J. Dairy Sci. 87:3398–3406

Reducing Concentrate Supplementation in Dairy Cow Diets While Maintaining Milk Production with Pea-Wheat Intercrops*

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ABSTRACT

In the first of 2 experiments, 40 dairy cows were used to evaluate the milk production potential and concentrate-sparing effect of feeding dairy cows a basal diet of pea-wheat intercrop silages instead of perennial ryegrass silage (GS). Dairy cows were offered GS or 2 intercrop silages prepared from wheat and either Magnus peas (MW, a tall-straw variety) or Setchey peas (SW, a short-straw variety) ad libitum. The respective intercrops were supplemented with 4 kg/d of a dairy concentrate (CP = 240 g/kg dry matter; MW4 and SW4), and the GS were supplemented with 4 (GS4) or 8 (GS8) kg/d of the same concentrate. The second experiment measured the forage DM intake, digestibility, rumen function, and microbial protein synthesis from the forages by offering them alone to 3, nonlactating cows (3 × 3 Latin square design with 21-d periods). Forage dry matter intake was greater in cows fed the intercrop silages than those fed GS. Milk production was greater in cows fed SW4 than those fed GS4 or MW4, but similar to cows fed GS8. Dietary treatment did not affect milk fat, protein, or lactose concentrations. The intercrops had greater N retention, and were more digestible than the GS, and these factors probably contributed to the greater forage DM intakes and greater milk production from the intercrop silages compared with the GS. Rumen volatile fatty acid concentrations were similar across forages, but urinary purine derivative excretion was greater in the cows fed the intercrop silages than the GS, suggesting that rumen microbial protein synthesis was enhanced by feeding the intercrops. In conclusion, similar milk yield and milk composition can be obtained by feeding SW and 4 kg of concentrates as that obtained with GS and 8 kg of concentrates. Feeding intercrop silages instead of GS with the same amount of concentrates increased forage intakes, N retention, and microbial protein synthesis.
(**Key words:** bi-crop, cereal-legume, rumen function, pea-wheat)

Abbreviation key: GS = grass silage, **GS4** = GS + 4 kg/d concentrates, **GS8** = GS + 8 kg/d concentrates, **MW** = magnus pea/wheat intercrop silage, **MW4** = MW + 4 kg/d concentrates, **SW** = Setchey pea/wheat intercrop silage, **SW4** = SW + 4 kg/d concentrates, **WSC** = water-soluble carbohydrates.

INTRODUCTION

Global demand-led fluctuations in the price of soya and the European bans on feeding fish or animal protein meals to livestock have generated interest in feeding homegrown, protein- and/or energy-rich forages in the United Kingdom. Whereas several studies have evaluated the potential of legumes to provide dietary protein for ruminants, few have focused on the benefits of including cereal-legume intercrops in livestock rations. When legumes are fed as the sole forage, their protein is often poorly used (Broderick, 2003) because of high rates of degradation and lack of simultaneously supplied, readily fermentable carbohydrate in the rumen. Furthermore, legumes are often difficult to ensile because of their low sugar content and high buffering capacity (Lattemae et al., 1996), and their production can increase environmental N pollution (Evans et al., 1996; Ledgard, 2001). Compared with legumes, cereal-legume intercrops improve the efficiency of N utilization by combining the N-scavenging ability of the cereal with the biological N-fixation capacity of the legume. Pea-wheat intercrops produce high yields, higher feed intakes, and higher N retention than grass silage (Adesogan et al., 2002; Salawu et al., 2002a, 2002b). How-

Received March 18, 2004.
Accepted April 20, 2004.
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*This research was supported by the Florida Agricultural Experiment Station, and approved for publication as Journal Series No. R-10392.
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ever there is little published information on milk production in cows fed cereal-legume intercrops. Previously, we showed that, compared with grass silage-based rations, an intercrop comprising a long-straw pea variety (Magnus) and wheat had a slight concentrate-sparing effect and gave marginal improvements in milk production (Salawu et al., 2002b). Recently, we also found that the digestibility and N retention in sheep of intercrops containing the long-straw Magnus peas were lower than those containing a short-straw (Setchey) pea variety. We therefore postulated that feeding intercrops containing Setchey peas instead of Magnus peas would give a greater milk response than that from the Magnus pea intercrop or that from cows fed grass silage. The objective of this study was to examine the validity of this theory by determining the effects on milk production, digestibility, rumen function, and microbial protein production in dairy cows, of feeding grass silage or intercrop silages containing wheat and either Setchey or Magnus peas. A second objective was to determine the concentrate-sparing effect of feeding the intercrop silages instead of grass silage.

