

Maize silage LINK Project Consortium

PROJECT H5105200

REPORT

Prediction of the in vivo metabolisable energy value and the in situ degradability of maize silage from near infrared reflectance spectroscopy and determining the relationship between in situ and in vitro determinations of degradability:

Measurement of digestibility and degradability

C. Rymer and D.J. Humphries

Food Production and Quality Division
School of Agriculture, Policy and Development
University of Reading
READING
RG6 6AR

SUMMARY

A total of 90 samples of maize silage (MS) were collected from commercial farms in the UK over a two year period (2009/10 and 2010/11). The objective of the project was to determine the ability of near infrared reflectance spectroscopy (NIRS) to predict digestible organic matter (DOMD) and metabolisable energy (ME) contents as measured *in vivo* using sheep at maintenance, and the *in situ* degradability (measured using cows) of MS dry matter (DM), nitrogen (N) and starch. In this report, the measurement of the *in vivo* and *in situ* data are described. Silage dry matter (DM) contents ranged from 211 to 436 g/kg, crude protein contents from 64 to 112 g/kg DM, starch contents from 98 to 367 g/kg DM and neutral detergent fibre contents from 349 to 646 g/kg DM. The predicted metabolisable energy (ME) contents ranged from 9.1 to 12.0 MJ/kg DM. Silages collected in the second year of the study were slightly (approx 2%) more digestible than those collected in year 1, and had a slightly higher crude protein content and pH although this was not related to the increased digestibility. The *in situ* rate of dry matter degradation was slow compared with the silages currently in the *Feed into Milk* (FiM) database, and the calculated effectively rumen degraded dry matter content (using the FiM model) was also much lower. However, if the 'a' fraction was considered soluble, the effectively rumen degraded dry matter content was similar. It is proposed that for maize silage this is a more rational approach as to assume that small starch particles degrade at the same rate as large NDF particles is erroneous. The estimation of the effectively degraded N content of the silage was not improved by fitting more than a single curve, described by $N \text{ degradability} = 73.2 + 11.4(1 - e^{-0.021t})$ where t is time (h). Although mean N solubility was similar to the FiM database, it was very variable (ranging from 30 to 73%). Determining starch degradability was complicated by the heterogenous nature of the maize silage, and the difficulty of accurately analysing starch content in forage samples. Starch was completely degraded and the rate of starch degradation was rapid (0.096/h). If the FiM model was used to estimate the effective degradability of starch, only 55% was degraded which is unlikely. The modified FiM model predicts a more realistic effective starch degradability of 81%, and the maize silage samples studied would then supply between 86 and 306 g effectively degraded starch/kg DM.

INTRODUCTION

Maize silage is a major feed for ruminants, particularly dairy cows, where as much as 75% of the forage can be fed as maize silage. The area dedicated to forage maize has increased substantially from 35 000 ha in 1990 to approximately 132 000 ha in the latest DEFRA survey (DEFRA, 2011), so that approximately 2 million cattle are now fed maize silage. Maize is also a flexible alternative to wheat and can either be harvested for forage maize or diverted to grain maize production, including its use as a biofuel. Climate change, with a projected increase in ambient temperature of 2°C during the 21st century, may significantly increase the amount of forage maize grown, as the ambient temperature zone for successful cultivation will move further north.

The use of maize silage fed with grass silage, or as a buffer feed with high protein spring grass, can reduce methane production and nitrogen pollution. Substituting grass silage with maize silage increased N retention (Browne et al., 2005), increased the efficiency of N utilisation (Burke et al., 2007), and reduced N and methane excretion (Dijkstra et al., 2009). When fed with red clover silage, maize silage increased the partitioning of dietary N to milk N rather than urinary N (Dewhurst et al., 2010).

A system (be it dairy, beef or sheep) that uses maize silage needs to have accurate data on the chemical composition and nutritive value of that silage if it is to be used efficiently. Indeed, all diet formulation systems, such as the *Feed into Milk* system adopted in the UK, rely on accurate estimates of the energy and nutrient content of forage feeds produced on farm. This involves both the determination of the total amount of energy and nitrogen available, and also the rate at which nutrients supplying energy and N are degraded in the rumen.

Maize silage ring test studies completed by the UK Forage Analytical Assurance (FAA) group showed very poor agreement in the estimate of energy by different silage laboratories (ranging from 10.6 to 12.0 MJ ME/kg DM for a single sample) and poor relationships with the FAA master laboratory (R^2 range of 0.25 to 0.62). Modern dairy feeding models now recognise the importance of balancing the supply of energy and protein both within the rumen (rumen energy to protein ratios) and within the cow (Metabolisable Protein to ME) ratios. The determination of the rate and extent of rumen degradable dry matter and N are key inputs required by the Feed into Milk system, as well as a reliable estimate of the feed's ME content. Clearly, this requires the ability to predict nutritive values using rapid techniques such as near infrared reflectance spectroscopy (NIRS).

The FAA group has successfully applied wet NIRS techniques to estimate the nutrient values of grass silage. A previous LINK project (LK0658), introduced new NIRS equations for whole crop wheat and barley silages during 2006. For maize silage, there are standard industry equations for the prediction of dry matter, crude protein, NCGD, starch, ash and NDF content, but there are no agreed methods to predict the ME or dry matter, starch and nitrogen degradabilities. Currently, individual silage

laboratories use different methods to predict ME (for example by using equations based on NCGD) and degradability values are based on fixed values derived for the FiM model.

In addition to the lack of consistent prediction of the ME content of maize silage, there is no means of reliably predicting its rumen degradability characteristics. There is no UK published work on a large scale survey of maize silage degradabilities for dry matter, nitrogen or starch, and the feed industry currently has to rely on fixed estimates of these important characteristics. The objective of this project was therefore to determine the ME content and the rate and extent of rumen dry matter, nitrogen and starch degradability for a wide range of maize silages. These silage samples were then submitted to Eurofins to derive wet scanning NIRS predictions.

MATERIALS AND METHODS

Sample identification, collection and processing

The Maize Growers Association (MGA) and other commercial partners combined their databases to assist in the identification and collection of 90 maize silages of known variety, harvest date and harvest treatment (i.e. rolling/chopping/silage additive etc). The silages were collected from various UK farm sites over a period of two years. Ten of the samples with differing maturities and physiological characteristics were provided by Syngenta Seeds. In Appendix 1, Table A.1 summarises the UK region of origin and cereal varieties. A map showing the sites where the silage samples were taken from is presented in Figure 1; the large star indicates where the ten (Syngenta) samples were located. The main criterion when selecting samples was to ensure that as wide a range of sample dry matter contents as possible were obtained. This was on the basis that this should also result in as wide a range of ME contents as possible were obtained, to improve the accuracy of ME prediction. In the first year, most of the samples were collected from the south west of England, and along the M4 corridor. This geographical bias was addressed in the second year, to ensure that samples were also collected from other major maize growing regions in the country.

A single sample of around 400 kg fresh weight was removed mechanically from a clean area of the maize silage clamp face. The sample was placed in a large plastic bag and sealed in a 1000 l plastic container for transport to Reading. Samples were numbered sequentially at source to aid identification. At the point of collection a photograph was taken of the clamp face and area the sample was taken from and a close up image was taken of the silage sample showing visually the physical form of the maize silage. Each sample consisted of approximately 110 kg dry matter, and, collectively, the aim was to acquire samples ranging in DM content from <250g/kg to >400g/kg. On the day of arrival at Reading, each sample was mixed for five minutes in a clean diet mixer (Dataranger). The Penn State Forage and TMR Particle Separator was used to determine forage particle length and particle size distribution in a representative 1.8 kg sample of each maize (Kononoff et al., 2003). Dry matter content was determined initially by microwave oven then confirmed by drying triplicate samples (400 g fresh weight) at 100°C for 23 hours.

