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Faecal NIRS for predicting growth rate in grazing cattle

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PART 1

ABSTRACT

NAP3.116: Predicting growth performance using NIRS

MLA funding support through NAP3.116 was provided to assist in the development of faecal NIRS technology for predicting growth rate in cattle. Specifically, the funding was allocated to cover the costs of processing and NIRS analysis of faecal samples derived from small herds of growing cattle weighed at regular 4-week or 6-week intervals (monitor herds). Faecal samples, bulked within herds, were collected at twice the weighing frequency. Growth rates co-incident with the time of faecal sampling were calculated from liveweight gain curves and calibration equations for predicting growth rate were developed by relating faecal spectra to measured growth rates using ISI software and MPLS regression.

Overall, samples and data from 32 herd-years (one herd year = faecal samples and data from one monitor herd over 12 months) comprising 629 faecal samples collected over a four year period and from 5 different sites were included in the calibration set. Calibration equation statistics were acceptable with respect to the Standard Error of Calibration and the Standard Error of Cross Validation. However, validation tests carried out during the course of the project indicated a substantially larger calibration set will be required to improve predictive accuracy on samples from populations not included in the calibration set. Even with a greatly increased calibration set it may not be possible to develop a single calibration equation that can be applied usefully across all locations and pasture communities of northern Australia. The development of a number of “local” equations may offer a practical alternative.

There are sufficient samples and data on hand to double the size of the calibration set and to increase sites sampled from 5 to 15. Collection from 18 monitor herds at 10 different locations is continuing.

PART 2

EXECUTIVE SUMMARY

NAP3.116: Using faecal NIRS to predict growth rate in grazing cattle

Previous research conducted in project CS.253 (*Predicting diet digestibility and crude protein content from the faeces of grazing cattle*) provided results that suggested faecal NIRS (Near Infrared Reflectance Spectroscopy) prediction of growth rate in cattle might be feasible with beneficial applications in the grazing beef industry. An initial investigation using faecal samples and liveweight gain data from an experimental herd at Lansdown Research Station produced results that strengthened such a notion. Further work was deemed worthwhile as the required methodology is relatively inexpensive particularly where data and samples could be acquired from existing grazing trials.

MLA funding was provided by way of project NAP3.116 to encourage the development of the technology, primarily in support of the necessary faecal NIRS analyses. Several monitor herds were established on sown pastures at the CSIRO Lansdown Research Station near Townsville. In addition cattle in selected treatments of Queensland DPI grazing trials at Glentulloch near Injune, Galloway Plains near Calliope, Wambiana south of Charters Towers, and Rosebank near Longreach, were designated as monitor herds. Sampling requirements and measurements merely involved weighing the cattle at regular intervals of 4-6 weeks together with faecal sampling on weigh days (rectal grab samples) and mid-way between scheduled weigh days (sampling from fresh faecal pats). NIR spectra were obtained from dried, ground faecal samples. Reference values for growth rate were calculated from the cumulative liveweight gain curves for each monitor herd.

Calibration equations were developed in progression using a step-wise process of calibration, validation, expansion and recalibration. The first three calibration equations were developed using data from two monitor herds at Lansdown, firstly with the herd data kept separate and then by combining the two sets. The results for all three equations were most encouraging as indicated below.

Calibration equation statistics for predicting growth rate from faecal NIRS

Calibration Equation	Herd	No. samples	SEC[1] g/d	SECV[2] g/d	RSQ	Range in ADG (g/d)
ADG(1).EQA	Herd 1	95	63	81	0.97	40 – 1500
ADG(2).EQA	Herd 2	94	63	75	0.96	160 - 1500
ADG(3).EQA	1 + 2	188	50	61	0.98	40 - 1500

[1] Standard error of calibration
[2] Standard error of cross validation

As data sets (faecal spectra and reference growth rates) from different sites/herds became available, each set was used first to test the predictive accuracy of the current, existing equation (validation test) and then to expand the calibration set for recalibration purposes. In this way the calibration set was built up to the current level of 629 samples comprising 32 herd-years (one herd-year represents the samples from a single monitor herd of one year’s duration) of information spanning the period June 1997 – May 2001 and 5 different sites.

None of the calibration equations developed to date has provided accurate predictions of growth rate when applied to samples unrelated to those in the calibration set (i.e. samples from different locations or different years) but there has been a clear trend for the predictive accuracy to improve as the calibration set expands. On the other hand, the actual calibration statistics (SEC, SECV, and RSQ) deteriorated with the expansion of the calibration set such that the SEC of the most recent equation stands at approximately 140 g/d. In the broad context this indicates that the probability of predicted growth rate being within 100 g/d or 200 g/d of actual growth rate is limited to approximately 60% and 85% respectively.

One of the difficulties with developing robust calibration equations for predicting growth rate is that of determining valid reference values from the regular weighing of cattle. Gut-fill and total body water account for a high proportion of the liveweight of cattle and changes in tissue weight (growth) that occur between successive weighings will generally be confounded to a greater or lesser degree by disproportionate changes in gut fill and body water. This means that "measured growth rates" used as reference values in developing calibration equations are likely to include a substantial error component and this will contribute to poor calibration statistics. Thus, the calibration equations are almost certainly somewhat better than the statistics indicate (Coates 2002). Similarly, validation tests are likely to exaggerate prediction errors.

Some other problem areas were identified. When cattle were in a compensatory growth phase, predicted growth rate was usually under-estimated. Conversely, when cattle were in a phase of rapid weight loss, predicted growth rate was often over-estimated (i.e. predicted weight loss was under-estimated). There was also an interaction between animal age/weight and the prediction errors. The errors were greater in older or heavier cattle, least in weaners. It is logical, too, that condition would also have an effect since the higher the condition score the greater will be the rate of weight loss when nutritional status declines. In a test case involving steers at Lansdown, predicted growth rates at points in time were often markedly different from measured growth rates, but calculated cumulative liveweight gain over an extended period was agreeably close to observed liveweight gain.

The weight of cattle relative to mature size has an effect on potential liveweight gain. Thus, annual liveweight gain of young cattle is usually greater than that of older, heavier cattle grazing the same pasture. It was satisfying to observe that faecal NIRS apparently coped with this age/weight/maturity effect on growth rate. Where weaner, yearling, and 2-year-old steers grazed the same pasture, predicted growth rates were usually highest for the weaners and lowest for the 2-year-old steers and the differences, when converted to cumulative liveweight gain, were consistent with the observed differences.

Faecal NIRS for predicting growth rate in cattle is not yet sufficiently developed to be considered a useful tool for beef producers. Validation tests to date have demonstrated an unacceptable level of predictive accuracy for samples unrelated to those in the calibration set. Although validation tests have shown a trend for continued improvement in predictive accuracy as the calibration set expands, it appears that substantial further expansion will be needed to develop a robust, useful, calibration equation. At this stage it cannot be determined whether an expanded calibration set will, in fact, meet the predictive accuracy required for the technology to be of practical benefit to the industry. Current indications are that a single calibration equation for use across all localities and vegetation types may be beyond the scope of the technology. However, "local" equations for application in designated situations may provide a useful alternative. It is estimated that there are sufficient samples and data on hand to almost double the current calibration set and to increase the sites covered from 5 to 15. Moreover, collection from 18 monitor herds at 10 different locations is continuing.

CONTENTS

BACKGROUND

Project CS.253 (1995-98) established that faecal NIRS could be used to predict dietary attributes (dietary crude protein, digestibility and dietary non-grass proportions) in free grazing cattle. The benefits of a simple, rapid and inexpensive technology that enables diet quality of free grazing cattle to be estimated with reasonable accuracy are quite obvious and a range of applications has been suggested (Coates 1999, 2000). Some applications depend on deriving an estimate of animal performance via a nutritional model using the predicted diet quality and other factors that influence performance. With respect to dietary attributes, most nutritional models are driven by protein and digestibility data. At present however, there is no nutritional model for calculating growth rate from diet quality attributes that is suitable for cattle grazing pastures in the northern half of Australia.

If one accepts that faecal NIRS analysis can reliably predict the protein and energy status of the diet (and this necessarily demands that faecal composition is highly correlated with diet composition), and if dietary protein and energy are the major nutritional determinants of growth rate, then it follows that it may be possible for growth rate of grazing cattle to be predicted directly by faecal NIRS analysis rather than inputting faecal NIRS derived dietary attributes into a nutritional model. Obviously there are other nutritional factors, as well as a range of non-nutritional factors, that influence growth rate (Table 1). Therefore, any prediction of growth rate by faecal NIRS analysis would most likely presuppose a given context in which the prediction may be considered valid. The “given context” would be one in which (i) there were no external limitations (nutritional or non-nutritional) to performance other than the protein and energy status of the diet and (ii) the prediction applied to a specific class of animal with respect to growth potential (genotype, sex, weight, age and condition).

Table 1. List of nutritional and non-nutritional factors that may influence growth rate

Nutritional factors
Protein
Energy (digestibility and voluntary intake)
Other essential nutrients (e.g. vitamins and minerals)
Amount and accessibility of forage on offer
Toxic compounds in the diet
Water quality

Non-nutritional factors
Disease and parasites
Climatic stressors (e.g. temperature, humidity, wind, rain etc)
Class of animal (genotype, sex, age, weight, condition, temperament)

There is the possibility, however, that the “given context” could be of lesser importance if there were, in the faeces, an endogenous compound with a concentration related to growth rate.

The hypothesis that faecal NIRS can be used to predict growth rate in grazing cattle can be readily tested. The only requirement is to physically measure growth rate and collect faecal samples at regular intervals over any chosen period so that appropriate reference values for growth rate can be assigned to faecal NIRS spectra for calibration and validation purposes.

OBJECTIVE

To develop faecal NIRS calibration equations for predicting growth rate in grazing cattle and to assess the predictive reliability of equations.

METHODOLOGY

Sites

Monitor herds were established at sites at different locations in Queensland (Table 2). Each monitor herd consisted of a small group of growing cattle (steers or heifers) grazing a specific pasture type at the relevant site. No specific mineral deficiencies were suspected at any of the sites except for a phosphorus deficiency in some paddocks at Lansdown; this was remedied by phosphorus supplementation.

Management of cattle

For each herd, grazing was continuous over the trial period. Stocking rate was light so that low dry matter on offer would not limit growth rate, i.e. growth rate would be determined by quality of feed on offer, not quantity. Normal husbandry measures were applied so that growth would not be significantly influenced by disease or parasites.

