Studies on the Use of Wet Sorghum Distiller's Grains in Lactating Cows

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ABSTRACT : The aim of this study was to evaluate the effect of incorporating wet sorghum distiller's grains (WSDG) as part of their diet on the lactating performance of dairy cows. Twenty-seven Holstein milking cows were selected, all in the early lactating stage, with an average weight of 550 kg, and producing an average of 30 kg of milk daily. The cows were divided into three groups according to milk yield and lactation and were fed different total mixed rations. The diets were formulated according to NRC (1989) recommendations in three rations to (1) control diet, (2) 15% WSDG diet and (3) 30% WSDG diet. The three different diets were all formulated as iso-nitrogen and iso-energetic diets. After one week adaptation period, the experimental feeding was conducted for 8 weeks. Three ruminal cannulated cows were also examined in order to investigate ruminal fermentation of the three total mixed rations. The results showed that the milk yield, as corrected to the 4.0% fat standard, had no significant difference among the control, 15% WSDG and 30% WSDG treatment groups ($p>0.05$). The daily dry matter intake of the control group was higher than the other groups ($p<0.05$). With respect to milk composition, milk fat, milk protein and total solids, there was no significant difference among the treatment groups ($p>0.05$). The energy efficiency of the 30% WSDG group were significantly higher than the other treatment groups ($p<0.05$). Ruminal pH value showed no difference among the treatment groups ($p<0.05$). Ammonia-nitrogen concentration in the control group was higher than the other treatment groups ($p<0.05$). The concentration of total ruminal volatile fatty acid was similar in all three dietary groups. (***Asian-Aus. J. Anim. Sci. 1999. Vol. 12, No. 6 : 895-900***)

Key Words : Sorghum Distiller's Grains, Lactation, Dairy Cattle, Rumen Characteristics

INTRODUCTION

Distiller's grains is a good protein supplement with rich nutrients, comparable to corn gluten meal, soybean meal, coconut meal or linseed meal (Warner, 1970). Since sorghum is more resistant than corn to microbial breakdown in the rumen, sorghum distiller's grains is also slightly more resistant than corn grains (Mertens, 1977). Therefore, it should be a good source of ruminal undegradable protein for lactating cows.

The production of one thousand tons of liquor annually by the Bureau of Taiwan monopoly produces thousands of tons of byproducts, or stillage. These byproducts contain large amount of protein, calcium and phosphate and they are good sources of animal feed if properly used. Furthermore, if improperly disposed of, they can create severe environmental problems. The aim of this study is therefore to evaluate the effect of incorporating wet sorghum distiller's grains (WSDG) as part of the bovine diet on the lactating performance of dairy cows.

MATERIAL AND METHODS

Experimental ration formulation

Three experimental diets were formulated into the three total mixed rations. Diet 1 was a control diet without sorghum distiller's grains (WSDG), diet 2 included 15% WSDG, while diet 3 added 30% WSDG to the total mixed ration. All experimental diets were formulated isonitrogenously and isoenergetically, according to the NRC (1989) nutrient requirements with applying a 10% safety factor to allow for variable ingredient composition. The experimental cows averaged 550 kg in body weight, and produced on average 30 kg of 4.0% fat corrected milk (FCM) daily.

Table 1 presents the diet formulation and analysis, indicating that the experimental diets were fed as total mixed rations (TMR) with concentrate and roughage at a ratio of 55:45 (dry matter basis). The concentrate was mainly yellow corn, soybean (meal and full fat), wheat bran, fat and WSDG. Roughage consisted of one part alfalfa hay and two parts of corn silage. The analyzed chemical composition of the WSDG (dry matter basis) produced by the distillery was as follows: crude protein 21.89%, NDF 39.37%, ADF 22.47%, crude fat 5.94%, calcium 0.37%, and phosphorus 0.62%. The concentrates were mixed daily with roughage, and the moisture content of the corn silage was measured weekly for adjustment of the as-fed ration composition.

Animal management in feeding trials

Twenty-seven cows, each producing more than 30 kg of milk daily, were selected and evenly distributed to the three dietary treatment groups according to milk yield and lactation. The cows were confined for individual feeding during the feeding period, and were released for exercise after feeding. The cattle were

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dewormed twice monthly during the experimental period.

