Effects of wet corn distiller's grains with solubles and nonprotein nitrogen on feeding efficiency, growth performance, carcass characteristics, and nutrient losses of yearling steers[1,2]

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ABSTRACT: Wet distiller's grains with solubles (**WDGS**) are a common by-product feedstuff generated by the grain–ethanol industry, and it is used extensively by the cattle feeding industry. Distillers grains are typically high in protein; however, the protein in WDGS has a low ruminal degradability, and thus may result in a deficiency of RDP in the diet even when dietary CP concentrations are high. Assessment of the RDP needs in diets containing WDGS is needed to aid the cattle feeding industry in managing feed costs and potential environmental issues. To that end, we conducted 2 feeding studies to evaluate the supplemental RDP requirements of beef cattle fed steam-flaked corn-based finishing diets. In Exp. 1, 525 yearling steers (initial body weight = 373 ± 13 kg) received treatments in a 2 × 3 + 1 factorial. Dietary factors included WDGS (15 or 30% of DM) and nonprotein N (**NPN**; 0, 1.5, or 3.0% of DM) from urea (0, 0.52, and 1.06%). The control diet without WDGS contained 3.0% NPN (1.06% urea) and cottonseed meal. Diets were formulated to have equal crude fat concentrations. Overall gain efficiency among steers fed 15% WDGS was greatest for 1.5% NPN and least for 0% NPN ($P = 0.07$, quadratic), whereas gain efficiency decreased linearly ($P < 0.09$) as NPN increased in the 30% WDGS diets. Dressing percent was greater ($P < 0.01$) for the Control diet than for 15 or 30% WDGS. In Exp. 2, 296 steer calves (initial BW = 344 ± 12 kg) were fed 1 of 4 experimental diets that included a Control diet without WDGS (contained 3% NPN from urea, and cottonseed meal) and 15% WDGS diets with either 1.50, 2.25, or 3.00% NPN (0.52, 0.78, and 1.04% urea, respectively, on a DM basis). Overall gain efficiency on either a live or carcass-adjusted basis was not different among treatments ($P > 0.15$). Dietary NPN concentration did not influence growth performance ($P > 0.21$). Increasing dietary WDGS concentration resulted in decreasing ($P < 0.05$) diet digestibility (determined with an internal marker) and increasing ($P < 0.05$) N volatilization losses (determined by diet and manure N:P ratio); however, the effects of NPN level on digestibility and N losses were somewhat inconsistent across experiments. Results suggest that optimum performance for cattle fed 15% WDGS occurred when the diet contained between 1.5 and 2.25% NPN. However, no supplemental NPN was needed to support optimum performance in diets containing 30% WDGS.

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INTRODUCTION

Wet distiller's grains with solubles (**WDGS**), the most common feedstuff generated by the ethanol industry, are extensively used by the cattle feeding industry. A growing body of information is available describing the feeding value of corn-based WDGS in diets based on dry-rolled corn (**DRC**). However, less information is available on the feeding value of WDGS in diets based on steam-flaked corn (**SFC**) and there appears to be a grain processing × WDGS interaction on feedlot performance of cattle (Cole et al., 2009; Galyean et al., 2012). Distillers grains are high in CP; however, the CP in distiller's grains has a relatively low ruminal degradability (NRC, 2000; NASEM, 2016). Therefore, although the CP concentration of diets containing WDGS may seem adequate, there could be a deficiency in RDP. This may be especially true in diets based on SFC because the RDP requirement of cattle fed diets based on SFC is greater than cattle-fed diets based on DRC (Galyean, 1996). However, the effects of dietary WDGS inclusion on the optimal form and quantity of dietary CP and RDP are not known. In addition, the effects on feeding logistics, diet digestibility, and nutrient losses are not known.

Previous research has demonstrated the benefits of using nonprotein nitrogen (**NPN**: urea) for feedlot cattle fed high-concentrate diets. Healy et al. (1995) reported greater ADG when urea replaced soybean meal (at a constant CP level of 13%) in finishing diets based on SFC. With DRC-based diets, Milton et al. (1997) noted that ADG increased quadratically with increasing dietary urea, being optimal in the range between 0.35 and 0.7% urea. In contrast, Vasconcelos et al. (2007) noted a linear decrease in ADG by steers fed 10% sorghum WDGS diets supplemented with 0.68, 0.89, and 1.09% of urea, compared with control animals fed 0% sorghum WDGS and supplemented with cottonseed meal and urea.

Therefore, the objectives of these experiments were to determine the effects of supplemental NPN in finishing diets based on SFC and containing WDGS on animal performance, carcass traits, nutrient digestion, and N losses.

MATERIALS AND METHODS

All procedures and protocols used in these experiments were reviewed and approved by the WTAMU-Cooperative Research, Education, and Extension Team (CREET) Animal Care and Use Committee (protocol number 2008-03).

Experiment 1

Animal management and treatments. Five hundred and sixty-four crossbred steers were procured from an order buyer. One hundred and nine steers were transported 2,517 km from an auction market in Lakeland, Florida to the West Texas A&M Research Feedlot south of Canyon, TX, and the remaining steers traveled an average of 338 km directly from ranches in Oklahoma. Steers were processed within 48 h of arrival and adapted to a high-concentrate finishing diet over 21 d by decreasing dietary roughage concentrations from 40 to 25 to 17 to 8% (with 0% WDGS) in 7-d intervals. Processing included individual identification, vaccination against viral antigens of IBR, PI_3, and BVD type I and II (Vista 3; Intervet/Schering-Plough Animal Health, Millsboro, DE), administration of a Clostridial bacterin-toxoid (Vision 7 with Spur; Intervet/Schering Plough Animal Health), treatment for internal and external parasites (Ivomec Plus, Merial Ltd., Duluth, GA; and Safe-Guard, Intervet/Schering-Plough Animal Health), excision of any existing implant(s), horn tipping to a diameter of approximately 2.54 cm, and implanting with Revalor-IS (16 mg estradiol and 80 mg trenbolone acetate: Intervet/Schering-Plough Animal Health).

Two days before the experiment began, steers were weighed before feeding to obtain a sorting BW. Five hundred and fifty steers were selected for the study and blocked by BW into 8 blocks based on sorting weight. Treatments were randomized to pens and steers were randomly assigned to treatments within block. Steers were weighed again the first day of the experiment before the first feeding of the day and were sorted into treatment pens as they exited the squeeze chute/individual scales. Steers were moved to their respective study pen and treatments began when feed was delivered later that morning. Initial BW for the study was the average of the BW determined on these 2 d. Scales used for weighing procedures were validated with 20, 22.7-kg certified weights before use and calibrated when needed. Acceptable accuracy required > 97.5% agreement between the actual and theoretical weight, and the scale was calibrated if the validation was below this threshold.

Treatments were arranged in a 2 × 3 + 1 factorial of dietary WDGS concentration (15 or 30% of DM) and 0, 1.5, or 3.0% nonprotein nitrogen (**NPN**) derived from urea (0, 0.52, and 1.06% urea); a control diet based on SFC (i.e., 0% WDGS) was also fed in which supplemental protein was supplied by urea (3.0% NPN; 1.06% urea) and cottonseed meal to obtain a calculated dietary CP of 13.5% (Table 1). Diets were formulated to equalize fat and forage content, and CP was allowed to increase with increasing NPN concentrations. To prevent potential digestive or feed refusal problems, steers assigned to receive the 30% WDGS diets were first fed 15% WDGS diets, with the appropriate urea concentrations, for at least 3 d before being fed the 30% WDGS diets.

Table 1. Ingredient and analyzed chemical composition of experimental diets in Exp. 1 (DM basis)

		WDGS, % of DM					
		15%			30%		
		NPN, % of DM			NPN, % of DM		
Item	Control	0	1.5	3.0	0	1.5	3.0
Steam-flaked corn	76.47	66.50	66.49	66.48	52.57	52.57	52.56
Cottonseed meal	3.87	-	-	-	-	-	-
Urea[1]	1.06	-	0.52	1.06	-	0.52	1.06
Wet corn distiller's grains with solubles	-	14.85	14.85	14.84	29.73	29.73	29.72
Supplement[2–4]	2.39	3.43	2.93	2.40	3.44	2.92	2.40
Corn steep liquor	4.12	4.12	4.12	4.12	4.13	4.13	4.13
Yellow grease	2.01	0.99	0.99	0.99	-	-	-
Alfalfa hay	10.09	10.11	10.10	10.11	10.13	10.12	10.12
Analyzed chemical composition							
DM, %	82.73	69.95	69.98	70.02	60.80	60.83	60.86
CP, %	13.61	12.87	15.03	15.60	16.56	18.11	18.94
RDP[5], %	8.59	6.78	8.28	9.83	8.91	10.40	11.96
Nonprotein N, %	3.25	0.60	1.80	3.30	0.60	1.75	3.10
ADF, %	8.00	9.95	9.95	9.45	11.75	12.45	11.25
NDF, %	13.85	15.40	18.45	17.45	20.05	22.55	20.35
Crude fat, %	4.85	5.05	4.85	4.85	4.65	4.85	4.50
Ca, %	0.99	0.88	0.87	0.86	0.93	0.89	0.80
P, %	0.33	0.36	0.37	0.35	0.42	0.43	0.41
K, %	0.78	0.81	0.84	0.82	0.90	0.90	0.87
Mg, %	0.20	0.21	0.21	0.20	0.23	0.24	0.21
S, %	0.17	0.23	0.24	0.24	0.31	0.32	0.30
Na, %	0.19	0.21	0.21	0.21	0.22	0.23	0.22
Zn, mg/kg	81	85	88	79	90	92	85
Fe, mg/kg	214	342	241	262	259	279	230
Mn, mg/kg	54	50	46	45	50	54	45
Cu, mg/kg	21	19	18	21	20	20	19

[1]Urea was included in the supplement,but is presented separately for clarity. Urea was replaced with ground corn in the diet (i.e., lower supplement inclusion rate) for treatments with 0% NPN.

[2]Supplement for the 0% NPN diets contained (DM basis): 30.286% ground corn; 50.420% limestone; 5.714% potassium chloride; 2.542% magnesium oxide; 7.886% salt; 1% yellow grease; 0.001% cobalt carbonate; 0.112 copper sulfate; 0.002% ethylenediamine dihydroiodine; 0.148% manganese oxide; 0.429% Selenium premix (0.2% Se); 0.415% zinc sulfate; 0.197% vitamin A; 0.077% vitamin E; 0.482% Rumensin-80 (Elanco Animal Health, Indianapolis, IN); and 0.289% Tylan-40 (Elanco Animal Health).