Measurements

Rainfall records were maintained at each site. Cattle were weighed at regular 4-week or 6-week intervals and faecal samples were collected per rectum on weigh days. Faecal collections were made between weigh days by sampling fresh faecal pats in the paddock. On each sampling occasion faecal samples were bulked within herds. Where separate age groups were present, bulking was confined to within age group on weigh days.

Faecal samples were processed using the standard protocol of drying in a forced draft oven at 65 °C and grinding through a Tecator Cyclotec cyclone mill fitted with a 1mm screen. Faecal NIR spectra were derived and stored by scanning 65 °C oven-dry samples in a NIRSystems 6500 spectroscope fitted with a spinning sample cup module.

Cumulative liveweight gain curves were plotted for each monitor herd (or age group within herd) using the average of recorded liveweights. Growth rates (Average Daily Gain (ADG) in grams per day) coinciding with the time of faecal sampling were calculated from the cumulative liveweight gain curves to provide the appropriate reference values for calibration. Where liveweight change was unduly confounded with change in gut fill so that the calculated reference value was deemed to be invalid, the relevant faecal sample was discarded from the calibration set. This occurred most frequently at the beginning of each growing season when the diet changed from dry to green.

Calibration equations were developed with ISI (Infrasoft International) software; math treatment 1,4,4,1 with SNV and detrend in the band width 700 –2500 nm. ; and modified partial least squares (MPLS) regression.

Table 2. Particulars of monitor herds used for generating data for predicting growth rate in cattle (Project NAP3.116)

Herd	Site	Pasture type	Breed	Sex	Age groups	Duration
1	Lansdown	Urochloa/stylo	DM	Hfrs	Weaner	June 97 – Dec 98
2		Urochloa/stylo	DM	Hfrs	Weaner	June 97 – Dec 98
3		Urochloa/stylo	DM	Hfrs	Weaner	July 98 – Aug 99
4		Urochloa/stylo	DM	Hfrs	Yearling	June 98 – Aug 99
5		Urochloa/stylo	DM	Steers	Weaner	June 98 – Sep 99
6		Urochloa/stylo	DM	Steers	Yearling	June 98 – Sep 99
7		Uro/stylo/siratro	DM	Steers	Weaner	Nov 98 – Aug 99
8		Urochloa/stylo	DM	Steers	Weaner	Sep 99 – July 00
9		Urochloa/stylo	DM	Steers	Weaner	Aug 99 – July 00
10		Urochloa/stylo	BR	Steers	Weaner	Nov 99 – July 00
11		Urochloa/stylo	DM	Steers	Yearling	Sep 99 – July 00
12		Uro/stylo/siratro	DM	Steers	Weaner	Sep 99 – June 00
13		Uro/stylo/siratro	DM	Steers	Yearling	Sep 99 - June 00
14		Buffel/stylo	DM	Steers	Weaner	Nov 98 – Oct 99
15		Buffel/stylo	DM	Steers	Yearling	Nov 99 – June 00
16	Glentulloch	Native	BX	Steers	Weaner	Nov 97 – Aug 98
17		Native	BX	Steers	Weaner	Nov 97 – Aug 98
18		Native	BX	Steers	Weaner	Nov 97 – Aug 98
19		Native	BX	Steers	Weaner	Nov 97 – Aug 98
20	Galloway Plains	Native	BX	Steers	Yearling	Aug 99 – May 00
21		Native	BX	Steers	Yearling	Aug 99 – May 00
22		Native/stylo	BX	Steers	Yearling	Aug 99 – May 00
23		Native/stylo	BX	Steers	Yearling	Aug 99 – May 00
24	Wambiana	Native	BX	Steers	Yearling	June 98 – May 99
25		Native	BX	Steers	Yearling	June 98 – May 99
26		Native	BX	Steers	Yearling	May 99 – May 00
27		Native	BX	Steers	Yearling	May 99 – May 00
28		Native	BX	Steers	Yearling	May 00 – May 01
29		Native	BX	Steers	Yearling	May 00 – May 01
30	Rosebank	Mitchell/Flinders	BX	Steers	Yearling	Apr 99 – July 00
31		Mitchell/Flinders	BX	Steers	Yearling	Apr 99 – July 00
32		Mitchell/Flinders	BX	Steers	Yearling	Apr 99 – July 00

DM Droughtmaster
BR Brangus
BX Brahman cross

RESULTS

The assigned growth rates for the 32 monitor herds are presented in Appendix 1.

Calibration equations

First calibration

The first calibration equation, ADG(1) was developed on 1997-98 data from a Lansdown monitor herd of heifers grazing a Urochloa dominant grass/stylo pasture (*Urochloa mosambicensis* in association with *Stylosanthes hamata* cv. verano and *S. scabra* cv. Seca). There were 95 faecal samples in the calibration set (Appendix 1, Herd 1) and the calibration statistics (Table 3) surpassed expectations.

Second calibration

A separate calibration equation, ADG(2), was developed using data from another Lansdown herd (Appendix 1, Herd 2) grazing a similar pasture but with stylo dominance. Calibration statistics were similar to those from Herd 1 (Table 3).

Table 3. Calibration equation statistics for predicting growth rate from faecal NIRS

Calibration Equation	Herd	No. samples	SEC[1] g/d	SECV[2] g/d	RSQ	Range in ADG (g/d)
ADG(1).EQA	Herd 1	95	63	81	0.97	40 – 1500
ADG(2).EQA	Herd 2	94	63	75	0.96	160 - 1500
ADG(3).EQA	1 + 2	188	50	61	0.98	40 - 1500

[1] Standard error of calibration
[2] Standard error of cross validation

Predictions using equation ADG(1) on Herd 2 samples, and equation ADG(2) on Herd 1 samples were also promising (Table 4) but this was to be expected considering cattle in Herds 1 and 2 were similar (breed, sex and age), the pastures were similar except for grass : legume proportions, and the data were collected in the same year.

Table 4. Validation statistics for prediction of growth rate from faecal NIRS

Calibration equation	Herd	SEP[1]	RSQ
ADG(1).EQA	Herd 2	113	0.90
ADG(2).EQA	Herd 1	100	0.92

[1] Standard error of prediction

Third calibration

Calibration equation ADG(3) was developed by combining samples from Herds 1 and 2 and the calibration statistics were an improvement on those for the separate equations (Table 3).

Fourth calibration

All samples in the calibration set of ADG(3) were from heifers grazing stylo-based pastures at Lansdown. Dietary energy status rather than dietary protein was probably the primary limiting factor with respect to growth for much of the year. With grass-only pastures, whether native or introduced, dietary protein is usually the primary limiting factor. Therefore, applying the equation ADG(3) to samples from cattle grazing grass pastures would be unlikely to provide accurate predictions of growth rate. Such a validation test was conducted on samples from monitor herds 16-19 from Glentulloch west of Injune. Indeed, predicted growth rate was poorly related to measured growth rate such that only 35% of the predictions were within 200 g/d of measured growth rate.

However, when the samples from Glentulloch were combined with the samples from Lansdown Herds 1 and 2, the calibration statistics of the resultant calibration equation, ADG(4), were again very satisfactory (Table 5).

Table 5. Calibration equation statistics for predicting growth rate from faecal NIRS

Calibration Equation	No. samples	SEC g/d	SECV g/d	RSQ	Range in ADG (g/d)
ADG(4).EQA	255	77	83	0.95	-300 – 1500
ADG(5).EQA	297	88	99	0.94	-300 – 1500
ADG(6).EQA	368	99	113	0.92	-300 – 1500
ADG(7).EQA	565	139	146	0.87	-430 – 1880
ADG(8).EQA	629	138	146	0.86	-430 – 1880

Fifth and sixth calibrations

The process of validation followed by expanding the calibration set continued with the addition of samples from monitor herds 20-23 from Galloway Plains near Calliope, and herds 24-29 from Wambiana south of Charters Towers. Predicting samples from Galloway Plains with equation ADG(4) was no more successful than predicting samples from Glentulloch with equation ADG(3) since only one third of the predictions were within 200 g/d of measured growth rate. There was a slight deterioration in calibration statistics when samples from Galloway Plains were added to the main calibration set to develop ADG(5) (Table 5). Predicting samples from Wambiana with equation ADG(5) showed some improvement compared with previous validation tests in that nearly 60% of predictions were within 200 g/d of measured growth rate. For all samples where the difference between predicted and measured was greater than 200 g/d, growth rate was under-estimated. There was a further deterioration in the statistics of calibration equation ADG(6) developed after adding Wambiana samples to the main calibration set (Table 5).

Seventh calibration

Lansdown monitor herds 5-15 provided an additional 200 samples for validation and subsequent expansion. Predicted growth rates using equation ADG(6) were still not closely related to measured growth rates but there was an improvement compared with previous validation tests such that 65% of predictions were within 200 g/d of measured growth rate and 35% within 100 g/d. Once again, for the 35% of samples where the difference between predicted and measured value was greater than 200 g/d, 55 of the 70 were under-estimated and, of those 55, all but 5 had measured growth rates in excess of 800 g/d. This bias towards under-estimation at high measured growth rate was clearly associated with compensatory growth early in the wet season. Moreover, the under-estimates of greatest magnitude were associated with compensatory growth of steers in the early wet season of their second year post-weaning (samples from steers in their third year post-weaning were not included).

There was a marked deterioration in the calibration statistics when the extra 200 samples were added to the calibration set for the development of ADG(7). SEC and SECV increased to 139 and 146 g/d respectively and the RSQ value dropped to 0.87 (Table 5).

Eighth calibration

Monitor herds 30-33 at Rosebank near Longreach provided samples from yet another pasture type quite dissimilar to those contributing to the ADG(7) calibration set, especially with respect to the high proportion of non-leguminous forbs in the Rosebank diets. Predictions based on equations ADG(6) and ADG(7) were poorly correlated with measured growth rate. Only about 50% of the predictions were within 200 g/d of measured growth rate and yet again the majority (>85%)were associated with an under-estimation of growth rate. In contrast to the Lansdown samples from herds 5-15, the under-estimation did not appear to be linked to compensatory gain early in the growing season. In fact, predictions based on ADG(6) and ADG(7) for all the Rosebank faecal samples from the winter months June-July-

August of 1999 were under-estimated by an average of 530 and 370 g/d respectively and these accounted for the majority of the underestimates of more than 200 g/d (65% for ADG(5) and 75% for ADG(6)). It was noteworthy that the predicted amount of dietary non-grass during these winter months, presumably forbs resulting from March-April rain, averaged more than 50% (range of 35 –76%).

