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Effects of grass and maize silage feed value, offering soybean meal with maize silage, and concentrate feed level in late pregnancy, on ewe and lamb performance

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ABSTRACT

In many countries, daily herbage accumulation on pasture declines towards zero during the winter period; thus, many pregnant ewes are housed and offered conserved forages supplemented with concentrate prior to parturition. The effects of forage type and feed value (**FV**), offering soybean meal with maize silage during mid and late pregnancy, and concentrate feed level in late pregnancy on the performance of ewes and their progeny (to slaughter) were evaluated. Ewes ($n = 151$) were assigned to one of nine treatments from mid-pregnancy until lambing. Medium FV and high FV grass silages (metabolisable energy concentrations of 10.7 and 12.0 MJ/kg DM) were offered *ad libitum* supplemented with either 15 or 25 kg concentrate/ewe during late pregnancy. Low and high DM maize silages (starch concentrations of 80 and 315 g/kg DM) were offered *ad libitum* either alone or with soybean meal (200 g/d) and supplemented with 15 kg concentrate during late pregnancy. A final treatment consisted of high FV grass silage supplemented with 5 kg soybean/ewe over the final 4 weeks of pregnancy. Ewes and lambs were put to pasture in a rotational-grazing system within 3 days of lambing. There were no interactions ($P > 0.05$) between grass silage FV and concentrate feed level for ewe or lamb traits. Increasing grass silage FV increased food intake ($P < 0.001$) during late pregnancy, ewe BW and body condition score (**BCS**) at lambing ($P < 0.001$), lamb BW at birth ($P < 0.001$) and weaning ($P < 0.05$), and reduced age at slaughter ($P = 0.06$). Increasing concentrate feed level increased metabolisable energy ($P < 0.05$) intake during late pregnancy but had no effect ($P > 0.05$) on ewe or lamb performance. Increasing maize DM at harvest and offering soybean meal with maize silage increased food intake ($P < 0.001$) and ewe BW and BCS at lambing ($P < 0.05$ or $P < 0.01$). Offering soybean meal with maize silage increased lamb BW at birth ($P < 0.01$) and reduced age at slaughter ($P < 0.05$). Reducing supplementation of high FV grass silage to 5 kg of soybean meal had no effect ($P > 0.05$) on animal performance. Replacing grass silage with maize silage did not affect ($P > 0.05$) BW gain of lambs. It is concluded that increasing the FV of the grass silage offered during pregnancy had the greatest positive impact on ewe and lamb performance.

Implications

Increasing the feed value of grass silage offered during mid and late pregnancy increased BW and body condition score of ewes at lambing and the performance of their lambs to slaughter. Increasing the DM of maize at harvest, and soybean meal with maize silage, increased forage intake and ewe BW and body condition score at lambing. There was no response to offering more than 15 kg of concentrate supplement with grass-silage-based diets in late pregnancy; in the case of high feed-value grass silage the level of supplementation can be reduced to 5 kg of soybean meal.

Introduction

The main factors affecting the efficiency of mid-season grass-based systems of prime-lamb production are litter size, grassland management, feed value (**FV**) of the forage offered during the winter-housing period, shearing at housing, body condition score (**BCS**) at mating and rearing male lambs entire (Keady and Hanrahan, 2006). In Ireland, and other countries with a temperate climate, daily herbage accumulation on pasture declines towards zero during winter; thus, many ewes are housed and offered conserved forages during mid and late pregnancy; lambing is normally seasonal and targeted to coincide with the start of grass growth in spring. Grass silage is the main forage produced in Ireland and the UK for livestock feeding during winter. Crop yield is the major factor affecting the cost of silage production (Keady et al.,

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2002) but forage digestibility and FV decline as crop yield increases (Keady et al., 2000). Keady et al. (2013a) concluded that each increase of 10 g/kg in digestible organic matter digestibility (**DOMD**) increased milk yield of dairy cows by 0.33 kg/day and carcass gain of beef cattle by 21.2 g/day.

Major developments in plant breeding coupled with improvements in agronomic practices, particularly the development of the complete plastic mulch (**CCPM**) system, have considerably increased the potential yield and feeding value of maize at Northern latitudes (Keady, 2005). The CCPM system (see Keady, 2005), enables DM yield to be increased by up to 5 t/ha, depending on sowing date and variety (Keady unpublished). This increased yield potential of forage maize means that the cost of maize silage is similar to that of grazed grass when offered to lactating dairy cows (Keady et al., 2002). Previous studies have shown that partially or totally replacing grass silage with maize silage increases the performance of beef cattle (Keady, 2005; Keady et al., 2007b, 2013b), dairy cows (Keady, 2005; Keady et al., 2008) and finishing lambs (Keady and Hanrahan, 2013, 2015).

The hypotheses that informed the study design were: (i) maize silage can replace grass silage as the forage offered to ewes during mid and late pregnancy, (ii) the FV of grass silage and the maturity of maize when harvested for ensilage are positively associated with ewe and progeny performance when offered to ewes during mid and late pregnancy, (iii) the performance of ewes on maize-silage during pregnancy would be improved if supplemented with protein and (iv) the amount of concentrate provided to ewes in late pregnancy can be substantially reduced when a high FV grass silage is offered.

Material and methods

Forages

Two grass silages, differing in FV, were produced from herbage harvested from the primary growth of predominantly perennial ryegrass swards. Herbage was cut using a mower conditioner (Kuhn FC 302G; Kuhn S.A., Saverne, France). The herbage to produce high FV (GH) and medium FV (GM) grass silages was ensiled on 3 May and 5 June, respectively, following a 24-h wilting period and treated with a bacterial inoculant (Ecosyl; Ecosyl Products, Stokesley, North Yorkshire, England) designed to apply 10^6 colony-forming units (cfu) per gram of herbage when applied at the rate of 3 l/t. The inoculant (3 l/t) was applied and the herbage harvested and ensiled in trench silos as described by Keady and Hanrahan (2013).

Two maize silages, differing in DM at harvest, (low DM [ML], high DM [MH]), were produced using the variety 'Benicia'. The ML silage was produced from a crop sown in the open on 27 April while that used to produce the MH was sown, under the CCPM system, on 5 April. Both maize crops were planted using a Samco maize drill (Samco Engineering Ltd., Adare, Co. Limerick, Ireland) and harvested on 8 October, using a self-propelled precision-chop harvester fitted with a grain cracker, and ensiled with an inoculant-based additive (Silo-King MS; Fulton, Illinois, USA), which was applied at 1.5 and 2.0 l/t (1 l delivered 20×10^4 cfu per gram of forage) to the ML and MH silages, respectively. The additive was applied and the maize ensiled in trench silos as described above for grass silage.

