# Wet Corn Distillers Byproducts Compared with Dried Corn Distillers Grains with Solubles as a Source of Protein and Energy for Ruminants[1]

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**ABSTRACT:** Five trials investigated the feeding value of wet and dried corn distillers byproducts as a source of protein and energy for growing and finishing cattle and investigated the effect of heat damage on the feeding value of dried distillers byproducts. In a calf growth trial, no differences in rate of gain or protein efficiency were observed among calves fed wet distillers byproducts (wet distillers grains + thin stillage; WDB) or one of three composites of dried distillers grains + solubles (DDGS) having a low, medium, or high concentration of ADIN. A finishing trial compared the energy value of dry-rolled corn (DRC) with WDB or the three DDGS composites, fed at 40% of the diet DM replacing DRC. Cattle consuming WDB or DDGS gained faster ($P < .05$) and more efficiently ($P < .05$) than cattle fed DRC. Although gains were similar, cattle fed WDB consumed less feed ($P < .10$) and were more efficient ($P < .10$) than cattle fed DDGS. Level of ADIN in DDGS did not affect efficiency of gain ($P > .10$). In a lamb finishing trial, the addition of 5 or 10% ethanol did not affect ($P > .10$) daily gain, DMI, or feed efficiency. In two metabolism trials with steers, grain byproducts (wet distillers grains, dry distillers grains plus solubles, wet corn gluten feed, dry corn gluten feed, hominy feed) and DRC had similar effects on ruminal pH and total VFA. Feeding thin stillage or condensed solubles reduced ($P < .10$) ruminal pH and tended to reduce acetate:propionate. Wet corn distillers byproducts, fed at 40% of the diet DM, contain more $NE_g$ than did DRC and drying WDB reduces its $NE_g$ content. Acid detergent insoluble N is a poor indicator of protein and energy value in distillers grains.

Key Words: Corn, Distillers, Cattle, Protein, Energy

J. Anim. Sci. 1994. 72:3246–3257

## Introduction

Traditionally, distillers byproducts have been dried and sold as a protein source for ruminants and nonruminants. Drying wet distillers grains is expensive and may account for more than 40% of the energy costs incurred by the alcohol plant (Stock and Klopfenstein, 1982), and drying may produce changes that reduce its nutritional value. The effects of drying on the nutritional value of dry distillers grains have been debated (Van Soest and Sniffen, 1984; Britton et al., 1986; Chase, 1987; Klopfenstein, 1987; Van Soest, 1989; Weiss et al., 1989). Wet distillers grains (Farlin, 1981; DeHaan et al., 1982; Firkins et al., 1985) and thin stillage (Hanke et al., 1983; Aines et al., 1985; Rust et al., 1990) have been efficiently used as protein and energy sources in ruminant diets. When fed at 40% of the diet DM, the combination of wet distillers grains and thin stillage averaged 69 and 28% more $NE_g$ for yearlings and calves, respectively (Larson et al., 1993), compared with dry-rolled corn. Feeding dried distillers grains plus solubles as an energy source has been presumed to be too expensive; however, the increased energy value of wet distillers byproducts may change these economics. Therefore, the following trials were conducted 1) to determine the protein and energy value of wet and dry distillers byproducts; 2) to determine the effects of heat damage, as measured by ADIN, on protein and energy utilization; and 3) to determine the effect of wet and dry distillers byproducts on ruminal fermentation compared with other corn byproducts.

## Procedure

*Byproduct Production.* Wet distillers byproducts (**WDB**; wet grains and thin stillage) were produced at

[1]Published with the approval of the director as paper no. 10671, journal ser., Nebraska Agric. Res. Div.

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Received April 4, 1994.
Accepted September 1, 1994.

the University of Nebraska Agricultural Research Development Center farm-scale alcohol plant and transported, every other day, to the research feedlot. Fermented corn mash was screened and pressed, separating the solids (wet grains) from the liquid. The liquid fraction was distilled, removing the alcohol and forming the byproduct thin stillage. For each distillation, the byproducts were weighed, sampled, and measured for DM (oven-dried at 55°C for 48 h) content. The ratio of wet distillers grains:thin stillage production (DM basis) was computed monthly and diets were altered accordingly to ensure the byproducts were fed in the same ratio as were produced at the plant. The WDB fed in these trials consisted of 62.5% wet distillers grains and 37.5% thin stillage (DM basis). The wet grains were mixed into the diet and the thin stillage was consumed as drinking water. After the thin stillage was consumed, animals were allowed ad libitum access to fresh water.

Dry matter calculations in all studies reported herein include the DM contribution from thin stillage. Because drying will volatize ethanol present in wet distillers grains and thin stillage, dry matter intake included an estimate of the ethanol content of wet distillers grains (10.7%, DM basis) and thin stillage (12.2%, DM basis) based on the data of Larson et al. (1993) collected with the same production equipment.

Eleven batches of dried distillers grains plus solubles (**DDGS**) were obtained from commercial distilleries. Acid detergent insoluble N was determined (Goering et al., 1970) on each batch. Based on the ADIN determinations, three composites of DDGS were formed (low, medium, and high) containing 5.9, 13.9, and 14.8% ADIN, respectively.

*Growing Trial.* For protein evaluation, 60 English crossbred calves (mean BW = 204 kg ± 17 kg) were allotted randomly and individually fed one of five supplemental protein treatments for 56 d (April to May 28, 1992). Calves were trained to use Calan gates (American Calan Inc., Northwood, NH) and were housed in a modified-open front barn with a gutter flush system. Diets (Table 1) were composed of approximately 32% sorghum silage, 50% ground corncobs, and 18% (DM basis) supplement and were formulated (DM basis) to contain a minimum of 11.5% CP, .50% Ca, .30% P, and .60% K. Distillers byproducts (WDB and DDGS: low, medium, and high ADIN) plus their respective dry supplement served as the distillers byproduct supplement and a urea-ground corn supplement (fine ground corn plus its respective dry supplement) served as the control. The distillers byproduct supplement was combined with the urea-ground corn supplement to provide increasing protein from the distillers byproducts (25, 34, 43, and 52% of the supplemental protein). Twelve calves were allotted to the urea control and 12 calves were allotted to each source of distillers byproduct (four distillers byproducts, four levels of protein; three calves per level of each byproduct). Protein efficiency was calculated for each treatment using the slope-ratio technique (Klopfenstein et al., 1985). Crude protein content of the WDB, DDGS composites, sorghum

