The substitution of lucerne hay with ammoniated wheat straw in diets for lactating dairy cows

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The effect of substituting lucerne hay (LH) with ammoniated wheat straw (AWS) in diets for lactating Holstein Friesland cows was investigated in two trials. In Trial 1 four roughage diets containing LH and AWS in the following ratio's of 100:0; 67:33; 33:67 and 0:100, were offered *ad libitum* to eight Holstein Friesland cows according to a 4 × 4 Latin square change-over design. A concentrate mixture supplying 162 g crude protein (CP) and 11.5 MJ ME/kg dry matter (DM) was provided to all cows at 1% of starting body mass per day. In Trial 2 two complete diets containing LH or AWS as roughage sources were mixed to contain similar concentrations of energy, CP and neutral detergent fibre (NDF). The AWS diet was then combined with the LH diet in the following ratio's: 0:100, 25:75, 50:50, 75:25 and 100:0. Diets were fed *ad libitum* to 10 Holstein Friesland cows according to a 5 × 5 Latin square change-over design. In Trial 1 dry matter intake (DMI) declined linearly ($p < 0.01$) at a rate of 2.04 kg/d at increasing levels of AWS in the diet. Milk yield (MY) and 4% fat corrected milk yield (FCM) were similarly affected, i.e. 1.0 and 0.97 kg/d ($p < 0.01$) respectively. The fat and lactose contents of the milk of cows were unaffected although protein content declined linearly ($p < 0.01$). The reduction in DMI and MY are probably caused by the bulkiness of the diets as reflected by increasing NDF levels of the diets and/or palatability of AWS in comparison to LH. Increasing AWS levels in Trial 2, where NDF content of the experimental diets varied less, also resulted in a linear decrease ($p < 0.05$) in DMI of 0.43 kg/d. Daily MY was similarly affected, decreasing ($p < 0.01$) by 0.80 kg/d. The response of milk fat content (MF%) to increased levels of AWS was curvilinear ($p < 0.01$). The highest predicted MF% of 3.63 was obtained for the 50:50 AWS and LH diet combination. As a result, FCM was unaffected by inclusion level of AWS up to 50% of the diet. At higher AWS levels (75 and 100%) FCM was reduced ($p < 0.01$). It was more economical to use AWS at R215/t than LH at prices exceeding R375/t. At these prices LH may be completely substituted with AWS in post-peak lactation diets of dairy cows.

Twee proewe is uitgevoer om die effek van die vervanging van lusernhooi (LH) met geammonifiseerde koringstrooi (AKS) in diëte vir lakterende Holstein Friesland-koeie, te bepaal. In Proef 1 is vier ruvoerdiëte bestaande uit LH en AKS in die volgende verhoudings 100:0; 67:33; 33:67 en 0:100, *ad libitum* aan 8 Holstein-Friesland koeie volgens 'n 4 × 4 Latynse vierkant-omskakelproefontwerp, gevoer. 'n Suiwelkonsentraat met 162 g RP en 11.5 MJ ME/kg DM, is daagliks teen 1% van aanvangsliggaamsmassa aan al die koeie in die proef voorsien. In Proef 2 is twee diëte met dieselfde energie, RP en neutraal bestande vesel (NDF)-peile met LH of AKS as ruvoerbronne gemeng. Die AKS-dieet het die LH-dieet in die volgende verhoudings: 0:100, 25:75, 50:50, 75:25 en 100:00 verplaas. Diëte is daagliks *ad libitum* aan 10 koeie volgens 'n 5 x 5 Latynse vierkant-omskakelproefontwerp gevoer. In Proef 1 het droëmateriaalinname (DMI) lineêr teen 2.04 kg/d ($p < 0.01$) met hoër AKS-peile in die dieet afgeneem. Melkproduksie (MP) en 4% vetgekorrigeerde melkproduksie (VGM) het ooreenstemmend met 1.0 en 0.97 kg/d ($p < 0.01$) onderskeidelik afgeneem. Vet en laktosepersentasies is nie beïnvloed nie, maar die proteïenpeil het lineêr ($p < 0.01$) afgeneem. Verskille in lywigheid en/of smaaklikheid van AKS teenoor LH is waarskynlik die oorsaak vir die afnames in DMI en MP. In Proef 2 waar kleiner verskille in veselinhoud tussen volledig gemengde diëte voorgekom het, het hoër insluitingspeile van die AKS-dieet die DMI van koeie lineêr met 0.43 kg/d ($p < 0.05$) laat afneem. Daaglikse melkproduksie het ooreenstemmend met 0.80 kg/d ($p < 0.01$) afgeneem. Die afname in die vetpersentasie van melk weens hoër AKS-peile was kurwilineêr ($p < 0.01$). Die hoogste voorspelde vetpersentasie van 3.63 is met die 50:50 dieetkombinasie verkry. Gevolglik is VGM-produksie tot en met die 50%-insluiting van die AKS-dieet nie benadeel nie. By hoër peile (75 en 100%) het VGM kwadraties afgeneem ($p < 0.01$). Dit was meer winsgewend om AKS teen R215/t te voer wanneer LH-pryse hoër as R375/t is. Met hierdie pryse kan LH ten volle deur AKS in na-piek-laktasie-diëte vervang word.