[3]Supplement for the 3% NPN diets contained (DM basis): 30.286% urea; 50.420% limestone; 5.714% potassium chloride; 2.542% magnesium oxide; 7.886% salt; 1% yellow grease; 0.001% cobalt carbonate; 0.112 copper sulfate; 0.002% ethylenediamine dihydroiodine; 0.148% manganese oxide; 0.429% Selenium premix (0.2% Se); 0.415% zinc sulfate; 0.197% vitamin A; 0.077% vitamin E; 0.482% Rumensin-80 (Elanco Animal Health); and 0.289% Tylan-40 (Elanco Animal Health).

[4]Supplement for the 1.5% NPN diets contained a blend (50:50, DM basis) of supplements for 0% and 3% NPN diets.

[5]RDP values calculated using values from Table 2.

Steers were housed in 56 pens (8 pens/treatment), each containing 8 to 10 steers. Pens were soil surfaced (167 m^2), contained a concrete 3-m fence-line feed bunk, and every pen was equipped with a single automatic water tank. Water tanks were cleaned weekly throughout the feeding period. Steers were weighed before the morning feeding on day 51 and on the day they were shipped to the abattoir. Steers were reimplanted (Reavlor-S; Intervet/Schering-Plough) on day 51 on feed and fed an average of 129 d. On each weighing day, feed bunks were cleaned and any feed remaining was collected, weighed, and analyzed for DM to determine DM refusals. In addition, orts resulting from any feed spoilage were removed, weighed, analyzed for DM, and the dry quantity refused was deducted from DM offered. Scales used for feed refusals were validated before each use with certified weights and calibrated as needed. Dry weight of WDGS delivered to the facility and delivered to feed bunks over the study was calculated in order to determine feed shrinkage by mass balance.

Cattle health was visually evaluated at least once daily during the experiment. Unhealthy cattle were pulled for further examination, appropriate treatment was administered based on the recommendations of a licensed veterinarian, and cattle were returned to their home pen, unless isolation was warranted. Cattle determined to be noncompetitive were weighed before removal from the study to avoid any possible adverse effects unrelated to treatment.

Blood samples were collected from all animals via jugular venipuncture before feeding on day 1 and at the end of the feeding period to determine plasma urea nitrogen (**PUN**) concentration from pen composites. Blood samples were collected into 10-mL vacutainer tubes containing lithium heparin (Becton Dickinson, Franklin Lakes, NJ) as an anticoagulant, centrifuged for 20 min at 3,000 × *g*, and plasma was decanted. A 1-mL sample of plasma from every steer within each pen was obtained, composited within pen, and stored at −70 °C until analyzed. A direct colorimetric assay based on diacetylmonoxime was utilized for PUN determination (Stanbio Laboratory, Boerne, TX).

Experimental diets and dietary ingredients. Feed bunks were evaluated visually every morning at approximately 0700 by trained personnel to determine the amount of feed to deliver to each pen that day. Feed calls were decided with the goal of having 0 to 0.25 kg of feed remaining in the bunk each morning. If feed bunks were empty at 0700 for 2 consecutive days, feed calls were increased depending on bunk score history during the previous 7 d, cattle appetite, and days on feed.

Diets were manufactured and fed twice/day (beginning at 0800 and 1400) using a 2.27 m^3 (80 ft^2) stationary paddle mixer (Model No. 84–8; Roto-Mix, Inc., Dodge City, KS). During batch preparation, the allowable weighing tolerance for dietary ingredients (except supplements) ranged from ± 1 to 4 kg (as-fed basis) of desired weights, depending on ingredient inclusion rate [1 kg for cottonseed meal, steep liquor, and yellow grease, 2 kg for alfalfa hay and WDGS, and 4 kg for SFC (Table 1)] using the MicroBeef ProControl batching system. Supplements were prepared in advance and weighed on a scale with a sensitivity of ± 23 g, and manually delivered into the mixer. Scale resolution on

Table 2. Protein and NE values for dietary ingredients used in experiments 1 and 2

Ingredient	CP, % DM	RDP, % CP	RDP, % DM	NE_m, Mcal/kg	NE_g, Mcal/kg
Steam-flaked corn[1,2]	8.0	43.0	3.4	2.41	1.69
Cottonseed meal[2–4]	46.1	57.0	26.3	1.79	1.16
Corn steep liquor[3–5]	17.4	67.2	11.7	2.08	1.40
Yellow grease[1]	-	-	-	4.74	3.51
Alfalfa hay[2–4]	17.0	82.0	13.9	1.24	0.68
Urea	281.0	100.0	281.0	-	-
WDGS[3,6]	33.4	52.0	17.5	-	-

[1]NE values were obtained from previous trials conducted at WT research feedlot (Ponce et al., 2006 for steam-flaked corn).

[2]CP values from composite samples of ingredients derived from monthly samples collected throughout the study.

[3]RDP values obtained from NRC (2000).

[4]NE values obtained from NRC (2000).

[5]CP value of corn steep liquor obtained from Wagner et al. (1983) and RDP value obtained from Patterson et al. (2001).

[6]WDGS = wet distillers grain with solubles. RDP was calculated from chemical analyzed CP fractions from Table 4 as described by Sniffen et al. (1992). The assumed K_p value was 3.5%/h, and the assumed K_d values were: 150%/h, 3.5%/h, and 0.1%/h for B1, B2 and B3 fractions, respectively (NRC, 2000).

Table 3. Ingredient and analyzed chemical composition of experimental diets in Exp. 2 (DM basis)

		15% WDGS		
		NPN, % of DM		
Item	Control	1.50	2.25	3.00
Steam-flaked corn	76.16	66.21	65.71	65.45
Cottonseed meal	3.61	-	-	-
Wet corn distiller's grains with solubles	-	15.41	15.41	15.41
Supplement[1–4]	2.15	2.16	2.15	2.15
Urea[4]	1.05	0.54	0.81	1.06
Corn steep liquor	3.99	3.98	3.99	3.98
Yellow grease	4.07	2.77	3.00	3.02
Alfalfa hay	8.95	8.92	8.93	8.93
Analyzed chemical composition				
DM, %	80.35	67.76	67.82	67.83
CP, %	13.05	13.65	14.50	15.25
RDP[5], %	8.16	8.02	8.74	9.45
Nonprotein N, %	2.85	1.65	2.25	2.8
ADF, %	8.6	9.2	9.9	9.65
NDF, %	15.1	17.4	18.2	18.4
Crude fat, %	6.75	6.15	6.35	6.45
Ca, %	0.70	0.80	0.74	0.74
P, %	0.28	0.32	0.33	0.32
K, %	0.70	0.75	0.82	0.78
Mg, %	0.19	0.18	0.25	0.20
S, %	0.17	0.23	0.25	0.24
Na, %	0.17	0.19	0.20	0.20
Zn, mg/kg	70	69	74.5	72
Fe, mg/kg	133	131	163	329
Mn, mg/kg	47	44	44	65
Cu, mg/kg	17	13	17	17

[1]Supplement for the 1.5% NPN diets contained (DM basis): 19.85% urea; 55.078% limestone; 7.491% potassium chloride; 3.332% magnesium oxide; 10.427% salt; 1% yellow grease; 0.002% cobalt carbonate; 0.147 copper sulfate; 0.002% ethylenediamine dihydroiodine; 0.193% manganese oxide; 0.562% Selenium premix (0.2% Se); 0.544% zinc sulfate; 0.258% vitamin A; 0.101% vitamin E; 0.632% Rumensin-80 (Elanco Animal Health); and 0.379% Tylan-40 (Elanco Animal Health).

[2]Supplement for the 2.25% NPN diets contained (DM basis): 27.133% urea; 50.191% limestone; 6.826% potassium chloride; 3.036% magnesium oxide; 9.242% salt; 1% yellow grease; 0.001% cobalt carbonate; 0.134 copper sulfate; 0.002% ethylenediamine dihydroiodine; 0.176% manganese oxide; 0.520% Selenium premix (0.2% Se); 0.496% zinc sulfate; 0.235% vitamin A; 0.092% vitamin E; 0.576% Rumensin-80 (Elanco Animal Health); and 0.346% Tylan-40 (Elanco Animal Health).

[3]Supplement for the control and the 3% NPN diets contained (DM basis): 33.125% urea; 45.956% limestone; 6.25% potassium chloride; 2.78% magnesium oxide; 8.534% salt; 1% yellow grease; 0.001% cobalt carbonate; 0.123 copper sulfate; 0.002% ethylenediamine dihydroiodine; 0.161% manganese oxide; 0.469% Selenium premix (0.2% Se); 0.454% zinc sulfate; 0.216% vitamin A; 0.084% vitamin E; 0.527% Rumensin-80 (Elanco Animal Health); and 0.316% Tylan-40 (Elanco Animal Health).

[4]Urea was included in the supplement, but is presented separately for clarity.

[5]RDP values calculated using values from Table 2 except for WDGS (CP = 32.37 % DM and RDP = 52.26% CP).

the mixer and the surge bin from which feed deliveries were allocated was 0.454 kg from the quantity of feed called for each feeding. Adequate cleanout time was allowed in the feed mixer and surge bin between treatment preparations to decrease potential carryover of the previous treatment prepared. Additionally, a flush batch of feed, similar in composition to the Control diet, was prepared after each feeding and fed to cattle not enrolled in any experiment to avoid treatment contamination. Feed was delivered to pens using a specialized feed truck equipped with 3 individual bins each containing a screw auger. The length of time required to discharge the feed for 1 pen at one feeding was approximately 15 s.

Steam-flaked corn was prepared approximately 4 times/week. Generally, corn was steamed for 35 min after tempering to 18% moisture overnight (18 to 22 h) and was flaked to a bulk density of approximately 347 g/L (27 lb/bu). Bulk density was determined on corn samples obtained from both ends of the rolls every 20 min during flaking and collected samples were composited across the day. The roll gap was adjusted as needed to maintain a

Table 4. Analyzed chemical composition of wet distiller's grains with solubles[1] used in Exps. 1 and 2

		Experiment 2[2]		
Item	Experiment 1 (90:10[2])	90:10	80:20	70:30
DM, %	37.71	-	-	-
CP, %	33.40	33.00	32.45	32.37
Soluble CP, % of CP	13.5	14.5	12.5	10.0
NPN, % of CP	0.10	-	-	-
ADICP[3], %	5.20	4.35	4.80	4.65
NDICP[3], %	8.55	9.40	9.95	11.25
ADF, %	18.70	16.00	16.60	16.95
NDF, %	36.25	32.60	34.85	33.30
Lignin, %	6.15	3.10	5.20	4.65
Starch, %	4.80	3.55	6.00	5.25
Crude fat, %	12.25	13.45	14.65	14.50
Ash, %	5.71	5.14	5.14	5.13
Ca, %	0.08	0.06	0.08	0.04
P, %	0.65	0.86	0.83	0.80
K, %	0.72	0.96	0.92	0.91
Mg, %	0.23	0.34	0.32	0.30
Na, %	0.16	0.15	0.17	0.18
Cl, %	0.20	0.18	0.22	0.20
S, %	0.57	0.68	0.70	0.74
Cu, mg/kg	5.0	7.5	7.0	7.00
Fe, mg/kg	112	138	122	126.0
Mn, mg/kg	16.0	25.5	20.0	16.5
Mo, mg/kg	0.90	-	-	-
Zn, mg/kg	55.0	57.0	55.0	56.0
DCAD[4], mEq/100 g	−15.50	-	-	-

[1]From analysis of composite samples of WDGS derived from weekly feed bunk samples collected throughout the study.