Table 1. Composition of diets fed in growing calf trial

| | Distillers byproduct and ADIN level[a] | | | | |
|---|---|---|---|---|---|
| | | | DDGS | | |
| Item | Control | WDB | Low | Medium | High |
| Sorghum silage | 32.12 | 32.12 | 32.12 | 32.12 | 32.12 |
| Corncobs | 50.00 | 50.00 | 50.00 | 50.00 | 50.00 |
| Finely ground corn | 14.03 | — | — | — | — |
| Wet distillers grains | — | 9.52 | — | — | — |
| Thin stillage | — | 5.71 | — | — | — |
| Dried distillers grains plus solubles | | | | | |
| Low ADIN | — | — | 15.23 | — | — |
| Medium ADIN | — | — | — | 15.23 | — |
| High ADIN | — | — | — | — | 15.23 |
| Dry supplement | 3.85 | 2.65 | 2.65 | 2.65 | 2.65 |
| Ammonium sulfate | .23 | .13 | .13 | .13 | .13 |
| Urea | 2.01 | .98 | .98 | .98 | .98 |
| Salt | .30 | .30 | .30 | .30 | .30 |
| Limestone | .34 | .36 | .36 | .36 | .36 |
| Dicalcium phosphate | .89 | .80 | .80 | .80 | .80 |
| Vitamin premix[b] | .01 | .01 | .01 | .01 | .01 |
| Trace mineral premix[c] | .05 | .05 | .05 | .05 | .05 |
| Selenium premix[d] | .02 | .02 | .02 | .02 | .02 |

[a]%, DM basis; DDGS = dried distillers grains + solubles, WDB = wet distillers grains + thin stillage.
[b]15,000 IU of vitamin A, 3,000 IU of vitamin D, and 3.7 IU of vitamin E/g of premix.
[c]10% Mg, 6% Zn, 4.5% Fe, 2% Mn, .5% Cu, .3% I, and .05% Co.
[d]30 mg of selenium/kg of premix.

silage, and corncobs was analyzed by Kjeldahl N (AOAC, 1975). Diets were fed at an equal percentage of body weight to all animals and adjustments in feed offered were made weekly. Calves were implanted with Compudose (Elanco Animal Health, Indianapolis, IN) at the beginning of the trial. Initial and final weights were the average of three consecutive days' weights taken before feeding. A one-day weight was taken at 28 d.

To estimate ruminal escape values, approximately 1 g of each distillers byproduct source was placed in Dacron bags (7.5 × 12.5 $cm^2$; 50-$\mu$m pore size) and incubated for 12 h in the rumen of a steer fed a corncob-based diet (Goedeken et al., 1990). Escape protein values were estimated in duplicate. Escape values of proteins were estimated as the percentage of N remaining after 12 h of incubation in situ without correction for microbial attachment.

Intake and gain were analyzed as a completely randomized design according to the GLM procedures of SAS (1989). Animal was used as the experimental unit in all statistical evaluations. Initially, the urea treatment was excluded from the model. The model included distillers byproduct source, level of distillers byproduct, and the interaction of distillers source and level. No interaction ($P > .10$) was observed, and thus the data were then pooled across level of distillers protein and compared with urea. The following contrasts were then tested: urea vs average of all distillers byproducts, wet distillers vs average of DDGS, linear effect of ADIN level, and quadratic effect of ADIN level. Gain above the urea control and protein intake were subjected to nonlinear regression (NLIN procedure of SAS, 1989). This model forces a common intercept at the urea control. The slope derived from the nonlinear regression was used as the mean protein efficiency for each treatment. Mean protein efficiencies for each treatment were compared using a one-tailed $t$-test (Steel and Torrie, 1980). Protein efficiency and escape protein were correlated to ADIN level using procedures outlined by SAS (1989).

*Finishing Trial.* One hundred sixty English crossbred yearling steers (mean BW = 392 ± 18 kg) were used in a 99-d finishing trial (May 19 to August 24, 1992). Steers were blocked by weight and allotted randomly within block to one of five treatments (four pens per treatment, eight steers per pen). Treatments (DM basis) consisted of dry-rolled corn (**DRC**), or DRC replaced by 40% WDB or 40% DDGS containing either low, medium, or high ADIN. Final diets (DM basis; Table 2) contained 85% DRC and dry supplement or DRC, distillers byproducts and dry supplement, 5% corn silage, 5% alfalfa hay, and 5% molasses and were formulated (DM basis) to contain a minimum of 12% CP, .7% Ca, .35% P, .7% K, 28 mg of monensin (Elanco Animal Health)/kg of diet, and 11 mg of tylosin (Elanco Animal Health)/kg of diet. All cattle were adapted to final diets in 21 d using four grain adaptation diets containing 45 (3 d), 35 (5 d), 25 (6 d), and 15% (7 d) forage (DM basis). The forage was a mixture of ground alfalfa hay and corn silage; silage was assumed to be 50% grain and 50% forage.

Cattle were implanted with Compudose, offered feed once daily for ad libitum consumption, and were housed in an open-front confinement barn. Initial weights were the average of two weights taken on consecutive days before the morning feeding. To minimize variation in gut fill, hot carcass weights adjusted for a 62% dressing percentage were used to calculate final weights. At slaughter, hot carcass weight and liver abscess score were recorded. Livers were scored by modification of the procedures reported by Elanco Products Company (1974) using the following system: 0 = healthy liver, 1 = one to four small abscesses, 2 = one to four medium abscesses, 3 = one or more large abscesses, and 4 = adherence of abscess to diaphragm or digestive tract. Fat thickness at the 12th rib, quality grade, and yield grade were recorded after carcasses were chilled for 48 h.

Net energy for gain of each diet was calculated using the procedures outlined by Larson et al. (1993). These calculations include the $NE_g$ of each grain adaptation diet as well as the final finishing diet. The net energy required for gain (**$NE_gR$**) was calculated by the equation $NE_gR = .0557\ BW^{.75}\ (ADG^{1.097})$, where $NE_gR$ is the net energy required for daily weight gain (ADG; NRC, 1984). Maintenance net energy required (**$NE_mR$**) was calculated by the equation $NE_mR = .077\ BW^{.75}$ (NRC, 1984). The NE content of the diet for gain and maintenance was assumed to fit the relationship: $NE_g = .877\ NE_m - .41$ (derived from NRC, 1984; Zinn, 1989). By the process of iteration, the $NE_g$ and $NE_m$ contents of the diets were calculated to fit the equation $DMI = (NE_gR/NE_g) + (NE_mR/NE_m)$. The energy content of distillers byproducts was calculated by substitution, assuming basal ingredients possess the same energy value (NRC, 1984) across all diets.

Samples of wet distillers grains, thin stillage, and DDGS (low, medium, and high) were collected weekly and analyzed for DM content (55°C for 48 h) and Kjeldahl N (AOAC, 1975). Weekly samples were combined to form a trial composite, which was analyzed for fat content (chloroform-methanol extraction; Moore et al., 1986).

