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Predicting the Feed Intake of Artificially Reared Pre-Weaned Lambs from Faecal and Dietary Chemical Composition

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Abstract: Predicting feed intake in suckling lambs consuming both milk and pasture can be challenging, and thus intake values are often derived from solely milk or solid feed consumption. The present study investigated if dry matter (DM), organic matter (OM), and metabolisable energy (ME) intakes of lambs given a combination of milk and pellets under controlled conditions could be predicted with enough precision using dietary and faecal chemical composition. A total of 34 pre-weaned lambs bottle-fed milk replacer with or without access to pellets and kept in metabolic cages for four days were used. To develop the prediction equations, 54 faecal samples with detailed information on their chemical compositions, and the feed consumed by the lambs, were used. Pellet DMI was predicted from neutral detergent fibre concentration in faeces and pellets, pellets %DM, and live weight (LW) of lambs. Milk DMI was predicted from faecal Nitrogen concentration and LW. Milk and pellet DMI and their ME content were combined to predict DMI/d and ME intake/d. The equations developed were validated against 40 spot faecal samples randomly selected from the lambs. DM, OM, and ME intakes were predicted with high accuracy and precision. The results showed that the developed equations can be used with enough accuracy to predict ME, OM, and DM intakes in pre-weaned lambs ingesting milk and pellets concurrently, thus the results revealed that the established equations may be used to predict ME, OM, and DM intakes in pre-weaned lambs drinking milk and pellets at the same time, allowing feeding regimens for young lambs to be developed.

Keywords: lamb; milk; pellet; feed intake; diet composition; faeces composition



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1. Introduction

Feed intake is the most variable and the most difficult measurable factor affecting lamb growth [1]. It is known that feed intake in lambs is affected both by live weight of the animal and the diet composition, especially the fibre content. Therefore, it should be possible to predict intake based on the live weight of the animal and diet and/or faecal composition. Under pastoral conditions, pre-weaned lambs obtain their nutrient intake from both milk and pasture—both parameters being difficult to measure. The various techniques for measuring milk or pasture intake often lack accuracy and precision and thus do not reflect intake [2,3]. Therefore, estimated feed intake values are typically predicted using data from lambs fed milk or solid feed under indoor conditions. The inability to estimate milk and pasture intake in lambs with ease and accuracy limits the management of feed intake and hence animal performance [4]. Thus, methods to assess young lambs' nutritional intake are required to calculate nutrient balances and nutrient use efficiencies.

Faecal material consists primarily of the undigested residues of feed intake and may contain characteristics and nutritional information of the diet consumed [1]. Therefore, predicting feed intake from faecal chemical composition may provide a precise estimation of the intake of lambs under pastoral conditions. Faecal chemical components such as nitrogen (N), neutral detergent fibre (NDF), acid detergent fibre (ADF), and lignin have

been used to predict intake in grazing sheep [5,6]. However, no evidence on estimating milk and solid feed intake in lambs using faecal chemical composition exists to date.

The objective of the present study was to determine whether the dry matter (DM), organic matter (OM), and metabolisable energy (ME) intakes of lambs fed a combination of milk and pellets could be predicted with enough precision from faecal and dietary chemical composition. If this was found to be the case, it could be a useful tool for making feed intake management decisions.

2. Materials and Methods

The studies took place at Massey University, Palmerston North, New Zealand, from August to December 2014 and September to December 2015 for Experiments One and Two, respectively. The Massey University Animal Ethics Committee approved the studies and animal handling procedures (MUAEC 14/64 and MUAEC 15/54 for Experiments One and Two, respectively).

The study was categorised into two phases:

The first phase was the development of prediction equations to determine milk and pellet intake from faecal chemical composition in young lambs kept in metabolic crates, which allowed for total faecal collection during the pre-weaning stage from two experiments.

In phase two, the equations developed from phase one were evaluated with lambs consuming a known amount of milk and pellets in individual pens and spot faecal samples (samples taken randomly at any given time over a range of live weights) collected directly from the rectum.

2.1. Phase One: Generation of Prediction Equations

2.1.1. Experiment One

Background.