[2]Ratio of corn to sorghum grain used in the ethanol production process. In Exp. 2, 90:10, 80:20, and 70:30 were fed from day 1 to 14, day 15 to 110, and day 111 to slaughter, respectively (13, 95, and 83 d).

[3]ADICP = ADF insoluble CP, and NDICP = NDF insoluble CP.

[4]Dietary cation anion difference.

constant corn bulk density. A portion of daily SFC composite samples was used for DM determination, and the remaining daily samples were composited by month and analyzed for starch availability using the procedure of Xiong et al. (1990). The average DM in fresh SFC was 81.7% and starch availability averaged 55.2% of total starch throughout the study. The WDGS were obtained approximately 3 times/week from the White Energy ethanol plant in Hereford, TX, and was stored under shelter in an open-front commodity barn until consumed. Grain composition of the WDGS was 90% corn and 10% sorghum grain.

Samples of the WDGS and SFC were collected 5 times/week for DM determination (forced-air oven at 60 °C for at least 48 h) and a portion of each WDGS sample was air-dried and composited for later analyses. The amount of the samples was regulated relative to pan surface area, to allow complete drying of the sample. Dry matter of remaining ingredients was determined once per week. Ingredient DM content was used to calculate diet DM content each week and to determine actual dry composition of the diets over the course of the study. Diet samples were taken directly from the feed bunks once per week, immediately after feeding, dried in a forced-air oven at 60 °C for at least 48 h, and ground in a Wiley mill to pass a 2-mm screen. Diet samples were composited and analyzed in duplicate for CP (Method 988.05; AOAC, 1990), NPN (Method 941.04; AOAC, 2002), ADF (Method 973.18; AOAC, 1990), and NDF (Vogel et al., 1999). The WDGS, feed ingredients, and diet samples were analyzed in duplicate (Tables 2 and 4) for CP, protein fractions, ADF, NDF, ether extract, and minerals by a commercial laboratory (Dairy One, 2015).

Carcass evaluation. Cattle were shipped to a commercial abattoir when they were estimated to have a fat thickness of approximately 1.3 cm, based on visual appraisal (average days on feed = 130).

Table 5. Effect of wet distiller's grains with solubles (WDGS) and nonprotein N (NPN) on performance by finishing steers in Exp. 1

		WDGS, % of DM						
		15%			30%			
		NPN, % of DM			NPN, % of DM			
Item	Control	0	1.5	3.0	0	1.5	3.0	SE
Pens	8	8	8	8	8	8	8	-
Initial BW, kg[1]	373	374	372	372	372	373	373	13
Final BW, kg[1,8,9]	600	597	611	598	588	587	588	12
Adjusted Final BW, kg[2,8]	600	591	600	598	586	585	586	9
Day 1 to 55								
DMI, kg/d[4,8]	9.36	8.93	9.11	9.38	8.79	8.89	9.23	0.28
ADG, kg/d[8,9]	2.04	1.91	2.02	2.08	1.91	1.91	1.91	0.07
ADG:DMI[3,5,6,8,9]	0.218	0.213	0.220	0.222	0.216	0.214	0.205	0.007
Day 1 to end								
DMI, kg/d[4]	9.75	9.47	9.78	9.82	9.45	9.45	9.76	0.26
ADG, kg/d[3,7,9]	1.71	1.67	1.78	1.74	1.68	1.66	1.67	0.04
Adjusted ADG, kg/d[8,9]	1.76	1.68	1.75	1.74	1.66	1.65	1.65	0.04
ADG:DMI[3,6,7,9]	0.175	0.176	0.182	0.178	0.178	0.175	0.172	0.01
Adjusted ADG:DMI[8,9]	0.180	0.177	0.179	0.177	0.175	0.174	0.168	0.008
Calculated NE values[10,11]								
NE_m, Mcal/kg of DM	2.17	2.15	2.17	2.13	2.15	2.14	2.10	-
NE_g, Mcal/kg of DM	1.49	1.48	1.49	1.46	1.48	1.47	1.43	-
WDGS[12] NE_m, Mcal/kg of DM	-	2.42	2.55	2.29	2.35	2.35	2.19	-
WDGS[12] NE_g, Mcal/kg of DM	-	1.55	1.68	1.42	1.65	1.65	1.48	-

[1]A pencil shrink of 4% was applied.

[2]Adjusted BW was calculated as hot carcass weight divided by the overall average observed dressing percent (64.22%).

[3]WDGS × NPN Interaction ($P < 0.15$)

[4]Linear effect of NPN ($P < 0.05$)

[5]Linear effect of NPN within 15% WDGS ($P = 0.07$)

[6]Linear effect of NPN within 30% WDGS ($P < 0.05$)

[7]Quadratic effect of NPN within 15% WDGS ($P = 0.02$)

[8]Control vs. 30% WDGS ($P < 0.09$)

[9]15 vs. 30% WDGS ($P < 0.05$)

[10]Dietary NE values calculated from performance data using energy requirements equations for maintenance and shrunk weight gain from NRC (2000).

[11]Determined using the standard reference weights of 435, 462, and 478 for < 26.8, 26.8 to 27.7%, and > 27.7% empty body fat (NRC, 2000); empty body fat was determined by the equation from Guiroy et al. (2001).

[12]Actual NE_m and NE_g were determined by the replacement technique using the NE values shown in Table 2 (NRC, 2000).

Personnel from the West Texas A&M University Beef Carcass Research Center collected complete carcass data on the kill floor and in the cooler and one individual recorded railed-out carcasses that were trimmed. Hot carcass weight used for railed-out carcasses was the greater of actual HCW recorded or hot weight calculated based on the pen average dressing percentage.

Net energy calculations. Dietary NE_m and NE_g concentrations were calculated from animal performance as described by Zinn and Shen (1998), with modifications employed using empty body fat estimated by the equation of Guiroy et al. (2001) to select the appropriate standard reference BW of 435, 462, and 478 kg for < 26.8%, 26.9 to 27.7%, and > 27.7% empty body fat (NRC, 2000) to account for unequal body composition across treatments. Observed diet NE_m and NE_g concentrations calculated from performance of cattle fed the Control diets in both experiments (Tables 5 and 8) were 98% of tabular values for ingredients used for the Control diets (Table 2). Therefore, the NE values for each feed ingredient were discounted 2% to account for that difference. The NE values used for SFC were derived from a previous study at our facility (Ponce et al., 2006) involving DRC (tabular values of 2.18 and 1.50 Mcal/kg for NEm and NEg, respectively) and SFC (estimated to be 2.4 and 1.70 Mcal/kg for NEm and NEg, respectively). The NE

Table 6. Effects of wet distiller's grains with solubles (WDGS) and nonprotein N (NPN) on carcass characteristics by finishing steers in Exp. 1

		WDGS, % of DM						
		15%			30%			
		NPN, % of DM			NPN, % of DM			
Item	Control	0	1.5	3.0	0	1.5	3.0	SE
Hot carcass weight, kg[1,2]	385	379	385	384	376	376	376	6
Dressing percent[1,3]	65.12	64.26	63.97	64.28	63.95	64.04	63.94	0.35
Fat thickness, cm	1.24	1.21	1.24	1.29	1.23	1.20	1.25	0.08
LM area, cm^2	92.31	91.10	89.99	91.96	93.21	91.66	92.69	1.53
Yield grade	2.77	2.75	2.86	2.83	2.63	2.67	3.06	0.20
Marbling score[4]	400	387	405	402	395	400	393	11
Average Choice and Prime, %	11.49	4.20	9.20	11.81	9.03	14.65	10.56	-
Choice, %	33.89	36.39	42.05	36.79	35.14	30.21	28.89	-
≥ Choice, %	45.38	40.59	51.25	48.59	44.17	44.86	39.44	-
Select, %	54.62	58.02	48.75	48.23	53.75	51.08	57.60	-
Standard, %	0	1.39	0	3.18	2.08	4.06	2.95	-
Yield grade 1, %[1,2]	14.24	13.85	10.14	11.35	25.14	15.24	22.81	-
Yield grade 2, %	39.90	52.19	47.36	47.26	42.92	49.51	40.17	-
Yield grade 3, %[1,3,5]	41.53	21.18	35.63	32.50	23.61	32.74	26.88	-
Yield grade 4 and 5, %[5]	4.34	12.78	6.88	8.89	8.33	2.50	10.14	-

[1]Control vs. 30% WDGS ($P < 0.05$).

[2]15 vs. 30% WDGS ($P < 0.01$).

[3]Control vs. 15% WDGS ($P < 0.001$).

[4]Marbling score: 300 = slight; 400 = small, etc.

[5]Quadratic effect of NPN ($P < 0.10$).

values used for yellow grease and cottonseed meal were tabular values from the NRC (2000) and the NE values of WDGS were calculated by difference/replacement assuming the change in diet NE values were solely attributable to the ingredient being substituted into the diet. Caution is warranted in interpreting these NE values because the calculations assume no interactions or associative effects among dietary ingredients.

Diet physical characteristics and feeding logistics. Dietary samples were collected from the feed bunk on 6 occasions during Exp. 1 to determine diet density (Fig. 1). Uncompacted density was determined by pouring a fresh diet sample into a 11.4-L bucket and removing excess feed with a straight edge. Compacted diet density was determined in a similar fashion, except that feed was compacted by lifting the filled bucket 30 cm and dropping it 10 times, and then excess feed was removed with a straight edge. Additionally, temperature was measured on diet samples collected for density determination using a laboratory thermometer.