A sample of each silage was submitted to Eurofins for analysis of chemical composition and by NIRS (using both wet and dry materials). Samples of each silage were also submitted to Bioparametrics for determination of *in vitro* gas production profile.

Sample analysis

Digestibility

Digestible organic matter content (DOMD) values were determined to predict the ME content of the silage. Digestibility of individual maize silages were measured *in vivo* using 12 mature wether sheep, of similar breed, liveweight and condition score. Samples were characterised in batches of three (i.e. using three sheep) using a balanced Latin square design to reduce between animal variation. The allocation of sheep to forages and weeks of the study is shown in Figure 2a.

In vivo digestibility was estimated by making complete collections of faeces in metabolism cages over a 5 day period following a 16 day adaptation to the diet (Figure 2b). Maize silage was fed as the sole diet, supplemented with a sheep mineral/vitamin supplement (17 g/d) and 2 g urea per animal per day applied in solution (diluted in 20ml water) sprinkled on top of the forage. The amount of maize silage fed to each sheep was calculated to be sufficient to maintain liveweight (24 g DM/kg liveweight). The sheep were weighed on a weekly basis and any necessary adjustments in the diets were made. All diets (including the mineral/vitamin supplement and the urea solution) were fed in equal portions two times per day.

Following the introduction of the test diet (day 1) the sheep were housed in individual pens with a plastic mesh lying area to allow drainage. Each pen was fitted with a self-fill water bowl and a feed trough, and was hosed clean on a daily basis at feeding time. The sheep were fed twice daily at 0900 and 1600 h, with any refused feed being removed prior to the morning feed and recorded. After 16 d adaptation to the test feed the sheep were placed in metabolism cages for the commencement of faeces collection (timescale summarised in Figure 2b).

Complete collections of faeces were made at the same time each day during the collection period. Each day the faeces were placed into individual plastic bags labelled with the sheep identity, the forage number and the day number. The contents of the five bags collected per sheep over the trial period were stored at 3-4°C. At the end of the collection period the total faeces were weighed and then thoroughly mixed. Three representative samples of approximately 400g were taken for dry matter determinations. A further sample of mixed faeces was stored frozen. Refused feed was bulked over the collection period for determination of dry matter and ash contents.

During the course of the study it was noticed that there appeared to be diet selection occurring and that the refused feed removed from the feed trough was of a different physical composition from the feed offered. If this feed selection was biased toward certain nutrients (such as starch) then this might affect the estimation of the silage's ME content. To determine whether this apparent selection did affect the estimation of nutrient intake, six samples of refused feed from individual sheep periods with a visually

different appearance from the original maize silage sample were selected at random and analysed for dry matter, ash, crude protein and starch.

In situ degradability

Monofilamentous polyester bags (40-45µm pore size, 110-230 mm flat plus 6mm hem) were attached to a curtain ring and suspended inside the cows' rumens on a 400 g snap shackle, which in turn was attached to the rumen cannula. Dry matter content of the sample was determined prior to filling the bags, with sample sizes standardised at 10 g DM and duplicate bags being prepared for each cow and time period. Bags were incubated inside the rumen of three cows for 3, 6, 12, 24, 48 and 72 h, with 0 h bags being processed immediately. Post-incubation all bags (including 0 h bags) were immersed in cold water to inhibit microbial activity. The bags were then gently rinsed to remove any extraneous materials from the exterior, gently squeezed of excess moisture and frozen. Once a complete set of samples was obtained, the bags were defrosted, placed in a net bag and cold washed in a detergent-free washing machine. The bags were then dried at 60°C for 72 h. Once cooled the samples were reweighed. The samples were then ground in a Cyclotec mill (1mm screen) for laboratory analysis. Feeds and residues were analysed for dry matter, nitrogen, starch and ash. The mean *in situ* degradability of each maize silage and its composite fractions of nitrogen, organic matter and starch were then calculated.

Chemical analysis

Dry matter

To determine the dry matter content, 400 g of each maize sample was placed in triplicate in a 100°C oven for 23 hours (DM = (mass of dried sample – mass of fresh sample) x 100).

Dry matter content was also estimated using a microwave oven technique. Two 100 g samples of fresh maize were placed into duplicate trays of equal mass. Fresh samples with a dry appearance were placed in microwave set at full power (850 W) for two minutes prior to being reweighed and the weight recorded. The sample was then placed in the microwave for one minute three times, with the weights obtained being recorded after each treatment. The sample was then placed in the microwave for 30 s and reweighed. This was repeated until constant weights (within 0.1 g) were obtained. Samples were turned after each treatment to ensure even drying, and were rested for two minutes between each treatment to allow the evaporation of water vapour and to prevent over-heating. Any moisture inside the microwave was removed with a paper towel between each drying period. Initially very dry samples were found to reach a stable weight with fewer drying periods. Some wet samples required several two minute microwave treatments to remove the initial moisture.

Organic matter

A previously dried and milled sample was dried (60°C) in an oven for 1 h to remove residual moisture. A sample (3 g) was then weighed into a crucible and ashed in a muffle oven at 500°C for 18 h. Once cool the crucible was reweighed, and organic matter content (OM, g/kg DM) was calculated as:

$$\text{OM} = ((\text{sample weight in} - \text{ash weight out})/\text{sample weight in}) \times 1000$$

Nitrogen

Nitrogen content was determined using the Kjeldahl method. Samples were prepared by drying at 60°C, grinding and milling to a fine powder in a planetary ball mill. The homogenous sample was then boiled in concentrated sulphuric acid with Kjeltab catalyst to decompose the nitrogen resulting in an ammonium sulphate solution. The addition of concentrated sodium hydroxide solution liberated ammonia gas (through conversion of NH_4^+ to NH_3), which was driven off by steam distillation and condensed into a boric acid based indicator solution. This receiving solution was then subjected to a back titration to quantify the amount of ammonia ions in the solution, and hence the nitrogen content.

Starch

Starch content can be defined as the total available carbohydrate less water soluble carbohydrate. Total available carbohydrate is soluble in hot water, and is broken down to reducing sugars by incubation with amyloglucosidase and mild acid hydrolysis. To determine total available carbohydrate, the sample was again dried, ground and milled in a planetary ball mill, prior to being boiled for two hours and simultaneously mixed every 15 minutes. Amyloglucosidase solution (0.2% w/v in acetate buffer, pH 4.5) was added, and the solution incubated at 55°C for 1.5 h, and mixed as before. The solution was then filtered, and the filtrate, and a range of reducing sugar standards, incubated with 0.133M sulphuric acid at 70°C for 30 minutes. When cooled, the hydrolysate was analysed for reducing sugar concentration on a continuous flow autoanalyser system.

(a) The carbohydrate content of the sample was calculated as:

$$\text{CHO} = \frac{C \times D \times 100}{W}$$

where CHO is the total carbohydrate, D is the dilution factor, which is the extract volume prior to hydrolysis (ml), C is the concentration of reducing sugar in the hydrolysate (mg/l) and W is the weight of sample taken (mg).

