R6299: Intake of poor quality roughages and the effect of feeding forage mixtures

A Final Technical Report on a Research Project Funded by the Department for International Development's Livestock Production Programme

APRIL 1995 - MARCH 1998

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EXECUTIVE SUMMARY

Ruminant rations in developing countries are often based on poor quality roughages. One of the main constraints to improved use of these forages is their limited intake. In order to develop new feeding strategies using these forages to improve production and the efficiency of feed utilisation, it is important to be able to characterise the feeds adequately to be able to predict likely effects of single forages and combinations and to understand the factors controlling intake. Therefore, project R6299 proposed to contribute to the DFID purpose 1 of the Semi-Arid Production System through achievement of the following objectives;

1. To develop a method, suitable for use in developing countries, to evaluate feeds and provide information on expected *in vivo* parameters including intake, rate of passage and digestibility.
2. To study the interactions between fibrous feeds in order to provide information on factors influencing animal responses to forage mixtures, and to examine methods which might assist in predicting expected effects *in vivo*.

The objectives were addressed through a series of feeding trials with sheep, carried out in the UK, plus a demonstration/exploration of the method with sheep and cattle in Brazil. In each of the UK trials, 24 wether lambs were individually fed in pens allowing separation of faeces and urine, and thereby estimation of digestibility. Twelve or sixteen treatments were allocated using incomplete block designs for 24 animals over four periods. Each period consisted of three weeks and intake, digestibility, rate of passage and feeding behaviour were determined during the last seven days following adaptation to diet.

The project has provided a method which is able to rank feeds in terms of *in vivo* parameters. STIR was more highly correlated with intake than any of the other parameters considered and the only parameter strongly correlated with rate of passage. Although digestibility was equally, if not better, predicted by *in vitro* gas production parameters, STIR showed potential, within feeds, to predict the effect of particle size. Predictions for intake and rate of passage responses to changes in particle size, for a given feed, fell within 95% confidence limits. However, the slopes within feeds appeared to differ from slopes between feeds and further work is required to clarify these relationships.

Studies of mixtures of fibrous feeds showed that intake responses to supplementation with iso-nitrogenous feeds may depend on the cell wall content of the supplement and the quality of the basal forage. When cell wall content is high, the positive effect of supplementation on forage intake, mediated through increased digestibility and rate of passage of the basal forage, may be limited. Associative effects between feeds on intake, rate of passage and digestibility were observed, and although further work is required to explore these relationships in more detail, the ranking of the size of interactions *in vitro* appeared to reflect those observed in *in vivo* digestibility. There also appeared to be an interaction between the effect of chop length and supplementation, with greater substitution rates being observed for the shortest chopped material.

The project has already produced two publications of conference presentations and three full papers in refereed scientific journals are planned. One MSc and 1 BSc student have received training during the course of the project and produced dissertations. Other UK institutes have shown interest in the method and students at Reading University have been exploring use of the method with cattle. Dissemination of the results to overseas institutions, through article re-prints, would allow field testing of the method in nutrition research in the tropics.

The project contributes to the development goals of DFID through provision of a novel feed evaluation technique. Feed evaluation plays a vital role in development of new feeding systems which can improve performance of livestock in crop-livestock and livestock farming systems throughout the developing world. Effective feed evaluation is unlikely to rely on single estimates of quality. The contribution of STIR is to provide an estimate which reflects the physical structure of the feed and which takes account of animal effects without requiring large amounts of sample. Information on the interactions between fibrous feeds will also contribute to the design of feeding strategies in the tropics which often rely on high quality forages as supplements to roughages of poor nutritive value.

BACKGROUND

Identification of Demand

In many ruminant feeding systems in the tropics, the main feed resource is a poor quality roughage high in fibre and low in protein, resulting in low intakes, which represent one of the main constraints to increasing nutrient intake. Various strategies have been developed to improve intake. For example, supplementation with forages of better quality such as, leguminous hay or tree leaves high in nitrogen (N) and other concentrate feeds. Supplementation with forages has been shown to increase rate of passage and overall DM intake and to improve production. Other strategies, such as chopping, increasing the offer rate and spraying with molasses to alter palatability have also been shown to increase intake and improve animal performance. However, the mechanisms controlling intake in these and other situations are still not well understood and this lack of understanding may be one constraint to the application of novel management strategies.

In order to devise appropriate feeding regimes from a basis of knowledge of factors affecting intake, it is important to be able to characterise feeds in such a way that optimum conditions can be predicted. At present, techniques which provide information on the potential intake of feeds are often unreliable, particularly with the types of feeds found in the tropics. Many of these techniques rely on laboratory analysis and it is hypothesised that inclusion of the animal in the evaluation procedures may improve predictions.

Initially, scientists in national agricultural research institutions (NARS) will benefit from the development of new techniques and methodologies which they can use in the evaluation of forages, other feeds and feeding strategies. A greater understanding of mechanisms controlling feed intake will also assist in the development of new technologies. Ultimately the beneficiaries will be small holder farmers, as they benefit from the improved feeding strategies developed using the methodology.

Literature review

Short term intake rate as a potential predictor of in vivo parameters

Kenney and Black (1984) found that the acceptability of a particular feed, as measured by potential intake rate (PIR), affected diet selection and could be used to rank feedstuffs in order of preference. These workers also observed that PIR was negatively correlated with particle length of the feed. Moseley and Manendez (1989) observed a good correlation between voluntary intake and PIR, which was not affected by the basal ration the animals were consuming. However, increasing the fasting period before the measurements were made, particularly from 2-4 hours, increased intake rate, indicating that a definition of standard conditions for the measurement is essential. Previous studies at NRI also demonstrated that intake rate, determined in goats over 4 minute periods after 4 hours fasting, was related to voluntary intake, although only a limited number of feeds were studied (Gill and Romney 1994). Thus, it is apparent that PIR provides information about the feed, although it is not exactly clear how this relates to nutritive value. One of the first hypotheses under consideration is that PIR, which shall now be termed short term intake rate (STIR), is related to rate of passage and thus voluntary intake.

Effect of physical fill on intake and factors affecting fill

One of the primary factors limiting intake of poor quality forages is physical fill (Campling and Balch 1961), and the degree of fill is dependant on rates of digestion and passage (Ulyatt *et al.* 1986). The content of fibrous cell walls is a major factor in this respect, since these structures are less soluble and take up more space than the cell contents. A measure of cell wall content is one of the most common chemical components used to predict intake, with acid or neutral detergent fibre fractions (ADF or NDF) (Van Soest 1965) being cited the most frequently.

Resistance to comminution (reduction in particle size) is positively related to fibre content, however, relationships between fibre measured using neutral detergent solution (NDF) and dry matter intake (DMI) are not always consistent. Reid *et al.* (1988) found a significant effect of forage class (C3 grass or legume or C4 tropical grass) on the slope and intercept for regressions of DMI on NDF for both cattle and sheep, indicating that the fill effect of NDF may vary with different forages. This may be explained by the variance in distribution of the different structural polysaccharides. Minson (1990) observed that, for groups of forages with similar DM digestibility, fibre content is greater in legumes compared to grasses, temperate compared to

tropical grasses and leaf compared to stem. Wilson and Kennedy (1996) suggested that the lower digestibility of tropical grasses compared to temperate grasses and legumes reflects an interlocking and, therefore, more rigid cell structure.

As well as differences in resistance to breakdown, grasses generally have higher fractions of potentially digestible fibre and lower rates of digestion than legumes. Therefore, they are likely to remain buoyant for longer as fermentation gases continue to be released over a longer period, resulting in a slower rate of passage, although this is not a consistent observation. The effect of maturity on buoyancy is probably less than the effect of differences between grass and legumes. As plants mature, rate of fermentation decreases, which would tend to increase buoyancy, but the amount of fermentable material decreases having the opposite effect (Jung and Allen 1995). Thus, potential intake is dependent not only on the fibre content, but also on the original structure of the plant and the way in which it breaks down during digestion.

Mechanical manipulation of forages can also influence intake. It is well known that decreasing particle size of forages by grinding and pelleting can increase voluntary dry matter intake (VDMI) (e.g. Pond *et al.* 1984), as it reduces initial volume and retention time in the rumen. However, the disadvantage of too fine a digesta can be depression of digestibility, resulting in unchanged intake of digestible organic matter in the dry matter (DOMD) (Wilkins *et al.* 1972). Commonly, in the tropics, where cut and carry feeding is practised on smallholder farms, forages (including stovers, cultivated forages, banana pseudo-stems etc.) are hand chopped, with a view to maximising intake of a limited feed resource. However, effects of chopping are not always consistent and Osafo *et al.* (1997) reported positive effects on intake of chopping sorghum stover for sheep but not cattle.

Prediction of intake and other in vivo parameters

The relationship between rate of digestion and intake through its effect on rate of passage has resulted in a number of authors using *in vitro* measures of rate of digestion and *in situ* measures of degradability to predict intake. Parameters used have included gas volumes or DM disappearance at specific times during the fermentation, as well as parameters derived from fitting curves to the gas produced. Blummel *et al.* (1997) calculated a partitioning factor (PF), reflecting the variation of short chain fatty acid production per unit of substrate degraded, and showed this to account for 11% of the variation in DMI. Many authors have shown high

correlations between intake and *in vitro* or *in situ* parameters (e.g. Kibon and Orskov 1993; Khazaal *et al.* 1995; Blummel and Bullerdieck 1997; Ferret *et al.* 1997). However, it should be noted that, in most cases, groups of similar feeds were used. Cherney *et al.* (1988) showed that digestion rates increase as grind size decreases, and Allen (1996) suggests that this may result in an overestimation of DMI when *in vitro* or *in situ* digestibility rates of ground samples are used as a predictor. This observation may suggest that some description or measure of physical structure and ease of particle size breakdown should be used. Minson (1990) discussed a range of physical measurements which have been related to intake including leaf proportion, bulk density and grinding energy, although use of these methods is not common. Since STIR values will be determined on feeds "as offered", it is likely they will reflect the physical structure of the feed, showing a potential advantage over methods which rely on dried ground samples.

Effects of mixtures of feeds and prediction of interactions

Ruminant diets rarely consist of single feeds. Lusby and Wagner (1987) discussed the use of N-containing supplements to increase the intake of low to medium quality forages. Although in many countries availability of concentrate feed is low, the use of small quantities of better quality forages, such as cultivated grasses, legumes and tree fodders (Muinga *et al.* 1992; Bonsi *et al.* 1994; Goodchild and McMeniman 1994) may be a feasible alternative to the use of expensive protein supplements. Leng (1990) noted that farmers in developing countries recognise the benefit of adding small amounts of green forage to poor quality roughage diets and cites authors who have demonstrated that supplementation of a straw-based diet with forage of high digestibility boosts digestibility of the basal feed, even when levels of supplementation are low. One of the major ways in which N containing supplements are able to increase intake of poor quality forage is by increasing N supply to the cellulolytic bacteria in the rumen, permitting a more efficient breakdown of the fibre. As the fibre is broken down faster to particles small enough to leave the rumen, then limitations on intake due to fill are reduced. Manyuchi (1994) carried out a series of trials in Zimbabwe, supplementing veld hay with Napier grass and groundnut hay and found that, although the digestibility and N retention did not alter with supplementation, increased DM intakes coincided with increased rate of passage.