Table 1. Experimental diet formulation, g kg^{-1}

Ingredients	Control	15% WSDG	30% WSDG
Alfalfa hay	150.0	150.0	150.0
Corn silage	300.0	300.0	300.0
Distiller's grains	0.0	150.0	300.0
Full fat soybean	25.8	16.7	15.9
Soybean meal, 44%	125.0	101.3	69.0
Corn, dent	255.8	195.7	76.3
Wheat bran	113.5	48.3	22.3
Protect fat	8.0	16.4	46.0
Limestone	10.4	8.0	6.9
Common salt	3.0	3.0	3.0
Premix*	2.2	2.2	2.2
Dicalcium phosphate	3.3	5.4	5.4
Sodium bicarbonate	3.0	3.0	3.0
Total	1000.0	1000.0	1000.0
Calculated analysis			
Crude protein	165	165	165
Net energy, MJ/kg	6.90	6.90	6.90
Undegradable protein, % CP	37.5	37.5	37.5
Analyzed value			
Crude protein	164.2	163.4	171.2
NDF	323.8	336.8	378.5
ADF	176.5	200.2	223.9

* Each kilogram diet contains: Vitamin A, 10,000 IU; Vitamin E, 70 IU; Vitamin D_3, 1,600 IU; Fe, 50 mg; Zn, 40 mg; Mn, 40 mg; Co, 0.1 mg; Cu, 10 mg; Se, 0.1 mg.

After one week of adaptation, the cows began an 8 weeks feeding trial, during which they were individually fed ad libitum with 2-3 kg orts for three meals per day (03:00, 09:00 and 18:00 h). Water was provided individually with an automatic bowl type drinker. Cows were milked twice daily at 05:30 and 17:30 h.

During the feeding period, dry matter intake and milk yield were recorded daily. Milk samples were taken once weekly. The live-weight of the cows was measured at the beginning, in the fourth week and at the end of the trial. Feed samples were taken weekly and dried at 60℃ in a ventilated oven for 48 h. At the end of the trial, blood samples were taken 6 h postprandial.

Rumen studies

Three dry cows with rumen fistulas were randomly assigned to the three dietary groups according to a Latin square design. Each treatment period was 12 days with a 7-day preliminary period. Samples of 200 ml ruminal fluid were taken on the eleventh and twelfth day in the morning before feeding and 1, 2, 3, 4, 6 and 8 h postprandial. Ruminal pH was measured immediately after sample withdrawal. The samples were then filtered through four layers of cheese cloth and diluted with 25% metaphosphoric acid. After mixing, samples were sealed and preserved at -18℃ for later analysis of ammonia nitrogen and volatile fatty acids.

Chemical analysis

The analysis of feed samples was conducted according to the AOAC (1984) methods. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed according to the methods in Van Soest et al. (1991), using an automatic fiber analyzer (Fibertec System M, Tecator AB) after the starch was eliminated through heat stable α-amylase (Sigma, No A3306).

Milk composition, comprising fat, protein and total non-fat solids, was analyzed using a milk scanner (Foss Electric Co., Milko Scan 255 A/B types), according to the infra-red AOAC (1984) method. Analysis of serum nitrogen was prepared with an automatic blood chemical analyzer (Hitachi 7050), according to the method in Roseler et al. (1993). The pH value of rumen fluid was measured using a pH meter (Model 6007, Jenco). The concentration of ruminal ammonia nitrogen was analyzed by spectrophotometer (UV-2000, Hitachi) according to Chaney and Marbach (1962). The ruminal concentration of volatile fatty acids was determined using gas chromatography (G-3000, Hitachi) according to Erwin et al. (1961).

Statistical analysis

A completely randomized design for the feeding trial and a Latin square design for the ruminal studies was applied to determine the dietary effects. Analysis of variance was calculated with the General Linear Model procedure (GLM) of the Statistical Analysis System (1985). Duncan's new multiple range test was used to compare the treatment means according to Steel and Torrie (1960).