MATERIALS AND METHODS

Crop Details

Spring wheat (*Triticum aestivum* var. Axona) was grown with one of 2 contrasting spring pea (*Pisum sativum*) varieties near Aberystwyth, Wales, UK (52°N, 4°W) on a fertilized (50 kg/ha phosphate + potash; 0:24:24), 10-ha field. The site had an average annual rainfall of 117 cm and gleyed silty-clay loam soil. Two pea varieties were evaluated: Magnus, a tall-straw, pink-flowered variety, and Setchey, a short-straw, purple-flowered variety, which is sold as a tannin-containing variety for the game bird market. The forages were sown in May 1999 at respective seed rates of 188 and 62.4 kg/ha for Magnus and wheat (**MW**) or 117 and 62.4 kg/ha for Setchey and wheat (**SW**), with the goal of achieving a target pea to wheat ratio of 4:1. The intercrops were harvested with a disc mower fitted with a conditioner 14 wk after sowing. At this stage, the mean DM concentration of the intercrops was 313 g/kg, and both pea forages were at the yellow, wrinkled-pod stage, whereas the wheat was at the soft-dough stage. The intercrops were wilted overnight, precision-chopped with a forage harvester, and ensiled without additive application in 40-tonne bunker silos with concrete walls. The grass silage (**GS**) was made from a first cut, perennial ryegrass sward (*Lolium perenne* L.), which was also harvested and precision-chopped with a forage harvester and conserved without wilting or additive application in a 40-tonne bunker silo.

Animal Measurements

Experiment 1: Effect of forage type and concentrate level on milk production. The forages were fed as the basal ration to 40 multiparous, Holstein-Friesian cows (mean BW = 617 kg, SD = 63.3) that were between wk 10 to 12 of lactation in a continuous, 7-wk long experiment with a completely randomized design. The treatments evaluated included MW or SW intercrop silages fed ad libitum and supplemented with 4 kg/d of a dairy concentrate (**MW4** or **SW4**), and grass silage ad libitum, supplemented with either 4 (**GS4**) or 8 (**GS8**) kg/d of the same concentrate. The GS8 treatment was included to test the concentrate-sparing effect of feeding the intercrops instead of grass silage. Before the introduction of forage treatments, the cows were fed a grass silage diet supplemented with 8 kg/d of a dairy concentrate (CP = 240 g/kg DM), and covariance recordings of milk yield and composition and feed intake were taken for 2 consecutive weeks. The cows were housed in a free-stall barn and bedded on wood shavings, and they had ad libitum access to clean drinking water. Individual feed intake was measured daily with Roughage Intake Control feeders (Insentec B.V., Marknesse, The Netherlands). Each treatment group of 10 cows had access to 7 feeders.

Cows were milked twice daily at approximately 0600 to 0700 h and 1600 to 1700 h, and milk composition was recorded from 4 consecutive milkings each week. Cows received 2 kg/d of concentrates at milking and the remaining concentrate allocation through out-of-parlor feeders (Insentec B.V.) that were set to ensure cows received no more than half of their concentrate allowance within a 7.5-h period.

Sample collection. Silage samples were taken 3 times each week and composited into a weekly sample, which was immediately frozen (−20°C) and freeze-dried before chemical analysis. Concentrate samples were taken every week and composited into a single sample for analysis. Milk samples were collected twice daily (a.m. and p.m.) and analyzed for fat, protein, and lactose content (AOAC, 2000) by an infrared milk analyzer (Milkoscan 605, Foss Electric, Hillerød, Denmark). Additional milk samples were collected and frozen (−20°C) without preservative, prior to freeze-drying, and analysis of fatty acids by GC as fatty acid methyl esters, which were prepared using a one-step extraction and methylation procedure (Sukhija and Palmquist, 1988). The GC protocol and the column, injector, and detector used were described by Dewhurst et al. (2003).