The effects of diet on feed delivery logistics and efficiency were estimated using DMI, diet bulk density, and diet DM determined in the study. We extrapolated these data to a commercial feedyard scale to assess feed delivery implications of feeding diets containing 0 vs. 15% WDGS vs. 30% WDGS. For the Control/0% WDGS diet, DMI was assumed to be 9.75 kg/d (Table 5), diet compacted bulk density was 525 kg/m^3 (Fig. 1), and diet DM content was 82.7%. For the 15% WDGS diets, DMI was assumed to be 9.69 kg/d, diet compacted bulk density was 592 kg/m^3, and diet DM content was 69.98%. For the 30% WDGS diets, DMI was assumed to be 9.55 kg/d, diet compacted bulk density was 632 kg/m^3, and diet DM content was 60.83%. Feed trucks were assumed to have a volume capacity of 25.5 m^3 and(or) a weight capacity of 13,000 kg. The number of "trips/loads" required by feed trucks to feed a standard number of cattle was determined. Calculations were done assuming trucks were either filled to the same total net weight or that trucks were filled to the same volume.

Although the feeding logistic data are not replicated, they serve to gain insight on real costs that can be incurred when using wet and bulky feed ingredients in feedlot finishing diets.

Manure characteristics, apparent digestion, and nutrient losses. Procedures used to determine manure characteristics, apparent digestibility, and N volatilization losses have been previously described

Table 7. Effect of wet distiller's grains with solubles (WDGS) and nonprotein N (NPN) on manure characteristics, nutrient digestion, and N losses by finishing steers in Exp. 1

		WDGS, % of DM						
		15%			30%			
		NPN, % of DM			NPN, % of DM			
Item	Control	0	1.5	3.0	0	1.5	3.0	SE
Pens	8	8	8	8	8	8	8	-
Manure characteristics								
pH[1–3]	9.02	8.84	8.80	8.79	8.64	8.53	8.52	0.04
Ash, % DM basis[2,3]	51.5	46.6	46.1	48.6	44.6	39.9	44.4	0.97
N, % DM basis[2,3]	2.08	2.17	2.04	2.03	2.14	2.33	2.17	0.04
P, % DM basis[2,3]	0.60	0.62	0.59	0.60	0.66	0.73	0.68	0.02
N:P[2,3]	3.51	3.51	3.50	3.42	3.25	3.22	3.26	0.04
Apparent digestibility, %								
DM[1–4]	85.2	83.4	81.1	79.2	69.9	75.7	78.3	0.98
OM[1–4]	90.2	89.1	86.2	85.1	75.7	81.4	84.2	0.95
NDF[2,3]	48.9	44.0	33.5	37.1	28.3	31.8	34.8	2.81
Ether extract[2,3]	95.6	95.7	94.8	93.7	90.3	92.8	93.5	0.39
Starch[2,3]	99.5	99.0	99.2	99.2	98.4	99.0	99.3	0.10
P metabolism								
Intake, g/d[1–3]	36.1	34.1	33.2	35.4	38.8	39.7	39.0	0.48
Apparently absorbed, %[1–5]	80.8	75.4	72.4	64.4	57.2	68.3	75.2	2.18
Excreted, g/d[2,3,5]	29.8	27.9	26.8	29.1	32.6	33.6	32.9	0.49
N metabolism								
Intake, g/d[1–3]	181.3	202.6	224.9	248.5	262.8	277.8	317.2	6.26
Apparently absorbed, %	82.6	83.6	82.1	82.1	74.5	81.1	85.9	0.96
Urine N, g/d[1–3]	123.9	143.4	158.7	178.6	171.2	200.2	247.4	5.89
Excreted, g/d[1–3]	155.6	177.2	198.5	222.8	237.6	252.8	292.1	6.31
N volatilized								
% of intake[1–3,5]	30.2	40.9	48.3	51.3	52.1	53.9	58.9	1.30
g/d[1–3]	54.8	83.1	108.8	127.9	137.1	150.2	190.2	5.92
Kg/head[1–3]	7.0	10.7	14.0	16.5	17.7	19.3	24.6	0.77

[1]Linear effect of NPN ($P < 0.05$)
[2]Control vs. 30 % WDGS ($P < 0.09$)
[3]15 vs. 30% WDGS ($P < 0.02$)
[4]WDGS × NPN Interaction ($P < 0.15$)
[5]Control vs. 15% WDGS ($P < 0.10$)

(Cole et al., 2006). Briefly, 5 samples of fresh feces were collected from each pen on the last day of the feeding period and composited within pen. Fecal excretion of DM, N, and P and average apparent digestibility were determined for each pen using indigestible ADF as an internal marker (Schneider and Flatt, 1970). Nitrogen and P retention were estimated from animal performance using NRC (2000) equations. Urinary N and P excretion were calculated as the difference between nutrient intake and fecal + retained nutrients.

Ammonia emissions from the pen surface can represent 50% or more of the N fed to finishing beef cattle (Todd et al., 2011). To estimate N volatilization losses, 5 samples of air-dried manure were collected from the concrete feed bunk pads when cattle in that pen were sent to the packing plant and composited within each pen. Fresh feces and urine spots were avoided during the sampling because they represent the manure composition before most ammonia is lost (Cole et al., 2006, 2009). Apparent N volatilization losses were estimated based on the change in the N:P ratios of diets and air-dried pen manure using the following equation (Cole et al, 2006; Todd et al., 2011; Buttrey et al., 2012):

$$\text{N volatilization (\% of N intake)} = (\text{N:P of diet} - \text{N:P of manure}) / \text{N:P of diet}.$$

Feed ingredients, fresh feces, and air-dried manure samples were analyzed for DM by drying to a constant weight at 60 °C in a forced-draft oven. Organic matter content was determined by ashing

Table 8. Effects of nonprotein N (NPN) concentration on performance by finishing steers fed 15% wet distiller's grains with solubles in Exp. 2

		15% WDGS						
		NPN, % of DM				Contrasts[1]		
Item	Control	1.5	2.25	3.0	SE	1	2	3
Pens	9	9	9	9	-	-	-	-
Initial BW, kg[2]	344	345	344	344	12	0.51	0.23	0.56
Final BW, kg[2]	576	596	592	593	9.2	<0.01	0.70	0.68
Adjusted final BW, kg[3]	576	595	590	596	10.5	<0.01	0.92	0.39
Day 1 to 71								
DMI, kg/d	7.41	7.93	7.87	7.78	0.20	<0.01	0.20	0.88
ADG, kg/d	1.66	1.79	1.79	1.75	0.04	<0.01	0.28	0.40
ADG:DMI, kg:kg	0.222	0.225	0.228	0.225	0.008	0.40	0.88	0.38
Day 1 to slaughter								
DMI, kg/d	7.86	8.46	8.29	8.26	0.15	<0.01	0.22	0.65
ADG, kg/d	1.40	1.52	1.50	1.50	0.03	<0.01	0.65	0.81
Adjusted ADG, kg/d[3]	1.39	1.52	1.49	1.52	0.04	<0.01	0.99	0.49
ADG:DMI, kg:kg	0.177	0.180	0.181	0.182	0.006	0.14	0.40	0.88
Adjusted ADG:DMI, kg:kg	0.175	0.179	0.179	0.183	0.008	0.15	0.25	0.58
Calculated NE values[4,5]								
NEm, mcal/kg DM	2.23	2.20	2.23	2.23	-	-	-	-
NEg, mcal/kg DM	1.55	1.52	1.54	1.55	-	-	-	-
WDGS NEm, mcal/kg DM	-	2.06	2.02	2.05	-	-	-	-
WDGS NEg, mcal/kg DM	-	1.39	1.35	1.44	-	-	-	-

[1]Contrasts included: 1) control vs. average of 15% WDGS, 2) the linear effect of NPN among 15% WDGS, and 3) the quadratic effect of NPN among 15% WDGS.

[2]Pencil shrink of 4% was applied.

[3]Adjusted BW was calculated as hot carcass weight divided by the overall average observed dressing percent of 65.2%.

[4]Dietary NE values calculated from performance data using energy requirements equations for maintenance and shrunk weight gain from NRC (2000). Determined using the standard reference weights of 435, 462, and 478 for < 26.8, 26.8 to 27.7%, and > 27.7% empty body fat (NRC, 2000): empty body fat was calculated using the equation of Guiroy et al. (2001).

[5]Actual NE_m and NE_g of WDGS were determined by the replacement technique using the NE values presented in Table 2 (NRC, 2000).

in a muffle furnace at 600 °C for 16 h. After block digestion of undried samples, N and P content were determined colorimetrically using a flow injection analyzer (Quick Chem FIA+8000, Lachet Instruments, Milwaukee, WI: Methods 10-107-06-2-E and 15-115-01-4-A, respectively; AOAC, 1990). Fresh feces and ingredient samples were analyzed for indigestible ADF (Vogel et al., 1999) after a 96-h in vitro digestion in an Ankom Daisy System (Ankom Tech Corp., Fairport, NY).

Statistical analysis. Parametric data were analyzed as a randomized complete block design using the Mixed procedures of SAS. Pen was the experimental unit and the model included NPN concentration, WDGS concentration, and NPN × WDGS as fixed effects to test for the interaction, whereas the model included the fixed effect of treatment (n = 7) in the absence of an interaction. Block served as a random effect in all models. The same model was used to analyze nonparametric data using GLIMMIX procedures of SAS. Interactions were declared meaningful

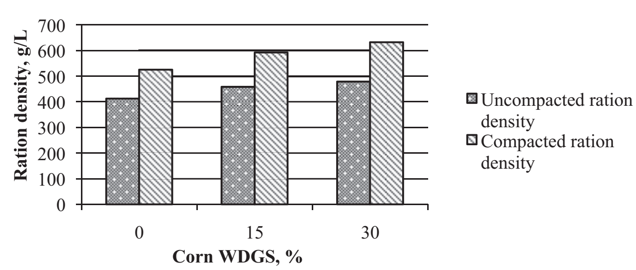

Figure 1. Density of experimental diets in Exp. 1. Uncompacted and compacted ration densities were different between 0 and 15% corn WDGS and between 15 and 30% WDGS (P < 0.001)

at a P < 0.15, and means were declared different at P < 0.10. Contrasts to separate means included linear and quadratic effects of NPN (within WDGS level if an interaction was detected), control vs. 15% WDGS, control vs. 30% WDGS, and 15 vs. 30% WDGS.

Experiment 2

Two hundred and ninety-six calves previously used in a receiving trial and allowed a recovery/

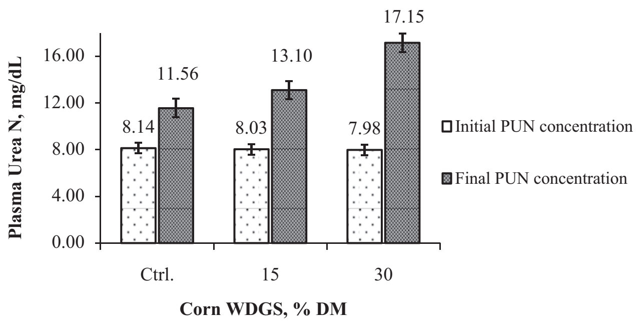

Figure 2. Effects of corn WDGS on plasma urea-N concentration in Exp. 1. Initial plasma urea N (SE = 0.45) did not differ ($P > 0.15$). There was no interaction between WDGS and NPN ($P > 0.15$). Final plasma urea N concentration (SE = 0.79) was different ($P < 0.05$) for control vs. 15% WDGS, control vs. 30% WDGS, and 15 vs. 30% WDGS.