Keywords: Ammoniated wheat straw, lucerne hay, dry matter intake, milk yield, milk composition, dairy cows

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Introduction

Considerable interest has been shown in the use of cereal straw in the diets of dairy cows. The nutritional value of cereal straws is characteristically low (Theander & Aman, 1984) resulting in a low intake and digestibility. It is also deficient in crude protein and minerals. Although it has mainly been used as bedding, it has occasionally been fed to low-producing animals. Cereal straw is nevertheless an important potential source of feed energy for ruminants owing to its high cellulose content (Sundstøl, 1988). The cellulose is, however, chemically bound to indigestible lignin, making it largely unavailable to the rumen micro-organisms. Numerous methods have been developed to release this energy component of straw. These include physical (chopping, pelleting, etc.) and chemical treatments. Physical treatment is often combined with a chemical pre-treatment. With physical methods the particle size of the roughage is reduced, resulting in an increased intake. Chemical methods are aimed at altering the ligno-cellulosic structure of the material itself. Of the latter, direct ammoniation with anhydrous ammonia (Sundstøl & Coxworth, 1984) seems to be the most practical 'on the farm' method. Ammoniation improves both palatability and digestibility of straw while the CP content is increased owing to the binding of nitrogen (N) to the chemical structure of the fibrous material (Sundstøl, 1988). Feeding trials with ruminant livestock have demonstrated improvements in intake and utilization of ammoniated versus untreated straw (Kristensen, 1984) while some milk production trials have also shown improvements in milk yield and milk composition (Kristensen, 1984; Ørskov *et al.*, 1988).

Although greatly enhanced by ammoniation, the energy content of treated straw is, however, still lower than that of high quality roughage such as LH (Ekern & Vik-Mo, 1979). Low intakes often limit the use of treated straw for highly producing dairy cows. Nevertheless, studies (Kristensen, 1984) have shown that treated straw may partly replace other roughages in diets for dairy cows at similar or slightly reduced intakes of total roughage DM. Thus, where cost and availability of high quality roughages are limiting factors, the partial or total inclusion of AWS may be economically justifiable.

The aim of this study was to evaluate AWS as a roughage source for lactating dairy cows and to determine the level of substituting LH. Two trials were conducted:

(1) AWS substituted LH (weight for weight basis) in four roughage diets that were fed *ad libitum* to lactating dairy cows together with a concentrate mixture.

(2) Two iso-nutritious complete diets containing either LH or AWS were mixed. Diets were com-

bined in various proportions with each other and fed *ad libitum* to lactating dairy cows.

In both trials diets were evaluated in terms of voluntary dry maker intake, milk yield and milk composition responses.

Materials and methods

Experimental procedure

Trial 1

Wheat straw (*Triticum aestivum*) was treated with 3% (30 kg/1000 kg) anhydrous ammonia according to the thermo-ammoniation or An-Stra-Verter® oven method. AWS was air-dried for one week before being hammermilled through a 25-mm screen. LH was similarly milled. AWS and LH were mixed in a stepwise manner with AWS substituting LH as follows: 100% LH, 67% LH and 33% AWS, 33% LH and 67% AWS and 100% AWS.