RESULTS AND DISCUSSION

Effect on dry matter intake

Table 2 presents the effect of dietary WSDG on the performance of lactating cows. The inclusion of WSDG significantly depressed feed intake ($p<0.05$). Cows progressively ate less feed as the level of WSDG inclusion increased in the diet ($p<0.05$). The progressive decrease in feed intake for diets of increasing WSDG concentration, may be attributed to the high dietary fiber with bulk density that limited space in the rumen for additional intake (Murdock et al., 1981). This negative correlation of feed intake to the NDF content of the diet agrees with the suggestion in Mertens and Ely (1983). Christensen (1991) also suggested that when dietary NDF exceeds 36-38% of the dietary maximum, it would depress DM intake. The NDF content in the 30% WSDG group may reach the mentioned NDF maximum.

Table 2. Effect of dietary treatment on lactation performance of dairy cows

Item	Control	15% WSDG	30% WSDG	SEM
Lactation performance, kg/day				
Dry matter intake	20.5[a]	19.8[b]	18.3[c]	0.77
Milk yield	27.9	27.6	27.6	0.68
4.0% FCM	26.2	25.7	25.5	0.85
Milk composition, %				
Milk fat	3.56	3.57	3.57	0.15
Milk protein	2.95	2.92	2.92	0.05
Milk lactose	4.80[ab]	4.83[a]	4.76[b]	0.05
Total solids	12.02	12.04	11.94	0.21
Milk composition yield, kg/day				
Milk fat	1.00	0.98	0.97	0.05
Milk protein	0.827[a]	0.800[b]	0.804[ab]	0.020
Milk lactose	1.34	1.33	1.31	0.04
Total solids	3.37[a]	3.31[ab]	3.28[b]	0.09
Protein and energy efficiency				
DM intake/milk yield	0.73[a]	0.73[a]	0.69[b]	0.03
DM intake/FCM yield	0.79[a]	0.78[ab]	0.74[b]	0.04
NE intake/FCM yield	1.30[a]	1.28[ab]	1.22[b]	0.06
CP intake/FCM yield	0.13	0.13	0.13	0.01
CP intake/milk protein yield	4.07	4.01	4.06	0.18

[a,b,c] Means within the same row without the same superscripts are significantly different ($p<0.05$).

Water content in the diet is also a limiting factor for feed intake. The dry matter content of the control, 15% WSDG and 30% WSDG diet were 52.74, 46.28 and 41.08%, respectively. This agrees with Lahr et al. (1983), who indicated that an increase in water content in the diet decreases dry matter intake of cattle. Adding water to the ration or feeding wet corn distillers' byproducts has also been shown to improve the NDF digestibility by slowing down the rate of feed passage through the rumen, with increasing particle size of the feed (Firkin et al., 1985; Ham et al., 1994).

Effect on milk yield

The level of WSDG did not significantly influence milk and the 4.0% fat corrected milk yield of lactating cows ($p<0.05$), although there was significantly lower feed intake in cows fed the diet with WSDG. Although most research indicates that the major factor depressing milk yield is a decrease in feed intake (Davis and Merilan, 1960; Wayma et al., 1962), however the lower feed intake with a high level of WSDG did not depress milk yield in this study. With iso-nitrogenous and iso-energetic rations in this trial, the high efficiency of feed utilization may be attributed to the more digestible nutrients in the high WSDG rations, agreeing with the observation of Ham et al. (1994), that there was better NDF digestibility in a diet including distiller's grains. Waller et al. (1980) indicated that the protein efficiencies of the four dietary additions, sorghum distillers' dried grains (DDG), sorghum distillers' dried grains with soluble (DDGS) and corn DDG, and corn DDGS were 150, 130, 200 and 180% of that of soybean meal. Other research had indicated that corn distiller's grains contain the same or better protein feed value, as compared to soybean meal (Palmquist and Conrad, 1982; Schingoethe et al., 1983). Poor lactation performance in the distiller's grains diet may be attributed to the acid detergent insoluble fiber caused by heat damage during drying processing (Voss et al., 1988). However, from the lactation performance in this trial, wet sorghum distiller's grains without heat damage from drying processing is apparently a good source of protein supplement for lactating cows.

