy allowing rumen micro-organisms to more efficiently utilize the ammonia rapidly released into the rumen from the highly soluble protein in pasture, which is otherwise lost to the animal in the absence of adequate energy available at that time.

The extent to which a feed is digested depends on its potential digestibility, its rate of digestion and how quickly it passes through the digestive tract. An increased rate of digestion will increase digestibility if passage rate is unaltered, whereas an increase in rate of passage, allows less time for microbial and host enzyme action and causes a reduction in digestibility. The overall digestibility of dry and organic matter in straw-pasture diets showed a positive associative effect despite a negative (faster) associative effect in rate of passage. This result could occur if the increase in the rate of digestion exceeded the increase in the rate of passage. The change in the two rates must have been similar with PBPS since overall digestibility was not affected by the inclusion of straw in the diet. The associative effect in MRT-DM was less than the associative effect in MRT-Cr for both pasture and PBPS. However ME utilization of the PBPS may still have been improved by the faster turnover, and more digestion of the high quality feed in the small intestines could have occured. A faster passage of digesta through the digestive tract usually results in a higher voluntary intake of food and thus higher growth rates.

5.4 Recommendations for further research

The results of this trial raise points that require further work to confirm. The suggested improvement in straw digestibility on feeding with pasture, or pasture digestibility by feeding with straw could be verified by incubating each feed type in dacron bags in rumen fluid of steers on a 100% diet of each feed type to measure the effect of the basal diet on the rate of disappearance of fibre material from the rumen.

Because digestibility values can be influenced by level of intake ad lib feeding trials with combinations of straw and pasture should be done. A method would have to be found to keep up the required intake of straw, probably by feeding it before steers are let out to graze. Growth performance could then be compared with a control group solely on pasture.

Duodenal fistulated steers could be used to measure the amount and ratio of N:OM reaching the small intestines from the rumen on mixed pasture and straw diets.

Retention time measurements could be repeated using the steady state technique to confirm results of the serial emptying method used in this work.

CONCLUSIONS

The results of this trial show that generally, feeding barley straw with a high quality, high moisture feed such as young pasture or PBPS increased retention time of DM in the reticulo-rumen. This would be due to the slower rate of breakdown of the fibrous portion of the diet.

The overall DMD of the pasture or PBPS diet was depressed with the addition of increasing levels of barley straw at a rate equal to that expected from the theoretical calculation from the regression equation.

As hypothesized, there was evidence of some associative effect on both DMD and MRT-DM when barley straw was fed with pasture or PBPS. The associative effect on DMD was small and negative with PBPS. This is consistent with other results from the literature with balanced mixed diets.

The results with pasture definitely deviated from other results in the literature. Feeding 20% and 50% straw DM with pasture resulted in a significant, positive, curvilinear effect of DMD on % straw in the diet with DMD being improved 1.8% units and 3.1% units respectively. It is argued that the positive associative effect on DMD with pasture and straw may be partly a result of high levels of ammonia-N in rumen fluid with 100% pasture (MacRae and Reeds, 1980) not being matched by a correspondingly high level of energy at the same time. Losses of dietary N in such situations may reach as high as 50% (Williams and Gordon, 1983) on young pasture and high quality lucerne hay. Feeding straw with pasture serves as a slow release source of energy possibly promoting microbial growth and synthesis and thus giving better utilization of the rumen ammonia-N. Because the potential digestibility of the straw fraction of the mixed diet is likely to be near maximum, it is suggested that the potential digestibility of pasture may have been raised to a level nearer its maximum from the 71% observed with the 100% pasture diet. For this to explain the positive associative effect on DMD, an increase in pasture DMD of 2.3% units with 20% straw and 6.2% units with 50% straw would be required.

The total OM mass of the rumen (taken as an indication of energy status) was higher at all sampling times on the mixed straw and pasture/PBPS diets than on 100% pasture or PBPS, impling a higher energy status of the rumen.

The trend towards increased turnover rate observed with all the components of rumen digesta measured when straw was fed with pasture or PBPS may have a positive effect on ME utilization as it could push more soluble carbohydrates of the high quality feed to the small intestines for digestion by host enzymes.

Supplementing a high quality diet such as pasture and PBPS with some amount of barley straw should make for better ME utilization, because of better capture of N (with pasture), and flushing of soluble carbohydrates to the small intestines. This will result in a better N and energy supply at the small intestines which has been shown to improve Kf.

These results would tend to substantiate those field results which have shown high animal productivity on roughage supplementation of high quality, high moisture diets.

ACKNOWLEDGEMENTS

In the course of preparing this thesis, I find myself indebted to many people too numerous to individually mention by name, who have freely given of their time to offer assistance to me.

I would like to thank my supervisor, Dr.A.M.Nicol for guidance, advise, encouragement and critical discussion of this work which I found invaluable. Dr.D.P.Poppi, who assisted in supervision for suggestions, advise and corrections to the script throughout the course of the work. Mr.A.S.Familton for expert surgical work in fistulating the steers. I would also like to thank Professor A.R.Sykes for the interest shown in my progress.

The funding for the research work was provided by the combined Beef Breeders Research Committee (Inc), and my course of study at Lincoln College was made possible by a grant from the Commonwealth Scholarships Committee, Wellington. I am extremely grateful to both organizations for the assistance. I wish to thank my employers, the Department of Animal Husbandry, Ministry of Agriculture, Ghana for granting me leave of absence to take up this scholarship.

Pressed beet pulp silage was provided by the New Zealand Agricultural Engineering Institute (NZAEI), Lincoln.

The assistance of Messrs.J.Hollick, N.Jay and staff of the Johnstone Memorial Laboratory for making available facilities and offering help with the trial. I will particularly want to mention Mr.M.Keeley and Miss H.Daly who helped handle and care for the steers.

Mrs.P.Wilson and staff of the Animal Sciences Analytical Laboratory, in particular Miss' R.Maxwell, A.Relling and P.Gibb for their help with various analysis.

The contribution of my fellow post-graduate students in the department, who cheerfully offered suggestions, criticisms, encouragement and their time to help me during the course of my study is acknowledged. I will for a long time treasure the memory of the big contribution made to this work by Mr.M.Young. Mr.R.Alam helped with some aspects of computing, and Miss J.Lassen kindly typed some parts of this thesis and offered help on occasions too numerous to mention. I am

very grateful.