Analysis of variance procedures for a randomized complete block design were performed as outlined by Steel and Torrie (1980). Pen was the experimental unit and model effects included block and treatment. Means were computed and comparisons were made by partitioning treatment degrees of freedom into treatment contrasts according to the GLM procedures of SAS (1989). Contrasts were DRC vs WDB, DRC vs the average of low, medium, and high ADIN DDGS,

WDB vs the average of low, medium, and high ADIN DDGS, and linear effect of low, medium, and high ADIN DDGS.

*Lamb Trial.* Forty-two lambs (mean BW = 33 ± 2 kg) were blocked by weight and allotted randomly within block to three treatments. Treatments were based on the addition of ethanol, 0, 5, or 10% (DM basis), replacing DRC. The 5% ethanol simulated the ethanol intake of the finishing trial (Larson et al., 1993). The 10% level was chosen as a higher level in an attempt to detect treatment differences. Lambs were adapted to final diets (Table 3) in 20 d using four adaptation diets containing 45 (3 d), 35 (3 d), 25 (7 d), and 15% (7 d) ground alfalfa hay (DM basis). Diets were mixed daily for 5 min, immediately before feeding, to minimize volatilization of the ethanol. Lambs were offered feed for ad libitum consumption amounts once daily for 64 d, and orts were collected every 3 d. Lambs were individually housed in .9-m × .9-m pens equipped with nipple waterers in an environmentally controlled room (25°C). Initial and final weights were the average of weights taken on three consecutive days before feeding.

Analysis of variance procedures for a randomized complete block design were performed as outlined by Steel and Torrie (1980). Means were computed and linear and quadratic contrasts were made according to the GLM procedures of SAS (1989). Experimental unit was individual lamb and model effects included block and treatment.

*Metabolism Trial 1.* Six British crossbred steers (388 ± 24 kg BW) that had been previously fitted with permanent plastisol cannulas in the rumen, duodenum, and ileum were used in a 6 × 6 Latin square design. Steers had been previously fistulated following the procedures outlined by Stock et al. (1991) and all procedures had been reviewed and accepted by the University of Nebraska Institutional Animal Care

Table 2. Composition of diets fed in cattle finishing trial and Metabolism Trial 2

| | Treatment[a] | | | | |
|---|---|---|---|---|---|
| Item | DRC control | 40% WDB | 40% DDGS[b] | 25% WDG + 15% CDS | 15% CDS |
| Dry-rolled corn | 79.00 | 41.00 | 41.00 | 41.00 | 64.30 |
| Wet distillers grains | — | 25.00 | — | 25.00 | — |
| Thin stillage | — | 15.00 | — | — | — |
| Dried distillers grains plus solubles | — | — | 40.00 | — | — |
| Condensed solubles | — | — | — | 15.00 | 15.00 |
| Corn silage | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Alfalfa hay | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Cane molasses | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Supplement | 6.00 | 4.00 | 4.00 | 4.00 | 5.70 |
| Finely ground corn | — | 1.92 | 1.92 | 1.92 | .29 |
| Soybean meal | 3.23 | — | — | — | 2.89 |
| Animal fat | .12 | .08 | .08 | .08 | .10 |
| Limestone | 1.32 | 1.35 | 1.35 | 1.35 | 1.24 |
| Dicalcium phosphate | .15 | — | — | — | .12 |
| Potassium chloride | .25 | .19 | .19 | .19 | .23 |
| Ammonium sulfate | — | .07 | .07 | .07 | .01 |
| Salt | .30 | .30 | .30 | .30 | .30 |
| Urea | .54 | — | — | — | .43 |
| Trace mineral premix[c] | .05 | .05 | .05 | .05 | .05 |
| Vitamin premix[d] | .01 | .01 | .01 | .01 | .01 |
| Rumensin premix[e] | .02 | .02 | .02 | .02 | .02 |
| Tylan premix[f] | .01 | .01 | .01 | .01 | .01 |
| Nutrient composition, %[g] | | | | | |
| Crude protein | 12.60 | 15.02 | 15.73 | 15.73 | 15.73 |
| Calcium | .70 | .70 | .70 | .70 | .70 |
| Phosphorus | .35 | .47 | .47 | .47 | .47 |
| Potassium | .70 | .70 | .70 | .70 | .70 |

[a]%, DM basis; DRC = dry-rolled corn, WDB = wet distillers grains + thin stillage, DDGS = dry distillers grains + solubles, WDG + wet distillers grains, CDS = condensed solubles.
[b]Diet composition for low, medium, or high ADIN DDGS (finishing trial), and DDGS, or DDGS + water (metabolism trial).
[c]10% Mg, 6% Zn, 4.5% Fe, 2% Mn, .5% Cu, .3% I, and .05% Co.
[d]15,000 IU of vitamin A, 3000 IU of vitamin D, and 3.7 IU of vitamin E/g of premix.
[e]132 g of monensin/kg of premix.
[f]88 g of tylosin/kg of premix.
[g]Based on trial CP composite values for WDG, DDGS and thin stillage, remaining CP values based on NRC (1984).

Table 3. Composition of diets fed in lamb trial

| Item | Control | Ethanol level[a] 5% | 10% |
|---|---|---|---|
| Dry-rolled corn | 79.00 | 74.00 | 69.00 |
| Alfalfa hay | 5.00 | 5.00 | 5.00 |
| Corn silage | 5.00 | 5.00 | 5.00 |
| Molasses | 5.00 | 5.00 | 5.00 |
| Ethanol | — | 5.00 | 10.00 |
| Dry supplement | 6.00 | 6.00 | 6.00 |
| Finely ground corn | .14 | .14 | .14 |
| Soybean meal | 3.22 | 3.22 | 3.22 |
| Limestone | 1.32 | 1.32 | 1.32 |
| Dicalcium phosphate | .15 | .15 | .15 |
| Potassium chloride | .25 | .25 | .25 |
| Salt | .30 | .30 | .30 |
| Urea | .54 | .54 | .54 |
| Trace mineral premix[b] | .03 | .03 | .03 |
| Vitamin premix[c] | .03 | .03 | .03 |
| Selenium premix[d] | .02 | .02 | .02 |
| Nutrient composition, %[e] | | | |
| Crude protein | 12.62 | 12.12 | 11.62 |
| Calcium | .70 | .68 | .66 |
| Phosphorus | .37 | .35 | .33 |
| Potassium | .70 | .68 | .66 |

[a]%, DM basis.
[b]10% Mn, 10% Fe, 10% Zn, 1% Cu, .3% I, .1% Co.
[c]30,000 IU of vitamin A, 6,000 IU of vitamin D, 7.5 IU of vitamin E/g of premix.
[d]30 mg of selenium/kg of premix.
[e]Based on tabular values (NRC, 1984).

Program. Steers were housed in 1.8-m × 2.6-m individual pens in a 25°C temperature-controlled room.

