1   **Supplementation strategies for lactating dairy cows offered very high quality grass**

2   **silages: starch-based or fibre-based concentrates offered with or without straw**

3   **A. Craig[a]*, A.W. Gordon[b], S. Stewart[b] and C.P. Ferris[a]**

4   [a]Agri-Food and Biosciences Institute, Sustainable Agri-Food Sciences Division, Large Park,

5   Hillsborough, County Down, Northern Ireland, BT26 6DR.

6   [b]Agri-Food and Biosciences Institute, Sustainable Agri-Food Sciences Division, Newforge

7   Lane, Belfast, Northern Ireland, BT9 5PX.

8   *Corresponding author: Aimee Craig, Agri-Food and Biosciences Institute, Sustainable Agri-

9   Food Sciences Division, Hillsborough, County Down, Northern Ireland, BT26 6DR.

10   E-mail: Aimee.Craig@afbini.gov.uk

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20 **ABSTRACT**

21 A three-period change-over design study using 24 mid-lactation multiparous Holstein-Friesian

22 dairy cows, examined supplementation strategies for a high quality grass silage (dry matter

23 (DM), 418 g/kg; crude protein (CP), 170 g/kg DM; metabolisable energy (ME), 12.1 MJ/kg

24 DM). Four treatments, in a 2×2 factorial arrangement, compared concentrate type (High-

25 starch or High-fibre) and straw inclusion (Straw or No-straw). Concentrates had a starch and

26 neutral detergent fibre content of 373 and 258 g/kg DM, respectively (High-starch), and 237

27 and 339 g/kg DM, respectively (High-fibre). In the No-straw treatments, silage and

28 concentrates were offered as a total mixed ration in a 57:43 DM ratio. In the Straw treatments,

29 chopped straw was added at 4% of total DM, replacing part of the silage component of the diet.

30 Following this study, the effect of diet on nutrient utilisation efficiency was examined using

31 four cows/treatment. There were no interactions between concentrate type and straw inclusion

32 for any cow performance or digestibility parameters. Silage dry matter intake (DMI) and total

33 DMI were reduced with the High-fibre concentrate ($P = 0.001$ and $P = 0.006$, respectively) and

34 straw inclusion ($P < 0.001$ and $P = 0.014$, respectively). Neither concentrate type nor straw

35 inclusion had a significant effect on milk yield or milk fat content. The High-starch concentrate

36 increased milk protein content ($P < 0.001$), while straw inclusion decreased milk protein

37 content ($P = 0.036$). Treatment had no effect on cow body weight, condition score, faecal

38 scores, digestibility coefficients or nitrogen and energy utilisation efficiency. In conclusion,

39 supplementing a high quality grass silage with a carefully formulated 'high starch' concentrate

40 improved DMI and milk protein content with no adverse effects on cow performance. Straw

41 inclusion in the diet had no beneficial effects on DMI, milk production or nutrient utilisation

42 efficiency.

43 **KEYWORDS:** Dairy cows; high quality grass silage; straw; concentrate energy source; fatty

44 acids; ration digestibility

1. Introduction

Achieving high nutrient intakes is a key objective in the management of high yielding dairy cows. For housed cows managed within grassland based production systems, this can be achieved by improving the quality of the grass silage component of the diet, and/or increasing concentrate feed levels (Ferris et al., 1997; 2001). The benefits of increasing silage quality are well known, with a review by Keady et al. (2013) indicating that for each 10 g/kg increase in silage dry matter (DM) digestibility, DM intake (DMI) and milk yield are increased by 0.22 kg/day and 0.33 kg/day, respectively. In addition, the concentrate sparing effects of higher quality silages have been clearly demonstrated (Ferris et al., 2003).

A recent survey of silage making practices in Northern Ireland (NI) demonstrated that while 22.4% and 64.9% of farmers still adopt either a two or three harvest silage production system, a significant number (12.7 %) now adopt a 'multi-harvest' system (four or more harvests) in an attempt to improve silage feed value (Ferris et al., 2019). While anecdotal evidence indicates that the adoption of multi-harvest systems is increasing, concerns are often raised that highly digestible silages are not utilised efficiently by dairy cows. Earlier or more frequent harvesting reduces the fibre concentration of silages (Kuoppala et al., 2008; Randby et al., 2012), and the reduction in fibre could have a negative impact on rumen function and digestive efficiency (Mertens, 1997). This situation may be exacerbated if cows offered very high quality silages are supplemented with high levels of starch-based concentrates which may depress rumen pH, leading to acidosis, a reduction in fibre digestibility and decreased intakes (Martin et al., 1994: Keady et al., 1999). The compromised rumen function associated with high starch concentrates has been shown to reduce milk fat concentrations on both grass silage based diets (Keady et al., 1998; 1999) and grazed grass based diets (Sayers et al., 2003). Similarly, Boerman et al. (2015) offered a high quality maize silage based diet to high yielding cows (46 kg milk/cow/day), and found milk fat content and fat corrected milk yield to be reduced by 3.7

70 g/kg and 1.5 kg/day, respectively, when a starch-based concentrate was offered compared to a

71 fibre-based concentrate. As a consequence, supplementing very high quality silages with more

72 fibrous concentrates is often advocated. However, there are benefits of offering starch-based

73 concentrates, including: increased milk protein concentrations (Keady et al., 1998), milk yields

74 and DMIs (Boerman et al., 2015).

75 The addition of chopped straw to the diet of high yielding cows offered high quality silage is

76 often advocated in the UK and Ireland to combat the negative effects of the lower fibre content

77 of the silage. Straw inclusion in the diet is associated with increased retention time of digesta

78 in the rumen (Nandra et al., 1993), which may allow other feed components to be more

79 efficiently digested and absorbed. Neutral detergent fibre (NDF) is associated with chewing

80 activity, increased cudding, and increased saliva production which in turn helps stabilise rumen

81 pH (Welch and Smith, 1970). On the other hand, straw inclusion can reduce total DMI due to

82 the high concentration of slowly fermentable carbohydrate (Van Soest, 1975). Indeed, there is

83 little evidence that improvements in animal performance can be achieved by incorporating

84 straw into the diets of dairy cows (Brown et al., 1990; Ferris et al., 2000), while high levels of

85 straw inclusion (>1 kg/head/day) have been found to reduce animal performance due to dilution

86 of the ME concentration of the diet (Ferris et al., 2000).

87 To date, no studies appear to have examined the interaction between concentrate type and straw

88 inclusion in high quality grass silage based diets. In addition, given that modern dairy cow

89 rationing programmes can account for fermentable energy and protein, the effectiveness of the

90 fibre content of the diet, and predict the acid load in the rumen, it may be possible to design

91 starch-based concentrates that can be offered as a supplement to a very high quality grass silage,

92 without negative effects on rumen function, while still delivering the benefits of starch-based

93 concentrates. Consequently, the current study was designed to examine the effect of

94   concentrate type (starch-based or fibre-based), and straw inclusion (straw or no straw), on cow

95   performance and nutrient utilisation, when offered alongside a very high quality grass silage.

2. Materials and methods

97   This study was conducted at the Agri-Food and Biosciences Institute (AFBI), Hillsborough,

98   Northern Ireland. All experimental procedures were conducted under an experimental licence

99   granted by the Department of Health, Social Services & Public Safety for Northern Ireland in

100   accordance with the Animals (Scientific Procedures) Act 1986.

2.1   Animals and housing

102   Twenty-four mid-lactation (mean of 149 (s.d. 52) days calved) multiparous (mean lactation

103   number 3.8 (s.d. 1.2)) Holstein-Friesian dairy cows were used in a three-period, each of four

104   weeks duration, partially balanced change-over design experiment involving four treatments.