In order to predict animal performance from mixed diets (i.e. forages and supplements) a combination of methods of feed evaluation is required. If the above hypothesis holds, STIR could be used to provide information on rate of passage which would be complementary to

information on rates of digestion, generated in project R5180, completed in April 1997, using *in vitro* gas production. Although, obviously, the behaviour of substrates *in vitro* is likely to differ in the rumen, this method may provide useful information for prediction of likely associative effects. For example, Prasad *et al.* (1994) compared *in vitro* gas production with *in vivo* digestibility and observed similar trends for the effect of supplementing straw with a concentrate mixture

PROJECT PURPOSE

The project was designed to contribute to indicative output .4 for the Semi-Arid Production System of the Livestock Production Programme (LPP):

> Performance of livestock (including draught animals) in semi-arid crop livestock and livestock production systems improved.

The project addressed the purpose through development of a method which can be used in evaluation of feeds and which is appropriate for use in developing countries where sophisticated equipment is unavailable. Existing techniques often rely on dried ground samples, whereas the proposed method will allow evaluation of material 'as fed', thereby accounting for structural characteristics. The project also proposed to study the interactions between fibrous feeds, which would assist in development of feeding strategies where high quality forages are used as supplements.

RESEARCH ACTIVITIES

Experimental methods - general

Determination of STIR values

In all experiments the basic procedures used to determine STIR values were the same. However the numbers of feeds offered on any day to any one animal and the time between measurements varied. In experiment 1, all animals of the same species were maintained on similar rations. In

experiments 2-4, where STIR values were determined in the week following a 3-month feeding trial, lambs were maintained on the same diet they had received during the last period of the trial.

On the day of measurement, animals were offered 25% of their normal daily ration, in order to avoid unnecessary stress by denying them feed at a time when they were accustomed to receiving it. After one hour, all feed was removed and animals fasted for four hours. Following this period, small amounts of feed placed in a clean feed bowl were offered to each animal for a period of 4-5 minutes. Time spent actively eating, defined as prehension or mastication of feed, was determined accurately using a stopwatch. At the end of the period, all spillage was carefully collected and the amount of remaining feed used to determine STIR value as;

$$\text{STIR value (g DM/min)} = \frac{(W1 - W2)*(DM/100)}{T}$$

where: W1 = Weight of feed offered to the animal
W2 = Weight of feed remaining
DM = Percentage DM of the feed
T = Time spent actively eating

In experiment 1, STIR values were determined with each animal at the same time with one operator per animal. In order to avoid bias, the operators changed animals after each STIR estimation. In experiments 2-4, four STIR values were determined at a time by two operators. A single STIR value was determined for each feed for each animal over 3-4 days, using a sequence designed to take account of any effect of place in the sequence or day. Four STIR values were determined with each animal on each day and operators alternated between animals to avoid

In all experiments, an additional one or two days of training were allowed. Although procedures and sequences were identical to those used in subsequent days, data collected on these days were not used in the final analysis. Although it was not possible to predict accurately the amount that each animal would consume, quantities ensuring refusals were estimated from the 'training' days. Any measurements in which all the feed offered was consumed were treated as missing values. Mean STIR values were estimated from the data as the adjusted means from analysis of

variance. Data were analysed in GENSTAT using the REML (Residual Maximum Likelihood) procedure designed to handle unbalanced data-sets.

Determination of in vitro gas production parameters

Determination of gas production parameters in experiments 2 and 3 were carried out with additional support from another LPP funded project, R5180.

Experiment 1: Preliminary evaluation of the STIR method

The first experiment was carried out in the state of Minas Gerais, Brazil at the Coronel Pacheco field station of Empresa Brasileira de Pesquisa Agropecuaria - Centro Nacional de Pesquisa Gado de Leite (EMBRAPA-CNPGL), in collaboration with Dr Airdem Goncalves de Assis.

Objectives:

- To determine the sensitivity of the method to particle size
- To determine whether sheep and cattle rank feeds differently

  To assess the potential of the method for use in mixed diets

  To assess whether the position in the sequence of feeds affects the STIR value

Animals and methods

Eight Holstein-Zebu dry cows aged 6-8 years and four wether sheep of unspecified breed, aged 1.5-6 years, from the EMBRAPA farm were used. Dietary history was different for the two species. Cattle received silage as part of their diet during previous lactations together with Coast grass hay and Napier grass. Sheep were maintained on native pasture with some Napier grass and had no previous experience of silage or hay.

The test feeds were offered over four days using an incomplete 10 x 16 latin square, repeated twice for cattle. Animals were animals re-randomised on the second occasion, such that values were determined for 10 feeds with each animal on each day. By the end of the period 10 or 20 values for each feed were determined for sheep and cattle, respectively.

Data Analysis

The data were subjected to analysis of variance using the statistics package GENSTAT, to identify differences between STIR values of different feeds, as well as any effects of position in the sequence of feeds offered on the same day.

Experiment 2: Measurement of short term intake rate (STIR) to predict *in vivo* parameters in sheep

The second experiment was carried out using facilities at Wye College in the UK. Lambs used and some feeds were purchased with the assistance of Wye lecturers, who provided support to NRI staff and college students responsible for day to running of trials.

Objectives.

To determine whether STIR values can be used to rank a range of feeds in terms of their potential intake, digestibility and rate of passage.

Animals and methods

Twenty four Suffolk x Kent lambs with an initial liveweight of 18.0 (s.d. 2.46) kg were housed individually, in pens allowing separation of urine and faeces. Animals were offered a single feed *ad libitum* at 115% of the previous days intake. Twelve different feeds (see table 1 for composition) were offered to animals in an incomplete block design consisting of four 21-day periods. Water was available *ad libitum.*

In the last seven days of each period, accurate DM intakes were determined and digestibility estimated from total faecal collection. Feed samples were analysed for dry matter DM, crude protein (CP), organic matter (OM) and acid detergent fibre (ADF) contents according to standard procedures. Rate of passage in the whole digestive tract was estimated using chromium (Cr) as a marker, mordanted to each feed using the method described by Uden *et al.* (1980 and 1982). Sheep were fed 30-50 g portions of the mordanted material before the morning feed and faecal samples collected at 6, 10, 14, 20, 24, 28, 32, 36, 44, 48, 58, 81, 129 and 144 hours after feeding. The concentration of Cr in the faeces was estimated using atomic absorption spectrophotometry, following wet digestion according to Christian and Coup (1954). Feeding behaviour was

observed during two consecutive 24-hour periods. Records of whether an animal was eating or ruminating were taken every five minutes. Total time spent on each activity were used to estimate eating rate (g/min) and eating, ruminating and total chewing indices (min/kg DM) as an indication of feed processing time.

Table 1: *Summary of treatment feeds used in experiment 2 and their nutrient composition (g/kg DM)*

Treatment code	Feedstuffs	Crude protein (g/kgDM)	Acid detergent fibre(g/kg DM)	Water soluble carbohydrate (g/kg DM)
	Long forages			
DRG	Dried rye grass	59	421	178.5
THY	Timothy hay	95	409	105.7
MHY	Meadow hay	57	503	60.9
RHY	Rye grass hay	63	493	116.8
ST1	Straw 1	41	598	10.9
ST2	Straw 2	37	555	21.0
	Other feeds			
SBP+	Sugar beet pulp	99	258	239.6
MGF	Maize gluten feed	213	200	57.5
WF	Wheat feed	171	170	75.6
AA*	Alfa-A	192	367	131.9
HF†	Hi Fi light	108	515	65.0
P	Lucerne pellets	194	459	52.9

+ Soaked overnight in water in the ratio 4:1 water:SBP on a kg:kg basis
* Chopped lucerne containing molasses
† Chopped lucerne and oat straw containing molasses

STIR values for each feed were determined in the week following the last period of the *in vivo* trial. Feeds were offered using a randomised complete block design such that, daily, each animal was used to determine STIR values for four feeds. Thus, over a period of three days, individual animals received each of the 12 feeds once. The sequence for days one and two were repeated, so that the first two days were considered as a training period and data collected on these days were excluded from the final analysis.

In addition, samples of all feeds were subjected to the gas production technique of Theodorou *et al* (1994). Samples (1g) were fermented in triplicate in 100 ml serum bottles in both N-rich and

N-free media inoculated with fresh rumen fluid. The N-free medium was described by Menke *et al.* (1979) and the N-rich medium by Theodorou *et al.* (1994). Gas readings were recorded at time intervals up to 70 hours, at which time the residues were recovered by filtration to be dried and weighed to determine dry matter disappearance (DMD).

Data analysis

Mean values for the *in vivo* parameters, adjusted for between animal and period variation, were estimated by carrying out an analysis of variance using the statistics package GENSTAT. Mean STIR values were estimated as described above, using the REML procedure. STIR values were regressed against *in vivo* parameters and coefficients of determination (R^2) estimated. R^2 were also calculated for CG production, CP and ADF contents, on *in vivo* parameters and for the difference between the N-free and N-rich media in the CG production observed at each of the four times on CP contents.

The faecal Cr data were analysed using the model of Dhanoa *et al.* (1985) (equation 1) which contains an exponential term and a double exponential term, derived by considering digesta flow as a multi-component exponential process. Two rate constants, k1 and k2, were estimated using the model and are considered to represent outflow rate constants for the two largest compartments in the digestive tract, likely to be the rumen and possibly the caecum. Transit time (TT), mean retention time (MRT) and rate of passage (rop) were estimated from parameters obtained by fitting the model. TT is the time between administration of the Cr and its first appearance in the faeces, while MRT is the mean time before appearance of Cr in the faeces. Rop is the inverse of MRT and represents the proportion of material passing through the tract in an hour (Dhanoa *et al.* 1985).

Experiment 3: Effect of supplementation with fibrous feeds and the use of *in vitro* gas production parameters to predict interactions between feeds

Experiment 3 was also carried out at Wye college as for experiment 2.

Objectives

- To examine the relationships between forages and fibrous supplements

- To determine whether *in vitro* gas production can be used to predict interactions between feeds

Animals and methods

Twenty-four Suffolk x Kent wether lambs, with an initial mean live weight of 31 kg (s.d. 2.91) were housed under identical conditions to those used in experiment 2. Lambs were offered either barley straw (BS) or meadow hay (MHY) *ad libitum* at 115% of the previous days intake. Forages were either offered alone or together with a supplement of Alfa-A (AA), a commercial source of chopped lucerne mixed with molasses, or wheat feed (WF), at one of two offer rates (low and high), giving a total of 12 treatments (table 2). Both AA and WF had similar CP concentrations, but very different contents of fibre and ether extract (EE) (table 3). Supplementation rates were 14.6 (low), or 29.3 (high) g DM/kg $LW^{0.75}$, amounts calculated to supply 25 or 50% of total DMI for a 30 kg lamb consuming 2.5% of its liveweight (LW) as DM.