Calibration equation ADG(8) was developed from the expanded calibration set. Calibration statistics were similar to those for equation ADG(7) and the plot of predicted ADG against measured ADG is shown in Fig. 1. The same data is used in Fig. 2 where relationships are plotted for the different sites in isolation. The axis scales are the same for each graph enabling a visual comparison between sites to be made. Site statistics for the relationship of predicted to measured growth rate are presented in Table 6.

Table 6. Statistical features of predicted values for equation ADG(8) for the different sites (Lansdown has been divided into 3 sub-groups: Herds 1-2 for 1997-98 (Lansdown A); weaner cattle for 1998-2000 (Lansdown B); and yearling cattle for 1998-2000 (Lansdown C)).

Site	SEP (g/d)	Bias (g/d)	RSQ	No. of samples
Lansdown A	97	-23	0.93	192
Lansdown B	148	2	0.89	131
Lansdown C	195	19	0.83	60
Glentulloch	153	0	0.88	67
Galloway Plains	192	-13	0.73	46
Wambiana	141	22	0.83	72
Rosebank	182	-3	0.39	71

Statistical parameters like RSQ are influenced by the range of values within the sample group. Thus the RSQ for the Rosebank samples was very low at 0.39 but the SEP was smaller than for the Lansdown C and Galloway Plains sample groups where the RSQ values were much higher. A more practical guide to the reliability of predictions within the ADG(8) calibration set for the different sites is presented in Table 7. Predictions within 100 g/d of actual growth rate may be considered a reasonable practical limit to attainable accuracy (100 g/d is equivalent to only 3 kg/month) and the results in Table 7 indicate a 60% probability of predictions being with the 100g/d threshold while 86% of predictions were within 200 g/d of measured growth rate. However, the 14% of predictions outside the 200 g/d threshold present a problem. Moreover, the results in Table 6 and Table 7 relate to the calibration set and predictions on samples outside the calibration set are likely to be less reliable.

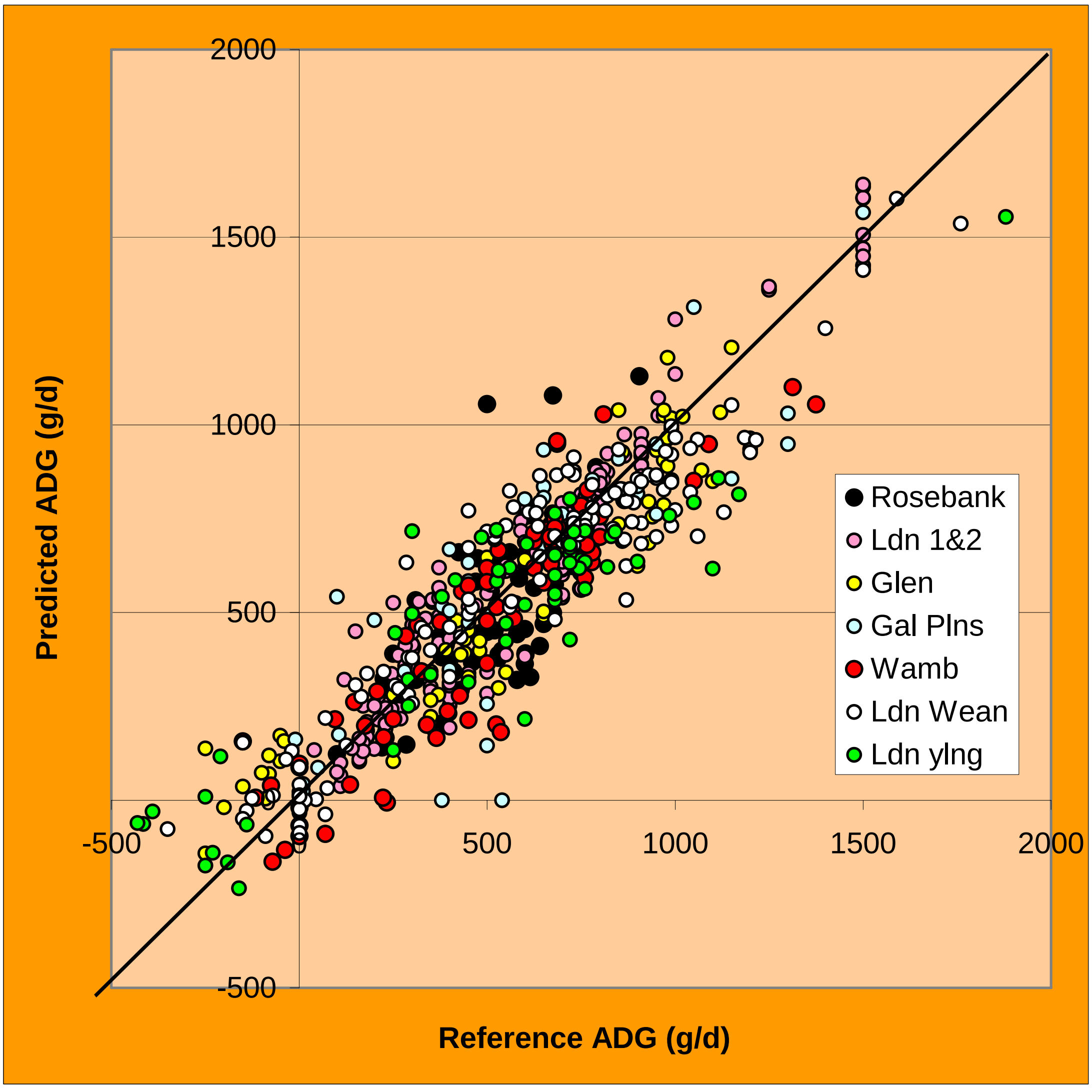

Figure 1. Relation between predicted average daily gain (ADG) and measured ADG for samples in the calibration set of ADG(8).

Rosebank: steers grazing Mitchell grass downs 1999-00
Ldn 1&2: heifers grazing Urochloa/stylo pastures at Lansdown 1997-98
Glen: steers grazing native pasture at Glentulloch 1997-98
Gal Plns: steers grazing native pasture (NP) or NP/stylo at Galloway Plains 1999-00
Wamb: steers grazing native pasture at Wambiana 1998-99
Ldn Wean: weaner steers and heifers grazing sown grass/legume pastures at Lansdown 1998-00
Ldn ylng: yearling steers and heifers grazing sown grass/legume pastures at Lansdown 1998-00

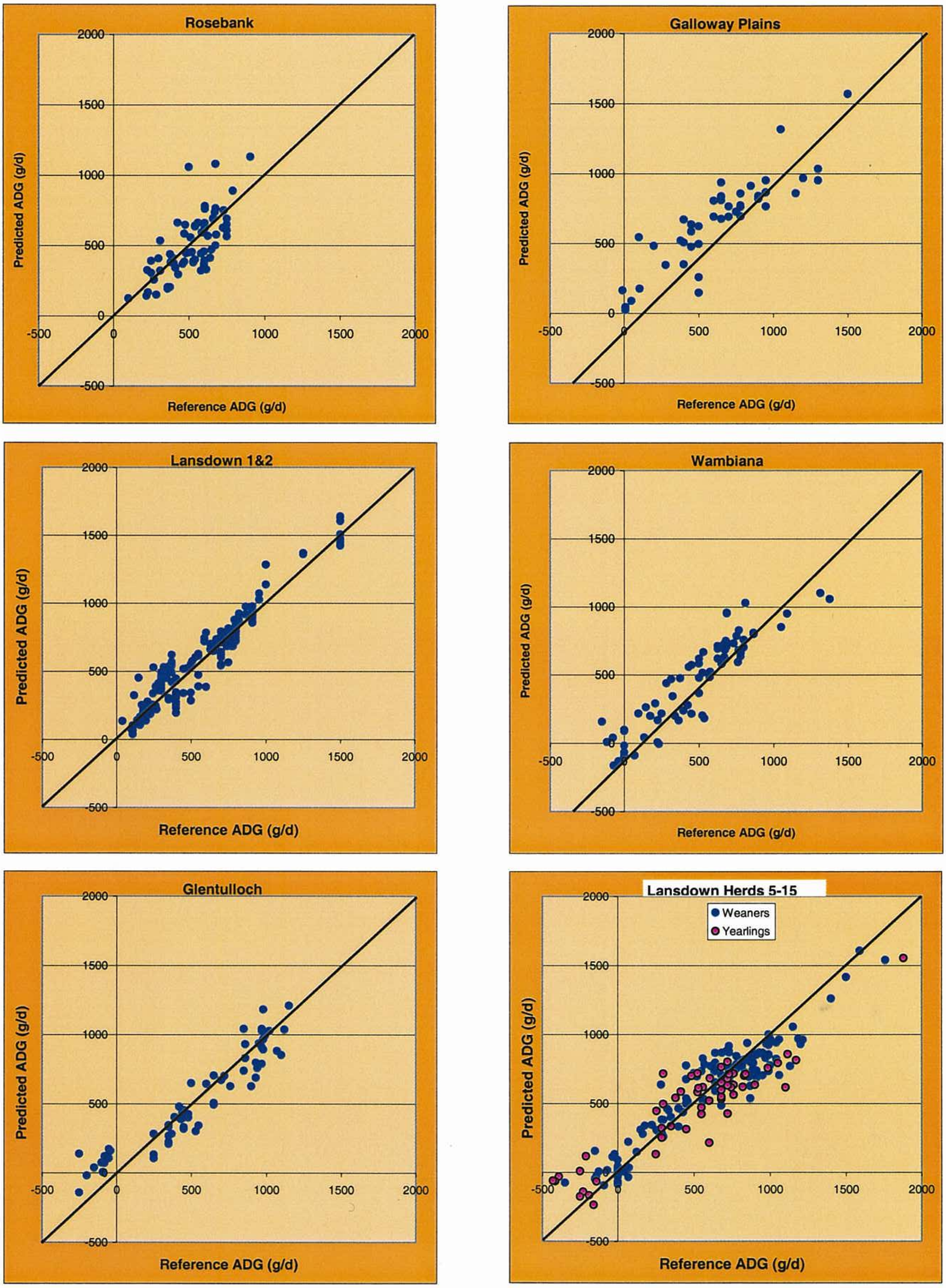

Figure 2. Relation between predicted and assigned ADG for samples in ADG(8).CAL for the separate sites

Table 7. The relationship between predicted and measured growth rates within calibration set AGD(8) showing the percentage of predicted values within 100 g/d or 200 g/d of measured growth rate.