These roughage combinations were offered *ad libitum* to eight multiparous Holstein Friesland cows of mean (± SD) live weight of 586 ± 28 kg live weight at 55 ± 3 days of lactation. Cows were blocked according to live weight, lactation number and milk yield and assigned randomly to the four diets according to a double 4 × 4 Latin square change-over design (Patterson & Lucas, 1962). Experimental periods of 3 weeks were preceded by a 2 week adaptation period. A concentrate mixture supplying 162 g CP, 15 g Ca, 6 g P and 11.5 MJ ME/kg DM was fed daily at 1% of starting body weight to all cows irrespective of roughage diet.

Cows were housed individually in stalls and milked twice daily at 05:30 and 15:30. Stalls were cleaned and rebedded every day during morning milking. Fresh drinking water was available at all times. Fresh feed was supplied in the stalls during morning and afternoon milking. Feed refusals were removed during the morning milking to determine daily feed intake.

Samples of feed and feed refusals were collected daily, pooled on a weekly basis and analysed for DM content. Feed samples were analysed for crude fibre (CF) and CP by using the methods of the AOAC (1984). The *in vitro* organic matter digestibility (IVOMD) was determined according to the method of Engels & Van der Merwe (1967). The methods of Van Soest (1963) and Van Soest & Wine (1967) were used to determine the neutral detergent fibre (NDF) and acid detergent fibre (ADF) fractions of the roughage. Individual milk yields were recorded daily, while proportional composite milk samples were collected twice a week for analysis, using a Multi-Spec M Infra-red Analyser (Wheldrake, York, England).

Trial 2

Wheat straw was ammoniated with 3% anhydrous ammonia according to the stack method (Sundstøl *et al.*, 1978). A reaction time of approximately 6 weeks was allowed before the stack was opened. Treated straw bales were allowed to dry before being hammermilled through a 25-mm screen. Two basal diets containing LH and AWS as roughages were formulated and mixed. Diets were formulated to contain approximately 10.95 MJ ME/kg DM, 16% CP and 30% NDF. Feed grade urea was used to equalize the CP content in the AWS diet with the LH diet. The AWS and LH diets were then combined as follows: 100% LH, 25% AWS and 75% LH, 50% AWS and 50% LH, 75% AWS and 25% LH, and 100% AWS.

These diets were fed *ad libitum* to ten multiparous Holstein Friesland cows according to a 5 × 5 Latin square design (Patterson & Lucas, 1962). The mean (± SD) live weight of cows was 564 ± 12 kg and they were 58 ± 5 d into their lactations. Cows were blocked into two groups on the basis of live weight, lactation number and milk yield. Cows were randomly assigned to treatment sequences. The daily feed intake of cows was adjusted weekly to yield approximately 10% refusals.

The same experimental procedures as described in Trial 1 were used.

Statistical analysis

Standard procedures for a 4 × 4 Latin square (Trial 1) and a 5 × 5 Latin square (Trial 2) change-over design (Patterson & Lucas, 1962) were used. Direct and residual effects were assessed. Since residual effects were not significant they were not presented. The structure of the data allowed the degrees of freedom for direct treatment effects to be partitioned in orthogonal polynomials, depicting linear and quadratic trends associated with the substitution of LH with AWS.

Results and discussion

Chemical composition of diets

Ammoniation improved the nutritive value of the wheat straw. The CP content and IVOMD of the wheat straw increased with thermo-ammoniation by 7.2 and 13.1 percentage units to 10.1% and 54.7% respectively. Similarly the stack treatment increased CP content and IVOMD by 6.3 and 12.8 percentage units to 9.4% and 51.3% respectively. These improvements were consistent with other reports for various cereal straws and ammoniation methods (Cottyn & De Boever, 1988). Both treatments in the present two trials also increased ADF and decreased NDF fractions of the straw fibre by respectively +1.5 and -2.1 percentage units, as was reported by Givens *et al.* (1988). Although of average quality, the LH used in the trials differed markedly from the AWS containing 17% CP and having a IVOMD of 62% (on DM basis). The NDF and ADF contents of the LH were lower than that of AWS. Substituting LH by AWS thus resulted in a reduction in CP content, IVOMD and estimated ME content while CF, NDF and ADF contents increased (Table 1). Complete diets used in Trial 2 were iso-nutritious in terms of CP, IVOMD and estimated ME (Table 2). The AWS basal diet had a slightly higher fibre concentration than the LH basal diet resulting in generally higher concentrations of ADF and NDF in the combined diets as AWS ratio increased.