Animals and management

Crossbred ewes (110 Belclare × Scottish Blackface and 41 Charmoise × Scottish Blackface; aged 2.75–4.75 years, initial BW 69.7 (SD 8.4) and 62.1 (SD 6.5) kg, respectively; BCS 3.7 (SD 0.33) and 3.7 (SD 0.32), respectively), due to lamb in mid-March, were allocated at random, within breed and age, to one of nine treatments. The ewes, which had been synchronised for the cycle prior to joining using progesterone-impregnated sponges, were joined with Suffolk rams on 18 October and had not returned to service. The nine treatments consisted of: GH or GM grass silage, each supplemented with 15 (GH15, GM15) or 25 (GH25, GM25) kg concentrate during late pregnancy; MH or ML maize silage offered either alone (MH, ML) or with 200 g soybean meal per ewe daily (MHS, MLS; on top of the silage) and supplemented with 15 kg concentrate during late pregnancy; and GH silage supplemented with 5 kg of soybean meal during late pregnancy (GH5S). Ewes offered the grass and maize silages received 20 and 30 g/day of a mineral and vitamin mixture, respectively, mixed with the concentrate during the final 6 weeks of pregnancy, or dusted on top of the silage for the 2 weeks prior to the start of concentrate supplementation in the case of ewes on the GH5S treatment. The ewes were housed, on 5 December, in groups of 4 or 5 in slatted-floor pens ($n = 32$), and shorn within 2 days; the study was initiated on 10 December. The silages were offered once daily in sufficient quantities to allow a refusal of 50–100 g/kg offered. For ewes receiving treatments involving 15 or 25 kg concentrate this was offered during the final 6 or 7 weeks of pregnancy, respectively; in the case of ewes assigned to the GH silage + 5 kg soybean meal, the supplement was offered over the final 4 weeks of pregnancy. The allowance of concentrate was stepped from 0.1 to 0.3 kg/day, 0.2 to 0.7 kg/day and 0.4 to 0.8 kg/day for ewes offered 5, 15 and 25 kg of supplement during late pregnancy, respectively. The concentrate consisted of (g/kg fresh weight) soybean meal (335), barley (320), citrus pulp (320) and molasses (25). Supplements were offered once daily at ~10 AM. Annual booster vaccine (Heptavac-P; MSD Animal Health, Buckinghamshire, England), for pasteurella pneumonia and clostridial disease, was administered 2 weeks prior to lambing.

Ewes lambed indoors and were put to pasture, with their lambs, within 3 days of lambing. Grazing groups and management were as described by Keady and Hanrahan (2018). All lambs were weaned at 14 weeks and managed as a single flock, without any concentrate supplementation, until drafted for slaughter. Lambs were treated for internal parasites as described by Keady and Hanrahan (2018). Ewe and ram lambs were drafted at weaning if BW exceeded 41 and 42 kg, respectively, and subsequently at monthly intervals if BW exceeded 44 and 45 kg, respectively.

Measurements

The yield of forage maize, and its DM concentration, was determined as described by Keady and Hanrahan (2013). Silage offered, and refusals, was sampled daily for determination of oven DM. Daily intake of DM per pen was calculated over four consecutive days each week and expressed on a per ewe basis. The intake of digestible undegradable protein (**DUP**) and the supply of metabolisable protein (**MP**) were calculated according to the equations of AFRC (1993). Dried samples of the silage, as offered, were bulked weekly for the determination of ADF, NDF and ash. Starch concentration of the maize silages was determined for one sample per week, which was dried at 60 °C. A sample of fresh silage, as offered, was taken once weekly for the determination of pH and the concentrations of ethanol, propanol, CP, ammonia nitrogen, acetic acid, propionic acid, butyric acid, valeric acid and lactic acid. A composite sample of silage, as offered, was taken once weekly for NIRS analysis to predict silage intake, DM digestibility (DMD), DOMD and metabolisable energy (**ME**) concentrations for the grass silages, and ME concentration for the maize silages. Silage DM was determined by oven drying at 85 °C for 22 h. Chemical composition of silage was determined as described by Purcell et al. (2016). Samples of the pelleted concentrate and of soybean meal were retained daily and bulked weekly for the determination of oven DM (100 °C) and CP. A blood sample was taken from the jugular vein of each animal at weeks 6 and 2 prior to expected lambing date and plasma was harvested, stored and analysed as described by Keady and Hanrahan (2015).

Ewe BCS as described by Russel et al. (1969) and BW were recorded at the start of the study, at 6 weeks pre-lambing, at lambing and at 5 and 14 (weaning) weeks post-lambing. Litter size (lambs born per ewe lambing) and lambing assistance score (3-point scale:1 = unassisted, 2 = minor assistance and 3 = major intervention) were recorded. Lambs were tagged and weighed within 24 h of birth; lambs dead at this time are referred to as born dead. Lambs were weighed at average ages of 5, 10 and 14 (weaning) weeks, and at intervals of 4 weeks between weaning and drafting for slaughter; average BW gain was calculated for the intervals birth to 5, 5–14 and birth to 14 weeks. Total lamb mortality refers to lambs that were not alive at the 5-week weight point.

Lambs were slaughtered, within 18 h of drafting, at an abattoir approved by the European Union as described by Keady and Hanrahan (2015). Carcass weight (cold) was recorded for each lamb together with the carcass conformation class and fat score assigned by abattoir staff, based on visual assessment, according to the European Lamb Carcass Classification Scheme. There were five conformation classes: E (= good), U, R, O and P (= poor), which were coded as 5, 4, 3, 2 and 1, respectively, for data analysis, and 5 fat scores: 1 (leanest) to 5 (fattest).

Statistical analysis

Animal performance data were analysed using Proc GLM, Proc MIXED and Proc GENMOD of SAS Institute Inc (2016) (v 9.4) as appropriate. Ewe age (classified as 3 or >3) and ewe genotype were included in all models. Pre-experimental BW was used as a covariate for ewe BW and pre-experimental BCS was used as a covariate for BCS (both expressed as deviations from the means of the individuals genotype class). Litter size, expressed as a deviation from the mean of individual's genotype class, was included as a covariate in the analyses of all ewe traits. The models for blood composition traits included a random effect for ewe and week-prior-to-lambing as a fixed effect in addition to the fixed effects already described for ewe traits; variation among ewes was used to evaluate differences among treatments. Ewes (n = 9) that failed to lamb or died were excluded from these analyses.

In the case of data on intake, pen within treatment was the experimental unit and these data were analysed using Proc MIXED with pen as a random term. Dam age and genotype, lamb sex and birth type (litter size of dam) were included as fixed effects for lamb BW at birth, together with dam as a random term; birth type was replaced by birth-rearing class in the models for BW gain, weaning weight and slaughter data. Data on non-essential fatty acids (**NEFA**) and b-hydroxy butyrate (**BHB**) concentrations exhibited significant skewness and were transformed to logarithms prior to analysis. Lamb mortality was analysed as a binomial using Proc GENMOD with a logit link function; back-transformed means are reported.