Experiment 2. Effect of forage type on rumen function, microbial yield, and digestibility. The effect of the forages on rumen function, purine derivative excretion, and apparent digestibilities of DM, OM, N, and NDF were measured using 3 ruminally fistulated, multiparous, nonlactating, Holstein-Friesian cows in an experiment with a 3 × 3 change over design and 21-d periods. Cows were held in individual tie stalls during this experiment, and the first 14 d of each period were used for dietary adaptation and the last 7 d for measurements. The silages were fed alone ad libitum in 2 equal portions at 0900 and 1600 h. Forage refusals were collected and weighed every day before the morning feed. Urine and fecal output were measured daily during the measurement period, and samples of feces and forages were taken and subsequently composited for analysis. The total urine output was collected (with 2.8 L of 2 *M* sulfuric acid) and a subsample (25 mL) was taken and stored (–20°C) until it was analyzed for nitrogen concentration. A further subsample of urine was diluted 5-fold with distilled water prior to freezing at –20°C and subsequently analyzed for purine derivatives. Rumen contents were sampled for VFA and ammonia every 2 h for 2 d in the last week of each period. Samples were automatically withdrawn using a weighted sampling probe with a mesh filter submerged in the rumen and acidified over a 24-h period. Additional samples were also taken manually for pH determination at 2, 5, 8, and 12 h after fresh forage was offered. Blood samples were taken from the jugular vein into evacuated tubes containing lithium heparin (Vacutainer, Becton Dickinson Inc., NJ) on 2 occasions in the last week of each period: 2 h after the a.m. milking and 2 h before the p.m. milking. Blood was held on ice and spun at 1700 × *g* for 25 min at 4°C to separate plasma, which was decanted and stored at –20°C until analysis.

Chemical analysis. Oven DM and total ash content of the feeds were determined according to AOAC (1990). Crude protein (N × 6.25) in the silages and concentrates was determined using a Leco FP 428 N analyzer. Starch (Solomonson et al., 1984), water-soluble carbohydrate (**WSC**) (Ministry of Agriculture Fisheries and Food, 1986), NDF, and ADF (Van Soest et al., 1991) concentrations were determined on freeze-dried silage samples milled to pass through a 1-mm screen. Silage VFA, ammonia, and lactic acid concentrations were determined using the methods described by Dewhurst et al. (2000). Free and bound proanthocyanidin concentrations were determined using the butanol-HCl method (Jackson et al., 1996). Rumen VFA and ammonia were respectively determined by GC and by a test kit (No. 66-50; Sigma-Aldrich Co. Ltd., Poole, United Kingdom) on a Labsystems discrete analyzer (Dewhurst et al., 2000). Freeze-dried fecal and forage samples were analyzed for ash, starch, NDF, and ADF using the analytical methods described above. The N concentration of feces and urine was also determined using the Leco analyzer. Urinary purine derivatives (allantoin and uric acid) were determined using the HPLC method described by Dewhurst et al. (1996). Rumen microbial protein synthesis was estimated using the equations and assumptions described by Chen and Gomez (1992). All feed analysis results and feed intakes are quoted on an oven-DM basis.

Statistical Analysis

The mean data from the last 5 wk of experiment 1 were analyzed using the one-way ANOVA directive within the Genstat statistical package (Genstat, 1997). For experiment 2, statistical analysis was conducted using results from the final week of each experimental period. The data were analyzed using the residual maximum likelihood directive within the Genstat statistical package. Dietary treatments were used as the "fixed" model, with "period" and "cow" as the "random" model. For both experiments, covariate measurements were included in the model as appropriate (DMI, milk yield, and milk composition). For both experiments, significance was declared at the 5% probability level, and tendencies at the 10% level. Where treatments were different, the Tukey procedure was used to separate least square means.

RESULTS

Feed Composition

Tables 1 and 2 show the composition of the concentrate fed in experiment 1 and the forages, respectively. The MW and SW intercrops contained 800 and 500 g/kg DM of peas, respectively. The GS had a lower DM content than the intercrop silages, and this led to a more extensive, homolactic fermentation, with greater levels of lactic acid and a lower pH. The intercrop silages, particularly MW, had moderate levels of lactic acid and appreciable levels of acetic, propionic, and butyric acids. The CP concentrations of the silages were similar and relatively high. The ammonia-N concentrations of the silages were also similar, and the total proanthocyanidin content of the intercrop silages was similar and low. Starch concentration was greater in the intercrops, particularly in SW than in GS.

Feed Intake, Milk Yield, and Composition (Experiment 1)

The feed intake and milk production from cows in experiment 1 are shown in Table 3. Irrespective of the level of concentrate offered, forage DMI was higher ($P < 0.001$) in cows fed intercrops than those fed grass silage. Cows fed SW4 had the highest ($P < 0.001$) forage DMI and total DMI, whereas cows fed GS4 had the

Table 1. Ingredient composition (%, as mixed) and nutrient composition (% of DM, unless stated otherwise) of the concentrate.