Danoso et al. [7] previously described the experimental design. At 24 h post-partum, 28 sets of Romney twin lambs were selected for the study. One male lamb from each litter was hand-reared indoors after being taken from the dam. The other twin from the set was left with the dam and was not part of the experiment. The kept lambs were allocated to one of four treatment groups, giving a total of seven lambs per treatment based on various milk and pellet combinations (Table 1). Lambs in treatment one were fed milk replacer (MR) only [MO]; those in treatment two were given MR in addition to being allowed ad libitum access to pellets (MP_{ad}); and those in treatments three (MP₃) and four (MP₆₀) were provided with 30% and 60%, respectively, of the ad libitum group's average pellet intake the day before whilst being fed MR. All lambs were bottle fed MR as a proportion of their live weight (LW). Liquid MR (Milligans Feed Limited, Oamaru, New Zealand) was freshly prepared everyday with ordinary tap water with an average temperature of 39 °C. The MR to water ratio was 1:4. Lambs were fed four times daily, and the amount of MR given was adjusted as lambs grew. The amount of MR powder fed to lambs was calculated to provide 1.5 times their maintenance requirements using the formulae [7]: MR per day (g) = 66.48 + 14.3 LW (kg). Performance Pellets were obtained from Reliance Feeds in Canterbury, New Zealand, and offered in feeders to MP_{ad}, MP₃₀, and MP₆₀ lambs from day one until the completion of the study at an average LW of 18 kg.

Present study.

Total faecal collection: The present study utilised milk and pellet intake and faecal data from 14 lambs randomly selected from the 4 treatment groups (MO, MP₃₀, MP₆₀, and MP_{ad}). At a mean LW of 17 kg, four lambs from each treatment were housed in metabolic cages for four days to enable total faecal collection. Only two lambs from the MP_{ad} were placed in the metabolic cages as the remaining five lambs had exceeded the 17 kg LW by the time they had to be placed in the cages. Feeding continued as usual and the daily milk and pellet intake of the lambs were recorded during the four-day period as amount offered minus refusal. Total faeces excreted were collected and weighed daily. Faeces were

collected per lamb over the four-day period. The samples were freeze-dried, ground, and stored at -20°C pending further analysis.

Table 1. Treatment and live weights of lambs at various stages of faecal collection in experiments one and two.

Treatment ^a	n	Live Weight, kg			
		Initial	Final	Digestibility	Spot ^b Faecal Sampling
Experiment One [7]					
MO	4	4.97	18.16	17	8, 12, 16, 18
MP ₃₀	4	5.11	18.74		
MP ₆₀	4	4.99	18.50		
MP _{ad}	2	5.02	18.86		
Experiment two [8]					
NMLP	5	5.34	18.98	9, 16	9, 12, 15, 18
NMHP	5	5.31	18.57		
HMLP	5	5.57	19.01		
HMHP	5	5.44	18.77		

^a MO = milk only; MP_{ad} = pellets offered ad libitum; MP₃₀ = milk + 30% of ad libitum pellets intake; MP₆₀ = milk + 60% of ad libitum pellets intake; NMHP = normal-protein milk + high-protein pellet; NMLP = normal-protein milk + low-protein pellet; HMHP = high-protein milk + high-protein pellet; HMLP = high-protein milk + low-protein pellet. ^b Samples taken randomly at a given live weight.

2.1.2. Experiment Two

Background.

Details of the experimental design has been reported by Danso et al. [8]. In brief, 28 sets of Romney twin lambs born to a mixed-age ewe were chosen at birth. The twin set had at least one male lamb. Lambs were left to nurse from their dam for 24 h after birth before being separated from the dam, taken indoors, and hand-reared. Lambs were raised in individual pens indoors. The experiment did not include the other twin from the set, who was left with their dam. The kept lambs were allotted to a 2×2 randomised group factorial design, consisting of seven lambs in a treatment. The treatments were made up of two levels of protein in iso-energetic milk replacer (high CP to ME ratio milk (HM) and normal CP to ME ratio milk (NM)) offered as a percentage of the lamb's LW, as well as two protein levels in iso-energetic pellets (low CP:ME pellets (LP) and high CP:ME pellets (HP)) offered *ad libitum*; creating four experimental groups (NMHP, NMLP, HMHP, HMLP). The study design resulted in lambs having varying CP:ME intake ratios. The HM was obtained by combining 80% NM and 20% milk protein concentrate ((MPC); Fonterra, Palmerston North, New Zealand) on an as-is basis, resulting in the HM with 31.2% crude protein. Liquid MR (NM or HM) was freshly prepared everyday with warm tap water at 30°C at a ratio of 1:4 for MR and tap water, respectively, to give approximately 19.6% DM MR as feed. The amount of MR offered (on an as is basis) and the frequency of feeding were modified as lambs grew and aged. Lambs were bottle fed milk five times a day, totalling 15% of their LW in the first two weeks. From the 15th day, bottle feeding was reduced to four times a day, totalling 10% of their body weight until the end of the study. The average initial amount of milk powder offered as is, was 175 g/d at 5 kg LW, and this was gradually increased to 360 g/d at 18 kg LW at the end of the study. To stimulate greater pellet ingestion, the amount of milk provided per kilogram LW was reduced. The LP pellets mix was made up of 55.5% barley, 34.8% broll (bran/pollard mix) 6.8% soybean meal, and 3% molasses. The HP pellets mix constituted 39.5% barley, 35.6% broll (bran/pollard mix), 21.8% soybean meal, and 3% molasses. All lambs had ad libitum access to pellets in feeders from the first till the last day of the study.