Site	% within 100 g/d	% within 200 g/d
Lansdown A	73	95
Lansdown B	56	82
Lansdown C	43	73
Glentulloch	50	89
Galloway Plains	53	73
Wambiana	56	85
Rosebank	50	84
Total	**59**	**86**

Reliability of predictions. The process of calibration, validation and expansion carried out to date indicates that further expansion of the calibration set is needed if reliable predictions of growth rate are to be achieved. In the step-wise process used so far, predicted daily gains using the most up-to-date equation on batches of samples from new monitor herds have been poorly related to measured growth rate. Nevertheless, there has been a definite trend for the accuracy of the predictions on new samples to improve as the calibration set continues to expand in both number and diversity of samples (sites and years). On the down side, calibration statistics have deteriorated as the calibration set expanded (Tables 3 and 5).

Considering the diversity of factors that influence growth rate (Table 1), many of which are unrelated to diet quality and/or have little or no direct influence on faecal composition, the chances of making consistently accurate predictions of growth rate by means of faecal NIRS may be considered overly optimistic. Apart from the non-nutritional factors affecting growth rate, there are also various nutritional factors that may have little or no effect on faecal composition *per se*, or on the NIR spectral characteristics of dried and ground faeces, or, more specifically, on those parts of the NIR spectra of importance to the current growth rate calibration equation. Of particular significance to this latter category would be (i) nutritional limitations to intake other than limitations due to protein or energy deficits (eg. mineral deficiencies and toxic or inhibitory compounds) and (ii) physical limitations to intake such as dry matter on offer and sward structure. Conversely, there may well be various compounds, hormonal or non-hormonal, that stimulate intake.

Specific problem areas. Some of the non-nutritional factors became very apparent during the course of this work. The 1999-2000 season at Lansdown provided some insight into some such factors. There was a long dry season in 1999 from April to October. Substantial weight losses were recorded in growing cattle from the end of June to early November (50 and 75 kg/hd in No. 8 and No.7 steers respectively). Good rain was received in November (117 mm), December (122 mm) and January (43 mm) and compensatory gains were evident. February and March were characterized by excessively wet conditions (680 mm in February and 260 mm in March) when cattle growth rates declined dramatically despite an abundance of green feed. When the excessively wet period ended there was a return to good growth rates and compensatory gains were again evident during April and May.

Growth rates for the period November to May are presented in Fig. 3 for steers of three different age categories – No.9, No.8, and No.7 steers (approximately 10, 22 and 34 months old in November 1999). The three age groups grazed as one mob and so had equal feed opportunities.

Fig.3 clearly illustrates problems of faecal NIRS predictions of growth rate in relation to:

(i) compensatory gain following periods of nutritional stress
(ii) limitations to weight gain caused by weather conditions
(iii) the interaction of age/weight with (i) and (ii) above.

When compensatory growth is marked it is clear that faecal NIRS predictions of growth rate are under-estimated, at least in older cattle. This was most pronounced in the early wet following severe weight losses during the dry season. It occurred to a lesser extent following the period when weight gains were apparently limited by excessively wet conditions. Conversely, when growth rate is limited by non-nutritional stressors such as protracted inclement weather, growth rates tend to be over-estimated. It may be reasonably inferred, therefore, that faecal NIRS predictions of growth rate are influenced primarily by those faecal characteristics that are determined by diet quality.

The magnitude of either over-estimation or under-estimation of growth rate by faecal NIRS was clearly influenced by age. There was minimal effect in the youngest group of steers where predicted and measured growth rates were similar throughout the entire period. Conversely, the effect was most pronounced in the oldest group of steers where the differences between predicted and measured growth rates were, on occasion, in orders of magnitude. The effect in the steers of intermediate age, while quite pronounced, was considerably less than in the oldest steers.

This age effect was also apparent with respect to predicted weight losses during the dry season. Weaner steers (No.9) maintained weight during the late dry season in September and October and predicted ADG was in good agreement with measured ADG. Yearling steers (No.8) suffered moderate weight losses (eg. measured ADGs of –430 and –250 g/d for September 9 and October 8 samplings respectively) and predicted ADG under-estimated the rate of weight loss. The oldest steers (No.7) suffered weight losses of 600 g/d throughout September and October but predicted losses were less than 100 g/d.

Effect of age on growth rate. As cattle increase in age and weight and draw closer to mature size, growth rates decline. This is due not only to there being a limit to mature size but also to changes in the partitioning of energy into bone, muscle and fat as cattle mature. The effect of steer age on liveweight gain was again well illustrated in the Lansdown experiment where the steers of three age groups grazed as one mob. Liveweight change during the period of common grazing, September 1999 – June 2000, was 176, 168, and 135 kg/hd for the young, intermediate and old steers respectively. This being so, can faecal NIRS prediction of growth rate cope with this phenomenon? The results presented in Table 8 provide evidence that faecal NIRS predictions of growth rate do, in fact, differ between growing cattle of different ages. Not only do predicted growth rates differ but so do the predictions of diet quality (protein and digestibility). The differences in predicted diet quality would explain, at least in part, the differences in predicted growth rate. It is possible, however, that there may be some endogenous metabolite in the faeces that is influenced by either age or actual growth rate and that is influential in the growth rate equation.

Table 8. Predicted growth rate, dietary crude protein, and digestibility of steers of three different ages grazing as a single mob. No.9 – weaners; No.8 – yearlings; No.7 – 2-year-olds.

	Predicted ADG (g/d)			Predicted diet protein %			Predicted digestibility %		
Steer age	No.9	No.8	No.7	No.9	No.8	No.7	No.9	No.8	No.7
Date									
25-11-99	1536	1312	1218	14.6	12.3	11.1	69	62	65
22-12-99	934	797	797	9.8	9.0	9.0	62	60	59
18-01-00	877	700	706	9.8	7.9	8.1	61	57	58
03-03-00	708	586	479	8.0	6.5	6.0	55	52	49
06-04-00	819	715	598	8.7	7.5	7.1	60	57	56
04-05-00	967	814	728	9.3	8.4	8.2	61	58	57

Cumulative liveweight change. Results indicate that, even within the calibration set, predicted ADG often differed quite markedly from the assigned reference value (measured ADG). It has been demonstrated that compensatory gain and non-nutritional stressors can contribute to these differences and that the magnitude of such differences can be influenced by age or maturity. It also needs to be recognized that the reference or measured growth rates may incorporate a substantial error component and that prediction errors are not the sole reason for differences between predicted and measured ADG. Measured growth rates are determined as the average daily change in liveweight between two weighings. Such a procedure represents a true measure of growth (either positive or negative) only if gut fill and body water remain constant as a proportion of total weight. Changes in gut fill from one weighing to the next are the main cause of error in measured growth rate and the error can be substantial. The shorter the interval between successive weighings the greater the potential for large errors in measured growth rate. This is because even small changes in gut fill can override changes in tissue weight.

Because of the range of factors that can influence the difference between predicted and measured ADG at any point in time, an alternative test of the reliability of faecal NIRS predictions of growth rate would be to generate a liveweight gain curve over a given period and compare it with the comparable measured LWG curve. This process was adopted for the steers of different ages in the Lansdown experiment in 1999-2000 (Fig. 4).

Fig. 4 illustrates some of the features already discussed, viz,

- (i) under-prediction of weight losses in older cattle during the late dry season
- (ii) under-prediction of liveweight gain early in the wet season when compensatory gains were being made (most apparent during December)
- (iii) over-prediction of liveweight gain during the excessively wet period in February and March
- (iv) under-prediction of liveweight gain following the excessively wet period when steers again made compensatory gains (most apparent in May)

Despite the short term differences between predicted and measured gains, there was little difference between predicted and measured cumulative liveweight gain at the end of the trial in June 2000. The biggest difference occurred in the youngest steers even though predicted gains tracked closely to measured gains throughout the trial period except during the transition period between the dry and the wet in November. In the two older groups where short term differences in gain were substantial, the cumulative effect for the entire period was negligible.

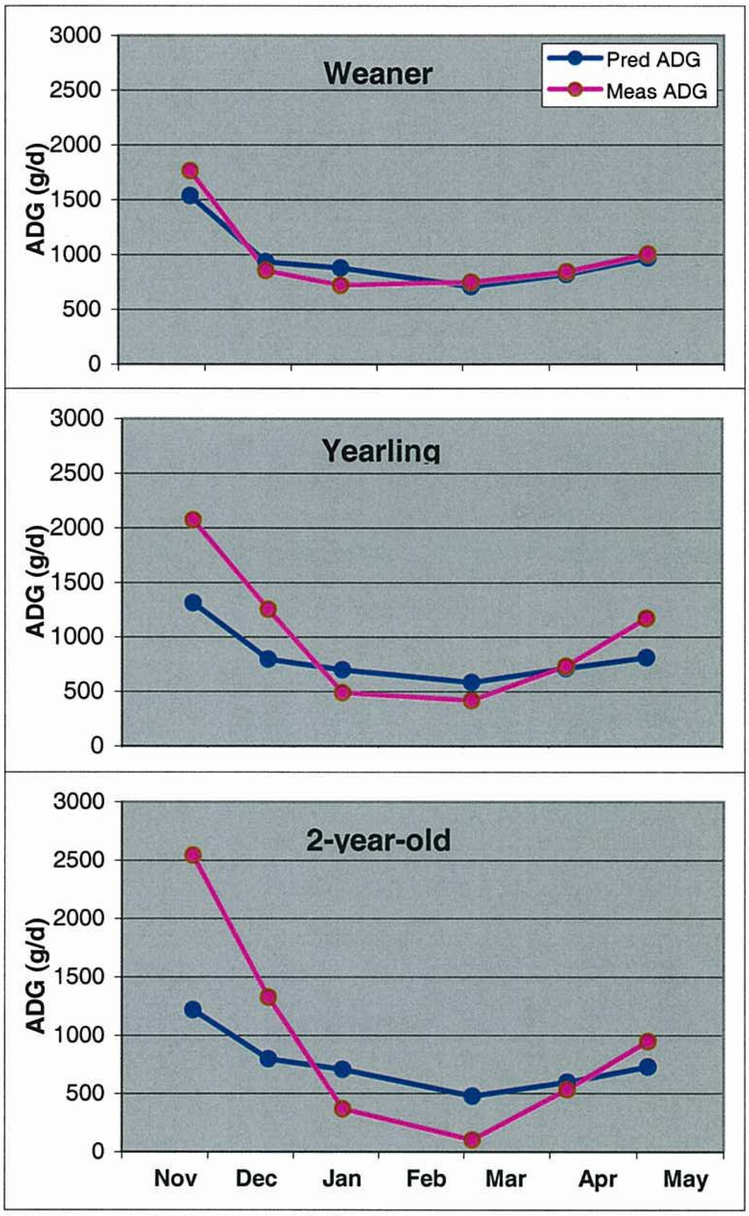

Figure 3. Predicted and measured growth rates (ADG) for steers of different ages grazing together. Compensatory gains were observed in the early wet (November and December) but growth rate was limited by excessively wet weather during the mid-wet (January - March). Another period of compensatory growth occurred after the excessive wet (May).