Composition	Concentration
Ingredient	
Wheat	30.0
Palm kernel expeller	15.0
Corn gluten feed	14.0
Extracted rapeseed meal	11.0
Extracted sunflower meal	9.0
Molasses	5.0
Expeller linseed meal	5.0
Peanut meal	5.0
Solvent-extracted soybean meal	2.0
Vegetable oil	1.5
Nutrient	
Mineral and vitamins[1]	2.5
Oven DM, % (as-fed)	85.05
ME (MJ/kg DM)[2]	12.9
OM	91.96
Acid hydrolysis ether extract	4.85
CP	23.4
NDF	25.06
ADF	12.55
Starch	34.01
Water-soluble carbohydrates	8.69

[1]Premix supplied (on a concentrate DM basis) (per kg): 11,600 IU of vitamin A, 2300 IU of vitamin D_3, 29 IU of vitamin E, 35 mg of Cu, 140 mg of Mn, 0.46 mg of Se, and 14 mg of Zn.

[2]Predicted from equation E3 of Thomas et al. (1988).

lowest ($P < 0.05$) total DMI. Crude protein intake was similar ($P > 0.05$) in cows fed GS8 and SW4, and these values were greater ($P < 0.05$) than those in cows fed GS4. Crude protein intake was also similar ($P > 0.05$) in cows fed SW4 and MW4. Starch intake was greater ($P < 0.05$) in cows fed intercrop-based diets than cows fed grass silage-based diets, and it was also greater ($P < 0.05$) in cows fed SW4 and GS8 than those fed MW4 and GS4, respectively. Neutral detergent fiber intake was greatest ($P < 0.05$) in cows fed SW4, and the values in cows fed MW4 and GS8 were similar ($P > 0.05$) and greater ($P < 0.05$) than in those fed GS4. Milk yields and fat-corrected milk yield from cows fed GS8 and SW4 were similar and higher ($P < 0.001$) than those from cows fed GS4 or MW4. Milk composition was not affected by dietary treatment. However, milk fat, protein, and lactose yields were higher ($P < 0.08$) in cows fed GS8 and SW4, compared with levels in cows fed GS4 or MW4.

Table 2. Chemical composition (% of DM) of the pea-wheat intercrops and grass silage.

	Intercrop silages		
	Magnus-wheat	Setchey-wheat	Grass silage
pH	4.36	4.06	3.75
DM	32.2	28.9	24.4
Ash	7.99	6.81	8.13
CP	17.7	16.6	18.6
NH_3-N	0.48	0.41	0.38
WSC[1]	0.99	1.06	1.94
Starch	16.2	20.0	0.73
ADF	33.9	30.2	31.1
NDF	52.0	52.0	53.4
Lactic acid	4.88	6.76	11.2
Acetic acid	2.05	1.71	1.46
Propionic acid	0.094	0.051	0.034
Butyric acid	0.23	0.022	0.031
Free proanthocyanidins[2]	0.28	0.41	NM[3]
Bound proanthocyanidins[2]	0.54	0.45	NM[3]
Total proanthocyanidins[2]	0.82	0.86	NM[3]

[1]WSC = Water-soluble carbohydrates.

[2]Expressed as % quebracho tannin equivalent.

[3]NM = Not measured.

There were few treatment effects on milk fatty acid profile (Table 4). The most consistent effects were the greater proportions of odd-chain fatty acids, particularly ($P < 0.05$) $C_{15:0}$, $C_{17:0}$, *anteiso*$C_{15:0}$, and *anteiso*$C_{17:0}$ in the milk of cows offered the intercrop silages. There were no effects of treatment on levels of polyunsaturated fatty acids in milk.

DMI, Digestibility, Microbial Yield and N Balance, and Rumen Function (Experiment 2)

Table 5 shows the DMI and digestibility results from experiment 2. Cows fed the intercrop silages had greater ($P < 0.05$) DMI, and greater ($P < 0.05$) DM, CP, and starch digestibility than those fed the GS. Acid detergent fiber digestibility was similar across all treatments, but SW had a lower NDF digestibility than MW. Nitrogen intake was greater ($P < 0.05$) in cows fed intercrops than those fed GS, but fecal N output was less ($P < 0.05$) in cows fed MW than those fed GS and SW (Table 6). Cows fed the intercrop silages had greater ($P < 0.05$) N balance and N retention than those fed GS. Cows fed SW had greater ($P < 0.05$) urinary allantoin and total purine derivatives, and therefore produced more ($P < 0.05$) microbial N than cows fed GS. Cows fed SW also had numerically greater ($P > 0.05$) efficiency of microbial N production (g microbial N/kg digestible OM intake), than cows fed other diets.