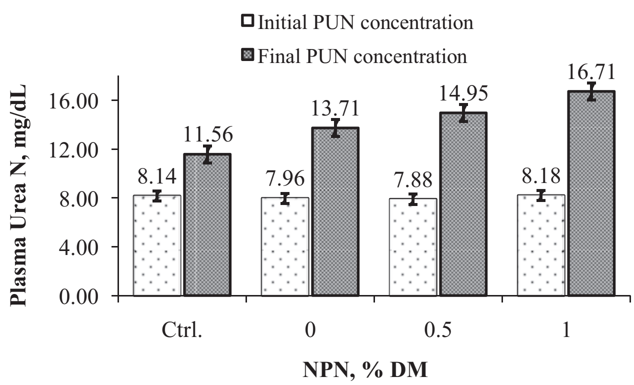

Figure 3. Effects of NPN on plasma urea-N concentration in Exp. 1. Initial plasma urea N (SE = 0.45) did not differ ($P > 0.15$). There was no interaction between WDGS and NPN ($P > 0.15$). Final plasma urea N concentration (SE = 0.70) increased linearly ($P < 0.01$) as NPN increased.

standardization period of at least 30 d were used in Exp. 2. Steers were weighed to obtain a sorting BW and were implanted with Revalor-XS (80 mg trenbolone acetate and 16 mg estradiol; Intervet/Schering-Plough Animal Health). This BW was used to block steers by BW. Within 5 d, animals were weighed a second time before the first feeding of the day and sorted into treatment pens as they exited the chute/scales. Cattle were moved to their respective study pen (9 pens/treatment; 8 to 9 steers/pen) and treatments began later that morning when feed was delivered. Initial BW for the study was the average of these 2 BW measures. Steers were individually weighed on day 71 and transported to slaughter after an average of 165 d.

Treatments included 1.50, 2.25, or 3.00% NPN derived from urea (0.52, 0.78, 1.06% urea, DM basis) in diets containing 15% WDGS and a control diet based on SFC and supplemented with 1.06% urea (3.0% NPN) and cottonseed meal to contain 13.5% dietary CP (Table 3). As in Exp. 1, WDGS samples were collected throughout the experiment for chemical analysis (Tables 2 and 4). Grain composition of the WDGS in this experiment averaged 78% corn and 22% sorghum. Animal management, feeding, and feed manufacturing followed the same procedures as detailed for Exp. 1. Manure characteristics, apparent digestion, and nutrient losses were determined as described in Exp. 1.

Parametric data were analyzed as a randomized complete block design using the Mixed procedures of SAS. Pen was the experimental unit and the model included treatment as fixed effect and block as a random effect. Nonparametric data were analyzed with the same model using GLIMMIX procedures of SAS. Means were declared different at $P < 0.10$. Contrasts included linear and quadratic effects of NPN and control vs. the average of 15% WDGS.

RESULTS AND DISCUSSION

Nutrient Composition and Physical Characteristics of Diets and WDGS

Analyzed chemical composition of diets generally agreed well with formulation targets (Table 1 for Exp 1 and Table 3 for Exp. 2). The WDGS from Exp. 1 was derived from a 90:10 blend of corn and grain sorghum, whereas the corn:grain sorghum ratio of WDGS used in Exp. 2 varied from 90:10 to 70:30 (Table 4).

Uncompacted ration densities in Exp. 1 [412, 458, and 479 ± 7 g/L (32, 36, and 37 lb/bu) for 0, 15 and 30% WDGS, respectively; Fig. 1] were different between 0 and 15% WDGS and between 15 and 30% WDGS ($P < 0.001$). Compacted diet densities [525, 592, and 632 ± 6 g/L (40.8, 46.0, and 49.1 lb/bu) for 0, 15, and 30% WDGS, respectively] were also different between 0 and 15% WDGS and between 15 and 30% WDGS ($P < 0.001$). Although ration density increased with WDGS concentration, diets containing WDGS were wetter (17.3, 30.0, 39.2% moisture for 0, 15, and 30% WDGS, respectively) and cattle consumed a similar amount of DM (Table 5) when fed the Control (9.75 kg/d) or WDGS-containing diets (9.62 kg/d). If we assume that feed trucks would be filled to the same total net weight, the quantity of feed that would have to be delivered to provide the same quantity of feed DM would be 14% greater for 15% WDGS than Control diets and 30% greater for 30% WDGS diets compared with the Control diet using compacted diet density values. If we assume that feed trucks would be filled to the same total volume, feeding 15% WDGS would require 3% more loads

Table 9. Effects of nonprotein N (NPN) on carcass characteristics by finishing steers fed 15% wet distiller's grains with solubles (WDGS) in Exp. 2

		15% WDGS						
		NPN, %DM				Contrasts[1]		
Item	Control	1.5	2.25	3.0	SE	1	2	3
Pens	9	9	9	9	-	-	-	-
Hot carcass weight, kg	376	388	385	389	6.8	0.01	0.89	0.38
Dressing percent	65.2	65.2	65.0	65.5	0.2	0.88	0.26	0.18
Fat thickness, cm	1.13	1.23	1.18	1.26	0.08	0.29	0.83	0.50
LM area, cm^2	89.18	90.02	88.86	90.94	2.02	0.65	0.61	0.30
Yield grade	2.70	2.88	2.85	2.87	0.13	0.26	0.96	0.91
Marbling score[2]	401	398	412	395	10.4	0.92	0.86	0.18
Average Choice and Prime, %	4.56	8.02	16.75	8.02	-	0.08	1	0.02
Choice, %	39.29	30.09	28.11	32.28	-	0.20	0.80	0.68
≥ Choice, %	43.85	38.12	44.86	40.30	-	0.69	0.79	0.42
Select, %	53.68	59.11	52.36	55.69	-	0.75	0.64	0.43
Standard, %	2.47	2.78	2.78	4.01	-	0.77	0.70	0.82
Yield grade 1, %	12.24	14.97	12.90	14.81	-	0.68	0.98	0.70
Yield grade 2, %	52.47	40.12	41.80	36.51	-	0.07	0.66	0.62
Yield grade 3, %	32.52	36.57	40.06	36.09	-	0.46	0.96	0.59
Yield grade 4 and 5, %	2.8	8.33	5.24	12.59	-	0.12	0.41	0.25

[1]Contrasts included: 1) control vs. average of 15% WDGS, 2) the linear effect of NPN among 15% WDGS, and 3) the quadratic effect of NPN among 15% WDGS.

[2]Marbling score 300 = slight; 400 = small, etc.

of feed than if feeding 0% WDGS and feeding 30% WDGS would require 11% more loads of feed than if feeding a 0% WDGS diet.

Silva et al. (2019) also reported that more feed (as-fed basis) must be manufactured and delivered when sorghum WDGS partially replaced SFC in finishing diets. Silva et al. (2019) determined that to feed animals diets containing 15% sorghum WDGS (DM basis) required 23% more loads of feed/day compared with animals receiving 0% sorghum WDGS diets when feed trucks were filled to an equal net weight basis and 10% more loads when feed trucks were filled to an equal volume basis. Somewhat in contrast, Hicks (2008) reported that inclusion of 10 or 20% corn WDGS (DM basis) in SFC-based diets decreased the number of truck loads required by 13 and 3%, respectively. However, utilization of 30% WDGS increased the number of truck loads by 7%. Variation in DM content of the WDGS might exert a significant effect on diet density and could explain differences between studies. The DM content of WDGS utilized by Hicks (2008) was 2% lower than our WDGS. Additional data are required to define more specifically the effects on dietary ingredients on feeding logistics.

The physical and handling characteristics of feedlot diets can impact feed milling and feed delivery logistics in commercial feedyards. These characteristics may affect how efficiently feed mills and feed trucks are used, and the number of truckloads of feed that may be required to feed a specified number of cattle each day. Feed trucks have both limited volume and limited weight capacity, therefore, when diets are bulky and/or high in moisture, more loads/trips are generally required to completely feed all animals in the feedyard. In addition, dietary energy dilution can translate into greater DMI which may require greater mill output per unit of time within the day and a greater quantity of total feed that must be delivered.

In Exp. 1, diets containing 15% WDGS were 1.4 °C warmer than Control diets (30.6 vs. 29.2 °C, respectively; $P < 0.001$), and diets containing 30% WDGS were 1.3 °C warmer than diets containing 15% WDGS (31.9 vs. 30.6 °C, respectively; $P < 0.001$). It is unclear whether temperature of feed consumed might impact DMI or animal performance; however, we speculate that during summer (i.e., when Exp. 1 occurred), higher feed temperatures might have negative effects on DMI. Decreased DMI has been observed during hot weather conditions (Gaughan and Mader, 2009). A lower feed temperature could potentially help to bring metabolic heat production in balance with the capacity of the animal to dissipate heat (Gaughan and Mader, 2009) and increase feed intake. To our knowledge, this variable has not been addressed before, and awaits further exploration.

Table 10. Effects of nonprotein N (NPN) concentration and 15% wet distillers grains with solubles (WDGS) on manure characteristics, nutrient digestion, and nutrient losses by finishing steers fed 15% wet distiller's grains with solubles (WDGS) in Exp. 2

		15% WDGS						
		NPN, % of DM				Contrasts[1]		
Item	Control	1.5	2.25	3.0	SE	1	2	3
Pens	9	9	9	9	-	-	-	-
Manure characteristics, DM basis								
pH	8.50	8.56	8.38	8.07	0.05	0.06	0.04	0.78
Ash, %	38.0	34.5	38.8	35.7	1.2	0.21	0.89	0.29
N, %	2.13	2.17	2.17	2.15	0.03	0.35	0.28	0.65
P, %	0.68	0.73	0.74	0.71	0.02	0.11	0.25	0.68
N:P	3.12	2.97	2.95	3.01	0.03	0.04	0.38	0.40
Apparent digestion, %								
DM	79.0	77.6	78.4	76.4	1.14	0.07	0.36	0.78
OM	84.2	82.5	83.1	81.5	1.07	0.06	0.40	0.81
P metabolism								
Intake, g/d	26.0	32.2	29.9	27.3	0.48	0.04	0.03	0.49
Apparently absorbed, %	43.3	52.1	61.4	41.8	5.81	0.15	0.40	0.18
Excreted, g/d	20.3	26.4	24.1	21.3	0.048	0.05	0.03	0.48
N metabolism								
Intake, g/d	181.3	214.1	203.4	190.5	2.8	0.04	0.03	0.47
Apparently absorbed, %	77.1	76.5	77.4	73.8	1.5	0.14	0.23	0.11
Excreted, g/d	158.1	190.2	179.5	166.1	2.8	0.03	0.02	0.52
Urine N, g/d	116.6	140.2	133.6	116.5	4.0	0.03	0.02	0.47
N volatilization								
% of intake	55.3	55.3	56.6	56.8	0.4	0.15	0.13	0.55
g/d	100.2	118.6	115.2	108.3	1.9	0.02	0.03	0.62
Kg/head	16.4	19.4	18.8	17.8	0.5	0.02	0.02	0.43

[1]Contrasts included: 1 = control vs. average of 15% WDGS, 2 = the linear effect of NPN among 15% WDGS, and 3 = quadratic effect of NPN among 15% WDGS.