(b) The starch content of the sample was then calculated as:

$$\text{Starch} = (0.9 \times (\text{TC} - \text{WC}) \times 100) / \text{SR}$$

where Starch is the starch content, a factor of 0.9 is applied to correct for water gained on hydrolysis, TC is the Total Carbohydrate content as obtained from (a), WC is the Water Soluble Carbohydrate

content as obtained from (a) in a separate sample that was not subjected to the amyloglucosidase hydrolysis, and SR is the starch recovery (%)

Soluble dry matter and nitrogen

The soluble dry matter and nitrogen contents of each silage were determined to correct for losses of small particles at 0 h in the *in situ* technique. A sample (1 g dry matter) was weighed out and soaked in 100 ml of distilled water for 1 h, swirling every 15 minutes. The sample was then filtered through a pre weighed filter paper and oven dried at 100°C overnight and then re weighed.

Kjeldahl nitrogen analysis was then performed on the residue.

Soluble DM content (%) = $\frac{(\text{wt sample} * \text{DM}/100) - (\text{wt residue}) * 100}{\text{Wt sample} * \text{DM}/100}$

$$\text{Wt sample} * \text{DM}/100$$

Nitrogen solubility (%) = $\frac{((\text{DM in} * \text{N\% of control}) - (\text{Wt of residue} * \text{N \% of residue}))}{100}$

100

100

$$/(\text{DM in} * \text{N\% residue}) * 100)$$

100

Statistical analysis

The means, standard deviations, minimum and maximum values were determined for parameters for the entire sample set (n=90) and also for the two years of sampling (year 1, n=48, year 2 n=42).

Differences between the years were determined by analysis of variance.

DOMD and ME

The dry matter content of the silage was corrected for volatile fermentation products in the calculation of digestible organic matter in the dry matter (DOMD). This was done using the correction proposed by Haigh (1979) for maize silage:

$$\text{Corrected dry matter (CDM)} = (0.95 \times \text{oven dry matter}) + 3.3$$

where dry matter is expressed as a percentage. The DOMD on a true dry matter basis (DOMD_{TDM}, g/kg CDM) was then calculated from:

$$\text{DOMD}_{\text{TDM}} = 100 - \{(100 - \text{DOMD}) \times (\text{ODM}/\text{CDM})\}$$

where ODM is oven dry matter (%) and CDM is corrected dry matter. The ME_{TDM} (MJ/kg CDM) content of the silage was then predicted from (AFRC, 1993):

$$\text{ME}_{\text{TDM}} = 15.7 \times \text{DOMD}_{\text{TDM}}$$

In situ degradability data

The Ørskov and McDonald (1979) model was fitted to the *in situ* degradability data,

$$\text{Degradability}_t (\%) = a + b(1 - e^{-ct})$$

Where Degradability_t is degradability at time t , a is the fraction ‘instantaneously’ available, b is the slowly degraded material and c is the rate of degradation of b . For dry matter degradability, best subsets and then stepwise regression was used to determine whether there was any relationship between the chemical composition of maize silage and the rate of dry matter degradation and the effective degradability of dry matter using the proposed modified FiM model (see below).

Dry matter and N degradability was corrected for material that was ‘lost’ at 0 h by determining the solubility of dry matter and N. In the FiM model, the degradable material that is available at 0 h is then determined as the soluble material (s) and a proportion (Bd) of the remaining ‘ a ’ material:

$$Bd = b(a - s) / (100 - a)$$

The effective degradability of soluble material and small particles (ED_{ssp}) is then calculated as:

$$ED_{ssp} = (0.9s) / (0.9 + k_{liq}) + (Bd \cdot c) / (c + k_{liq})$$

Where k_{liq} is the fractional outflow rate of liquid (0.077 for a 700 kg cow consuming 25 kg DM/d of a diet comprising 400 g/kg forage).

The effective degradability of large particles (ED_{lp}) was calculated as:

$$ED_{lp} = bc / (c + k_f)$$

Where k_f is the fractional outflow rate of large forage particles (0.047 for a 700 kg cow consuming 25 kg DM/d of a diet comprising 400 g/kg forage).

The effective degradability of dry matter or N may then be calculated as the sum of ED_{ssp} and ED_{lp} .

This approach resulted in unrealistically low estimates of the amount of material degraded in the rumen. This is a particular issue with a forage such as maize silage, in which small particles (mostly starch) are ascribed a degradation rate derived from the large particles (mostly NDF). The effective degradability of material (dry matter, N, organic matter and starch) was therefore also calculated as:

$$EDDM(a=s) = ((0.9a) / (0.9 + k_{liq})) + ((bc) / (c + k_f))$$

thus assuming that the soluble and small particles in maize silage have a common degradation rate of 0.9, and are subject to the liquid outflow rate. This is an adaptation of the FiM approach, rather than reverting to the earlier estimation of effective degradability ($a + (bc / (c + k))$), in which it was assumed that the ‘ a ’ fraction was completely and instantaneously available.

The analysis of starch degradability is complex as the heterogenous nature of the silage makes it extremely difficult to obtain truly representative samples of silage for use in the *in situ* technique. The analysis of starch in the residues is also complicated by the various stages involved in the analysis. In

some cases, this resulted in more than 100% of the degraded organic matter being accounted for, after taking account of losses from determined degraded N, starch and neutral detergent soluble materials. In these instances, the estimated starch degradability was corrected, being calculated as the degraded organic matter content after subtraction of losses from degraded crude protein and neutral detergent solubles. The Ørskov and McDonald (1979) model was then fitted to individual silage samples.

RESULTS AND DISCUSSION

Sample description

The sites from which samples were collected is summarised in Table A1 of Appendix 1. A range of varieties were represented in this study, although some farmers did not know or did not report which variety was used. Five of the silages were reported to have been exposed to frost before harvest, but as with the variety, this was not always known. Plastic had been used with four of the silage samples.

Chemical and physical composition

A summary description of the chemical composition and particle size of the silages is presented in Table 1, with values for individual silages presented in Appendix Table A.2. A good range in silage dry matter was achieved, from 211 to 436 g/kg fresh weight, although these extremes represented very few silages because of the difficulty in sourcing extremely wet or extremely dry silage. The distribution of samples of different dry matter ranges that was achieved is illustrated in Figure 3. Most samples had dry matter contents between 301 and 350 g/kg, reflecting perhaps the norm for maize silage production in the UK. 78% of the silages used in this study had dry matter contents between 251 and 350 g/kg, and this increases the confidence in prediction equations generated to characterise silages that are typically produced in the UK. The remaining samples mostly had dry matter contents between 351 and 400 g/kg. Dry matter content was the criterion for silage selection because of its indication of plant maturity before ensilage. A large range was required so as to increase the accuracy of the prediction equations, but to achieve this some atypical silages had to be identified. These comprised the two extreme groups (n=5 and n=4), which had dry matter contents between 201-250 and 401-450 g/kg respectively.

There was no significant difference in the chemical composition of the silages between the two years, with the exception of crude protein. The crude protein content of silages in Year 2 was slightly higher than in Year 1, but in both years the crude protein content was low (approximately 86 g/kg DM), as would be expected for maize silage. Both starch and NDF content varied considerably (with ranges of 98-367 and 349-646 g/kg DM respectively), reflecting great variation in the maturity of the maize that was harvested. Dry matter content was positively related to starch and negatively related to NDF content, with the DM content of the silage accounting for 23.4% of the variation in starch content 17.8% of the variation in NDF content. The relationship between dry matter content and the starch and dry matter content of maize silage is illustrated in Figure 4. As observed by Givens and Deaville (2001), the relationship between NDF and DM content was non-linear, although the quadratic

equation derived with the samples in this study accounted for less of the variation than in the study reported by Givens and Deaville (2001). The equation in this study was:

$$\text{NDF} = 1360 - 5.12 \text{ DM} + 0.00720 \text{ DM}^2, \quad R^2=34.2\% \text{ (} R^2=63.6\% \text{ for Givens and Deaville, 2001)}$$

The relationship between dry matter and starch was not improved by introducing a quadratic term in this study.