Table 2: *Summary of treatments in experiment 3*

Treatment code	Treatment Description
MHY	Meadow hay alone, offered *ad libitum*
BS	Barley straw alone, offered *ad libitum*
AA	Alfa-A alone, offered *ad libitum*
WF	Wheat feed alone, offered *ad libitum*
MAAL	Meadow hay offered *ad libitum* plus 14.6 g DM/kg $LW^{0.75}$ as Alfa-A
MAAH	Meadow hay offered *ad libitum* plus 29.3 g DM/kg $LW^{0.75}$ as Alfa-A
MWFL	Meadow hay offered *ad libitum* plus 14.6 g DM/kg $LW^{0.75}$ as Wheat feed
MWFH	Meadow hay offered *ad libitum* plus 29.3 g DM/kg $LW^{0.75}$ as Wheat feed
BAAL	Barley straw offered *ad libitum* plus 14.6 g DM/kg $LW^{0.75}$ as Alfa-A
BAAH	Barley straw offered *ad libitum* plus 29.3 g DM/kg $LW^{0.75}$ as Alfa-A
BWFL	Barley straw offered *ad libitum* plus 14.6 g DM/kg $LW^{0.75}$ as Wheat feed
BWFH	Barley straw offered *ad libitum* plus 29.3 g DM/kg $LW^{0.75}$ as Wheat feed

In the last seven days of each period, accurate DM intakes, digestibility, rate of passage of the straw or hay and feeding behaviour were determined using identical procedures to those followed in experiment 2.

Similarly, samples of all feeds were subjected to the gas production technique of Theodorou *et al.* (1994) in N-rich and N-free media as described for experiment 2, except that gas readings continued to be taken until 96 hours after inoculation to ensure better characterisation of the curve. In addition to single feed samples, substrate mixtures, in proportions reflecting those observed in the *in vivo* trial were also fermented.

Table 3: *Nutrient composition of feeds (g/kgDM) used in experiment 3*

Feed	OM	CP	ADF	NDF	EE
Meadow Hay	931	80.2	391	678	1.7
Barley Straw	939	31.6	521	828	0.3
Wheat feed	938	167	177	486	35.2
Alfa-A	878	162	347	445	2.45

STIR values were determined for a range of 12 feeds. These included the four feeds used in the digestibility trial as well as another hay used in a production trial funded by R5180, in which intake and LW change was determined. The straw and the hay used in the production trial were offered chopped, as fed to the lambs in the present experiment, or unchopped, as used in the production trial. In addition, two other forages, two other feeds from experiment 2 (Hi-Fi light (HF), Lucerne pellets (P) and bran (B) were included. The design and procedures used were identical to those followed in experiment 2.

Data analysis

Analysis of variance was carried out on all the data for daily forage intake and rate of passage parameters and standard errors of difference used to identify significant differences between forage only and supplemented treatments, within forage supplement combinations. For DM digestibility and behaviour parameters, sub-sets of data reflecting each of the four forage/supplement combinations were analysed separately. Analysis of variance was used to estimate the significance of a quadratic component in the relationship between each parameter and proportion of total DM intake as supplement. The presence of a significant quadratic component was taken as an indication of significant interactions between the two feeds. The sizes of interaction, between the forage and supplement for the different parameters, were estimated as percentage differences (equation 2) from predicted values. These were calculated

assuming a straight line relationship between each parameter and proportion of supplement DM (equation 3).

$$\% \text{ Difference} = \frac{(VALobs - VALpred)}{VALpred} \times 100 \quad \text{.....(equation 2)}$$

where VALobs = observed value of parameter x
VALpred = predicted value of parameter x

$$VALpred = VALsupp0 + ((VALsupp1 - VALsupp0) \times P) \quad \text{.....(equation 3)}$$

where VALsupp0 = Value of parameter x when the proportion of supplement = 0
VALsupp1 = Value of parameter x when the proportion of supplement = 1
P = proportion of supplement DM in total DM

STIR values were estimated as described above using the REML procedure.

Experiment 4: Evaluation of the potential of STIR to predict effects of chop length on *in vivo* parameters

Experiment 4 was also carried out at Wye college as for experiments 2 and 3.

Objectives:

to determine whether measurement of STIR value can be used to predict *in vivo* responses to changes in forage chop length

to confirm findings in experiment 3 on the interactions between feeds

Animals and methods

Twenty-four crossbred wether lambs with an initial liveweight of 35.4 (s.d. 3.21) kg were housed individually in pens allowing separation of urine and faeces. The lambs were de-wormed at the commencement of the experiment and provided with fresh water and mineral salt licks throughout the trial. Lambs were offered either meadow hay (MHY) or barley straw (BS) at one

of four different chop lengths, either with or without a supplement of wheat feed (WF) to give a total of 16 treatments (table 4). Forages were chopped using a mobile feed chaffer, giving finely chopped material (C1), or a precision harvester, where increasing speed and decreasing the numbers of blades reduced the chop length, to give two medium chops (C2 and C3). Longest material was provided by unchopped forage (C4). Diets were offered to the animals over four periods of 21 days, using an incomplete block design. Supplemented animals received 32.5 g/kg $LW^{0.75}$ of WF, an amount estimated to provide 50% of total DMI for a 30 kg lamb consuming 2.5% of its LW as DM, and similar to the highest offer rate in experiment 3. Forages were offered *ad libitum* at 115% of the previous days intake and WF offered in the morning before animals received the forage. Nutrient composition of the feeds used in experiment 4 are given in table 5

In the last seven days of each period, accurate DM intakes, digestibility, rate of passage of the forage and feeding behaviour were determined, using identical procedures to those followed in experiment 2.

Table 4: *Summary of treatments used in experiment 4*

Treatment code	Treatment Description: All forages offered *ad libitum* at 115% of previous days intake
M1	Meadow hay chopped choosing a mobile feed chaffer
M2	Meadow hay chopped with a precision harvester (18 blades/slow feed)
M3	Meadow hay chopped with a precision harvester (9 blades/fast feed)
M4	Meadow hay unchopped
M1S	M1 + 32.5 g/kg $LW^{0.75}$ Wheat feed
M2S	M2 + 32.5 g/kg $LW^{0.75}$ Wheat feed
M3S	M3 + 32.5 g/kg $LW^{0.75}$ Wheat feed
M4S	M4 + 32.5 g/kg $LW^{0.75}$ Wheat feed
B1	Barley straw chopped choosing a mobile feed chaffer
B2	Barley straw chopped with a precision harvester (18 blades/slow feed)
B3	Barley straw chopped with a precision harvester (9 blades/fast feed)
B4	Barley straw unchopped
B1S	B1 + 32.5 g/kg $LW^{0.75}$ Wheat feed
B2S	B2 + 32.5 g/kg $LW^{0.75}$ Wheat feed
B3S	B3 + 32.5 g/kg $LW^{0.75}$ Wheat feed
B4S	B4 + 32.5 g/kg $LW^{0.75}$ Wheat feed

STIR values were determined for the nine feeds used during the trial (WF plus each forage at four different chop lengths), plus two feeds used in experiment 2 (AA and HF). In addition, one

grass and four maize silages were included. These silages had been used in a trial at Reading University, in which STIR values of silage mixtures were determined with cattle (Harrison *et al.* 1998). The sixteen feeds were offered in a complete randomised block design, such that daily, each animal was used to determine STIR values for four feeds and by the end of the four days had received each of the 16 feeds once.

Table 5: *Nutrient composition of feeds (g/kgDM) used in experiment 4*

Feed	OM	CP	ADF	NDF
Meadow Hay	935.3	87.5	420.1	664.9
Barley Straw	944.4	29.4	514.4	832.0
Wheat feed	947.4	168.8	133.8	431.6

Experiment 1 showed that successful measurement of a STIR value may depend on previous experience of unfamiliar or unusual feeds. In order to examine the effect of a short period of training on the success of measuring STIR value, half of the lambs were offered approximately 100g of each silage, each day, for three days before the start of measurements.

Data analysis

In vivo parameters were analysed using analysis of variance in GENSTAT as a partially confounded 2 x 2 x 4 factorial, separating out effects of supplement (S), forage (F), length (L) and interactions between them. Effects from the output of the analysis of variance were used to estimate mean values adjusted for animal and period effects. Mean STIR values were estimated using the REML procedure as in experiments 2 and 3. As for experiment 2, STIR values for the forages of different chop length offered alone were regressed against *in vivo* parameters and coefficients of determination (R^2) estimated. Relationships were established for all data together as well as within forage type.

OUTPUTS

Experiment 1: Preliminary evaluation of the STIR method

STIR values were obtained for all 16 feeds with cattle (table 6), although 11 of the 20 observations for the poor quality hay had to be abandoned, as animals were reluctant to consume the material. Sheep refused to ingest any of the silages or hays offered and all values attempted had to be abandoned. It might be assumed that in the present experiment the sheep were unwilling to taste feeds of which they had no previous experience, particularly under the relatively stressful conditions with many people nearby and feed being available for a very short time. Kaitho *et al.* (1996) studied palatability of a range of fodder trees by measuring intake relative to that of a basal diet of Teff straw. These workers concluded that at least 5 days were required for animals to become familiar with the feeds and for valid measurements to be obtained. It may be that a similar period of adaptation to novel feeds is required in order to measure STIR values.

Table 6: *STIR values for the feeds offered in experiment 1*

Feed	STIR value in cows g DM/minute	STIR value in sheep g DM/minute
Penniseteum cut after 30 days, cut to 1 cm	92.4	8.61
Penniseteum cut after 30 days, cut to 2 cm	83.5	10.52
Penniseteum cut after 30 days, cut to 4 cm	57.0	8.08
Penniseteum cut after 45 days, cut to 1 cm	79.8	5.07
Penniseteum cut after 45 days, cut to 2 cm	85.0	8.76
Penniseteum cut after 45 days, cut to 4 cm	42.6	5.12
Penniseteum cut after 60 days, cut to 1 cm	88.2	3.49
Penniseteum cut after 60 days, cut to 2 cm	81.7	7.4
Penniseteum cut after 60 days, cut to 4 cm	37.0	5.90
Coast grass hay (good quality) (C1)	83.3	void
Coast grass hay (poor quality) (C2)	34.6	
Maize silage (S1)	123.8	
Maize silage (S2)	138.7	
Mixture of S1 and C1	103.7	
Mixture of S1 and C2	99.3	
Mixture of S2 and C1	115.1	
s.e.d.	*5.89*	*1.43*

Ranking of feeds of different chop length appeared to differ between species. For cattle, STIR values were similar for forages cut to 1 or 2 cm, whereas values were significantly less ($p<0.001$) for forage of 4 cm length. In contrast, STIR values determined with sheep were similar for forage chopped at 1 or 4 cm, but significantly higher when chopped at 2 cm. These results may reflect differences in the ability of different species to select. Osafo *et al.* (1997) suggested that the negative response to chopping in terms of intake for cattle resulted from a reduced ability to select a better quality diet. In the present experiment, sheep may have been unable to select from material chopped at 1 cm, whereas at greater chop lengths they were able to pick the better quality leafy material that they could consume at a faster rate. As chop length increased from 2 to 4 cm, this advantage was lost and intake rate reduced as animals required greater processing time to consume the longer material. Cattle may not have been able to select at any of the chop lengths and consequently the lower STIR values for the longer material reflected the greater processing time required.

Although STIR values were obtained for mixtures with cattle, the experiment was not a success. The hay and silage were of such different consistencies that they were impossible to mix uniformly and cattle appeared to find it easy to select out the preferred silage. It may be that STIR values of mixtures are invalid unless a homogeneous mixture can be obtained and animals are unable to select out preferred fractions.