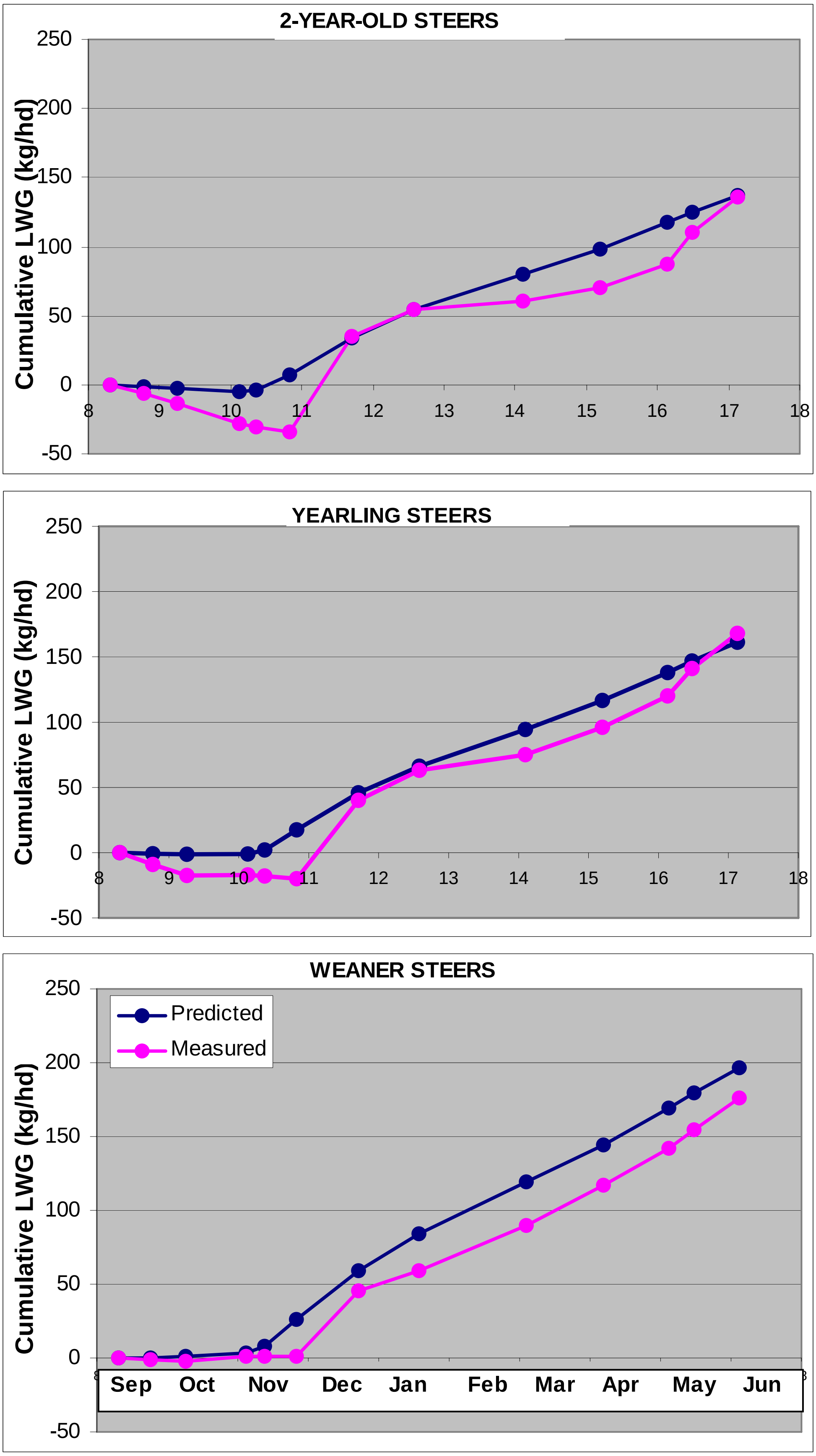

Figure 4. Cumulative liveweight gain curves for weaner (No.9), yearling (No.8) and 2-year-old (No.7) steers grazing a Urochloa/stylo pasture at Lansdown, September 1999 to June 2000.

CONCLUSIONS

1. Faecal NIRS for predicting growth rate in grazing cattle has the potential to be a useful tool for both research and commercial purposes.

2. The predictive reliability of the most recent equation (based on a calibration set of 629 samples sourced from 32 monitor herds at five different locations and spanning a 4-year period June 1997 to May 2001) is not considered to be adequate for widespread use and the calibration set needs to be expanded to incorporate samples from more localities, pasture types and years.

3. Regardless of the magnitude of any future expansion of the calibration set, present indications are that there will always be situations where predicted growth rate will differ substantially from actual growth rate. Such situations would include (i) times of marked compensatory gain (e.g. early wet season gains following a long dry season) when predicted growth rate will under-estimate actual growth rate, (ii) times when growth rate is limited by non-nutritional stressors such as protracted, inclement weather when predicted growth rate will over-estimate actual growth rate, and (iii) situations where growth rate is limited by mineral deficiency, minor essential nutrients or toxic substances, when predicted growth rates will over-estimate actual growth rate.

4. Although untested as yet, it would be reasonable to assume that faecal NIRS predictions of growth rate would be unable to differentiate between animals of different genetic potential for liveweight gain.

5. When cattle of different ages (maturity) graze the same pasture, measured liveweight gains generally decrease with increasing maturity except when compensatory gains occur. At any given sampling occasion where cattle graze in common, faecal NIRS consistently predicts lower growth rates for the older cattle.

6. With the current equation, animal age has a marked effect on differences between predicted and measured growth rate. Differences associated with compensatory gain, non-nutritional stressors, and periods of weight loss are much more pronounced in older, heavier cattle. There may be some potential to reduce large, age-related differences by developing separate calibration equations for different age categories but this would be impractical in the foreseeable future.

7. Although untested as yet, predictive reliability may be improved by developing calibration equations specific to certain pasture types e.g buffel grass pastures, Mitchell/Flinders grass communities; native speargrass pastures; sown grass/legume pastures.

8. Work to date has been confined to growing cattle and no attempt has been made to predict weight change in breeding cows.

RECOMMENDATIONS

It is quite clear that faecal NIRS analysis for predicting growth rate requires further development to improve predictive reliability to the level where it can be beneficially applied as a management tool. One cannot conclude from the results to date whether the required predictive reliability will be achieved simply by increasing the number and diversity of samples in the calibration set or whether "local"[1] equations offer a better alternative, at least in some situations, to a "universal"[2] equation. The perceived requirement at present is to continue the validation and expansion procedure with samples from new monitor herds and to evaluate progress on a continuing basis.

This requirement has, in fact, been accommodated in project NAP3.121 (*Improving reliability of faecal NIRS calibration equations for predicting diet quality and productivity in cattle*) and there are currently 18 monitor herds at 10 different locations across Queensland. In addition there are data on hand from other monitor herds still to be processed.

SUCCESS IN ACHIEVING OBJECTIVES

The objective of developing faecal NIRS calibration equations for predicting growth rate in grazing cattle and of assessing the predictive reliability of such equations has been achieved. The contractual agreement with MLA was actually based on the processing and analysis of samples from the equivalent of 10 monitor herds in each of 2 years, i.e. 20 herd years. The data included in this report was derived from a total of 32 herd-years.

INTELLECTUAL PROPERTY

The intellectual property arising out of NAP3.116 is represented in (i) the calibration equations for predicting growth rate, (ii) the faecal NIR spectra files and matching reference values (measured growth rates) and (iii) the calibration set of faecal samples being held in storage. The calibration equations are not static and will be subject to continued expansion and refinement. Equations can only be transferred to other users if the NIRS instruments are cross-standardised. Other users could generate their own calibration equations if they had access to both the faecal samples for scanning on their own instruments and the relevant reference values for relating to the spectra. In other words, the intellectual property can only be shared, transferred or sold by agreement between relevant parties and by following a protocol of agreed procedures.

TECHNOLOGY TRANSFER

There is already widespread awareness amongst beef producers, extension officers, research personnel, consultants and agribusiness of faecal NIRS technology in general and of faecal NIRS predictions of growth rate as part of that technology. However, that awareness would not, at present, include a proper understanding of the current limitations with respect to predictive reliability and specific areas of difficulty. The widespread distribution of this report, or part thereof, will improve that understanding.

[1] local equation: equation specific to a defined situation such as a region or pasture type
[2] universal equation: equation for broad application; no restriction on the origin of the sample to be tested

FUNDING

MLA provided funding support of $25,000 to NAP3.116. The CSIRO contribution to the project was estimated to be in the order of $100,000.

IMPACT

At the present time, the technology is not sufficiently developed to actively promote the use and benefits of this aspect of faecal NIRS technology so it is premature to make an assessment of impact.

ACKNOWLEDGEMENTS

I acknowledge with gratitude the funding support provided by MLA and the continued support of CSIRO for this work. I also wish to thank the DPI scientists in charge of grazing trials at Glentulloch (Trevor Hall), Galloway Plains (Ron Hendricksen), Rosebank (Desiree Jackson) and Wambiana (Peter O'Reagain) for making faecal samples and liveweight data available to this project.

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2. **Coates, D.B.** (2000) Faecal NIRS – what does it offer today's grazier? *Tropical Grasslands* **34**:230-239.