Finally, I'll like to acknowledge the sacrifice, patience, love and prayers of my family and friends both in Ghana and New Zealand. To my father whose death during the course of my stay in New Zealand has deprived me of a guide, financier and friend. I am sorry we couldn't share in this work like in everything else. Thank you for everything.

REFERENCES

ADAS (1976). Sugar beet pulp for feeding. Ministry of Agriculture Fisheries and Food. Advisory Leaflet 363

Agricultural Research Council (1980). The nutrient requirements of ruminant livestock. Commonwealth Agricultural Bureaux.

Alvey, N.; Galwey,N.; Lane, P. (1982). An introduction to Genstat. Academic Press Inc. London.

Anderson, D.C. (1978). Use of cereal residues in beef cattle production systems. Journal of Animal Science 46 :849

Andersen, P.E.; Reid, J.T.; Anderson, M.J.; Stroud, J.W. (1959). Influence of level of intake upon apparent digestibility of forages and mixed diets by ruminants. Journal of Animal Ssience 18 : 1299

Balch, C.C. (1960). In "Digestive physiology and nutrition of the ruminant." (D. Lewis, ed.) Butterworths, London.

Balch, C.C.; Campling, R.C. (1962). Regulation of voluntary food intake in ruminants. Nutrition Abstracts and Reviews 32 :669

Balch, C.C.; Campling, R.C. (1965). Rate of passage of digesta through the ruminant digestive tract. In "Physiology of digestion in the ruminant." (R.W.Dougherty,ed.). Butterworths, London.

Barry, T.N. (1981). Protein metabolism in growing lambs fed on fresh rye grass-clover pastures ad lib. 1. Protein and energy deposition in response to abomasal infusion of casein and methionine. British Journal of Nutrition 46 :521

Bines, J.A.; Davey, W.F. (1978). Metabolic changes associated with intake by cows of complete diets containing straw and concentrates in different proportions. British Journal of Nutrition 39 :567

Blaxter, K.L.; Graham, N.M.C.; Wainmam, F.W. (1956). Some observations on the digestibility of food by sheep, and on related problems. British Journal of Nutrition 10 :69

Blaxter, K.L.; Wilson, R.S. (1963). The assesment of a crop husbandry technique in terms of animal production. Animal Production 5 :27

Bray, A.C.; Till, A.R. (1974). Metabolism of sulphur in the gastro-intestinal tract. In "Digestion and metabolism in the ruminant." (I.W. MacDonald and A.C.I. Warner, ed.). Proceedings IV International Symposium on Ruminant Physiology.

Briggs, P.K.; Hogan, J.P.; Reid, R.L. (1957). The effect of volatile fatty acids, lactic acid and ammonia on rumen pH in sheep. Australian Journal of Agricultural Research 8 :674

Bryant, A.M. (1964). Variations in the pH and volatile fatty acid concentration within the bovine reticulo-rumen. New Zealand Journal of Agricultural Research 7 :694

Bull, L.S.; Rumpler, W.V.; Sweeney, T.F.; Zinn, R.A. (1979). Influence of ruminal turnover on site and extent of digestion. Federation Proceedings 38 :2713

Byers, F.M.; Johnson, D.E.; Matsushima, J.K. (1976). Associative effects between corn and corn silage on energy partitioning by steers. In "Energy metabolism of farm animals." (M.Vermorel, ed.). Proceedings 7th symposium. E.A.A.P. Publication No.19 :253

Byers, F.M. ; Johnson, D.E. ; Preston, T.R. (1982). Associative effects on energy utilization in beef cattle. In "Energy metabolism of farm animals." E.A.A.P. Publication No.25

Campher, J.P.; Roux, C.Z.; Meissner, H.H. (1983). Influence of roughages on rumen retention time of concentrates. South African Journal of Animal Science 13(1) :48

Campling, R.C.; Freer, M. (1966). Factors affecting the voluntary intake of food by cows. 8. Experiments with ground pelleted roughages. British Journal of Nutrition 20 :229

Campling, R.C.; Freer, M.; Balch, C.C. (1963). Factors affecting the voluntary intake of food by cows. 6. A preliminary experiment with ground pelleted hay. British Journal of Nutrition 17 :263

Church, D.C. (1975). In "Digestive physiology and nutrition of ruminants. Volume 1. 2nd Edition. pg.291-293. Metropolitan Printing Company, Oregon.

Church, D.C. (1976). In "Digestive physiology and nutrition of the ruminant. Volume 2. 2nd Edition. Metropolitan Printing Company, Oregon.

Church, D.C.; Santos, A. (1981). Effect of graded levels of soybean and of NPN-molasses supplement on consumption and digestibility of wheat straw. Journal of Animal Science 53 ;1609

Cole, N.A.; Johnson, P.R.; Owens, F.M.; Males, J.R. (1976). Influence of roughage levels and corn processing methods on microbial protein synthesis by beef steers. Journal of Animal Science 43 :497

Colucci, P.E.; Chase, L.E.; van Soest, P.J. (1982). Feed intake, apparent diet digestibility and rate of particulate passage in dairy cattle. Journal of Dairy Science 65 :1445

Coombe, J.B.; Dinius, D.A.; Wheeler, W.E. (1979). Effect of alkali treatment on intake and digestion of barley straw by beef steers. Journal of Animal Science 49 :169

Cruickshank, G.J.; Poppi, D.P.; Sykes, A.R. (1985). Intake and duodenal protein flow in early weaned lambs grazing white clover, lucerne, rye grass and prairie grass. (In Press. Proceedings of the New Zealand Society of Animal Science).