The inventory loss (shrink) of WDGS during Exp. 1 averaged 6.2%. Although these data are not replicated, they serve to gain additional insight on real costs that can be incurred when using wet feed ingredients in beef cattle finishing diets.

Experiment 1

Growth performance. Final shrunk BW (live and carcass-adjusted; Table 5) was less ($P \leq 0.09$) for steers fed 30% WDGS than steers fed either 0 or 15% WDGS regardless of NPN supplementation (NPN ×WDGS; $P > 0.15$).

Dry matter intake in Exp. 1 (Table 5) increased linearly as dietary NPN increased in diets containing either 15 or 30% WDGS, both through reimplanting on day 55 ($P = 0.04$) and overall ($P = 0.05$). Similarly, Zinn et al. (2003) noted a linear increase in DMI when steers were supplemented with either 0, 0.4, 0.8, and 1.2% urea in diets based on steam-flaked barley (84-d trial), which was supported by a linear increase in the extent of ruminal and total tract starch digestibility as urea concentration increased. This might suggest that the rate of digestion of high-concentrate diets might be partially regulating feed intake. Indeed, Zinn and Owens (1983) controlled DMI (1.2, 1.5, 1.8, and 2.1% of BW) of cannulated steers and detected a linear increase in the extent of ruminal starch digestion as DMI increased. Dry matter intake from day 1 to 55 in Exp. 1 was not different between the Control and 15% WDGS; however, DMI tended to be lower ($P = 0.06$) for animals fed 30% WDGS than animals fed the Control diet. However, DMI over the entire trial was not influenced by WDGS.

Average daily gain through reimplanting (day 55: Table 5) was greater ($P = 0.02$) for steers fed the Control than 30% WDGS diet. Similarly, animals fed 15% WDGS gained weight more rapidly than those fed 30% WDGS ($P = 0.02$). Nonprotein N did not influence ADG through reimplanting; however, an interaction between NPN and WDGS was detected for overall ADG ($P = 0.12$). A positive linear effect of NPN on ADG was detected ($P = 0.07$) when 15% WDGS was fed, whereas no effect of NPN on ADG was evident (P > 0.15) when 30% WDGS was fed. Overall, carcass-adjusted ADG was not different (P > 0.10) between steers fed the Control and those fed 15% WDGS, but steers fed Control and 15% WDGS diets had greater (P < 0.05) adjusted ADG than those fed 30% WDGS.

Gain efficiency (ADG/DMI) through reimplanting (Table 5) was not different (P > 0.10) between the Control and 15% WDGS diets, but gain efficiency was negatively impacted when steers were fed 30% WDGS compared with 15% WDGS (P = 0.02). Gain efficiency through reimplanting decreased (P = 0.03) as dietary NPN concentration increased for steers fed 30% WDGS, but gain efficiency through reimplanting tended to increase (P < 0.07) as NPN concentration increased for steers fed 15% WDGS diets (WDGS × NPN interaction; P = 0.02). Overall gain efficiency (live-basis) depended on WDGS and NPN (interaction, P = 0.06). Overall gain efficiency increased in a quadratic fashion as NPN concentration increased in diets containing 15% WDGS (P = 0.02); whereas, increasing NPN in diets containing 30% WDGS resulted in a linear decrease (poorer) in gain efficiency (P = 0.07). Overall live-based gain efficiency did not differ (P > 0.10) between steers fed the Control diet and those fed 15 or 30% WDGS diets. However, gain efficiency was lower (P < 0.05) when diets contained 30% WDGS compared with 15% WDGS. Gain efficiency on a carcass-adjusted basis was not different between the Control and 15% WDGS. However, carcass-adjusted gain efficiency was lower (P = 0.02) for steers fed 30% WDGS diets than for steers fed Control or 15% WDGS diets.

Performance by cattle in Exp. 1 suggests that replacement of SFC with up to 15% WDGS requires including between 1.5 and 3% of diet DM as NPN; however, no supplemental NPN was required when 30% WDGS was included in the diet. Ruminal fermentation and digestibility of 15% WDGS diets might likely require supplementation of at least half of what seems to be the optimum dietary RDP requirement for SFC-based diets (Galyean, 1996).

Net energy calculations. As previously noted, NE_m and NE_g concentrations of the Control diet, calculated from cattle performance, were 98% of tabular values used to formulate the Control diets in both experiments (Tables 5 and 8). Therefore, the NE values for each dietary ingredient were discounted 2% to account for that difference in calculating the NE values of other diets. Based on the process of substitution, WDGS fed in Exp. 1 had an average NE_g value of 1.55 Mcal/kg when included at 15% of diet DM, across all NPN levels. The highest NE_g was 1.68 Mcal/kg for the diet containing 1.5% NPN and 15% WDGS. In addition, the NE_g value for WDGS was 1.59 Mcal/kg across all NPN levels for 30% WDGS diets; NEg was numerically lowest (1.48 Mcal/kg) at 3.0% NPN when 30% WDGS was fed. The NE_g values for WDGS fed in Exp. 1 was 92 to 94% of the value for SFC (1.69 Mcal/kg) that was assumed in the substitution.

Carcass characteristics. No interactions (P > 0.15) between WDGS and NPN were detected for any carcass traits in Exp. 1 (Table 6). Hot carcass weight was less (P < 0.05) for cattle fed the 30% WDGS diets than for cattle fed 15% WDGS or Control diets because of lower ADG and final BW driven by the estimated energy dilution of replacing SFC with WDGS in the absence of a commensurate increase in DMI (Table 5). Dressing percent was greater (P < 0.05) for steers fed the Control diet than for those fed diets containing either 15 or 30% WDGS. Fat thickness, longissimus (**LM**) area, yield grade, and marbling score did not differ (P > 0.10) among treatments. However, more carcasses from steers fed 30% WDGS were yield grade 1 (P = 0.04) than from steers fed other treatments. Steers fed the Control diet had more yield grade 3 carcasses (P = 0.05) than those fed 15 or 30% WDGS diets. There tended (P < 0.10) to be a quadratic effect of NPN supplementation on the proportion of yield grade 3 and yield grade 4 + 5 carcasses, although the reason for these effects are not clear.

Manure characteristics, nutrient digestion, and nutrient losses. The pH of pen surface manure decreased (P < 0.05) with increasing dietary WDGS and with increasing dietary NPN in pens fed diets containing WDGS (Table 7). Manure ash content also decreased (P < 0.05) with increasing dietary WDGS, but was not affected by dietary NPN content. Manure N and P concentrations were greater (P < 0.05) and N:P ratios were less in pens fed the 30% WDGS diets than in pens fed the 15% WDGS or Control diets.

Apparent digestibility of DM, OM, NDF, and ether extract decreased (P < 0.05) with increasing dietary WDGS (Table 7). There was a WDGS × NPN interaction (P < 0.10) for DM and OM digestibility. The digestibility of DM and OM tended (P < 0.09) to decrease with increasing NPN in the 15% WDGS diets, whereas it increased (P < 0.05) with increasing NPN in the 30% WDGS diets.

Steers fed the 15% WDGS diets tended ($P < 0.10$) to have lower P intake and excretion than steers fed the Control diet, whereas steers fed the 30% WDGS diets had greater ($P < 0.05$) P intake and excretion than steers fed the Control and 15% WDGS diets (Table 7). However, apparent P absorption was greater in Control than WDGS diets and tended to decrease with increasing dietary WDGS. There was a WDGS × NPN interaction ($P < 0.05$) for P absorption, with P absorption decreasing with increasing NPN in diets containing 15% WDGS, but increasing with increasing NPN in 30% WDGS diets.

Nitrogen intake, urinary N excretion, and total N excretion increased ($P < 0.05$) with increasing dietary WDGS and increasing dietary NPN (Table 7). Apparent N digestion was not affected by WDGS or NPN. Nitrogen volatilization losses as a % of N intake, g/d, and kg/steer increased ($P < 0.05$) with increasing dietary WDGS and with increasing dietary NPN.

Plasma urea nitrogen concentrations. As expected, there was no effect of NPN or WDGS on PUN concentrations on day 1, before treatments were applied in Exp. 1 (Figs. 2 and 3). No WDGS × NPN interactions were observed for PUN concentrations at the end of the feeding period in Exp. 1 ($P > 0.74$). As the dietary concentration of WDGS increased, PUN increased as well [Fig. 2: control vs. 15% ($P < 0.05$), 15 vs. 30% ($P < 0.05$)], likely due to greater total N intake (Table 7). Plasma urea N also increased linearly ($P < 0.01$) as dietary NPN increased (Fig. 3). Boyd et al (2018) and Koenig et al (2018) also noted that PUN concentrations increased as dietary WDGS and urea concentration increased. Jenkins et al. (2011) noted that blood urea N increased with dietary CP and metabolizable protein concentration; however, blood urea N was not affected by RDP balance or metabolizable protein balance adjusted for RDP deficiencies. Johnson and Preston (1995) and Cole et al. (2003) suggested PUN concentration is an indicator of protein status and possible N wastage in ruminants. As expected, dietary CP concentration dramatically influenced PUN concentration. The very high PUN concentration, greater N losses and simultaneous lower ADG and gain efficiency for the 30% WDGS diet may indicate supra-optimal N intake. Regardless of treatments used in the present study, PUN concentrations at the conclusion of the feeding period were greater than what seems to be the range to sustain optimum animal performance while minimizing N loss to the environment (i.e., 5 to 9 mg/100 mL; Johnson and Preston, 1995; Cole et al., 2003).