Orthogonal contrasts were used to evaluate the effects of FV and level of concentrate supplementation (15 vs 25 kg), and their interaction for the treatments based on grass silage and for the differences among the maize-based diets (maize DM at harvest, offering soybean meal with maize silage and their interaction). Two *a priori* comparisons were also evaluated: grass vs maize as the forage for silage, based on the difference between the average of the two maize-based silage treatments without soybean meal and the average of the two grass silages supplemented with 15 kg concentrate, and the performance on GH silage plus 5 kg soybean meal vs GH silage supplemented with 15 kg concentrate.

Results

Mean DM yield and DM concentration for the maize grown in the open and under the CCPM system were 10.4 and 14.2 t/ha, and 185 and 259 g/kg, respectively. The chemical composition of the silages is presented in Table 1. The grass silages differed in FV as indicated by the differences in DMD, DOMD, ME, CP and DM concentrations, and predicted DM intake. The maize silages differed in maturity at harvest as indicated by the means for DM, starch, NDF and ADF concentrations. The CP concentration of the soybean and concentrate was 225 and 481 g/kg DM, respectively.

Table 1
Chemical composition of the silages.

Variable	Silage type			
	Grass		Maize	
	Medium	High	Low	High
DM (g/kg)	205	243	180	259
pH	3.9	3.8	4.0	3.9
Composition of DM (g/kg)				
CP	107	172	80	76
Ethanol	11.2	8.6	18.3	7.7
Propanol	0.38	0.03	5.17	0.56
Acetic acid	12.1	5.0	28.3	18.3
Propionic acid	0.84	0.28	0.67	0.11
Butyric acid	1.42	0.23	0.31	0.03
Valeric acid	0.03	0.00	0.04	0.00
Lactic acid	86	111	33	44
ADF	371	289	381	262
NDF	614	489	663	521
Ash	74	91	43	34
Starch	–	–	80	315
DM digestibility[1]	698	788	–	–
DOMD[1,2] (g/kg DM)	668	750	–	–
Metabolisable energy[1] (MJ/kg DM)	10.7	12.0	9.2	10.8
FIM intake[3] (g/kg $W^{0.75}$)	82	92	–	–

[1] Determined by NIRS.
[2] Digestible organic matter in the DM.
[3] Feed-into-milk (FIM) intake (Keady et al., 2004).

The effects of treatment on DM, ME and DUP intake, and MP supply, are presented in Table 2 and Figs. 1 and 2. Increasing the FV of grass silage, increasing maize DM at harvest and offering soybean meal with maize silage all increased ($P < 0.01$ or <0.001) silage DM intake and total DM intake for weeks −13 to −8 and −7 to −1; the corresponding intakes of DUP and ME, and MP supply for weeks −7 to −1 were also increased ($P < 0.001$). Concentrate feed level was positively associated with the intakes of DUP ($P < 0.001$) and ME ($P < 0.05$), and with MP supply ($P < 0.001$). Relative to maize silage, grass-silage treatments increased ($P < 0.001$) the intake of silage DM during weeks −13 to −8, and during weeks −7 to −1 increased ME intake ($P < 0.001$) and tended to increase MP supply ($P < 0.06$). Supplementing GH silage with 5 kg soybean meal did not alter ($P > 0.05$) the intakes of silage DM, ME or DUP, or MP supply when compared with GH15. There were no interactions ($P > 0.05$) between grass silage FV and concentrate feed level, or between maize silage type and whether soybean meal was offered or not for silage DM, ME or DUP intake, or for MP supply. The intake of total DM (Fig. 1b), ME (Fig. 2a) and DUP (Fig. 2b) tended to increase during the final 7 weeks of pregnancy for all treatments. The supply of MP (Fig. 2c) increased for all treatments during late pregnancy. The ratio of MP supply to MP required (Fig. 2d) was greater than, or equal to, 1 for all treatments during the final 6 weeks of pregnancy, with the exception of the ML treatment and the treatments based on GM silage.

The least squares means for blood plasma composition variables at weeks 6 and 2 pre-lambing are presented in Fig. 3. The concentration of BHB (Fig. 3a) was increased ($P < 0.001$) at week 2 pre-lambing relative to week 6 and was lower ($P < 0.05$) for GH than GM and for MH compared to ML. The plasma concentration of NEFA (Fig. 3b) was also greater ($P < 0.001$) at week 2 than week 6 but there was a significant ($P < 0.001$) treatment-by-week interaction. At 6 weeks, pre-lambing NEFA concentration was lower for ewes offered GH silage than for those offered GM silage ($P < 0.001$) but the corresponding difference at week 2 was not significant ($P > 0.3$). Offering soybean meal with the maize silages reduced ($P < 0.06$) NEFA concentration at week 6 but the difference at week 2 was in the opposite direction and was not significant ($P > 0.13$). The treatment-by-week interaction was also significant for blood urea (Fig. 3d) concentration ($P < 0.001$) reflecting the absence of any week difference for ewes offered GH silage in contrast to

Table 2
Effects of grass silage feed value, maize silage DM, concentrate feed level and supplementation with soybean meal on food intake and supply of metabolisable protein of ewes.

Variable[1]	Diet[2]								GH5S	SEM	Significance of contrasts							
	Grass silage feed value (G) by concentrate level (C)				Maize silage DM (M) by soybean meal supplement (S)													
	GH15	GH25	GM15	GM25	MH	MHS	ML	MLS			G	C	G×C	M	S	M×S	MH + ML vs GH15 + GM15	GH5S vs GH15
Silage DM intake pre-lambing (kg/day)																		
Weeks −13 to −8	1.48	1.43	1.06	0.98	1.21	1.35	0.86	1.06	1.41	0.046	***	ns	ns	***	**	ns	***	ns
Weeks −7 to −1	1.28	1.15	0.76	0.73	1.14	1.26	0.74	0.92	1.39	0.053	***	ns	ns	***	**	ns	ns	ns
Total DM intake[3] (kg/day)	1.54	1.58	1.02	1.16	1.40	1.70	1.00	1.36	1.48	0.053	***	ns	ns	***	***	ns	ns	ns
DUP intake[3] (g/day)	40.2	47.0	29.7	38.4	37.4	64.3	29.2	57.4	40.7	1.083	***	***	ns	***	***	ns	ns	ns
ME intake[3] (MJ/day)	18.7	19.4	11.5	13.4	15.7	19.4	10.2	14.3	17.9	0.613	***	*	ns	***	***	ns	***	ns
MP supply[3] (g/day)	131.4	145.2	81.2	102.6	117.5	168.8	78.3	131.3	124.6	4.47	***	***	ns	***	***	ns	$P<0.06$	ns

[1] DUP = digestible undegradable protein; ME = metabolisable energy; MP = metabolisable protein.
[2] GH15 = high feed-value grass silage + 15 kg concentrate; GH25 = high feed-value grass silage + 25 kg concentrate; GM15 = medium feed-value grass silage + 15 kg concentrate; GM25 = medium feed-value grass silage + 25 kg concentrate; MH = high DM maize silage + 15 kg concentrate; MHS = high DM maize silage + soybean meal + 15 kg concentrate; ML = low DM maize silage + 15 kg concentrate; MLS = low DM maize silage + soybean meal + 15 kg concentrate; GH5S = high feed-value grass silage + 5 kg soybean meal.
[3] For weeks −7 to −1 relative to lambing.