Present study.

The present study utilised milk and pellet intake and faecal data from 20 lambs randomly selected from the four experimental groups (NMHP, NMLP, HMHP, HMLP). To

enable the total faeces collection, five lambs from each treatment group were housed in metabolic cages at 9 kg LW (period one) and 16 kg LW (period two) for four days. Feeding continued as usual and the daily milk and pellet consumed by the lambs were recorded during the four-day period as amount offered minus refusal. During each period of the digestibility study, total faeces voided by each lamb were collected, weighed daily over a 4-day period and pooled together. The pooled sample was then sub-sampled, frozen, and stored at -20°C pending subsequent analysis. A total of 40 faecal samples were collected across the two digestibility periods.

2.2. Phase Two: Evaluation of Prediction Equations (Cross-Validation)

All 56 lambs in experiments one and two were spot faecal sampled during the hand-rearing periods. Samples from experiment one were collected at approximately 8 kg, 12 kg, 16 kg, and 18 kg LW while those from experiment two were collected at approximately 9 kg, 12 kg, 15 kg, and 18 kg LW (Table 1). Lambs involved in the total faecal collection study in experiment one were excluded from the 18 kg LW spot sample collection and those in experiment two were excluded from the 9 kg and 18 kg LW spot sampling. All samples collected were stored at -20°C until further analysis. Forty spot faecal samples were selected over a range of LWs and feed intakes to create variation, freeze-dried and analysed.

2.3. Chemical Analysis

All diet and faecal samples were analysed for nitrogen (N) following the Leco total combustion method (AOAC method 968.06) and dry matter (DM) in a convection oven at 105°C (AOAC methods 930.15 and 925.10), according to AOAC (1990). Ash was determined using a furnace at 550°C (AOAC method 942.05) and organic matter (OM) was calculated by subtracting the ash content from the DM. Gross energy (GE) was measured using the bomb calorimeter (Leco, AC 350, Leco Corporation, St Joseph, MI, USA). The Tecator Fibretec System (AOAC method 2002.04) was used to determine the neutral detergent fibre (NDF) in both the pellet and faecal samples following according to the method described by Robertson and Van Soest [9].

The total DM, GE, N, OM, and NDF in the faeces were determined by multiplying the measured content in the faecal sample by the quantity of faeces excreted by each lamb over the 4-day period. The chemical composition of the milk replacer, the milk protein concentrate, and the three pellet types used in experiments one and two are presented in Table 2.

Table 2. Chemical composition (on dry matter basis) of milk replacer and pellets fed to lambs in experiments one and two.

Item	Diet ^a Composition						
	Experiment One		Experiment Two				
	MR	Pellets ^b	NM	MPC	HM ^c	LP ^d	HP ^d
Dry matter, %	96.9	88.2	97.7	96.4	97.4	87.3	87.5
Ash, %	5	8.9	5.4	7.4	5.8	3.4	3.9
Crude protein, %	24.4	16.9	24.0	60.2	31.2	13.6	19.5
Gross energy, kJ/g	22.7	15.2	22.8	19.3	22.1	16.4	16.5
Neutral detergent fibre, %	n/a ^e	11.8	n/a	n/a	n/a	21.6	20.1

^a Diet: MR = Milk replacer; NM = Normal protein milk; MPC = Milk protein concentrate; HM = High-protein milk; LP = Low-protein pellets; HP = High-protein pellets. ^b Composed of barley, soya bean meal, canola, peas, wheat, maize, oats, molasses, vegetable oil, grass seed meal, minerals, vitamins, prebiotics, and essential oils. ^c Composed of 80% NM and 20% MPC. ^d Composed of wheat middling, soya bean, barley, and molasses. ^e n/a = not applicable.

