On farm

Objective measurement of fodder quality across animal species

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Final Report prepared for MLA by:

Peter Flinn, Stephanie Knott, Leo Cummins & Dawn Dalley
Department of Primary Industries
Pastoral and Vetenarieny Institute
Private Bag 105, Hamilton, Victoria 3300

Meat and Livestock Australia Ltd
Locked Bag 991
North Sydney NSW 2059

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FOREWORD

Fodder is defined as the wide range of crop and pasture species that are grown, harvested and lightly processed to facilitate both on-farm use and domestic and export trade.

The fodder industry is worth approximately $900 million per year to the Australian economy, representing a 50% increase over the past 10 years. Around 5 to 6 million tonnes of hay and around 2 million tonnes of silage are produced per year, with 25-30% of production traded off-farm. Of this, around 500,000 tonnes of hay is exported each year, mainly to Japan but also to other Asian countries and the Middle East.

This project follows on from two previous RIRDC projects (DAV-104A and CSJ-1A) and is aimed at a uniform and comprehensive quality specification system for the Australian fodder industry, based on objective measurements.

This publication covers the measurement and comparison of preference, short-term intake rate, *in vivo* digestibility and total intake of a series of hay types between four animal species: sheep, beef cattle, dairy cows and horses.

This project was funded from a number of sources. Industry revenue was matched by funds provided by the Federal Government through RIRDC, with contributions from RIRDC Core Funds, Meat and Livestock Australia, Dairy Research and Development Corporation and the Victorian Department of Primary Industries.

This report, a new addition to RIRDC's diverse range of over 600 research publications, forms part of both our Fodder Crops and Horses R&D programs. These programs aim to facilitate the development of a sustainable and profitable Australian fodder industry, and to assist in developing the Australian horse industry and enhance its export potential.

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Simon Hearn
Managing Director
Rural Industries Research and Development Corporation

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The FEEDTEST team at Hamilton, including Suzanne Dalton, Caroline MacDonald, Glenys Downes, Jo Behncke, Brad Walter, Chris Heine, Andrew Phelan and Trevor Flinn processed the large number of samples of hay, feed refusals and faeces generated in this project.

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EXECUTIVE SUMMARY

The objectives of this project were:

- To measure and compare the ranking of *in vivo* digestibility, total intake, preference and intake rate of a series of hays across beef cattle, lactating dairy cows, horses and sheep.
- To use the “standard” fodder samples obtained as a basis for a uniform objective procedure for specification of fodder quality.

Twenty-one different hays were purchased for this project, comprising 9 cereals, 11 legumes and one Italian ryegrass. Most of these were selected on the basis of nutritive value tests from hay samples processed by the FEEDTEST laboratory at Hamilton during the 2000/01 season.

Preference and short-term intake rate were measured with 3 separate blocks of hay: 9 cereal hays , 9 legume hays and a crossover of 4 cereal and 4 legume hays. The tests were undertaken with dairy cows, sheep, steers and horses. Preference was measured by offering each animal 2 hays for 10 minutes, and measuring the relative amounts consumed. The short-term intake rate of each hay was determined by removing one bin from each pen and offering a single hay to each animal (across all 4 animal types) for 5 minutes and measuring the amount consumed.

Near infrared spectroscopy (NIR) was used to analyse 1,038 hay samples for crude protein (CP), dry matter digestibility (DMD), neutral detergent fibre (NDF) and water soluble carbohydrates (WSC) (the latter on cereal hays only) collected during the preference tests.

There were some significant differences in preference between hays within each animal species, but there was also some overlap. It was noticeable that some hays stood out, with high or low preference across all or most animal species. Among the legumes, the high quality hays LUC5 (lucerne) and PER (Persian clover) were frequently preferred, and when fed to dairy cows and sheep, LUC2 (lucerne) and VET (vetch) were ranked lowest in preference. These latter two hays were of poor quality, and were contaminated either with soil or mould. They were replaced with two different lucerne hays LUC6 and LUC7 in subsequent trials. Among the cereals, OAT3 and OAT7 (oaten hays) were frequently preferred, whilst STR (barley straw) was consistently ranked lowest in preference, often followed by OAT4 (oaten hay).

A clear result from the preference tests was that the ranking in preference between hays was not the same for all four animal species. Within the limits of experimental error, there were no constants with which to multiply the preference means from a particular species to concur with the preference means from another species. This suggests that it is not possible for sheep to be used as the “model” to estimate preference rankings for hay in dairy cows, steers or horses.

The ranking of short-term intake rate showed some similarities to preference ranking, but there was less difference between hays, particularly for legume hays eaten by sheep and horses. Despite this, there was a strong relationship between preference and short-term

intake rate across all animal species, with between 74% and 90% of the variance in preference being accounted for by short-term intake rate.

The resources available in this project were insufficient to undertake a comprehensive study of the characteristics of hay which influence preference by animals. However, when simple linear regressions were derived between preference means and various nutritive value measurements, it was found that, in general, DMD and NDF were more strongly correlated with preference than other measurements. CP was apparently a very poor indicator of preference. WSC was also found to be a poor indicator of preference in the case of cereal hays, despite being commonly reported as positively correlated with preference.

Some caution is warranted in interpreting these apparent relationships. The same relationships may not necessarily be observed in a set of hays of more similar quality. The hays used in this project were deliberately selected to be as diverse in quality as possible. Hay is also a heterogeneous product, with considerable variation in quality possible both between and within bales of a given hay. It was found that there was a tendency for greater variability in the quality measurements within the legume hays than within the cereal hays. This may partly explain what appears to be a greater variation in preference for the legume hays than for the cereal hays across animal species.

Four separate digestibility and intake trials were conducted, one for each of the 4 animal species. In each trial the same 4 cereal hays, 3 legume hays and 1 Italian ryegrass hay were fed, but in the case of sheep and dairy cows, 2 additional cereal hays and 1 legume hay were also fed. This resulted in 11 hays being evaluated with sheep and dairy cows, and 8 of these hays with horses and steers. With the exception of the Italian ryegrass hay, all hays fed were a subset of those used in the preference trials.

In all 4 trials, digestibility and voluntary intake were measured at the *ad libitum* level of feeding, for 6 animals per hay. *In vivo* digestibility was measured as the percentage difference between feed consumed and faeces excreted, and expressed as both DMD and organic matter digestibility (OMD). Voluntary intake was measured as both dry matter intake (DMI) and organic matter intake (OMI).

Values for *in vivo* DMD for a variety of hays, measured at the *ad libitum* level of intake, varied from 54 to 69% (dairy cows), 47 to 67% (sheep), 44 to 68% (horses) and 54 to 70% (steers). Similar but slightly higher ranges were found for *in vivo* OMD. DMD and OMD of many of the hays were lower in sheep and horses than in dairy cows and steers, especially the cereal and grass hays.

Whilst correlations were generally high for DMD or OMD between the various animal species, the precision of measurement was sometimes different between two given animal species, and there was often a bias. Statistically, the DMD and OMD values of the hays fed to steers were the same as for dairy cows, despite the apparently different values for one hay (OAT3). This is an important finding, as it suggests that beef steers can be used in future to produce DMD or OMD values on hay which can also be used for dairy cows.

In the case of DMD, there were significant differences in precision and bias between sheep and horses, but only just. If one hay (OAT4) had been omitted, there would have been no significant difference.

Other comparisons showed that horses were significantly different to steers in precision and bias for both DMD and OMD. The same result was found for the sheep-steer comparison in the case of DMD. For the sheep-dairy cow and horse-dairy cow comparisons, precision was statistically the same but bias was large. This was also the case for OMD in the sheep-steer comparison.

Based on the hays fed in this project, *in vivo* digestibility values of hays fed to sheep cannot necessarily be applied to steers, dairy cows or horses without great caution, even though the relative rankings in some cases appear similar. However, the tests for precision and bias should be considered together. Differences in precision between animal species are the more serious, and it was found that for the sheep-dairy cow comparison, precision was not a problem, and was marginal for the sheep-horse and sheep-steer comparisons. Whilst there were large biases between sheep and steers, and between sheep and dairy cows, it may be possible to adjust for bias if precision is similar.

The two firm conclusions are that digestibility values from steers can be used for dairy cows, and that those from steers cannot be used for horses.

When the same statistical procedure used to compare preference rankings between animal species was applied to *in vivo* DMI and OMI, a different result was obtained, with proportionality occurring in some cases. It was found that the DMI and OMI means from steers were directly proportional to DMI and OMI means from both dairy cows and horses. A similar proportionality was also apparent in the sheep-steers comparison, but it was not strong.

These results suggest that, on the basis of the hays fed in this study, it is possible for DMI and OMI data from steers to be used as a basis to estimate DMI or OMI values for hay in dairy cows and horses.

The implications from the results of this research are as follows:

- On the basis of the hays fed, it is not possible for sheep to be used as a model to estimate preference rankings of hay in dairy cows, steers or horses.

- It may be possible, however, to measure short-term intake rate across all animal species as an alternative to preference, given the reasonably close relationship between the two measurements, thus reducing time and resources.

- Across a range of hay quality, DMD and NDF are likely to be better predictors of preference than CP or WSC.

- There is now a set of hay "standards", with measured *in vivo* digestibility and intake values for four different animal species, available for use by fodder testing laboratories as a basis for prediction of these parameters in unknown samples.

- Because the digestibility of hays fed to steers was the same as for dairy cows, it may not be necessary to conduct this measurement with dairy cows in future work, representing a considerable cost saving.

- It is not fully clear whether, and under what conditions, digestibility measurements on fodder using sheep can be used for dairy cows, steers or horses.

- Because the intake of hays fed to steers was proportional to that for dairy cows and horses, it may not be necessary to conduct this measurement with dairy cows or horses in future, again representing a cost saving.

It is recommended that:

- Preference or short-term intake rate should be measured on a larger set of hays, including cereal hays closer in nutritive value than the ones used in this project, and also in pasture hays.

- Preference or short-term intake rate should be measured specifically using the animal species of interest.

- A comprehensive study should be conducted to determine the components of fodder influencing preference, using sufficient hay samples to produce robust laboratory predictions of the properties of interest.

- The hays with measured *in vivo* digestibility and voluntary intake should be added to the collection of samples managed by AFIA and made available to appropriate fodder testing laboratories.

- On the basis of results found in this study, future digestibility measurements on fodder types of interest to the dairy industry can be conducted using steers.
- More research should be conducted to confirm or otherwise whether digestibility measurements using sheep can be used as a basis for predicting digestibility of fodder for dairy cows, steers or horses.

- On the basis of results found in this study, future measurements of voluntary intake on fodder of interest to the dairy and horse industries can be conducted using steers.

CONTENTS

1. INTRODUCTION

The fodder industry in Australia has developed strongly over the past seven years. The production of hay and silage has been an essential part of the Australian agricultural scene for many years, but principally for use on-farm. While fodder has been traded in the past on an *ad hoc* basis, it is only comparatively recently that the fodder industry has become recognised in its own right as an important contributor to agricultural production on both domestic and export markets. The gross value of production at the farm gate is around $900 million per year, an increase of 50% over the past 10 years (RIRDC 2001).

The initiative of RIRDC in the mid-1990's to review the fodder industry and subsequently to fund research into aspects of quality assessment (projects DAV-104A and CSJ-1A) has underpinned the industry's development. A major task in project DAV-104A was to convene a national forum, covering all sectors of the fodder industry from producers to end-users, in order to seek agreement on the most important quality indicators together with standard methods for their measurement. However the most significant development at the forum was the decision to form a national peak body to coordinate the industry, the Australian Fodder Industry Association (AFIA). AFIA is now widely recognised and consulted on all matters affecting the industry. It is an important lobby group and has active committees on such topics as quality evaluation, exports and transport. It has organised seven successful annual conferences and conducts regular industry seminars.

At the 1995 forum, the major objective measurements to define fodder quality were agreed to be dry matter (DM), metabolisable energy (ME) and crude protein (CP), with a prediction of voluntary intake at a later date, if available. Exhaustive debate has since taken place on the appropriate laboratory methods to estimate DM, ME and CP, and the agreed methods have been included in a comprehensive laboratory manual, commissioned by AFIA and funded by RIRDC, due for publication in early 2003. Recently, it was agreed that methods for determining acid detergent fibre (ADF), neutral detergent fibre (NDF) and water soluble carbohydrates (WSC) would also be included in the manual.

Project DAV-104A resulted in the production of 16 hay "standards", to be used by Australian fodder testing laboratories to calibrate their estimation of dry matter digestibility (DMD) and hence ME (Flinn and Heazlewood 1999). These hays were fed to wether sheep, at both maintenance and *ad libitum* feeding levels, and measurements of *in vivo* DMD, organic matter digestibility (OMD) and voluntary intake were made on each hay. Research has also been conducted on the development of a laboratory technique, based on a measurement of shear energy, to predict voluntary intake (project CSJ-1A).

AFIA has also adopted a quality grading system for fodder, based on ME and CP (Flinn and Heazlewood 1999). There are separate tables with alphanumeric grades for legume/pasture and cereal hay or silage. These grades are routinely quoted by some laboratories and utilised to some extent in domestic fodder trading, but have not been used by the export hay industry.

A review workshop, again involving key industry personnel, was organised by RIRDC in 2000 to set directions for future fodder quality research. It became clear that additional work was needed, building on that already completed in the earlier projects. All measurements of digestibility and intake on the hays in the two previous projects were conducted using sheep, which is the international standard. However, although DMD data obtained with sheep are widely used as the basis for predicting DMD of fodder for beef and dairy cattle, there are conflicting views on whether this can be done with acceptable accuracy (Schneider and Flatt 1975, Heaney 1979).

Secondly, there has been interest from the Australian horse industry for a more objective approach to fodder quality. There are some 1.2 million horses in Australia across a range of sporting and recreational pursuits, and the horse industry is one of Australia's largest, worth more than $8 billion per year (RIRDC 2001). Until recently, there has been very little objective information available on fodder quality for horses, and nutrient values used have originated largely from the USA or UK (Kohnke *et al.*1999). The digestibility of roughages in horses has been found to be lower than in sheep (Smolders *et al.*1990). Due to the quite different digestive systems in horses, the standard hay samples produced earlier using sheep cannot necessarily be used as a basis for predicting digestibility, and hence digestible energy (DE) of fodder for horses.