The chemical composition of these silages was similar to that in the FiM database except for ash (which was much higher in the FiM database, 60 g/kg compared with 39 g/kg in these samples). The silages characterised by Givens and Deaville (2001) were also similar, but those reported by De Boever et al. (2002) had a lower NDF and higher starch content, perhaps reflecting different climatic conditions between Belgium and the UK.

There was a wide range in the geometric mean particle size of the silage samples, assessed using the Penn State Particle Separator, with a minimum of 8.3 and a maximum of 19.1 mm. There was a small negative relationship between particle size and silage dry matter content, with particle size accounting for 17.8% of the variation in dry matter, but no relationship between particle size and pH ($R^2=10.5\%$).

Digestibility

The mean, and the ranges observed, of the digestibility of dry matter, organic matter, DOMD and predicted ME are presented in Table 2. The silages in year 2 were more digestible ($P<0.01$) than those in year 1, even though the silages in year 2 represented a greater range with lower minimum values than those observed in year 1. This difference in digestibility between the two years (approximately 2.5%) was not reflected in any difference in the *in situ* rumen degradability, and regression analysis showed that it was not related to the increased crude protein content observed in year 2 silages (relationship between dry matter digestibility and silage crude protein content, $R^2=0.003$, $P=0.606$).

Digestibility values for the individual silages, with their coefficients of variation, are presented in the Appendix in Table A.3. Determining whole tract apparent digestibility in mature wethers is a robust and reproducible determination, reflected by the coefficients which were generally below 5%.

The range of DOMD values (and therefore calculated ME values) were similar to those used in the study by Givens and Deaville (2001), suggesting that there has not been a substantial change in the last ten years in the composition and nutritive value of maize silages, and also that the silages characterised by Givens and Deaville (2001) can be included in this database for the prediction of DOMD and ME.

With regard to the selection by sheep of the forage, the analysis of the original feed and the refused feed sample are presented in Table 3. Differences in composition between feed offered and refused can be explained in the main by study practice, the dry matter content in refused feed being lower (<20%) than offered feed because of water introduced to the feed trough from the drinking bowl. Paired sample t-test suggested no significant ($P=0.223$) difference in the starch content of offered and

refused feed, which would indicate that the sheep were not preferentially selecting the starchier fractions of the silage. The only significant ($P=0.003$) difference between the composition of feed offered and refused was the ash content which was 27.2% higher in the refused feed (Table 3). In terms of overall average nutrient intake the differences observed in nutrient composition between feed offered and refused affected intake by -3.5%, 1.7% and -1.4% for ash, starch and protein respectively (mean of the six samples analysed).

Degradability and solubility of dry matter

Data for *in situ* rumen degradability of dry matter are summarised in Table 4. These provide the mean and range of the estimates of a, b and c, and the solubility of dry matter which is used in the *Feed into Milk* diet formulation system to correct for the loss of small particles from the *in situ* system at 0 h. The effectively degraded dry matter content (for a 700 kg cow consuming 25 kg/d of a diet comprising 400 g/kg forage), and correcting for the loss of small particles, is also presented. No significant differences were observed in these parameters between Years 1 and 2. In Appendix Table A.4, the mean ($n=3$) *in situ* degradability determined at each time point, determination of solubility and the estimated values of a, b and c for each individual silage is presented. The R^2 values for these fitted curves were high (>0.9) indicating that the Ørskov and McDonald (1979) model was appropriate for these data. The coefficients of variation for the determination of degradability are also presented, and show that this method has similar repeatability to the determination of whole tract apparent digestibility. The use of the *in situ* technique is problematical for a material such as maize silage that is highly heterogenous, but for the determination of dry matter degradability this did not result in especially high coefficients of variation.

Compared with the FiM database, the mean values for a and b are similar, but the estimated solubility of dry matter was lower in these samples compared with the FiM database (14 compared with 31%) and the rate of degradability was also slower (0.02 compared with 0.1). Using the FiM model, the calculated mean effective degradability of dry matter (EDDM) was very low (313 g/kg), which seems unrealistic, particularly when the DOMD values of the silages are considered. This is a consequence of the relatively low solubility and degradation rate, but as explained in the Materials and Methods, this seems to be more of a shortcoming of the FiM model when characterising a feed such as maize silage, rather than the silage itself. When EDDM is calculated assuming that $a=s$ much more realistic estimates of EDDM are produced, equivalent to 78% of the whole tract apparent dry matter digestibility (rather than 46%, as was the case with the FiM model). The values in the FiM database are also more realistic using this modified model, as the estimate of EDDM is then 645 g/kg (similar to that observed as the mean of this dataset) rather than 936 g/kg.

The rate of degradability ('c') was not related to any of the chemical composition parameters ($R^2<0.16$). However, the 'c' value is dependent on the relative values of 'a' and 'b', so that a highly degradable silage with a high 'a' value can have a relatively low 'c' value. The estimate of EDDM is therefore a better indicator of degradability as it takes account of the three terms that describe the

kinetics of degradability. EDDM (calculated using the modified FiM model) was regressed using best subsets regression with the parameters describing silage chemical composition, and also the mean particle size. The terms selected from this regression were then tested using stepwise regression. EDDM was related ($R^2=0.433$, $P=0.003$, $s=30.4$) to the silage's NDF, CP and DM content with the equation:

$$\text{EDDM} = 568 - 0.431\text{NDF} + 1.18\text{CP} + 0.200\text{DM}$$

Insofar as silage DM content is an indicator of plant maturity, this relationship suggests that the more mature a silage (with a higher DM content, lower NDF content and higher starch content, although starch content was not related to EDDM *per se*) is more degradable.

Degradability and solubility of N.

The estimation of dry matter degradability for all of the 90 silage samples yielded curves to which the Ørskov and McDonald (1979) equation could be fitted, which could allow for the prediction of kinetics of rumen dry matter degradability for individual silages. The same was not the case for the rumen degradability of N, which was probably because of the low N content of maize silage. Any contamination with rumen microbial material, especially in the early stages of incubation, potentially constituted a relatively large proportion of the N detected in the residues. In addition, the heterogeneity of maize silage, coupled with its low N content, resulted in any errors in the determination of the N content of *in situ* residues producing atypical degradation curves. The N degradability data from most of the silage samples could therefore not be fitted to the Ørskov and McDonald (1979) equation, and it would not be possible to produce reliable predictions of the N degradability kinetics for individual silages.

However, the *Feed into Milk* model for the prediction of N supply requires that all feeds be ascribed estimates of a, b and c for both DM and N. To determine whether all the samples of maize silage could have their N degradability described by a single set of parameters, or whether there were distinct populations within the study set, a single curve was fitted to all the data. The silage samples were then divided into quintiles, on the basis of DM content, N solubility, soluble N content and washable N loss (0 h degradability). The estimates of a, b and c for each of these quintiles, together with the measured N content and N solubility, were then used to calculate the predicted effectively degraded N content for each silage, using both the *Feed into Milk* model and the modified model (proposed for maize silage, in which all 'a' material is treated as soluble), assuming a 700 kg cow was fed 25 kg DM/d comprising 400 g/kg forage. A *t* test was then used to compare the predicted effectively degraded N content of the maize silages when either the single, fixed model was used, or the models based on segregating the silages on the basis of nitrogen solubility or 0 h degradability.