Czerkawski, K.W.; Brackenbridge, G. (1969). Distribution of polyethelene glycol in suspensions of food particles, especially sugar beet pulp and dried grass pellets. British Journal of Nutrition 23 :559

Davendra, C. (1975). The utilization of rice straw by sheep. Level of crude protein and urea as the sole source of dietary nitrogen. Malaysian Agricultural Journal 50 :187

Davendra, C.; Raghavan, G.V. (1978). Agricultural by-products in South-East Asia : Availability, utilization and potential value. World Review of Animal Production 14 :11

Drew, K.R. (1967). The winter nutrition of romney hoggets. Proceedings of New Zealand Society of Animal Production 27 :210

Drew, K.R. (1968). Winter feeding hoggets. Proceedings of New Zealand Society of Animal Production 28 :94

Egan, J.K.; Doyle, P.T. (1982). The effects of stage of maturity in sheep upon intake and digestion of roughage diets. Australian Journal of Agricultural Research 33 :1099

Emmanuel, B.; Lawlor, M.J.; McAleese, D.M. (1969). The rumen buffering system of sheep fed pelleted roughage-concentrate rations. Motility of cows receiving diets of hay, oat straw, and oat straw with urea. British Journal of Nutrition 23 :805

Evans, E. (1981a). An evaluation of the relationships between dietary parameters and rumen liquid turnover rate. Canadian Journal of Animal Science 61 :91

Evans, E. (1981b). An evaluation of the relationships between dietary parameters and rumen solid turnover rate. Canadian Journal of Animal Science 61 :97

Faichney, G.J. (1975). The use of markers to partition digestion within the gastro-intestinal tract of ruminants. In "Proceedings, 4th International Symposium on Ruminant Physiology." (I.W.MacDonald and A.C.I.Warner, ed.)

Faichney, G.J.; White, G.A. (1983). In Methods for analysis of feeds eaten by ruminants. C.S.I.R.O.

Fairburn, C.B. (1974). Feeding sugar beet pulp to farm livestock. ADAS Quarterly Review 15 :114

Fenner, H.; Barnes, H.C. (1966). Effect of feeding reed canary hay and corn silage, pure and combined, on digestibility and acceptability for sheep and cows. Journal of Dairy Science 49 :1454

Forbes, T.J.; Raven, A.M.; Irwin, J.H.D. (1969). The use of coarsely milled barley straw in finishing diets for young beef cattle. Journal of Agricultural Science Cambridge 73 :365

Gibb, M.J.; Treacher, T.T. (1972). Effects of grazing pasture on herbage intake and growth of lambs. Journal of British Grassland Society 26 :195

Grovum, W.L.; Williams, V.J. (1977). Rate of passage of digesta in sheep. 6. The effect of level of food intake on mathematical predictions of the kinetics of digesta in the reticulo-rumen and intestines. British Journal of nutrition 38 :425

Harland, J. (1981). Pressed beet pulp. The feed for the eighties. British Sugar Beet Review 49(1) :26

Hartnell, G.F.; Satter, L.D. (1979). Determination of rumen fill, retention time and ruminal turnover rates of ingesta at different stages of lactation in dairy cows. Journal of Animal Science 48(2) :381

Hildebrandt, H.H. (1958). Kieler Milchw. Forschungsber 10 :137 Quoted in Kaufmann et al (1980)

Horton, G.M.J. (1979). Feeding value of rations containing non-protein nitrogen or natural protein, and of ammoniated straw for beef cattle. Journal of Animal Science 48 :38

Hungate, R.E. (1966). In "The rumen and its microbes. Academic Press, N.Y.

Hyden, S. (1961). Determination of the amount of fluid in the reticulo-rumen of sheep, and its rate of passage to the omasum. Kungl. Lantbrukshogskolans Annaler 27 :51

Jackson, M.G. (1977). The alkali treatment of straws. Animal Feed Science and Technology 2 :105

Jacobs, S. (1965). The determination of nitrogen in biological materials. In "Methods of biochemical analysis". Volume 13. (D.Glick, ed.). Interscience Publishers, New York.

Johns, A.T. (1955). Pasture quality and ruminant digestion. 2. Levels of volatile fatty acids and ammonia in the rumen of sheep on a high production pasture. New Zealand Journal of Science and Technology 37A :323

Johnson, A.B.; Arnold, J.L.; Ellis, W.C.; Smith, W.W.; Lippke, H.; Greene, L.W. (1983). Associative grazing: Wheat with sorghum grain stubble. In "Beef cattle research in Texas." Texas Agricultural Experiment Station. PR-4093 :73

Joyce, J.P. (1971). Feeding value of barley for sheep. Proceedings New Zealand Society of Animal Production 31 :92

Kaufmann, W.; Hagemeister, H.; Dirksen, G. (1980). Adaptations to changes in dietary composition, level and frequency of feeding. In " Digestive physiology and metabolism in ruminants." (Y.Ruckebusch and P.Thivend , ed.). 5th International Symposium. A.V.I. Publishing Company.

Kelly, P. (1983). Sugar Beet Pulp---A review. Animal Feed Science and Technology 8 :1

Kay, R.N.B. (1969). Effects of dietary tannic acid on the solubility of polyethylene glycol. Proceedings Nutrition Society 28 :22A-23A

Kennedy, P.M.; Christopherson, R.J.; Milligan, L.P. (1976). The effect of cold exposure of sheep on digestion, rumen turnover time and efficincy of microbial synthesis. British Journal of Nutrition 36 :231

King, K.W.; Moore, W.E.C. (1957). Density and size as factors affecting passage rate of ingesta in the bovine and human digestive tracts. Journal of Dairy Science 40 :528

Kotb, A.R.; Luckey, T.D. (1972). Markers in nutrition. Nutrition Abstracts and Reviews 42(3) :28

Lindgren, E. (1981). Prediction of the energy value of mixed diets for lactating cows from digestibility experiments with sheep. Swedish Journal of Agricultural Research 11 :177

Loosli, J.K.; Williams, H.H.; Thomas, W.E.; Ferris, F.H.; Maynard, L.A. (1949). Synthesis of amino acids in the rumen. Science 110 :144

MacRae, J.C. (1976). Utilization of the protein of green forage by ruminants at pasture. In "From plant to animal protein. Reviews in Rural Science". Symposium Proceedings (T.M. Sutherland, J.R. MacWilliam and R.A. Leng, ed.). pg. 93

MacRae, J.C.; Reeds, P.J. (1980). In "Protein deposition in animals. (P.J. Buttery and D.E. Lindsay, ed.). pg 231. Butterworths, London.