2.4. Statistical Analysis

2.4.1. Phase One: Generation of Prediction Equations

Data from the 34 lambs kept in the metabolic crates were used in developing the prediction equations. The forward selection method of stepwise regression was used to

select the best independent variable(s) (concentrations of NDF, N, ash, and DM in diet and faeces and the LW of lambs) that best predicted intake of the dependent variables (dry matter intake (DMI), organic matter intake (OMI) and ME intake) in phase one using the PROC REG procedure [10]. The significant ($p < 0.05$) independent variable(s) selected in the stepwise regressions were used to develop the prediction of DMI, OMI, and ME intake. The accuracy of the prediction equations was examined using relative prediction error (RPE) [11,12], the concordance correlation coefficient (CCC) [13,14] and the coefficient of determination (R^2). A RPE value less than 10% indicates a satisfactory prediction, a RPE between 10% and 20% is an indication of an acceptable prediction, and a RPE greater than 20% indicates poor prediction [11]. The following are the CCC values and their meanings: A reasonable prediction is between 0.21 and 0.40; a moderate prediction is between 0.41 and 0.60; a significant prediction is between 0.61 and 0.80; and an almost perfect prediction is between 0.81 and 1.00 [11,15].

2.4.2. Phase Two: Evaluation of Prediction Equations

The data from the 40 lambs chosen in phase two was used to validate the equations generated using phase one data. For the parameters (DMI, OMI, and ME intake), linear regression analyses were undertaken using the measured values as independent variables and the projected values as dependent variables to see if the intercept was equal to zero and the slope was equal to unity. The R^2 was utilized as a precision indicator, while the intercept and slope reflected the model's accuracy [16].

3. Results

3.1. Development of Prediction Equations (Phase One)

Daily lamb milk dry matter intake DMI (DMI_m) over the two experiments ranged from 189.9 g/d to 310.1 g/d and daily dry matter intake for pellets (DMI_p) ranged from 0 g/d to 231.7 g/d. The ranges of daily organic matter intake (OMI) were 178.6 g/d to 293.9 g/d and 0 g/d to 221.3 g/d for milk (OMI_m) and pellets (OMI_p), respectively.

The best models to predict lamb DMI_m and OMI_m included faecal N concentration (fN) and the LW of lambs (Equations (1) and (2), respectively).

$$\text{DMI}_m, \text{ g/d} = 65.11 (\pm 10.57) + 2.98 (\pm 1.52) \text{ fN} + 12.91 (\pm 0.39) \text{ LW} \\ (R^2 = 0.96; \text{ RPE} = 3.48\%; \text{ CCC} = 0.98), \quad (1)$$

$$\text{OMI}_m, \frac{\text{g}}{\text{d}} = 60.65 (\pm 9.73) + 2.63 (\pm 1.39) \text{ fN} + 11.84 (\pm 0.36) \text{ LW} \\ (R^2 = 0.96; \text{ RPE} = 4.81\%; \text{ CCC} = 0.97). \quad (2)$$

Neutral detergent fibre intake (NDFi) was predicted from faecal NDF (fNDF, %) on the basis that there was no NDF present in the milk replacer and therefore any fNDF present must have originated in the pellet. The simple regression between NDFi and fNDF and the multiple regression between NDFi, fNDF and LW are shown in Equations (3) and (4), respectively. The inclusion of LW in the estimated lamb NDFi equation showed a significant effect ($p < 0.001$). By including LW in the regression model, the RPE was reduced by 14.3% and R^2 and CCC were increased by 20% and 14%, respectively.

$$\text{NDFi} = -0.87 (\pm 2.42) + 0.89 (\pm 0.10) \text{ fNDF} \\ (R^2 = 0.61; \text{ RPE} = 45.4; \text{ CCC} = 0.76), \quad (3)$$

$$\text{NDFi} = -23.9 (\pm 3.55) + 0.91 (\pm 0.07) \text{ fNDF} + 1.62 (\pm 0.22) \text{ LW} \\ (R^2 = 0.81; \text{ RPE} = 31.1; \text{ CCC} = 0.90). \quad (4)$$