A recent development has been the interest shown by the Japanese dairy industry in the relative preference of cows for different cereal hays. Australia now exports over 400,000 tonnes of cereal hay per year to Japan, and exporters are demanding a rapid test to estimate preference ranking. Sections of the industry use WSC in hay as a measure of preference, and there is evidence of a positive relationship (Birrell 1989, Fisher *et al.*1999). However the factors which influence preference are poorly defined, and it has not been compared across animal species. An indication of the importance now placed on preference as a measure of fodder quality is the adoption by AFIA at its conference in 2000 of preference as a key quality indicator in addition to DM, ME, CP and intake.

The 2000 review concluded that there should be a nationally uniform fodder specification system based on the determinants of fodder quality that are applicable across animal types and forms of production, and that is suitable for the domestic and export fodder trade. RIRDC has since adopted this objective for its fodder quality program, and collaborative funding for some research has been obtained from the fodder and horse committees of RIRDC, with contributions from Meat and Livestock Australia (MLA), the Dairy Research and Development Corporation (DRDC) and the Victorian Department of Primary Industries. A considerable proportion of the RIRDC funds has originated from a voluntary levy organised by hay exporters.

The rationale for the RIRDC program is to measure digestibility, intake, preference and intake rate on a range of hays, undertake comprehensive chemical and physical analyses of the hays and identify the characteristics that best explain the above primary aspects of quality. The uniform quality specification system would then be used to develop fodder grading systems applicable to each industry sector and to utilise the rapid technique of near infrared spectroscopy (NIR) to develop calibrations for the relevant characteristics.

This type of research is expensive and time-consuming, but it is essential to establish whether the rank between hays in digestibility, intake, preference and intake rate remains the same for sheep, beef cattle, dairy cows and horses. If so, the system developed for sheep would be suitable for the other animal types and additional fodder types could be measured using only sheep, thus reducing costs considerably. If not, further research would be required for each animal type.

2. OBJECTIVES

The objectives of this project were:

- to measure and compare the ranking of *in vivo* digestibility, total intake, preference and intake rate of a series of hays across beef cattle, lactating dairy cows, horses and sheep.

- to use the "standard" fodder samples obtained as a basis for a uniform objective procedure for specification of fodder quality.

3. METHODOLOGY

3.1 Hays

Appropriate quantities of 21 different hays were purchased for this project, comprising 9 cereals, 11 legumes and one Italian ryegrass. Most of these were selected from hay samples processed by the FEEDTEST laboratory at Hamilton during the 2000/01 season. The basis of selection was a wide range in nutritive value as indicated by the samples submitted, with an emphasis on predicted DMD, NDF and WSC. For the cereal hays in particular, there was an attempt to select some with similar DMD but differing WSC, and *vice versa*.

It was originally intended to use 9 cereal hays and 9 legume hays only. However, two of the legumes (one lucerne and one vetch) had to be replaced during the preference measurements, after it was found that the dairy cows and sheep refused to eat them due to mould, soil contamination and overall poor quality. In the digestibility trials, it was also found that the animals would not eat enough of the barley straw, so this was replaced with an Italian ryegrass hay from NSW Agriculture, Wagga.

All hays purchased were transported to the Pastoral and Veterinary Institute (PVI), Hamilton. A coring device was used to take a number of separate samples from most of the hays. These samples were submitted for NIR analysis, to ascertain the variability in quality among bales and to compare values with those obtained on samples of the hays submitted earlier, if available. Sufficient numbers of bales of each hay for feeding to dairy cows were transported from Hamilton to the Dairy Research Institute (DRI), Ellinbank.

The hays were chopped to a length of 10-15 cm using a "Whoppa Choppa" and mixed thoroughly prior to feeding. The one exception to this was in the case of the digestibility trials with dairy cows, where the hay was not chopped.

3.2 Animals

All measurements with sheep, beef cattle and horses were conducted at PVI Hamilton, and dairy cow measurements were conducted at DRI Ellinbank.

For the preference measurements, the animals used were 18 x 3-year-old Merino wether sheep, average liveweight 50-60 kg; 12 x 18-month-old Hereford steers, average liveweight 350 kg, from the PVI farm; 12 thoroughbred racehorses, average age 6 to 7 years and loaned by various owners in the Hamilton district; and 27 lactating Holstein-Friesian dairy cows, average liveweight 500 kg and average age 3.8 years, from the DRI dairy herd.

For the digestibility and intake measurements, the same steers, horses and dairy cows were used, together with 66 Merino wethers.

All animals were housed indoors in single pens. Prior to commencing the experiment, the animals were familiarised with the feeding facilities and the procedures to be used. They were all routinely monitored for health and welfare, using standard protocols approved by the relevant Institute's Animal Ethics Committee. Specific veterinary care was undertaken with the horses, paying particular attention to their teeth and feet.

3.3 Experimental design

3.3.1 Preference and intake rate measurements

The experiment was conducted from August to December 2001 with 3 separate blocks of hay: 9 cereal hays, 9 legume hays and a crossover of 4 cereal and 4 legume hays. The hays chosen for the crossover trial were those ranked 1, 3, 5 and 7 by sheep in both the legume and cereal groups. The tests were undertaken with 3 groups of 9 dairy cows, 2 groups of 9 sheep, 1 group of 12 steers and 1 group of 12 horses. Each animal had access to 2 feed bins and all animals were exposed to each hay at least twice before the experiment commenced, to remove any effects of novelty. Animals were trained to eat from both feed bins, with bins removed after 10 minutes. A pasture hay of average quality was fed to all animals (except dairy cows) on each day before the measurement periods, to avoid undue hunger. In the case of dairy cows, 3 kg grain was fed to each cow in the dairy at the time of milking.

Preference was measured by offering each animal 2 hays for 10 minutes, and measuring the relative amounts consumed. Within each block, each hay was compared in a pair with every other hay, with tests carried out an hour apart and between 4 and 6 tests undertaken each day. A typical example of a randomised trial design is shown in Table 1.

Table 1: A typical design for preference measurement in a block of 9 different hays tested using 9 animals

	Animal																	
	1		**2**		**3**		**4**		**5**		**6**		**7**		**8**		**9**	
Period	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**
1	9	3	2	5	3	6	6	9	8	2	4	7	5	8	1	4	7	1
2	1	8	6	1	4	2	7	5	3	7	8	6	9	4	5	3	2	9
3	7	2	3	4	1	5	4	8	9	1	5	9	6	7	2	6	8	3
4	4	5	9	7	7	8	1	2	6	4	2	3	3	1	8	9	5	6

L=left, R=right

Table 1 shows that, within each period, each hay was offered twice. Each animal was offered 8 of the 9 hays, with the absent hay different for each animal. Each hay was allocated 4 times to a left bin and 4 times to a right bin, with 36 possible pairwise combinations of 9 hays. For each animal by period cell, the 2 hays were offered twice, swapping between left and right bins in the second test.

In addition to the preference measurements, the short-term intake rate of each hay was determined by removing one bin from each pen and offering a single hay to each animal (across all 4 animal types) for 5 minutes and measuring the amount consumed.

Preference measurements were conducted firstly with dairy cows, then sheep and later horses and steers. Because the dairy cows refused to eat the lucerne (LUC2) and vetch (VET) hays, it was decided to replace these hays with 2 others, lucernes LUC6 and LUC7, for subsequent measurements with horses and steers. To ensure that all the legume hays could be ranked, additional measurements of preference and intake rate were conducted for dairy cows and sheep by comparing the 2 new hays with the 7 remaining hays.

3.3.2 *In vivo* digestibility and intake measurements

Four separate digestibility and intake trials were conducted, one for each of the 4 animal species, from November 2001 to July 2002. In each trial the same 4 cereal hays, 3 legume hays and 1 Italian ryegrass hay were fed, but in the case of sheep and dairy cows, 2 additional cereal hays and 1 legume hay were also fed. This resulted in 11 hays being evaluated with sheep and dairy cows, and 8 of these hays with horses and steers. With the exception of the Italian ryegrass hay, all hays fed were a subset of those used in the preference trials.

In all 4 trials, digestibility and voluntary intake were measured using 6 animals per hay. In the case of sheep, the 11 hays were fed to 66 Merino wethers in 1 period. The same 11 hays were fed to lactating dairy cows, but using 13 animals in 4 periods and 14 animals in 1 period. However, measurements were not possible on some cows due to them not eating or experiencing health problems necessitating their removal from the experiment. The 8 hays fed to both thoroughbred horses and Hereford steers utilised 12 animals in 4 periods. In all cases the animals were randomly allocated to the respective treatments.

In each trial, the animals were fed at an *ad libitum* level of feeding only, so that digestibility and voluntary intake could be measured at the same time. This decision was made on the basis of limited resources and due to negligible differences being observed in *in vivo* DMD and OMD values measured at maintenance and *ad libitum* feeding levels using sheep in the earlier project DAV-104A (Flinn and Heazlewood 1999). A 7-day introduction, followed by a 5-day adaptation, was used in each trial to allow the animals to adjust to each hay diet. This was followed by 2 consecutive 4-day measurements, during which each animal was fitted with a faecal harness (or in the case of horses the “Horse Nappy”), allowing all faeces excreted to be collected. Each day, animals were fed a measured amount of hay, and all hay not eaten was collected, with a representative sample dried at 60^{o}C to constant weight. Faeces were also collected daily and similarly treated, except that the drying temperature was 100^{o}C. At the end of each trial, *in vivo* DMD values were calculated, as the percentage difference between the dry matter of hay eaten and the faecal dry matter excreted, for the 6 animals on each hay. *Ad libitum* dry matter intake (DMI) values were also calculated for 6 animals on each hay. Means and standard errors were calculated for both measurements. Similar calculations were performed to obtain *in vivo* OMD and OMI after ash content had been determined in samples of both feeds and faeces.

3.4 Laboratory analyses

3.4.1 Samples from preference/intake rate trials

Each time a hay was subjected to a preference test with a given animal type, 2 representative samples of the chopped material were taken from it. One sample (around 100g) was weighed, dried overnight at 100^{o}C then reweighed to determine dry matter (DM) content. The other sample (around 200g) was dried overnight at 60°C, coarsely ground in a hammermill to pass a 4 mm screen, then a carefully mixed sub-sample reground in a cyclone mill to pass a 1 mm screen.

All ground hay samples were scanned on a model 5000 NIR spectrophotometer (Foss-NIRSystems Inc., Silver Spring, MD, USA) using ISI software (Infrasoft International, Port Matilda, PA, USA). Existing NIR calibration equations, based on more than 400 samples, were used to predict CP, DMD, NDF and WSC (the latter on cereal hays only). The equations had been derived using appropriate hay samples previously analysed by reference methods 4, 5, 12 and 13 in the AFIA laboratory methods manual (AFIA 2003).

Overall, 1,038 hay samples were collected and analysed by NIR during the preference measurements, in the separate legume, cereal and crossover blocks, and in the repeated trials for sheep and dairy cows to include replacement hays. These samples comprised 230 (dairy cows), 280 (sheep), 264 (horses) and 264 (steers).

No additional hay samples were collected during the measurements of short-term intake rate, as these were conducted on the same days as the preference measurements for all animal species except dairy cows. Short-term intake rate for dairy cows was measured after the preference tests were completed.

3.4.2 Samples from digestibility/intake trials

(a) Hay fed

During each digestibility/intake trial for all 4 animal species, samples of each hay were taken daily during the 2 x 4-day measurements across all periods. Each day a sub-sample of each hay was weighed, dried overnight at 100°C then reweighed to determine DM content. The remaining portions were pooled and mixed to produce 2 samples of each hay per period, 1 corresponding to each of the 2 x 4-day measurements. Altogether there were 229 hay samples, comprising 79 (dairy cows), 22 (sheep), 64 (horses) and 64 (steers). The hay samples were dried overnight at 60°C, coarsely ground in a hammermill to pass a 4 mm screen, after which carefully mixed sub-samples were reground in a cyclone mill to pass a 1 mm screen.

All hay samples were analysed for ash content by ashing for 2 hours in a muffle furnace at 600°C, and were also scanned by NIR as in 3.4.1. The spectra were stored for later calibration or prediction as required.

Portions of the unground hay samples were retained, and mixed carefully to produce 1 composite sample for each hay per animal species, resulting in a total of 38 samples. These samples were sent to CSIRO in WA for testing of shear energy.

(b) Hay refusals

The dried samples of the hay refusals from each animal were pooled and mixed to produce 2 samples per period for each animal species, 1 corresponding to each of the 2 x 4-day measurements. Altogether there were 439 samples, comprising 115 (dairy cows), 132 (sheep), 96 (horses) and 96 (steers). The samples were coarsely ground in a hammermill to pass a 4 mm screen, after which carefully mixed sub-samples were reground in a cyclone mill to pass a 1 mm screen.

All samples of hay refusals were analysed for ash, DMD and OMD. DMD and OMD were estimated using a pepsin-cellulase enzymatic technique (method 5, AFIA 2003). Analytical values for pepsin-cellulase dry matter or organic matter disappearance were adjusted using a linear regression based on existing "standard" hay samples of known *in vivo* DMD or OMD. The estimated DMD and OMD values on the refusals were used to adjust the figures obtained for *in vivo* DMD and OMD on all hays evaluated across the 4 animal species.

(c) Faeces

The dried faeces samples collected from each animal were pooled and mixed as for the hay refusals (3.4.2.2), and again there were 439 samples in all. Sub-samples were ground in a hammermill to pass a 1 mm screen.

All faeces samples were analysed for ash content. These values, together with ash values on the hay samples and hay refusals, were used to calculate *in vivo* OMD for all hays evaluated.