MacRae, J.C.; Uylatt, M.J. (1974). Quantitative digestion of fresh herbage by sheep. 2. The sites of digestion of some nitrogenous constituents. Journal of Agricultural Science Cambridge 82 :309

Malawer, S.J.; Powell, D.W. (1967). An improved turbidimetric method for analysis of polyethelene glycol utilizing an emulsifier. Gastroenterology 53(2) :250

Margan, D.E.; Faichney, G.J.; Graham, N.M.; Donnelly, J.B. (1982). Digestion of ground and pelleted diets in the stomach and intestines of young sheep from two breeds. Australian Journal of Agricultural Research 33 :617

Mertens, D.R. (1977). Dietary fibre components: Relationship to the rate and extent of ruminal digestion. Federation Proceedings 36 :187

Minson, D.J. (1963). The effect of pelleting and waffering on the feeding value of roughage---A review. Journal of the British Grassland Society 18 :39

Minson, D.J. (1966). The apparent retention of food in the reticulo- rumen at two levels of feeding by means of an hourly feeding technique. British Journal of Nutrition 20 :765

Mosely, G. (1981). Herbage quality and physical breakdown in the foregut of sheep. Proceedings New Zealand Society of Animal Production 41 :142

Mould, F.L.; Orskov, E.R.; Mann, S.O. (1983). Associative effects of mixed feeds. 1. Effects of type and level of supplementation and the influence of rumen fluid pH on cellulolysis in vitro, and dry matter digestion of various roughages. Animal Feed Science and Technology 10 :15

Nicol, A.M.; McLean, J.W. (1970). The influence of pasture species and exogenous oestrogen treatment on carcass composition of lambs. New Zealand Journal of Agricultural Research 13 :385

Nolan, J.V. (1974). Quantitative models of nitrogen metabolism in sheep. In "Digestion and metabolism in the ruminant." Proceedings 4th International Symposium on ruminant physiology. (I.W. McDonald and A.C.I. Warner, ed.). pg. 416

O'Donovan, P.B. (1983). Untreated straw as a livestock feed. Nutrition Abstracts and Reviews 53(7) :442

O'Donovan, P.B.; Ghadaki, M.B. (1973). Effect of diets containing different levels of wheat straw on lamb performance, feed intake and digestibility. Animal Production 16 :77

O'Donovan, P.B.; Silva, J.M.da.; Euclides, V.P.B. (1983). Beef production from native and improved grasslands in west-central Brazil---- Nutritional considerations. World Animal Review 47 :30 (FAO Publication).

Orskov, E.R. (1977). Nutritional principles and evaluation of by-product, wastes products and new feeds for ruminants. Livestock Production Science 4 :165

Owens, F.N.; Isaacson, H.R. (1977). Rumen microbial yields : Factors influencing synthesis and by-pass. Federation Proceedings 36 :198

Owens, F.N.; Kazemi, M.; Galyean, M.L.; Mizwicki, K.L.; Solaiman, S.G. (1979). Ruminal turnover rate --- Influence of feed additives, feed intake and roughage level. Oklahoma Agricultural Experimental Station Report. Miscellaneous Publication 104 :27

Pienaar, J.P.; Roux, C.Z.; van Zyl, A.B. (1983). A comparison of methods used to estimate a rate constant for outflow from the rumen. South African Journal of Animal Science 13(2) :136

Poppi, D.P. (1981). Voluntary intake of leaf and stem fractions of tropical forages offered to cattle and sheep. PhD Thesis. University of Queensland.

Prange, R.W. (1981). Kinetics of digesta passage in lactating cows. PhD Thesis. University of Wisconsin.

Prange, R.W.; Stern, M.D.; Rode, L.M.; Santos, K.A.S.; Jorgenson, N.A.; Satter, L.D. (1979). The effects of altering hay:grain ratios on digestibility and rate of passage of dry matter in lactating dairy cattle. Journal of Animal Science 49(Supplement 1) :398(Abstract).

Purser, D.B.; Moir, R.J. (1966). Rumen volume as a factor involved in individual sheep differences. Journal of Animal Science 25 :509

Putnam, P.A.; Davis, R.E. (1965). Post-ruminal fibre digestibility. Journal of Animal Science 24 :826

Reid, C.S.W. (1965). Quantitative studies of digestion in the reticulo-rumen. 1. Total removal and return of digesta for quantitative sampling in studies of digestion in the reticulo-rumen of cattle. Proceedings New Zealand Society of Animal Production 25 :65

Ryan,T.A.; Joiner, B.L.; Ryan, B.F. (1981). Minitab reference manual. Pennsylvania State University.

Satter, L.D.; Slyter, L.L. (1974). Effect of ammonia concentration on rumen microbial protein production in vitro. British Journal of Nutrition 32 :199

Savage, G.P. (1977). Studies on nitrogen digestion in the bovine. PhD Thesis. University of Newcastle Upon Tyne. U.K.

Schneider, B.W.; Flatt, W.P. (1975). In "Evaluation of feeds through digestibility experiments". pg.272. University of Georgia Press.

Scott, J.D.J.; Lamont, N.; Smeaton, D.C.; Hudson, S.J. (1980). In Sheep and cattle nutrition. Agricultural Reseach Division. Ministry of Agriculture and Fisheries, New Zealand.

Schwartz, H.M.; Schoeman, C.A. and Faber, M.S. (1964). Utilization of urea by sheep. 1. Rates of breakdown of urea and carbohydrates in vivo and in vitro. Journal of Agricultural Science, Cambridge 63 :289

Sheenan, W.; Quirke, J.F. (1982). A comparative study of the feeding value of dried molassed beet pulp and ensiled wet pulp for sheep. Irish Journal of Agricultural Research 21 :129

Steel, R,G.D.; Torrie, J.H. (1981). In Principles and procedures of Statistics. A biometrical approach. 2nd Edition. McGraw-Hill.

Stewart, C.S. (1977). Factors affecting the cellulolytic activity of rumen contents. Applied Environmental Microbiology 33 :497

Sutherland, T.M. (1975). The overall metabolism of nitrogen in the rumen. In "From plant to animal protein. Reviews in rural science II." (T.M. Sutherland, J.R. McWilliam, and R.A. Leng, ed.)