3. **Coates, D.B.** (2002) Is NIRS only as good as the reference method? *Spectroscopy Europe*

APPENDIX 1
Reference values for ADG in calibration set ADG(8).CAL

Sample Number	Herd	Date	Reference ADG (g/d)
3131	LDN 2	26-Jun-97	372
3132	LDN 2	26-Jun-97	372
3133	LDN 2	26-Jun-97	372
3134	LDN 2	26-Jun-97	372
3137	LDN 2	04-Jul-97	354
3139	LDN 2	11-Jul-97	336
3141	LDN 2	18-Jul-97	318
3146	LDN 2	25-Jul-97	300
3147	LDN 2	25-Jul-97	300
3148	LDN 2	25-Jul-97	300
3149	LDN 2	25-Jul-97	300
3150	LDN 2	25-Jul-97	300
3193	LDN 2	01-Aug-97	282
3196	LDN 2	08-Aug-97	264
3199	LDN 2	15-Aug-97	246
3202	LDN 2	22-Aug-97	228
3205	LDN 2	29-Aug-97	210
3235	LDN 2	12-Sep-97	650
3238	LDN 2	19-Sep-97	600
3241	LDN 2	25-Sep-97	550
3244	LDN 2	03-Oct-97	500
3305	LDN 2	10-Oct-97	400
3306	LDN 2	10-Oct-97	400
3307	LDN 2	10-Oct-97	400
3308	LDN 2	10-Oct-97	400
3309	LDN 2	10-Oct-97	400
3316	LDN 2	17-Oct-97	300
3324	LDN 2	31-Oct-97	200
3332	LDN 2	07-Nov-97	180
3333	LDN 2	07-Nov-97	180
3334	LDN 2	07-Nov-97	180
3335	LDN 2	07-Nov-97	180
3336	LDN 2	07-Nov-97	180
3522	LDN 2	14-Nov-97	180
3525	LDN 2	21-Nov-97	170
3528	LDN 2	27-Nov-97	170
3513	LDN 2	05-Dec-97	160
3514	LDN 2	05-Dec-97	160
3519	LDN 2	11-Dec-97	160
3531	LDN 2	19-Dec-97	150
3541	LDN 2	02-Jan-98	1500
3542	LDN 2	02-Jan-98	1500
3543	LDN 2	02-Jan-98	1500
3544	LDN 2	02-Jan-98	1500
3545	LDN 2	02-Jan-98	1500
3557	LDN 2	09-Jan-98	1250
3560	LDN 2	16-Jan-98	1000
3563	LDN 2	23-Jan-98	955
3570	LDN 2	30-Jan-98	910
3571	LDN 2	30-Jan-98	910
3573	LDN 2	30-Jan-98	910
3574	LDN 2	30-Jan-98	910
3671	LDN 2	05-Feb-98	865
3688	LDN 2	13-Feb-98	820
3691	LDN 2	20-Feb-98	810
3698	LDN 2	27-Feb-98	800
3699	LDN 2	27-Feb-98	800
3700	LDN 2	27-Feb-98	800
3701	LDN 2	27-Feb-98	800
3702	LDN 2	27-Feb-98	800
3709	LDN 2	06-Mar-98	790
3785	LDN 2	13-Mar-98	780
3788	LDN 2	20-Mar-98	770
3795	LDN 2	27-Mar-98	760
3796	LDN 2	27-Mar-98	760
3797	LDN 2	27-Mar-98	760
3798	LDN 2	27-Mar-98	760
3799	LDN 2	27-Mar-98	760
3809	LDN 2	03-Apr-98	750
3819	LDN 2	09-Apr-98	740
3822	LDN 2	21-Apr-98	725
3829	LDN 2	30-Apr-98	700
3830	LDN 2	30-Apr-98	700
3831	LDN 2	30-Apr-98	700
3832	LDN 2	30-Apr-98	700
3839	LDN 2	08-May-98	670
3842	LDN 2	15-May-98	630
3845	LDN 2	22-May-98	590
3848	LDN 2	29-May-98	550
3851	LDN 2	05-Jun-98	530
3864	LDN 2	13-Jun-98	500
3867	LDN 2	19-Jun-98	450
4040	LDN 2	03-Jul-98	400
4047	LDN 2	17-Jul-98	350
4071	LDN 2	31-Jul-98	300
4078	LDN 2	14-Aug-98	250
4106	LDN 2	11-Sep-98	700
4129	LDN 2	25-Sep-98	800
4243	LDN 2	08-Oct-98	700
4269	LDN 2	23-Oct-98	750
4276	LDN 2	05-Nov-98	770
4333	LDN 2	19-Nov-98	770
4351	LDN 2	03-Dec-98	750
4398	LDN 2	17-Dec-98	800
4412	LDN 2	31-Dec-98	750
3119	LDN 1	20-Jun-97	310
3120	LDN 1	20-Jun-97	250
3126	LDN 1	26-Jun-97	372
3127	LDN 1	26-Jun-97	372
3128	LDN 1	26-Jun-97	372
3129	LDN 1	26-Jun-97	372
3130	LDN 1	26-Jun-97	372
3136	LDN 1	04-Jul-97	354
3138	LDN 1	11-Jul-97	336
3140	LDN 1	18-Jul-97	318
3142	LDN 1	25-Jul-97	300
3143	LDN 1	25-Jul-97	300
3144	LDN 1	25-Jul-97	300
3145	LDN 1	25-Jul-97	300
3192	LDN 1	01-Aug-97	282
3195	LDN 1	08-Aug-97	264
3198	LDN 1	15-Aug-97	246
3201	LDN 1	22-Aug-97	228
3204	LDN 1	29-Aug-97	210
3234	LDN 1	12-Sep-97	600
3237	LDN 1	19-Sep-97	550
3240	LDN 1	25-Sep-97	500
3243	LDN 1	03-Oct-97	450
3302	LDN 1	10-Oct-97	400
3303	LDN 1	10-Oct-97	400

Reference values for ADG in calibration set ADG(8).CAL

Sample Number	Herd	Date	Reference ADG (g/d)
3304	LDN 1	10-Oct-97	400
3315	LDN 1	17-Oct-97	350
3323	LDN 1	31-Oct-97	270
3327	LDN 1	07-Nov-97	230
3328	LDN 1	07-Nov-97	230
3329	LDN 1	07-Nov-97	230
3330	LDN 1	07-Nov-97	230
3331	LDN 1	07-Nov-97	230
3521	LDN 1	14-Nov-97	200
3524	LDN 1	21-Nov-97	170
3527	LDN 1	27-Nov-97	140
3510	LDN 1	05-Dec-97	110
3511	LDN 1	05-Dec-97	110
3512	LDN 1	05-Dec-97	110
3518	LDN 1	11-Dec-97	100
3536	LDN 1	02-Jan-98	1500
3537	LDN 1	02-Jan-98	1500
3538	LDN 1	02-Jan-98	1500
3539	LDN 1	02-Jan-98	1500
3540	LDN 1	02-Jan-98	1500
3556	LDN 1	09-Jan-98	1250
3559	LDN 1	16-Jan-98	1000
3562	LDN 1	23-Jan-98	955
3565	LDN 1	30-Jan-98	910
3566	LDN 1	30-Jan-98	910
3567	LDN 1	30-Jan-98	910
3568	LDN 1	30-Jan-98	910
3569	LDN 1	30-Jan-98	910
3670	LDN 1	05-Feb-98	865
3687	LDN 1	13-Feb-98	820
3690	LDN 1	20-Feb-98	810
3693	LDN 1	27-Feb-98	800
3694	LDN 1	27-Feb-98	800
3695	LDN 1	27-Feb-98	800
3696	LDN 1	27-Feb-98	800
3697	LDN 1	27-Feb-98	800
3708	LDN 1	06-Mar-98	790
3784	LDN 1	13-Mar-98	780
3787	LDN 1	20-Mar-98	770
3790	LDN 1	27-Mar-98	760
3791	LDN 1	27-Mar-98	760
3792	LDN 1	27-Mar-98	760
3793	LDN 1	27-Mar-98	760
3794	LDN 1	27-Mar-98	760
3808	LDN 1	03-Apr-98	750
3818	LDN 1	09-Apr-98	740
3821	LDN 1	21-Apr-98	725
3824	LDN 1	30-Apr-98	700
3825	LDN 1	30-Apr-98	700
3826	LDN 1	30-Apr-98	700
3827	LDN 1	30-Apr-98	700
3828	LDN 1	30-Apr-98	700
3838	LDN 1	08-May-98	670
3841	LDN 1	15-May-98	630
3844	LDN 1	22-May-98	590
3847	LDN 1	29-May-98	550
3850	LDN 1	05-Jun-98	510
3863	LDN 1	13-Jun-98	470
3866	LDN 1	19-Jun-98	400
4038	LDN 1	03-Jul-98	300
4045	LDN 1	17-Jul-98	200
4069	LDN 1	31-Jul-98	120
4076	LDN 1	14-Aug-98	40
4104	LDN 1	11-Sep-98	700
4127	LDN 1	25-Sep-98	800
4241	LDN 1	08-Oct-98	700
4267	LDN 1	23-Oct-98	750
4274	LDN 1	05-Nov-98	800
4331	LDN 1	19-Nov-98	740
4349	LDN 1	03-Dec-98	700
4396	LDN 1	17-Dec-98	750
4410	LDN 1	31-Dec-98	750
E693	GTCH	23-Nov-97	980
E696	GTCH	23-Nov-97	990
E699	GTCH	23-Nov-97	970
E702	GTCH	23-Nov-97	970
E706	GTCH	16-Dec-97	980
E709	GTCH	16-Dec-97	970
E712	GTCH	16-Dec-97	980
E715	GTCH	16-Dec-97	990
E721	GTCH	30-Dec-97	950
E724	GTCH	30-Dec-97	980
E727	GTCH	30-Dec-97	970
E732	GTCH	13-Jan-98	930
E735	GTCH	13-Jan-98	930
E738	GTCH	13-Jan-98	940
E741	GTCH	13-Jan-98	900
E772	GTCH	28-Jan-98	760
E775	GTCH	28-Jan-98	850
E778	GTCH	28-Jan-98	720
E781	GTCH	28-Jan-98	700
E790	GTCH	16-Feb-98	1150
E793	GTCH	16-Feb-98	1120
E796	GTCH	16-Feb-98	1020
E799	GTCH	16-Feb-98	1100
E804	GTCH	02-Mar-98	860
E807	GTCH	02-Mar-98	850
E810	GTCH	02-Mar-98	1070
E813	GTCH	02-Mar-98	860
E821	GTCH	17-Mar-98	650
E824	GTCH	17-Mar-98	650
E827	GTCH	17-Mar-98	650
E830	GTCH	17-Mar-98	600
E988	GTCH	01-Apr-98	530
E991	GTCH	01-Apr-98	550
E1002	GTCH	20-Apr-98	440
E1005	GTCH	20-Apr-98	450
E1008	GTCH	20-Apr-98	480
E1011	GTCH	20-Apr-98	350
E1060	GTCH	30-Apr-98	420
E1063	GTCH	30-Apr-98	440
E1066	GTCH	30-Apr-98	480
E1069	GTCH	30-Apr-98	500
E1074	GTCH	12-May-98	390
E1077	GTCH	12-May-98	430
E1080	GTCH	12-May-98	450
E1083	GTCH	12-May-98	450
E1091	GTCH	02-Jun-98	370
E1094	GTCH	02-Jun-98	350
E1097	GTCH	02-Jun-98	350