3.5 Data Analysis

3.5.1 Preference and intake rate

The quantity of each hay consumed during the preference measurements was averaged over test runs within each animal by period cell (Table 1). This removed the effect of left versus right bin. Random effects (those other than hay type) were specified to account for the design structure. The Residual Maximum Likelihood Function (REML) (Genstat 5 Committee 1993) was used to analyse the preference data. For each animal species and each hay block, every hay was characterised by 2 quantities: a mean consumption adjusted for competition, and a competitive effect of the hay on the consumption of companion hays. This analysis was also conducted when all hays were combined into one set.

The REML procedure was also used to analyse the measurements of short-term intake rate.

An approximate chi-square statistic (Kotz and Johnson 1983) was derived to test the hypothesis that preference means from one animal species were directly proportional to those from another animal species.

Correlations were calculated between preference and short-term intake rate of the cereal and legume hays for each animal species.

Simple linear regressions were derived between preference means and mean values of CP, DMD, NDF and WSC respectively as estimated by NIR, for each animal species and for cereal hays and legume hays separately.

The variation in estimates of nutritive value between hay samples tested with each animal species was also measured, in order to observe the effect of quality variation within each hay type.

3.5.2 *In vivo digestibility and intake*

A method comparison routine for testing precision and bias (Jorgensen 1985) was used in order to determine whether *in vivo* DMD and OMD differed between animal species for the hays tested.

The same procedure used to determine proportionality in the preference data (Kotz and Johnson 1983) was also used to determine whether DMI and OMI measured using one animal species were directly proportional to the values obtained using another animal species.

4. RESULTS

4.1 Hays

The 21 hays purchased, together with their nutritive value as estimated by laboratory tests, are shown in Table 2. NIR analysis was used in all cases except WSC determined on legume hays, where the reference method was used (method 13, AFIA 2003).

Table 2: Nutritive value analyses of hays selected for the project (FEEDTEST, PVI Hamilton)

Code	Hay type	Source ID	CP[1]	CP[2]	DMD[1]	DMD[2]	NDF[1]	NDF[2]	WSC[1]
LUC1	Lucerne	TN bulk	17.4	16.9	61.5	62.7	47.2	48.3	ND
LUC2	Lucerne	FK poor	11.6	18.2	43.3	49.0	63.4	59.7	0.9
LUC3	Lucerne	TN AM	19.1	18.2	63.3	63.8	47.4	46.1	5.1
LUC4	Lucerne	TN PM	18.6	17.3	64.4	62.8	46.2	47.6	6.2
LUC5	Lucerne	Grosse	22.8	19.8	75.9	67.5	34.4	44.1	5.5
LUC6	Lucerne	FK good	19.5	18.1	67.1	65.6	44.1	45.1	6.2
LUC7	Lucerne	TN 1999	18.9	ND	63.8	ND	45.2	ND	ND
BAL	Balansa clover		17.2	18.5	59.6	59.1	45.1	43.6	1.5
PER	Persian clover		18.5	17.9	70.4	69.3	39.5	40.6	12.2
MED	Medic		16.9	16.6	68.4	66.8	39.4	40.3	9.7
VET	Vetch		15.3	16.1	46.6	43.1	59.6	60.1	1.2
OAT1	Oaten	B 4079	5.1	ND	58.6	ND	57.9	ND	24.9
OAT2	Oaten	B 3963	9.3	9.0	57.1	57.8	58.9	55.5	2.5
OAT3	Oaten	B 4152	7.7	ND	61.5	ND	55.4	ND	11.5
OAT4	Oaten	B 4020	4.6	ND	49.7	ND	71.2	ND	10.3
OAT5	Oaten	B 4173	9.9	ND	57.6	ND	63.9	ND	10.4
OAT6	Oaten	B 3883	5.3	6.8	57.3	56.1	59.6	67.6	18.5
OAT7	Oaten	B 3938	7.0	ND	63.0	ND	53.2	ND	23.5
BAR	Barley		5.6	7.2	56.8	58.0	62.5	60.4	11.2
STR	Barley straw		4.6	1.4	43.0	40.8	82.0	92.5	ND
IRG	Italian ryegrass	Wagga	ND	ND	ND	ND	ND	ND	ND

CP = crude protein, % dry basis
DMD = dry matter digestibility, % predicted
NDF = neutral detergent fibre, % dry basis
WSC = water-soluble carbohydrates, % dry basis
[1]samples taken by other parties and submitted to FEEDTEST laboratory during 2000 hay season
[2]mean values from numerous samples taken from several bales following purchase
ND = not determined

4.2 Ranking and values for preference and short-term intake rate

The preference ranking and mean values for hay consumption, adjusted for competition effects, of legume hays, cereal hays and crossover trials containing both hay types, for all 4 animal species, are shown in Tables 3, 4 and 5. Ranking and mean values for short-term intake rate of legume hays and cereal hays for all 4 animal species are shown in Tables 6 and 7.

Table 3: Preference ranking and mean consumption (g per 10 minutes) for legume hays

Rank	Dairy cows		Sheep		Horses		Steers	
1	LUC5	1141.5^{a}	LUC5	119.5^{a}	LUC5	482.5^{a}	PER	530.2^{a}
2	PER	974.7^{ab}	LUC3	104.3^{ab}	LUC6*	418.7^{ab}	MED	417.3^{b}
3	MED	870.7^{b}	PER	93.4^{bc}	PER	353.9^{bc}	BAL	331.5^{bc}
4	BAL	580.2^{c}	LUC1	85.9^{bc}	LUC1	340.5^{bc}	LUC5	311.4^{c}
5	LUC1	504.3^{cd}	MED	83.4^{bc}	MED	325.2^{c}	LUC1	251.3^{cd}
6	LUC4	502.2^{cd}	LUC4	75.8^{c}	LUC3	312.5^{c}	LUC7*	166.1^{de}
7	LUC3	361.8^{d}	BAL	48.4^{d}	LUC7*	213.4^{d}	LUC6*	160.2^{de}
8	LUC2	87.6^{e}	LUC2	20.1^{e}	LUC4	191.0^{d}	LUC3	139.6^{e}
9	VET	46.6^{e}	VET	9.4^{e}	BAL	45.5^{e}	LUC4	94.2^{e}

*Replacement hays for LUC2 and VET

Within columns, values with different superscripts differ significantly ($P<0.05$)

Table 4: Preference ranking and mean consumption (g per 10 minutes) for cereal hays

Rank	Dairy cows		Sheep		Horses		Steers	
1	OAT3	959.3^{a}	OAT3	94.4^{a}	OAT7	323.0^{a}	OAT7	476.5^{a}
2	OAT7	881.3^{ab}	OAT7	93.2^{a}	OAT3	317.5^{a}	OAT1	347.0^{b}
3	OAT1	761.0^{b}	OAT6	76.0^{b}	OAT1	302.3^{ab}	OAT5	330.8^{b}
4	OAT5	552.4^{c}	OAT5	70.5^{bc}	OAT2	242.6^{bc}	OAT6	324.5^{b}
5	OAT2	504.9^{c}	OAT1	65.2^{bc}	OAT4	184.5^{c}	OAT3	310.8^{b}
6	OAT6	347.9^{d}	OAT2	58.3^{c}	BAR	101.0^{d}	OAT2	295.3^{b}
7	BAR	277.2^{d}	BAR	39.2^{d}	OAT5	93.7^{d}	OAT4	83.6^{c}
8	OAT4	206.6^{d}	OAT4	14.3^{e}	OAT6	45.9^{d}	BAR	62.2^{c}
9	STR	46.9^{e}	STR	4.1^{e}	STR	29.1^{d}	STR	44.4^{c}

Within columns, values with different superscripts differ significantly ($P<0.05$)

Table 5: Preference ranking and mean consumption (g per 10 minutes) for crossover between 4 legume hays and 4 cereal hays

Rank	Dairy cows		Sheep		Horses		Steers	
1	PER	1566.1^{a}	PER	140.3^{a}	LUC5	510.6^{a}	PER	760.3^{a}
2	LUC5	1057.0^{b}	LUC5	139.1^{a}	PER	504.5^{a}	LUC5	617.1^{ab}
3	OAT3	839.4^{bc}	LUC1	109.2^{ab}	LUC1	443.7^{a}	LUC1	566.7^{ab}
4	OAT1	606.5^{cd}	OAT3	81.4^{bc}	OAT3	209.1^{b}	BAL	514.9^{b}
5	BAL	521.8^{cde}	BAL	52.6^{cd}	OAT1	167.6^{bc}	OAT1	245.9^{c}
6	LUC1	435.5^{de}	OAT1	39.4^{d}	BAL	114.3^{bc}	OAT3	192.7^{c}
7	BAR	238.2^{de}	OAT6	36.1^{d}	OAT6	101.6^{bc}	OAT6	129.8^{c}
8	OAT6	154.8^{e}	BAR	24.1^{d}	BAR	67.7^{c}	BAR	67.9^{c}

Within columns, values with different superscripts differ significantly ($P<0.05$)

Table 6: Ranking of short-term intake rate and mean consumption (g per 5 minutes) for legume hays

Rank	Dairy cows		Sheep		Horses		Steers	
1	BAL	647.0^{a}	LUC5	116.8^{a}	LUC3	376.2^{a}	PER	492.3^{a}
2	LUC5	623.5^{a}	LUC3	91.1^{b}	LUC5	371.5^{a}	MED	453.2^{ab}
3	PER	606.0^{a}	LUC1	88.0^{b}	LUC6*	366.4^{a}	BAL	441.5^{ab}
4	LUC4	452.5^{b}	MED	86.1^{b}	PER	359.7^{a}	LUC5	390.6^{bc}
5	MED	410.5^{bc}	PER	84.3^{b}	MED	350.2^{a}	LUC1	377.9^{bc}
6	LUC1	375.0^{bc}	BAL	75.6^{b}	LUC1	345.9^{a}	LUC6*	365.9^{bc}
7	LUC3	305.0^{c}	LUC4	72.1^{b}	LUC7*	336.9^{a}	LUC7*	343.9^{cd}
8	VET	129.0^{d}	LUC2	45.7^{c}	LUC4	325.0^{ab}	LUC4	329.4^{cd}
9	LUC2	13.5^{d}	VET	35.0^{c}	BAL	283.2^{b}	LUC3	273.1^{d}

*Replacement hays for LUC2 and VET

Within columns, values with different superscripts differ significantly (P<0.05)

Table 7: Ranking of short-term in take rate and mean consumption (g per 5 minutes) for cereal hays

Rank	Dairy cows		Sheep		Horses		Steers	
1	OAT3	534.5^{a}	OAT3	88.6^{a}	OAT7	302.0^{a}	OAT7	454.5^{a}
2	OAT1	474.5^{ab}	OAT5	77.9^{ab}	OAT3	295.4^{a}	OAT3	453.8^{a}
3	OAT7	446.0^{bc}	OAT6	75.3^{ab}	OAT1	279.8^{ab}	OAT2	438.9^{ab}
4	OAT5	415.0^{bc}	OAT7	74.7^{ab}	OAT2	276.9^{ab}	OAT1	384.2^{ab}
5	OAT2	383.0^{cd}	OAT1	74.4^{b}	OAT4	247.3^{abc}	OAT6	367.6^{b}
6	OAT6	335.5^{de}	OAT2	67.2^{bc}	OAT5	195.9^{bcd}	OAT5	364.4^{b}
7	BAR	319.0^{de}	BAR	54.2^{cd}	OAT6	169.9^{cd}	OAT4	222.8^{c}
8	OAT4	298.5^{e}	OAT4	40.7^{d}	BAR	146.8^{d}	BAR	171.4^{c}
9	STR	49.0^{f}	STR	15.1^{e}	STR	14.6^{e}	STR	41.1^{d}

Within columns, values with different superscripts differ significantly (P<0.05)

Table 8 shows the results of the statistical comparison of preference among the 4 animal species. For these comparisons, all the legume and cereal hays were combined, and the comparisons are also shown graphically in Figure 1.

Table 8: Probability of the approximate chi-square statistic derived to test the hypothesis that preference means from one animal species were directly proportional to preference means from another animal species

Species comparison	Approximate chi-square statistic	Degrees of freedom	Probability[1]
Sheep vs Horses	114.0	17	<0.001
Sheep vs Steers	154.3	17	<0.001
Sheep vs Dairy	145.2	19	<0.001
Dairy vs Horses	162.8	17	<0.001
Dairy vs Steers	94.6	17	<0.001
Horses vs Steers	215.0	17	<0.001

[1] If P≤0.05, the approximate chi-square statistic is significant, and the preference means from one animal species are not directly proportional to those from another animal species

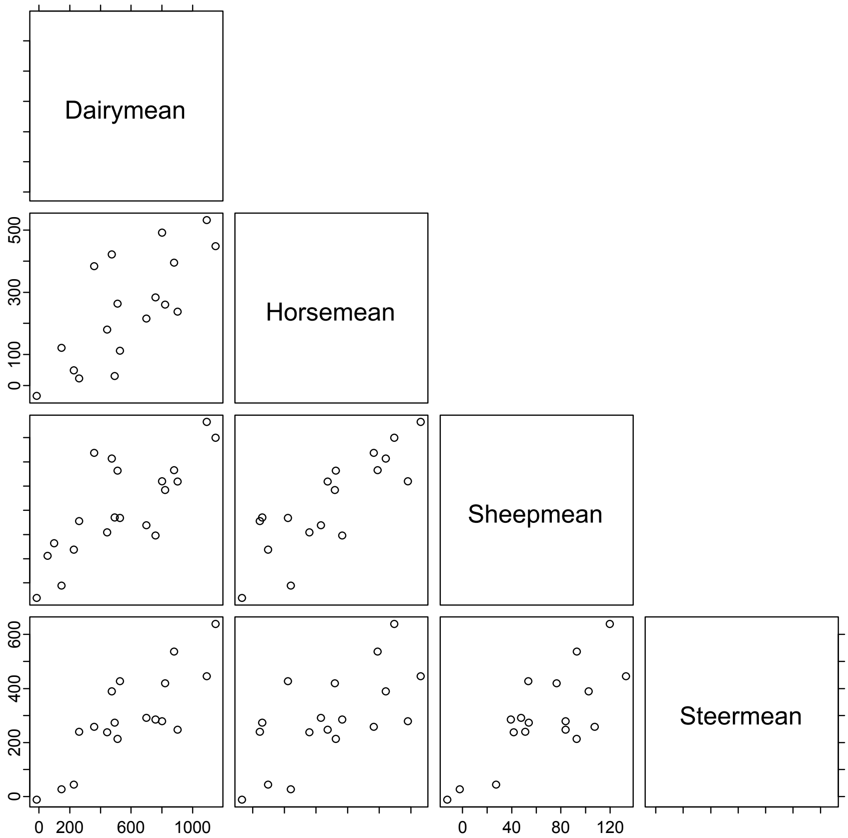

Figure 1: Plots showing the proportionality of preference means (g per 10 minutes) among the 4 animal species

The correlations between preference and short-term intake rate for the 4 animal species are shown in Table 9.