Mean rumen pH, ammonia, and VFA concentrations are presented in Table 7. Rumen pH was marginally lower ($P < 0.05$) in cows fed SW than in those fed MW or GS, whereas rumen ammonia concentration was unaffected by forage type. Total VFA concentration was lower ($P < 0.05$) in cows fed MW than those fed SW and GS. Cows fed the intercrops had a greater ($P < 0.05$) molar percentage of acetate and a lower molar percentage of propionate than those fed GS. The molar percentage of propionate in cows fed SW was also greater than that in cows fed MW, and the molar percentage of butyrate was greater in cows fed MW than those fed the

Table 3. Feed intake, milk yield, and milk composition of dairy cows fed pea/wheat intercrop silages differing in pea variety or grass silage with 2 levels of concentrate

	Treatment[1]				
	GS8	GS4	MW4	SW4	SED[2]
Forage DMI (kg/d)	10.7[a]	11.8[a]	14.0[b]	15.8[c]	0.50
Total DMI (kg/d)	17.5[a]	15.4[b]	17.2[a]	19.3[c]	0.71
Starch intake (kg/d)	2.39[c]	1.47[d]	3.38[b]	4.33[a]	0.20
CP intake (kg/d)	3.58[a]	3.01[c]	3.23[bc]	3.43[ab]	0.13
NDF intake (kg/d)	7.40[bc]	7.20[c]	8.01[b]	9.10[a]	0.38
Milk yield (kg/d)	24.5[a]	20.1[b]	20.8[b]	24.0[a]	0.81
4% FCM (kg/d)	24.1[ac]	20.4[b]	22.3[ab]	26.5[c]	1.44
Milk composition (g/kg)					
Milk fat	40.2	41.5	42.3	43.5	1.64
Milk protein	32.4	31.1	31.5	31.7	0.43
Milk lactose	47.1	46.1	46.7	46.9	0.38
Milk component yields (g/d)					
Milk fat	985[a]	829[b]	873[b]	1037[a]	49.7
Milk protein	792[a]	620[b]	651[b]	758[a]	26.3
Milk lactose	1151[a]	933[b]	977[b]	1133[a]	41.0

[a,b,c]Within a row, means without a common superscript letter differ ($P < 0.05$).

[1]GS8 = Grass silage with 8 kg/d concentrates; GS4 = Grass silage with 4 kg/d concentrates; MW4 = Magnus pea/wheat intercrop silage and 4 kg/d concentrates; SW4 = Setchey pea/wheat intercrop silage and 4 kg/d concentrates.

[2]SED = Standard error of difference between means.

other silages. The molar percentages of other VFA were unaffected by forage type.

DISCUSSION

Forage Composition

The DM yields and associated agronomic details of the intercrops were discussed by Salawu et al. (2001). The concentrations of protein and fiber were remarkably similar across forages and, therefore, do not explain the differences observed in the measures of animal performance. The main differences between the GS and the intercrop silages were that the intercrop silages had greater levels of starch, propionate, acetate, and tannins, and less lactate than GS. The higher pH, ammonia-N, butyric acid, and lower lactic acid concentration of MW suggests that the fermentation in this forage was less desirable than that in SW or GS. The chemical composition of the GS was typical of well-preserved, moderate-quality, first-cut, perennial ryegrass silage (McDonald et al., 1995). Although only the Setchey peas is marketed as a tannin-containing variety, both pea varieties contained proanthocyanidins. The higher content of peas in the MW intercrop contributed to the similarity in the level of proanthocyanidins in the 2 intercrop forages.