Dietary treatments (Table 4) included DRC control, 40% wet distillers grains, 20% thin stillage, 40% hominy feed (**HOM**), 40% dry corn gluten feed (**DCGF**), or 40% wet corn gluten feed (**WCGF**). Corn byproducts were fed to replace DRC on a DM basis except for thin stillage, which was infused through the ruminal cannula. Corn gluten feed (DCGF and WCGF) was received from Minnesota Corn Processors (Marshal, MN). Wet byproducts (distillers grains and WCGF) were frozen in drums, thawed as needed, and stored at 3°C until fed. Thin stillage was obtained weekly and stored at 3°C. Chromic oxide (.25% of diet DM) was used as an indigestible marker. Steers had ad libitum access to the 90% concentrate control (DRC) diet for 3 wk before initiation of the experiment. Diets were fed every 2 h by automatic feeders and thin stillage was stirred continuously and infused every 2 h for 15 min via a Watson-Marlow pump (Falmouth, Cornwall, U.K). Steers were fed as much DM as possible without significant (< 10%) amounts of orts accumulating after each 2-h period. Each period of the Latin square consisted of a 10-d adaptation period and a 4-d digesta sampling period.

Samples of corn and the corn byproducts were collected during each period and composited for chemical analysis. Dry matter, ash, Kjeldahl N (AOAC, 1975), starch (Herrera-Saldana and Huber, 1989), NDF (Robertson and Van Soest, 1977), and fat (chloroform:methanol extraction; Moore et al., 1986) were determined.

Diet, ort, and fecal samples were collected on d 11 to 14 of each period. Approximately 200 g of fecal (grab sample) contents were collected every 8 h. Sampling time was advanced 2 h daily, such that every other hour of a 24-h cycle was represented in digesta collections. Fecal samples were composited on a volume basis by steer across time, within each period. After the last fecal sample was completed, ruminal samples were taken every 2 h for 8 h. One liter of ruminal fluid was collected per sample by straining contents through four layers of cheesecloth. A combination electrode was used to determine ruminal pH, 1 mL of $HgCl_2$ was added to stop microbial activity, and the samples were composited by steer within period and frozen. Diet subsamples were oven-dried at 60°C for 48 h and fecal subsamples were dried in a Virtis freeze dryer. All diet and fecal samples were ground through a 1-mm screen in a Wiley mill. Feed, ort, and fecal samples were analyzed for Cr (Williams et al., 1962), DM, ash, Kjeldahl N, starch, and NDF as described previously. Ruminal subsamples were analyzed for VFA (Erwin et al., 1961) by gas-liquid chromatography (Hewlett-Packard, Avondale, PA) using a packed (10% SP1200/1% $H_3PO_4$ on chromosorb WAW) glass column equipped with a flame ionization detector. Ammonia N (McCullough, 1967) was determined using automated procedures (Technicon Industrial Systems, Elmsford, NY).

Data were analyzed as a Latin square design according to the GLM procedures of SAS (1989). The model included steer, period, and treatment. Treatment means were separated by the protected Least Significant Difference method (Steele and Torrie, 1980) when a significant ($P < .10$) treatment $F$-test was detected.

*Metabolism Trial 2.* Five British crossbred steers (480 ± 20 kg) that had been previously fitted with permanent ruminal plastisol cannulas were used in a 5 × 5 Latin square design. Fistulation procedures, pen size, and housing conditions were the same as described in Metabolism Trial 1. Treatments were DRC (control), 25% wet distillers grains + 15% condensed distillers solubles (**CDS**), 40% medium ADIN DDGS without or with water added to equal the moisture content of the wet distillers grains and CDS, and 15% CDS. All distillers byproducts replaced DRC on a DM basis. Thin stillage was not available for this trial and was replaced (DM basis) with CDS. The medium ADIN DDGS was the same feed as used in the growing and finishing trials. To adapt cattle to diets, steers were fed their appropriate diets (Table 2) every 2 h via automatic feeders for 13 d. Diets were offered as close to ad libitum as possible, but yet trying to minimize orts. Bunks were evaluated once

Table 4. Composition of diets fed in Metabolism Trial 2

| Item | Treatment[a] | | | | | |
|---|---|---|---|---|---|---|
| | DRC | WDG | TS | HOM | DCGF | WCGF |
| Dry-rolled corn | 77.00 | 37.00 | 57.00 | 37.00 | 37.00 | 37.00 |
| Wet distillers grains | — | 40.00 | — | — | — | — |
| Thin stillage | — | — | 20.00[b] | — | — | — |
| Hominy feed | — | — | — | 40.00 | — | — |
| Dry corn gluten feed | — | — | — | — | 40.00 | — |
| Wet corn gluten feed | — | — | — | — | — | 40.00 |
| Corn silage | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Alfalfa hay | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Molasses | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 |
| Dry supplement | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Finely ground corn | 2.09 | 2.92 | 3.04 | 2.33 | 3.25 | 3.25 |
| Limestone | 1.38 | 1.36 | 1.40 | 1.43 | 1.36 | 1.36 |
| Dicalcium phosphate | .11 | — | — | .03 | — | — |
| Potassium chloride | .23 | .33 | .17 | .18 | — | — |
| Salt | .30 | .30 | .30 | .30 | .30 | .30 |
| Urea | .80 | — | — | .64 | — | — |
| Trace mineral premix[c] | .05 | .05 | .05 | .05 | .05 | .05 |
| Vitamin premix[d] | .01 | .01 | .01 | .01 | .01 | .01 |
| Rumensin premix[e] | .02 | .02 | .02 | .02 | .02 | .02 |
| Tylan premix[f] | .01 | .01 | .01 | .01 | .01 | .01 |
| Nutrient composition, % | | | | | | |
| Starch | 58.9 | 36.7 | 50.3 | 50.8 | 41.2 | 39.7 |
| Crude protein | 11.8 | 16.4 | 11.6 | 12.4 | 11.5 | 13.1 |
| NDF | 14.4 | 27.3 | 14.3 | 19.3 | 27.4 | 25.4 |
| Fat | 4.1 | 8.2 | 5.4 | 4.2 | 5.4 | 5.5 |
| Ash | 4.3 | 5.3 | 4.9 | 5.0 | 4.6 | 5.8 |

[a]%, DM basis; DRC = dry-rolled corn, WDG = wet distillers grain, TS = thin stillage, HOM = hominy feed, DCGF = dry corn gluten feed, WCGF = wet corn gluten feed.
[b]Infused through ruminal cannula.
[c]10% Mg, 6% Zn, 4.5% Fe, 2% Mn, .5% Cu, .3% I, and .05% Co.
[d]15,000 IU of vitamin A, 3,000 IU of vitamin D, and 3.75 IU of vitamin E/g of premix.
[e]132 g of monensin/kg of premix.
[f]88 g of tylosin/kg of premix.

daily and feed offered was adjusted in .45-kg of DM increments according to the previous day's estimated intakes.