In the present trial, the position of the feed in the order in which they were offered did not have any significant effect on the STIR value determined. However, in a similar study with cattle consuming silage, Harrison *et al.* (1998) observed both day and order effects. It is recommended that, in experiments to determine STIR values, a design is used in which any effect of order and day can be accounted for in statistical estimation of means.

Conclusions

The STIR method was sensitive to differences in particle size, although different effects were observed in sheep compared to cattle, which is likely to reflect differences in feeding behaviour.

The STIR method is likely to be of use to evaluate mixed diets only where mixtures are homogeneous.

Although no effect of position in the sequence of feeds on STIR value was observed in the present trial, it is recommended that experimental designs to determine STIR for a range of feeds should allow any such effect to be accounted for in analysis of means.

Dietary history appeared to have a significant effect on the potential to obtain a STIR value, although there was no evidence of an effect on the value itself.

Experiment 2: Measurement of short term intake rate (STIR) to predict *in vivo* parameters in sheep

In vivo parameters

Feeds used in experiment 2 were selected to provide a range of feeds for which *in vivo* parameters differed widely. Table 7 demonstrates that this was achieved, with values of DM intake ranging from 172 - 1437 g/day, apparent DM digestibility from 44.0 to 80.1 and rate of passage from 0.0104 to 0.0329 h^{-1}.

Relationships between CP and ADF values and in vivo parameters

The most common chemical components used to predict the intake of forages include a measure of the cell wall content, with ADF and NDF being cited the most frequently. For the range of feeds used in the present trial, ADF was a poor predictor of intake and rate of passage (table 8). R^2 values were low for relationships between ADF and these parameters, except where hays and straw were considered separately, when R^2 of 0.740 for intake (Romney *et al.* 1998) and 0.636 for rate of passage were achieved. However, ADF was highly correlated with digestibility. In contrast, strong relationships between CP and intake were observed, while relationships with digestibility and rate of passage were weak.

Relationships between STIR values and in vivo parameters

STIR values were strongly related ($R^2 = 0.767$) to actual intake rates determined during behaviour observations in the feeding trial, although in all cases the short term rates were higher (table 7). Increased intake rates following a period of fasting has been demonstrated by a number of workers including Greenwood and Demment (1988) and Dougherty *et al.* (1989). The latter suggested that intervals of only three hours between grazing session alleviated most limitations on appetite on grazing cattle, and Moseley and Manendez (1989) suggested that

Table 7: *In vivo parameters for treatments in experiment 2. Values presented are adjusted means from analysis of variance*

	Miscellaneous feeds[1]						Hays and straws[2]					
	P	AA	HF	MGF	WF	SBP	THY	MHY	RHY	DRG	ST1	ST2
DM intake (g/day)	1437	1161	703	894	569	488	645	537	504	469	313	172
DM intake (g/kg $LW^{0.75}$)	154.7	113.9	68.4	95.5	59.3	47.2	67.0	51.1	47.8	49.6	31.7	21.3
Digestibility	46.4	61.2	51.6	69.9	62.4	80.1	55.1	52.8	50.0	59.2	44.0	48.7
Time spent eating	259	354	302	218	226	158	370	262	295	350	278	244
Time spent ruminating	296	510	528	157	186	278	510	587	578	593	495	462
Intake rate (g/min)	6.36	4.04	2.29	4.60	2.78	3.87	1.49	2.29	2.03	1.34	1.22	0.93
STIR value[3]	*22.8*	*9.97*	*6.87*	*8.79*	*7.63*	*18.7*	*4.11*	*3.25*	*3.44*	*4.92*	*2.47*	*2.66*
Chewing indexes												
Eating (mins/kg DM)	179	351	486	291	420	363	651	565	668	705	1094	1027
Ruminating (mins/kg DM)	278	570	905	214	322	650	907	1248	1331	1175	2104	1838
Total (mins/kg DM)	481	927	1376	576	715	984	1496	1792	1934	1975	3162	2950
Rate of passage (h^{-1})	0.0329	0.0296	0.0212	0.0193	0.0172	0.0176	0.0205	0.0186	0.0186	0.0187	0.0141	0.0104
Mean retention time (h)	34.4	33.0	50.7	55.2	60.8	60.1	48.0	54.6	56.1	53.2	78.4	90.2
Transit time (h)	6.7	9.1	15.1	12.6	17.1	23.2	15.1	14.8	15.3	17.1	19.2	24.8
k1 (h^{-1})	0.044	0.046	0.036	0.028	0.029	0.037	0.037	0.030	0.030	0.035	0.022	0.019
k2 (h^{-1})	0.708	0.456	0.189	0.299	0.181	0.181	0.183	0.190	0.137	0.178	0.113	0.128

[1]AA= Alfa-A; HF = Hi-Fi Light; MGF = Maize gluten feed; WF = Wheat feed; P = lucerne pellets; SBP = Sugarbeet pulp
[2]MHY = Meadow hay; RHY = Rye grass hay; DRG = Dried rye grass; ST1 = [Barley] straw; ST2 = [Wheat] straw; THY = Timothy hay
[3]STIR value was determined with the same animals during the week following the end of the feeding trial. Values are adjusted means from an analysis of variance

intake rate of sheep remained relatively constant after four hours. Therefore, a fasting period of four hours before measurement of STIR values was considered adequate to give maximum eating rates which were not constrained by appetite.

Relationships between STIR and DM intake, digestibility or rate of passage were weak when values for all feeds were included, but improved when values for sugarbeet pulp (for intake and rate of passage) or lucerne pellets (for digestibility) were excluded (table 8 and figure 1). It might be expected that, for sugarbeet pulp, with a high content of water soluble carbohydrate (251g/kg DM) metabolic feed-back factors may inhibit eating before physical fill. STIR is more likely to reflect physical characteristics of the feed, which can affect the rate at which the animal is able to ingest feeds. Since physical structure of the feed influences gut fill, it is likely that STIR values will be more appropriate as a predictor of intake or rate of passage for feeds where gut fill and not metabolic control factors predominate. An alternative explanation may be the absorptive properties of this feed. Wilson and Kennedy (1996) noted that buoyancy and specific gravity can also influence the ease of passage and rate at which particles are broken down ruminally. Although the material was soaked, it may absorb more water in the rumen, increasing particle size and buoyancy, reducing rate of passage and thereby intake, despite the relatively small particle size of ingested material resulting in a high STIR value. Decreasing particle size by grinding and pelleting has been known to increase intake (e.g. Pond *et al.* 1984). However, the increased rate of passage results in reduced digestibility, as observed for the lucerne pellets.

Relationships between in vitro gas production parameters and in vivo parameters

Cumulative gas (CG) production as greatest with the N-rich media although differences between the media decreased as CP content of the feed increased. The relationship between CP content and the difference between the N-free and N-rich media in CG production appeared to strengthen with incubation time (R^2 = 0.06, 0.41, 0.75 and 0.82 at CG12, CG24, CG52 and CG70, respectively). The potential for predicting DMI or rate of passage appeared to be relatively poor with both media although, in both cases, higher R^2 values were observed for parameters from the N-free media. Relationships between digestibility and CG production from the N-free media were also weak, unless values for SBP were excluded from the analysis. However, values of R^2 were much higher for CG12 and 24 with the N-rich media, as well as dry matter disappearance (DMD), and *in vitro* gas production may be a better predictor of digestibility than STIR for feeds of similar particle size.

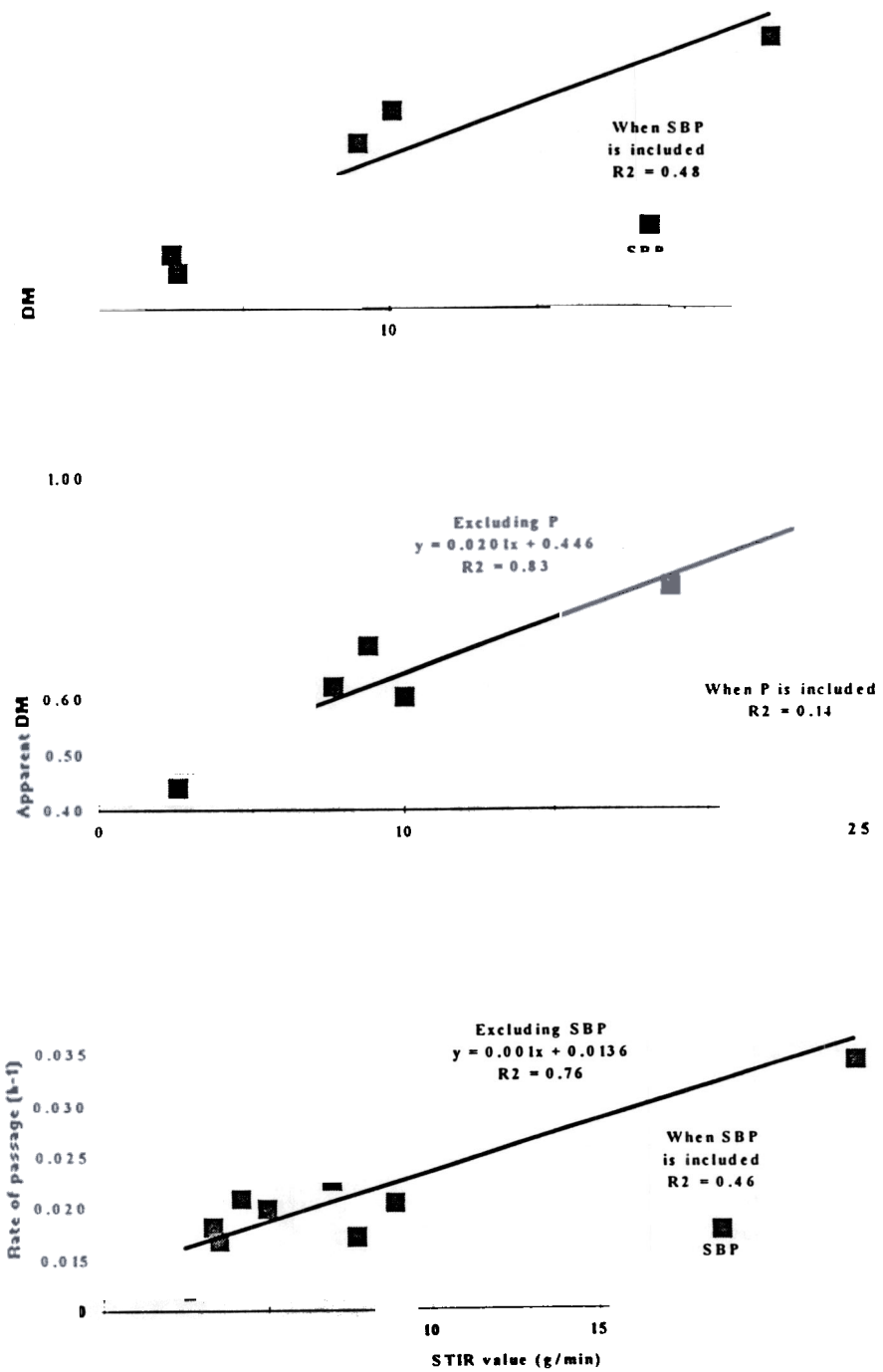

Figure 1: *Dry matter intake (DMI), apparent DM digestibility coefficients and rate of passage (rop) plotted against STIR value (g/min). Regression lines are for all data except sugarbeet pulp (DMI and rop) or lucerne pellets (digestibility)*