105   Each four-week period consisted of a 21 day feed adaption period, and a seven day

106   measurement phase. Cows were blocked according to pre-experimental milk fat + protein yield

107   into six blocks, each of four cows, and cows within each block randomly allocated to one of

108   the four treatments. Cows had a mean pre-experimental milk yield and body weight (BW) of

109   37.3 (s.d. 5.4) kg per day, and 633 (s.d. 53.0) kg, respectively.

110   For the two week period prior to the study commencing, cows were offered a non-experimental

111   grass silage supplemented with approximately 10 kg concentrate per day. Approximately half

112   of the concentrate was offered mixed with the silage using a diet feeder, and half offered via

113   an out-of-parlour feeding system (OPF). Three days prior to the start of the study, concentrates

114   were removed from the OPF, with the full concentrate allocation mixed with the silage in the

115   form of a total mixed ration (TMR) comprising 43% concentrate and 57% forage on a DM

116   basis.

117   Throughout the 12 week experimental period cows were housed in a free-stall house with

118   concrete flooring, and had access to individual cubicles that were fitted with rubber mats and

119   bedded with sawdust. The cubicle-to-cow ratio was ≥1:1 at all times, thus meeting the

120   recommendations of FAWC (1997). The floor area was cleaned every 3 hours using an

121   automated scraper system.

122   *2.2 Treatments*

123   The four treatments were organised in a 2 × 2 factorial arrangement, comprising two

124   concentrate types (High-starch or High-fibre) and two levels of straw inclusion (Straw or No-

125   straw). A high quality grass silage was offered throughout the study (volatile corrected oven

126   DM, 418 g/kg; CP, 170 g/kg DM (CP = N × 6.25); ME, 12.1 MJ/kg DM). The silage was

127   produced from a perennial ryegrass (*Lolium perenne*) based sward. Grass was harvested using

128   a precision-chop harvester on 3rd May 2017, following a 24 hour period of field wilting. Grass

129   was treated at harvest with a bacterial inoculant (ULV50, Biotal, Malvern, UK) at

130   approximately 20 ml per tonne of fresh herbage, before being ensiled in a bunker silo.

131   With the No-straw treatments, grass silage and concentrates were offered in the form of a total

132   mixed ration (TMR) comprising 57% silage and 43% concentrate, on a DM basis. Concentrates

133   were formulated and total rations balanced using NutriOpt (Nutreco, Amersfoort, Netherlands)

134   dairy cow rationing software. While the two concentrates differed in NDF and starch content,

135   they had a similar ME and CP content. The total rations were designed to promote rumen

136   function and nutrient utilisation, and took account of a number of parameters, including acid

137   load, structural fibre content and fermentable energy and protein balance. This approach was

138   taken to reduce the common confounding factors encountered when comparing fibre and starch

139   diets. The ingredient composition of the two concentrates is presented in Table 1.

140 With the Straw treatments, chopped barley straw was included in the diet at 4% of total DM,

141 replacing part of the grass silage component of the diet. Straw was chopped with a Kverneland

142 850 bale chopper (Klepp, Norway) to a nominal chop length of approximately 5 cm (hand

143 separation of a 10 g sub sample indicated that 5.6, 35.4, 20.9, 12.7, 9.5 and 6.4% of straw by

144 weight had chop lengths of < 2 cm, 2 – 3 cm, 3 – 5 cm, 5 – 7 cm, 7 – 9 cm, 9 – 15 cm and > 15

145 cm, respectively).

146 The rations were prepared daily at approximately 09.00 hours, and offered *ad libitum* at 107%

147 of the previous day's intake. Uneaten ration was removed the following day at approximately

148 08.00 hours. Rations were prepared using a mixer wagon (Vari-Cut 12, Redrock, Armagh, NI).

149 The total quantity of silage required for all four treatments was initially mixed for

150 approximately five minutes and then deposited on a clean silo floor. The quantity of silage

151 required for each individual treatment was then removed from this 'pile' in turn, placed back

152 in the mixer wagon, and the appropriate quantities of the concentrate and straw added to the

153 mix, and mixing continued for another five minutes. The rations were then transferred from the

154 mixer wagon to a series of feed boxes mounted on weigh scales, with cows accessing food in

155 these boxes via an electronic identification system, thus enabling individual cow intakes to be

156 recorded daily (Bio-Control Feeding System, Bio-Control, Rakkestad, Norway). Cows had free

157 access to fresh water at all times.

158 *2.3 Cow measurements*

159 Feed intakes were measured as described above. All cows were milked twice daily (between

160 06.00 and 08.00 hours and between 15.00 and 17.00 hours) throughout the experiment using a

161 50-point rotary milking parlour (Boumatic, Madison, WI, USA). Milk yields were

162 automatically recorded at each milking, and a total daily milk yield for each cow for each 24

163 hour period calculated. Milk samples were taken during four consecutive milkings at the end

164   of the fourth week of each period, treated with a preservative tablet (lactab Mark III, Thompson

165   and Cooper Ltd., Runcorn, UK), and stored at 4°C until analysed (normally within 48 hours).

166   Milk samples were analysed for fat, protein and lactose concentrations using an infrared milk

167   analyser (Milkoscan Combifoss^{TM}7; Foss Electric, Hillerød, Denmark), and a weighted

168   concentration of each constituent determined for each 24 hour sampling period. A mean

169   composition over the two day sampling period was subsequently calculated for each cow.

170   A further milk sample was taken, in proportion to milk yield, during two successive milkings

171   at the end of the final week of each experimental period. Samples were analysed for milk fatty

172   acids (FA), as follows: milk fat was extracted from 1.0 ml of homogenised milk using a

173   chloroform methanol extraction method (Bligh and Dyer 1959), and FA determined as methyl

174   esters (FAME). The FA composition was determined using gas-liquid chromatography, with

175   an aliquot (1.0 ul) of the FAME extract injected onto a CP Sil88 capillary column (100 meters

176   x 0.25 mm id x 0.2 µm film thickness) in a Agilent 7890 gas chromatograph (both Agilent

177   Technologies, Santa Clara, USA), equipped with a temperature programmable injector

178   operated in the split mode and a flame ionisation detector. The oven was initially held at 50°C

179   for 4 minutes then ramped at 8°C/min to 110°C, then 5°C/min to 170°C (hold time 10 min) and

180   finally ramped at 2°C/min to 225 °C (hold time 30 min). Fatty acids were identified by their

181   retention time with reference to commercially available FA standards (37 Supelco FAME mix)

182   and individual standards for those not in the mix (SigmaAldrich Co. Ltd., Gillingham, UK),

183   and were quantified using C13 FAME as an internal standard.

184   Body weight was recorded twice daily during the final week of each experimental period

185   (immediately after each milking) using an automated weighbridge, and a mean BW for each

186   cow determined. The body condition score (BCS) of each cow was estimated by a trained

187   technician at the end of the fourth week of each period, according to Edmonson et al. (1989)

188   on a 5 point (including quarter points) scale. Blood samples were collected from the coccygeal

189   vein of each cow prior to feeding at the end of the fourth week of each period, and centrifuged

190   (3000 rpm for 15 minutes) to isolate either the serum (tubes with a clot activator) or the plasma

191   (fluoride oxalate tubes). Serum beta-hydroxybutyrate (βHB) concentrations were determined

192   according to McMurray et al. (1984), and plasma glucose concentrations were determined

193   using the hexokinase method (Roche Diagnostics Ltd.). Serum non-esterified fatty acid

194   (NEFA) concentrations were determined using WaKo (Wakop Chemicals GmbH, Neuss,

195   Germany) kits. Serum urea concentrations were analysed using the Kinetic UV method (Roche

196   Diagnostics Ltd., Burgess Hill, UK).

197   Faecal scores were assessed weekly during the experiment. Scoring was undertaken at a

198   consistent time (prior to morning feeding) when cows were lying, and then compelled to rise.