Table 9: Coefficients of determination (R^2) relating preference and short-term intake rate for cereal and legume hays

	Dairy cows	Sheep	Horses	Steers
Cereal hays	0.85	0.90	0.77	0.79
Legume hays	0.74	0.90	0.79	0.77

The statistics of simple linear regressions relating preference means of either the legume or cereal hays to the various nutritive value measurements, as estimated by NIR, are shown in Table 10. These relationships are also shown graphically as bi-plots, determined from principal components analysis, in Figures 2 to 9. In these bi-plots, a measurement of nutritive value at an angle close to 0^o from preference has a strong positive correlation. Similarly, a measurement close to 180^o from preference has a strong negative correlation. A measurement at a 90^0 angle from preference would have no correlation.

Table 10: Relationships between preference (g per 10 minutes) and various nutritive value measurements for legume hays (n=9) and cereal hays (n=9) for each animal species

Measurement	Hay type	Dairy cows		Sheep		Horses		Steers	
		R^2	RSD	R^2	RSD	R^2	RSD	R^2	RSD
CP	Legumes	0.02	398.6	0.29	33.9	0.51	98.2	0.00	154.0
	Cereals	0.20	300.6	0.51	24.1	0.02	125.8	0.17	148.0
DMD	Legumes	0.86	152.6	0.93	10.9	0.83	57.2	0.36	123.0
	Cereals	0.77	159.9	0.86	12.9	0.58	82.4	0.64	97.7
NDF	Legumes	0.75	203.4	0.78	19.0	0.18	127.0	0.78	72.9
	Cereals	0.75	168.2	0.67	19.7	0.85	48.7	0.60	102.5
WSC	Cereals	0.48	243.3	0.28	29.2	0.36	101.3	0.34	132.1

R^2 = coefficient of determination
RSD = residual standard deviation
CP = crude protein, % dry basis
DMD = dry matter digestibility, % predicted
NDF = neutral detergent fibre, % dry basis
WSC = water-soluble carbohydrates, % dry basis

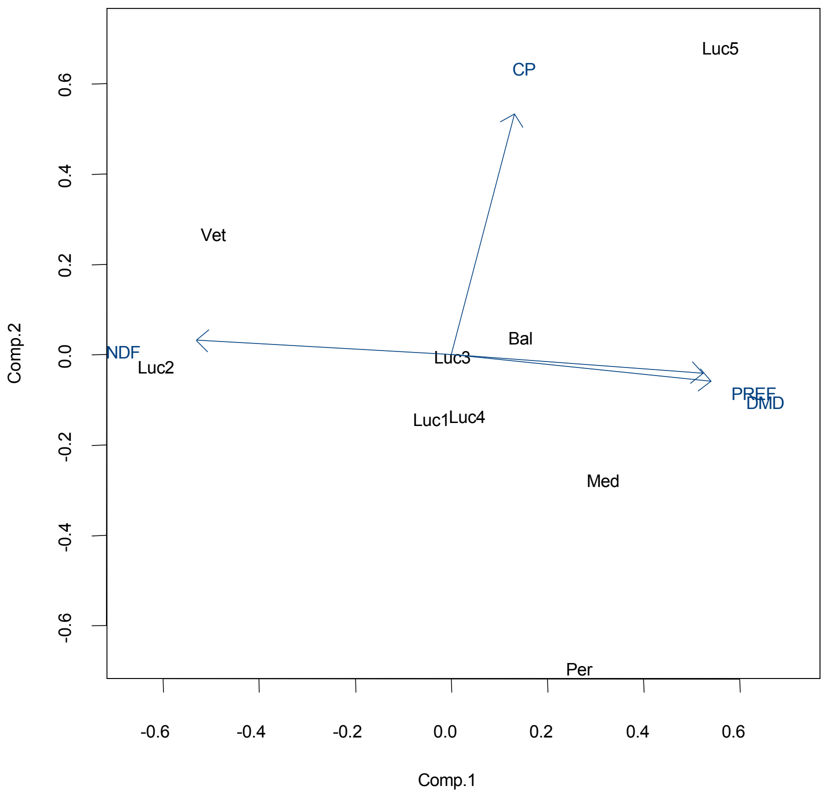

Figure 2: Principal component plot showing the correlations between preference and nutritive value measurements in legume hays for dairy cows

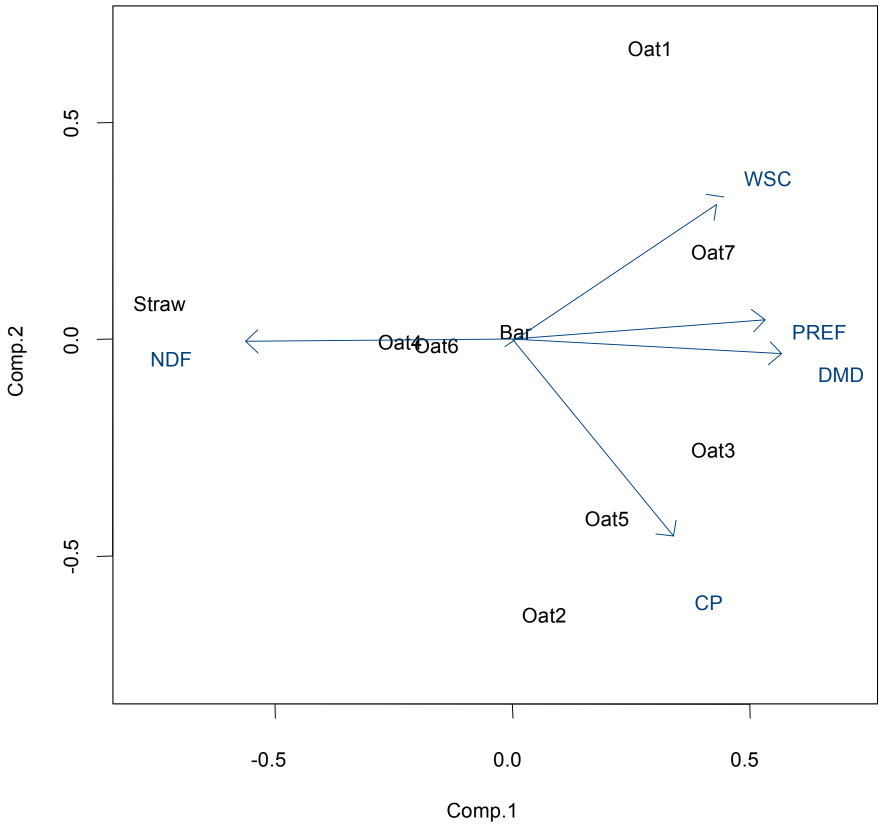

Figure 3: Principal component plot showing the correlations between preference and nutritive value measurements in cereal hays for dairy cows

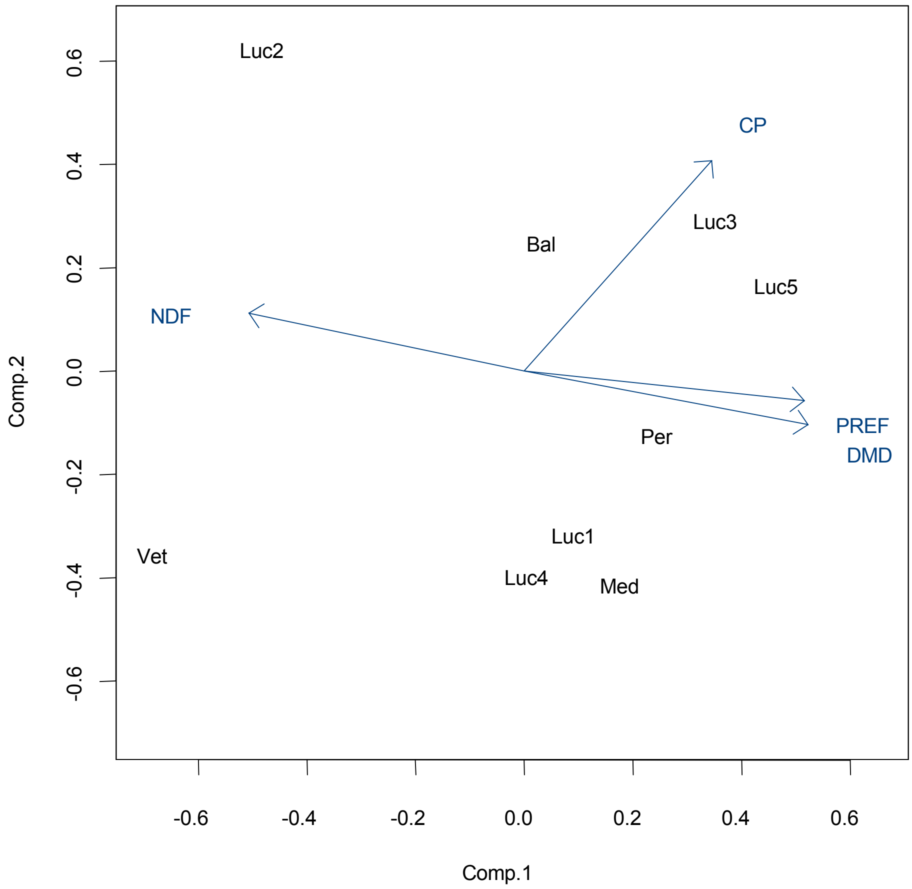

Figure 4: Principal component plot showing the correlations between preference and nutritive value measurements in legume hays for sheep

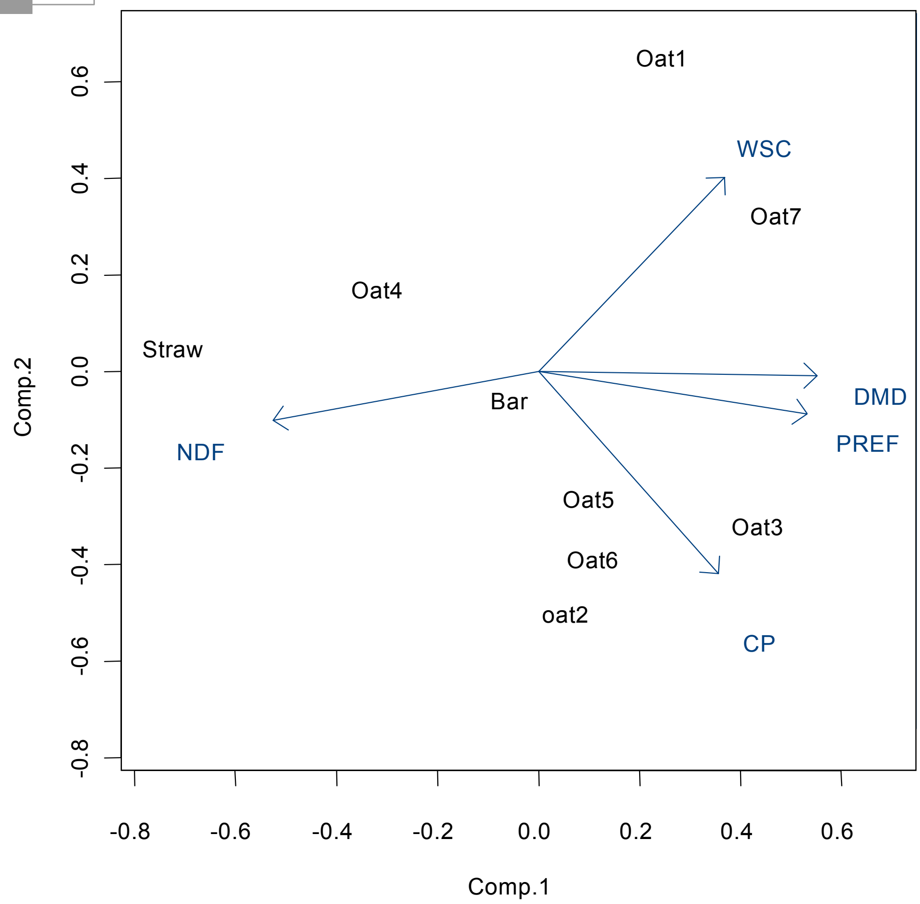

Figure 5: Principal component plot showing the correlations between preference and nutritive value measurements in cereal hays for sheep