Feed intake and production performance

Trial 1

Dry matter intake declined linearly ($p < 0.01$) by 2.04 ($SE_b = \pm 0.23$) kg DM/d with every 33% increase in AWS in the roughage diet (Figure 1a). MY and FCM was similarly affected ($p < 0.01$) with increasing AWS levels in the diet. The downward trends amounted to respectively 1.0 (SE_b =

Table 1 The chemical composition of combinations of lucerne hay (LH) and ammoniated wheat straw (AWS) used in Trial 1

	Roughage combinations of LH and AWS			
Fractions (% on DM basis)	100:0	67:33	33:67	0:100
Crude Protein	16.9	14.2	12.3	10.1
Acid-detergent fibre	31.8	39.6	49.8	52.6
Neutral-detergent fibre	42.3	52.2	65.6	76.4
IVOMD	61.7	59.1	57.9	54.7
ME (MJ/kg)	9.29	8.90	8.72	8.24

IVOMD = *In vitro* organic matter digestibility

ME = Metabolizable energy (Es, 1978 as cited by Sundstøl, 1988)

Table 2 The physical composition and chemical analysis of treatment diets containing lucerne hay (LH) and ammoniated wheat straw (AWS) in Trial 2

	Roughage combinations of LH:AWS				
Parameters	100:0	75:25	50:50	25:75	0:100
Ingredients (kg as fed):					
Lucerne hay	400	300	200	100	–
Ammoniated wheat straw	–	80	160	240	320
Maize meal	300	300	300	300	300
Wheat meal	180	198	215	233	250
Fish meal	70	70	70	70	70
Urea	–	2	4	6	8
Molasses meal	40	40	40	40	40
Minerals and salt mix	10	10	11	11	12
Chemical analysis (% on DM basis):					
Dry matter	91.3	91.7	92.1	92.2	91.8
Crude protein	16.8	16.4	15.9	16.1	16.3
Neutral detergent fibre	28.9	33.4	34.0	34.7	35.3
Acid detergent fibre	15.6	17.4	18.5	18.9	19.2
IVOMD	74.0	73.5	73.6	73.2	73.4
ME (MJ/kg)	11.14	11.07	11.07	11.02	11.05

IVOMD: *In vitro* organic matter digestibility

ME: Metabolizable energy (Es, 1978 as cited by Sundstøl, 1988)

± 0.4) and 0.97 (SE_b = ± 0.37) kg/d. While the fat and lactose contents of milk showed no trend ($p >$ 0.05), protein content (Figure 1d) was reduced ($p < 0.01$).

Rissanen *et al.* (1981) found that cows ingested twice as much hay as AWS. A decline in DMI was also observed in lambs when AWS substituted LH (Brand *et al.*, 1990). In our study, this trend affected milk yield negatively. It may possibly be attributed to the bulkiness and/or lower palatability of AWS compared to LH. Roughage NDF is the primary restrictive determinant of intake as it is directly related to roughage bulkiness, chewing time, rumen fill and rumen turn-over rate. Results in Trial 1 indicated that roughages high in fibre (as indicated by NDF-levels) limit high milk yield (Ørskov *et al.* 1988), mainly because of their inhibitory effect on DMI. ADF values are generally used as a measure of the indigestible components of fibre. It is negatively correlated with apparent digestibility and energy value (Mertens, 1985). The higher ADF content of AWS compared to LH (52.6 vs 31.8%) would, therefore, account further for the reduction in IVOMD with increasing AWS-levels in the diets. The combined effects of bulkiness and reduced digestibility were reflected by the lower MY of cows consuming roughage diets high in AWS. Differences in protein quality and quantity, and the fixed allocation of concentrate resulted in cows consuming less dietary protein and energy as AWS increased (Table 3). When compared to NRC (1989) requirements for maintenance and milk production, CP and ME intakes for cows on the 100 LH:0 AWS; 67 LH:33 AWS and 33 LH:67 AWS roughage diets were sufficient for the observed production levels. Cows receiving the 100% AWS diet consumed inadequate levels of CP and ME for their respective milk