Each metabolism period lasted for 14 d; d 14 was used for dosing and sampling. Liquid flow rate was measured by Cr:EDTA and Yb was used to measure passage rate of DRC; Er was used to measure passage rate of wet distillers grains and DDGS. At 0800 on d 14, 200 mL of Cr-EDTA (2.7 g Cr/L), and .5 kg of DM of Yb-labeled DRC (3,000 mg Yb/kg) were dosed to all steers. In addition, steers were dosed with 200 g of DM of Er-labeled DDGS (2,200 mg Er/kg), wet distillers grains (24,300 mg Er/kg), or DDGS + water (4,800 Er/kg), based on their assigned treatment. Ruminal fluid was collected via the cannula at 0 (before dosing), 6, 12, 18, and 24 h using the suction strainer technique (Raun and Burroughs, 1962). Immediately after collection, pH was determined via a combination electrode, and samples were frozen for later analysis of VFA. Ruminal fluid was analyzed for VFA as described previously on samples collected for each animal and hour of collection.

At 24 h, ruminal contents were evacuated, weighed, and subsampled for determination of DM and starch content, and contents were returned to the rumen. Subsamples were dried in a forced-air oven at 55°C for 48 h, and starch content was determined as described previously.

The Cr-EDTA was prepared as described by Binnerts et al. (1968). After samples were thawed and centrifuged, Cr concentration was determined with an air-acetylene flame using atomic absorption spectroscopy. Liquid dilution rates were calculated as described by Jacques et al. (1986). The Yb and Er treatments were prepared according to procedures outlined by Teeter et al. (1984). Each feed was allowed to soak in a tub with 28 m*M* Yb or Er for 12 h at 25°C. Excess marker solution was strained through four layers of cheesecloth, and a weighted garden hose was placed in the tub. The tub was covered with four layers of cheesecloth and the feed was rinsed with tap water for 6 h. The pH of the tap water + feed was adjusted to 4.5 with HCl. The feed was allowed to soak for an additional 6 h and was rinsed again with tap water for 6 h. Excess tap water was strained through four layers of cheesecloth, and the labeled DRC and DDGS were dried in a forced-air oven at 55°C for 48 h. Samples of the wet distillers grains and DDGS +

Table 5. Calf gains and protein efficiencies[a], growing trial

| Supplemental protein | Daily gain, kg[b] | Protein efficiency[c] | Protein escape, %[d] | ADIN, % of N |
|---|---|---|---|---|
| Urea | .45 | — | — | — |
| Wet distillers byproducts | .66 | 2.6 | 54.9 | 7.3 |
| DDGS[e] low ADIN | .65 | 2.0 | 38.0 | 5.9 |
| DDGS medium ADIN | .67 | 1.8 | 47.4 | 13.9 |
| DDGS high ADIN | .70 | 2.5 | 49.4 | 14.8 |
| SEM | .04 | .3 | — | — |

[a]Intake averaged 2.3% (DM) of body weight.
[b]Averaged across levels of supplemental protein; urea vs average of all distillers byproducts ($P < .001$).
[c]Gain above urea controls divided by protein intake above urea controls (slopes of regression lines).
[d]12-h Dacron bag escape values, % of CP.
[e]DDGS = dried distillers grains plus solubles.

water were dried, as previously described to determine the amount of wet byproduct to dose. On d 14, grab samples of ruminal digesta were taken, at the same time as liquid samples, 0, 6, 12, 18, and 24 h after dosing. Samples were dried at 55°C for 48 h in a forced-air oven and ground through a 2-mm screen. Marker was extracted by diethylenetriaminepentaacetic acid as outlined by Karimi et al. (1986), with one modification. Supernatant was double-filtered rather than centrifuged and then filtered. Marker concentration was determined by atomic absorption spectroscopy using a nitrous oxide-acetylene flame.

All data, except ruminal pH and VFA, were analyzed as a Latin square design according to analysis of variance procedures outlined by Steel and Torrie (1980). Animal was the experimental unit and the model included steer, period, and treatment. Means were separated using the Duncan's Multiple Range Test (alpha = .10) according to the GLM procedures of SAS (1989). The ruminal pH and VFA data were analyzed as a split plot design according to the GLM procedures of SAS (1989). Whole-plot variables were steer, treatment, and period with steer × treatment × period as the error term. Sub-plot variables were hour, its interactions with the whole-plot variables, and residual error. Means were separated using the Duncan's Multiple Range Test (alpha = .10) according to the GLM procedures of SAS (1989).

## Results

*Growing Trial.* Calves fed the urea control gained less ($P < .001$) than those fed the distillers byproducts (Table 5). No significant differences were observed ($P > .10$) in daily gains when averaged across protein levels with each distiller's byproduct. Cattle fed WDB had numerically higher protein efficiency values than those fed DDGS, but the differences were not significant ($P > .10$).

Protein efficiency values for the DDGS composites were similar. In general, escape protein content increased as ADIN concentration increased in the DDGS composites. However, the highest escape value occurred with WDB, which had a low ADIN concentration because it was not dried. Neither escape protein content nor protein efficiency was correlated (r = .29 and −.08, respectively; $P > .70$) with ADIN. We therefore conclude that the higher ADIN levels of the

Table 6. Effect of wet or dry distillers byproducts on finishing cattle performance

| | Distillers byproduct and ADIN level[a] | | | | | |
|---|---|---|---|---|---|---|
| | | | DDGS | | | |
| Item | Control | WDB | Low | Medium | High | SEM |
| Daily gain, kg[bc] | 1.46 | 1.69 | 1.66 | 1.68 | 1.71 | .12 |
| Dry matter intake, kg/d[de] | 10.99 | 10.68 | 11.48 | 11.36 | 11.73 | .55 |
| Gain/feed[bce] | .133 | .158 | .144 | .148 | .145 | .004 |
| $NE_g$ diet, Mcal/kg[bcf] | 1.24 | 1.45 | 1.31 | 1.35 | 1.38 | .04 |

[a]DDGS = dried distillers grains plus solubles, WDB = wet distillers byproducts.
[b]Control vs WDB ($P < .05$).
[c]Control vs average of DDGS composites ($P < .05$).
[d]Control vs average of DDGS composites ($P < .10$).
[e]WDB vs average of DDGS composites ($P < .05$).
[f]WDB vs average of DDGS composites ($P < .10$).

Table 7. Effects of ethanol on lamb performance

| Item | Ethanol, % of diet DM | | | |
|---|---|---|---|---|
| | Control | 5% | 10% | SEM |
| Daily gain, kg | .34 | .34 | .34 | .04 |
| Dry matter intake, kg/d | 1.92 | 2.03 | 2.03 | .14 |
| Gain/feed[a] | .177 | .170 | .167 | .004 |

[a]Linear effect ($P = .15$).