Terry, R.A.; Tilley, J.M.A.; Outen, G.E. (1969). Effect of pH on cellulose digestion under in vitro conditions. Journal of Science of Food and Agriculture 20 :317

Thomas, S.; Campling, R,C. (1977). Comparisons of some factors affecting digestibility in sheep and cows. Journal of British Grassland Society 32 :33

Thornton, R.F.; Minson, D.J. (1973). The relationship between apparent retention time in the rumen, voluntary intake and apparent digestibility of legume and grass diets in sheep. Australian Journal of Agricultural Research 24 :889

Tulloh, N.M. (1966). Physical studies of the alimentary tract of grazing cattle. IV. Dimensions of the tract in lactating and non-lactating cows. New Zealand Journal of Agricultural Research 9 :1008

Tyrell, H.F.; Moe, P.W. (1975). Effect of intake on digestive efficiency. Journal of Dairy Science 58 :1151

Uden, P. (1984a). The effect of intake, and hay:concentrate ratio upon digestibility and digesta passage. Animal Feed Science and Technology 11 :167

Uden, P. (1984b). Digestibility and digesta retention in dairy cows receiving hay or silage at varying concentrate levels. Animal Feed Science and Technology 11 :279

Uden, P.; Colucci, P.E.; van Soest, P.J. (1980). Investigation of chromium, cerium and cobalt as markers in digesta. Rate of passage studies. Journal Science of Food Agriculture 31 :625

Ulyatt, M.J. (1964a). Studies on some factors influencing food intake in sheep. Proceedings New Zealand Society of Animal Production 24 :29

Ulyatt, M.J. (1964b). The use of polyethylene glycol as a marker for measuring rumen water volume, and the rate of flow of water from the rumen of grazing sheep. New Zealand Journal of Agricultural Research 7 :713

Ulyatt, M.J. (1971). Studies on the causes of the differences in pasture quality between perennial rye-grass, short rotation rye-grass and white clover. New Zealand Journal of Agricultural Research 14 :352

Ulyatt, M.J.; MacRae, J.C. (1974). Quantitative digestion of fresh herbage by sheep. 1. Sites of digestion of organic matter, energy, readily fermentable carbohydrates, structural carbohydrates, organic acids and

lipid. Journal of Agricultural Science, Cambridge 82 :295

Ulyatt, M.J.; MacRae, J.C.; Clarke, R.T.J.; Pearce, P.D. (1975). Quantitative digestion of fresh herbage by sheep. IV. Protein synthesis in the stomach. Journal of Agricultural Science Cambridge 84 :453

van Soest, P.J. (1975). Physico-chemical aspects of fibre digestion. In "Digestion and metabolism in the ruminant." (I.W. McDonald and A.C.I. Warner, ed.). pg. 351. University of New England Publishing Unit.

Wainmann, F.W.; Smith, J.S.; Dewey, P.J.S. (1979). The predicted and observed metabolizable energy values of mixtures of maize silage and barley fed to cattle. In "Energy metabolism. Proceedings 8th Symposium. E.A.A.P. Publication No.26. (L. Mount,ed.). Butterworths.

Waldo, D.R.; Smith, L.W. (1972). Model of cellulose disappearance from the rumen. Journal of Dairy Science 55(1) :125

Welch, J.G.; Smith, A.M. (1971). Effect of beet pulp and citrus pulp on rumination activity. Journal of Animal Science 33(2) :472

Wheeler, W.E.; Dinius, D.A.; Coombe, J.B. (1979). Digestibility, rate of digestion and rumino-reticulum parameters of beef steers fed low quality roughages. Journal of Animal Science 49 :1357

White, T.W.; Hembry, F.G.; Reynolds, W.L. (1972). Influence of grinding, supplemental nitrogen source and roughage on digestibility of corn. Journal of Animal Science 34 :672

White, T.W.; Hembry, F.G.; Reynolds, W.L. (1975). Influence of feeding rice straw and urea supplement with whole and ground corn on feedlot performance, rate of passage and digestibility by steers. Journal of Animal Science 41(4) :1180

Wilkins, R.J. (1969). The potential digestibility of cellulose in forages and faeces. Journal of Agricultural Science 73 :57

Williams, C.H.; David, D.J.; Iismaa, O. (1962). The determination of chromic oxide in faeces samples by atomic absorption spectrophotometry. Journal of Agricultural Science Cambridge 59 :381

Williams, P.E.V.; MacDearmid, A.; Innes, G.M.; Brewer, A. (1983). Turnips with chemically treatd straw for beef production. Animal Production 37 :189

Williams and Gordon (1983).

APPENDICES

Appendix Method 1

Technique for mordanting chromiun on to fibre (Uden et al 1980)

(A) Fibre preparation

(i) The plant material (ground barley straw) was sown into a cloth bag and put through the laundering cycle of an automatic washing machine.

(ii) The fibre material was then thoroughly washed in water to remove all soluble material which would tend to reduce the recovery of chromium bound to the fibre. It was then rinsed with acetone, and dried in an oven at 70°C.

(B) Mordanting procedure

(i) Four volumes of a solution of sodium dichromate ($Na_2Cr_2O_7.2H_2O$) containing an amount of chromium equivalent to 12-14% of the weight of the fibre was added to one volume of plant material.

1g Cr_2O_3 = 1.96g $Na_2Cr_2O_7.2H_2O$

(ii) The tray with the material to be mordanted was then covered with aluminium foil and baked at 100°C for 24 hours. P;(iii) The fibre material was rinsed thoroughly in water and suspended in a solution of ascorbic acid overnight. The amount of acid added was equivalent to one half the weight of the fibre material.

(iv) The material was again washed with water until free of any soluble green material, and dried at 70°C.

A chromium concentration of about 12% (of weight of fibre) was found to be ideal to achieve a high recovery rate of chromium from the complex. The amount of chromium bound to fibre in the complex was about 2% of dry matter in this trial.

Appendix method 2

Determination of chromic oxide concentration in digesta samples (Williams, David and Iismaa, 1962).

This was by atomic absorption spectrophotometry.

(i) Rumen digesta samples previously dried at 70°C, were ground through a 1mm sieve and stored in honey pots at -8°C.

(ii) A 2.5g sample was oven dried at 110°C for 6 hours, from which 1g duplicate samples were weighed out into crucibles and ashed in a muffle furnace at 550°C for 6 hours for organic matter determination.

(iii) A blank, together with five chromium-free digesta samples (to serve as standards) were included with each batch for ashing. The standards were prepared by adding known quantities of chromic oxide (as potassium dichromate) to the ashed chromium-free samples.

(iv) The cooled, ashed samples were carefully transfered into 125ml wide-necked Erlenmeyer flasks with a paint brush. To all flasks (samples, standards and blank) were added 9ml of $H_3PO_4/MnSO_4$ and 10ml of $KBrO_3$ solutions.

(v) The resulting solutions were digested on a previously heated hot plate by gently boiling until effervescence ceased, and a purple colour appeared (approximately 10-15 minutes).