an increase in urea concentration, between weeks 6 and 2 pre-lambing, in plasma from ewes on the other 6 dietary treatments and especially for the diets based on maize silage. Plasma urea concentration was increased at both 6 and 2 weeks pre-lambing by increasing grass silage FV ($P < 0.01$), by reducing maize DM at harvest ($P < 0.01$) and by offering soybean meal with maize silage ($P < 0.001$). Ewes on MH diet without soybean meal had a plasma urea concentration that was below 2 mmol/l at both 6 and 2 weeks pre-lambing and this was also the case at 6 week pre-lambing for ewes on the ML treatment (Fig. 3d). Relative to ewes offered GM silage, those offered GH silage had higher ($P < 0.01$) plasma globulin concentrations at 6 and 2 weeks pre-lambing (Fig. 3e). Plasma glucose concentration increased ($P < 0.001$) between weeks 6 and 2 pre-lambing and was positively associated ($P < 0.001$) with both maize DM at harvest and grass silage FV (Fig. 3c). The concentration of P in plasma increased between weeks 6 and 2 pre-lambing ($P < 0.01$) was lower for maize silage plus soybean meal than for maize silage

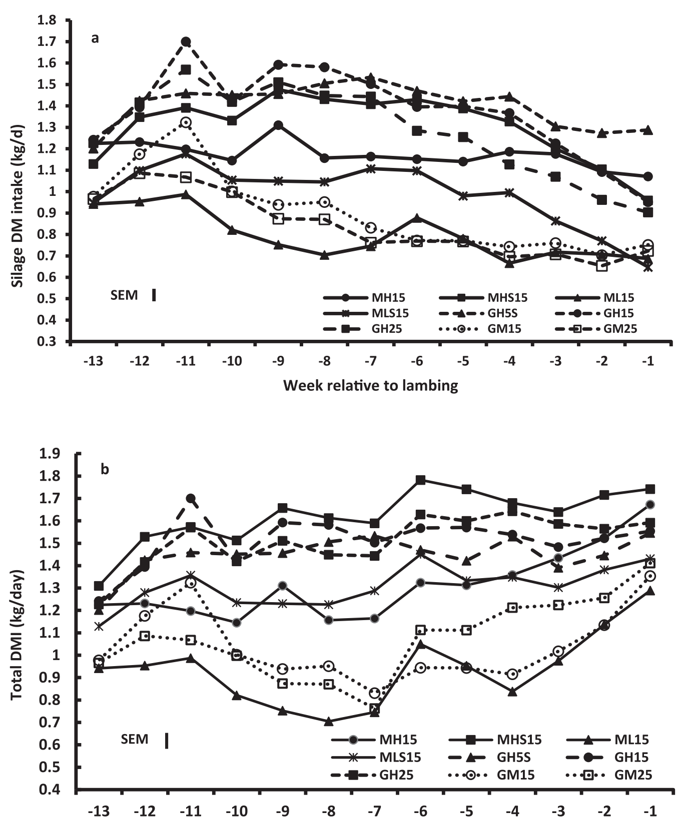

Fig. 1. Effects of silage type (MH, ML, GH, GM = high DM maize, low DM maize, high feed-value grass and medium feed-value grass, respectively), offering soybean meal (200 g/day) with maize silage (MHS, MLS) and level of concentrate feed offered to ewes during the final 7 weeks of pregnancy (5 = total of 5 kg soybean meal; 15, 25 = total concentrate of 15 and 25 kg, respectively) on intake, during final 13 weeks of pregnancy, of: (a) silage DM; (b) total DM.