The mean and range of values for N solubility and soluble N content are summarised in Table 5. N solubility ranged from 29.8 to 72.5%, with maize silage samples taken in year 1 being significantly ($P<0.001$) more soluble than those in year 2. The lower N content of year 1 silage samples, however,

meant that there was no significant difference ($P=0.085$) in the soluble N content of silages in the two years. These data for the individual silage samples are presented in Appendix Table A.6. The parameters describing the curves fitted for the mean of all data, and for the different quintiles based on dry matter content, N solubility, soluble N content and 0 h N degradability are summarised in Table 6. The Ørskov and McDonald (1979) model could not be fitted to the data with the highest 0 h N degradabilities, and so an effective degradability of N of 0.9 was assumed for these samples. The Ørskov and McDonald (1979) model was also unsuitable for the silage samples with a high soluble N content.

There was no evidence, on the basis of mean values for a, b and c and the standard errors, that separating maize silages on the basis of dry matter content produced degradability curves that were different from the single curve produced using all the samples of maize silage. This was also the case for intermediate quintiles for N solubility and soluble N content. However, the silages with the lowest and highest N solubility, lowest soluble N content, and 0 h N degradability did appear to have lower 'a' and higher 'b' and 'c' values. The mean EDN contents for these silages using the different models are presented in Table 7. With the FiM model, there were no significant differences in the estimates of EDN. With the modified FiM model, statistically significant differences ($P<0.001$, $P=0.005$ respectively) were observed for the estimates of EDN content for silages with N solubility between 29 and 45%, and for silages with a soluble N content between 3 and 6 g/kg. However, the difference in the EDN content using the two alternative models was extremely small (approximately 1 g EDN/kg) which is unlikely to be of any nutritional significance. On the basis of this evidence, therefore, there would be no benefit in using more than single, fixed, values for a, b and c (with $a=73.2$, $b=11.4$ and $c=0.021$). The actual estimate of effectively degraded N content of maize silage would then be moderated by variation in its N content and N solubility.

The mean N solubility and fitted 'a' value of these samples was similar to the FiM database value. However, the 'b' values of the FiM database and that of De Boever et al. (2002) were 19 and 22% respectively, whereas the 'b' value for the pooled population of silages in this study was just 11.4%. The rate of degradation of N, however, was similar for the silages in this study and that reported by De Boever et al. (2002) and lower than that in the FiM database (0.06).

Degradability of OM and starch.

The curve parameters describing organic matter degradability for the silage samples are summarised in Table 8. The determination of the effectively degraded organic matter content is derived somewhat differently than the estimate of 'fermentable' organic matter calculated by De Boever et al. (2002), but the values obtained are somewhat similar, although the maize silages show a greater range in EDOM. The mean EDOM content of the silages (determined *in situ* in cows) was 72% of the DOMD content (determined across the whole tract in sheep).

The parameters describing the degradability of starch are summarised in Table 9. The degradability curves for individual silages were generally such that the Ørskov and McDonald (1979) model could be fitted, although in many cases it had to be constrained to make $a+b \leq 100$. Although there was variation in the degradability parameters (with 'a' ranging from 33 to 92%, 'b' from 8 to 66%, and c from 0.02 to 0.27), the starch in the maize silages was highly degradable. High values of 'c' were associated with samples in which the 'b' value was relatively high, so that in all cases the effective degradability of starch was high. Starch degradability parameters are not included in the FiM database, so these values cannot be compared.

De Boever et al. (2002) assumed that all starch was potentially degradable, and certainly after 24 h incubation in the rumen virtually no starch was detected in the residues of the samples used in this study. Even after 12 h, most starch had been degraded. As with the estimate of effectively degraded dry matter, the estimate of the effective degradability of starch using the FiM model resulted in very low values being obtained, which in some instances were lower than the estimated 'a' values. The soluble starch content was not determined in this study, and so correcting for small particle loss of the starch fraction was difficult (and the very low values of effective degradability were obtained when it was assumed that starch solubility was zero). The modified FiM model, however (in which the 'a' fraction is treated as soluble, and so $s=a$) produced much more realistic estimates. The true effective degradability of maize silage starch probably lies somewhere between the two estimates, but is more likely to be closer to the estimate produced by assuming $s=a$. The estimates of effective degradability (calculated by assuming $s=a$) are summarised in Table 9, and indicate that between 70 and 90% of the starch would be degraded in the rumen, with a mean (for the 90 silage samples) of 81%. By this calculation, the amount of degraded starch supplied by these UK silages varies between 86 and 306 g/kg DM (with a mean of 187 g/kg DM, and moderated by the silage's starch content). This encompasses the calculated value of the Belgian maize silages characterised by De Boever et al. (2002), where the mean degraded starch content was 229 g/kg DM.

Relationship between microwave and oven DM

At sample reception and following mixing sample dry matter was initially determined by microwave oven. The microwave method of determining sample dry matter provided results similar to those obtained by oven dry matter. Dry matter values obtained by microwave method were on average ($n=90$) higher at 322 g/kg (SD 46.1) than oven dry matter (309 g/kg, SD 44.5). Variation between the two methods was similar at maize silage dry matters from 20 to 45% DM (Figure 4).

CONCLUSIONS

Samples of maize silage, typical of those currently produced in the UK, have been characterised. The 90 samples of maize silage ranged in predicted ME value from 9.1 to 12.0 MJ/kg DM. Using the FiM model to determine the effective degradability of dry matter, organic matter and starch produced unrealistic estimates of the amount of material degraded in the rumen. This is because of the

heterogenous nature of maize silage, with small starch particles being treated (in the model) like large fragments of NDF. It is proposed that, for maize silage, the correction for small particle loss is modified and that the 'a' fraction is treated like the soluble fraction (with a degradation rate of 0.9, and an outflow rate equivalent to the liquid outflow rate. N degradability is best described by a single curve, with no significant difference in estimated effectively degraded N content when silages were segregated on the basis of N solubility or soluble N content.

ACKNOWLEDGEMENTS

This work was funded within the LINK Sustainable Livestock Production Programme by DEFRA, and the support from all members of the Project Management Committee is gratefully acknowledged. Thanks are also due to staff in the Metabolism and the Meat and Growth Research Unit, especially Miss D Cockman, Mr D Cox, Mr C Green, Mr P Kirton and Mr R Pilgrim.

REFERENCES

- Burke, F. Murphy, J. J. O'Donovan, M. A. O'Mara, F. P. Kavanagh, S. Mulligan, F. J., 2007. Comparative evaluation of alternative forages to grass silage in the diet of early lactation dairy cows. *J. Dairy Sci.* 90: 2, 908-917
- De Boever, J.L., Vanacker, J.M., De Brabander, D.L., 2002. Rumen degradation characteristics of nutrients in maize silage and evaluation of laboratory measurements and NIRS as predictors. *Anim. Feed Sc. Technol.* 101,73-86.
- DEFRA (2011) <http://www.defra.gov.uk/statistics/files/defra-stats-foodfarm-landuselivestock-june-statsrelease-englandcropslivestocklabour-111024.pdf>
- Dewhurst, R. J. Davies, L. J. Kim, E. J., 2010. Effects of mixtures of red clover and maize silages on the partitioning of dietary nitrogen between milk and urine by dairy cows. *Animal.* 4, 732-738.
- Dijkstra, J. France, J. Ellis, J. L. Kebreab, E. Lopez, S. Reijs, J. W. Bannink, A., 2009. Effects of nutritional strategies on simulated nitrogen excretion and methane emission in dairy cattle. 7th International Workshop on Modelling Nutrient Digestion and Utilisation in Farm Animals, Paris, France, 10-12 September, 2009.pp 394-402.
- Givens, D.I., Deaville, E.R., 2001. Comparison of major carbohydrate fractions and cell wall digestibility in silages made from older and newer maize genotypes grown in the UK. *Anim. Feed Sci. Technol.* 89, 69-82.
- Haigh, P.M., 1979. A short note on the relationship between oven and toluene dry matter in maize silage. *J. Sci. Food Agric.* 30,543-545.