The lamb DM_{I_p} and OM_{I_p} were estimated from the predicted NDF_i, and the concentration of NDF (NDF_p, %), and DM (DM_p, %) in the pellets using the equation

$$\text{DM}_{I_p}, \text{ g/d (or OM}_{I_p}) = ([\text{NDF}_i, \text{ g/d}] / [\text{NDF}_p, \%]) \times \text{DM}_p, \% \quad (5)$$

The relationship between the measured lamb pellet DM and OM intakes and the predicted DM and OM intakes are presented in Table 3.

Table 3. Relationship between measured and predicted pellet dry matter intake (DM_{I_p}) and pellet organic matter intake (OM_{I_p}) of pre-weaned lambs offered milk and pellets concurrently.

Intake	<i>n</i> ^a	Measured ^b	SD ^c	SE ^d	Predicted ^e	SD	SE	R ²	RPE ^f , %	CCC ^g
DM _{I_p} , g/d	54	87.00	61.34	8.35	84.99	54.52	7.42	0.76	34.5	0.86
OM _{I_p} , g/d	54	82.08	57.80	7.87	80.26	51.70	7.04	0.77	33.9	0.87

^a Number of faecal samples. ^b Measured: actual mean value obtained from experiments one and two. ^c SD: standard deviation. ^d SE: standard error. ^e Predicted: mean value obtained from prediction equations. ^f RPE = relative predictive error. ^g CCC = concordance correlation coefficient.

Milk and pellet DMI, OMI and their metabolisable energy (ME) content were combined to predict the total DMI per day total OMI per and total ME intake per day and are shown in Table 4.

Table 4. Relationship between measured and predicted dry matter intake (DMI), organic matter intake (OMI) and metabolisable energy (ME) intake in pre-weaned lambs offered milk and pellets concurrently.

Intake	<i>n</i> ^a	Measured ^b	SD ^c	SE ^d	Predicted ^e	SD	SE	R ²	RPE ^f , %	CCC ^g
DMI, g/d	54	344.3	93.8	12.8	342.3	88.8	12.1	0.89	8.83	0.94
OMI, g/d	54	318.6	87.1	11.9	316.8	82.6	11.2	0.89	8.87	0.94
ME intake, MJ/d	54	1.71	0.40	0.05	1.71	0.39	0.05	0.93	6.04	0.96

^a Number of faecal samples. ^b Measured: actual mean value obtained from experiments one and two used to develop prediction equations. ^c SD: standard deviation. ^d SE: standard error. ^e Predicted: mean value obtained from prediction equations. ^f RPE = relative predictive error. ^g CCC = concordance correlation coefficient.

3.2. Cross-Validation (Phase Two)

The regression equations derived in phase one were validated against 40 independent spot faecal samples. The cross-validated results showed that the equations developed for estimate daily lamb milk OM (Equation (6)) and DM (Equation (7)) intakes were predicted with substantial accuracy as shown by their low RPE values (less than 10%) and high R² and CCC values (greater than 0.81).

$$\text{OMI}_{\text{pre}} = 26.3 (\pm 6.64) + 0.92 (\pm 0.03) \text{OMI}_{\text{mea}} \quad (6)$$

$$(R^2 = 0.97; \text{RPE} = 4.81\%; \text{CCC} = 0.97),$$

$$\text{DMI}_{\text{pre}} = 27.9 (\pm 7.29) + 0.95 (\pm 0.03) \text{DMI}_{\text{mea}} \quad (7)$$

$$(R^2 = 0.97; \text{RPE} = 7.16\%; \text{CCC} = 0.94).$$

For the pellets, the prediction accuracy of lamb NDF_i, DM_{I_p} and OM_{I_p} was not sufficient, although the R² and CCC values indicated a substantial prediction. The RPE was greater than 20%, indicating a non-satisfactory result (Table 5).

For total lamb DMI (Figure 1), OMI (Figure 2), and ME intake (Figure 3), a high accuracy of prediction was obtained, which was demonstrated by the acceptable RPE values of 15.1%, 14.9%, and 9.48% for DMI, OMI, and ME intake, respectively, and high R² and CCC values (0.79 and 0.88 for DMI, 0.80 and 0.88 for OMI, and 0.89 and 0.93 for ME intake, respectively). In all cases, intercepts were not different ($p > 0.05$) from zero and slopes were different ($p < 0.001$) from unity.