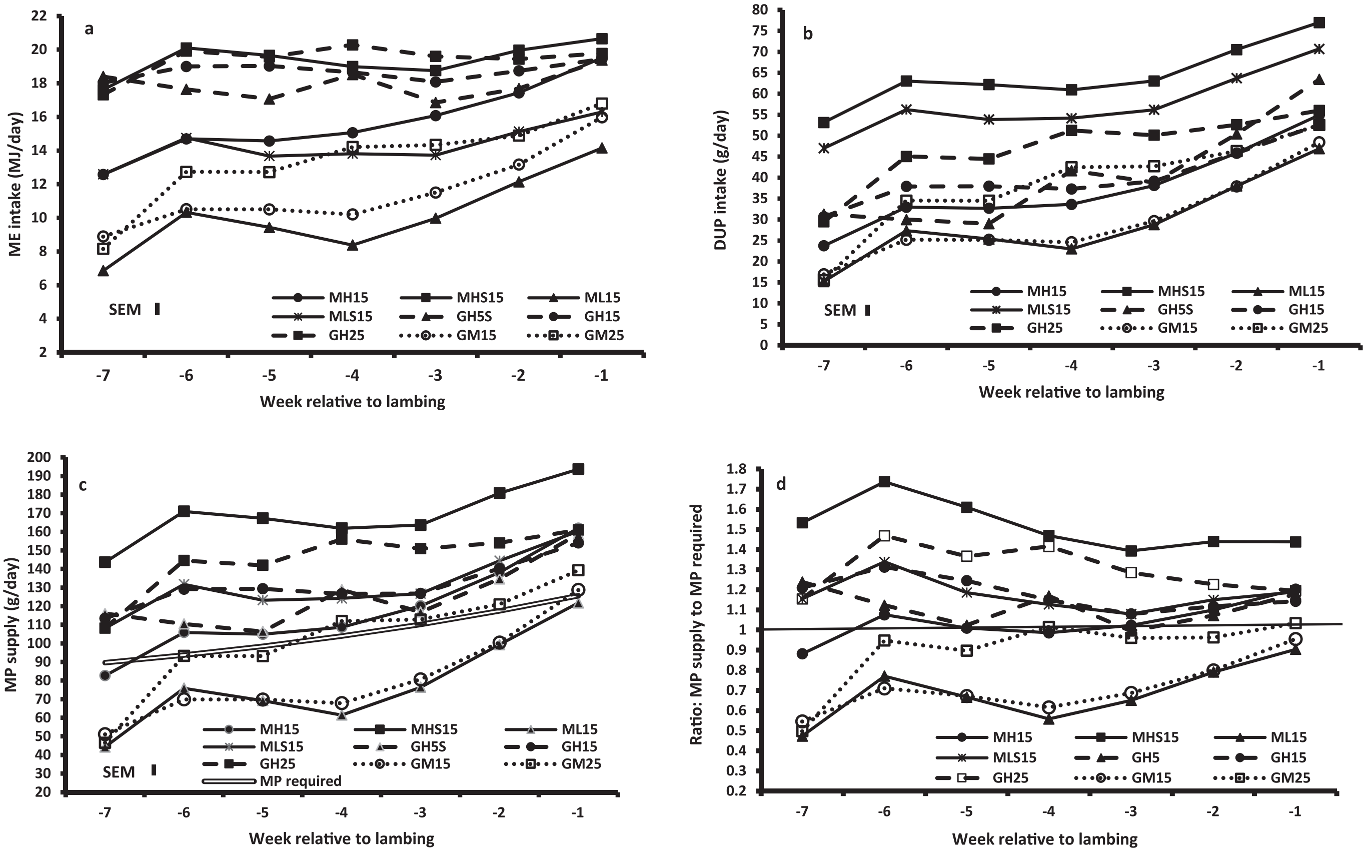

Fig. 2. Effects of silage type (MH, ML, GH, GM = high DM maize, low DM maize, high feed-value grass and medium feed-value grass, respectively), offering soybean meal (200 g/day) with maize silage (MHS, MLS) and level of concentrate feed offered to ewes during the final 7 weeks of pregnancy (5 = total of 5 kg soybean meal; 15, 25 = total concentrate of 15 and 25 kg, respectively) on: (a) metabolisable energy (ME) intake; (b) digestible undegraded protein (DUP) intake; (c) metabolisable protein (MP) supply; (d) ratio of MP supply to MP intake.

alone ($P < 0.05$), and higher for maize silage than grass silage ($P < 0.01$) (Fig. 3f).

The effects of treatment on ewe BW and BCS are presented in Table 3. Increasing the FV of grass silage increased ewe BW and BCS at 6 weeks pre-lambing, lambing, 5 weeks post-lambing and weaning ($P < 0.05$ or smaller). Increasing grass-silage FV was associated with a significantly lower BW gain over the period from lambing to weaning ($P < 0.01$). Ewes offered the MH silage had higher ($P < 0.05$ or smaller) BW and BCS at 6 weeks pre-lambing, lambing, 5 weeks post-lambing and weaning than those offered ML silage and their BW gain to lambing was greater. Offering soybean meal with maize silage increased BW and BCS at 6 weeks pre-lambing ($P < 0.01$ or smaller) and lambing ($P < 0.001$), and BW change to 6 weeks pre-lambing ($P < 0.001$), to lambing ($P < 0.001$) and from lambing to weaning ($P < 0.05$). There was a significant interaction ($P < 0.05$) between the effect of maize DM at harvest and offering soybean meal with maize silage for ewe BW at weaning, ewe BW gain between lambing and 5 weeks post-lambing, and for BCS at 5 weeks post-lambing and at weaning. Ewes offered the MH silage with soybean meal had a lower BW at weaning and a lower BCS at 5 weeks post-lambing and at weaning than those on MH, but these effects were of opposite sign for ewes offered the ML silage plus soybean meal. In relation to forage type, ewes offered grass silage were heavier at week 6 pre-lambing than those on maize silage ($P < 0.05$) but not at other time points and differences in BCS were not significant. However, ewes on grass silage, on average, lost BW between lambing and weaning, whereas those on maize silage gained BW ($P < 0.05$).

Mean litter size and number of lambs reared per ewe were 1.93 and 1.75, respectively, and were unaffected ($P > 0.05$) by treatment but differed significantly between the ewe genotypes. The incidence of twin births was 60% for both genotypes while the incidence of ewes with singles was 19% for the Belclare × S. Blackface and 38% for Chamoise × S. Blackface. Neither lamb mortality at birth (8.0%) nor total lamb mortality (9.9%) was influenced ($P > 0.05$) by dietary treatment or ewe genotype. Birth type had a significant effect ($P < 0.01$) on lamb mortality at birth; the back-transformed estimates (%) for singles, twins and triplets were 16.4 (95%CI 7.0–33.6), 3.1 (95%CI 1.3–7.3) and 15.2 (95%CI 6.3–32.1), respectively. Only two lambs died between birth and 5 weeks of age. Incidence of assistance at birth was significantly higher for ewes bearing singles (66%) and triplets (65%) than for those with twins (30%). Ewes offered grass silage supplemented with 25 kg concentrate required more assistance at birth ($P < 0.05$) than those offered grass silage plus 15 kg concentrate (67 vs 31%).

The effects of maternal diet on lamb performance traits are presented in Table 4. Increasing FV of grass silage increased lamb BW at birth ($P < 0.001$), and tended to increase BW at weaning ($P < 0.06$) and reduce age at slaughter ($P < 0.07$). The only significant effect associated with maize DM at harvest was increased lamb BW gain from 5 to 14 weeks ($P < 0.05$) for lambs from ewes on MH-based diets. Offering soybean meal with maize silage increased BW at birth ($P < 0.01$), reduced age at slaughter ($P < 0.05$) and carcass fat score ($P < 0.05$).

Discussion

The primary objectives of this study were to evaluate the effects of grass silage FV and DM concentration of maize at harvest, the level of concentrate feed offered with grass silage, adding a protein source to diets based on maize silage, and of a low level of concentrate supplement with high FV grass silage on the performance of ewes and their progeny. The medium FV grass silage used had a similar FV, as indicated