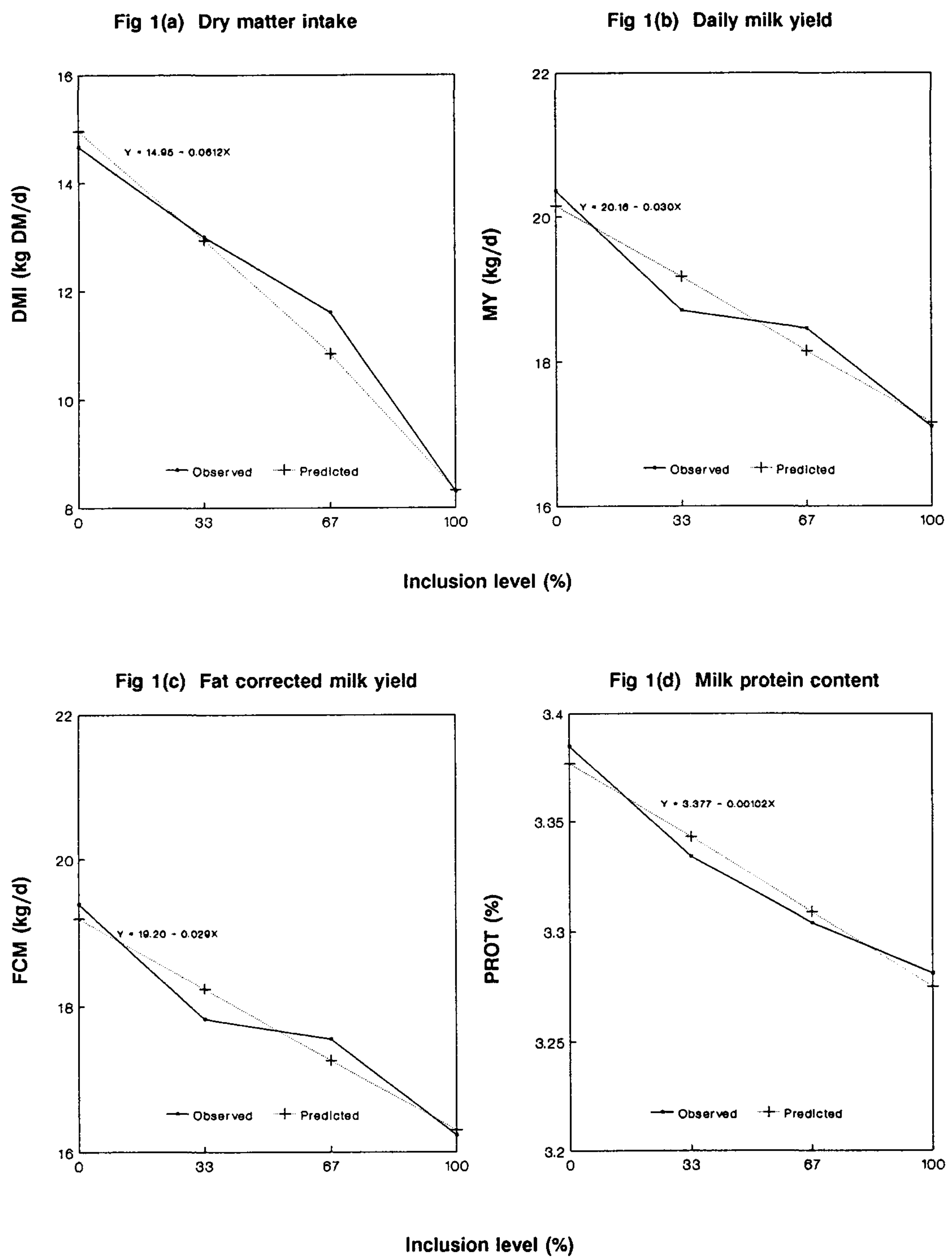

Figure 1 Effect of stepwise substitution of lucerne hay (LH) with ammoniated wheat straw (AWS), on dry matter intake (DMI), daily milk yield (MY), fat corrected milk yield (FCM) and milk protein content (PROT%).