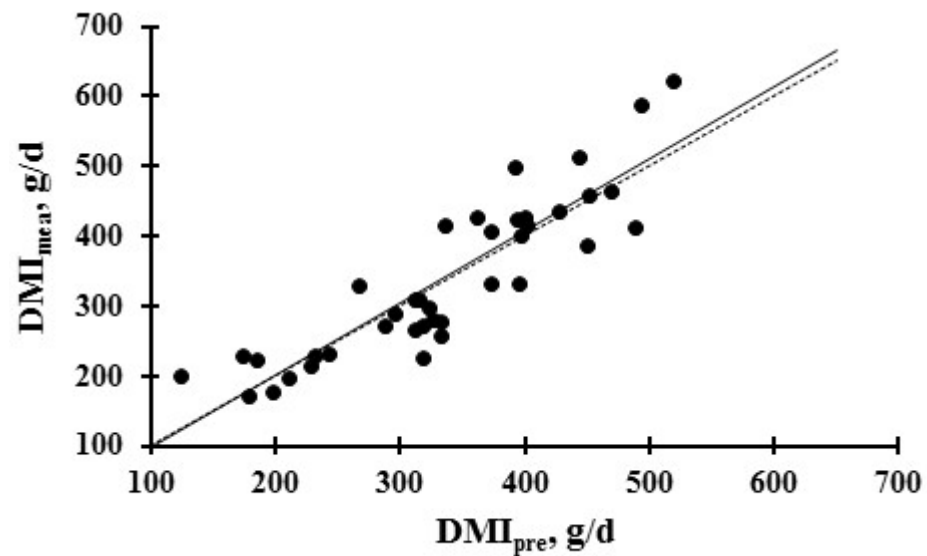
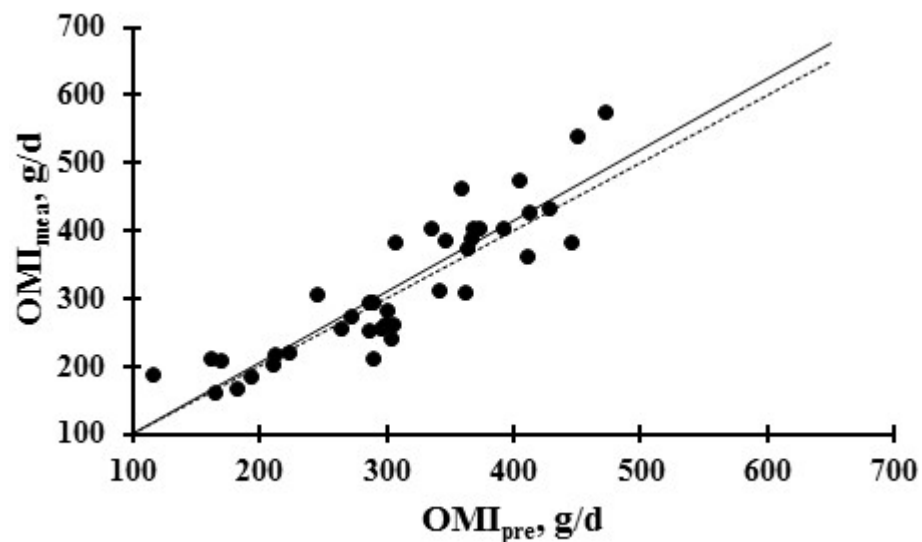
Table 5. Descriptive and equation statistics for cross validation data of pellet neutral detergent fibre (NDF_i), dry matter intake (DMI_p) and organic matter intake (OMI_p).

	<i>n</i> ^a	Measured ^b	SD ^c	SE ^d	Predicted ^e	SD	SE	R ²	RPE ^f , %	CCC ^g
NDF _i , g/d	40	14.36	14.60	2.31	11.37	10.70	1.69	0.71	58.64	0.78
DMI _p , g/d	40	91.6	88.9	14.1	72.0	67.5	10.7	0.64	61.42	0.75
OMI _p , g/d	40	83.5	80.9	12.8	65.69	61.34	9.70	0.65	60.99	0.75

^a Number of spot faecal samples. ^b Measured: actual mean value obtained from experiments one and two.