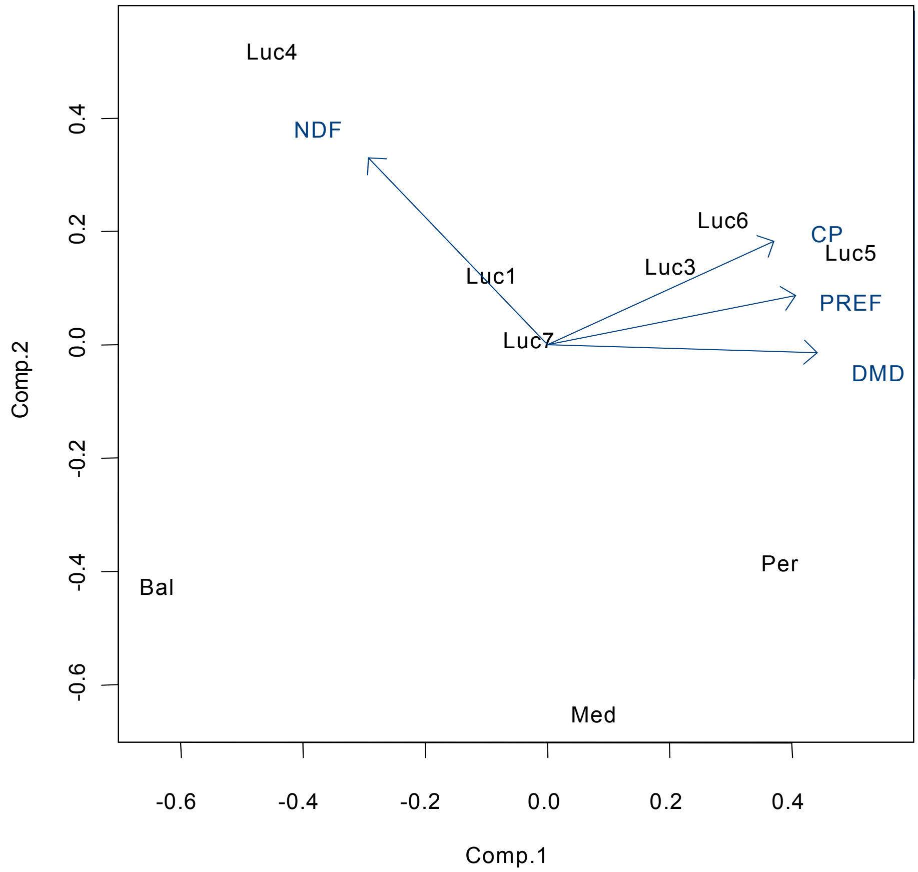

Figure 6: Principal component plot showing the correlations between preference and nutritive value measurements in legume hays for horses

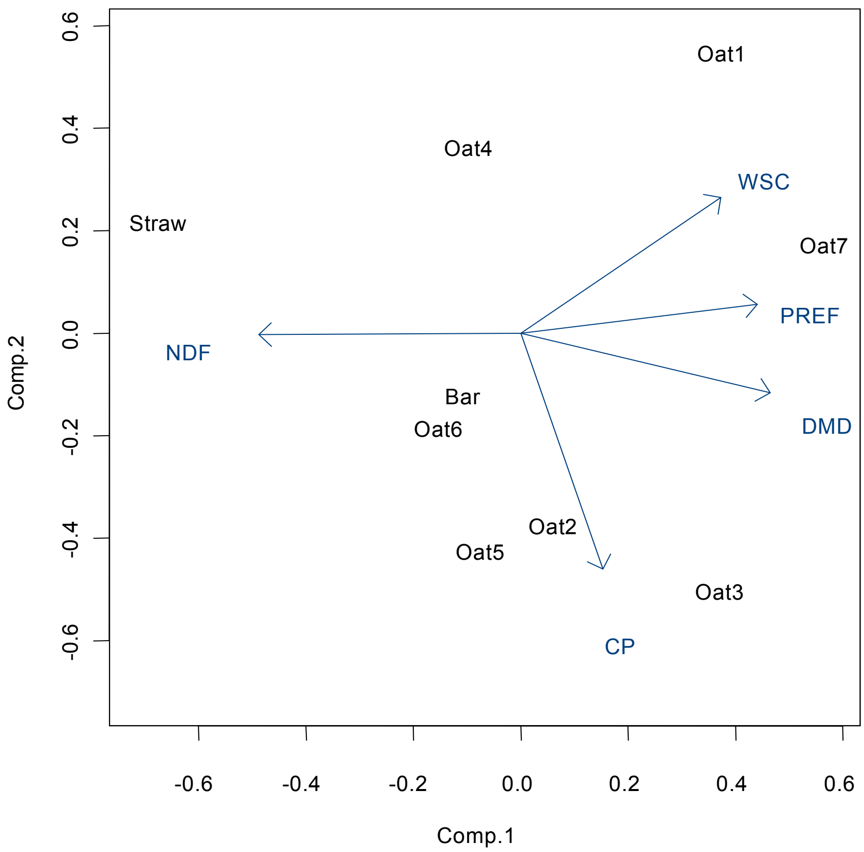

Figure 7: Principal component plot showing the correlations between preference and nutritive value measurements in cereal hays for horses

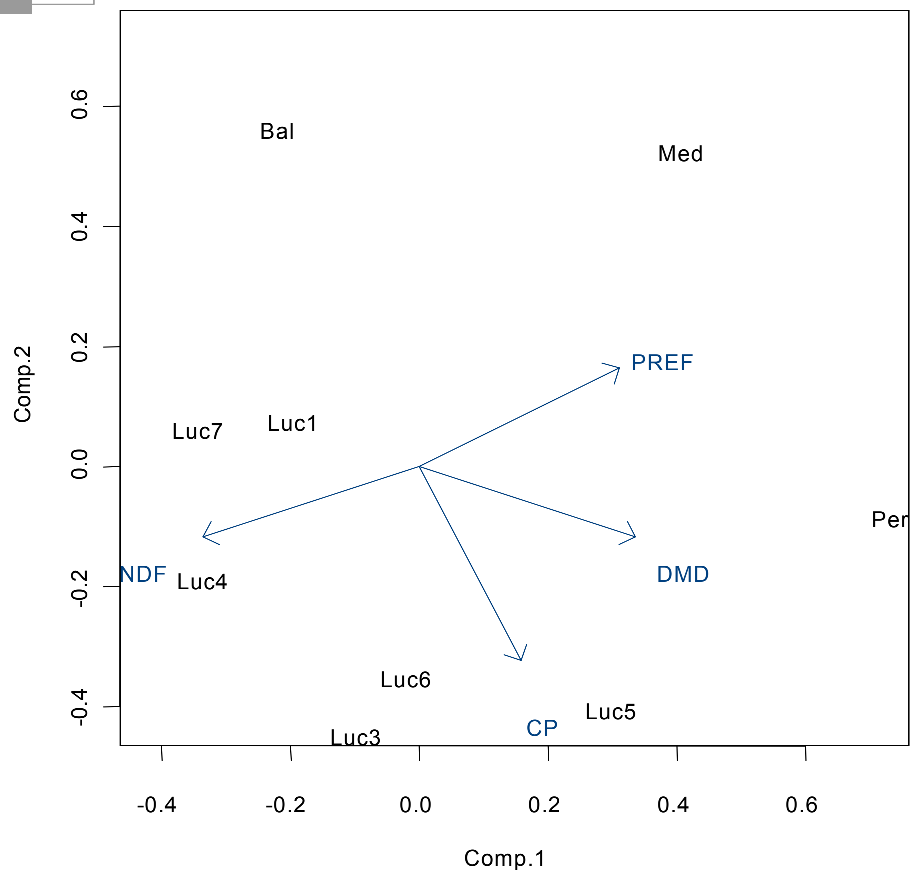

Figure 8: Principal component plot showing the correlations between preference and nutritive value measurements in legume hays for steers

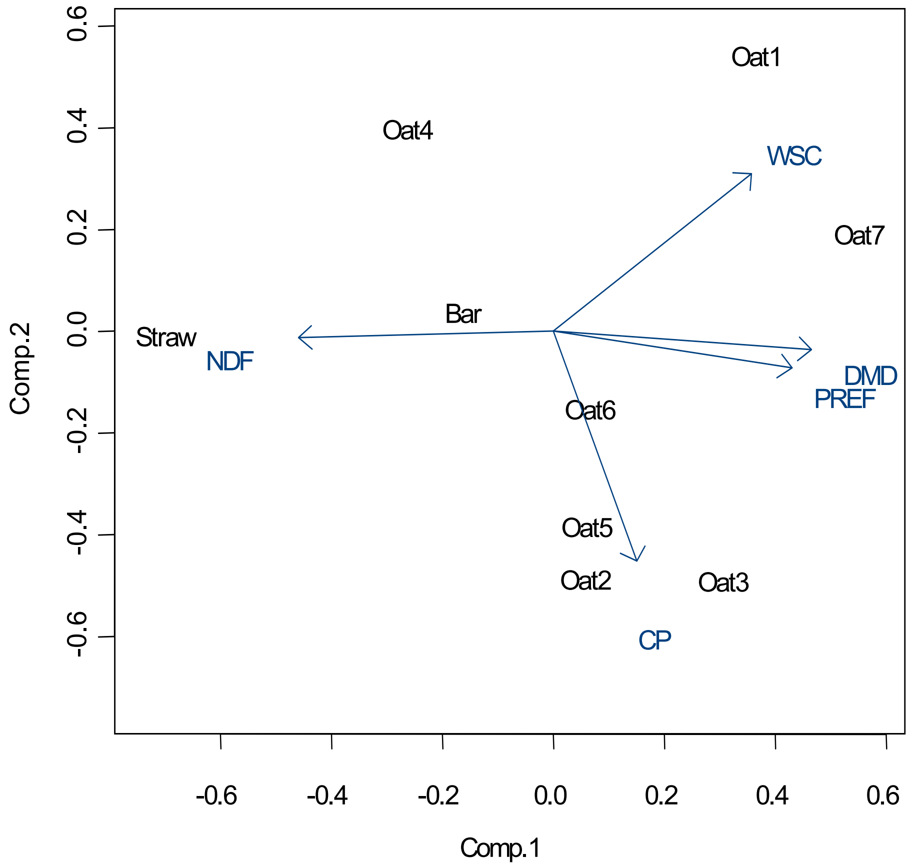

Figure 9: Principal component plot showing the correlations between preference and nutritive value measurements in cereal hays for steers

Tables 11 to 14 show the variation in estimates of nutritive value between hay samples tested during the preference trials with each animal species.

Table 11: Variation (mean, standard deviation) in crude protein (% dry basis) measured by NIR in hay samples taken during the preference trials with each animal species

Hay	Dairy cows		Sheep		Horses		Steers	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
LUC1	16.1	1.25	17.4	0.62	16.6	0.52	16.7	0.71
LUC2	16.0	1.43	18.6	1.90	-	-	-	-
LUC3	16.7	0.87	19.6	0.47	18.7	0.56	18.2	0.58
LUC4	16.2	1.11	17.0	0.62	16.4	0.66	17.1	0.48
LUC5	20.0	0.85	19.5	0.90	19.0	0.94	18.5	0.71
LUC6	-	-	18.4	0.94	18.4	0.64	17.9	0.76
LUC7	-	-	18.6	0.64	18.2	0.57	16.8	0.84
BAL	17.0	1.32	18.9	0.75	14.9	0.57	15.9	0.80
PER	14.2	2.32	18.3	0.41	18.2	0.65	18.4	0.86
MED	15.9	0.83	17.4	1.54	15.9	0.39	16.2	0.60
VET	17.3	1.10	15.6	0.35	-	-	-	-
OAT1	5.3	0.60	4.7	0.44	4.3	0.38	4.8	0.42
OAT2	8.6	0.75	8.4	0.77	7.8	0.72	8.3	0.69
OAT3	8.2	0.48	8.6	0.36	8.9	0.40	8.9	0.49

Hay	Dairy cows		Sheep		Horses		Steers	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
OAT4	6.5	0.96	5.1	0.46	4.4	0.35	4.7	0.42
OAT5	9.0	0.47	8.2	0.43	8.6	0.67	8.5	0.33
OAT6	6.6	0.90	8.5	0.61	7.1	0.40	7.3	0.32
OAT7	7.3	0.44	6.6	0.24	6.4	0.42	6.5	0.43
BAR	6.8	0.63	6.7	0.31	6.6	0.43	6.5	0.27
STR	4.7	0.49	3.4	0.35	4.0	0.57	5.5	0.79

Table 12: Variation (mean, standard deviation) in dry matter digestibility (%) measured by NIR in hay samples taken during the preference trials with each animal species

Hay	Dairy cows		Sheep		Horses		Steers	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
LUC1	59.0	3.13	61.5	2.51	63.4	0.69	62.6	1.02
LUC2	47.2	1.65	48.2	1.94	-	-	-	-
LUC3	61.2	1.26	63.8	2.11	65.5	0.90	63.5	0.92
LUC4	60.8	1.80	61.2	0.69	61.6	0.63	62.2	0.96
LUC5	67.9	0.83	67.1	1.43	67.3	0.71	66.6	1.04
LUC6	-	-	65.6	1.69	66.0	1.25	64.5	1.51
LUC7	-	-	62.0	1.09	63.4	1.57	60.3	2.23
BAL	60.9	0.84	59.4	0.99	60.0	0.61	59.7	0.52
PER	65.6	3.19	64.2	1.63	67.1	0.62	68.4	0.51
MED	64.2	1.51	62.8	2.99	65.1	0.57	66.0	0.85
VET	49.5	1.04	48.7	1.73	-	-	-	-
OAT1	58.0	1.10	57.3	0.64	57.1	0.68	59.9	0.64
OAT2	56.7	1.70	55.4	1.37	55.2	1.38	56.9	1.35
OAT3	61.2	0.74	61.1	0.73	60.4	0.70	61.5	0.94
OAT4	51.0	1.82	49.1	0.70	50.8	0.70	51.8	2.04
OAT5	56.7	1.18	54.0	0.83	54.2	1.42	55.6	1.14
OAT6	53.5	2.00	55.7	0.87	54.7	0.88	57.0	0.75
OAT7	60.8	1.15	61.3	1.04	62.4	0.74	62.6	1.38
BAR	56.8	0.81	55.2	0.75	54.8	1.10	56.6	1.32
STR	43.3	1.41	43.5	0.94	44.4	1.40	46.0	1.63

Table 13: Variation (mean, standard deviation) in neutral detergent fibre (% dry basis) measured by NIR in hay samples taken during the preference trials with each animal species