Kononoff, P.J., Heinrichs, A.J., Buckmaster, D.R. , 2003. Modification of the Penn State Forage and Total Mixed Ration Particle Separator and the effects of moisture content on its measurements. J. Dairy Sci. 86, 1858-1863.

Ørskov, E.R., McDonald, I., 1979. The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. J. Agric. Sci. 92, 499-503.



Figure 1. Map showing the sites of sample collection. (The large star indicates where ten samples were taken from the same site (Syngenta Seeds)).

	Sheep							Sheep					
Week	1	2	3	4	5	6	Week	7	8	9	10	11	12
1	A	B	C	D	E	F							
2	A	B	C	D	E	F	1	G	H	I	J	K	L
3	A	B	C	D	E	F	2	G	H	I	J	K	L
4	C	A	B	F	D	E	3	G	H	I	J	K	L
5	C	A	B	F	D	E	4	I	G	H	L	J	K
6	C	A	B	F	D	E	5	I	G	H	L	J	K
7	B	C	A	E	F	D	6	I	G	H	L	J	K
8	B	C	A	E	F	D	7	H	I	G	K	L	J
9	B	C	A	E	F	D	8	H	I	G	K	L	J
							9	H	I	G	K	L	J

Figure 2a. Allocation of sheep to forages and the organisation of diet changeovers for the first 12 maize silage samples. This sequence was repeated a further 6.5 times to complete the study.

Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Diet change		Acclimatisation										Into crate		Collection period						

Figure 2b. A timetable of sheep management during the experimental period

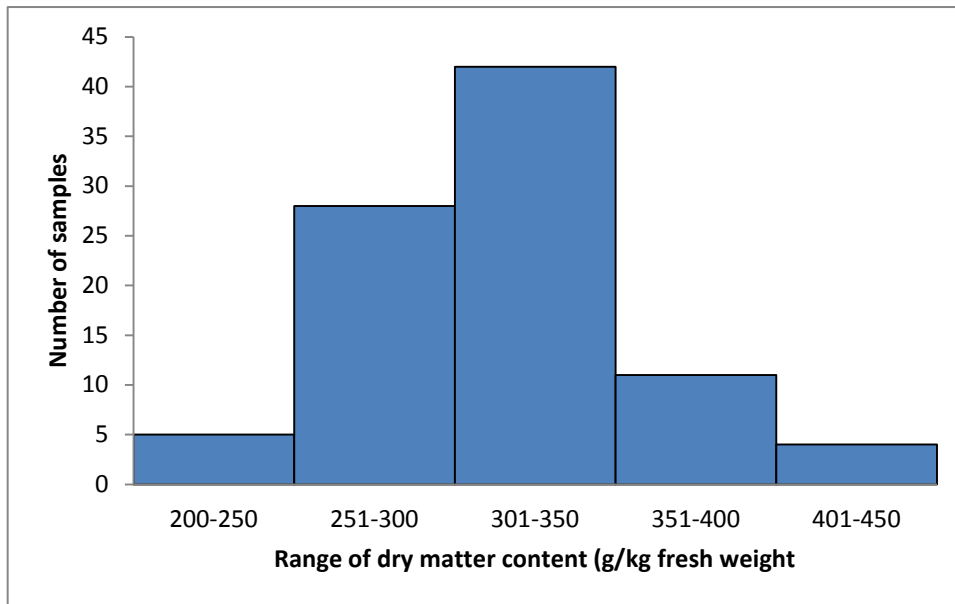


Figure 3. *Distribution of the dry matter contents of the silages used in the study*

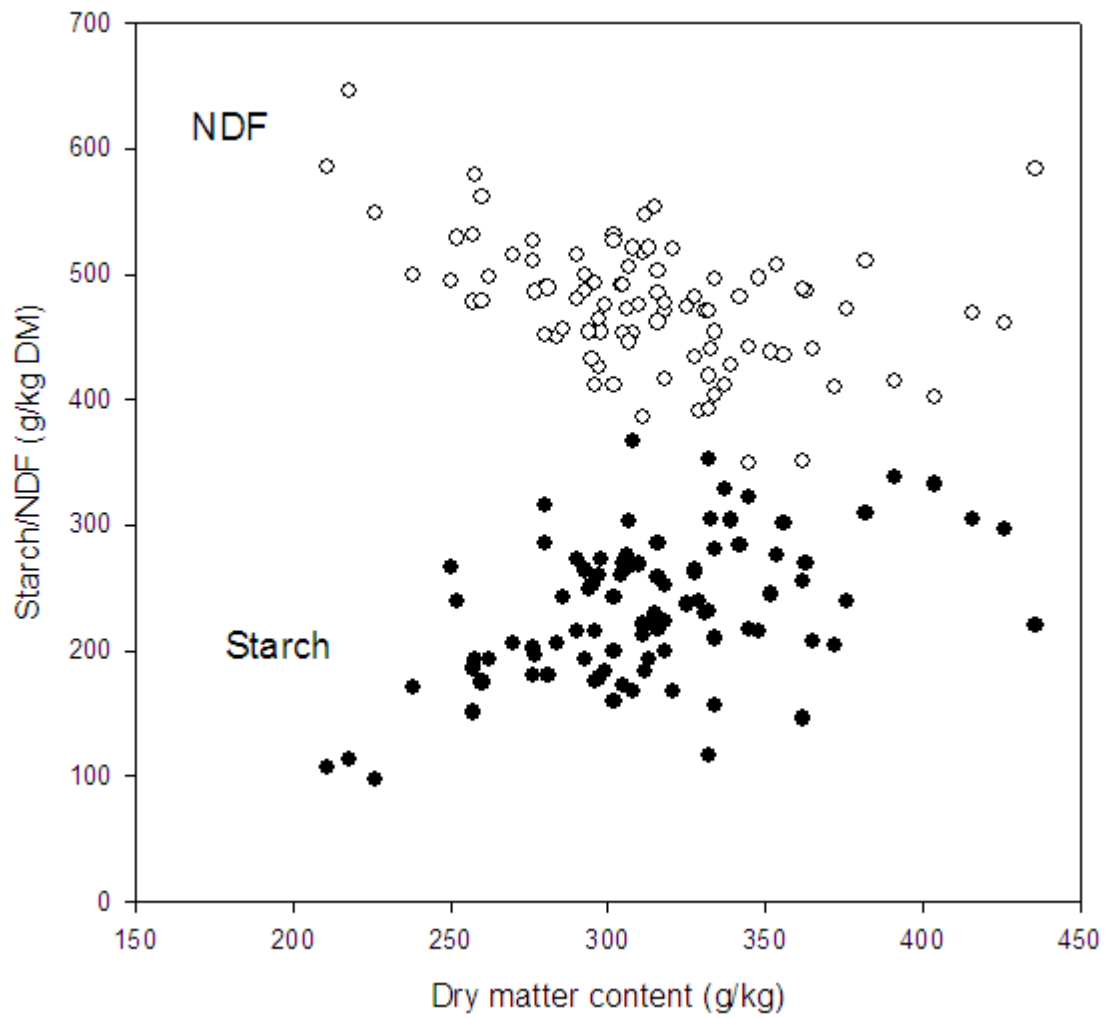


Figure 4. *The relationship between starch and neutral detergent fibre and dry matter content for maize silages used in this study*