^c SD: standard deviation. ^d SE: standard error. ^e Predicted: mean value obtained from prediction equations.

^f RPE = relative predictive error. ^g CCC = concordance correlation coefficient.

**Figure 1.** Cross validation: relationship between measured DMI_{mea} (dry matter intake) and DMI_{pre} (predicted dry matter intake) of young lambs consuming milk and pellets concurrently during the pre-weaning stage. The solid (–) line depicts the equation: $DMI_{mea} = -6.18 (\pm 29.95) + 1.03 (\pm 0.09) DMI_{pre}$ ($R^2 = 0.79$; RPE = 15.09%; CCC = 0.88). The dashed (–) line depicts $DMI_{mea} = DMI_{pre}$.**Figure 2.** Cross validation: relationship between OMI_{mea} (measured organic matter intake) and OMI_{pre} (predicted organic matter intake) of lambs fed milk and pellets concurrently during the pre-weaning stage. The solid (–) line represents the equation: $OMI_{mea} = -3.44 (\pm 27.24) + 1.05 (\pm 0.09) OMI_{pre}$ ($R^2 = 0.80$; RPE = 14.90%; CCC = 0.88). The dashed (–) line shows $OMI_{mea} = OMI_{pre}$.

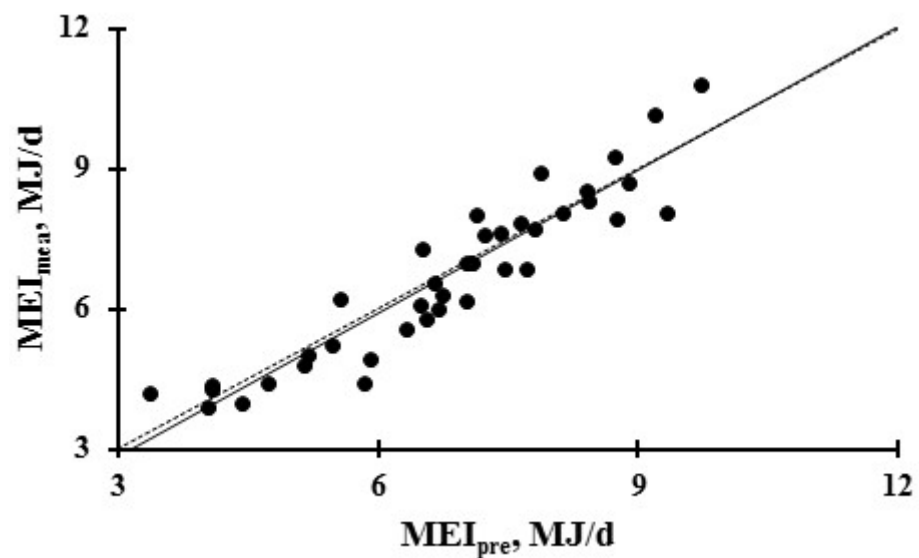


Figure 3. Cross validation: relationship between MEI_{mea} (measured metabolisable energy intake) and MEI_{pre} (predicted metabolisable energy intake) of young lambs fed milk and pellets concurrently during the pre-weaning stage. The solid (–) line represents the equation: $MEI_{mea} = -0.26 (\pm 0.45) + 1.02 (\pm 0.06) MEI_{pre}$ ($R^2 = 0.87$; $RPE = 9.48\%$; $CCC = 0.93$). The dashed (–) line shows $MEI_{mea} = MEI_{pre}$.

4. Discussion

The aim of the present study was to determine if DM, OM, and ME intakes of lambs fed a combination of milk and pellets could be predicted with sufficient accuracy using dietary and faecal chemical composition. If possible, this would provide a means to firstly develop suitable feeding strategies for young lambs and, secondly, to optimise feed rations to meet the requirements of lambs under a variety of feeding conditions.