Experiment 2

Growth performance. Final shrunk BW (Table 8) and carcass-adjusted final BW were less ($P < 0.01$) for steers fed the Control diet than for steers fed the 15% WDGS diets, but final BW was not affected by NPN on either a live, or carcass-adjusted basis. This differs from Exp. 1 where final BW were not different for Control and 15% WDGS diets, but also agrees in that NPN concentration within 15% WDGS diets did not affect final BW.

During the first 71 d of Exp. 2, DMI was greater ($P < 0.01$) for steers fed the 15% WDGS diets than for steers fed the Control diet, but DMI was not affected by dietary NPN concentration (Table 8). This contrasts with Exp. 1 in which there was no difference in DMI of Control and 15% WDGS diets, but there was a linear increase in DMI as dietary NPN concentration increased in steers fed 15% WDGS diets.

As noted in Exp. 1, May et al. (2009) reported lower DMI in finishing cattle when SFC was replaced by 25% dry corn distiller's grains. However, May et al. (2009) found greater DMI for steers fed 15% WDGS (10% sorghum:90% corn) compared with animals fed 0% WDGS diets. Similar to results of our Exp. 2, Leibovich et al. (2009) did not detect differences in DMI of cattle fed a diet containing 15% sorghum WDGS compared with cattle fed a diet containing 0% sorghum WDGS based on SFC and Uwituze et al. (2010) reported no difference in the DMI of feedlot heifers fed either 25% dry distiller's grains or a standard SFC-based control diet. Luebbe et al. (2012) noted no effect of WDGS on DMI when SFC-based diets contained between 0 and 45% WDGS. Buttrey et al. (2012) noted no effect of 20% WDGS on DMI of SFC- or DRC-based diets and Buttrey et al. (2013) noted no effect on DMI in SFC- and DRC-based diets containing 0 or 35% WDGS. Boyd et al. (2018) noted no effect of urea concentration on DMI of DRC-based diets containing 10, 15, or 20% WDGS, but reported that DMI decreased as WDGS concentration increased from 10 to 20% of diet DM. Jenkins et al. (2011) reported no effect of WDGS (10 or 20%) or urea (0, 0.5, or 1.0%) concentration on DMI of steers fed DRC-based diets. Assuming cattle eat to a constant energy intake in these different studies, these trial-to-trial variations in DMI may reflect differences in the energy values of the grain and(or) WDGS fed in the diets.

Average daily gain from day 1 to 71 (Table 8) was greater ($P < 0.01$) for steers fed the 15% WDGS diets compared with steers fed the Control, 0% WDGS diet. Overall ADG (live and carcass-adjusted) was also greater ($P < 0.01$) for steers fed the 15% WDGS diets than for those fed the Control diet. This agrees with results of May et al. (2009). However, this contrasts to results of Exp. 1 where there was no difference in ADG between Control and 15% WDGS diets. Buttrey and coworkers noted no effect of 35% (Buttrey et al., 2013) or 20% (Buttrey et al., 2012) WDGS on ADG of steers fed SFC- or DRC-based diets, whereas Luebbe et al. (2012) noted that ADG decreased linearly as WDGS concentration increased in SFC-based diets from 0 to 15, to 30, to 45, to 60% of diet DM, although the greatest decrease in ADG occurred between 45 and 60% WDGS.

In Exp. 2, ADG was not affected by NPN supplementation level (1.5 to 3.0%) in the 15% WDGS diets. In Exp 1, ADG increased quadratically as NPN concentration increased from 0 to 3.0% in 15% WDGS diets, with the greatest ADG in steers fed the 1.5% NPN (0.52% urea) diets. The Exp. 2 data confirm that 1.5% NPN met or exceeded the RDP requirements of steers fed 15% WDGS diets. Similarly, there was no effect of NPN on ADG in diets containing 30% WDGS in Exp. 1, suggesting no supplemental NPN was needed to meet the RDP requirements of steers fed the 30% WDGS diets. Jenkins et al. (2011) reported no effect of supplemental RDP (urea) on ADG of steers fed DRC-based diets containing 10 or 20% dried distillers gains and Boyd et al. (2018) noted no effect of NPN (urea) on ADG of steers fed DRC-based diets containing 10, 15, or 20% WDGS. Vasconcelos et al. (2007) noted a linear decrease in ADG by animals fed 10% sorghum WDGS supplemented with 0.68, 0.89, and 1.09 % urea, compared with control animals fed 0% sorghum WDGS diets supplemented with cottonseed meal and urea. Again, these variations in study results may be because of the differences in the energy value and/or RDP content of the WDGS and grain fed.

Milton et al. (1997) studied the effect of urea supplementation [i.e., 0, 0.35, 0.70, 1.05, and 1.4% urea levels (DM basis)] on finishing steers fed a diet based on DRC and noted that ADG increased quadratically, being optimal in the range between 0.35 and 0.7% urea. Similarly, with steam-flaked barley-based diets, Zinn et al. (2003) noted greatest ADG when diets contained 0.8% urea (vs. 0, 0.4, or 1.2% urea). Thus, based on ADG, it appears the supplemental RDP requirement for steers fed a SFC-based, 15% WDGS diet is similar to cattle fed DRC-based diets and about 50% of that for cattle fed a steam-flaked barley-based diet containing no WDGS.

Gain efficiency on either a live or carcass-adjusted basis was not altered by WDGS or NPN in Exp. 2 (Table 8); however, there was a tendency for gain efficiency to be greater ($P < 0.15$) for steers fed the 15% WDGS diets compared with those fed the Control diet. This contrasts with Exp. 1 in which there was no difference in gain efficiency between steers fed the 15% WDGS diets and those fed the Control diet. Buttrey et al. (2013) reported that steers fed a 35% WDGS diet had greater gain efficiency than steers fed a 0% WDGS diet and Buttrey et al. (2012) noted a trend for greater gain efficiency in steers fed 20% WDGS diets than 0% WDGS diets. Jenkins et al. (2011) noted no effect of 10 or 20% WDGS on gain efficiency in DRC-based diets; however, Luebbe et al. (2012) noted a linear decrease in gain efficiency as the concentration of WDGS increased in SFC-based diets.

In Exp. 2, there was no effect of NPN on gain efficiency, indicating that 1.5% NPN supplied adequate supplemental RDP in 15% WDGS diets. In agreement with results of Exp. 2, Boyd et al. (2018) noted that gain efficiency increased as dietary WDGS (10, 15, or 20%) and urea (0. 0.5, or 1.0%) concentrations increased. However, the results were somewhat confounded because several of the treatments were deficient in protein and/or RDP. However, results of our studies and that of Boyd et al. (2018) suggest that recycled N is inadequate to meet the RDP or metabolizable protein requirements of cattle fed low (< 20%) concentrations of WDGS, but is probably adequate in diets containing higher (30% or more) concentrations of WDGS. This agrees with the results of Stalker et al. (2007) who reported that supplementation of NPN was not necessary for animals individually fed a 58% corn cob-based diet with 30% dried DGS. In addition, Richeson et al. (2006) reported that overall growth performance did not differ when animals received cottonseed meal N:urea N ratios of 67:33, 33:67, or 0:100 in diets containing 25% wet corn gluten feed (CP level fed was 13.5% of DM). However, a negative control was not utilized in the study of Richeson et al (2006), and thus does not allow discerning if N source would have been important at a lower dietary CP concentration.

Clearly, differences in effects of WDGS on animal performance across studies might reflect variation in WDGS composition (Holt and Pritchard, 2004). Unfortunately, in most previous studies, key characteristics of the physical and chemical composition of WDGS, and(or) the blending ratio of condensed soluble to wet distiller's grains were not sufficiently described. Therefore, it is difficult to establish an appropriate comparison to our findings. Variation in the amount of solubles added to distiller's grains certainly alters end-product composition, as the solubles are high in moisture, fat, and CP (Holt and Pritchard, 2004). Therefore, the quantity of solubles added to distiller's grains will impact moisture, CP and fat content of WDGS. In addition, it is becoming more common for a portion of the oil in DGS to be removed, thus altering the fat, CP, and fiber composition of the DGS.

Excess dietary CP might be an additional factor related to the poorer animal performance noted when 30% WDGS was fed in the present experiment, especially as dietary NPN concentrations increased. In steers fed SFC-based diets, Gleghorn et al. (2004) noted decreased ADG when dietary CP concentrations exceeded 15% of dietary DM and Zinn et al. (1997) reported a negative effect on animal ADG and gain efficiency as dietary CP concentration increased [11.9, 14.8, 17.7, and 20.6% CP (8, 16, 24, or 32% cottonseed meal)] in SFC-based diets. Zinn et al. (1997) concluded that N excretion through urine in beef steers required 7.9 Kcal/g of N and Tyrrell et al. (1970) determined that 10.8 Kcal of digestible energy were required per g of excess urinary N excretion in dairy cows. Jennings et al. (2018) noted that maintenance energy requirements of steers increased approximately 4 to 6% when dietary CP concentrations were increased from 13.5 to 18% using a corn-based protein (corn gluten meal) source.

Net energy calculations. In Exp. 2, WDGS had calculated NEg values of 1.39, 1.35, and 1.44 Mcal/kg for diets containing 1.50, 2.25 and 3.00 % NPN, respectively. The mean of these energy values (1.39 Mcal/kg) is lower than in Exp. 1 and is 82% of the value we utilized for SFC (1.69 Mcal/kg). Importantly, the WDGS fed in Exp. 1 was 90% corn and 10% sorghum, whereas the weighted average in Exp. 2 was 77% corn and 23% sorghum. Silva et al. (2019) reported similar NEg values for sorghum-based WDGS (1.37 Mcal/kg). Using respiration calorimetry, Hales et al. (2012, 2013) reported average NEg values of 1.66 for corn-based WDGS, but noted that NEg values of WDGS seemed to decrease as the proportion of WDGS in the SFC-based diets increased. Luebbe et al. (2012) also reported that dietary NEg values calculated from animal performance decreased as the quantity of corn-based WDGS in the diet increased; suggesting the NEg of WDGS was lower than SFC. However, the NEg of the WDGS were not calculated by difference. The greater DMI of 15% WDGS vs. Control diets in Exp. 2 also suggests an energy dilution in diets containing WDGS. This energy dilution might be due to the higher sorghum and lower corn inclusion in ethanol production than in Exp. 1. Previous studies suggest that sorghum WDGS contains approximately 24% less NE than the SFC and cottonseed meal that were replaced (DeClerck, 2009; Silva et al., 2019). Our present data suggest that 22:78 sorghum:corn WDGS may also have a lower energy content than the ingredients it replaced (Tables 5 and 8).