Reference values for ADG in calibration set ADG(8).CAL

Sample Number	Herd	Date	Reference ADG (g/d)	Sample Number	Herd	Date	Reference ADG (g/d)
E1100	GTCH	02-Jun-98	350	E5568	GPLNS	08-May-00	450
E1111	GTCH	15-Jun-98	350	E1194	WAMB	20-Jun-98	500
E1114	GTCH	15-Jun-98	250	E1195	WAMB	20-Jun-98	325
E1117	GTCH	15-Jun-98	250	E1198	WAMB	22-Jul-98	175
E1120	GTCH	15-Jun-98	250	E1192	WAMB	22-Jul-98	208
E1162	GTCH	02-Jul-98	-80	E1246	WAMB	10-Aug-98	-75
E1165	GTCH	02-Jul-98	-50	E1247	WAMB	10-Aug-98	135
E1168	GTCH	02-Jul-98	-90	E1645	WAMB	23-Sep-98	500
E1176	GTCH	15-Jul-98	-150	E1646	WAMB	23-Sep-98	433
E1179	GTCH	15-Jul-98	-80	E1649	WAMB	14-Oct-98	500
E1182	GTCH	15-Jul-98	-250	E1650	WAMB	14-Oct-98	427
E1219	GTCH	05-Aug-98	-50	E1653	WAMB	02-Nov-98	575
E1222	GTCH	05-Aug-98	-100	E1654	WAMB	02-Nov-98	450
E1225	GTCH	05-Aug-98	-200	E1657	WAMB	02-Dec-98	625
E1251	GTCH	17-Aug-98	-40	E1658	WAMB	02-Dec-98	683
E1260	GTCH	17-Aug-98	-250	E1661	WAMB	16-Dec-98	625
E5517	GPLNS	30-Aug-99	10	E1662	WAMB	16-Dec-98	750
E5518	GPLNS	30-Aug-99	400	E1665	WAMB	12-Jan-99	731
E5519	GPLNS	30-Aug-99	500	E1666	WAMB	12-Jan-99	767
E5521	GPLNS	21-Sep-99	50	E1784	WAMB	02-Feb-99	778
E5522	GPLNS	21-Sep-99	105	E1785	WAMB	02-Feb-99	688
E5523	GPLNS	21-Sep-99	10	E2212	WAMB	18-Feb-99	773
E5524	GPLNS	21-Sep-99	500	E2213	WAMB	18-Feb-99	673
E5525	GPLNS	18-Oct-99	10	E2216	WAMB	12-Mar-99	667
E5527	GPLNS	18-Oct-99	-10	E2217	WAMB	12-Mar-99	625
E5533	GPLNS	22-Nov-99	900	E2220	WAMB	30-Mar-99	500
E5534	GPLNS	22-Nov-99	1150	E2221	WAMB	30-Mar-99	571
E5535	GPLNS	22-Nov-99	1500	E3184	WAMB	23-Apr-99	375
E5536	GPLNS	22-Nov-99	1050	E3185	WAMB	18-May-99	250
E5537	GPLNS	14-Dec-99	650	E3191	WAMB	23-Apr-99	283
E5538	GPLNS	14-Dec-99	700	E3192	WAMB	18-May-99	146
E5539	GPLNS	14-Dec-99	1200	E3186	WAMB	17-Jun-99	524
E5540	GPLNS	14-Dec-99	850	E3187	WAMB	06-Jul-99	233
E5541	GPLNS	10-Jan-00	780	E3188	WAMB	27-Jul-99	1
E5542	GPLNS	10-Jan-00	650	E3189	WAMB	18-Aug-99	-38
E5543	GPLNS	10-Jan-00	1300	E3193	WAMB	17-Jun-99	536
E5544	GPLNS	10-Jan-00	950	E3194	WAMB	06-Jul-99	223
E5545	GPLNS	25-Jan-00	780	E3195	WAMB	27-Jul-99	-116
E5546	GPLNS	25-Jan-00	650	E3196	WAMB	18-Aug-99	1
E5547	GPLNS	25-Jan-00	1300	E3955	WAMB	09-Sep-99	-71
E5548	GPLNS	25-Jan-00	950	E3957	WAMB	09-Sep-99	70
E5549	GPLNS	21-Feb-00	780	E3967	WAMB	26-Sep-99	1
E5550	GPLNS	21-Feb-00	650	E5688	WAMB	23-Mar-00	810
E5551	GPLNS	21-Feb-00	900	E5701	WAMB	23-Mar-00	800
E5552	GPLNS	21-Feb-00	950	E5713	WAMB	12-Apr-00	780
E5553	GPLNS	07-Mar-00	780	E5715	WAMB	12-Apr-00	800
E5554	GPLNS	07-Mar-00	600	E5725	WAMB	02-May-00	760
E5555	GPLNS	07-Mar-00	700	E5727	WAMB	02-May-00	650
E5556	GPLNS	07-Mar-00	750	E8033	WAMB	08-Aug-00	450
E5557	GPLNS	27-Mar-00	380	E8035	WAMB	08-Aug-00	395
E5558	GPLNS	27-Mar-00	450	E8043	WAMB	01-Sep-00	365
E5559	GPLNS	27-Mar-00	500	E8045	WAMB	01-Sep-00	225
E5560	GPLNS	27-Mar-00	500	E8053	WAMB	22-Sep-00	1
E5561	GPLNS	18-Apr-00	280	E8055	WAMB	22-Sep-00	1
E5562	GPLNS	18-Apr-00	200	E8065	WAMB	11-Oct-00	-150
E5563	GPLNS	18-Apr-00	100	E8083	WAMB	23-Nov-00	1375
E5564	GPLNS	18-Apr-00	450	E8085	WAMB	23-Nov-00	1313
E5565	GPLNS	08-May-00	400	E8093	WAMB	11-Dec-00	1090
E5566	GPLNS	08-May-00	400	E8095	WAMB	11-Dec-00	1050
E5567	GPLNS	08-May-00	600	E8103	WAMB	04-Jan-01	686

Reference values for ADG in calibration set ADG(8).CAL

Sample Number	Herd	Date	Reference ADG (g/d)
E8105	WAMB	04-Jan-01	865
E8113	WAMB	24-Jan-01	686
E8115	WAMB	24-Jan-01	865
E10339	WAMB	12-Feb-01	680
E10341	WAMB	12-Feb-01	765
E10349	WAMB	02-Mar-01	680
E10351	WAMB	02-Mar-01	667
E10359	WAMB	23-Mar-01	670
E10361	WAMB	23-Mar-01	530
E10369	WAMB	18-Apr-01	525
E10371	WAMB	18-Apr-01	315
E10379	WAMB	14-May-01	340
E10381	WAMB	14-May-01	95
4039	LDNWEAN	03-Jul-98	255
4046	LDNWEAN	17-Jul-98	290
4068	LDNWEAN	31-Jul-98	325
4075	LDNWEAN	14-Aug-98	290
4103	LDNWEAN	11-Sep-98	1200
4126	LDNWEAN	25-Sep-98	1150
4240	LDNWEAN	08-Oct-98	950
4266	LDNWEAN	23-Oct-98	685
4273	LDNWEAN	05-Nov-98	730
4330	LDNWEAN	19-Nov-98	780
4348	LDNWEAN	03-Dec-98	780
4395	LDNWEAN	17-Dec-98	970
4409	LDNWEAN	31-Dec-98	950
4482	LDNWEAN	14-Jan-99	890
4500	LDNWEAN	02-Feb-99	735
4518	LDNWEAN	11-Feb-99	520
4549	LDNWEAN	25-Feb-99	560
4599	LDNWEAN	25-Mar-99	640
4654	LDNWEAN	22-Apr-99	760
4753	LDNWEAN	20-May-99	430
4927	LDNWEAN	17-Jul-99	1
4043	LDNWEAN	03-Jul-98	450
4050	LDNWEAN	17-Jul-98	350
4072	LDNWEAN	31-Jul-98	400
4079	LDNWEAN	14-Aug-98	400
4107	LDNWEAN	11-Sep-98	1060
4130	LDNWEAN	25-Sep-98	1060
4244	LDNWEAN	08-Oct-98	990
4270	LDNWEAN	23-Oct-98	990
4277	LDNWEAN	05-Nov-98	990
4334	LDNWEAN	19-Nov-98	990
4352	LDNWEAN	03-Dec-98	930
4399	LDNWEAN	17-Dec-98	870
4413	LDNWEAN	31-Dec-98	870
4486	LDNWEAN	14-Jan-99	870
4504	LDNWEAN	02-Feb-99	870
4522	LDNWEAN	11-Feb-99	860
4553	LDNWEAN	25-Feb-99	820
4569	LDNWEAN	11-Mar-99	780
4603	LDNWEAN	25-Mar-99	760
4658	LDNWEAN	22-Apr-99	700
4757	LDNWEAN	20-May-99	300
4877	LDNWEAN	17-Jun-99	-150
4931	LDNWEAN	17-Jul-99	-350
4338	LDNWEAN	19-Nov-98	1130
4356	LDNWEAN	03-Dec-98	900
4405	LDNWEAN	17-Dec-98	815
4419	LDNWEAN	31-Dec-98	730
4492	LDNWEAN	14-Jan-99	635
4510	LDNWEAN	02-Feb-99	520
4528	LDNWEAN	11-Feb-99	450
4559	LDNWEAN	25-Feb-99	500
4574	LDNWEAN	11-Mar-99	450
4609	LDNWEAN	25-Mar-99	570
4637	LDNWEAN	13-Apr-99	730
4664	LDNWEAN	22-Apr-99	715
4716	LDNWEAN	06-May-99	460
4763	LDNWEAN	20-May-99	225
4771	LDNWEAN	04-Jun-99	180
4883	LDNWEAN	17-Jun-99	165
4891	LDNWEAN	01-Jul-99	125
4937	LDNWEAN	17-Jul-99	75
4949	LDNWEAN	28-Jul-99	45
4984	LDNWEAN	12-Aug-99	15
4996	LDNWEAN	26-Aug-99	-20
5034	LDNWEAN	23-Sep-99	70
5128	LDNWEAN	22-Nov-99	1590
5165	LDNWEAN	09-Dec-99	1400
5280	LDNWEAN	06-Jan-00	1185
5356	LDNWEAN	03-Feb-00	835
5508	LDNWEAN	10-Mar-00	285
5567	LDNWEAN	13-Apr-00	1000
5703	LDNWEAN	18-May-00	865
4337	LDNWEAN	19-Nov-98	1040
4355	LDNWEAN	03-Dec-98	975
4404	LDNWEAN	17-Dec-98	860
4418	LDNWEAN	31-Dec-98	730
4491	LDNWEAN	14-Jan-99	730
4509	LDNWEAN	02-Feb-99	730
4527	LDNWEAN	11-Feb-99	680
4558	LDNWEAN	25-Feb-99	640
4573	LDNWEAN	11-Mar-99	640
4608	LDNWEAN	25-Mar-99	910
4636	LDNWEAN	13-Apr-99	910
4663	LDNWEAN	22-Apr-99	910
4715	LDNWEAN	06-May-99	680
4762	LDNWEAN	20-May-99	300
4770	LDNWEAN	04-Jun-99	70
4882	LDNWEAN	17-Jun-99	-35
4890	LDNWEAN	01-Jul-99	-70
4936	LDNWEAN	17-Jul-99	-90
4948	LDNWEAN	28-Jul-99	-125
4983	LDNWEAN	12-Aug-99	-140
4995	LDNWEAN	26-Aug-99	-150
4992	LDNWEAN	26-Aug-99	1
5008	LDNWEAN	09-Sep-99	1
5030	LDNWEAN	23-Sep-99	1
5059	LDNWEAN	08-Oct-99	1
5083	LDNWEAN	21-Oct-99	1
5101	LDNWEAN	04-Nov-99	1
5155	LDNWEAN	25-Nov-99	1500
5156	LDNWEAN	25-Nov-99	1500
5241	LDNWEAN	22-Dec-99	1215
5242	LDNWEAN	22-Dec-99	1200
5276	LDNWEAN	06-Jan-00	950
5314	LDNWEAN	18-Jan-00	855
5315	LDNWEAN	18-Jan-00	610