Effect on milk composition

The level of dietary WSDG significantly influenced the milk composition, the percentage of milk lactose, daily yield of protein and total solids ($p<0.05$). Inclusion of WSDG significantly depressed daily yield of milk protein ($p<0.05$), but did not significantly influence the percentage or daily yield of milk fat. A significantly higher milk protein yield was observed in the group without WSDG as compared to the lower level of WSDG group ($p<0.05$), while there was also a trend of higher milk protein yield in the control without WSDG, as compared to the higher level WSDG group ($p=0.058$). This may be attributed to the poor amino acid balance in the distiller's grains, especially of lysine, limiting for the synthesis of milk protein (Owen and Larson, 1991; Palmquist and Conrad, 1982; Weiss et al., 1989). Some researchers also attributed this to high dietary fat content. Palmquist and Moser (1981) suggested that fat inclusion in a diet may interfere with the insulin functions that influence amino acid transfer into the mammary gland, thus inhibiting milk protein synthesis. They suggested a decrease of 0.03 unit milk protein as a result of each 100 g of dietary fat intake. Cant et al. (1991) also demonstrated a decrease in milk protein due to changing the energy utilization in the mammary gland, due to the inclusion of dietary fat.

They also found that high dietary fat impacted the mammary gland absorption of amino acids by depressing blood flow into the gland by 7%. Dietary fat however, was not the major factor that influence milk protein in this study. Although increasing dietary fat in the high level of WSDG diet in this trial (table 1), did not cause of the decrease in the percentage of milk protein.

Inclusions of high level of dietary WSDG significantly depressed the milk lactose, as compared to the low WSDG diet ($p<0.05$). This result is similar to the observation by Owen and Larson (1991) that milk lactose was significantly lower in the diet including 35.8% corn DDGS, as compared to the diet including 18.8% corn DDGS. Inclusion of a high level of WSDG also significantly decreased daily yield of milk total solids in the milk ($p<0.05$), including protein, fat, and lactose.

Effect on the protein and energy efficiency

Table 2 also presents the effect of level of dietary WSDG on the efficiency of nutrient utilization in lactating cows. The inclusion of dietary WSDG significantly influenced dry matter and energy efficiency ($p<0.05$). Lactating cows required 5.5% less DM intake to produce a unit of milk with a high level of WSDG ($p<0.05$), as compared to the control diet. Cows also needed 6.3% less DM intake to produce a unit of 4.0% FCM ($p<0.05$) with the high level of WSDG. This efficient feed conversion in diets with high level of WSDG is probably due to more efficient nutrient utilization, since all the experimental diets are iso-energetic and equal protein diets. Cows in the high level WSDG diet also required significantly less net energy to produce a unit of 4% FCM, as compared to the control group ($p<0.05$).

Effect on blood urea concentration

Table 3 presents the effect of WSDG inclusion on the urea nitrogen concentration of blood. Inclusion of WSDG significantly influenced the serum urea nitrogen concentration at the end of the feeding trial ($p<0.05$). This may reflect the level of ruminal ammonia concentration that was influenced by the inclusion of WSDG in the diet ($p<0.05$). Although WSDG contains a high level of undegradable protein, all the experimental diets were equal undegradable protein, therefore a lower ruminal ammonia concentration may not be attributed to the WSDG inclusion in the diet. High efficiency of energy utilization in the high level WSDG diet in this study may indicated a better NDF and nutrient utilization, since the levels of degradation end products, isobutyrate and isovalerate were significantly lower in the rumen (table 3).

High serum urea concentration will not only produce poor protein utilization, but may also damage to the liver function and the fertility of cows. Ferguson et al. (1988) suggested that a serum urea nitrogen level in excess of 20 mg dL^{-1} adversely effected the fertility of cows. Our data showed a concentration ranging from 14.3 to 15.2 mg dL^{-1}, which is below the critical level.