DDGS sources, presumably produced during drying, did not cause higher escape values. Further ADIN was not an accurate predictor of protein value of the DDGS sources.

*Finishing Trial.* Cattle fed the wet and dried distillers byproducts gained ($P < .05$) faster and more efficiently ($P < .05$) than cattle fed the DRC control diet (Table 6). Although gains were similar ($P > .10$), cattle fed WDB consumed less feed ($P < .05$) and were more efficient ($P < .05$) than cattle fed DDGS. Level of ADIN (low, medium, or high) in the DDGS did not ($P > .10$) affect cattle performance when DDGS was fed as a major source of energy. Liver abscess score, fat thickness, yield grade, and quality grade were not affected by treatment and averaged .11, 3 cm, 2.90, and 19.0 (low Choice = 19.0), respectively.

The estimated $NE_g$ content for the control diet (Table 6), based on animal performance, was 1.24 Mcal/kg, which is 9% lower than the energy values for the ingredients listed in the 1984 NRC (1.37 Mcal/kg). The DRC control diet contained less ($P < .05$) energy than the WDB or DDGS diets. The estimated $NE_g$ content of the DDGS composites was similar ($P > .10$). Based on a corn $NE_g$ value of 1.55 Mcal/kg (NRC, 1984), the $NE_g$ value of DDGS ranged from 1.77 to 1.97 Mcal/kg and averaged 1.87 Mcal/kg, whereas the WDB contained 2.16 Mcal/kg. In this trial, WDB, when fed at 40% of the diet DM, contained 39% more $NE_g$ and DDGS contained an average 21% more $NE_g$ than DRC.

Based on weekly composites, wet distillers grains ranged from 26.5 to 37.6% DM and averaged 32.0% DM, and thin stillage ranged from 3.2 to 6.1% DM and averaged 4.6% DM. Crude protein content ranged from 25.0 to 27.9% and averaged 26.4% protein. Thin stillage ranged from 12.6 to 21.8% and averaged 17.9% protein. Fat content (DM basis) of the wet distillers grains, thin stillage, and DDGS (low, medium, and high) was 16.6, 9.2, 13.3, 14.5, and 16.0%, respectively.

*Lamb Trial.* When ethanol replaced DRC (Table 7) at 0, 5, or 10%, no linear ($P > .10$) or quadratic effects were detected for daily gain or DMI. As ethanol increased, feed efficiency tended to decrease (linear, $P = .15$).

*Metabolism Trial 1.* Processing method affected the nutrient composition of corn byproducts (Table 8). Compared with corn, wet distillers grains contained minimal starch, four times more NDF, three times more CP and fat, and two times more ash. Compared with corn, thin stillage contained 65% less starch, similar amounts of NDF, twice the CP and fat, and almost four times the ash, and hominy feed contained 27% less starch and twice the NDF and ash, but similar amounts of CP and fat. Compared with corn, corn gluten feed contained approximately 70% less starch, twice as much CP, and 70% more fat.

Organic matter intake did not differ among treatments (Table 9); thus, starch, NDF, and N intake reflected relative differences in nutrient concentration among dietary feeds. Starch intake was highest ($P < .10$) with DRC and lowest ($P < .10$) with wet distillers grains, DCGF, and WCGF. Neutral detergent fiber intake was lowest ($P < .10$) with DRC and thin stillage. Nitrogen intake was highest ($P < .10$) with wet distillers grains.

Table 8. Chemical analysis of corn and corn byproducts (% of DM)

| Item | Corn and corn byproducts[a] | | | | | |
|---|---|---|---|---|---|---|
| | DRC | WDG | TS | HOM | DCGF | WCGF |
| Starch | 71.3 | 6.2 | 25.1 | 51.9 | 19.8 | 22.5 |
| NDF | 10.9 | 44.3 | 13.3 | 25.2 | 49.2 | 41.9 |
| Crude protein | 10.1 | 28.1 | 19.0 | 11.1 | 20.5 | 18.5 |
| Fat | 4.9 | 15.4 | 9.2 | 5.3 | 8.2 | 8.4 |
| Ash | 1.7 | 3.1 | 6.7 | 3.3 | 2.5 | 3.8 |
| Dry matter | 89.8 | 27.9 | 4.4 | 90.2 | 47.6 | 4.4 |

[a]DRC = dry-rolled corn, WDG = wet distillers grains, TS = thin stillage, HOM = hominy feed, DCGF = dry corn gluten feed, WCGF = wet corn gluten feed.

Table 9. Effect of corn byproducts on intake and total tract nutrient digestibility in Metabolism Trial 1

| Item | Treatment[a] | | | | | | SEM |
|---|---|---|---|---|---|---|---|
| | DRC | WDG | TS | HOM | DCGF | WCGF | |
| Intake, g/d | | | | | | | |
| OM | 6,585 | 5,864 | 6,226 | 5,948 | 6,498 | 6,241 | 423 |
| Starch | 4,045$^{b}$ | 2,306$^{c}$ | 3,177$^{d}$ | 3,180$^{d}$ | 2,879$^{cd}$ | 2,627$^{cd}$ | 242 |
| NDF | 990$^{bd}$ | 1,693$^{c}$ | 927$^{b}$ | 1,207$^{d}$ | 1,865$^{c}$ | 1,682$^{c}$ | 98 |
| N | 127$^{b}$ | 162$^{c}$ | 126$^{b}$ | 123$^{b}$ | 119$^{b}$ | 140$^{bc}$ | 10 |
| Digestibility, % | | | | | | | |
| OM | 82.8$^{b}$ | 81.3$^{bd}$ | 88.3$^{c}$ | 83.2$^{b}$ | 80.1$^{d}$ | 83.6$^{b}$ | 1.0 |
| Starch | 91.7$^{b}$ | 93.9$^{c}$ | 96.4$^{d}$ | 92.9$^{bc}$ | 94.0$^{c}$ | 94.5$^{cd}$ | .9 |
| NDF | 62.5$^{b}$ | 69.6$^{c}$ | 72.0$^{c}$ | 70.1$^{c}$ | 63.2$^{b}$ | 73.5$^{c}$ | 2.4 |
| N | 74.9$^{bc}$ | 79.1$^{d}$ | 78.5$^{bd}$ | 72.6$^{c}$ | 71.4$^{c}$ | 77.2$^{bd}$ | 1.6 |

[a]DRC = dry-rolled corn, WDG = wet distillers grains, TS = thin stillage, HOM = hominy feed, DCGF = dry corn gluten feed, WCGF = wet corn gluten feed.
[b,c,d]Means within a row with different superscripts differ ($P < .10$).