(vi) After cooling, the digests were diluted with de-ionized water to a weight of 100g. The flasks were then stoppered and shaken to thoroughly mix contents.

(vii) 10ml of each of the contents of the tubes were centrifuged at 3000 rpm for 10 minutes, and 1ml each of supernatant diluted with 4ml of CaCl2 solution (625mg/l).

(viii) Chromic oxide concentrations in the standards and digesta samples were determined by atomic absorption spectrophotometry (Model IC 151, Instrumentation Laboratory Inc., Massachussets).

(ix) Calculation of chromium concentration was by linear regression.

Regression equation for a straight line, $Y = a + bx$, where

b = slope of regression line

x = atomic absorption reading

a = a constant

y = concentration of Cr_2O_3 (mg/100g DM)

Appendix method 3

Determination of PEG concentration in rumen fluid (Malawar and Powell, 1967)

PEG concentration in rumen fluid was determined by the improved turbidimetric method.

(i) Frozen rumen fluid samples were thawed out overnight at room temperature. After good mixing, 1ml of fluid as well as a blank (distilled water) and standard solutions (made from known amounts of PEG in water) were pipetted into 50ml Erlenmeyer flasks.

(ii) To each of these were added sucessively, 10ml of distilled water, 1ml of 10% (w/v) of anhydrous barium chloride and 2ml of 0.3N barium hydroxide. Contents of flasks were mixed after each addition.

(iii) Next was added 2ml of 5% (w/v) $ZnSO_4.7H_2O$. The flasks were capped with parafilm, shaken vigorously and allowed to stand for 10 minutes. The solutions were then filtered through double thickness Whatman No.2 filter paper.

(iv) 1ml aliquots of the filterates were transfered into 16x150ml test tubes, and 3ml of gum arabic solution (12mg/l) added to stabilize the oil-in-water emulsion. This makes the determination procedure highly accurate and reproducible, while eliminating the need for precision timing necessary without it. Tubes were mixed by gentle agitation.

(v) Into each tube was pipetted 4ml of 30% (w/v) solution of trichloroacetic acid containing 5% (w/v) of anhydrous barium chloride. Tubes were capped with parafilm and mixed by inverting tubes five times.

(vi) Tubes were allowed to stand for about one hour, and solutions read against the blank in standard 4ml, 10mm light path absorption cells on a Shimadzu QV-50 spectrophotometer set at a wavelength of 650mu and a slit width of 0.04mm.

(vi) PEG concentrations in rumen fluid (mg/100ml) were read off a standard curve plotted from the spectrophotometer reading s obtained from the standard solutions of known PEG concentrations.

Appendix method 4

Determination of ammonia concentrations in rumen fluid (Savage, 1977).

Rumen ammonia concentrations were determined by distillation the rumen fluid samples using the Kjeltec System 1002 Distilling Unit, after lowering pH by adding a solution of sodium tetraborate.

(i) Frozen rumen samples were thawed out overnight at room temperature.

(ii) 10g duplicate samples of fluid were weighed out into digestion tubes, including distilled water as a blank. To all tubes were added 25ml of saturated sodium tetraborate, and distilled on a Kjeltec Unit.

(iii) The distillate was titrated with standardized HCl until indicator turned from green to grey.

Calculation of the concentration of ammonia in rumen fluid was as follows :

% ammonia-N = (a - b) x Normality of HCl x 14.008 / g of digesta x 10, where

a = ml of acid titrated into sample

b = ml of acid titrated into blank

14.008 = atomic weight of nitrogen.

Results were corrected for ammonium sulphate recovery rate

Corrected result: % ammonia-N = mg ammonia-N/l x 100 / % recovery

Appendix method 5

Determination of crude protein content of feeds

The nitrogen content of the feeds were determined by the Kjeldahl method, using $CuSO_4/K_2SO_4$ as a catalyst for digestion at 420°C. This was followed by steam distillation with sodium hydroxide (Jacobs, 1965).

Calculation : Total N is calculated as for ammonia-N. To obtain the crude protein value, the % total N is multiplied by a Kjeldahl factor which is :

Wheat ..... = 5.70

Milk ..... = 6.38

Other materials = 6.25

Correction : Results need to be corrected for ammonium sulphate recovery and dry matter %.

Corrected % N = % N x10,000 / % DM x % recovery

APPENDIX TABLE 1 Dry matter intake (Kg/hd/day) and the coefficients of dry and organic matter digestibility (%) of the different rations by individual steers

Level of straw in ration (%DMI)	Animal ID	DMI	DMD	OMD
(A) Pasture Trial				
0	B	4.4	68.3	70.2
0	S	5.0	72.9	73.9
0	R	4.2	71.9	73.6
0	C	6.4	71.5	73.2
20	B	4.1	64.4	66.1
20	S	4.6	68.8	70.9
20	R	5.7	72.6	74.6
20	C	4.9	69.7	71.5
50	B	4.9	61.7	66.2
50	S	4.6	66.7	68.9
50	R	4.8	65.2	66.5
50	C	4.1	63.1	64.6
100	B	2.3	53.4	57.8
100	S	2.5	45.3	47.8
100	R	5.5	57.6	60.2
100	C	3.5	48.1	49.2
(B) Beet Silage Trial				
0	B	2.5	70.1	74.2
0	S	2.5	66.1	71.4
0	R	4.4	75.6	78.8
50	B	5.3	56.3	58.0
50	S	5.3	65.4	67.2
50	R	6.1	62.3	64.5
100	B	4.5	48.7	49.5
100	S	4.6	51.5	52.2
100	R	5.5	57.6	59.0

APPENDIX TABLE 2 Rate Constants (K) and retention times (hrs) of dry matter (DM) PEG and Chromium of rumen digesta for individual steers on the different rations.