Table 3 The mean daily dry matter (DM), crude protein (CP) and metabolizable energy (ME) intake of Holstein Friesland cows consuming roughage combinations of lucerne hay (LH) and ammoniated wheat straw (AWS) in Trial 1

	Roughage combinations of LH:AWS			
	100:0	67:33	33:67	0:100
DM intake (kg/day):				
Concentrate	5.55	5.55	5.55	5.55
Roughage	14.95	12.91	10.87	8.83
Total	20.50	18.48	16.40	14.38
CP intake (kg/day):				
Concentrate	0.899	0.899	0.899	0.899
Roughage	2.527	1.836	1.335	0.892
Total	3.426	2.735	2.234	1.791
ME intake (MJ/d):				
Concentrate	63.8	63.8	63.8	63.8
Roughage	138.9	115.1	94.6	72.8
Total	202.7	178.9	158.4	136.6

ME: Metabolizable energy (Es, 1978 as cited by Sundstøl, 1988)

yields. Cows responded by milking from their body reserves. Although cows were not scored for body condition during the trial, it was observed that cows receiving the 100% AWS diet, lost some condition while on that feeding regime.

Trial 2

Average DMI of cows declined ($p < 0.05$) linearly with increased levels of the basal diet containing AWS (Figure 2a). The rate of the decline was 0.43 ($SE_b = 0.18$) kg DM/d for every 25% increase in the AWS diet ($r^2 = 0.41$). Average daily MY declined linearly ($p < 0.01$) at a rate of 0.80 (SE_b = 0.18) kg/d for every 25% increase in the AWS (Figure 2b) diet. A quadratic regression fitted ($p <$ 0.01) the response of milk fat content (Figure 2c) to increased levels of the AWS-based diet the best ($r^2 = 0.85$). The highest predicted milk fat content of 3.63 was obtained when the AWS and LH based diets were combined in a 50:50 ratio. As a result FCM (Figure 2d) was not affected negatively by the inclusion of up to 50% of the AWS basal diet. At higher levels FCM declined ($p <$ 0.01) more rapidly.

Several earlier reports on the use of treated or untreated wheat straw in complete diets for dairy cows showed a similar reduction in DMI and MY. Carrillo & Avila (1983) noted that the daily MY of Jersey cows receiving complete diets containing LH and ammoniated straw declined from 11.2 to 8.5 kg as the percentage straw increased. Milk fat content was not affected by treatment, as was also found in the present investigation.

In contrast Poore *et al.* (1989) found that when complete diets were formulated to contain 30% NDF, and with forage NDF coming either from chopped wheat straw or chopped LH in the ratios of 0:3; 1:2; 2:1 and 3:0, were fed to lactating dairy cows neither MY (38.4 kg/d) nor DMI (23.1 kg/d) was influenced by forage source. Milk fat percentage decreased linearly as wheat straw increased, which is in contrast with the present results. Brown *et al.* (1990) showed that when 50% of the LH