Among the byproduct treatments, steers infused with thin stillage had higher total tract NDF and starch digestibilities, resulting in the highest ($P < .01$) OM digestibility. Steers fed DCGF had the lowest ($P < .01$) NDF digestibility, which resulted in reduced ($P < .10$) OM digestibility. Starch, NDF, and OM digestibility of the remaining byproduct feeds tended to be intermediate to the results obtained with thin stillage and DCGF. Nitrogen digestibility of the wet byproducts (wet distillers grains, thin stillage, WCGF) was higher ($P < .01$) than that of the dry byproducts (hominy, DCGF).

Ruminal pH (Table 10) was similar among steers fed DRC, wet distillers grains, HOM, DCGF, or WCGF but was higher ($P < .10$) than that of steers infused with thin stillage. Although total VFA concentration was similar among all diets, steers infused with thin stillage had a higher ($P < .10$) propionate concentration, resulting in a reduced ($P < .10$) acetate:propionate ratio.

Ruminal $NH_3$ N concentration did not mimic dietary N concentration. Ammonia N concentration was highest ($P < .10$) on the DRC, HOM, and WCGF diets and lowest ($P < .10$) on the wet distillers grains and thin stillage diets; it was intermediate when DCGF was fed.

*Metabolism Trial 2.* Feeding 25% wet distillers grains and 15% CDS reduced ($P < .10$) DMI compared with all other treatments (Table 11). Feeding DDGS + water reduced ($P < .10$) DMI compared with DRC, DDGS, and CDS. Starch in the rumen as a percentage of DM was similar ($P > .10$) for the DRC, DDGS, and CDS, and DRC and DDGS was higher ($P < .10$) than WDG and DDGS + water. Particulate passage rate of DRC was not affected ($P > .10$) by addition of distillers byproducts in the diet. Particulate passage rate of the DDGS was faster ($P < .10$) than DDGS + water, whereas passage rate of WDG was intermediate compared with DDGS and DDGS + water. Liquid passage rate ranged from 4.3%/h for CDS to 6.3%/h for

Table 10. Effect of corn byproducts on ruminal fluid pH, VFA and $NH_3$ N concentrations in Metabolism Trial 1

| Item | Treatment[a] | | | | | | SEM |
|---|---|---|---|---|---|---|---|
| | DRC | WDG | TS | HOM | DCGF | WCGF | |
| Ruminal pH | 6.05$^{b}$ | 5.98$^{b}$ | 5.74$^{c}$ | 6.07$^{b}$ | 6.12$^{b}$ | 6.14$^{b}$ | .10 |
| Total VFA, m*M* | 112.74 | 111.64 | 115.03 | 112.16 | 111.18 | 108.46 | 6.88 |
| Acetate | 59.01 | 59.46 | 49.28 | 59.61 | 56.60 | 56.91 | 3.78 |
| Propionate | 32.39$^{b}$ | 26.51$^{b}$ | 45.41$^{c}$ | 31.05$^{b}$ | 29.68$^{b}$ | 29.76$^{b}$ | 3.95 |
| Isobutyrate | .97 | .95 | .80 | .82 | 1.21 | 1.13 | .12 |
| Butyrate | 14.78 | 14.85 | 13.32 | 15.66 | 18.63 | 15.44 | 1.69 |
| Isovalerate | 3.78$^{b}$ | 5.87$^{c}$ | 2.40$^{b}$ | 3.40$^{b}$ | 3.15$^{b}$ | 3.07$^{b}$ | .63 |
| Valerate | 1.80$^{b}$ | 4.01$^{c}$ | 3.82$^{c}$ | 1.62$^{b}$ | 1.92$^{b}$ | 2.16$^{b}$ | .37 |
| Acetate:propionate | 1.89$^{b}$ | 2.37$^{b}$ | 1.19$^{c}$ | 2.11$^{b}$ | 2.06$^{b}$ | 1.94$^{b}$ | .21 |
| $NH_3$ N, mg/dL | 19.76$^{b}$ | 9.51$^{c}$ | 9.13$^{c}$ | 15.82$^{bd}$ | 11.18$^{ce}$ | 14.27$^{de}$ | 1.76 |

[a]DRC = dry=rolled corn, WDG = wet distillers grains, TS = thin stillage, HOM = hominy feed, DCGF = dry corn gluten feed, WCGF = wet corn gluten feed.
[b,c,d,e]Within a row, means with unlike superscripts differ ($P < .10$).

Table 11. Effect of distillers byproducts on DMI and ruminal characteristics in Metabolism Trial 2

| | Treatment[a] | | | | | |
|---|---|---|---|---|---|---|
| Item | DRC | 40% WDG+ 15% CDS | 40% DDGS | 40% DDGS+ water | 15% CDS | SEM |
| DM intake, kg/d | 9.41[b] | 6.74[c] | 9.18[b] | 8.15[d] | 9.43[b] | .62 |
| Starch, % of DM | 4.49[b] | 2.13[c] | 3.86[b] | 2.33[c] | 3.30[bc] | .56 |
| Passage rate, %/h | | | | | | |
| DRC | 5.8 | 5.0 | 6.3 | 6.8 | 4.5 | 1.2 |
| DB | — | 5.4[bc] | 6.3[b] | 3.8[c] | — | .7 |
| Liquid flow | 6.0 | 4.8 | 5.9 | 6.3 | 4.3 | .8 |

[a]DRC = dry-rolled corn, WDG = wet distillers grains, CDS = condensed distillers solubles, DDGS = dry distillers grain + solubles, DB = distillers byproducts.
[b,c,d]Means within a row with unlike superscripts differ ($P < .10$).

DDGS + water; however, differences were not significant ($P > .10$).

No time × treatment interactions were observed ($P > .10$) for ruminal pH or VFA; therefore, data were pooled across hours (Table 12). Ruminal pH was lower ($P < .10$) for CDS than for DRC and DDGS + water and was similar ($P > .10$) for DRC, DDGS, WDG + CDS, and DDGS + water.

Total VFA were higher ($P < .10$) for CDS than for DDGS + water, whereas all other treatments were intermediate and a similar pattern was noted for each VFA measured. The DRC was similar ($P > .10$) to all distillers byproduct diets for propionate, isobutyrate, butyrate, isovalerate, valerate, total VFA, and acetate: propionate ratio, and was different ($P < .10$) only from DDGS + water for acetate. Propionate concentration was higher ($P < .10$) for CDS than for WDG + CDS, DDGS, and DDGS + water.

## Discussion

Many commercial feed laboratories use ADIN as an estimate of N digestibility for protein sources. Similar protein efficiencies in the growing trial support prior research (Plegge et al., 1985; Britton et al., 1986; Rogers et al., 1986; Nakamura et al., 1994) that suggested ADIN was a poor indicator of protein damage in protein supplements. Distillers byproducts are a good source of bypass protein, and drying seems to have little effect on the value of the protein for growing calves. The growing trial data indicate distillers byproducts can be fed wet or dry, and equal protein value will be obtained.