Hay	Dairy cows		Sheep		Horses		Steers	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
LUC1	51.6	3.50	47.2	1.50	45.0	0.83	46.4	1.00
LUC2	63.6	2.19	60.8	2.48	-	-	-	-
LUC3	49.5	1.64	44.8	1.71	43.5	1.14	45.2	1.15
LUC4	49.4	1.90	48.9	1.10	48.2	0.85	46.7	0.99
LUC5	43.4	0.94	43.8	1.86	42.7	1.06	43.3	1.13
LUC6	-	-	44.1	1.62	43.8	1.16	44.5	1.39
LUC7	-	-	44.3	0.91	43.5	2.15	45.9	1.79
BAL	44.9	0.93	46.2	1.15	44.3	0.77	44.2	0.46
PER	47.2	5.07	44.5	1.51	40.6	1.12	39.4	0.98
MED	43.3	1.99	42.5	0.89	41.0	0.84	39.1	1.14
VET	59.4	1.45	60.2	1.53	-	-	-	-
OAT1	57.9	1.46	56.4	0.87	56.0	0.52	56.8	0.69
OAT2	62.5	3.22	62.1	2.63	62.0	2.36	61.5	2.46
OAT3	57.4	1.54	54.7	1.83	56.6	1.54	56.8	2.00
OAT4	69.9	2.09	68.3	0.79	65.5	0.93	67.0	2.41
OAT5	62.9	1.63	65.2	1.32	66.1	1.24	65.8	1.23
OAT6	71.3	1.87	68.0	0.95	68.7	0.86	66.4	1.23

Hay	Dairy cows		Sheep		Horses		Steers	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
OAT7	59.5	2.28	55.2	1.06	53.6	0.76	56.1	1.92
BAR	63.2	1.54	65.7	1.26	66.4	1.20	66.7	1.83
STR	81.7	1.27	79.8	1.34	79.0	2.13	78.4	1.93

Table 14: Variation (mean, standard deviation) in water-soluble carbohydrates (% dry basis) measured by NIR in hay samples taken during the preference trials with each animal species

Hay	Dairy cows		Sheep		Horses		Steers	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
OAT1	22.4	1.64	24.1	0.93	25.4	0.88	25.0	1.13
OAT2	5.3	0.28	4.5	0.63	5.9	0.79	5.2	0.34
OAT3	13.2	0.97	11.0	1.00	10.2	0.68	10.1	0.75
OAT4	10.9	1.22	11.0	1.02	14.7	0.95	14.0	1.98
OAT5	14.3	1.50	12.2	1.06	10.9	0.99	11.4	0.69
OAT6	11.2	0.95	10.5	0.68	12.5	0.82	12.9	1.10
OAT7	21.2	3.48	22.8	1.26	26.3	1.02	24.2	2.52
BAR	13.9	1.07	11.1	0.23	11.2	0.93	12.1	1.08
STR	1.8	0.57	2.6	0.79	2.6	0.54	1.4	0.67

4.3 In vivo digestibility and intake

The mean (± standard error, SE) values for *in vivo* DMD and OMD at *ad libitum* feeding levels, and for DMI and OMI, for all hays fed to the different animal species, are shown in Tables 15 to 18. Graphical comparisons of *in vivo* DMD and OMD across animal species are also shown in Figures 10 and 11.

Table 15: *In vivo* dry matter digestibility (DMD%), *ad libitum,* of hays fed across animal species (6 animals per hay except where identified)

Hay	Code	Dairy cows		Sheep		Horses		Steers	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE
Oaten	OAT1	60.9	0.8	51.9	0.8	49.4	0.9	59.0	0.7
Oaten	OAT2	57.9	1.8	53.8+	0.6	53.0	1.4	59.7	1.4
Oaten	OAT3	55.2	1.1	54.9#	0.8	53.8	1.1	61.3	1.1
Oaten	OAT4	53.8*	0.6	46.5	0.7	43.5	1.3	54.2	0.5
Lucerne	LUC1	58.4	1.2	57.0	0.5	53.8	1.2	58.9	1.2
Lucerne	LUC6	60.4	0.9	59.1	0.8	59.2	1.0	61.0	0.7
Persian clover	PER	69.3*	0.4	67.1	0.3	67.6	1.0	70.1	0.6
Italian ryegrass	IRG	62.1	0.9	55.8	0.8	55.9	1.3	62.7	1.1
Oaten	OAT5	57.1#	1.9	51.6	0.6	-	-	-	-
Barley	BAR	61.7*	2.5	52.7	0.7	-	-	-	-
Lucerne	LUC7	57.0	0.8	57.9	0.5	-	-	-	-

* 4 animals per hay
\# 5 animals per hay
\+ 7 animals per hay

Table 16: *In vivo* organic matter digestibility (OMD%), *ad libitum,* of hays fed across animal species (6 animals per hay except where identified)

Hay	Code	Dairy cows		Sheep		Horses		Steers	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE
Oaten	OAT1	62.5	0.8	53.7	0.8	51.3	0.8	60.7	0.7
Oaten	OAT2	59.1	1.8	55.3+	0.6	55.6	1.4	60.6	1.3
Oaten	OAT3	56.9	1.1	56.4#	0.9	55.7	0.9	62.8	1.1
Oaten	OAT4	56.6*	0.6	49.1	0.7	47.0	1.0	56.3	0.4
Lucerne	LUC1	58.9	1.2	57.0	0.4	55.2	1.0	59.2	1.3
Lucerne	LUC6	61.1	0.9	59.0	0.8	60.4	0.9	61.6	0.7
Persian clover	PER	70.0*	0.4	67.1	0.3	69.1	1.5	70.9	0.7
Italian ryegrass	IRG	64.0	0.9	57.4	0.7	59.0	1.0	65.0	1.0
Oaten	OAT5	58.5#	2.2	52.3	0.5	-	-	-	-
Barley	BAR	63.6*	2.5	54.6	0.8	-	-	-	-
Lucerne	LUC7	61.2	0.8	60.8	0.6	-	-	-	-

* 4 animals per hay
\# 5 animals per hay
\+ 7 animals per hay

Table 17: *In vivo* dry matter intake (DMI, g/day), *ad libitum,* of hays fed across animal species (6 animals per hay except where identified)

Hay	Code	Dairy cows		Sheep		Horses		Steers	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE
Oaten	OAT1	11899	811	785	35	10373	826	6051	343
Oaten	OAT2	14776	699	1026+	18	8576	259	6980	325
Oaten	OAT3	13132	552	1195#	45	10239	538	7478	282
Oaten	OAT4	12076*	895	859	34	8396	1069	6241	356
Lucerne	LUC1	14001	933	1333	61	9260	447	7273	516
Lucerne	LUC6	14674	1416	1388	35	12087	602	8184	733
Persian clover	PER	17175*	436	1322	33	10187	627	7649	641
Italian ryegrass	IRG	13522	473	1049	48	10375	538	6784	515
Oaten	OAT5	11777#	272	868	22	-	-	-	-
Barley	BAR	12050*	771	732	45	-	-	-	-
Lucerne	LUC7	17200	1241	1576	30	-	-	-	-

* 4 animals per hay
\# 5 animals per hay
\+ 7 animals per hay

Table 18: *In vivo* organic matter intake (OMI, g/day), *ad libitum,* of hays fed across animal species (6 animals per hay except where identified)

Hay	Code	Dairy cows		Sheep		Horses		Steers	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE
Oaten	OAT1	11099	759	730	32	9766	748	5616	303
Oaten	OAT2	13639	673	950+	17	8106	254	6418	304
Oaten	OAT3	12292	500	1109#	42	9610	499	6954	250
Oaten	OAT4	11223*	825	798	32	7962	993	5797	320
Lucerne	LUC1	12936	838	1227	57	8684	403	6709	468
Lucerne	LUC6	13521	1310	1264	33	11249	575	7527	680
Persian clover	PER	15563*	421	1164	29	9327	523	6833	563
Italian ryegrass	IRG	12567	434	955	44	9842	547	6222	465
Oaten	OAT5	10954#	272	791	20	-	-	-	-

Hay	Code	Dairy cows		Sheep		Horses		Steers	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE
Barley	BAR	11458*	725	694	42	-	-	-	-
Lucerne	LUC7	16025	1174	1452	29	-	-	-	-

* 4 animals per hay
\# 5 animals per hay
\+ 7 animals per hay

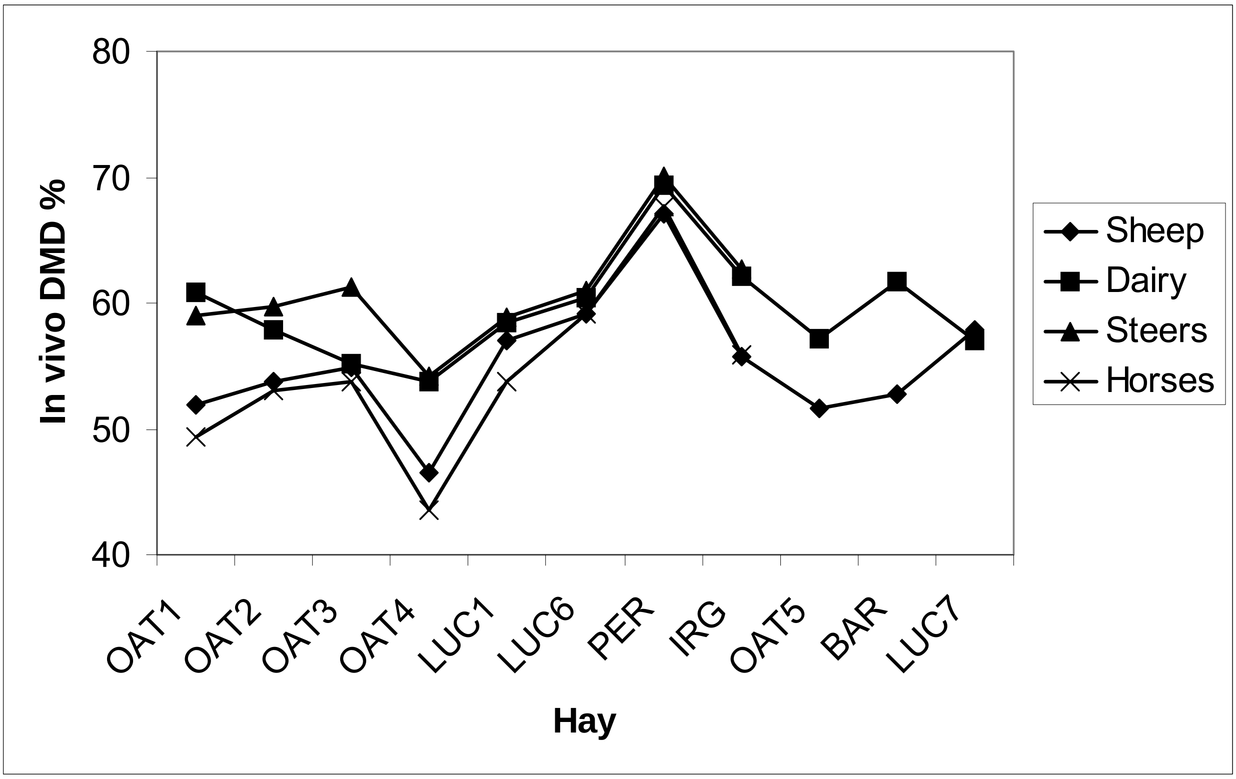

Figure 10: Comparison of *in vivo* dry matter digestibility across animal species

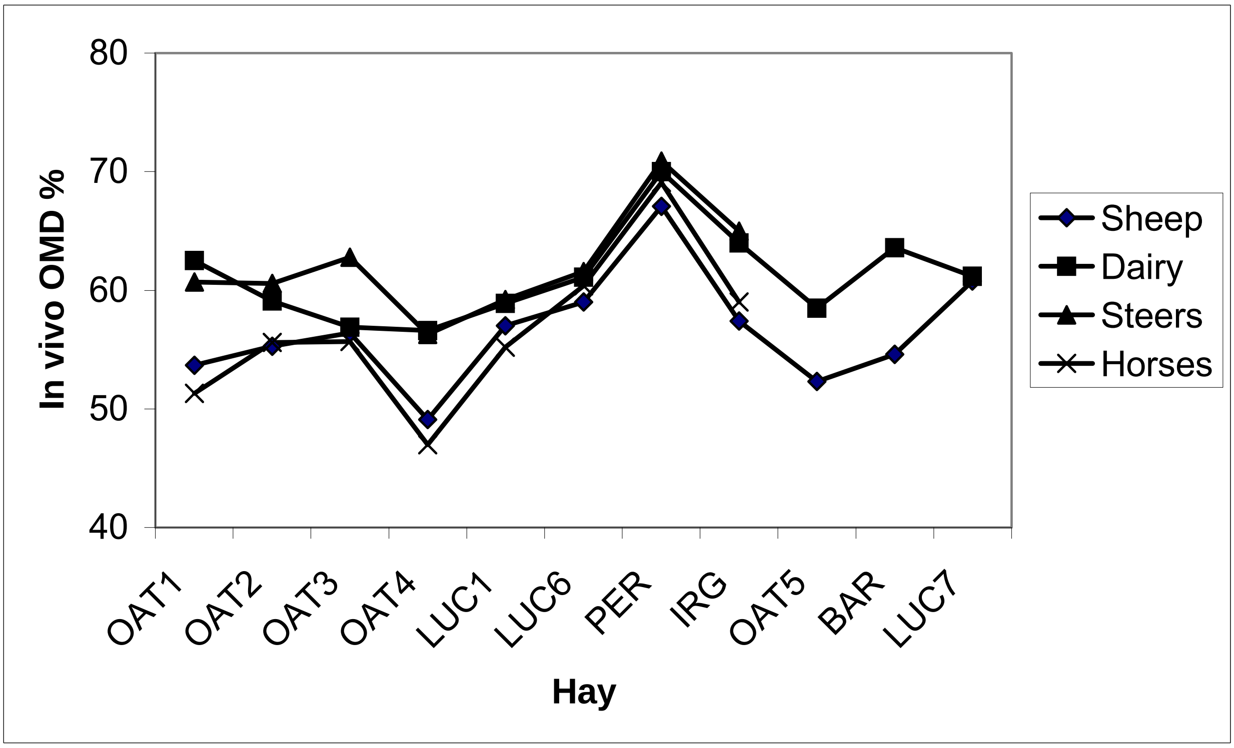

Figure 11: Comparison of *in vivo* organic matter digestibility across animal species

Table 19 shows the results of the statistical comparison of *in vivo* DMD and OMD among the 4 animal species. This comparison is also shown graphically in Figure 12.