Table 8: *Values of R^2 for the relationships between STIR and in vitro parameters and DM intake, digestibility and rate of passage*

		Dry Matter Intake			Digestibility			Rate of passage		
		All feeds	Excluding SBP	Excluding P	All feeds	Excluding SBP	Excluding P	All feeds	Excluding SBP	Excluding P
	STIR	0.480	0.858	0.123	0.142	0.000	0.827	0.464	0.763	0.125
	CP	0.696	0.702	0.750	0.137	0.346	0.328	0.492	0.490	0.104
	ADF	0.075	0.131	0.273	0.673	0.757	0.695	0.023	0.043	0.411
N-rich	CG12	0.016	0.067	0.083	0.749	0.674	0.782	0.005	0.024	0.036
	CG24	0.005	0.071	0.062	0.852	0.720	0.879	0.006	0.049	0.059
	CG52	0.057	0.031	0.001	0.667	0.349	0.637	0.020	0.006	0.011
	CG70	0.101	0.090	0.011	0.538	0.168	0.493	0.036	0.024	0.006
	DMD	0.004	0.005	0.0.32	0.814	0.665	0.804	0.007	0.000	0.018
N-free	CG12	0.114	0.135	0.241	0.463	0.720	0.517	0.050	0.058	0.096
	CG24	0.258	0.282	0.373	0.400	0.680	0.513	0.141	0.151	0.161
	CG52	0.413	0.453	0.565	0.393	0.630	0.545	0.326	0.349	0.392
	CG70	0.322	0.407	0.529	0.495	0.602	0.608	0.315	0.376	0.480
	DMD	0.326	0.337	0.544	0.334	0.675	0.416	0.229	0.232	0.335

Conclusions

- STIR was highly correlated with DM intake and showed greater potential as a predictor than any of the other values (CP, ADF, *in vitro* gas production parameters) considered.

  Digestibility appeared to be equally as well, if not better predicted, by *in vitro* gas production parameters, with those from the N-rich media appearing to perform better than those from the N-free medium.

- STIR was the only parameter strongly related to rate of passage.

Experiment 3: Effect of supplementation with fibrous feeds and the use of *in vitro* gas production parameters to predict interactions between feeds

Supplements as single feeds

Although protein and NDF contents for Alfa-A (AA) and Wheat feed (WF) were similar, AA contained almost twice as much of the less digestible fibre components, represented by ADF (table 3). Therefore, it might be expected that rates of digestion were higher for this feed.

Evidence for this was provided by *in vitro* fermentation of the four feeds as single substrates, which showed that the initial rate of fermentation, as indicated by the rate constant b, determined by fitting the model described by France *et al.* (1993), was highest for WF (0.087) followed by AA (0.057) and Meadow hay (MHY) (0.042) with the lowest rate being observed for barley straw (BS) (0.031).

Consequently, it might be hypothesised that, for WF, factors controlling intake are primarily metabolic and that fermentation by-products inhibit intake before gut fill becomes limiting. Intake patterns (figure 2) show that, whereas for the two basal roughages, intake is concentrated in the first 10-12 hours after feed is offered, animals consume WF little and often throughout the day. The pattern for AA is closer to that for the straw and hay. Since intakes of WF are lower than for AA (81.2 cf 104.8) and the rate of passage greater (0.0254 cf 0.0197 h^{-1}), it can be concluded that animals stop eating at a lower gut fill for WF than AA, supporting the hypothesis that gut fill is not the first limiting factor.

Intake

Response to supplementation for different forage/supplement mixtures was not consistent (tables 9 and 10, figure 3). Figure 3 shows that substitution rates for MHY were similar for both supplements (mean from linear fit = 0.35 and 0.38 for AA and WF respectively). A general trend towards substitution was also observed for mixtures of straw and AA, although the substitution rate was only 0.14. This supports evidence discussed by Forbes (1995), who suggested a positive relationship existed between substitution rate and forage quality. In contrast, there was a positive effect of supplementation of straw with WF, with forage intake being significantly greater ($p<0.05$) at the lower level of supplementation compared to forage offered alone.

For WF, the positive effects on forage intake for diets based on barley straw may reflect the positive interaction observed for digestibility and increased rate of passage discussed below. The reason for the absence of a positive effect of AA on BS intake is unclear, but may reflect the higher contribution to gut fill compared to WF, as discussed above. When BS was supplemented with AA, similar increases in rate of passage occurred and a tendency towards a positive interactive effect on digestibility was also observed, though the effect was not significant. However, although these effects may explain the lower substitution rates compared to MHY,

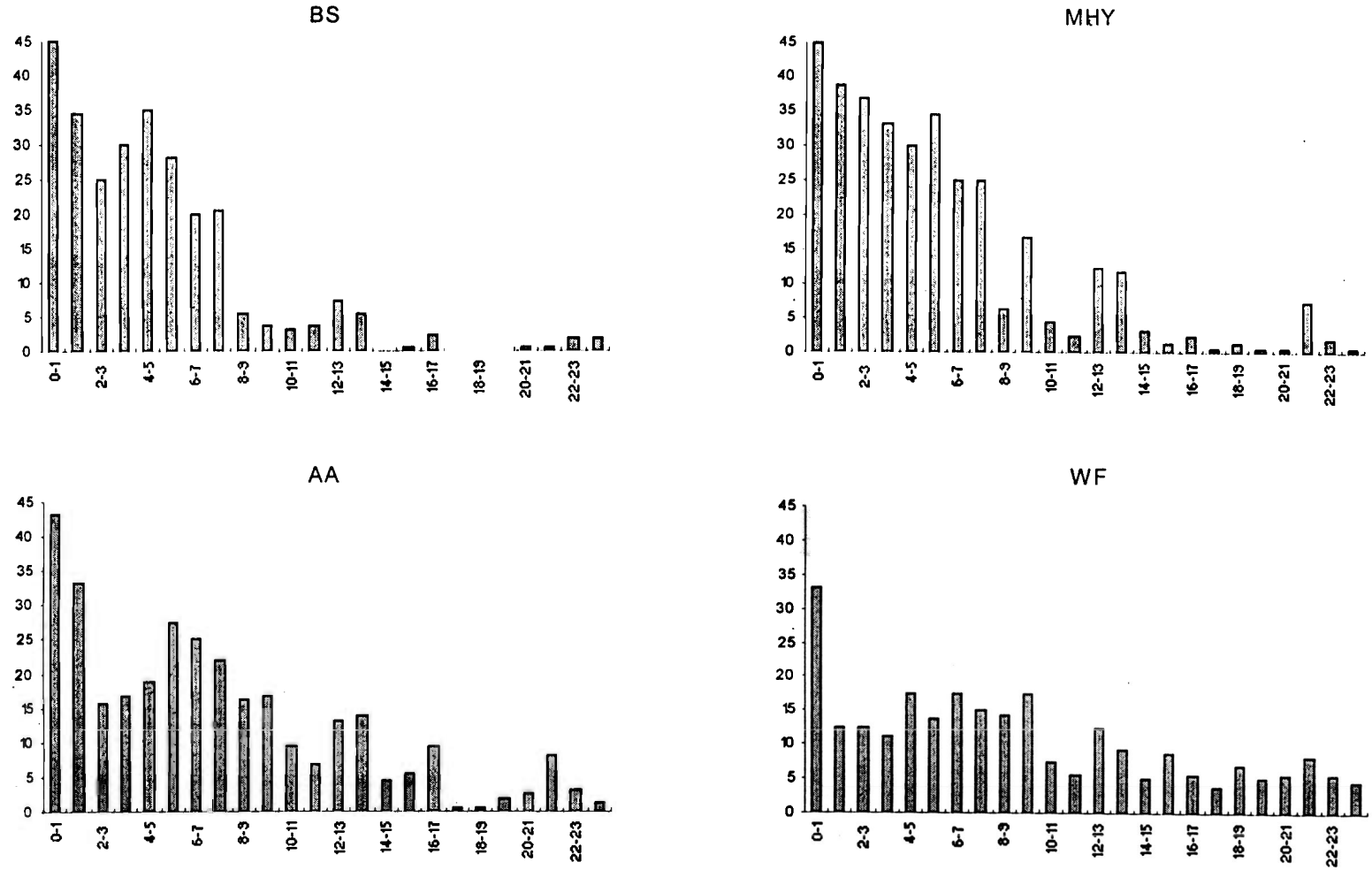

Figure 2: *Time spent eating in each hour plotted against hours after feeding for animals consuming single feeds ad-libitum in experiment 3. BS = Barley straw, MHY = Meadow hay, AA = Alfa-A and WF = Wheat feed*

Table 9: *Daily forage intake during the last 7 days of a 21 day experimental period and rate of passage parameters, determined using forage samples mordanted with chromium. Within each forage/supplement combination, different superscripts signify significant differences between the means. Values presented are adjusted means from an analysis of variance.*

	Barley straw supplemented with Alfa-A			Barley straw supplemented with Wheat feed			Meadow hay supplemented with Alfa-A			Meadow hay supplemented with Wheat feed			sed
	No supp	Low supp	High supp	No supp	Low supp	High supp	No supp	Low supp	High supp	No supp	Low supp	High supp	
	BS	BAAL	BAAH	BS	BWFL	BWFH	MHY	MAAL	MAAH	MHY	MWFL	MWFL	
Proportion of supplement	0	0.32	0.52	0	0.31	0.47	0	0.2	0.38	0	0.2	0.38	
Forage intake (g DM/day)	380	389	344	380	464	426	787^{a}	672^{b}	636^{b}	787^{a}	779^{a}	669^{b}	43.8
Forage intake (g/kg $LW^{0.75}$)	27.5^{ab}	28.9^{a}	23.3^{b}	27.5^{a}	32.9^{b}	31.5^{ab}	55.9^{a}	48.0^{b}	44.7^{b}	55.9^{a}	55.0^{a}	45.6^{b}	2.38
Rate of passage (h^{-1})	0.009^{a}	0.011^{ab}	0.013^{b}	0.009^{a}	0.012^{b}	0.013^{b}	0.014	0.014	0.015	0.014	0.014	0.015	0.0014
Mean retention time (h)	116.8^{a}	94.8^{b}	80.2^{b}	116.8^{a}	86.3^{b}	77.9^{b}	71.0	69.3	65.8	71.0	73.1	69.4	9.35
Transit time (h)	26.1^{a}	19.2^{b}	18.3^{b}	26.1^{a}	15.9^{b}	20.7^{c}	17.9	16.8	17.6	17.9	17.4	16.5	2.35
k1 (h^{-1})	0.016	0.018	0.021	0.016	0.017	0.022	0.023	0.023	0.026	0.023	0.024	0.024	0.0041
k2 (h^{-1})	0.127	0.146	0.152	0.127	0.138	0.118	0.152	0.115	0.112	0.152	0.164	0.124	0.0492

Table 10 : *Interactions (observed values as a percentage of values predicted assuming no interactions) of intake parameters derived from total intake over 7 days and observations during 2 consecutive 24 hour periods in which time spent eating and ruminating were determined. Significances of a quadratic fit to data within forage/supplement combinations are given*

	Barley straw supplemented with Alfa-A			Barley straw supplemented with Wheat feed			Meadow hay supplemented with Alfa-A			Meadow hay supplemented with Wheat feed		
	Low	High	*Sig of Quad.	Low	High	*Sig of Quad.	Low	High	*Sig of Quad.	Low	High	*Sig of Quad.
	BAAL	BAAH		BWFL	BWFH		MAAL	MAAH		MWFL	MWFH	
Proportion of supplement	0.32	0.52		0.31	0.47		0.22	0.37		0.20	0.38	
DM digestibility	4.6	1.1	0.210	7.9	5.1	*	-0.8	-0.9	0.487	-1.3	1.6	0.591
Intake rate (g/min)	-27.4	-27.4	*	-9.9	-4.5	0.582	2.7	-3.6	0.864	6.8	13.7	0.232
Chewing indices												
Eating index (mins/kg)	-10.4	-17.2	0.161	-23.9	-37.8	**	-14.8	17.0	*	-18.9	-33.4	**
Ruminating index (mins/kg)	-26.9	-19.1	**	-24.8	-38.1	***	-12.8	-19.8	*	-15.3	3.4	0.789
Chewing index (mins/kg)	-20.2	-18.2	**	-24.4	-38.0	***	-13.5	-18.7	**	-16.7	-9.5	0.054

they may have been insufficient to overcome the greater impact of AA on gut fill compared to WF.