199   Scoring was on a scale of 1 – 5 as follows: 1) very watery 2) thin; when the faeces lands the

200   'splatter' goes a long way 3) ideal; forming a cowpat to a height of 2-3 cm 4) thick; well-

201   formed and stacked in rings or 5) firm; stiff balls of faeces (Hulsen et al., 2006).

202   *2.4 Nutrient utilisation*

203   On completion of the 12 week feeding study, four cows from each treatment (n = 16) were

204   selected for use in a nutrient utilisation study. Cows were selected from each treatment group,

205   with selected cows balanced for daily milk yield and BW. Cows were tied by the neck in

206   individual stalls, with stalls fitted with a rubber mat. Cows continued to access their

207   experimental rations from feed boxes at the front of each stall. Experimental rations were

208   offered *ad libitum* daily at 09:00 hours (+10% of previous day's intake). Uneaten food was

209   removed the following day at 08:00 hours. Cows had access to fresh water at all times via a

210   drinker located within each stall.

211   Measurement of nutrient utilisation commenced 24 hours after cows were placed in this

212   experimental byre, with a six-day total faeces and urine collection period. Faeces were

213   collected in a plastic collection tray (96 cm ×108 cm × 36 cm) placed behind each cow. Urine

214   was collected into a 25 litre plastic container via a flexible plastic tube which was attached to

215   a urine separation system. This was held in position over the vulva by attaching it using Velcro

216   fasteners to a 'patch' which was glued (Bostik, Paris, France) either side of the cow's tail head.

217   Approximately 300 ml of 50% sulphuric acid was added to each urine collection container

218   daily to reduce ammonia losses. The total weight of faeces and urine produced during each 24

219   hour collection period was recorded, and a sample of each (5% by weight) retained for

220   subsequent analysis. Faeces and urine samples were stored in a fridge ($< 4^{o}C$) and bulked on

221   day 3 (day 1 - 3) and day 6 (day 4 - 6). During the nutrient utilisation study, cows were milked

222   twice daily (06.30 and 16:30 hours) within the experimental cow byre. During this time milk

223   samples were taken at each milking, bulked in proportion to yield for days 1 - 6, and

224   subsequently analysed for gross energy (GE), and nitrogen (N) concentrations. Each bulked

225   urine and milk sample was analysed for N concentrations, while a further sample of each was

226   freeze-dried (Heto Lyolab 3000, Fisher Scientific, Loughborough, Leicestershire, UK) and

227   analysed for GE concentrations using a bomb calorimeter (Parr 6400 Bomb Calorimeter,

228   Moline, IL, USA). Similarly, a sample of the bulked faeces sample for each cow was analysed

229   for N concentrations (fresh basis), while a subsample was dried at 85°C for 72 hours, and the

230   dry sample analysed for acid detergent fibre (ADF), ash and GE concentrations.

231   *2.5 Feed analysis*

232   A sample of the grass silage offered was taken daily throughout the experiment and dried at

233   85°C for 18 hours to determine oven DM content. Twice a week a sample of grass silage was

234   dried at 60°C and dried samples bulked for each 14 day period, with the bulked sample milled

235   through a sieve with 0.8 mm aperture, and analysed for NDF, ADF and ash concentrations.

236   Each week a fresh silage sample was analysed using near infrared reflectance spectroscopy

237   (NIRS) for ME concentration according to Park et al. (1998). A further fresh silage sample was

238   taken weekly and analysed for GE, N, pH, ammonia-N and volatile components. A sample of

239   straw and each concentrate was taken weekly, and one sub-sample dried at 85°C for 24 hours

240   to determine oven DM content. An additional sub-sample was dried at 60°C for 48 hours,

241   bulked for each 14 day period, milled through a 0.8 mm sieve, and subsequently analysed for

242   N, NDF, ADF, ash and GE. The concentrates were also analysed for starch concentrations.

243   During the nutrient digestibility study, feed stuffs where analysed for the same chemical

244   components as during the main study. Silages were sampled daily and analysed for oven DM

245   (85°C), with fresh samples analysed for GE, N, pH, ammonia-N and volatiles. Dried samples

246   were bulked for each 3-day period (day 1-3 and day 4-6), and subsequently analysed for ADF,

247   NDF and ash concentrations. A sample of straw and each concentrate type offered during each

248   nutrient digestibility study were sampled and analysed for oven DM (85°C). A further sample

249   was dried at 60°C and subsequently analysed for GE, NDF, ADF, N, and ash concentrations.

250   The concentrates were also analysed for starch concentrations. A sample of ration refused by

251   each cow was taken daily and analysed for oven DM content. All chemical analysis of the feed

252   stuffs offered where undertaken as described by Purcell et al. (2016).

253   *2.6 Statistical analysis*

254   Two cows did not complete period three due to health reasons (mastitis and oedema of the

255   udder) and where subsequently treated as missing values during period three in the statistical

256   analysis. Animal data recorded during the final week of each experimental period (DMI, milk

257   yield, milk composition, BW, BCS, blood metabolites and faecal scores) were analysed using

258   linear mixed model methodology according to the three-period change over experimental

259   design, with constant + treatments as the fixed model, and block + block $\times$ cow + block $\times$

260   period as the random model. In all cases the method of residual maximum likelihood (REML)

261   was used as the estimation method. One cow was removed from the nutrient utilisation study

262   due to mastitis. Data from the nutrient utilisation study was analysed using linear mixed model

263   methodology with the REML estimation method. Period was fitted as a random effect and a

264   factorial arrangement of Concentrate and Straw were fitted as fixed effects. If any of the fixed

265   effects were significant ($P<0.05$) then Fisher's LSD Test was used to compare individual levels

266   of the effects. All data were analysed using GenStat (18.1; VSN International Limited, Oxford,

267   UK).

268   **3.0 Results**

269   The term 'high quality silage' in this paper encompasses both the intake potential of the silage

270   and its nutritive value. The silage offered had a DM of 418 g/kg, a CP of 170 g/kg DM, and a

271   predicted ME content of 12.1 MJ/kg DM. The High-starch and High-fibre concentrates had a

272   similar CP and gross energy content, but differed in NDF (258 v. 339 g/kg DM) and starch

273   (373 vs 237 g/kg DM) contents, as planned (Table 2).

274   *3.1 Cow Performance*

275   There were no interactions between concentrate type and straw inclusion for any of the

276   parameters in Table 3, and as such only the main effects of treatment are presented. Both silage

277   DMI and total DMI were reduced with the High-fibre concentrate ($P = 0.001$ and $P = 0.006$,

278   respectively) and with straw inclusion in the diet ($P < 0.001$ and $P = 0.014$, respectively).

279   Neither concentrate type, nor straw inclusion had an effect on milk yield or milk fat content (P

280   > 0.05) which averaged 33.1 kg/d and 45.0 g/kg respectively (Table 3). Cows offered the High-

281   starch concentrate had a higher milk protein content than those offered the High-fibre

282   concentrate ($P < 0.001$), while straw inclusion resulted in a reduction of milk protein content

283   ($P = 0.036$). However, neither concentrate type nor straw inclusion had a significant effect on

284   fat yield, protein yield, or fat + protein yield ($P > 0.05$).