Level of straw in ration (%DMI)	Animal ID	DM			PEG				Cr	
		K	RT	R^2	K	RT	R^2	K	RT	R^2
(A) Pasture Trial										
0	B	0.06	18.2	0.99	0.07	13.7	0.99	0.03	33.7	0.99
0	S	0.04	22.7	0.92	0.21	4.7	0.94	0.02	57.1	0.78
0	R	0.04	25.6	0.97	0.14	7.3	0.93	0.02	64.9	0.99
0	C	0.06	15.6	0.98	0.12	8.7	0.99	0.02	41.8	0.97
20	B	0.06	15.9	0.96	0.20	4.9	0.99	0.08	11.9	0.99
20	S	0.04	22.7	0.98	0.08	12.7	0.99	0.04	28.2	0.90
20	R	0.03	33.3	0.95	0.07	14.3	0.99	0.01	80.7	0.95
20	C	0.04	22.7	0.96	0.10	10.2	0.93	0.03	39.2	0.97
50	B	0.05	21.7	0.99	0.13	7.9	0.95	0.04	24.0	0.97
50	S	0.05	20.8	0.99	0.14	7.4	0.99	0.03	30.7	0.99
50	R	0.03	32.3	0.99	0.06	16.7	0.97	0.02	58.1	0.95
50	C	0.04	28.6	0.99	0.09	10.8	0.93	0.03	32.7	0.99
100	B	0.03	33.3	0.99	0.06	17.0	0.92	0.03	35.3	0.99
100	S	0.02	47.6	0.95	0.07	14.1	0.99	0.01	73.0	0.90
100	R	0.03	35.7	0.98	0.10	10.3	0.79	0.01	82.0	0.83
100	C	0.03	31.3	0.99	0.07	15.2	0.99	0.03	38.2	0.95
(B) Beet Silage Trial										
0	B	0.06	17.7	0.99	0.21	4.7	0.99	0.04	25.3	0.99
0	S	0.05	20.8	0.98	0.07	14.5	0.99	0.03	29.5	0.92
0	R	0.03	34.1	0.99	0.04	25.1	0.99	0.02	66.2	0.89
50	B	0.05	21.0	0.99	0.22	4.6	0.98	0.06	16.6	0.99
50	S	0.03	31.3	0.99	0.13	7.8	0.98	0.02	42.4	0.96
50	R	0.03	29.9	0.99	0.08	13.0	0.99	0.02	46.5	0.99
100	B	0.03	33.9	0.99	0.06	17.1	0.92	0.03	35.3	0.99
100	S	0.03	33.0	0.99	0.21	4.8	0.98	0.03	34.8	0.98
100	R	0.03	35.6	0.98	0.10	10.3	0.79	0.01	82.0	0.83

APPENDIX TABLE 3 Total dry matter (Kg), rumen volume (l) and pH of reticulo-rumen contents of individual steers at the different sampling times

Level of straw in ration(%DMI)	Animal ID	0hr			4hrs			8hrs			12hrs		
		DM	Vol.	pH	DM	Vol.	pH	DM	Vol.	pH	DM	Vol.	pH
(A) Pasture Trial													
0	B	4.4	40.3	6.8	3.4	34.7	7.1	2.8	33.8	7.2	2.3	32.5	7.4
0	S	4.5	44.8	6.9	3.2	39.6	6.9	3.0	37.4	7.3	2.5	35.5	7.3
0	R	4.7	40.2	7.1	3.8	34.0	7.2	3.2	31.1	7.1	2.9	29.4	7.1
0	C	6.8	45.1	6.7	5.5	41.6	6.8	3.9	38.7	7.2	3.2	36.2	7.3
20	B	3.9	37.7	6.8	3.6	35.4	6.9	2.6	32.8	6.8	1.9	28.5	7.0
20	S	5.8	50.4	6.5	4.7	47.5	7.0	3.8	44.5	7.3	3.5	40.9	7.4
20	R	6.2	58.2	6.9	5.2	54.1	6.9	4.6	54.0	7.1	4.4	50.0	7.2
20	C	4.0	36.0	7.2	3.0	32.9	7.2	2.6	36.3	7.2	2.3	30.9	7.1
50	B	5.6	52.4	6.8	4.6	49.2	7.0	3.9	46.6	7.0	3.2	43.6	7.1
50	S	7.2	49.7	6.9	5.7	44.5	7.0	4.7	44.9	7.4	4.1	42.6	7.2
50	R	6.2	54.2	6.8	5.6	50.1	7.0	4.9	46.5	7.4	4.3	45.4	7.4
50	C	5.1	38.2	7.0	4.4	35.8	7.2	3.9	33.4	7.0	3.3	32.0	7.3
100	B	7.7	57.7	7.4	6.9	55.1	7.5	6.2	53.9	7.5	5.4	50.4	7.4
100	S	4.4	33.5	7.2	3.9	31.2	7.2	3.8	30.2	7.2	3.4	28.1	7.2
100	R	9.0	63.6	6.9	7.7	59.7	6.9	6.9	54.7	7.2	6.4	53.8	7.1
100	C	5.5	45.0	6.9	4.7	41.3	7.2	4.3	39.9	7.3	3.7	37.4	7.4
(B) Beet Silage Trial													
0	B	1.6	28.4	6.6	1.4	25.1	6.9	1.0	23.4	7.0	0.8	20.4	7.2
0	S	1.8	32.9	6.9	1.5	30.5	7.2	1.2	26.2	7.3	1.0	25.1	7.2
0	R	4.2	56.5	5.8	3.7	51.1	5.9	3.4	51.1	6.4	2.9	51.4	6.4
50	B	5.0	48.3	6.6	4.2	44.6	6.7	3.4	40.9	7.2	2.8	40.8	6.9
50	S	6.7	57.1	6.7	5.7	53.8	7.2	5.2	50.4	7.2	4.5	48.0	7.1
50	R	7.1	62.8	6.8	6.2	57.8	6.9	5.3	54.3	7.0	4.8	52.8	7.1
100	B	7.7	57.7	6.9	6.9	55.1	6.8	6.2	53.9	6.7	5.4	50.4	6.8
100	S	7.8	63.6	6.7	7.1	60.5	6.7	6.4	57.8	6.9	5.4	54.5	6.8
100	R	9.0	63.6	6.9	7.7	59.7	6.9	6.9	54.7	7.3	6.4	53.8	7.0

APPENDIX TABLE 4 Concentrations of ammonia (mgN/l), PEG(g) and chromium of rumen digesta from individual steers at the different sampling times.