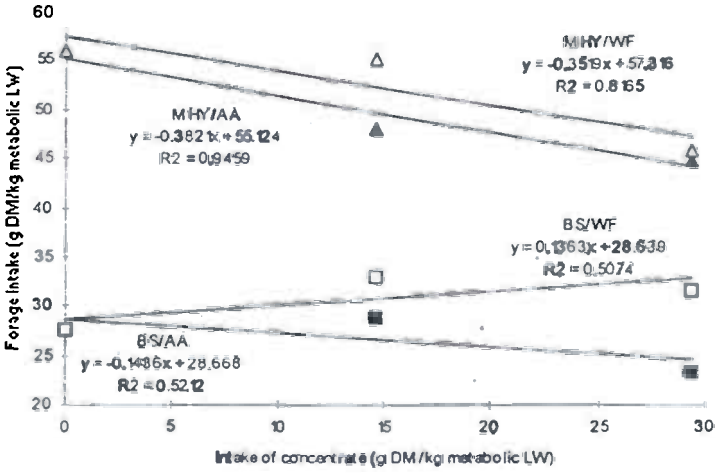

Figure 3: *Forage intake plotted against concentrate intake. Trendlines are fitted to each forage supplement combination (Meadow hay (MHY) or Barley straw (BS) with Alfa-A (AA) or Wheat feed (WF)) to show substitution rates. Open and closed symbols represent forage intakes with supplements of WF and AA respectively*

Digestibility

A significant ($p<0.05$) positive interaction for digestibility was observed in BS supplemented with WF, with no significant interactions observed for any of the other forage supplement combinations (table 10). The lack of interaction for diets based on MHY may reflect the higher protein content of this forage. Minson (1990) suggested a CP content of 62 g/kg DM as a threshold below which digestion was inhibited and reported a number of trials in where forage intake increased following supplementation with protein. The hay used in the present trial had a protein content of 80.2 g/kg DM, compared to 31.6 g/kg DM for straw. Despite the similar CP content of AA compared to WF, there was no significant quadratic component for straw AA combinations, although there appeared to be a trend towards small positive interactions.

Feeding behaviour

For all feed combinations there appears to be a negative interaction for all three chewing indices, with lower processing times than expected. This might be explained by the greater total intakes

on the supplemented diets. Bae *et al.* (1979) reported decreased ruminating times per gram of NDF as DM intake increased, and observed a curvilinear response in rumination time as hay intake increased. The latter workers observed an increase in number of chews per minute and suggested that rumination became more efficient at higher intakes. An alternative explanation is that as DMI increases, digesta flow involves larger particles, resulting in greater faecal particle size as observed by Okine and Mathison (1991). This may explain why responses in digestibility to increased N supply were low.

Rate of passage

Manyuchi *et al.* (1996) suggested that the absence of a substitution effect when veld hay was supplemented with Napier grass was partly due to an increase in digesta outflow. In the present experiment, rate of passage and mean retention time of the straw, but not the hay increased in response to supplementation (table 9). This response appeared to be mediated by decreased transit times and increases in rates of passage through both the rumen and the caecum, as represented by the rate constants k1 and k2. The negative interaction for chewing times may suggest that the increased rates of passage reflected passage of larger particles, although similar interactions for MHY did not have the same effect.

Prediction of in vivo parameters from STIR values and in vitro interactions

Figure 4 shows that, for the four treatments in which single feeds were offered *ad libitum*, observed values of DM intake, rate of passage and, to a lesser extent, digestibility for the single feed treatments were lower than might have been predicted from the relationships developed in experiment 2. However, all but the rate of passage for the straw only diet fell within the 95% confidence limits, suggesting that the relationships performed well for single feeds.

It might be expected that interactions *in vitro* will be most likely to reflect interactions in terms of rumen degradation and the impact of these changes on rate of passage and whole tract digestibility. However, it is clear from the discussion above that interactions in supplemented diets are complex. The general ranking of the interactions observed *in vitro* were similar to those observed *in vivo* for digestibility, with the largest interactions being observed for the BS/WF mixtures (table 11). In the final technical report for the LPP project R5180, the use of *in vitro* observations were discussed in more detail and reported encouraging results using parameters determined from fitting the France model (France *et al.* 1993). These workers observed a

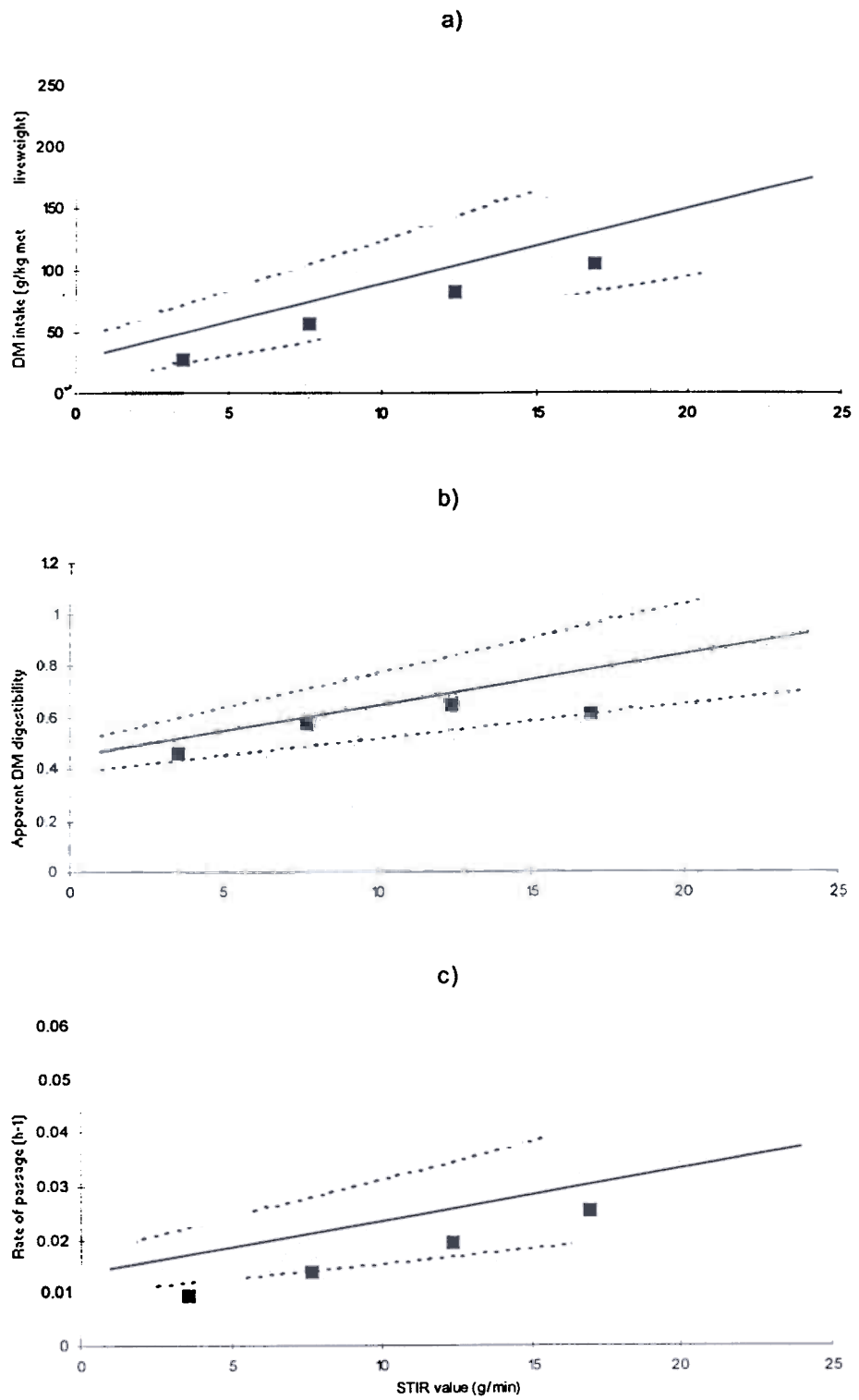

Figure 4: *Observed values for a) DM intake (g/kg $LW^{0.75}$), b) apparent DM digestibility and c) rate of passage plotted against STIR value (g/min) for the feeds used in experiment 3 when offered alone, ad libitum. Fitted lines (___) and 95% confidence limits (----) are given for relationships using data from experiment 2.*

Table 11: *Interactions (observed values as a percentage of values predicted assuming no interactions) of in vitro gas production parameters from mixtures of substrates fermented in a N-rich or N-free media. Significances of a quadratic fit to data within forage/supplement combinations are given*

	Barley straw supplemented with Alfa-A			Barley straw supplemented with Wheat feed			Meadow hay supplemented with Alfa-A			Meadow hay supplemented with Wheat feed		
	Low	High	*Sig of Quad.	Low	High	*Sig of Quad.	Low	High	*Sig of Quad.	Low	High	*Sig of Quad.
	BAAL	BAAH		BWFL	BWFH		MAAL	MAAH		MWFL	MWFH	
Proportion of supplement	0.32	0.52		0.31	0.47		0.22	0.37			0.38	
N-rich media												
12	4.9	6.0	**	3.8	7.5	**	-1.4	-1.0	ns	8.3	8.9	***
27	4.4	6.3	**	9.1	11.8	***	0.7	1.9	ns	5.6	6.6	***
48	2.0	3.8	ns	7.7	11.1	***	-0.6	0.3	ns	5.5	7.0	***
96	-0.1	1.8	ns	6.4	10.6	***	-0.9	-0.4	ns	5.1	7.6	***
DMD	-0.4	-0.3	ns	2.9	5.9	**	0.3	2.3	ns	3.0	5.1	***
N-free media												
12	11.8	10.6	**	15.5	13.4	**	0.0	0.9	ns	4.8	9.3	***
27	12.0	12.0	***	24.6	25.6	***	1.9	4.5	*	9.6	16.1	***
48	25.1	22.8	***	47.5	44.5	***	3.3	4.4	**	10.6	16.0	***
96	37.2	25.4	***	50.7	43.7	***	1.6	1.8	**	6.9	11.3	***
DMD	38.3	26.3		46.0	39.1		2.5	2.2	ns	2.5	4.0	***

positive relationship between total DM intake and the rate constant b and between DM digestibility and the lag time. Further work is required to explore these relationships in more detail.