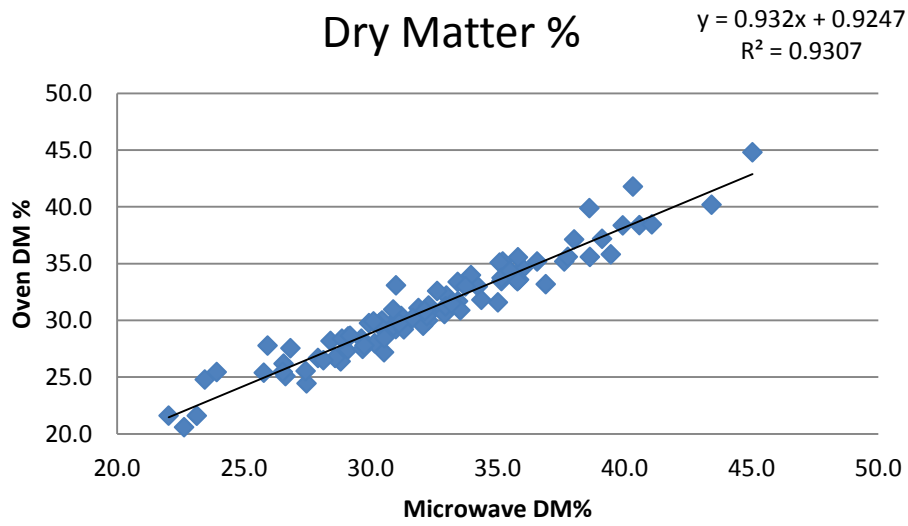


Figure 4. Relationship between the dry matter content of silage when determined by oven or microwave.

Table 1. Chemical composition of the silage samples used in this study (n=90)

	Overall				Year 1 (n=48)				Year 2 (n=42)				P ¹
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	
Dry matter (g/kg fresh weight)	313	42.8	211	436	318	43.9	211	426	308	41.4	218	436	0.287
<i>Chemical composition, g/kg dry matter</i>													
Organic matter	961	5.9	939	975	961	5.9	939	970	960	6.0	949	975	0.568
Ash	39	5.9	25	61	39	5.9	30	61	40	6.0	25	51	0.568
Crude protein	83	8.8	64	112	81	9.3	64	107	86	7.5	72	112	0.013
Starch	233	56.9	98	367	237	56.1	107	339	227	58.0	98	367	0.411
Neutral detergent fibre	476	51.3	349	646	474	53.4	349	586	479	49.3	351	646	0.664
pH	3.7	0.19	3.3	4.2	3.6	0.15	3.3	4.1	3.8	0.20	3.4	4.2	<0.001
Mean particle size (mm) ²	12.1	2.25	8.3	19.1	12.2	1.88	9.9	17.6	12.0	2.62	8.3	19.1	0.652

¹Significance of the difference between the mean values for the two years.

²Geometric mean particle size determined using the Penn State Particle Separator.

Table 2. The mean, minimum and maximum digestibility of dry and organic matter of the maize silage samples used in the study.

Digestibility (g/kg)	Overall				Year 1 (n=48)				Year 2 (n=42)				P ¹
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	
Dry matter	675	43.8	523	796	668	38.7	550	760	685	48.1	523	796	0.003
Organic matter	688	44.0	532	810	681	38.4	568	766	697	48.9	532	810	0.002
DOM in corrected dry matter (DOMD _{TDM}) ²	682	35.3	578	763	674	25.4	613	720	691	39.3	578	763	0.017
Predicted ME (MJ/kg DM _{corrected}) ³	10.7	0.53	9.1	12.0	10.6	0.40	9.6	11.3	10.8	0.62	9.1	12.0	0.017

¹Significance of the difference between the mean values for the two years.

²Corrected for losses from fermentation products, with corrected dry matter calculated as (0.95*oven dry matter+3.3)

³Calculated as 0.0157*DOMD

Table 3. Analysis of feed offered (maize silage) and refused from individual sheep periods

	Chemical composition (g/kg)			
	Dry Matter	Ash	Starch	Crude protein
Feed 3553	416	40.4	305	77.9
Refs 4603	334	53.4	67	85.0
Feed 3535	257	30.3	186	63.7
Refs 4606	220	40.8	128	65.3
Feed 3585	297	48	178	85.2
Refs 4779	189	74.1	163	114.4
Feed 3587	334	42	156	90.0
Refs 4755	273	52.1	197	101.6
Feed 3586	362	31	146	8.17
Refs 4767	266	55	170	10.14
Feed 3508	293	46	193	6.76
Refs 4507	286	51	156	6.63
<i>Feed (average)</i>	<i>327</i>	<i>39.6</i>	<i>194</i>	<i>7.8</i>
<i>Refs (average)</i>	<i>261</i>	<i>54.4</i>	<i>147</i>	<i>8.9</i>

Table 4. The mean, minimum and maximum data describing the *in situ* rumen degradability of dry matter of the maize silage samples used in the study.

	Overall				Year 1 (n=48)				Year 2 (n=42)				P ¹
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	
Solubility (%)	13.8	5.41	3.2	28.1	14.2	5.52	3.2	26.6	13.2	5.28	3.3	28.1	0.375
a (%) ²	41.7	5.65	25.3	54.1	42.0	6.02	25.3	54.1	41.3	5.24	31.2	51.8	0.560
b (%) ³	46.7	6.47	34.4	65.0	46.3	6.02	35.6	64.7	47.2	7.00	34.4	65.0	0.543
c (/h) ⁴	0.021	0.0068	0.009	0.042	0.021	0.0075	0.009	0.042	0.021	0.0060	0.012	0.038	0.825
EDDM _{FIM} (g/kg) ⁵	313	45.3	214	475	314	46.9	215	393	312	43.9	214	475	0.827
EDDM _{a=s} (g/kg) ⁶	524	39.7	391	604	524	40.0	391	600	523	39.8	400	604	0.870

¹Significance of the difference between the mean values for the two years.

²'Instantly' degradable material, comprising both soluble material and small particles

³Slowly degradable material, comprising large particles

⁴Rate of degradation of 'b'

⁵Effectively degraded dry matter content, for a 700 kg cow consuming 25 kg DM/d of a diet comprising 400 g/kg forage using the FIM model.

⁶Effectively degraded dry matter content, for a 700 kg cow consuming 25 kg DM/d of a diet comprising 400 g/kg forage using the modified FIM model assuming a=s.

Table 5. *The mean, minimum and maximum observed solubility of N and soluble N contents of the maize silage samples used in the study.*

	Overall				Year 1 (n=48)				Year 2 (n=42)				P ¹
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	
N solubility (%)	54.3	9.98	29.8	72.5	57.8	7.51	41.1	70.3	50.2	10.95	29.8	72.5	<0.001
Soluble N content (g/kg DM)	7.3	1.69	3.6	11.3	7.6	1.52	4.7	11.3	6.9	1.82	3.6	11.2	0.085

¹Significance of the difference between the mean values for the two years.

Table 6. The estimates of N degradability parameters (a, b and c)¹ for all samples of maize silage, and for different quintiles based on dry matter content, N solubility and soluble N content.