In the finishing trial, level of ADIN in the DDGS did not affect daily gain, DMI, or feed efficiency; however, cattle fed the DDGS diets were 9.5% (average) more efficient ($P < .05$) than cattle fed the DRC diets but nearly 8% less ($P < .05$) efficient than cattle fed the WDB diet. Ward and Matsushima (1981) evaluated dried distillers grains as an energy source for finishing cattle by replacing 0, 15, or 30% of the DRC with dried distillers grains and found performance to be similar for all diets. Their distillers grains were from corn, sorghum, and a mixture of grains and contained less fat and more CP than the DDGS used in our trials. In addition, the fiber in sorghum may not be as digestible as the fiber in corn. Thus, the combination of less fat and less digestible fiber may have reduced their $NE_g$ value of dried distillers grains.

Table 12. Effect of distillers byproducts on VFA concentrations in Metabolism Trial 2

| | Treatment[a] | | | | | |
|---|---|---|---|---|---|---|
| Item | DRC | 40% WDG+ 15% CDS | 40% DDGS | 40% DDGS+ water | 15% CDS | SEM |
| Ruminal pH | 5.83[b] | 5.68[bc] | 5.75[bc] | 5.94[b] | 5.50[c] | .35 |
| Total VFA, m*M* | 115.6[bc] | 105.3[bc] | 103.0[bc] | 95.9[c] | 123.3[b] | 7.5 |
| Acetate | 57.1[b] | 54.0[bc] | 54.8[bc] | 47.7[c] | 56.4[b] | 2.8 |
| Propionate | 39.7[bc] | 30.0[c] | 30.4[c] | 31.0[c] | 47.9[b] | 5.2 |
| Isobutyrate | .7 | .8 | .7 | .6 | .7 | .1 |
| Butyrate | 14.3 | 15.0 | 13.8 | 13.1 | 14.4 | 2.2 |
| Isovalerate | 2.1[bc] | 3.3[b] | 2.0[bc] | 1.6[c] | 1.8[c] | .5 |
| Valerate | 1.7 | 2.2 | 1.4 | 2.0 | 2.2 | .3 |
| Acetate:propionate | 1.6 | 1.9 | 1.9 | 1.8 | 1.3 | .2 |

[a]DRC = dry-rolled corn, WDG = wet distillers grains, CDS = condensed distillers solubles, DDGS = dry distillers grains + solubles.
[b,c]Means within a row with unlike superscripts differ ($P < .10$).

Steers fed the 40% WDB diet were 18.8% more efficient compared with steers fed the DRC diet. Similar to our results, Larson et al. (1993) reported a 14 and 20% increase in efficiency for finishing calves and yearlings, respectively, when WDB replaced 40% of the DRC in finishing diets. Additionally, Farlin (1981) reported 12 and 11% increases in feed efficiency when WDG replaced 50 or 75% of the corn in finishing diets, and Firkins et al. (1985) reported an 11% increase in efficiency when 50% WDG replaced DRC in finishing diets.

The WDB used in the finishing trial contained 2.16 Mcal of $NE_g$ (1.39 times more energy than corn), whereas DDGS contained an average 1.87 Mcal of $NE_g$ (1.20 times more energy than corn). Similar to these results, Larson et al. (1993) reported WDB contained an average of 2.53 Mcal of $NE_g$/kg (1.6 times more energy than corn) for yearlings and 1.96 Mcal of $NE_g$/kg (1.3 times more energy than corn) for calves.

Factors that may account for increased feed efficiency include increased energy in distillers byproducts, a possible reduction in subacute acidosis, a change in microbial population, and the effect of added moisture. Both WDB (13.8% fat) and DDGS (14.6% fat) contained over 2.8 times more fat (corn oil) than DRC (4.9%). However, the additional fat content could only account for 9 or 10% more energy for WDB and DDGS, respectively, than corn. In addition, WDB may contain ethanol (Larson et al., 1993), which should not be present in DDGS due to volatilization during the drying process. Kreul et al. (1994) reported that supplementing 4% of the diet with ethanol did not affect finishing performance of steers. Based on these results and the results of the lamb trial, ethanol does not seem to affect efficiency of feed conversion of DRC finishing diets.

Increased feed efficiency when feeding distillers byproducts may in part be due to reduced subacute acidosis (Farlin, 1981; Firkins et al., 1985; Larson et al., 1993), which would reduce gain and efficiency (Stock et al., 1990). High starch intake leads to increased production of ruminal organic acids that may result in subacute acidosis (Burrin and Britton, 1986). The corn byproducts used in our studies contained less starch and more fat and NDF than corn. However, in the metabolism studies, the high-fiber byproducts did not affect ruminal pH or concentration of total VFA. Because steers were fed or infused every 2 h, intake patterns may have been artificially altered and may be different from feedlot situations. Except for the diet containing DCGF, all other byproducts had OM digestibility similar to DRC, which agrees with the data of Firkins et al. (1984). Ruminal fiber digestibility is usually low in finishing diets (Axe et al., 1987; Stock et al., 1987). However, total-tract NDF digestion was approximately 70% (excluding DCGF), which indicates a significant amount of postruminal NDF digestion probably occurred. Therefore, replacing starch (grain) with a combination of highly digestible fiber (DeHaan, 1983) that is most likely digested postruminally and with fat and protein should reduce the total amount of acids produced in the rumen, thereby reducing the potential for subacute acidosis.

One notable exception, with the VFA data, was the increased propionate concentration when 20% thin stillage was infused or when 15% CDS was fed, suggesting an alteration of microbial populations. Thin stillage and CDS reduced ruminal pH, which may have reduced protozoal populations. Reduced protozoal populations have been associated with a lower ruminal pH (Purser and Moir, 1959; Mendoza, 1991) and lower acetate:propionate ratio (Whitelaw et al., 1972).

Moisture content of the corn byproducts also may affect performance. Adding water to DDGS reduced ($P < .10$) DMI and rate of passage from the rumen. The additional moisture added to DDGS or when WDB was fed may have resulted in a larger particle size that might slow the rate of passage (Firkins et al., 1985) and increase NDF digestibility as was observed in Metabolism Trial 1. Lahr et al. (1983), Hanke et al. (1983), and Ham et al. (1993) reported reduced intakes but similar feed efficiencies when water was added to reduce DM content of diets of similar formulation. Thus, moisture content of WDB probably plays a minor role in the improvement of efficiency of gain of finishing cattle.

## Implications

Feed efficiency of finishing diets may not be maximized by feeding diets high in starch. A combination of highly degradable corn fiber, fat and protein, such as with wet distillers grains and thin stillage, may be needed to maximize performance. Understanding the mechanisms of energy utilization with distillers byproducts may allow for formulation of finishing diets using different byproducts that combine these same factors so that maximum efficiency of gain can be provided at an economical price.

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