Feed Intake

The lower intake of the grass silage compared with the intercrops may be partly due to the low pH and high lactic acid concentrations of the grass silage. However, low pH and high lactic acid are usually associated with low DM grass silages, whereas the DM concentration of the grass silage in this study was not low (McDonald et al., 1995). The superior intake of the cows fed the intercrops probably also reflects their inherent intake-enhancing characteristics, such as their high starch content, rumen degradation rate (Adesogan et al., 2001), high CP, and legume content (Dewhurst et al., 2003). Previous work has also demonstrated superior intakes in cows and sheep fed cereal-legume intercrops, compared with those fed the component crops alone (Anil et al., 2000; Haj-Ayed et al., 2000) or grass silage. This work, therefore, corroborates previous findings and, for the first time, shows that intercrops are more readily consumed than first-cut grass silage.

Milk Yield

Although published reports on the agronomic yield potential of cereal-legume intercrops abound (De Rezende and Ramalho, 2000), only a few have presented their nutritive values, and fewer still have presented animal-based estimates of their quality and potential for enhancing milk production in dairy cows. In one of the few studies in the latter area, Salawu et al. (2002b) showed that pea-wheat intercrops elicited better intakes and milk production in dairy cows than moderate-quality, second-cut, grass silage, and concluded that such intercrops are better forages for low-input systems than moderate-quality, second-cut grass silage. How-

Table 4. Fatty acid composition (% of total fatty acids) of milk from dairy cows fed pea/wheat intercrop silages differing in pea variety or grass silage with 2 levels of concentrate.

	Treatment[1]				
	GS8	GS4	MW4	SW4	SED[2]
$C_{6:0}$	2.98	2.98	2.99	2.90	0.090
$C_{8:0}$	1.70	1.60	1.63	1.63	0.061
$C_{10:0}$	3.71	3.26	3.50	3.51	0.194
$C_{12:0}$	4.45[a]	3.82[b]	4.09[ab]	4.16[ab]	0.222
$C_{14:0}$	13.4[a]	12.4[b]	13.4[a]	13.1[ab]	0.377
$C_{14:1}$	1.28[a]	1.12[b]	1.00[c]	1.17[ab]	0.053
$C_{15:0}$	1.16[a]	1.16[a]	1.35[b]	1.33[b]	0.07
iso $C_{15:0}$	0.21	0.23	0.24	0.25	0.013
anteiso $C_{15:0}$	0.41[a]	0.41[a]	0.47[b]	0.48[b]	0.025
$C_{16:0}$	38.7	38.4	37.1	37.7	1.56
$C_{16:1}$	1.44	1.46	1.27	1.27	0.102
$C_{17:0}$	0.53[a]	0.55[ab]	0.57[ab]	0.60[b]	0.023
iso $C_{17:0}$	0.28	0.31	0.31	0.32	0.016
anteiso $C_{17:0}$	0.42[ab]	0.39[a]	0.48[b]	0.45[bc]	0.024
$C_{18:0}$	9.73	11.1	11.1	10.3	0.64
$C_{18:1}$	16.2	17.5	17.0	17.0	1.09
trans vaccenic acid	0.79	0.85	0.98	0.95	0.083
cis vaccenic acid	0.32	0.36	0.36	0.39	0.025
cis-9,trans-11, $c_{18:2}$ (CLA)	0.29	0.29	0.31	0.33	0.045
$C_{18:2}$	1.19	1.18	1.13	1.29	0.145
$C_{18:3}$	0.36	0.37	0.36	0.38	0.039
$C_{20:0}$	0.41	0.41	0.43	0.54	0.116

[a,b,c]Within a row, means without a common superscript letter differ ($P < 0.05$).

[1]GS8 = Grass silage with 8 kg/d concentrates; GS4 = Grass silage with 4 kg/d concentrates; MW4 = Magnus pea/wheat intercrop silage and 4 kg/d concentrates; SW4 = Setchey pea/wheat intercrop silage and 4 kg/d concentrates.

[2]SED = Standard error of difference between means.

ever, they noted that the intercrop silage had only a marginal concentrate-sparing effect, and hence a limited role in high-input systems. They hypothesized that the concentrate sparing-effect and milk production from cows fed intercrops could be enhanced if the intercrops contained short-straw pea varieties instead of the long-straw variety they used. This study validates the hypothesis of Salawu et al. (2002b) and suggests that certain intercrop silages can be beneficial in high-input dairy production systems. Cows fed SW produced at least 3 kg more milk than those fed MW or grass silage with the same level of supplementary concentrates. The improvement in milk yield from SW is partly attributable to greater intakes of CP (relative to GS4), starch, and NDF and intake in cows fed SW, which probably increased the availability of substrates for production of microbial protein and milk. The greater starch intake is due to the greater DMI and higher starch content (Broderick, 2003) of SW, and these resulted from the shorter-straw length of the Setchey

Table 5. Digestibility coefficients for pea/wheat intercrop silages and grass silage consumed by dry dairy cows.