285 The FA profile of the milk produced was unaffected by concentrate type, with the exception of

286 total concentrations of C4:0 - C15:0 (greater in the High-starch treatment, P = 0.004), C16:0

287 concentrations (greater in the High-fibre treatment, P = 0.037) and conjugated linoleic acid

288 (CLA; greater in the High-fibre treatment, P < 0.001). Concentrations of total saturated fatty

289 acids (SFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA)

290 were unaffected by concentrate type (Table 3). Straw inclusion decreased total C4:0 - C15:0

291 concentrations (P < 0.001) and C16:0 concentrations (P = 0.002), but increased concentrations

292 of C18:0 (P < 0.001), C20:0 (P < 0.001) and total n-9 PUFA (P < 0.001); however, there was

293 no effect of straw inclusion on CLA concentrations. Straw inclusion reduced the concentration

294 of SFA in milk and increased total MUFA concentrations (P < 0.001) compared to the No-

295 straw treatments, with a consequent reduction in the Saturated:Unsaturated FA ratio (P < 0.001)

296 in milk.

297 Treatment had no effect on either cow BW or BCS (Table 3; P > 0.05). Serum concentrations

298 of βHB and NEFA, and plasma concentrations of glucose, did not differ significantly between

299 treatments (average 0.43 mM, 0.12 meq/L and 3.61 mM, respectively: Table 4). Cows offered

300 the High-fibre concentrate had an increased serum urea content compared to those offered the

301 High-starch concentrate (P < 0.001). Straw inclusion tended to decrease serum urea

302 concentrations (P = 0.053). There was an interaction between concentrate type and straw

303 inclusion for serum urea, with mean values for High-starch/No-straw, High-starch/Straw,

304 High-fibre/No-straw and High-fibre/Straw being 3.13, 2.53, 3.16, 3.37 mM, respectively (SED

305 = 0.138; P < 0.001). Serum urea was higher when straw was offered with the High-fibre

306 concentrate, but not when straw was offered with the High-starch concentrate (P < 0.001). Diet

307 had no effect on mean faecal scores (average 2.6; s.d., 0.31).

308 *3.4 Nutrient Utilisation*

309   There were no significant interactions (P > 0.05) between concentrate type and straw inclusion

310   in the diet for any of the nutrient utilisation parameters presented in Tables 5, 6 or 7, and

311   consequently only the main effects of treatment are presented. Neither total DMI nor milk

312   yields differed between treatments within the sub-group of cows used in the nutrient utilisation

313   study (P > 0.05). Similarly, none of the digestibility coefficients examined were affected by

314   treatment (Table 5).

315   Neither total N intake, nor N output in faeces, urine, manure or milk, were affected by

316   concentrate type (P > 0.05; Table 6).   When straw was included in the diet, cows had a lower

317   N intake (P = 0.009) and a lower faecal N output (P = 0.028) compared to cows on the No-

318   Straw treatment. None of the N use coefficients were affected by either concentrate type or

319   straw inclusion in the diet (P > 0.05).

320   Neither GE intake, nor energy output in faeces, urine or milk were affected by treatment (Table

321   7). However, there was a trend (P = 0.050) for urinary energy output to be reduced when straw

322   was included in the diet. None of the energy use coefficients were affected by either concentrate

323   type or straw inclusion in the diet (P > 0.05).

324   **4. Discussion**

325   Grass silage is a major forage source for dairy cows in the more western parts of the UK and

326   Ireland. In NI the average DM, CP and ME contents of commercial farm silages analysed by

327   AFBI between 1996 – 2015 (n > 90,000 silages) were 280 g/kg, 123 g/kg DM and 10.7 MJ/kg

328   DM, respectively (Yan et al., 2017). Thus the silage used in the current study (DM, 418 g/kg;

329   CP, 170 g/kg DM; ME, 12.1 MJ/kg DM, Table 2) was of a much higher quality than the NI

330   average, reflecting the early cutting date and rapid field wilting. The silage was also well

331   fermented, as indicated by its low ammonia-N content and lactate dominated fermentation.

332   Within NI there has been an increasing move to multi-cut systems (>3 cuts/year) in an attempt

333   to improve the quality of silages produced (Ferris et al., 2019), and consequently high quality

334   silages, such as the one used in the current study, are likely to become more common on NI

335   farms. This study was designed to examine supplementation strategies for high quality silages,

336   to ensure optimum performance and high levels of nutrient use efficiency. On many farms

337   current practice is to supplement very high quality silages with a fibre-based concentrate, or to

338   add straw to the diet to help 'maintain rumen function', and thus reduce the likelihood of

339   digestive upset or metabolic diseases. Within the current study there was no interaction

340   between concentrate type and straw inclusion for any of the parameters examined (except for

341   plasma urea), and as such concentrate type and straw inclusion are discussed separately.

342   Silage intakes in the current study were higher than those recorded in many previous studies

343   (Rinne et al., 1999; Dewhurst et al., 2003; McNamee et al., 2015), although comparable intakes

344   to those observed in the current study have been recorded by Randby et al. (2012) and Kuoppala

345   et al. (2008) with highly digestible silages. Both digestibility (Huhtanen et al., 2007; Steen et

346   al., 1998) and DM content (Steen et al., 1998) are key determinants of silage DMI. Steen et al.

347   (1998) also found a positive correlation between silage protein concentration and silage DMI.

348   Therefore, the very high intakes observed in this study are likely attributable to the high DM,

349   CP and digestibility of the silage offered.

350   *4.1 Effect of concentrate type*

351   The impact of concentrate type on DMI has not been consistent. For example, Aston et al.

352   (1994) and Huhtanen et al. (2008) found DMI to increase as the fibre concentrations of the

353   concentrate increased, while Keady and Mayne (2001) found no effect of either a starch- or

354   fibre-based concentrate on DMI. The reduction in DMI when high starch diets are offered is

355   frequently associated with a depression in rumen pH, which may reflect subacute acidosis, a

356 consequence of high levels of rapidly fermentable carbohydrates with some starch-based diets

357 (Martin et al., 1994). However, in the current study DMI was 0.8 kg DM/day lower when the

358 High-fibre concentrate was offered (Table 3).

359 The higher DMI with the starch-based diet is likely to reflect, in part, the fact that the High-

360 starch concentrate offered was formulated using NutriOpt (Nutreco, Amersfoort, Netherlands)

361 to optimise rumen health by taking parameters such as 'acid load' and 'structural fibre index'

362 into consideration. The 'acid load' parameter within the NutriOpt rationing programme is

363 calculated based on total fermentation products, which includes both volatile fatty acid (VFA)

364 production in the rumen and silage fermentation products (e.g. lactic acid) consumed from the

365 diet. The 'structural fibre index' takes into account the effectiveness of dietary fibre to promote

366 rumination. An 'acid load' of less than 50 units and a 'structural fibre index' of greater than

367 100 units is considered ideal for rumen health when both parameters are considered together.

368 The High-fibre and High-starch diets had a predicted acid load of 47 and 50, respectively, and

369 a 'structural fibre index' of 108 and 104, respectively. Rations were also formulated taking

370 account of 'rumen unsaturated fatty acid load (RUFAL)'. Rumen fermentation is influenced

371 by RUFAL, which is determined as the sum C18:1, C18:2 and C18:3 FA. In a review, Walker

372 et al. (2004) indicated that these FA are associated with disruption to rumen fermentation and

373 with milk fat depression. Based on NutriOpt, the High-starch and High-fibre diets were

374 predicted to contain 21 and 20 g/kg DM RUFAL, respectively, with these values below the

375 maximum recommended level of 25 g/kg DM (NutriOpt). The absence of effects of concentrate

376 type on faecal scores, and on any of the digestibility and nutrient utilisation efficiency

377 coefficients suggest both concentrate types were associated with good rumen health. The

378 reduction in DMI with the High-fibre concentrate in the current study may have been due to

379 increased rumen fill causing greater satiety (Allen, 1995).