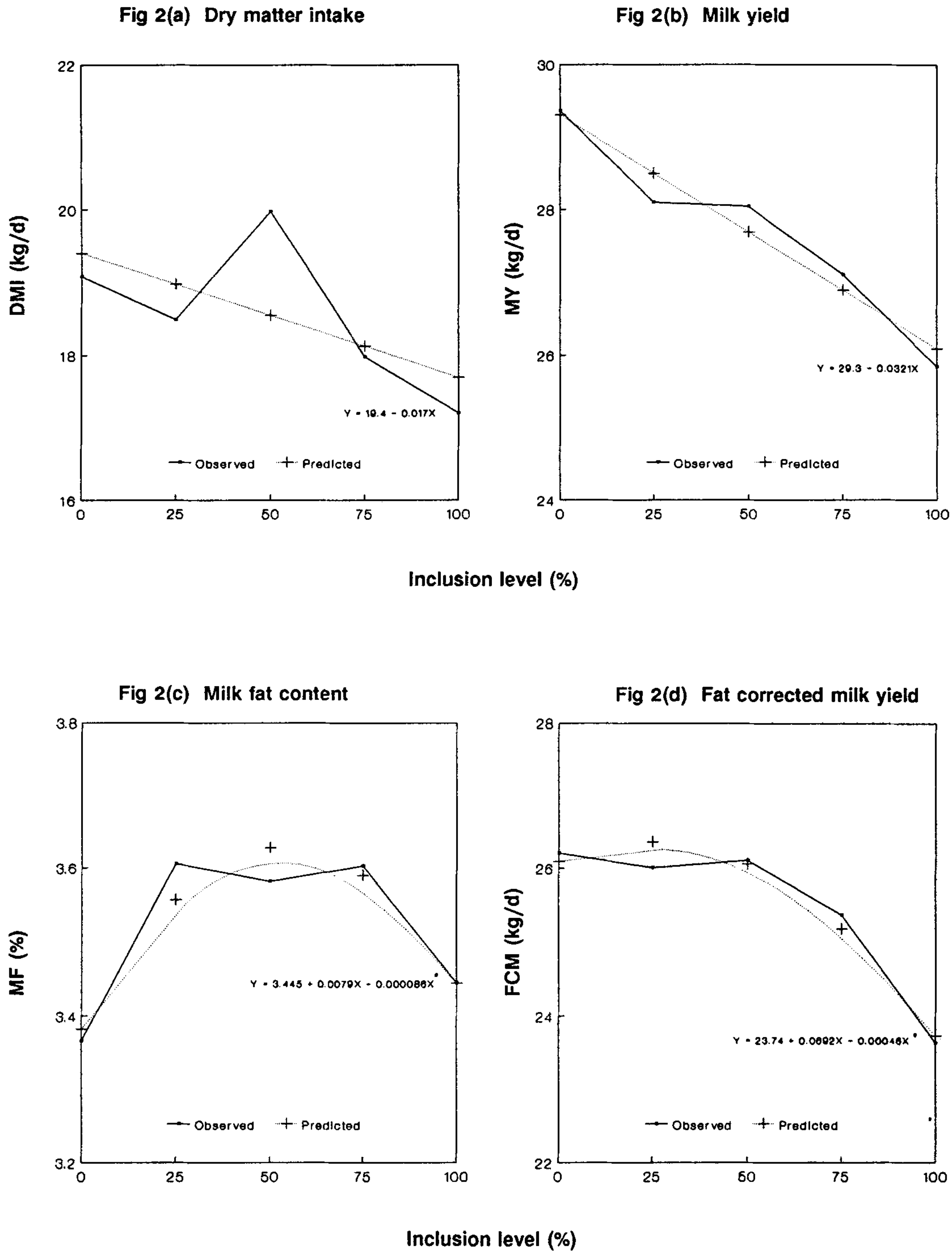

Figure 2 Effect of the substitution of lucerne hay (LH) with ammoniated wheat straw (AWS) in complete diets, on dry matter intake (DMI), milk yield (MY), milk fat content (MF%) and fat corrected milk yield (FCM).

in complete diets containing 45% roughage was replaced with chopped untreated or ammoniated wheat straw, neither DMI nor MY was affected by diet. Milk fat percentage increased for the diets containing straw resulting in an increase in 3.5% FCM.

A number of factors may account for the decline in DMI and MY obtained in the present studies. The NDF content of the total diet was shown by several research groups to affect similar reductions. Beauchemin & Buchanan-Smith (1989) found that milk yield decreased linearly ($p < 0.01$) from 20.8 to 19.1 kg/day as NDF content in the diet increased from 26 to 34%. Linear decreases in MY and a curvilinear decrease in DMI and FCM associated with increases in diet NDF were also reported in a review of 20 trials, involving various roughages (Briceno *et al.*, 1987).

Whether or not total NDF alone elicited these responses is uncertain. This effect was ascribed to differences between roughages in the rate and extent of NDF degradation in the rumen (Varga & Hoover, 1983). The extent of NDF degradation was negatively correlated with NDF content. The clear differences between LH and AWS in the present study may stem from a similar situation.

Recently the NRC (1989), recommended that minimum dietary NDF and ADF levels for highly producing dairy cows in early lactation be between 25 to 28% and 19 to 21%, respectively. As lactation proceeds these levels should be increased to prevent milk fat depression. On this basis, the NDF levels in the diets in the present trials were higher than those required for high milk yields, while ADF levels were again inadequate to prevent milk fat depression with the exception of the AWS only diet. The quadratic trend obtained for milk fat content in this study did not accord with literature results, and is difficult to explain.

Intake and milk yield may also be influenced by total dietary protein level and quality (Oldham, 1984) by providing more amino acids, increasing available energy and altering the efficiency whereby nutrients are ultimately used. The advantage of legumes (such as LH) in this regard is well known (Van Soest & Mertens, 1984). Differences in protein quality between roughages may have contributed to the differences in intake and milk production. Only about 50% of the added N in ammoniated straw is ultimately used by the rumen micro organisms for microbial protein synthesis (Males, 1987). Similarly Mason *et al.* (1989) reported that much of the added N becomes unavailable because of the formation of insoluble nitrogenous compounds through the reaction of ammonia with carbohydrates. This discrepancy must be taken into consideration when formulating diets that contain AWS. Males (1987) suggested that a value of 5.5% CP be used instead of the 8.5 to 9.0% usually obtained by chemical analysis.