Conclusions

- Relative sizes of interactions between feeds in *in vitro* gas production were similar to those observed in DM digestibility *in vivo*, demonstrating the potential to predict animal responses to feeding mixtures of feeds. However, further work is required to define the relationships more clearly.

- Animal responses to protein supplementation of a diet based on poor quality forage differs depending on the fibrous content of the supplement. For fibrous supplements, the benefits in terms of improved digestibility and increase in rates of passage is insufficient to overcome the contribution to gut fill by the supplement and substitution still occurs.

Experiment 4: Evaluation of the potential of STIR value to predict *in vivo* responses in DM intake, digestibility and rate of passage to changes in chop length

Intake

As in experiment 3, meadow hay (MHY), with a lower fibre content and higher CP content had a greater intake compared to barley straw (BS) (1077 cf 526 g/day for hay and straw main effects, respectively). Supplementation reduced intake ($p<0.001$), although there was a significant supplement x forage interaction ($p<0.001$), since hay intake decreased to a much greater extent (17%) in response to supplementation compared to straw (3%). Lower substitution rates for straw compared to hay were also observed in experiment 3.

Although there was no significant interaction between supplement and chop length, there was a tendency for the substitution rate of wheat feed (WF) to decrease as length of chop increased, such that there was a positive effect of supplementation on intake of the unchopped straw. Observed rates for Chops 1 to 4 were 0.16, 0.05, 0.03 and -0.09 for BS and 0.57, 0.46, 0.44 and

Chop length had a significant effect on intake ($p<0.001$), although this mainly reflected the higher intakes for the shortest chopped forages. Intakes for the remaining chopped material for the same forage were similar. It might be expected that intake would be lowest for the unchopped material. However, it appeared that there may have been confounding with an increase in selectivity for the longer chopped material, with similar intakes observed for the unchopped and medium chopped forages. As discussed earlier, Osafo *et al.* (1997) showed that chopping forages can reduce the opportunity for an animal to select, whereas increased intakes have been observed in response to increasing offer rates and allowing animals the opportunity to select the more palatable or nutritious parts (e.g. Fernandez-Rivera *et al.* 1994). In both cases DM digestibility was highest for the unchopped material, suggesting that animals were able to increase the quality as well as the quantity of their diets.

Digestibility

Digestibility of MHY was significantly greater ($p<0.001$) than straw, as might be expected for the better quality forage, with a lower fibre content and greater concentration of protein. Chop length also had a significant effect on digestibility, with the lowest values being observed in forages at the shortest chop length and the greatest values being observed for unchopped forage.

In experiment 3, DM digestibility of WF was estimated as 64.5%. If it is assumed that digestibility was the same in the present experiment and is not affected by feeding together with straw or hay, digestibility of the basal forages in the supplemented diets can be estimated using the observed intake values (tables 12a and b). Mean digestibilities estimated in this way for hay and straw in supplemented diets were 51.6 and 56.3% respectively, compared to observed values in unsupplemented diets of 46.1 and 55.0%. Although these results should be treated with caution, since the assumptions cannot be proved, the larger difference between estimated and observed values for straw may be taken as evidence to support the findings in experiment 3, where a positive associative effect on digestibility was observed for diets based on BS and supplemented with WF.

Table 12a: *In vivo parameters for Barley straw offered at 4 different chop lengths with and without supplement. Values given are adjusted means from the analysis of variance and significance is given for the main effects of Supplement (S), Forage (F), Length (L) and the interaction between S and F*

	Barley straw fed alone				Barley straw fed with supplement				Significance			
	Chop 1	Chop 2	Chop 3	Chop 4	Chop 1	Chop 2	Chop 3	Chop 4				
	B1	B2	B3	B4	B1	B2S	B3S	B4S	S	F	L	SxF
Proportion of concentrate					0.43	0.48	0.47	0.46				
Forage intake (g/day)	646	511	517	461	574	489	504	498	***	***	***	***
									20.1	20.1	28.4	28.4
Total intake (g/day)					1011	939	958	926	***	***	**	***
									20.3	20.3	28.7	28.7
Forage intake (g/kg $LW^{0.75}$)	43.0	34.6	35.2	32.0	39.1	32.4	34.4	33.0	***	***	***	***
									1.27	1.27	1.80	1.80
Total intake (g/kg $LW^{0.75}$)					69.0	62.4	64.2	62.8	***	***	***	***
									1.27	1.27	1.80	1.80
DM digestibility	43.6	46.9	46.3	47.7	55.4	58.1	57.8	58.8	***	***	***	*
									7.8	7.8	11.0	11.0
Time spent eating	250	261	285	307	229	252	269	303	***	***	***	*
									7.8	7.8	11.0	11.0
Time spent ruminating	617	561	565	515	574	528	552	512	na	na	***	ns
									9.8	9.8	13.8	13.8
Intake rate (g/min)	2.63	2.08	1.85	1.47	4.41	3.77	3.67	3.18	***	***	***	***
												0.119
Chewing indices												
Eating (mins/kg DM)	424	505	552	589	226	294	290	315	***	***	***	***
									8.7	8.7	12.3	12.3
Ruminating (mins/kg DM)	1009	1070	1101	1034	550	604	608	533	***	ns	***	***
									14.5	14.5	20.5	20.5
Total (mins/kg DM)	1433	1574	1654	1623	776	898	898	847	***	***	***	***
									17.8	17.8	25.1	25.1
Rate of passage (h^{-1})	0.016	0.011	0.113	0.014	0.018	0.014	0.013	0.016	***	***	*	ns
									0.0005	0.0005	0.0007	0.0007
Mean retention time (h)	67.0	89.9	86.6	81.1	59.3	82.7	78.4	73.6	**	***	*	ns
									2.94	2.94	4.15	4.15
Transit time (h)	13.9	16.8	17.0	17.1	11.8	12.7	13.1	11.3	***	***	ns	*
									0.59	0.59	0.84	0.84
k1 (h^{-1})	0.043	0.023	0.029	0.042	0.032	0.015	0.013	0.030	ns	ns	ns	ns
									0.0041	0.0041	0.0059	0.0059
k2 (h^{-1})	0.245	0.163	0.197	0.189	0.235	0.183	0.194	0.215	ns	ns	ns	ns
									0.0146	0.0146	0.0207	0.0207

Table 12b: *In vivo parameters for Meadow hay offered at 4 different chop lengths with and without supplement. Values given are adjusted means from the analysis of variance and significance is given for the main effects of Supplement (S), Forage (F), Length (L) and the interaction between S and F*

	Meadow hay fed alone				Meadow hay fed with supplement				Significance			
	Chop 1	Chop 2	Chop 3	Chop 4	Chop 1	Chop 2	Chop 3	Chop 4				
	M1	M2	M3	M4	M1S	M2S	M3S	M4S	S	F	L	SxF
Proportion of concentrate					0.30	0.32	0.32	0.31				
Forage intake (g/day)	1276	1166	1129	1134	1023	963	935	990	***	***	***	***
									20.1	20.1	28.4	28.4
Total intake (g/day)					1466	1419	1379	1440	***	***	**	***
									20.3	20.3	28.7	28.7
Forage intake (g/kg $LW^{0.75}$)	83.1	76.9	74.7	74.9	67.9	63.5	62.7	64.6	***	***	***	***
									1.27	1.27	1.80	1.80
Total intake (g/kg $LW^{0.75}$)					97.3	93.3	92.3	94.1	***	***	***	***
									1.27	1.27	1.80	1.80
DM digestibility	52.3	55.9	53.5	58.1	56.5	59.7	57.6	61.7				
Time spent eating	344	375	371	429	291	334	322	393				
Time spent ruminating	588	549	518	521	571	543	532	545				
Intake rate (g/min)	3.81	3.24	3.11	2.55	4.96	4.29	4.29	3.62				
Chewing indexes												
Eating (mins/kg DM)	257	308	353	425	199	237	230	290	***	***	***	***
									8.7	8.7	12.3	12.3
Ruminating (mins/kg DM)	464	461	474	507	402	392	377	403	***	ns	***	***
									14.5	14.5	20.5	20.5
Total (mins/kg DM)	721	769	827	933	601	629	608	694	***	***	***	***
									17.8	17.8	25.1	25.1
Rate of passage (h^{-1})	0.020	0.020	0.021	0.017	0.022	0.023	0.022	0.020	***	***	*	ns
									0.0005	0.0005	0.0007	0.0007
Mean retention time (h)	51.0	49.8	52.1	59.5	46.1	45.6	46.9	54.8	**	***	*	ns
									2.94	2.94	4.15	4.15
Transit time (h)	104	12.3	12.7	13.4	11.6	11.5	12.1	10.8	***	***	ns	*
									0.59	0.59	0.84	0.84
k1 (h^{-1})	0.033	0.034	0.046	0.026	0.033	0.037	0.041	0.024	ns	ns	ns	ns
									0.0041	0.0041	0.0059	0.0059
k2 (h^{-1})	0.267	0.238	0.261	0.221	0.215	0.217	0.216	0.207	ns	ns	ns	ns
									0.0146	0.0146	0.0207	0.0207

N.B. Interactions between S & L and F & L were not significant except for the total chewing index ($p<0.05$)

Feeding behaviour

As chop length increased, the rate at which the animal was able to ingest feed increased ($P<0.001$), similarly for both forages. Consequently, the eating index decreased. In contrast, the ruminating index did not follow such a consistent pattern. For MHY there is an apparent trend for ruminating index to increase as chop length increases, although chops 1 and 2 are similar. In contrast, the time required to ruminate 1 kg of unchopped barley straw is similar to that observed for the shortest chop and lower than both middle chops. This reduction in rumination time required for the unchopped straw may reflect the greater amount of time spent masticating during ingestion, since total processing time, or chewing index increases in order of chop length for both forages. An alternative explanation may be that animals were able to select a better quality diet that required less rumination.

There was a significant effect of supplementation on all behaviour parameters, except for the time spent ruminating. However, these results are difficult to interpret, since it is not possible to separate out linear effects, resulting from inclusion of WF in the diet, from any interactive effects between WF and the basal forage.

Rate of passage

Rate of passage was greater ($p<0.001$) for MHY (0.0204) compared to BS (0.0141), reflecting shorter mean retention times ($p<0.001$) and transit times ($p<0.001$). The effect of chop length was small, although for both forages there was a tendency for mean retention time to increase and rate of passage to decrease ($p<0.001$) as chop length increased. An exception was the higher rate of passage for unchopped BS compared to chops 2 and 3, which again may reflect selection of the better quality material. Supplementation increased rate of passage ($p<0.001$) and decreased mean retention time ($p<0.01$) for both forages at all lengths.

STIR

As in experiment 2, STIR value was very closely related ($R^2 = 0.978$) to actual intake rate. As discussed earlier, the faster intake rates determined following four hours fasting were not unexpected. R^2 for relationships between STIR value and DMI or rate of passage were high (0.854 and 0.760, respectively), although there were some anomalies in the data (figure 5).