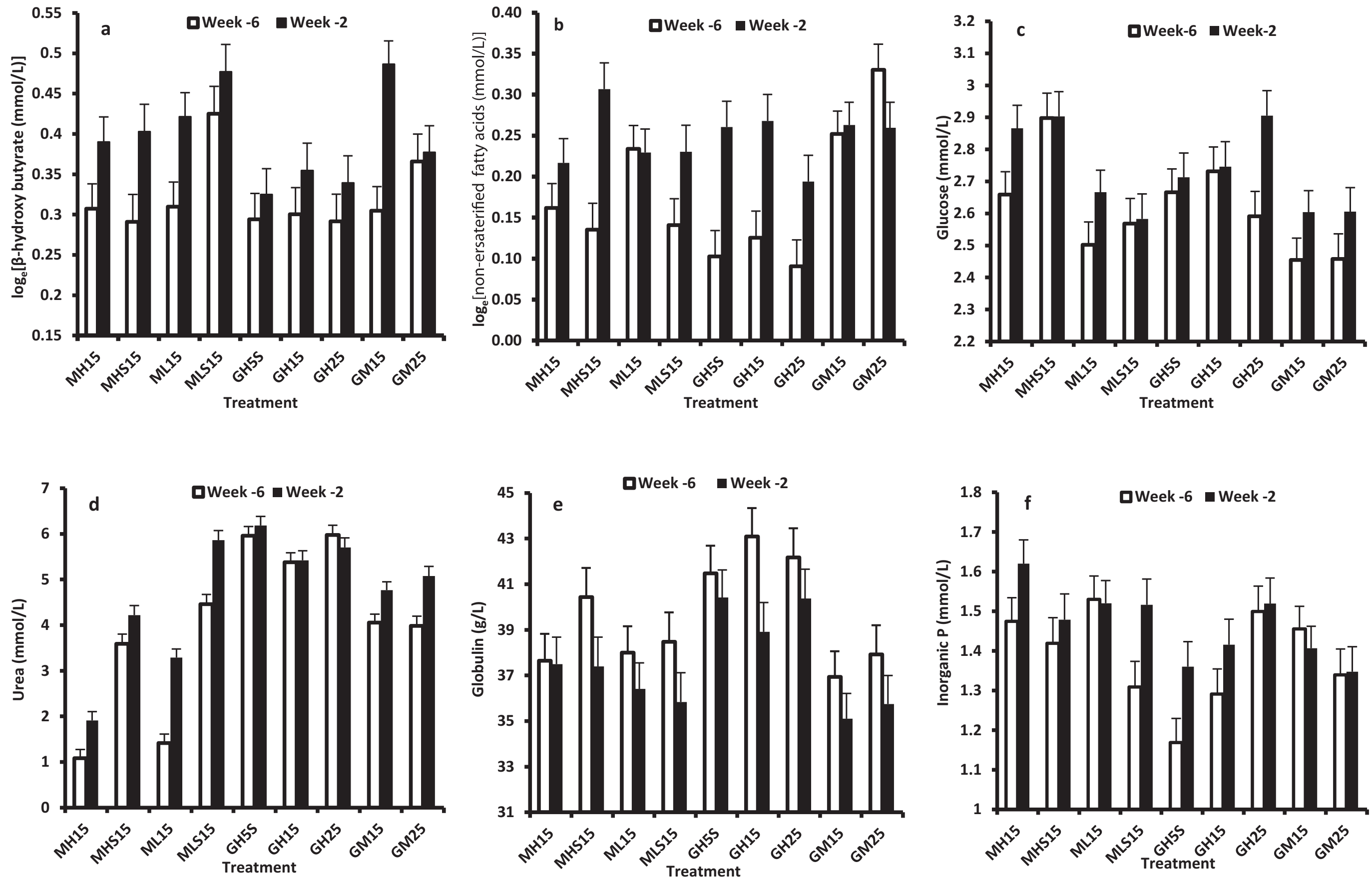

Fig. 3. Effects of silage type (MH, ML, GH, GM = high DM maize, low DM maize, high feed-value grass and medium feed-value grass, respectively), offering soybean meal (200 g/day) with maize silage (MHS, MLS) and level of concentrate feed offered to ewes during the final 7 weeks of pregnancy (5 = total of 5 kg soybean meal; 15, 25 = total concentrate of 15 and 25 kg, respectively) on blood plasma composition at weeks 6 and 2 prior to lambing: (a) beta-hydroxy butyrate; (b) non-essential fatty acids; (c) glucose; (d) urea; (e) globulin; (f) inorganic phosphorus (P).

Table 3
Effects grass silage feed value, maize silage DM, concentrate feed level and supplementation with soybean meal on ewe BW, BW change and body condition score of ewes.

Variable	Diet[1]								GH5S	SEM	Significance of contrasts							
	Grass silage feed value (G) byconcentrate level (C)				Maize silage feed value (M) by soybean meal inclusion (S)													
	GH15	GH25	GM15	GM25	MH	MHS	ML	MLS			G	C	G×C	M	S	M×S	MH + ML vs GH15 + GM15	GH5S vs GH15
Live weight (kg)																		
Week 6 pre-lambing	74.3	74.7	65.7	65.4	70.0	76.9	64.8	72.6	77.0	1.10	***	ns	ns	***	***	ns	*	ns
Lambing	71.7	73.6	61.8	63.0	65.9	75.2	62.5	70.3	71.3	1.60	***	ns	ns	*	***	ns	ns	ns
Week 5 post-lambing	68.1	68.2	61.8	64.0	68.5	68.2	61.5	66.7	67.6	1.47	***	ns	ns	**	ns	P < 0.08	ns	ns
Weaning	69.6	70.9	66.5	66.8	74.7	70.8	66.0	70.9	68.9	1.84	*	ns	ns	*	ns	*	ns	ns
BW gain (g/day)																		
Start to week 6 pre-lambing	183	188	−5	−10	82	230	−27	143	237	23.3	***	ns	ns	***	***	ns	**	ns
Start to lambing	62	86	−41	−29	−4	95	−38	48	58	17.2	***	ns	ns	*	***	ns	P = 0.08	ns
Lambing to week 5 post-lambing	−159	−139	−12	15	85	−170	−32	−93	−94	42.9	***	ns	ns	ns	***	*	*	ns
Lambing to weaning	−45	−18	32	27	64	−35	25	3	−29	21.2	**	ns	ns	ns	*	ns	*	ns
Condition score																		
Week 6 pre-lambing	3.84	3.90	3.24	3.25	3.67	3.92	3.37	3.54	3.94	0.079	***	ns	ns	***	**	ns	ns	ns
Lambing	4.02	4.01	2.76	3.03	3.35	4.12	3.02	3.59	3.78	0.131	***	ns	ns	**	***	ns	ns	ns
Week 5 post-lambing	3.60	3.37	2.59	2.77	3.62	3.37	2.81	3.15	3.36	0.123	***	ns	P = 0.09	***	ns	*	ns	ns
Weaning	3.44	3.52	3.06	3.12	3.87	3.30	3.12	3.24	3.20	0.153	**	ns	ns	*	ns	*	ns	ns

[1] GH15 = high feed-value grass silage + 15 kg concentrate; GH25 = high feed-value grass silage + 25 kg concentrate; GM15 = medium feed-value grass silage + 15 kg concentrate; GM25 = medium feed-value grass silage + 25 kg concentrate; MH = high DM maize silage + 15 kg concentrate; MHS = high DM maize silage + soybean meal + 15 kg concentrate; ML = low DM maize silage + 15 kg concentrate; MLS = low DM maize silage + soybean meal + 15 kg concentrate; GH5S = high feed-value grass silage + 5 kg soybean meal.

Table 4
Effect of diet offered to ewes (silage type, grass silage feed value, maize silage maturity, concentrate feed level and supplementation with soybean meal) on the performance of their progeny.