Reference values for ADG in calibration set ADG(8).CAL

Sample Number	Herd	Date	Reference ADG (g/d)
5352	LDNWEAN	03-Feb-00	630
5421	LDNWEAN	03-Mar-00	640
5422	LDNWEAN	03-Mar-00	560
5504	LDNWEAN	16-Mar-00	550
5555	LDNWEAN	06-Apr-00	450
5556	LDNWEAN	06-Apr-00	560
5563	LDNWEAN	13-Apr-00	990
5647	LDNWEAN	04-May-00	1040
5648	LDNWEAN	04-May-00	880
5699	LDNWEAN	18-May-00	885
5782	LDNWEAN	04-Jun-00	565
5825	LDNWEAN	20-Jun-00	335
5885	LDNWEAN	12-Jul-00	265
5889	LDNWEAN	12-Jul-00	150
5005	LDNWEAN	09-Sep-99	1
5028	LDNWEAN	23-Sep-99	1
5056	LDNWEAN	08-Oct-99	1
5131	LDNWEAN	25-Nov-99	1760
5238	LDNWEAN	12-Dec-99	850
5311	LDNWEAN	18-Jan-00	715
5426	LDNWEAN	03-Mar-00	745
5552	LDNWEAN	06-Apr-00	840
5644	LDNWEAN	04-May-00	1000
4038	LDNYLG	03-Jul-98	255
4045	LDNYLG	17-Jul-98	290
4069	LDNYLG	31-Jul-98	290
4076	LDNYLG	14-Aug-98	250
4104	LDNYLG	11-Sep-98	1100
4127	LDNYLG	25-Sep-98	1050
4241	LDNYLG	08-Oct-98	750
4267	LDNYLG	23-Oct-98	525
4274	LDNYLG	05-Nov-98	525
4331	LDNYLG	19-Nov-98	605
4349	LDNYLG	03-Dec-98	760
4396	LDNYLG	17-Dec-98	760
4410	LDNYLG	31-Dec-98	760
4483	LDNYLG	14-Jan-99	745
4501	LDNYLG	02-Feb-99	525
4519	LDNYLG	11-Feb-99	380
4550	LDNYLG	25-Feb-99	300
4600	LDNYLG	25-Mar-99	300
4655	LDNYLG	22-Apr-99	820
4928	LDNYLG	17-Jul-99	-390
3869	LDNYLG	19-Jun-98	600
4042	LDNYLG	03-Jul-98	550
4049	LDNYLG	17-Jul-98	450
4073	LDNYLG	31-Jul-98	550
4080	LDNYLG	14-Aug-98	600
4108	LDNYLG	11-Sep-98	720
4131	LDNYLG	25-Sep-98	720
4245	LDNYLG	08-Oct-98	720
4271	LDNYLG	23-Oct-98	720
4278	LDNYLG	05-Nov-98	720
4335	LDNYLG	19-Nov-98	720
4353	LDNYLG	03-Dec-98	720
4400	LDNYLG	17-Dec-98	680
4414	LDNYLG	31-Dec-98	680
4487	LDNYLG	14-Jan-99	680
4505	LDNYLG	02-Feb-99	680
4523	LDNYLG	11-Feb-99	680

Sample Number	Herd	Date	Reference ADG (g/d)
4554	LDNYLG	25-Feb-99	680
4604	LDNYLG	25-Mar-99	560
4659	LDNYLG	22-Apr-99	530
4758	LDNYLG	20-May-99	350
4878	LDNYLG	17-Jun-99	-210
4932	LDNYLG	17-Jul-99	-415
5006	LDNYLG	09-Sep-99	-430
5057	LDNYLG	08-Oct-99	-250
5312	LDNYLG	18-Jan-00	485
5427	LDNYLG	03-Mar-00	415
5553	LDNYLG	06-Apr-00	730
5645	LDNYLG	04-May-00	1170
5035	LDNYLG	23-Sep-99	-140
5357	LDNYLG	03-Feb-00	900
5568	LDNYLG	13-Apr-00	985
5704	LDNYLG	18-May-00	830
5011	LDNYLG	09-Sep-99	-160
5033	LDNYLG	23-Sep-99	-190
5063	LDNYLG	08-Oct-99	-230
5086	LDNYLG	21-Oct-99	-250
5127	LDNYLG	22-Nov-99	1880
5279	LDNYLG	06-Jan-00	1115
5319	LDNYLG	18-Jan-00	840
E11567	RBK		660
E2459(1)	RBK	06-May-99	660
E2975(1)	RBK	16-Jun-99	540
E2976(1)	RBK	07-Jul-99	410
E2977(1)	RBK	21-Jul-99	400
E3043(1)	RBK	04-Aug-99	390
E4235(1)	RBK	11-Aug-99	360
E4243(1)	RBK	25-Aug-99	310
E4251(1)	RBK	08-Sep-99	225
E4283(1)	RBK	24-Nov-99	675
E5664(1)	RBK	25-Jan-00	540
E5672(1)	RBK	01-Mar-00	500
E11585	RBK	08-Dec-99	675
E11592	RBK	15-Dec-99	675
E11600	RBK	30-Dec-99	625
E11607	RBK	12-Jan-00	600
E11615	RBK	09-Feb-00	470
E11623	RBK	08-Mar-00	510
E11631	RBK	22-Mar-00	480
E11636	RBK	05-Apr-00	310
E11644	RBK	12-Apr-00	250
E11666	RBK	07-Jun-00	615
E11568	RBK	28-Apr-99	750
E2460(2)	RBK	06-May-99	750
E2467(2)	RBK	19-May-99	750
E2990(2)	RBK	02-Jun-99	750
E2991(2)	RBK	16-Jun-99	640
E2992(2)	RBK	30-Jun-99	530
E2993(2)	RBK	07-Jul-99	530
E2994(2)	RBK	21-Jul-99	460
E2995(2)	RBK	04-Aug-99	410
E4236(2)	RBK	11-Aug-99	375
E4244(2)	RBK	25-Aug-99	285
E4252(2)	RBK	08-Sep-99	250
E4260(2)	RBK	16-Sep-99	220
E4284(2)	RBK	24-Nov-99	905
E5665(2)	RBK	25-Jan-00	540

Reference values for ADG in calibration set ADG(8).CAL

Sample Number	Herd	Date	Reference ADG (g/d)
E11570	RBK	14-Oct-99	100
E11586	RBK	08-Dec-99	790
E11593	RBK	15-Dec-99	750
E11601	RBK	30-Dec-99	670
E11608	RBK	12-Jan-00	650
E11616	RBK	09-Feb-00	520
E11624	RBK	08-Mar-00	560
E11637	RBK	05-Apr-00	425
E11645	RBK	12-Apr-00	380
E11569	RBK	28-Apr-99	605
E2463(5)	RBK	06-May-99	605
E2469(5)	RBK	19-May-99	604
E3020(5)	RBK	02-Jun-99	604
E3021(5)	RBK	16-Jun-99	602
E3022(5)	RBK	30-Jun-99	602
E3023(5)	RBK	07-Jul-99	600
E3024(5)	RBK	21-Jul-99	580
E3025(5)	RBK	04-Aug-99	470
E4239(5)	RBK	11-Aug-99	430
E4247(5)	RBK	25-Aug-99	360
E4255(5)	RBK	08-Sep-99	270
E4263(5)	RBK	16-Sep-99	230
E5668(5)	RBK	25-Jan-00	475
E11589(5)	RBK	08-Dec-99	730
E11596(5)	RBK	15-Dec-99	725
E11604(5)	RBK	30-Dec-99	680
E11611(5)	RBK	12-Jan-00	580
E11619(5)	RBK	09-Feb-00	500
E11627(5)	RBK	08-Mar-00	585
E11640(5)	RBK	05-Apr-00	375
E11648(5)	RBK	12-Apr-00	300