380 While concentrate type had no effect on milk yield, milk protein content was reduced by 0.8

381 g/kg when the High-fibre concentrate was offered (Table 3). A similar reduction in milk

382 protein content with fibre-based concentrates has been observed previously with grass silage

383 based diets (Ferris et al., 2000) and grazed grass based diets (Sayers et al., 2003; Gordon et al.,

384 1995). The reduction in milk protein concentration with the High-fibre concentrate treatments

385 is likely related to the lower DMI with this treatment, combined with increased rumen

386 propionate production (Rook, 1979), and increased microbial protein synthesis (Sayers et al.,

387 2003) in the High-starch treatment.

388 While starch-based concentrates are often associated with a reduction in milk fat concentrations

389 (Keady et al., 1998; 1999), no such effect was observed in the current study. While this may

390 appear to be surprising given the difference in concentrate fibre and starch levels, it likely

391 reflects the fact that both diets were formulated to have similar 'structural fibre indexes'.

392 Although milk fat content was unaffected by treatment, the milk FA profile differed (Table 3).

393 *De novo* synthesis of FA (C4:0 - C15:0) was greater (0.8 g/100 g total FA) in the High-starch

394 treatments compared to the High-fibre treatments, with these FA largely synthesised by chain

395 elongation using acetate, which is driven by fibre in the diet (Grummer, 1991). Therefore, it

396 might be expected that the High-fibre diet would have increased the synthesis of C4:0 - C15:0

397 FAs, as found previously (Boerman et al., 2015). While the increase in total C4:0 - C15:0 FA

398 in the High-starch concentrate treatments is unexplained, the actual differences between

399 treatments were relatively small. However, C16:0, which is partly synthesised *de novo* in the

400 mammary glands was greater with the High-fibre diet (0.5 g/100 g total FA). Concentrations

401 of CLA were greater (0.03 g/100 g total FA) when the High-fibre diet was offered. Conjugated

402 linoleic acid is of interest due to possible human health benefits and is formed by the

403 biohyrogenation of dietary linoleic acid (Griinari and Bauman, 1999). Despite the changes in

404   individual FA within the profile, there was no significant difference in total saturated or

405   unsaturated FA when cows where offered either a High-starch or a High-fibre concentrate.

406   That concentrate type had no effect on cow BW, BCS (Table 3), and blood metabolites (βHB,

407   Glucose and NEFA, Table 4)) recorded during each measurement period, suggests cows had a

408   similar energy status. Cows gained 94 kg BW (s.d. 24.7 kg) and 0.1 (s.d. 0.11) units of BCS

409   over the 12 week experimental period. While part of the former will can be attributed to 'gut-

410   fill' associated with the very high silage DMI, cows were undoubtedly in positive energy

411   balance throughout the study, a reflection of the high DMI observed. The higher serum urea

412   concentrations observed in cows offered the High-fibre concentrate, compared to the High-

413   starch concentrate, occurred despite the two concentrates having similar CP concentrations,

414   and may reflect the High-fibre diet providing less readily fermentable energy to support

415   microbial growth to utilise rumen ammonia. Nevertheless, the nutrient utilisation study

416   provided no evidence that concentrate treatments impacted on N utilisation efficiency, or

417   indeed on energy utilisation efficiency (Table 6 and 7).

418   Again, literature evidence on the impact of concentrate type on nutrient utilisation is mixed.

419   For example, some studies indicate increased apparent diet digestibility when high starch

420   concentrates are offered (Aston et al., 1994). Keady et al. (1999) reported that fibre

421   digestibility was reduced with increased starch content of the concentrate, the latter likely due

422   to a reduction of cellulolytic activity. The absence of an effect on fibre digestibility in the

423   current study may be due to the fact that the diet was offered as a TMR. Supporting this

424   suggestion, Keady et al. (1998) found no effect of starch level on fibre digestibility when

425   concentrates where offered in small amounts during the day. Furthermore, the apparent

426   digestibility of ADF was lower in the previous studies than the current study (<0.60 v. 0.76

427   g/g) which may indicate that the fibre fractions within the current study where more easily

428   digested as a whole.

429   *4.2 Effect of straw inclusion*

430   Straw inclusion reduced total DMI by 0.7 kg/day (Table 3). The inclusion of straw in the diet

431   will increase rumen retention time and reduce the rate of passage of digesta through the

432   digestive tract leading to satiety and reduced DMI (Nandra et al., 1993). Despite the reduction

433   in DMI, milk yield was not significantly affected by straw inclusion, although milk protein

434   content was reduced by 0.4 g/kg with the straw treatments (Table 3). The latter is likely due to

435   the dilution of ME in the diet when straw is included, in agreement with previous studies (Blair

436   et al., 1974; Ferris et al., 2000).

437   Milk fat content was unaffected by straw inclusion to the diet, which agrees with the findings

438   of Ferris et al. (2000), who offered straw at levels between $0 - 3$ kg/cow/d. In contrast, Owen

439   et al. (1969) and Blair et al. (1974) observed an increase in milk fat content with the addition

440   of milled straw to the diet (at 24% and 47.5% of the total diet); however, the overall diets

441   offered and straw inclusion levels adopted were very different from those in the current study.

442   The concentrates offered in the current study were balanced to contain optimum levels of

443   structural fibre, and this may have negated any possible effects of straw inclusion on milk fat.

444   Although milk yield was unaffected by straw inclusion, both milk fat yield and milk protein

445   were reduced, with this due to the numerically lower milk yield (0.8 kg/d) and milk fat content

446   (0.5 g/kg), and significantly lower protein content (0.4 g/kg) with the straw treatment.

447   As straw inclusion was expected to promote rumen acetate production, and *de novo* FA

448   synthesis, the increasing concentrations of C4:0 - C15:0, C16:0 with the No-straw treatment

449   was unexpected (Table 3). The C18:0, C18:1 and C20:0 fats in milk are mostly derived from

450   stearic acid in the diet (Moate et al., 2008), and their higher concentrations with the straw

451   treatment reflects the fact that straw contains a high proportion of stearic acid (42% of total

452   FA; Tyagi et al., 2010). In general, straw inclusion resulted in a small improvement in the fatty

453   acid profile of the milk which could be considered as beneficial concerning human health

454   (Vafeiadou et al., 2015), as the concentrations of SFA decreased and concentrations of MUFA

455   increased.

456   There was no effect of straw inclusion on BW or BCS (Table 3), while serum βHB and NEFA,

457   and plasma glucose concentrations, all of which can provide an indication of energy status,

458   were also unaffected (Table 4). The tendency ($P = 0.053$) for a reduction in serum urea

459   concentration when cows were offered straw reflects the dilution of total diet protein content

460   associated with straw. However, the interaction between concentrate type and straw inclusion

461   suggests that a starch-based concentrate promoted a rumen environment that was more

462   effective at utilising rumen ammonia, while the reverse occurred when straw was offered

463   alongside a fibre-based concentrate.

464   Surprisingly, straw inclusion had no effect on faecal scores or digestive efficiency during the

465   nutrient utilisation study. Ferris et al. (2000) observed that the inclusion of increasing levels of

466   straw in the diet actually decreased the digestibility of DM, N and energy, although the highest

467   inclusion level in that study, was considerably higher than in the current study (3 kg/cow/d).

468   While straw inclusion may have been expected to improve nutrient utilisation by stabilising

469   the rumen environment and reducing the rate of passage of digesta, nutrient utilisation was not

470   improved in either the study by Ferris et al. (2000) or the current study (Table 5). Total N intake

471   was reduced when straw was included in the diet within the nutrient utilisation study, a

472   consequence of the lower DMI observed and the low protein content of straw, and this was

473   associated with a corresponding reduction in output of faecal and manure N (Table 6).