	Estimated value			SE			P			R ²
	a	b	c	a	b	c	a	b	c	
Mean of all samples	73.2	11.4	0.021	0.68	3.48	0.0137	<0.001	0.031	0.194	0.951
<i>Quintiles based on dry matter content</i>										
210-280 g/kg	70.6	9.5	0.031	0.52	1.34	0.0110	<0.001	0.002	0.055	0.971
280-300 g/kg	73.0	16.9	0.012	0.61	11.01	0.0113	<0.001	0.199	0.366	0.961
300-320 g/kg	72.6	11.8	0.020	1.01	5.99	0.0202	<0.001	0.121	0.382	0.897
320-340 g/kg	73.6	13.1	0.019	0.83	5.63	0.0154	<0.001	0.080	0.293	0.937
>340 g/kg	76.2	8.9	0.033	1.05	2.44	0.0245	<0.001	0.022	0.253	0.881
<i>Quintiles based on nitrogen solubility</i>										
29-45%	64.3	19.9	0.017	1.11	8.87	0.0140	<0.001	0.088	0.288	0.946
45-53%	70.5	13.5	0.027	0.68	2.25	0.0108	<0.001	0.004	0.068	0.972
53-56%	76.5	15.5	0.006	0.61	45.26	0.0208	<0.001	0.749	0.794	0.876
56-61%	74.6	8.6	0.043	1.17	1.90	0.0283	<0.001	0.011	0.201	0.873
62-73%	80.1	12.6	0.008	0.49	17.24	0.0155	<0.001	0.506	0.617	0.929
<i>Quintiles based on soluble N content</i>										
3.6-5.7 g/kg	65.0	17.6	0.024	0.75	3.11	0.0094	<0.001	0.005	0.065	0.977
5.7-6.8 g/kg	71.7	12.3	0.027	0.80	2.60	0.0139	<0.001	0.009	0.124	0.954
6.8-7.7 g/kg	77.1	8.1	0.021	0.99	5.29	0.0284	<0.001	0.202	0.502	0.818
7.7-8.7 g/kg	74.8	35.2	0.003	1.04	227.87	0.0247	<0.001	0.885	0.898	0.831
8.7-11.3 g/kg	54.6	27.4	0.612	0.00	0.00	0.0000	<0.001	<0.001	<0.001	0
<i>Quintiles based on 0 h losses</i>										
0 h loss 50-60%	57.6	20.1	0.041	1.39	2.38	0.0144	<0.001	0.001	0.046	
0 h loss 60-70%	66.4	16.1	0.012	0.89	3.17	0.0120	<0.001	0.007	0.098	
0 h loss 70-80%	75.5	17.4	0.006	0.78	50.0	0.0217	<0.001	0.730	0.783	
0 h loss 80-90%	85.0	3.5	0.018	0.20	1.38	0.0137	<0.001	0.063	0.252	
0 h loss >90%		<i>No fit possible</i>								

Table 7. Comparison of different models with single, fixed values derived from mean of all silage samples used in the study ($a=73.2$, $b=11.4$, $c=0.021$) for describing the degradability of N in maize silage.

Basis of separating silage samples	Mean value for effectively degraded N content of silage ¹ (g/kg DM)		SEM	Significance (P) of difference between models
	Fixed value	Alternative model		
<i>Using FiM model</i>				
N solubility 29-45%, $a=64.3$, $b=19.9$, $c=0.017$	7.1	7.1	0.20	0.956
N solubility 62-73%, $a=80.1$, $b=12.6$, $c=0.008$	8.8	8.6	0.26	0.535
Soluble N content 22-36 g/kg, $a= 65.0$, $b=17.6$, $c=0.024$	5.1	5.4	0.13	0.117
0 h degradability	7.2	7.6	0.20	0.130
<i>Using modified FiM model</i>				
N solubility 29-45%, $a=64.3$, $b=19.9$, $c=0.017$	9.1	8.3	0.12	<0.001
N solubility 62-73%, $a=80.1$, $b=12.6$, $c=0.008$	9.8	10.4	0.29	0.115
Soluble N content 22-36 g/kg, $a= 65.0$, $b=17.6$, $c=0.024$	8.9	8.2	0.16	0.005
0 h degradability	9.5	9.3	0.14	0.151

¹Effectively degraded N content calculated using FiM model or modified FiM model (where all 'a' is treated as soluble) and outflow rates for liquid and particles based on a 700 kg cow consuming 25 kg DM/d of a diet consisting of 400 g/kg forage.

Table 8. The mean, minimum and maximum data describing the in situ rumen degradability of organic matter of the maize silage samples used in the study.

	Overall				Year 1 (n=48)				Year 2 (n=42)				P ¹
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	
a (%) ²	40.6	5.84	24.6	54.1	41.1	6.15	24.6	54.1	40.1	5.49	29.8	51.2	0.441
b (%) ³	47.6	6.77	34.7	66.7	47.2	6.53	36.0	66.1	48.1	7.09	34.7	66.7	0.528
c (/h) ⁴	0.023	0.0144	0.009	0.141	0.024	0.0189	0.009	0.141	0.022	0.0063	0.012	0.038	0.446
EDOM _{a=s} (%) ⁵	52.0	5.15	38.9	80.8	52.5	5.86	38.9	80.8	51.5	4.20	39.1	60.0	0.395
EDOM _{a=s} (g/kg DM) ⁶	491	45.3	373	740	495	51.4	373	740	487	37.4	375	562	0.400

¹Significance of the difference between the mean values for the two years.

²'Instantly' degradable material, comprising both soluble material and small particles

³Slowly degradable material, comprising large particles

⁴Rate of degradation of 'b'

⁵Effective degradability organic matter content of the silage calculated using the modified FiM model (assuming a=s) and assuming an outflow rate of 0.047/h (for the rage portion of a diet consumed by a 700 kg cow consuming 25 kg DM/d of a diet comprising 400 g/kg forage)

⁶Effectively degraded organic matter content of the silage calculated using the modified FiM model, assuming a=s, and assuming an outflow rate of 0.047/h (for the forage portion of a diet consumed by a 700 kg cow consuming 25 kg DM/d of a diet comprising 400 g/kg forage)

Table 9. The mean, minimum and maximum data describing the *in situ* rumen degradability of starch of the maize silage samples used in the study.

	Overall				Year 1 (n=48)				Year 2 (n=42)				P ¹
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	
a (%) ²	66.1	15.82	33.1	91.9	59.9	14.60	33.1	88.6	73.2	14.22	42.8	91.9	<0.001
b (%) ³	33.3	15.59	7.7	65.6	39.5	14.40	11.0	65.6	26.1	13.86	7.7	55.7	<0.001
c (/h) ⁴	0.096	0.0480	0.021	0.269	0.096	0.0434	0.021	0.198	0.096	0.0534	0.034	0.269	0.963
EDSTA _{FiM} (%) ⁵	54.9	11.5	22.1	76.6	56.2	12.77	22.1	72.8	53.4	9.81	33.3	76.6	0.264
EDSTA _{a=s} (%) ⁶	80.8	4.64	70.4	89.7	79.1	3.88	70.4	88.4	82.7	4.71	72.1	89.7	<0.001
[EDSTA] _{a=s} (g/kg) ⁷	187	45.0	86	306	187	44.7	91	279	187	45.9	86	306	0.971

¹Significance of the difference between the mean values for the two years.

²'Instantly' degradable material, comprising both soluble material and small particles

³Slowly degradable material, comprising large particles

⁴Rate of degradation of 'b'

⁵Effectively degradable starch using the FiM model, for a 700 kg cow consuming 25 kg DM/d of a diet comprising 400 g/kg forage assuming no soluble organic matter present.

⁶Effectively degradable starch using the modified FiM model (where a=s), for a 700 kg cow consuming 25 kg DM/d of a diet comprising 400 g/kg forage assuming no soluble organic matter present.

⁷Effectively degraded starch content calculated using the modified FiM model (where all 'a' is treated as soluble), as for (6).