For DMI, relationships within groups of the same forage type at different chop lengths were different to those between groups (figure 5a). Hence, if the equation for all data was used to predict the effect of chop length within forage type, there would be a tendency to over-estimate intake of the shorter chop lengths and underestimate it for the longer material. These results may suggest, therefore, that STIR is best able to rank across feeds at similar particle sizes and within feed for different particle sizes. However, it should be noted that all values fell within the 95% confidence limits for the relationship developed in experiment 2. Results for the rate of passage were similar (figure 5b), although relationships within feed types were weak and there was a less symmetrical spread of points around the linear fit. Again, all but the value for straw at chop 2 fell within the 95% confidence limits determined in experiment 2, suggesting that STIR shows potential as a predictor of rate of passage both across feed types and for different particle sizes within feed types.

Experiment 2 demonstrated that other feed parameters such as fibre content or gas production parameters may perform better as potential predictors of digestibility than STIR value. *In vitro* digestibility (Tilley and Terry 1963) has been found to be a good predictor of *in vivo* digestibility of temperate feeds and has been used in practical feed evaluation of temperate feeds for many years. However, it is clear that any estimation of digestibility using parameters determined on dried, ground feeds cannot take account of differences in digestibility resulting from differences in particle size, such as those observed in the present trial. R^2 values for relationships between STIR and digestibility within feed types were greater than for all the data combined. Furthermore, figure 5c shows that the slope of the relationship within feeds is negative and similar for both hay and straw, compared to a positive slope for a line fitted to all the data. Although more work would be required these results indicate that STIR has the potential to predict effects of particle size on digestibility, through its ability to predict rate of passage.

For animals having no previous experience of the silages, 50 out of a total of 60 values had to be abandoned and, of these, 31 were because animals totally refused to even try the silage. For animals which had received small amounts together with their normal feed allowance for a total of only three days before the start of measurements, only 17 out of 60 observations had to be abandoned and of these, only 10 were because animals totally refused to try the feed. These results clearly indicate that refusals resulting from unfamiliarity can be easily overcome in a short time, although longer periods may be required for less palatable feeds.

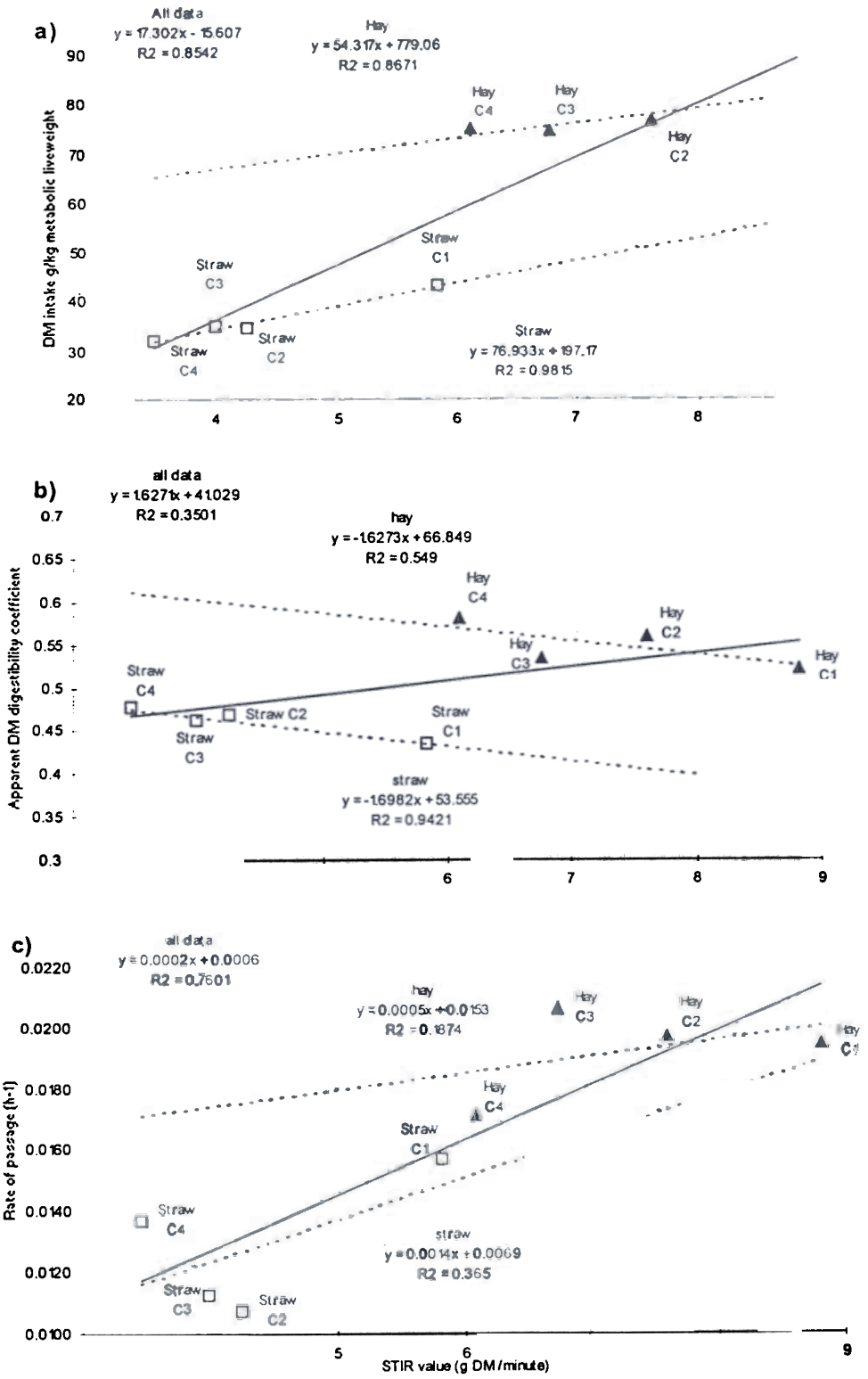

Figure 5: *a) DM intake (g/kg $LW^{0.75}$); b) DM digestibility coefficient and c) rate of passage (h^{-1}) plotted against STIR value for hay and straw at 4 different chop lengths (C1-4). Lines have been fitted to all the data as well as individual lines to the hay and straw points seperately*

Conclusions

STIR values may be more appropriate to predict effects of chop length on *in vivo* feeds, although general trends appeared to persist across feeds.

Substitution rate decreased as chop length increased. This may have implications when devising recommendations on supplementation of poor quality forages.

CONTRIBUTION OF OUTPUTS

Publications

Published or in press

The following publications have been prepared and copies are attached in Annex 1

Romney, D.L. and Gill, M. 1998. Measurement of short term intake rate (STIR) to predict *in vivo* parameters in sheep. *Proceedings of the British Society of Animal Science, 1998* p. 98

Romney, D.L., Cadario, F.C., Owen, E. and Murray, A.H. 1997. Comparison of parameters from the Theodorou gas production technique using nitrogen-free and nitrogen-rich media as predictors of DM intake and digestibility. *Proceedings of the British Society of Animal Science meeting on in vitro techniques, Reading University, July 1997* (in press)

Other written outputs

The experiments at Wye have also offered a training opportunity for 1 MSc and 1 BSc student, who have produced the following;

F. Cadario 1996. Use of *in vitro* gas production technique for predicting *in vivo* apparent digestibility and voluntary intake of feedstuffs for sheep. *MSc dissertation, Reading University*

D. Hurst 1998. The effects of supplementation and chop length on voluntary food intake and digestibility of meadow hay and barley straw in wether lambs and assessment of the relationship between short term intake rate and *ad libitum* intake and digestibility of the forages. *Integrated Science Project. Course-193 .Bsc dissertation, Wye College, University of London*

Interest in the method has been shown by other Universitites including Reading, where a number of PhD students have been studying use of the method in cattle. Although the project has not contributed any funds to this work, students and staff from Reading have visited NRI to discuss the technique and produced the following publication.

Harrison, S., Romney, D.L., Phipps, R.H. and Owen, E. 1998. Short term intake rate STIR. as a method of ranking the intake potential of forage mixtures by dairy cows. *Proceedings of the British Society of Animal Science 1998,* p. 193

Scientific papers in preparation

The following papers are planned and will be submitted in the first instance to the journal "Animal Science", which has wide distribution overseas, including developing countries.

Romney D L Development of a new method to predict *in vivo* parameters using short term intake rate:

Murray A H, Romney D L and Wood C D The use of the *in vitro* gas production technique to identify *in vivo* digestive interactions of sheep fed low quality roughage diets supplemented with high quality forages

Romney D L, Hearst, D, and Murray, A.H. Use of short term intake rate (STIR) to predict changes in *in vivo* parameters resulting from chop length

Contribution to DFIDs development goals

In many crop-livestock or livestock production systems in the tropics, availability of feed is one of the primary constraints to improved production. Researchers, together with farmers, can address the constraint in many ways, including introduction of new or improved varieties or

species of forage, physical or chemical treatments of existing feeds, or development of feeding strategies which improve the efficiency of utilisation. Decision on the most appropriate technology will depend on an understanding of farmers priorities and interactions with the environment. However, feed evaluation and prediction of animal responses will always play a vital role.

The project has demonstrated that STIR values can be used to provide information on *in vivo* parameters for single feeds. STIR has the advantage over existing methods in that it is able to take account of physical structure of the feed, which can be of particular importance for poor quality fibrous forages, such as those often found in tropical feeding systems. Involvement of the animal may also allow palatability factors to be accounted for. The method still requires relatively small quantities of feed and is appropriate for developing countries, since it requires no sophisticated or expensive equipment. The project has also demonstrated that *in vitro* gas production shows potential to predict expected associative effects of mixtures, although further work is required to clarify relationships. Information on animal responses to supplementation regimes and interactions with chop length will also be of use when designing new feeding strategies.

Promotion pathways

Target institutions in the first instance will be NARS although, ultimately, smallholder farmers will benefit from improved technologies which address the constraint of inadequate feed supply. Through presentation of preliminary findings from the work at scientific meetings, there has been the opportunity to discuss the technique with scientists from developing countries. Wider dissemination of results will arise from publication of full scientific articles.

Follow up action/research

The project has shown that STIR can rank feeds in terms of *in vivo* parameters. Further work and development of a database of STIR, together with associated intake, rate of passage and digestibility estimates will strengthen predictive equations.

Dissemination of details of the method, through distribution of re-prints, as they become available, to NARS and other research organisations, will allow them to utilise the method in feed evaluation.

Effective feed evaluation cannot rely on single estimates of feed value and the best use of the STIR method will be in conjunction with other techniques. These estimates of nutritive value of individual feeds are helpful when designing diets, but are not always additive in mixed diets. *In vitro* gas production shows potential to predict associative effects of feeds. However, further research is required to examine relationships between interactions observed *in vitro* and *in vivo* and to develop a system which uses STIR values, gas production parameters and other estimates of feed value to design the most promising diets which can be tested in the field.

Use of fodder trees or herbaceous legumes, as supplements to poor quality forage, is widely considered as an appropriate strategy to improve livestock production on smallholder farms. Although a great deal is known of the effects of supplements on intake and feed utilisation, most research has focused on feeds with rapid rates of digestion and low fibre contents. Further research is required to understand the processes involved when fibrous feeds are used as supplements, in order to work with farmers to devise appropriate feeding strategies.

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