Variable	Diet[1]								GH5S	SEM	Significance of contrasts							
	Grass silage feed value (G) by concentrate level (C)				Maize silage feed value (M) by soybean meal inclusion (S)													
	GH15	GH25	*GM15*	*GM25*	MH	MHS	ML	MLS			G	C	G×C	M	S	M×S	MH + ML vs GH15 + GM15	GH5S vs GH15
Birth weight (kg)	5.13	5.14	4.60	4.56	4.65	5.29	4.62	4.92	4.85	0.167	***	ns	ns	ns	**	ns	ns	ns
Weaning weight (kg)	33.9	33.4	32.5	31.1	33.2	33.3	32.1	31.5	32.9	1.03	$P < 0.06$	ns	ns	ns	ns	ns	ns	ns
Growth rate (g/day)																		
Birth to 5 weeks	299	305	310	277	295	310	309	301	298	11.5	ns	ns	$P < 0.06$	ns	ns	ns	ns	ns
5 to 14 weeks	298	283	276	271	296	274	267	259	284	12.3	ns	ns	ns	*	ns	ns	ns	ns
Birth to weaning	297	291	288	272	296	287	280	275	289	10.1	ns	ns	ns	ns	ns	ns	ns	ns
Slaughter weight (kg)	44.0	44.7	43.9	44.5	45.5	43.6	44.6	42.6	45.2	0.74	ns	ns	ns	ns	**	ns	$P < 0.10$	ns
Carcass weight[2] (kg)	19.7	19.4	19.3	19.0	19.0	19.2	18.8	18.5	19.4	0.42	ns	ns	ns	ns	ns	ns	ns	ns
Carcass fatness[3]	2.78	2.77	2.80	2.97	2.99	2.69	2.98	2.85	2.92	0.107	ns	ns	ns	ns	*	ns	*	ns
Dressing proportion (g/kg)	442	429	434	427	422	428	426	429	426	8.2	ns	ns	ns	ns	ns	ns	$P < 0.06$	ns
Age at slaughter[3] (days)	156	164	171	182	169	143	176	165	176	9.5	$P < 0.07$	ns	ns	$P = 0.10$	*	ns	ns	ns

[1] GH15 = high feed-value grass silage + 15 kg concentrate; GH25 = high feed-value grass silage + 25 kg concentrate; GM15 = medium feed-value grass silage + 15 kg concentrate; GM25 = Medium feed-value grass silage + 25 kg concentrate; MH = high DM maize silage + 15 kg concentrate; MHS = high DM maize silage + soybean meal + 15 kg concentrate; ML = low DM maize silage + 15 kg concentrate; MLS = low DM maize silage + soybean meal + 15 kg concentrate; GH5S = high feed-value grass silage + 5 kg soybean meal.
[2] Adjusted to fat class = 3.
[3] Adjusted to carcass weight = 19.0 kg.

by DMD and ME concentrations, to the mean for silages produced in Ireland (Keady, 2000). The two maize silages differed in FV and were representative of the range of maize silages produced in Ireland and the UK (Keady, 2005).

Inadequate intake of protein has detrimental effects on animal performance (Phipps et al., 1981). The maize silages were deficient in protein as evidenced by the observation that at 6 weeks pre-lambing mean urea concentration for ewes offered maize silage without soybean meal was well below 2 mmol/l and was also below 2 mmol/l at 2 week pre-lambing in the case of ewes on the MH15 treatment; such values are well below the normal range of 3.4–7.3 mol/l reported by Castlejon and Leaver (1994), which implies that these feeds were deficient in protein. Keady and Hanrahan (2013), using finishing lambs, reported a positive relationship between protein intake and blood urea concentration (0.13 mmol/l per 1 g increase in protein intake). As there were no interactions between grass silage FV and concentrate feed level, and the only interactions between maize DM at harvest and offering soybean meal with maize silage were for ewe BW and BCS at weaning and for BCS at week 5 post-lambing, subsequent discussion is focused on the main effects.

Grass silage

Digestibility affects both intake and nutritive value of silage, and, consequently, is the most important factor influencing the performance of animals offered diets based on grass silage. Keady et al. (2013a) concluded that each increase of 10 g/kg in digestibility increased silage DM intake of dairy cows, beef cattle and pregnant ewes by 0.22, 0.07 and 0.05 kg/day. The difference in DM intake between the two grass silages in the current study was similar during mid and late pregnancy (0.048 and 0.052 kg for each 10 g/kg increase in digestibility, respectively). The higher DM intake due to higher FV increased ME and DUP intakes by 53 and 28%, respectively, and improved ewe performance. The mean response of 1.0 kg in ewe BW at lambing per 10 g/kg increase in silage digestibility was somewhat lower than the responses of 1.3 and 1.26 kg in ewe BW per 10 g/kg increase in silage digestibility reported by Keady et al. (2013a) and Keady and Hanrahan (2018). During the final 6 weeks of pregnancy, time of peak nutrient demand, ewes offered GH silage gained 0.15 units of BCS whilst those offered GM silage lost 0.35 units. However, from lambing to weaning ewes offered GM silage gained BW and BCS while those on GH silage lost BW and BCS, suggesting differences in the partitioning of nutrients between growth and lactation. It is argued that the ewes on GM silage produced less milk energy output, as indicated by lower BW gain by their lambs, and partitioned more energy to replenishing body reserves between lambing and weaning than ewes offered GH silage during mid and late pregnancy. However, the ewes offered the GH silage had a higher BCS at weaning which could have long-term effects in relation to productivity and/or management decisions implemented between post-weaning and pre-joining the following season.

Previous authors have reported that increasing silage FV increased the performance of beef cattle (Steen et al., 2002; Keady et al., 2008), dairy cows (Gordon, 1980; Keady et al., 1999), finishing lambs (Keady and Hanrahan, 2013, 2015) and pregnant ewes (Keady and Hanrahan, 2018). A key measure of the adequacy of the plane of nutrition offered to ewes during pregnancy is its impact on lamb BW at birth. The mean increase in lamb BW at birth per 10 g/kg increase in DOMD of grass silage was 67.7 g, which is similar to the response reported by Keady and Hanrahan (2018) but greater than the average response (52.3 g) reported by Keady et al. (2013a).

The increase in BW at weaning for lambs born to ewes offered GH silage was due to a combination of higher BW at birth and the trend in BW gain from birth to weaning. A comparison of GH and GM silages for the differences in lamb BW at weaning and at birth showed that BW at weaning increased by 3.3 kg for each 1 kg increase in BW at birth. This is consistent with results in Keady et al. (2007a) and Keady and Hanrahan (2009a, 2009b, 2018) who reported that each 1 kg increase in lamb BW at birth increased BW at weaning by 3.35, 3.16, 3.41 and 3.3 kg, respectively. Keady and Hanrahan (2009b) concluded that of the response in BW at weaning 47% was due to higher BW gain, most likely due to higher milk energy output by ewes between birth and weaning and that the remaining 53% was attributable to BW at birth *per se*.

While there was no difference in carcass weight, as lambs were drafted at target weights, increasing the FV of grass silage offered to ewes during pregnancy reduced the age at slaughter by 16 days. Based on the responses reported by Grennan and McNamara (2005), this reduction of 16 days in age at slaughter is equivalent to the response that would be expected from feeding 19 kg concentrate per lamb between birth and slaughter.