474   However, this did not impact on N utilisation efficiency, perhaps due to a reduction in the

475   ability of rumen bacteria to capture ammonia due to straw inclusion in the diet. There was also

476   a trend for reduced energy intake when straw was offered and a corresponding decrease in

477   urinary energy, but no impact on faecal, urine or milk energy as a proportion of GE intake

478   (Table 7).

479   The results of this experiment have a number of practical implications. For example, this study

480   has demonstrated that modern dairy cow rationing programs can be used to formulate a high

481   starch concentrate which can be used to supplement a very high quality grass silage, with no

482   adverse effects on performance, while actually promoting intakes and milk protein content. In

483   addition, this can be achieved with moderate yielding cows without the need to include straw

484   in the diet. While there may have been an expectation that that supplementing a starch-based

485   concentrate with straw would improve digestibility while maintaining intakes, and

486   supplementing a fibre-based concentrate with straw would reduce intakes and milk yield, the

487   absence of interactions in this study does not support these expectations. Furthermore, in

488   common with the findings of earlier research, this study has failed to demonstrate any practical

489   benefits of including straw in dairy cow diets, irrespective of concentrate type, provided that

490   the concentrate fraction of the diet is designed appropriately and the diet is offered as a total

491   mixed ration.

492   **5.0 Conclusion**

493   In the present study, neither concentrate type nor straw inclusion had a significant impact on

494   milk yield or milk fat + protein yield. A High-starch concentrate, increased DMI and milk

495   protein content compared to a High-fibre concentrate, and had no negative effects on faecal

496   scores or nutrient utilisation when offered alongside a high quality silage. Straw inclusion

497   reduced DMI and milk protein content, and had no beneficial effect on milk fat content or

498   nutrient utilisation. Therefore, there is little evidence that straw inclusion in the diet of dairy

499   cows is beneficial, and a carefully formulated High-starch diet can be fed alongside a high

500   quality silage, without the use of straw as an additional fibre source.

References

Allen, M. 1995. Fibre requirements: finding an optimum can be confusing. Feedstuffs. 67:13.

Aston, K., Thomas, C., Daley, S.R. and Sutton, J.D. 1994. Milk production from grass silage diets: effects of the composition of supplementary concentrates. Anim. Prod. 59, 335-344.

Blair, T., Christensen, D.A. and Manna, J.G. 1974. Performance of lactating dairy cows fed complete pelleted diets based on wheat straw, barley and wheat. Can. J. Anim. Sci. 54, 347-354.

Bligh, E. G. and W. J. Dyer. 1959. A rapid method of total lipid extraction and purification. Can. J. Biochem. Physiol. 37: 911–917.

Boerman, J. R., Potts, S. B., VandeHaar, M. J. and Lock, A. L. 2015. Effects of partly replacing dietary starch with fiber and fat on milk production and energy partitioning. J. Dairy Sci. 98, 7264-7276.

Brown, W.H., Khalaf, S.S., Marmolejo, A., Swingle, R.S. and Whiting, F.M. 1990. Partial replacement of alfalfa hay with chopped wheat straw in diets for lactating dairy cows. J. Dairy Sci. 73: 3172-3177.

Dewhurst, R.J., Fisher, W.J, Tweed, J.K.S. and Wilkins, R.J. 2003. Comparison of grass and legume silages for milk production. 1 Production responses with different levels of concentrate. J. Dairy Sci. 86, 2598-2611.

Edmonson, A.J., Lean, I.J., Weaver, L.D., Farver, T. and Webster, G., 1989. A body condition scoring chart for Holstein dairy cows. J. of Dairy Sci. 72: 68-78.

531 Ferris, C. P., Gordon, F. J., Patterson, D. C., Kilpatrick, D. J., Mayne, C. S. and McCoy, M. A.
532   2001. The response of dairy cows of high genetic merit to increasing proportion of
533   concentrate in the diet with a high and medium feed value silage. J. Agric. Sci. 136,
534   319-329.

535 Ferris, C. P., Gordon, F. J., Patterson, D. C., Mayne, C. S. and McCoy, M. A. 1997. The
536   response of high genetic merit dairy cows to changes in silage quality and level of
537   supplementary concentrate. In: Proceedings of the British Society of Animal Science,
538   Scarborough, 1997. p. 40.

539 Ferris, C. P., Gordon, F. J., Patterson, D. C., Mayne, C. S. and McCoy, M. A. 2003. A short-
540   term comparison of the performance of four grassland-based systems of milk
541   production for autumn-calving dairy cows. Grass Forage Sci. 58, 192-209.

542 Ferris, C. P., Laidlaw, S., and Gordon, A. W. 2019. Silage making practices on Northern
543   Ireland dairy farms and factors perceived by farmers to influence silage quality. In:
544   Proceedings of the British Society of Animal Science Annual Conference 2019, p78.
545   Edinburgh, UK.

546 Ferris, C. P., Patterson, D. C., Gordon, F. J. and Kilpatrick, D. J. 2000. The effects of
547   incorporating small quantities of straw in grass/grass silage-based diets for dairy cows.
548   Grass Forage Sci. 55, 146-158.

549 Gordon, F.J., Patterson, D.C., Yan, T., Porter, M.G., Mayne, C.S. and Unsworth, E.F. 1995.
550   The influence of genetic index for milk production on the response to complete diet
551   feeding and the utilization of energy and nitrogen. Anim. Sci. 61, 199-210.

552 Griinari, J.M and Bauman, D.E. 1999. Biosynthesis of conjugated linoleic acid and its
553   incorporation into meat and milk in ruminants. In: Yurawecs, M.P., Mossoba, M.M.,
554   Kramer, J.K.G., Nelson, G. and Pariza, M.W. (Eds) Recent Advances in Conjugated
555   Linoleic Acid Research, pp: 180-200.

556 Grummer R.T. 1991. Effect of feed on the composition of milk fat. J. Dairy Sci. 74, 3244-3257.

557 Huhtanen, P., Rinne, M. and Nousiainen, J. 2007. Evaluation of the factors affecting silage
558   intake of dairy cows: a revision of the relative silage dry-matter intake index. Animal
559   1: 758-770.

560 Huhtanen, P., Rinne, M. and Nousiainen, J. 2008. Evaluation of concentrate factors affecting
561   silage intake of dairy cows: a development of the relative total diet intake index. Animal
562   2: 942-935.

563 Hulsen J. Cow signals : a practical guide for dairy farm management. Roodbont, 2008.

564 Keady, T. W. J., Hanrahan, J. P., Marley, C. L. and Scollan, N. D. 2013. Production and
565   utilization of ensiled forages by beef cattle, dairy cows, pregnant ewes and finishing
566   lambs - A review. Agric. Food Sci. 22, 70-92.

567 Keady, T. W. J. and Mayne, C.S. 2001. The effects of concentrate energy source on feed intake
568 and rumen fermentation parameters of dairy cows offered a range of grass silages.
569 Anim. Feed Sci. Tech. 90: 117-129.

570 Keady, T. W. J., Mayne, C. S. and Marsden, M. 1998. The effects of concentrate energy source
571 on silage intake and animal performance with lactating dairy cows offered a range of
572 grass silages. Anim. Sci. 66, 21-33.

573 Keady, T. W. J., Mayne, C. S., Fitzpatrick, D. A. and Marsden, M. 1999. The effects of energy
574 source and level of digestible undegradable protein in concentrates on silage intake and
575 performance of lactating dairy cows offered a range of grass silages. Anim. Sci. 68,
576 763-777.

577 Kuoppala, K., Rinne, M., Nousiainen, J. and Huhtanen, P. 2008. The effect of cutting time of
578 grass silage in primary growth and regrowth and the interactions between silage quality
579 and concentrate level on milk production of dairy cows. Livest. Sci. 116, 171-182.