Level of straw in ration (%DMI)	Animal ID	0hr			4hrs			8hrs			12hrs		
		NH_3	PEG	Cr	NH_3	PEG	Cr	NH_3	PEG	Cr	NH_3	PEG	Cr
(A) Pasture Trial													
0	B	221	92.0	2.1	119	42.8	3.8	87	33.8	3.4	89	21.6	3.0
0	S	206	55.0	5.3	134	28.1	5.0	106	5.6	4.5	84	1.8	4.4
0	R	269	39.2	0.2	206	19.1	0.3	131	10.4	0.3	143	3.1	0.3
0	C	210	87.0	10.6	114	59.5	6.1	57	36.7	5.1	59	21.0	4.7
20	B	168	33.9	0.4	118	22.4	0.8	84	12.1	0.5	82	3.7	0.4
20	S	88	80.1	3.2	74	49.3	3.4	41	37.9	3.1	32	29.3	2.9
20	R	162	96.6	5.5	75	60.5	5.3	60	42.3	5.3	83	31.9	4.9
20	C	201	102.4	5.3	146	47.4	4.1	112	27.8	3.9	116	12.9	3.7
50	B	146	96.4	7.2	81	36.7	4.6	56	16.5	4.4	76	7.2	3.7
50	S	151	111.8	6.6	74	73.4	6.2	59	53.9	5.3	71	25.6	5.0
50	R	120	96.8	5.4	29	70.8	4.5	36	55.0	3.9	49	36.6	3.6
50	C	194	37.3	0.4	124	14.9	0.6	66	6.7	0.5	68	4.6	0.4
100	B	10	97.1	5.9	7	57.4	4.9	5	38.0	4.3	9	25.4	4.0
100	S	16	53.1	0.6	10	29.8	0.5	8	22.0	0.5	12	14.9	0.5
100	R	15	43.8	2.7	7	24.0	2.7	7	7.6	2.5	0	4.4	2.4
100	C	15	99.0	8.0	8	58.0	3.8	0	47.4	3.8	7	39.2	3.3
(B) Beet Silage Trial													
0	B	12	59.5	2.7	11	20.7	2.3	16	10.4	1.8	20	2.6	1.6
0	S	20	75.4	6.2	20	38.8	5.1	22	25.5	3.6	25	19.8	3.4
0	R	8	74.7	2.7	22	42.6	2.8	27	36.2	2.8	24	30.6	2.4
50	B	9	66.6	2.6	10	36.5	2.0	10	29.4	1.7	6	7.9	1.3
50	S	13	33.1	1.6	26	9.3	2.6	40	4.9	2.5	39	2.3	2.1
50	R	12	85.0	5.4	11	53.8	5.3	9	37.7	4.8	16	26.0	4.4
100	B	10	97.1	5.9	8	57.4	4.9	7	38.0	4.3	9	25.4	4.0
100	S	13	74.6	2.4	10	44.2	2.2	10	36.6	2.0	12	12.5	1.9
100	R	5	43.8	2.7	3	24.0	2.7	0	7.6	2.5	0	4.4	2.4

APPENDIX TABLE 5 Total organic matter (Kg), NH_3 (gN) and the NH_3:OM ratio (10^{-3}) of the reticulo-rumen contents of individual steers at the different sampling times

Level of straw in ration (%DMI)	Animal ID	0hr			4hrs			8hrs			12hrs		
		OM	NH_3	Ratio	OM	NH_3	Ratio	OM	NH_3	Ratio	OM	NH_3	Ratio
(A) Pasture Trial													
0	B	3.9	8.9	2.3	2.9	4.1	1.4	2.4	2.9	1.2	1.9	2.9	1.5
0	S	3.8	12.1	3.2	2.7	8.2	3.0	2.5	4.9	2.0	2.1	5.1	2.4
0	R	4.2	8.3	2.0	3.4	4.6	1.4	2.9	3.3	1.2	2.6	2.5	1.0
0	C	6.0	9.5	1.6	4.9	4.7	1.0	3.4	2.2	0.7	2.8	2.1	0.8
20	B	3.6	3.3	0.9	3.2	2.6	0.8	2.3	1.3	0.6	1.7	0.9	0.5
20	S	5.2	8.5	1.6	4.2	5.6	1.3	3.3	3.7	1.1	3.0	3.4	1.1
20	R	5.4	11.7	2.2	4.5	7.9	1.8	3.9	6.1	1.6	3.7	5.8	1.6
20	C	3.5	5.8	1.7	2.6	2.5	1.0	2.2	2.2	1.0	2.0	2.6	1.3
50	B	4.9	6.3	1.3	4.0	1.4	0.4	3.4	1.7	0.5	2.7	2.1	0.8
50	S	6.5	9.6	1.5	5.1	5.5	1.1	4.1	3.0	0.7	3.6	2.9	0.8
50	R	5.6	7.9	1.4	5.0	4.1	0.8	4.4	2.6	0.6	3.8	3.5	0.9
50	C	4.5	5.8	1.3	3.9	2.7	0.7	3.5	2.0	0.6	2.9	2.3	0.8
100	B	7.1	0.9	0.1	6.3	0.4	0.1	5.6	0.1	0.1	4.9	0.1	0.1
100	S	4.0	0.5	0.1	3.5	0.3	0.1	3.4	0.2	0.1	3.0	0.3	0.1
100	R	8.3	0.6	0.1	7.1	0.5	0.1	6.4	0.4	0.1	5.8	0.5	0.1
100	C	5.0	0.5	0.1	4.2	0.3	0.1	3.9	0.2	0.1	3.2	0.3	0.1
(B) Beet Silage Trial													
0	B	1.4	0.3	0.2	1.1	0.3	0.3	0.8	0.4	0.5	0.7	0.4	0.6
0	S	1.5	0.6	0.4	1.2	0.7	0.6	0.9	0.7	0.8	0.8	0.6	0.8
0	R	3.6	1.1	0.3	3.1	1.0	0.3	2.8	1.1	0.4	2.4	1.3	0.5
50	B	4.5	0.6	0.1	3.8	1.2	0.3	3.0	1.6	0.5	2.5	1.6	0.6
50	S	6.1	0.5	0.1	5.2	0.5	0.1	4.6	0.5	0.1	4.0	0.3	0.1
50	R	6.4	0.8	0.1	5.5	0.6	0.1	4.6	0.5	0.1	4.2	0.9	0.2
100	B	7.1	0.3	0.1	6.3	0.2	0.1	5.6	0.1	0.1	4.9	0.1	0.1
100	S	7.2	0.8	0.1	6.5	0.6	0.1	5.8	0.6	0.1	4.9	0.7	0.1
100	R	8.3	0.6	0.1	7.1	0.5	0.1	6.4	0.4	0.1	5.8	0.5	0.1