Table 3. Effects of dietary treatment on serum urea nitrogen and ruminal characteristics of lactating cows

Item	Control	15% WSDG	30% WSDG	SEM
Serum urea nitrogen				
SUN, mg/dL	15.21[a]	14.68[b]	14.31[b]	0.44
Ruminal characteristics				
pH	6.34	6.29	6.32	0.07
NH3-N,mg/dL	32.02[a]	27.58[b]	24.42[c]	0.91
Total VFA, mM	123.54	127.98	122.23	4.58
Acetate, molar %	66.39	67.04	67.30	0.43
Propionate, molar %	16.68[ab]	16.33[b]	17.40[a]	0.39
A/P ratio	4.11	4.12	3.98	0.12
Isobutyrate, molar %	1.32[a]	1.07[b]	0.98[c]	0.05
Butyrate, molar %	12.55[a]	12.87[a]	11.88[b]	0.32
Isovalerate, molar %	1.83[a]	1.52[b]	1.33[c]	0.04
Valerate, molar %	1.24[a]	1.16[b]	1.10[c]	0.03

[a,b,c] Means within the same row without the same superscripts are significantly different ($p<0.05$).

Effect on ruminal characteristics

Table 3 also shows the effect of dietary WSDG on the ruminal characteristics of dairy cows. Adding different levels of WSDG did not significantly influence the ruminal pH value and ammonia nitrogen level before feeding. The ruminal pH values in these experimental animals were higher than 6.3 before feeding, decreased to 6.15 after feeding and gradually increased afterward (figure 1).

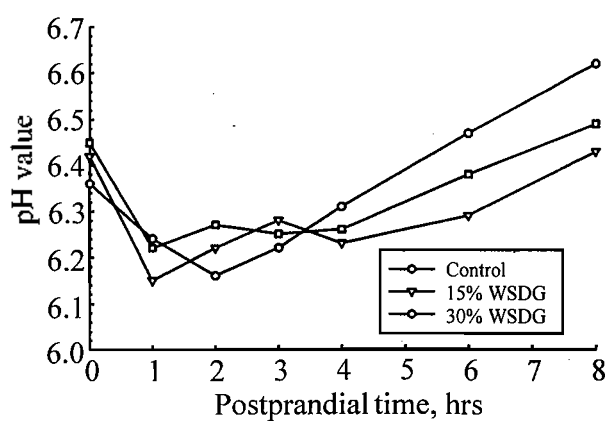

Figure 1. Effects of dietary treatment on pH value of rumen content in dairy cows

Ammonia concentration in the rumen increased after feeding, reached a maximum at 2 h after feeding, and gradually declined afterward (figure 2). However inclusion of WSDG progressively depressed ruminal ammonia concentration ($p<0.05$) as the level of WSDG inclusion increased. This may be attributed to the low degradability of WSDG, as described by Chiou et al. (1995). The ammonia nitrogen level remained above 21.4 mg/dl, higher than the minimum level of 5 mg/dl required for maximum microbial growth (Satter and Roffler, 1975).

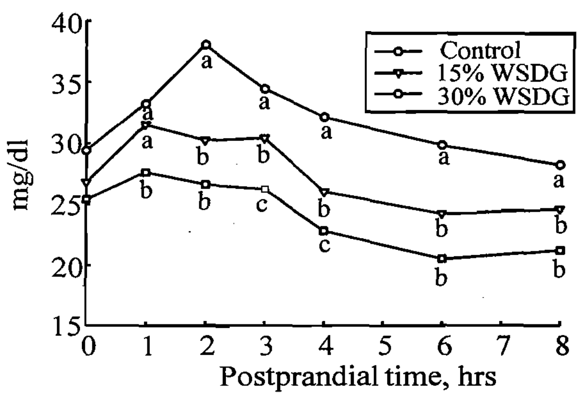

Figure 2. Effect of dietary treatment on ammonia nitrogen concentration of rumen content in dairy cows

Inclusion of a high level of WSDG did not significantly influence ruminal total VFA concentration ($p>0.05$), with the mean daily total VFA concentration in the range of 122 to 128 mM. The total VFA concentration changed from between 116.5 and 131.2 mM before feeding, to the peak of between 140 and 149 mM one hour after feeding and then declined afterward. This suggests that high level of WSDG did not depress ruminal fermentation.

Inclusion of WSDG also significantly influenced molar percentage of various volatile fatty acids except acetate ($p<0.05$). An increase in the WSDG level progressively depressed various VFA percentages significantly, with the exception of acetate and propionate.