	Intercrop silages			
	Magnus-wheat	Setchey-wheat	Grass silage	SED[1]
DM intake (kg/d)	11.1[a]	12.0[a]	7.42[b]	0.47
Digestibility coefficients (g/g)				
DM	0.724[a]	0.669[a]	0.591[b]	0.024
OM	0.743[a]	0.690[a]	0.615[b]	0.022
Crude protein	0.783[a]	0.721[a]	0.590[b]	0.023
Starch	0.941[a]	0.918[a]	0.609[b]	0.015
ADF	0.599[a]	0.532[a]	0.593[a]	0.032
NDF	0.653[a]	0.564[b]	0.591[ab]	0.030

[a,b,c]Within a row, means without a common superscript letter differ ($P < 0.05$).

[1]SED = Standard error of difference between means.

Table 6. Nitrogen balance and microbial protein yield estimates (based on urinary excretion of purine derivatives) for dry dairy cows offered pea-wheat intercrop silages or grass silage.

	Intercrop silages			
	Magnus-wheat	Setchey-wheat	Grass silage	SED[4]
Nitrogen intake (kg/d)	0.34[a]	0.32[a]	0.22[b]	0.02
Fecal N (kg/d)	0.072[a]	0.090[b]	0.087[b]	0.004
Urinary N (kg/d)	0.115	0.116	0.122	0.009
N-balance (kg/d)	0.152[a]	0.121[a]	0.018[b]	0.013
N retention (%)	42.1[a]	36.9[a]	7.60[b]	2.93
Urinary uric acid (mmol/d)	18.15	22.19	16.14	1.16
Urinary allantoin (mmol/d)	187.2[ab]	244.4[a]	133.5[b]	17.51
Urinary total PD[1] (mmol/d)	205.4[ab]	266.6[a]	149.6[b]	17.07
Microbial N[2] (g/d)	134.5[ab]	186.8[a]	86.78[b]	14.59
g microbial N/kg DOMI[3] (g/kg)	16.60	23.50	19.76	2.18

[a,b,c]Within a row, means without a common superscript letter differ ($P < 0.05$).

[1]PD = Purine derivatives.

[2]Calculated on the basis of the equation of Chen and Gomez (1992).

[3]DOMI = Digestible organic matter intake.

[4]SED = Standard error of difference between means.

peas, and a better ratio of peas to wheat (1:1) in SW than that in MW (4:1). Although both of the pea-wheat intercrop silages contained proanthocyanidins, the levels were lower than that (20 to 40 g/kg DM), which confers nutritional benefits due to improved efficiency of protein utilization (Mangan, 1988).

Milk Composition

Salawu et al. (2002b) found that, although milk production was increased by feeding intercrop silages instead of grass silage, milk constituent levels were decreased. In contrast, there were no effects of dietary treatment on milk constituent concentrations in this study. This difference is partly attributable to the higher starch concentration and greater DM digestibility of the intercrop silages in this study. This difference therefore confirms that forages containing high proportions of legumes can be used to enhance milk production without depressing milk fat (Hoffman et al., 1998) or milk protein contents (Mustafa et al., 2000). In fact, milk fat, protein, and lactose yields were higher in cows fed SW4 than those fed GS4, and these responses are attributable to the respectively greater NDF, CP, and starch intakes in cows fed SW4.

Odd-chain fatty acids in milk generally result from de novo synthesis in the rumen, and so levels might reflect overall rumen activity. The higher levels of odd-chain fatty acids in milk from cows fed intercrop silages probably reflect increased rumen microbial synthesis. This is indirectly supported by the higher microbial protein synthesis that was found in cows fed SW in

Table 7. Mean rumen pH, volatile fatty acids, and ammonia N concentrations in dry dairy cows fed pea-wheat intercrop silages or grass silage.

	Intercrop silages			
	Magnus-wheat	Setchey-wheat	Grass silage	SED[1]
pH	6.66[b]	6.59[b]	6.69[a]	0.024
Ammonia-N (mg/L)	198	201	173	17.5
Total volatile fatty acids (mmol/L)	67.4[a]	76.4[b]	79.5[b]	3.91
Molar percentages of volatile fatty acids				
Acetic acid	70.8[a]	70.0[a]	65.9[b]	0.35
Propionic acid	13.9[a]	15.8[b]	20.5[c]	0.28
n-Butyric acid	10.1[a]	9.4[b]	9.1[b]	0.21
iso-Butyric acid	1.57	1.26	1.15	0.129
n-Valeric acid	1.27	1.34	1.41	0.105
Iso-Valeric acid	2.31	2.22	1.96	0.111

[a,b,c]Within a row, means without a common superscript letter differ ($P < 0.05$).