Economic analysis

The effect of different prices of LH on the margin over feed cost/kg milk produced was determined using intake and milk production responses from Trial 2 (Figure 3). At a price of R215/t for AWS and a milk price of R0.85/kg, margin over feed cost for the 100% AWS-diet was approximately 41.2 c/kg. Increasing LH prices resulted in a rapid decline in the gross margin of the 100% LH-diet. Diets containing 25 to 75% of LH had higher gross margins than the 100% AWS diet when LH cost R340/t. At a price of R360/t for LH only the diet containing 25% LH had a slightly higher gross margin than the 100% AWS diet. At a lucerne price of about R335/t the 100% LH diet had a similar margin over feed cost as that of AWS. The mixed diet containing 25% LH did not show such a rapid decline in gross margins given a similar income as the 100% AWS-diet as LH at approximately R375/t.

Conclusions

The DMI of Holstein Friesland cows in both trials was negatively affected ($r < 0.05$) by increasing

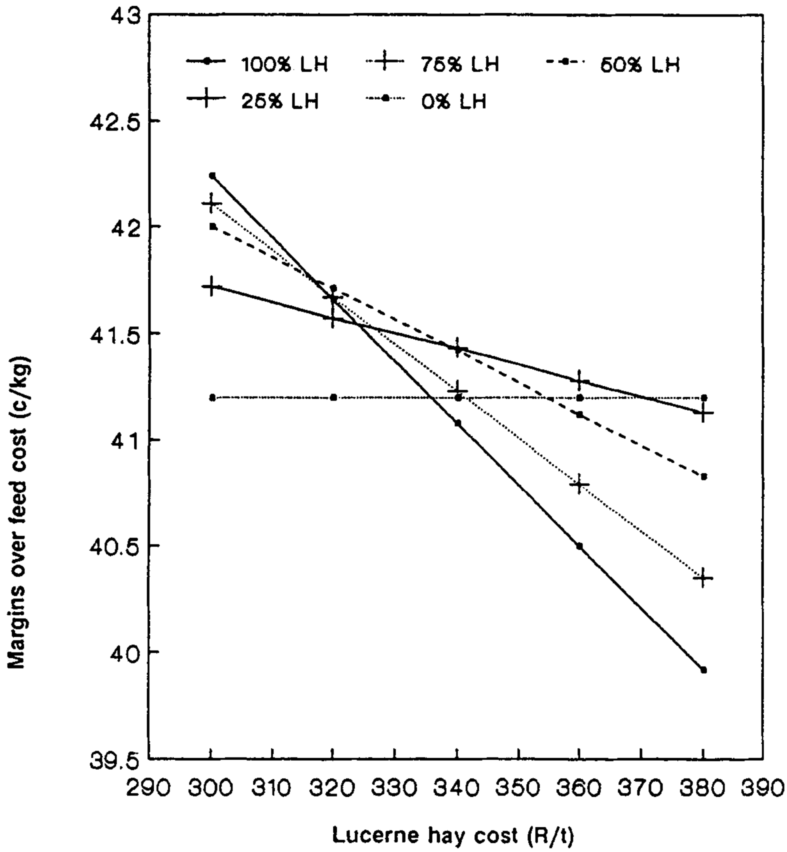

Figure 3 Effect of lucerne hay (LH) cost on economic efficiency of diets.

AWS in the total diet. Milk yield was similarly affected. Increasing AWS in the diets in Trial 1 resulted in a lower CP and energy intake because of the fixed allocation of the concentrate mixture. The lower feed value of AWS vs LH should be taken into consideration when diets for lactating dairy cows are formulated. In Trial 2 fat content was not affected ($p > 0.05$) up to the 50% AWS inclusion level, therefore FCM was not affected to the same extent as MY.

The economic analysis indicated that at LH prices up to R370/t, AWS could be included in the diet at levels varying from 0 to 75%. The 100% AWS diet is at a LH price higher than R370/t more economical than the diet with a 25% AWS inclusion level.

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