In developing a model to predict feed intake of dairy cows, Keady et al. (2004) concluded that increasing silage FV and the level of concentrate supplementation increased substitution rate for silage-based diets. In the current study, increasing level of concentrate supplement offered with the GM and GH silages resulted in mean substitution rates of 0.18 and 0.75 kg silage DM per 1 kg increase in concentrate DM intake, respectively. Thus, increasing concentrate level increased ME intake during the final weeks of pregnancy by 0.6 and 1.9 MJ/day for the ewes offered GH and GM silages, respectively. The improvement in ME intake due to the higher level of concentrate supplementation was only 0.26 times the response obtained by increasing silage FV. Thus, the lack of an effect of increased concentrate level on animal performance probably reflects the magnitude of the difference achieved in ME intake and is similar to the results of previous studies from this research centre (Keady and Hanrahan, 2010).

Maize silage

Increasing DM maize at harvest alters chemical composition of the resulting silage due to reduced concentrations of ADF and CP, and increases in starch and ME concentrations (Phipps et al., 2000; Keady et al., 2003, 2008, 2013b; Keady and Hanrahan, 2013). The increase in forage intake associated with increased DM at harvest was similar during mid and late pregnancy and was reflected in increased ME intake and MP supply. Ewes offered the MH silage were 4.2 kg heavier at lambing and BCS was 0.4 units higher, and these differences persisted until weaning. It has been reported that the optimum stage of maturity at which to harvest maize for ensiling as a feed for dairy cows is at a DM concentration of 302 g/kg (Phipps et al., 2000) and 280 g/kg (Keady et al., 2008). From a review of the literature, Keady (2005) concluded that there was a quadratic relationship between maize DM concentration at ensiling and milk yield of dairy cows. Thus, using the equation of Keady (2005), maize ensiled at DM concentrations of 200, 250, 300, 350, 400 and 450 g/kg would result in daily milk yields of 27.56, 28.22, 28.67, 28.60, 28.34 and 27.77 kg, respectively. Consequently, maize with a DM of 259 g/kg (HDM in the present study) is expected to yield ~99% of the performance achieved by maize ensiled at the optimum DM.

The increased nutrient intake due to higher maize DM at harvest was partitioned to increased body reserves (BCS) rather than to foetal growth, as indicated by the absence of any difference in lamb BW at birth. There was no indication of an effect of maize DM at harvest on ewe milk production given the absence of an effect on BW gain of lambs between birth and 5 weeks. However, the improved BW gain of lambs from ewes offered MH silage from weeks 5 to 14 may be attributable to a more sustained plateau in lactation, as these ewes gained less BCS than the ewes offered the ML silage during the latter period. The effect of the difference in lamb BW at weaning due to maize DM at harvest was carried through to slaughter as lambs were drafted 14 days earlier, similar to the effect of increasing grass-silage FV.

While ME intake was increased by replacing GM silage with maize silage, it was reduced when GH silage was replaced by maize silage. Previously, Keady et al. (2008) observed, with dairy cows, that partially (0.4) replacing medium FV and high FV grass silages with maize silage resulted in total daily DM intake increases of 2.25 and 0.51 kg/cow, respectively. Similarly, Keady et al. (2003) observed that with grass silages of low (ME 10.2 MJ/kg DM), medium (ME 11.0 MJ/kg DM) and high (ME 12.0 MJ/kg DM) FV, replacing of 0.4 of the grass silage with maize silage resulted in a response in total DM daily intake of $+1.85$, $+1.45$ and -0.10 kg/cow, respectively.

Metabolisable protein supply and metabolisable energy

With the exception of ML without soybean meal and GM silage supplemented with 15 kg concentrate, all treatments met MP supply requirements (AFRC, 1993) during the final 6 weeks of pregnancy. The increased nutrient intake due to offering soybean meal with maize silage was reflected in ewes being heavier ($+8.6$ kg) and in better condition ($+0.7$ units) at lambing and producing heavier lambs ($+0.7$ kg) at birth. An analysis of the relationship between the treatment (least squares) means for MP supply and lamb BW at birth and lamb mortality identified a significant ($P < 0.01$) positive linear increase of 0.08 (SE 0.014) kg in BW at birth, and a negative ($P = 0.08$) linear decrease of 0.013 (SE 0.0063) in lamb mortality, for each increase of 10 g/d in MP supply. The effect of MP supply on lamb mortality at birth is consistent with the direction of the effect of MP supply on BW at birth. The positive effect of MP supply on lamb BW at birth is contrary to previous studies in which ewes were offered diets based on grass (Annett et al., 2005) or grass silage (Dawson et al., 1999). This difference in response is probably because ME intake was restricted in the studies cited while in the current study the forages were offered *ad-libitum* thus ME intake was not deliberately restricted. Thus, MP supply and ME intake followed similar patterns. According to the recommendations of AFRC (1993), only the treatments based on GH and MH silages supplied sufficient ME to meet the needs of the ewes in late pregnancy, which is consistent with the changes in BCS. Ewes offered GM silage had the highest BCS loss and concentrations of blood BHB. Russel (1984) stated that plasma BHB values >0.8 mmol/l are indicative of energy deficiency.

Lamb performance at pasture

Achieving high levels of lamb performance from grazed pasture is one of the main factors affecting efficiency of prime-lamb production from grass-based systems (Keady and Hanrahan, 2006). The grazing management used was targeted to achieve the post-grazing sward heights of Keady (2010), which increased as the season progressed to prevent lambs having to graze the lower horizons of the sward canopy, which have lower digestibility. Lamb BW gain from birth to weaning (286 g/day) was within the range of previously published values (Keady et al., 2007a; Keady and Hanrahan, 2009a, 2009b) and is similar to the performance reported by Keady et al. (2018) for data from 12 consecutive years of a rotational-grazing system of prime-lamb production. In the current study, the plane of nutrition offered to ewes during mid and late pregnancy altered lamb BW gain from birth to weaning by up to 9%, which illustrates that with good grassland-management practices all lambs can be finished in grass-based systems prior to the end of the grazing season in the absence of concentrate feeding.

Conclusion

Increasing FV of the grass silage offered to ewes during mid and late pregnancy and offering soybean meal with maize silage had the greatest effects on the performance of ewes, based on responses in lamb BW at birth and age at slaughter. Increasing maize DM concentration (maturity) at harvest increased food intake and lamb BW at birth; maize silage can effectively replace grass silage in the diet of pregnant ewes. There was a positive relationship between MP supply and lamb BW at birth with a negative effect on the incidence of dead-born lambs. While the range of nutritional regimes examined impacted on ewe BW and BCS at lambing and on age of lambs at slaughter, the maternal diet was not an important determinant of the postnatal growth of their progeny.

Ethics approval

All animal procedures used in this study were conducted under experimental licence from the Irish Department of Health and Children (Dublin) in accordance with the Cruelty to Animals Act 1876 and the

European Communities (Amendment of Cruelty to Animals Act 1876) Regulations 2002 and 2005.

Data and model availability statement

None of the data were deposited in an official repository.

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Author contribution

Both authors were involved in the conceptualisation and design of the work; funding acquisition; analysis and interpretation of the data; project administration and supervision; and drafting and critically revising the manuscript.

Declaration of interest

None.

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