[1]SED = Standard error of difference between means.

experiment 2, compared with those fed the other silages.

Digestibility and Nitrogen Balance

The results of the digestibility trial in experiment 2 agree with the higher intake of intercrop silages than grass silage observed in experiment 1 and in previous studies (Adesogan et al., 2002; Salawu et al., 2002a). However, for the first time, this study revealed that pea-wheat intercrop silages can have high in vivo digestibility values. The values found exceeded those reported previously, indicating the variability in quality that is possible in such intercrops. The digestibilities of DM and OM were higher in the intercrops than in the grass silage because the peas in the intercrops are more rapidly and extensively degraded in the rumen than grass silage (Adesogan et al., 2001; Salawu et al., 2002a). The higher proportion of peas in the MW compared with SW is likely to have contributed to the higher NDF digestibility of MW due to the higher inherent digestibility of peas (Mustafa et al., 2000). Nevertheless, the digestibilities of DM, OM, starch, and protein were similar in both intercrop silages.

The higher N balance and N retention in cows fed the intercrop silages, compared with grass silage, is due to a combination of the higher N intake, higher protein digestibility, and lower or similar fecal and urinal N losses. Adesogan et al. (2002) also found that N balance and N retention were greater in sheep fed intercrop silages instead of grass silage. However, unlike the findings in this study, they also noted that urinary N concentrations were greater when the intercrops were fed instead of grass silage. This difference is probably attributable to a better balance in N and energy supply to the rumen from the intercrops in this study, compared with that for the intercrops in the previous study. High losses of urinary N were also found when pea silage was fed to sheep without a balanced energy supply (Salawu et al., 2002a).

Rumen Function and Microbial Yield

Compared with values for cows fed MW, the lower rumen pH of cows fed SW matches their higher total VFA concentration and is probably a consequence of the higher starch content of the SW forage. However, the rumen pH of cows fed SW remained above 6.0 and, as such, there was little risk of subacute ruminal acidosis or loss of cellulolytic activity (Mould et al., 1983). The lower acetate:propionate ratios of cows fed grass silage instead of intercrop silages is partly due to the higher lactic acid concentration of the grass silage. The results of the calculated microbial yields and daily excretion of purine derivatives (uric acid and allantoin) confirmed our speculation that microbial yields are improved when intercrop silages are fed instead of grass silage (Adesogan et al., 2002). Although protein concentrations of the intercrops and grass silage were similar, the higher intercrop silage intake implied that, like starch intake, N intakes from the intercrops were greater than that from the grass silage. Since cows fed the intercrop silages had greater N balance and N retention than cows fed grass silage, more N and starch was available for microbial growth on the intercrop-based diets. Compared with that for cows fed grass silage, the higher microbial yields of cows fed the intercrops, particularly SW, is attributable to the greater, perhaps more balanced and synchronized ruminal supply of N and readily fermentable carbohydrate in cows fed the intercrop silages. Others have also shown that increasing dietary energy supply improves microbial efficiency and milk yield when dietary protein is not limiting (Broderick, 2003). However, where CP is limiting for microbial growth (Tolera and Sundstol, 2000) or not matched by an adequate supply of metabolizable energy (Gabler and Heinrichs, 2003), urinary excretion of purine derivatives increased with increasing CP supply.

CONCLUSIONS

This study showed that feeding an SW intercrop silage as the basal part of the ration instead of first-cut, perennial ryegrass silage, halved the concentrate requirement for dairy cows without adversely affecting milk yield or quality. Therefore, pea-wheat intercrops may be a viable cost-saving option for dairy farmers. The study also demonstrated the importance of using a short-straw pea variety in the intercrop, instead of a long-straw variety, for improving ruminal microbial yields and milk production.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the funding of this project by the United Kingdom Milk Development Council and the assistance of the farm and technical staff of the Institute of Rural Sciences, University of Wales Aberystwyth, the Institute of Grassland and Environmental Research, Aberystwyth, for their assistance with various aspects of the study.

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