Inclusion of WSDG did not significantly influence molar percentage of acetate in ruminal content, although high WSDG levels did significantly increase the propionate concentration ($p<0.05$). High propionate generally occurs in a high nonstructural carbohydrate diet. The high WSDG diet would be expected to produce low ruminal propionate since distiller's grains has a low level of readily available carbohydrate, as indicated by Palmquist and Conrad (1982). They however, obtained similar rumen VFA concentration with higher molar ratio of acetate to propionate by the inclusion of distillers' grains. In fact, Schingoethe et al. (1983) found that adding fresh corn distiller's grains increased propionate concentration in the rumen content. They also concluded that the high molar concentration of propionate for wet distiller's grains, possibly reflecting consumption of a diet of higher in energy and was of questionable biological significance since it had no apparent affect on milk composition. This agrees with the results of this trial indicating that high levels of WSDG significantly increased propionate, hence showed a trend toward decreasing the ratio of acetate to propionate. Although a lower ratio of acetate to propionate generally reduces the concentration of milk fat, it did not occur in this trial.

Dietary WSDG also significantly reduced concentration of isobutyrate and isovalerate in the rumen ($p<0.05$). This indicated that there was more undegradable protein in the rumen as the dietary level of WSDG increased, since isobutyrate and isovalerate are derived from valine and leucine, respectively, in the ruminal fermentation (Van Soest, 1982).

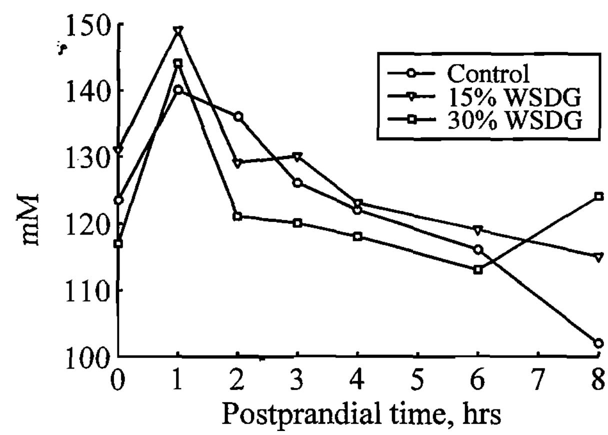

Figure 3. Effect of dietary treatment on total volatile fatty acids concentration of rumen content in dairy cows

CONCLUSION

It appears that wet sorghum distiller's grains (WSDG) is a good source of undegradable protein supplement for lactating cows. With the maximum 30% inclusion in the lactating diet, although feed intake was depressed, however milk yield was not affected due to the better energy and protein utilization, as compared to soybean meal.

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REFERENCES

AOAC. 1984. Official Methods of Analysis. 13th Ed. Association of Official Analytical Chemists. Washington, DC.

Cant, J. P., E. J. DePeters and R. L. Balwin. 1991. Effect of dietary fat and postruminal casein administration on milk composition of lactating dairy cows. J. Dairy Sci. 74:211-219.

Chaney, A. L. and E. P. Marbach. 1962. Modified reagents for determination of urea and ammonia. Clinic. Chem. 8: 130-132.

Chiou, P. W. S., K. J. Chen, K. S. Kuo, J. C. Hsu and B. Yu. 1995. Studies on the protein degradabilities of feedstuffs in Taiwan. Anim. Feed Sci. Technol. 55:215-226.

Christensen, D. A. 1991. Is cereal silage a viable alternative to alfalfa: Animal perspective. Page 27 in Proc. 1991 W. Can. Dairy Semin. Adv. Dairy Tecnnol. Vol. 3. Univ. Alberta, Edmonton, AB., Can.

Davis, A and C. P. Merilan. 1960. Effect of constant environmental temperature and relative humidity on feed digestion by lactating Holstein cows. J. Dairy Sci. 43:871-879.

Erwin, E. S., G. J. Marco and E. M. Emery 1961. Volatile fatty acid analysis of blood and rumen fluid by gas chromatography. J. Dairy Sci. 44:1768-1770.

Ferguson, J. D., T. Blanchard, D. T. Galligan, D. C. Hoshall and W. Chalupa. 1988. Infertility in dairy cattle fed a high percentage of protein degradable in the rumen. J. Am. Vet. Med. Assoc. 192:659-662.