Table 19: Statistical comparisons of *in vivo* dry matter digestibility (DMD%, *ad libitum*) and organic matter digestibility (OMD%, *ad libitum*) among animal species

Species comparison	Correlation (r)		t-probability (P) (precision test)[1]		t-probability (P) (bias test)[2]	
	DMD	OMD	DMD	OMD	DMD	OMD
Sheep vs Horses	0.99	0.98	0.045	0.019	0.051	0.617
Sheep vs Steers	0.93	0.91	0.049	0.383	0.001	<0.001
Sheep vs Dairy	0.73	0.74	0.164	0.268	0.003	<0.001
Dairy vs Horses	0.82	0.80	0.069	0.146	0.010	0.016
Dairy vs Steers	0.88	0.87	0.776	0.975	0.205	0.244
Horses vs Steers	0.95	0.92	0.004	0.017	0.001	0.002

[1] If P≤0.05, the precision of measuring DMD or OMD is different between the two animal species
[2] If P≤0.05, there is a bias between the two animal species in DMD or OMD

Table 20 shows the results of the statistical comparison of *in vivo* DMI and OMI among the 4 animal species. This comparison is also shown graphically in Figure 13.

Table 20: Probability of the approximate chi-square statistic derived to test the hypothesis that means of *in vivo* dry matter intake (DMI, g/day, *ad libitum*) or *in vivo* organic matter intake (OMI, g/day, *ad libitum*) from one animal species were directly proportional to means of these measurements from another animal species

Species comparison	Approximate chi-square statistic		Probability[1]	
	DMI	OMI	DMI	OMI
Sheep vs Horses	37.7	38.4	<0.001	<0.001
Sheep vs Steers	11.9	11.5	0.10	0.12
Sheep vs Dairy	32.7	32.5	<0.001	<0.001
Dairy vs Horses	19.5	18.6	0.01	0.01
Dairy vs Steers	5.8	6.2	0.56	0.52
Horses vs Steers	8.4	8.5	0.30	0.29

In all cases, degrees of freedom = 7

[1] If P≤0.05, the approximate chi-square statistic is significant, and the DMI or OMI means from one species are not directly proportional to those from another species

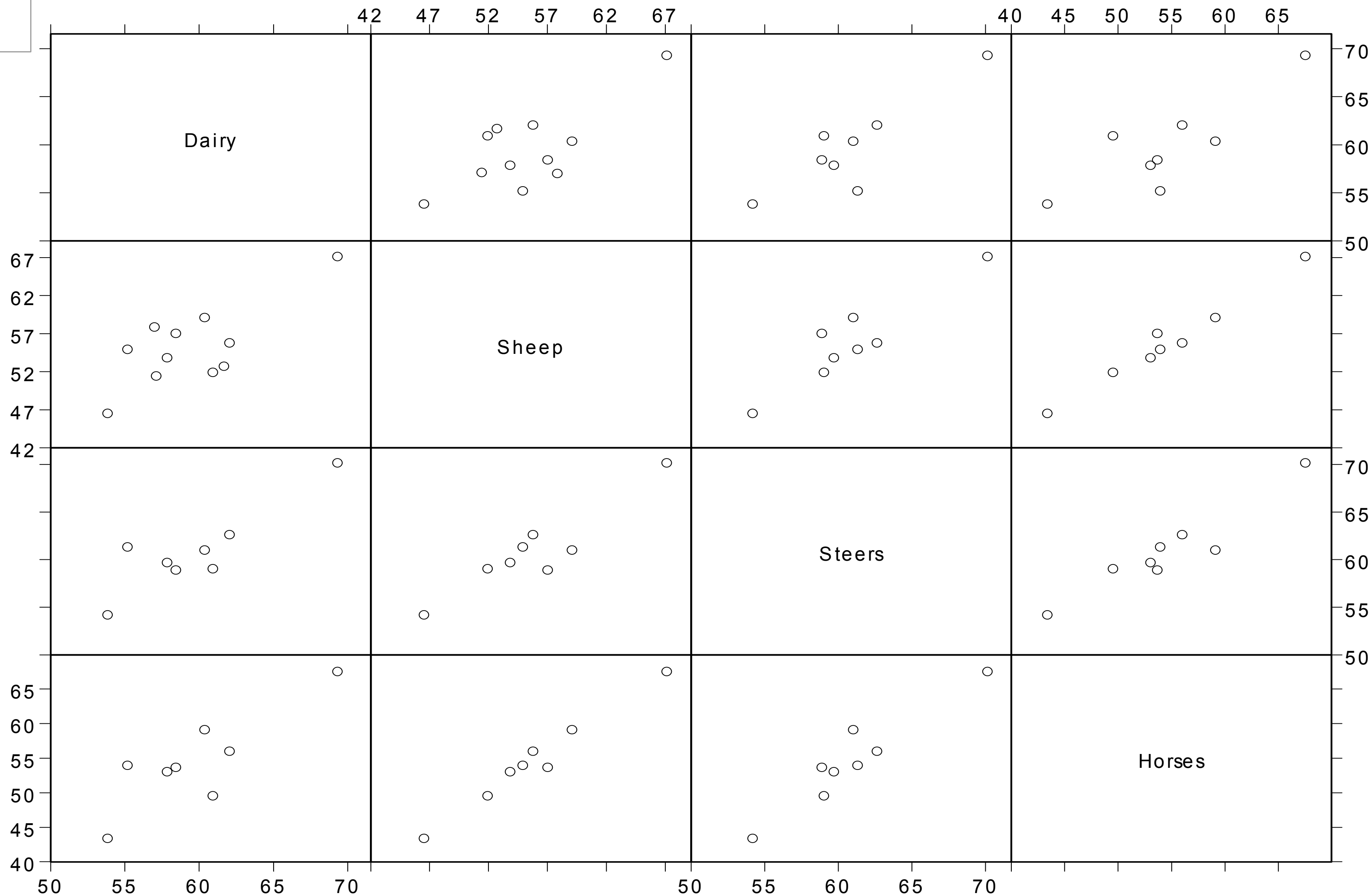

Figure 12: Plots showing the comparison of *in vivo* dry matter digestibility (DMD%) among the 4 animal species

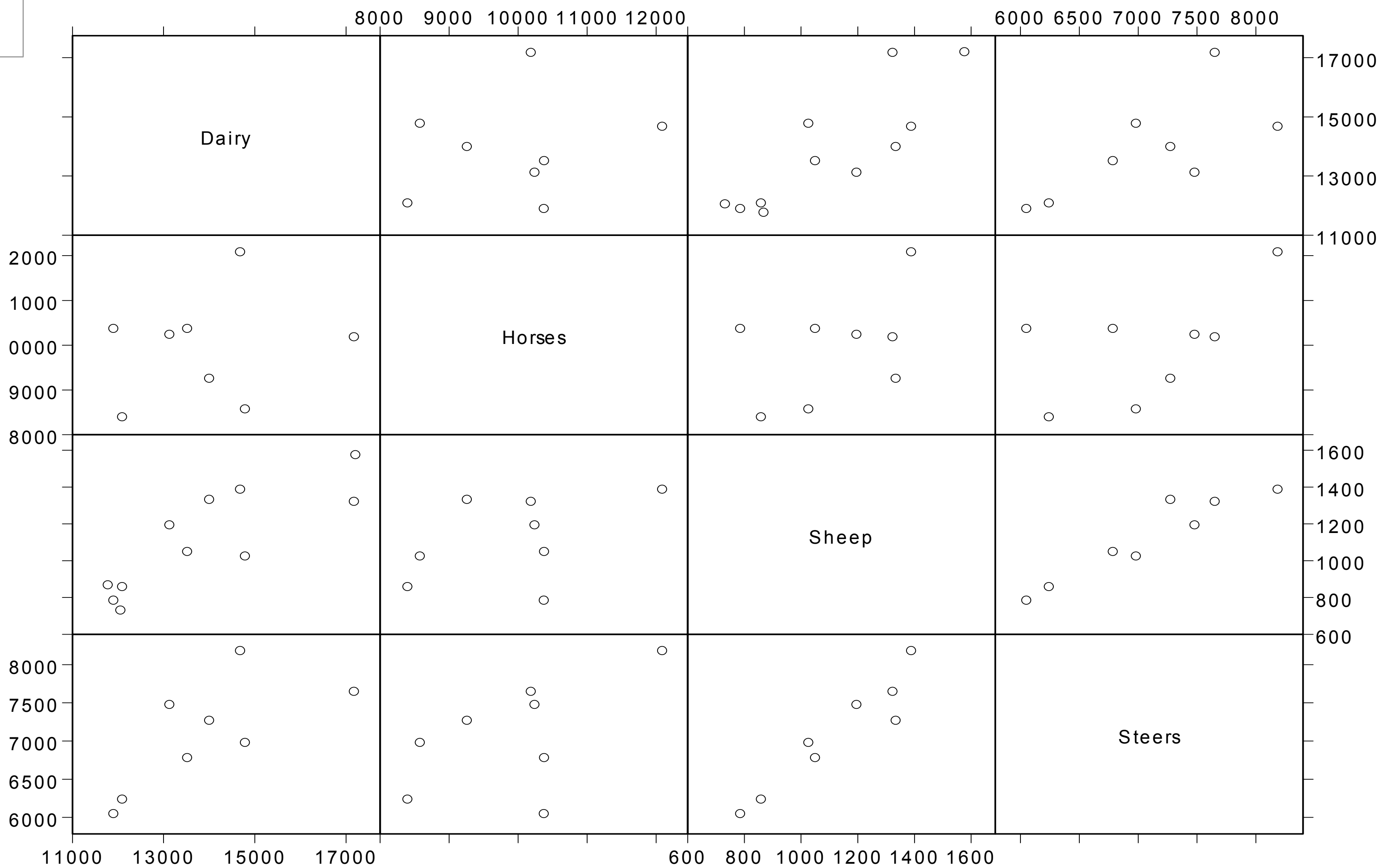

Figure 13: Plots showing the proportionality of the means of *in vivo* dry matter intake (DMI, g/day, *ad libitum*) among the 4 animal species

Table 21 shows the shear energy values, measured by CSIRO, WA, on composite hay samples taken during the digestibility/intake trials.

Table 21: Shear energy values, kJ/m^2, (CSIRO, WA) on composite hay samples from the digestibility/intake trials across animal species

Hay	Code	Dairy cows	Sheep	Horses	Steers
Oaten	OAT1	12.79	11.53	13.12	13.89
Oaten	OAT2	9.87	13.51	11.17	13.27
Oaten	OAT3	10.99	11.25	10.77	10.58
Oaten	OAT4	15.94	16.89	13.58	14.02
Lucerne	LUC1	12.56	11.82	10.97	13.53
Lucerne	LUC6	12.77	10.42	8.98	13.19
Persian clover	PER	-	9.49	10.75	11.48
Italian ryegrass	IRG	-	12.51	12.88	12.63
Oaten	OAT5	12.21	-	-	-
Barley	BAR	12.28	12.51	-	-
Lucerne	LUC7	11.92	10.89	-	-

5. DISCUSSION

Table 2 indicates that, for most samples, there was reasonably good agreement between the values obtained for CP, DMD and NDF on one-off samples submitted by owners of the hay and mean values obtained on numerous core samples taken from bales after purchase. However, wide discrepancies were observed in some measurements for hays LUC2, LUC5, OAT6 and STR. Sampling procedures were the most likely cause, and for example, it was later found that the original sample of LUC5 tested was taken from the windrow, rather than the baled hay.

It can be seen from Tables 3, 4 and 5 that there were some significant differences in preference between hays within each animal species, but there was also some overlap. It was noticeable that some hays stood out, with high or low preference across all or most animal species. Among the legumes, the high quality hays LUC5 and PER were frequently preferred, and when fed to dairy cows and sheep, LUC2 and VET were ranked lowest in preference. These latter two hays were of poor quality, and were contaminated either with soil or mould. They were replaced with LUC6 and LUC7 in subsequent trials. Among the cereals, OAT3 and OAT7 were frequently preferred, whilst STR was consistently ranked lowest in preference, often followed by OAT4.

It was observed that, in the case of horses, the Balansa clover hay (BAL) was ranked lowest of the legume hays (Table 3) and also quite low in the crossover trial (Table 5). It was also ranked lower than most other legumes in short-term intake rate for horses (Table 6). This was in accordance with some anecdotal evidence from the horse industry.

Research in the USA has found that that ruminants prefer lucerne hay cut in the afternoon over that cut in the morning (Fisher *et al.* 2000). An opportunity existed to confirm this finding during the preference measurements in this project. LUC3 and LUC4 were 2 lucerne hays cut from the same paddock on the same day, with LUC3 cut in the morning and LUC4 cut in the evening. From Table 3, it is apparent that for dairy cows and steers, there was no difference in preference between the two hays, and that sheep and horses actually preferred the morning-cut to the evening-cut hay. In the case of short-term intake rate, there was a similar trend, except that dairy cows ate more of the evening-cut hay (Table 6).

An important objective of this work was to establish whether the ranking in preference between hays was the same for all four animal species. Table 8 indicates clearly that this was not the case. The hypothesis was that preference means from one animal species were directly proportional to preference means from another animal species. For this to be true, the approximate chi-square statistic for each comparison would not be significant. However, Table 8 shows that in all possible comparisons between species, the chi-square statistic was highly significant ($P<0.001$). Hence, within the limits of experimental error, there were no constants with which to multiply the preference means from a particular species to concur with the preference means from another species. This suggests that it is not possible for sheep to be used as the "model" to estimate preference rankings for hay in dairy cows, steers or horses.

The ranking of short-term intake rate (Tables 6 and 7) showed some similarities to preference ranking, but there was less difference between hays, particularly for legume hays eaten by sheep and horses. Despite this, there was a strong relationship between preference and short-term intake rate across all animal species (Table 9), with between 74% and 90% of the variance in preference being accounted for by short-term intake rate.