580 Martin, P.A., Chamberlain, D.G., Robertson, S. and Hirst, D. 1994. Rumen fermentation
581 patterns in sheep receiving silages of different chemical composition supplemented
582 with concentrates rich in starch or digestible fibre. J. Agric. Sci. 122, 145-150.

583 McMurray, C. H., Blanchflower, W. J. and Rice, D. A. 1984. Automated kinetic method for D-
584 3-hydroxybutyrate in plasma or serum. Clin. Chem. 30:421–425.

585 McNamee, B.F., Woods, V.B., Kilpatrick, D.J., Mayne, C.S., Agnew, R.E. and Gordon, F.J.
586 2005. The prediction of grass silage in the supplemented diets of lactating dairy cows.
587 Livest. Prod. Sci. 92, 233-240.

588 Mertens, D. R. 1997. Creating a system for meeting the fiber requirements of dairy cows. J.
589 Dairy Sci. 80, 1463-1481.

590 Moate, P.J., Chalupa, W. Boston, R.C. and Lean, I. J. 2008. Milk fatty acids II: Prediction of
591 the production of individual fatty acids in bovine milk. J. Dairy Sci. 91, 1175 – 1188.

592 Nandra, K.S., Hendry, A. and Dobos, R.C. 1993. A study of voluntary intake and digestibility
593 of roughages in relation to their degradation characteristics and retention time in the
594 rumen. Anim. Feed Sci. Tech. 43, 227-237.

595 Owen, J.B., Miller, E. I. and Bridge, P.S. 1969. Complete diets given ad libitum to dairy cows
596 – the effect of the level of inclusion of milled straw. J. Agric. Sci. 72, 351-357.

597 Park, R. S., Agnew, R. E., Gordon, F. J. and Steen, R. W. J. 1998. The use of near infrared
598 reflectance spectroscopy (NIRS) on undried samples of grass silage to predict chemical
599 composition and digestibility parameters. Anim. Feed Sci. Tech. 72: 155-167

600 Purcell, P. J., Law, R. A., Gordon, A. W., McGettrick, S. A. and Ferris, C. P. 2016. Effect of
601 concentrate feeding method on the performance of dairy cows in early to mid lactation.
602 J. Dairy Sci. 99: 2811-2824.

603 Randby, A. T., Weisbjerg, M. R., Norgaard, P. and Heringstad, B. 2012. Early lactation feed
604   intake and milk yield responses of dairy cows offered grass silages harvested at early
605   maturity stages. J. Dairy Sci. 95, 304-317.

606 Rinne, M., Jaakkola, S., Kaustell, K. and Heikkila, T. 1999. Silages harvested at different stages
607   of grass growth v. concentrate foods as energy and protein sources in milk production.
608   Anim. Sci. 69, 251-263.

609 Rook, J.A.F. 1979. The role of carbohydrate metabolism in the regulation of milk production.
610   Proc. Nutr. Soc. 38, 309.

611 Sayers, H. J., Mayne, C. S. and Bartram, C. G. 2003. The effect of level and type of supplement
612   offered to grazing dairy cows on herbage intake, animal performance and rumen
613   fermentation characteristics. Anim. Sci. 76, 439-454.

614 Steen, R.W.J., Gordon, F.J., Dawson, L.E.R., Park, R.S., Mayne, C.S., Agnew, R.E.,
615   Kilpatrick, D.J. and Porter, M.G. 1998. Factors affecting the intake of grass silage by
616   cattle and predication of silage intake. Anim. Sci. 66: 115-127.

617 Tyagi, N., Thakur, S.S. and Shelke, S. 2010. Effect of bypass fat supplementation on productive
618   and reproductive performance in crossbred cows. Tropical Animal Health and
619   Production. 42. 1749 – 1755.

620 Vafeiadou, K., Weech, M., Altowaijri, H., Todd, S., Yaqoob, P., Jackson, K.G. and Lovegrove,
621   J.A. 2015. Replacement of saturated with unsaturated fats had no impact on vascular
622   function but benefical effects on lipid biomarkers, E-selectin and blood pressure: results
623   from the randomized, controlled dietary intervention and vascular function (DIVAS)
624   study. Am. J. Clin. Nutr. 102: 40-48

625 Van Soest, P.J. 1975. Physico-chemical aspects of fibre digestion. In: MacDonald, I.W and
626   Warner, A.C.I. (Eds) Digestion and Metabolism in the Ruminant. Sydney, Australia:
627   Commonwealth Scientific and Industrial Research Organisation. pp. 351-365.

628 Walker, G.P., Dunshea, F.R. and Doyle, P.T. 2004. Effects of nutrition and management on
629   the production and composition of milk fat and protein: a review. Austr. J. Ag. Res.
630   55, 1009-1028.

631 Welch, J.G. and Smith, A. M. 1970. Forage quality and rumination time in cattle. J. Dairy Sci.
632   53, 797.

633 Yan, T., Archer, J., Zhao, Y. G. and Grant, N. 2017. A review of grass silage quality in NI from
634   1996 to 2015 using data from the Hillsborough Feeding Information System -
635   regression between silage nutritive value and harvesting year. In: Proceedings of the
636   Annual Meeting of the British Society of Animal Science, p76, Chester, UK.

637   Table 1: Ingredient composition of the High-starch and High-fibre concentrates offered (%,

638   fresh basis).

	High-starch	High-fibre
Maize meal	54.2	22.7
Wheat		10.9
Soyabean meal (high protein)	4.5	5.9
Rapeseed meal	4.5	4.4
Soya hulls (toasted)	11.3	18.2
Sugar beet pulp (dry)	9.0	19.1
Maize gluten	9.0	11.4
Protected protein (Sopralin[a])	4.5	2.7
Protected fat (Maxfat CS[a])		1.8
Mineral/Vitamin mix (Maxcare Dairy[a])	1.8	1.8
Rumen buffer (Acid Guard[a])	1.1	1.1
Yeast (Actisaf[b])	0.1	0.1

639   [a] Trouw Nutrition, Belfast, Northern Ireland,UK
640   [b] Lesaffre, Marcq-en-Baroeul , France

641   Table 2: Chemical composition of the grass silage, concentrates and straw offered during the 12 week experimental period.

	Grass silage	(s.d)	Concentrates				Straw	(s.d)
			High-starch	(s.d)	High-fibre	(s.d)		
Oven dry matter (g/kg)	404	(23.4)	891	(15.8)	898	(13.8)	859	(29.6)
VCODM (g/kg)	418	(24.3)						
Crude protein (g/kg DM)	170	(7.0)	163	(3.8)	164	(1.7)	34	(0.6)
Ash (g/kg DM)	95	(1.8)	69	(3.8)	76	(4.3)	44	(7.2)
Acid detergent fibre (g/kg DM)	237	(3.6)	112	(8.0)	169	(6.8)	528	(0.3)
Neutral detergent fibre (g/kg DM)	364	(7.7)	258	(13.6)	339	(15.4)	864	(0.4)
Starch (g/kg DM)			373	(12.4)	237	(8.9)		
Gross energy (MJ/kg DM)	19.8	(2.85)	18.0	(0.09)	18.0	(0.10)	18.8	(0.01)
Metabolisable energy[a] (MJ/kg DM)	12.1	(0.21)						
pH	4.2	(0.07)						
Lactic acid (g/kg DM)	83	(4.1)						
Acetic acid (g/kg DM)	8.4	(1.91)						
Ethanol (g/kg DM)	11.4	(4.90)						
Ammonia (g/kg total N)	60	(8.7)						

642   [a] Predicted using NIRS; VCODM: Volatile corrected oven dry matter

643 Table 3: Effects of concentrate type and straw inclusion on the feed intake, milk production
644 and composition, the fatty acid content of milk, and body tissue reserves as measured during
645 final week of each experimental period.