4.1. Prediction Equations (Phase One)

The significant linear regression between lamb organic matter intake (OMI) and faecal nitrogen (fN) (Phase one) found in this study supported the concept of the relationship between OMI and fN. This is based on the assumption that the amount of fN excreted per unit of organic matter (OM) ingested is constant [17,18]. However, this assumption was only confirmed for the prediction of milk OMI (OMIm), as the relationship between pellet OMI (OMIp) and fN was not significant. This finding was not in agreement with previous studies using older lambs and goats, which reported a positive linear relationship between herbage OMI and fN (Boval [4–6,19]). A review by Cordova et al. [20] found inconsistent results from 25 studies with regards to the use of fN concentration as an indicator of pasture intake in grazing ruminants. Previous research shows that the best association between fN concentration and N intake from solid feed occurred when the dietary nitrogen content was less than or equal to 2.4 g/kg DM [21]. This may explain the poor relationship between fN and OMIp in the present study, as the N concentration in the pellets was greater than 2.4 g/kg DM, with the exception of the low-protein pellets. There are no published reports of OMI estimation from fN in young lambs consuming both milk and solid feed to make a direct comparison with, but fN was not selected by the stepwise regression model, indicating a poor OMIp prediction from fN (data not shown). Thus, results of the present study somewhat support the theoretical concept of the relationship between lamb OMI and fN. Nevertheless, the prediction equations obtained for milk intake showed good precision and hence can be used to estimate milk OM and DM intakes in young lambs.

The concentration of NDF was the most important variable for estimating lamb pellet dry matter and organic matter intakes. The relationship between dietary NDF and the concentration of NDF in faeces (fNDF) was previously demonstrated by Fanchone et al. [22] in older sheep. In the present study, the concentrations of fNDF and pellet NDF (NDFi)

provided the best estimate of pellet intake when stepwise procedures were used to obtain the best multiple regression equation. The significant linear relationship between fNDF and NDFi in the present study was consistent with the observations made by Wofford and Holechek [20] in grazing cattle. However, the model has low predictive value based on the very high RPE values obtained in the present analysis.

Faecal chemical composition can have poor accuracy for predicting solid feed intake of ruminants [23], thus, it is important to include animal characteristics in intake prediction models. The potential feed intake of an animal is influenced by its demand for energy, its physical capacity for feed consumption such as live weight (or stomach capacity) and its physiological state [24,25]. The inclusion of live weight to the pellet and milk DMI prediction equations improved the R^2 and CCC and decreased the RPE. A significant effect of LW on the DMI_{pre} , OMI_{pre} , and MEI_{pre} models indicated that feed intake in young lambs was a linear function of their LW. The accuracy of the developed equations suggest that they can be used to estimate intake of pre-weaned lambs at different live weights.

4.2. Cross-Validation (Phase Two)

The cross-validation results demonstrated that the prediction equations developed were sufficiently accurate for predicting lamb ME intake from spot faecal samples. The validations were carried out utilizing a variety of lamb treatments and live weights, which should cover the majority of artificial lamb rearing scenarios. It has previously been demonstrated that simple and multiple linear regression models based on faeces composition can predict lamb feed consumption [6]. These authors predicted daily feed intake based on the total faecal collection, as the fN content used in the intake predictions were expressed in grams per day. This approach required that the feed intake of lambs could only be predicted by conducting a parallel digestibility study. Results of the present study demonstrated the possibility of predicting feed intake in pre-weaned lambs from the concentration of N and NDF in faecal material. A practical limitation for using the developed equations in the present study is the need for proximate laboratory analyses to determine the chemical composition of faecal and dietary samples, and their associative costs. However, it eliminates the labour associated with total faecal collection and the discomfort of keeping lambs in crates. The possibility of using alternate laboratory analysis such as the spectroscopic techniques that have successfully been used to predict feed intake in sheep and cattle [22,26,27] should be considered, as they may help reduce costs. Furthermore, the prediction of the feed intake by the developed equations needs to be validated with other feed types such as pasture and alternative concentrate diets. This is especially relevant for unweaned lambs in outdoor grazing farm systems.

5. Conclusions

The present study showed that faecal N is a reliable index to predict the milk OM and DM intake—but not pellet intake. The NDF concentration in both faeces and pellets were the most accurate in estimating pellet OM and DM intakes in lambs. The robustness of the ME intake equation indicated that under similar conditions to that of the present study, the ME intake of pre-weaned lambs can be estimated with sufficient accuracy. Not only do the ME intake equations provide information of theoretical interest to scientists, but they have a significant practical application in farming situations by enabling farmers to develop more accurate artificial feeding strategies for young lambs, which will be more attuned to the lambs requirements. These equations have been developed for indoor fed lambs only. Therefore, further validations with other feed types as well as lambs grazing with their dams are needed before these equations can utilised in any lamb rearing system type.

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