The resources available in this project were insufficient to undertake a comprehensive study of the characteristics of hay which influence preference by animals. However, the simple linear regressions derived between preference means and various nutritive value measurements (Table 10 and Figures 2 to 9) show that, in general, DMD and NDF were more strongly correlated with preference than other measurements. CP was apparently a very poor indicator of preference. WSC was also found to be a poor indicator of preference in the case of cereal hays, despite being commonly reported as positively correlated with preference.

Some caution is warranted in interpreting the apparent relationships between preference and the estimates of nutritive value. The same relationships may not necessarily be observed in a set of hays of more similar quality. The hays used in this project were deliberately selected to be as diverse in quality as possible. Tables 11 to 14 also indicate that hay is a heterogeneous product, with considerable variation in quality possible both between and within bales of a given hay. There was a tendency for greater variability in the quality measurements (Tables 11 to 14) within the legume hays than within the cereal hays. This may partly explain what appears to be a greater variation in preference for the legume hays than for the cereal hays across animal species.

Values for *in vivo* DMD for a variety of hays, measured at the *ad libitum* level of intake, varied from 54 to 69% (dairy cows), 47 to 67% (sheep), 44 to 68% (horses) and 54 to 70% (steers) (Table 15). Similar but slightly higher ranges were found for *in vivo* OMD (Table 16). It was evident from Figures 10 and 11 that DMD or OMD of many of the hays was lower in sheep and horses than in dairy cows and steers, especially the cereal and grass hays.

The statistical comparisons of DMD or OMD between the various animal species showed that, in general, correlations were high (Table 19) with the exception of sheep vs dairy cows. This lower correlation could indicate variability in a given hay or hays between the two species, and this could affect the results of the precision test. Table 19 indicates that the precision of measurement was sometimes different between two given animal species, and there was often a bias. Statistically, DMD and OMD of the hays fed were the same for dairy cows as for steers, despite the apparently different values for OAT3 (Figures 10 and 11). This is an important finding, as it suggests that beef steers can be used in future to produce DMD or OMD values on hay which can also be used for dairy cows.

The comparison between sheep and horses indicates that, for DMD, there were significant differences in precision and bias, but only just. If OAT4 had been omitted, there would have been no significant difference between sheep and horses. This contrasts with the findings of Smolders *et al.*(1990), who found that digestibility of roughages in horses was lower than in sheep. For OMD, there was no bias between sheep and horses, but precision differed, showing that the measurements with horses were more variable. The different results for bias between DMD and OMD for the sheep-horse comparison reflects the problem experienced with soil contamination of feed refusals collected from the horses. This problem did not exist when digestibility was expressed as OMD.

Other comparisons showed that horses were significantly different to steers in precision and bias for both DMD and OMD. The same result was found for the sheep-steer comparison in the case of DMD. For the sheep-dairy cow and horse-dairy cow comparisons, precision was statistically the same but bias was large. This was also the case for OMD in the sheep-steer comparison.

Based on the hays fed in this project, *in vivo* digestibility values of hays fed to sheep cannot necessarily be applied to steers, dairy cows or horses without great caution, even though the relative rankings in some cases appear similar. However, the tests for precision and bias should be considered together. Differences in precision between animal species are the more serious, and Table 19 shows that for the sheep-dairy cow comparison, precision was not a problem, and was marginal for the sheep-horse and sheep-steer comparisons. Whilst there were large biases between sheep and steers, and between sheep and dairy cows, it may be possible to adjust for bias if precision is similar.

The two firm conclusions from Table 19 are that digestibility values from steers can be used for dairy cows, and that those from steers cannot be used for horses.

When the same statistical procedure used to compare preference rankings between animal species was applied to *in vivo* DMI and OMI, a different result was obtained. Table 20 indicates that proportionality did occur in some cases. In the dairy cow-steer and horse-steer comparisons, the approximate chi-square statistic was not significant for both DMI and OMI. This means that the DMI and OMI means from steers were directly proportional to DMI and OMI means from both dairy cows and horses. A similar proportionality was also apparent in the sheep-steers comparison, but it was not strong. For all other comparisons, the approximate chi-square statistic was significant ($P \leq 0.01$) and thus proportionality did not occur. The lack of proportionality between sheep and dairy cows agrees with the results obtained in a study on grass silage (Cushnahan *et al.* 1994).

These results suggest that, on the basis of the hays fed in this study, it is possible for DMI and OMI data from steers to be used as a basis to estimate DMI or OMI values for hay in dairy cows and horses. In the case of dairy cows, similar results were found by researchers in Northern Ireland, where intake potential of grass silage by dairy cows is estimated from intake values from beef cattle, as part of the Hillsborough Silage Evaluation System (Agnew and Steen 1997).

6. IMPLICATIONS

The measurement of preference for different hays across four different animal species in one experiment represents the first comprehensive attempt in Australia, and perhaps the world, to rank hays in this manner. The results obtained will have particular relevance to the export hay industry, where Japanese clients in particular regard animal preference for hay as an important indicator of quality.

There were clear differences in preference among both the legume and cereal hays within each animal type. However, it was equally clear that, for the hays fed in this trial, the preference ranking of hays was different for all animal species. The implication of this finding is that it is not possible for sheep to be used as the "model" to estimate preference rankings for hay in dairy cows, steers or horses. This could have an unfortunate impact on future research in this field, as it would have been an attractive option to measure preference for large numbers of hays using sheep only, due to the lower costs involved in sheep measurements compared with those for other animal species.

To offset this disadvantage, however, it may be possible to measure short-term intake rate across all animal species as an alternative to preference, due to the reasonably close relationship found between these two measurements. This would involve less work and time, as one hay only, instead of two, can be offered to each animal for half the time needed in the measurement of preference.

Across a range of hay quality, DMD and NDF are likely to be good predictors of preference, unlike water-soluble carbohydrates, which appears to perform poorly. Whether this holds true for hays of similar quality requires further investigation. If it does, the value of water-soluble carbohydrates as an indicator of preference for cereal hays warrants a reappraisal by industry. However, there were insufficient resources to undertake a comprehensive study of relationships between preference and nutritive value, and some caution is needed in any research with hay, due to the variation in quality which can occur within a given hay, because it is such a heterogeneous product.

A major outcome of this project was the production of a set of hay samples with measured *in vivo* digestibility and voluntary intake values for four different animal species. This is a valuable addition to the 16 samples with similar data obtained with sheep only, from former RIRDC project DAV-104A. These combined samples will boost the capability of Australian fodder testing laboratories to accurately predict digestibility of fodder for sheep, steers, dairy cows and horses. For the horse industry in particular, this is a major advance, as in general there have been few if any fodder samples available to calibrate laboratory measurements of digestibility (and hence DE) for horses. It is hoped that, like the previous 16 samples, these hays can become the property of AFIA and be made available to appropriate fodder testing laboratories to standardise their techniques.

An important finding for the beef and dairy industries from this project was that the digestibility of the hays fed to steers was statistically the same as for dairy cows. Because it is easier and cheaper to measure digestibility with steers than for dairy cows, this represents a major cost saving and suggests that it is not necessary to conduct these measurements with dairy cows in future. Instead, digestibility could be measured on a larger number of fodders using steers, with the results also able to be used for dairy cows.

Whilst it was very clear from this study that digestibility measurements on hay using steers cannot be used for horses, the applicability of sheep digestibility values to horses, steers and dairy cows was more equivocal. Obviously, there would be great benefits to research and to industry if all future digestibility measurements on fodder could be made with sheep only. Apart from one cereal hay, the digestibility of the hays fed to sheep was statistically the same as for horses. Further work is required to confirm this, and a positive result would mean that laboratory predictions for digestibility based on sheep data could be used with some confidence for horses, greatly benefiting the horse industry.

Similarly, provided an adjustment is made for bias, this study showed that it may be possible to use sheep-based digestibility measurements for dairy cows. Again, this requires further study.

Caution is required in interpreting the dairy cow digestibility results, as they were generated using diets consisting entirely of hay, which represent atypical feeding conditions. Lactating dairy cows require a more balance diet, and different *in vivo* DMD or OMD values may have been obtained if the hay had been included as part of a diet containing grain and pasture. For many of the hays fed, the energy and protein requirements of the cows were not met, and digestibility is likely to be reduced on low protein diets.

Unlike the results for preference, it was clear from the voluntary intake measurements that the intake values measured on the hays fed to steers could be used as a basis to estimate intake values for both dairy cows and horses. Again, because such measurements are easier to make with steers than the other two animal species, this suggests that it is not necessary to measure intake using dairy cows or horses, another significant cost saving for future studies on fodder quality.

7. RECOMMENDATIONS

Preference and short-term intake rate were measured on a total of 18 hays across four animal species in this project. This was a comprehensive first attempt, but it is strongly recommended that these measurements be made on a much larger set of hays. The preference ranking of a new set of cereal hays, closer together in nutritive value than the hays in this project, is likely to be of particular interest to cereal hay exporters. Given that mixed pasture hay is produced in greater quantities than any other hay in Australia, it is also recommended that preference measurements be made on selected hays of this type.

On the basis of the preference results found in this project, it is recommended that either preference or short-term intake rate be measured specifically using the animal species of interest in future trials. For example, it is not appropriate to conduct these measurements with sheep if the ultimate objective is to determine preference of hay in dairy cows. If resources are limited, consideration could be given to measuring short-term intake rate only, due to the strong relationship of this measurement with preference.

A comprehensive study is warranted to determine the components of fodder influencing preference. This was not possible in this project, and even if it had been, there were insufficient hays upon which to base an NIR calibration or other laboratory measurements for a robust prediction system of the properties of interest.

The hays with measured *in vivo* digestibility and voluntary intake represent a valuable resource, and large samples of these hays should be carefully prepared and stored, so that they can augment the existing hay “standards” now being managed by AFIA for the benefit of appropriate fodder testing laboratories.

From the results obtained, it is likely that future digestibility measurements on fodder types of interest to the dairy industry can be conducted with some confidence using steers. Resources may not need to be devoted to making these measurements using dairy cows. There is some evidence from this project that digestibility measurements on fodder using sheep may possibly be used for horses and dairy cows under certain conditions. However, more research is needed in this area before a clear recommendation can be made.

If additional digestibility trials are undertaken with lactating dairy cows, consideration is required of the feeding conditions to be used. Clearly, there are associative effects between dietary components (McDonald *et al.* 1989) and diets that do not represent industry practice are best avoided.

On the basis of the results found, it is recommended that future measurements of voluntary intake on fodder of interest to the dairy and horse industries be made using steers.

8. REFERENCES

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9. PLAIN ENGLISH COMPENDIUM SUMMARY

Project Title:	**Objective measurement of fodder quality across animal species**
RIRDC Project No.:	DAV-187A
Researcher:	Peter Flinn, Stephanie Knott, Leo Cummins and Dawn Dalley
Organisation:	Department of Primary Industries Pastoral and Veterinary Institute, Private Bag 105 HAMILTON, Vic 3300
Phone: **Fax:** **Email:**	03 5573 0915 03 5571 1523 peter.flinn@nre.vic.gov.au
Objectives	To measure and compare the ranking of *in vivo* digestibility, total intake, preference and short-term intake rate of a series of hays across beef cattle, lactating dairy cows, horses and sheep, and to use the "standard" fodder samples obtained as a basis for a uniform objective procedure for specification of fodder quality.
Background	Two earlier RIRDC projects (DAV-104A and CSJ-1A) led to broad industry agreement on the major indicators of fodder quality and the standard methods for their measurement, together with a set of 16 "standard" hays to calibrate laboratory estimation of digestibility. However, this work was confined to sheep. The dairy, beef and horse industries need to know if laboratory predictions of fodder quality based on sheep data can be applied across animal species. There is also an industry demand for rapid estimation of relative animal preference for hay.

Project Title:	Objective measurement of fodder quality across animal species
Research	Preference and short-term intake rate were measured with dairy cows, sheep, steers and horses on a set of cereal and legume hays. The ranking of both measurements was compared and correlations were attempted with nutritive value estimates. A smaller set of hays was also fed to all four animal species for measurement of *in vivo* digestibility (DMD) and *ad libitum* intake (DMI), and comparisons made between the species.
Outcomes	Within each animal species, there were significant differences in preference between hays, but also some overlap. The preference ranking between hays was clearly different across animal species. There was a strong relationship between preference and short-term intake rate. For the specific set of hays studied, laboratory estimates of DMD and neutral detergent fibre (NDF) appeared to be better indicators of preference than either crude protein (CP) or water-soluble carbohydrates (WSC). *In vivo* DMD of the hays measured were the same for dairy cows as for steers, but those for horses were different to steers. *Ad libitum* DMI of hay by steers was directly proportional to that for both dairy cows and horses.
Implications	This project has shown that it is not possible for sheep to be used as a model to estimate preference rankings of hay in dairy cows, steers or horses. Across a range of hay quality, DMD and NDF are likely to be better predictors of preference than CP or WSC. A new set of hay "standards", with measured *in vivo* DMD and DMI across four animal species, is now available as a basis for laboratory prediction of these parameters in unknown samples. It appears that future *in vivo* DMD measurements on hays intended for dairy cows can be made with steers, representing a considerable cost saving. It is not fully clear from the limited data obtained whether *in vivo* DMD measurements on fodder using sheep can be used for the other animal species. It may also be possible to use steers for measuring *ad libitum* intake on hays intended for either dairy cows or horses.
Publications	Knott S.A., Cummins L.J., Dalley D., Flinn P.C., Kearney G. and Hannah M. (2002). Preference rankings for legume and cereal hays across livestock species. Animal Production in Australia 24: 320. Knott S.A., Cummins L.J., Dalley D., Flinn P.C., Kearney G. and Hannah M. (2002). The relationship between preference and short-term intake rate for legume and cereal hays. Animal Production in Australia 24: 321. Hannah M., Reynolds J., Kearney G., Flinn P.C., Knott S.A. and Dalley D. (2002). Determining hay preference in the presence of treatment competition. Proceedings GENSTAT Conference, Perth, WA.