Firkin, J. L., L. L. Berger, G. C. Jr. Fahey and N. R. Merchen. 1985. Evaluation of wet and dry distillers grains and wet and dry corn gluten feeds for ruminants. J. Anim. Sci. 60:847-860.

Ham, G. A., R. A. Stock, T. J. Klopfensteim, E. M. Larson, D. H. Shain and R. P. Huffman. 1994. Wet corn distillers byproducts compared with dried corn distillers grains with solubles as a source of protein and energy for ruminants. J. Anim. Sci. 72:3246-3257.

Lahr, D. A., D. E. Otterby, D. G. Johnson, J. G. Linn and R. G. Lundquist. 1983. Effects of moisture content of complete diets on feed intake and milk production by cows. J. Dairy Sci. 66:1891-1900.

Mertens, D. R., 1977. Importance and measurement of protein insolubility in ruminant diets. Proc. Georgia Nutr. Conf. pp. 30.

Mertens, D. R. and L. O. Ely. 1983. Relationship of rate and extent of digestion to forage utilization- a dynamic model evaluation. J. Anim. Sci. 54:895-905.

Murdock, F. R., A. S. Hodgson and R. E. Jr., Riley. 1981. Nutritive value of wet brewers grains for lactating diary cows. J. Dairy Sci. 64:1826-1832.

National Research Council. 1989. Nutrient Requirements of Dairy Cattle. 7th Rev. Ed. Nat'l Acad. Sci. Washington, DC.

Owen, F. G. and L. L. Larson. 1991. Corn distillers dried grains versus soybean meal in lactation diets. J Dairy Sci. 74:972-979.

Palmquist, D. L. and H. R. Conrad. 1982. Utilization of distillers dried grains plus solubles by dairy cows in early lactation. J. Dairy Sci. 65:1729-1733.

Palmquist, D. L. and E. A. Moser. 1981. Dietary fat effects on blood insulin, glucose utilization and milk protein content of lactating cows. J. Dairy Sci. 64:1664-1670.

Roseler, D. K., J. D. Ferguson, C. J. Sniffen and J. Herema. 1993. Dietary protein degradability effects on plasma urea nitrogen and milk urea nitrogen in Holstein cows. J. Dairy Sci. 76:525-534.

Satter, L. D. and R. E. Roffler. 1975. Nitrogen requirements and utilization in dairy cattle. J. Dairy Sci. 58:1219-1237.

Schingoethe, D. J., A. K. Clark and H. H. Voelker. 1983. Wet corn distillers grains in lactating dairy cow rations., J. Dairy Sci. 66:345-349.

Statistical Analysis System. 1985. Guide for personal computer 6.08 version, Statistical Analysis System Inc., Cary, NC.

Steel, R. G. D. and J. H. Torrie. 1960. Principles of Statistics. McGraw-Hill Book Company, NY.

van Soest, P. J., J. B. Robertson and B. S. Lewis. 1991. Methods or dietary fiber, neutral detergent fiber, and nonstarch polysaccharides on relation to animal nutrition. J. Dairy Sci. 74:3583-3597.

van Soest, P. J. 1982. Forage conservation. In: Nutritional Ecology of the Ruminant., O & B Books Inc. Corvallis, OR. pp. 139-151.

Voss, V. L. D. Stehr, L. D. Sattrer and G. A. Broderick. 1988. Feeding lactating dairy cows proteins resistant to ruminal degradation. J. Dairy Sci. 71:2428-2439.

Waller, J., T. Klopfenstein and M. Poos. 1980. Distillers feed as protein sources for growing ruminants., J. Anim. Sci. 51:1154-1166.

Warner, R. G. 1970. The place of distillers feeds in dairy rations- A review. Proc. Dist. Feed Res. Council. 25:11-18.

Wayma, O., H. D. Johnson, C. P. Merilan and I. L. Berry. 1962. Effect of *ad libitum* or force feeding of two rations on lactating dairy cows subject to temperature stress. J. Dairy Sci. 45:1472-1478.

Weiss, W. P., D. O. Erickson, G. M. Erickson and G. R. Fisher. 1989. Barley distillers grains and a protein supplement for dairy cows. J. Dairy Sci. 72:980-987.