	Concentrate type		Straw inclusion			P-Value	
	High-starch	High-fibre	No-straw	Straw	SED	Concentrate	Straw
Silage DMI (kg/d)	14.7	14.2	15.1	13.7	0.21	0.001	<0.001
Concentrate DMI (kg/d)	10.9	10.7	10.9	10.7	0.16	0.027	0.114
Total DMI (kg/d)	26.1	25.3	26.0	25.4	0.37	0.006	0.014
Milk yield (kg/d)	32.9	33.3	33.5	32.7	0.82	0.562	0.161
Fat (g/kg)	44.9	45.0	45.2	44.7	0.77	0.879	0.319
Protein (g/kg)	38.1	37.3	37.9	37.5	0.29	<0.001	0.036
Lactose (g/kg)	46.7	46.8	46.7	46.7	0.26	0.822	0.999
Fat yield (kg/d)	1.46	1.49	1.51	1.44	0.042	0.398	0.035
Protein yield (kg/d)	1.25	1.24	1.27	1.22	0.026	0.635	0.023
Fat+protein yield (kg/d)	2.71	2.73	2.77	2.66	0.064	0.692	0.403
Milk FA concentrations (g/100g total FA identified)							
Total C4:0 to C15:0	29.4	28.6	29.4	28.6	0.23	0.004	<0.001
C16:0	37.0	37.5	37.7	36.8	0.36	0.037	0.002
C18:0	8.4	8.4	8.0	8.7	0.17	0.749	<0.001
C18:1*cis*-9	16.7	16.9	16.3	17.3	0.29	0.259	<0.001
CLA,18:2*cis*-9, *trans*-11	0.43	0.46	0.44	0.45	0.010	<0.001	0.117
C18:2*cis*-9, *trans*-12	1.7	1.8	1.6	2.0	0.13	0.970	0.144
C20:0	0.13	0.14	0.13	0.14	0.003	0.455	<0.001
Total Saturated	74.6	74.3	74.9	73.9	0.43	0.399	0.002
Total MUFA	20.3	20.5	20.0	20.9	0.31	0.461	<0.001
Total PUFA	3.1	3.0	3.0	3.1	0.16	0.104	0.316
Total n-3 PUFA	0.8	0.8	0.8	0.8	0.02	0.199	0.084
Total n-6 PUFA	2.3	2.2	2.2	2.3	0.14	0.960	0.165
Total n-7 PUFA	2.4	2.3	2.3	2.3	0.06	0.341	0.492
Total n-9 PUFA	16.7	17.0	16.3	17.4	0.29	0.263	<0.001
Saturated:Unsaturated ratio	3.2	3.2	3.3	3.1	0.04	0.672	<0.001
Body weight (kg)	679	680	681	678	4.3	0.828	0.605
Body condition score	2.3	2.3	2.3	2.3	0.02	0.236	0.126

646 DMI, dry matter intake; FA, fatty acids, MUFA, monounsaturated fatty acids, PUFA poly-unsaturated
647 fatty acids
648

649 Table 4: Effects of concentrate type and straw inclusion on the blood metabolites of dairy cows

	Concentrate type		Straw inclusion			P-Value	
	High-starch	High-fibre	No-straw	Straw	SED	Concentrate	Straw
Serum BHB (mM)	0.51	0.35	0.50	0.35	0.227	0.295	0.345
Plasma glucose (mM)	3.65	3.57	3.62	3.61	0.055	0.065	0.665
Serum NEFA (mM)	0.12	0.12	0.12	0.12	0.018	0.759	0.726
Serum urea (mM)[a]	2.83	3.27	3.14	2.95	0.138	<0.001	0.053

650 [a] There was an interaction between concentrate type and straw inclusion for serum urea, with mean values for

651 High-starch/No-straw, High-starch/Straw, High-fibre/No-straw and High-fibre/Straw being 3.13, 2.53, 3.16, 3.37

652 mM, respectively (SED = 0.138; P < 0.001).

653 βHB, beta-hydroxybutyrate; NEFA, non-esterified fatty acids

654

655 Table 5: Effects of concentrate type and straw inclusion on dry matter intake and milk yield

656 during the nutrient utilisation study, and on total ration digestibility coefficients.

	Concentrate type		Straw inclusion			P-Value	
	High-starch	High-fibre	No-straw	Straw	SED	Concentrate	Straw
Silage DMI (kg/d)	12.5	12.5	13.4	11.5	0.58	0.825	0.007
Concentrate DMI (kg/d)	9.9	9.9	10.4	9.5	0.47	0.865	0.078
Total DMI (kg/d)	22.8	22.8	23.8	21.8	1.08	0.885	0.885
Milk yield (kg/d)	26.8	27.6	28.2	26.3	1.90	0.754	0.356
Digestibility coefficients (g/g)							
Dry matter	0.749	0.737	0.748	0.738	0.0119	0.291	0.406
Organic matter	0.748	0.742	0.749	0.740	0.0134	0.630	0.507
Nitrogen	0.604	0.601	0.600	0.605	0.0188	0.855	0.755
Gross energy	0.744	0.741	0.748	0.737	0.0138	0.720	0.441
ADF	0.757	0.757	0.769	0.755	0.0130	0.459	0.303
NDF	0.716	0.737	0.730	0.723	0.0151	0.185	0.621

657 DMI, dry matter intake; ADF, acid detergent fibre; NDF, Neutral detergent fibre

658

659   Table 6: Effect of concentrate type and straw inclusion on nitrogen (N) intake, nitrogen output

660   and nitrogen utilisation efficiency of dairy cows.

	Concentrate type		Straw inclusion			P-Value	
	High-starch	High-fibre	No-straw	Straw	SED	Concentrate	Straw
N intake/output (g/d)							
Total N intake	574	599	622	551	27.1	0.479	0.009
Faecal N	225	236	246	216	14.1	0.533	0.028
Urine N	158	176	170	164	11.3	0.124	0.587
Manure N	384	411	415	380	16.8	0.157	0.054
Milk N	154	155	162	146	9.5	0.978	0.122
N utilisation (g/g)							
Faecal N/N intake	0.396	0.399	0.400	0.395	0.0188	0.855	0.755
Urine N/N intake	0.280	0.297	0.276	0.300	0.0196	0.299	0.234
Manure N/N intake	0.676	0.695	0.675	0.695	0.0196	0.267	0.370
Milk N/N intake	0.271	0.262	0.264	0.270	0.0127	0.510	0.645
Faecal N/manure N	0.587	0.573	0.593	0.567	0.0236	0.466	0.293
Urine N/manure N	0.413	0.427	0.407	0.433	0.0236	0.466	0.293

661

662 Table 7: Effect of concentrate type and straw inclusion on energy intake, energy output and

663 energy utilisation efficiency in dairy cows.

	Concentrate type		Straw inclusion			P-Value	
	High-starch	High-fibre	No-straw	Straw	SED	Concentrate	Straw
Energy intake and output (MJ/d)							
GE intake	407	416	429	393	19.3	0.752	0.086
Faecal energy	103	106	106	102	6.2	0.637	0.404
Urinary energy	13	14	15	13	0.7	0.107	0.050
Milk energy	95	99	101	94	5.6	0.510	0.285
Energy utilisation (MJ/MJ)							
Faecal E/GEI	0.256	0.259	0.252	0.263	0.0138	0.720	0.441
Urine E/GEI	0.033	0.035	0.034	0.034	0.0016	0.108	0.613
Milk E/GEI	0.238	0.242	0.237	0.243	0.1172	0.652	0.592

664 GE, gross energy; E, energy; GEI, gross energy intake