Caution is warranted in interpreting NE values determined by difference, because these calculations assume no interactions or associative effects among dietary ingredients (Cole et al., 2009). However, these data provide a useful barometer for nutritionists to use in formulating diets containing WDGS.

Carcass characteristics. Hot carcass weight (Table 9) was lower ($P = 0.01$) for steers fed the Control diet than for steers fed the 15% WDGS diets. In contrast, in Exp. 1, there was no effect of 15% WDGS on HCW. Steers fed the Control diet tended to have fewer ($P < 0.08$) premium carcasses (high or average Choice and Prime) than steers fed the 15% WDGS diets. Again, this contrasts with Exp. 1 where there were no significant differences in carcass grades between Control and 15% WDGS diets. As in Exp. 1, fat thickness, LM area, yield grade, and marbling score were not different among treatments. Luebbe et al. (2012) noted a linear decrease in fat thickness, yield grade, and marbling score as dietary WDGS concentrations increased from 0 to 60%; however, as with our results, the differences between diets containing 0 and 15 or 30% WDGS were small or nonexistent.

We did observe an effect of 15% WDGS on dressing percent when 15% WDGS was fed in Exp. 1 but, not in Exp. 2. Similar to our findings, Leibovich et al. (2009) reported a 0.6% decrease in dressing percent for animals fed diets containing 15% sorghum WDGS compared with a control diet with no WDGS and Depenbusch et al. (2008) noted a 0.7% decrease in dressing percentage when animals were fed 25% sorghum WDGS. Luebbe et al. (2012) also noted a linear decrease in dressing percentage as WDGS dietary concentration increased from 0 to 60%, although the difference between diets containing 0 and 15 or 30% WDGS was small. Contrary to our results, Corrigan et al. (2009)

reported a small linear increase in dressing percent (63.0, 63.3, 63.9, and 63.8%) as corn WDGS increased (0, 15, 27.5, and 40%, respectively) in diets based on DRC, whereas they did not detect any effect of dietary WDGS on estimated dressing percentage in diets based on either high-moisture corn or SFC. However, results of Corrigan et al. (2009) are speculative because the authors did not directly measure individual final BW. Final BW in that study was indirectly calculated from HCW assuming a common dressing percentage of 63%. Although not critical when cattle are sold on a live weight basis, dressing percentage and HCW are important factors in pricing of slaughter cattle when they are sold on a grid system, which is becoming much more common. Therefore, any decrease in dressing percentage might alter economic returns for cattle feeders. The effects of feeding WDGS on dressing percent require further explanation.

The lower dressing percentages we observed in cattle fed diets containing WDGS might be an indicator of differences in gastrointestinal tract development and/or gut fill. The reasons for the lower dressing percentage in cattle fed the 15% WDGS diets than the Control diet are not entirely clear, but we speculate that the greater DMI observed in Exp. 2 for steers fed WDGS and the greater water and fiber content of WDGS than the ingredients it replaced might have altered gut fill and(or) weight of gut tissues. Ponce et al. (2014) noted that total gut fill was approximately 8 kg greater and empty weight of total splanchnic tissue was approximately 11 kg greater in steers fed 30% corn-based WDGS diets than in steers fed a control SFC-based diet. These greater weights (19 kg) were approximately equivalent to the reported differences in final live BW (17 kg). Similarly, Rompala et al. (1988) documented a detrimental effect of dietary bulk density on visceral organ mass of sheep. Rompala et al. (1988) fed ewe lambs 1.23 kg of a 72% concentrate control diet daily or 1.25 kg of the control diet enriched with 10% polyethylene powder daily. This feeding regimen provided both groups isoenergetic rations. Weights of empty gastrointestinal tract (i.e., reticulum, rumen, omasum, abomasum, large intestine), heart, kidneys, and lungs were greater for lambs fed the diets supplemented with polyethylene than lambs fed the control diet.

Effects of WDGS on yield grade might be expected because of treatment differences in final BW and ADG. As feedlot cattle approach finishing weights, body fat deposition increases at a faster rate than other body components (e.g., protein deposition; NRC, 2000). Results from Exp. 1 suggest that inclusion of 30% WDGS in finishing diets might influence fat deposition due to slower ADG observed for cattle fed 30% WDGS diets. However, we did not detect differences in fat thickness or marbling score across treatments. Previously, Buttrey et al. (2013) noted a decrease in marbling score of animals fed 35% corn WDGS compared with animals fed a standard SFC-based finishing diet. This decrease was explained by a reduction in the monounsaturated:saturated fatty acid ratio of the diet for cattle fed WDGS compared with animals fed SFC. This resulted in changes to the fatty acid composition of depot fat and tended to decrease shelf-life of beef cuts, although it did not adversely affect palatability of beef.

The remaining carcass responses observed in this study agree with previous research, in that no significant differences in most carcass traits were found when animals received WDGS (Larson et al., 1993; Depenbusch et al., 2008; Jenkins, et al., 2011; Buttrey et al., 2012, 2013; Luebbe et al., 2012). Similar to our results, Shain et al. (1998), Jenkins et al. (2011) and Boyd et al. (2018) did not find differences in any carcass traits with urea supplementation. However, contrary to our results, Milton et al. (1997) detected a linear increase in subcutaneous fat and yield grade as level of urea increased in DRC-based diets.

Manure characteristics, nutrient digestion, and nutrient losses. As in Exp. 1, the pH of pen surface manure tended ($P < 0.06$) to be lower in pens fed 15% WDGS diets than the Control diet (Table 10). Pen surface pH decreased ($P < 0.04$) with increasing dietary NPN. In contrast to Exp. 1, manure ash content was not affected by dietary WDGS, but in agreement with Exp., 1 manure ash was not affected by dietary NPN. In agreement with Exp. 1, manure N and P concentrations were not affected by 15% WDGS or NPN; however, in contrast to Exp. 1, manure N:P was greater ($P < 0.04$) in pens fed the Control diet than in pens fed the 15% WDGS diets.

As in Exp. 1, apparent digestibility of DM and OM tended to be lower ($P < 0.07$) in steers fed the 15% WDGS diets than for steers fed the Control diet. In contrast to Exp. 1, and to Zinn et al. (2003), NPN did not affect apparent digestibility of OM or DM. Cole et al. (2011) reported that calves fed 15% sorghum-based WDGS had apparent DM and OM digestibility similar to steers fed 0% WDGS or 10% corn-based WDGS. Hales et al. (2013) noted that apparent digestibility of energy and NDF decreased as dietary corn-based WDGS increased from 0 to 15 to 30 to 45% of diet DM in SFC based diets.

In contrast, with SFC-based diets, Luebbe et al. (2012) reported that NDF digestibility increased linearly as the concentration of corn-based WDGS increased from 0 to 15, to 30, to 45, to 60% of diet DM; whereas, digestibility of OM and starch linearly decreased as the concentration of WDGS in the diet increased. Zinn et al. (2003) noted a linear increase in the extent of ruminal and total tract starch digestibility of steam-flaked barley-based diets as urea concentration increased from 0 to 0.4 to 0.8 to 1.2% (84-d trial).

Steers fed the 15% WDGS diets had greater ($P < 0.05$) P intake and excretion than steers fed the Control diet; however, apparent P absorption was not affected by diet. Phosphorus intake and excretion decreased ($P < 0.03$) with increasing dietary NPN. These results differ considerably from Exp. 1. Cole et al. (2011) noted no effect of 15% sorghum-based WDGS on P absorption, fecal P excretion, or urinary P excretion compared with a 0% WDGS control diet.

As in Exp. 1, N intake, urinary N excretion, and total N excretion were greater ($P < 0.03$) in steers fed the 15% WDGS diets than the Control diet. However, in contrast to Exp. 1, N intake, urinary N excretion, and total N excretion decreased ($P < 0.04$) with increasing dietary NPN. Apparent N digestion was not affected by dietary WDGS or NPN. Cole et al. (2011) and Silva et al. (2019) also noted a lower N digestibility in steers fed SFC-based diets containing 15% WDGS than diets containing 0% WDGS. In contrast, May et al. (2010) and Hales et al. (2013) noted no effect of 15% sorghum-based WDGS or 15% corn-based WDGS on protein digestibility.

Nitrogen volatilization losses as a % of N intake were not affected by dietary WDGS or NPN in Exp. 2 and were similar to ammonia-N losses measured from feedyards using micrometeorology methods (Todd et al., 2011). In agreement with Exp. 1, Exp. 2 N volatilization losses in g/d and kg/steer were greater from pens fed the 15% WDGS diet than the Control diet. In contrast to Exp. 1, N losses (g/d, kg/steer) decreased ($P < 0.03$) with increasing dietary NPN concentration, most likely because of less N intake (Cole et al., 2005; Todd et al., 2011; Koenig et al., 2018). The results of Exp. 2 agree with Silva et al. (2019) and Buttrey et al. (2012), who also noted no significant effect of 15 or 20% WDGS on N volatilization losses as a % of N intake. However, the actual quantity of N volatilization losses (g/d, kg/steer) increased with increasing dietary WDGS and CP in cattle fed SFC- or DRC-based diets (Buttrey et al., 2012). Koenig et al. (2018) also noted that daily ammonia emissions increased as WDGS and dietary CP concentration increased. The main factor affecting ammonia emission from beef cattle is dietary N intake; however, other factors can also affect emissions. For example, emissions are lower during cold weather than hot weather (Todd et al., 2011). In addition, when a poorly digestible fiber source, such as WDGS, is fed, (Adams et al., 2004) or when less digestible grain sources such as DRC (vs. SFC) are fed (Buttrey et al., 2012) the feces and manure may also contain more fermentable carbohydrate, which may increase the capture of pen surface ammonia-N as microbial protein. This capture of ammonia-N might be greater during cold weather when ammonia release is at a slower rate than during warm or hot weather (Todd et al., 2011). Adams et al. (2004) noted that during a winter-spring feeding period increasing manure OM via either feeding a less digestible diet or by adding OM to the pen surface decreased N volatilization losses by almost 50%. However, there was no effect of manure OM on N volatilization losses during a summer feeding period.

IMPLICATIONS

In Exp. 1, growth performance (ADG and gain efficiency) by animals fed 15% WDGS was improved by supplementing between 1.5 and 3% NPN from urea. When 30% WDGS was fed, no benefit was evident in feeding supplemental NPN. Furthermore, feeding excess CP appeared to be detrimental to animal performance. Wet chemistry values from WDGS samples taken from this experiment may suggest that WDGS has a RDP value greater than NRC (2000) and NASEM (2016) values. However, the rate of digestion of the protein fractions needs to be clearly defined for WDGS to more closely quantify the RDP value of WDGS. The energy value of WDGS (90:10 corn:sorghum) in Exp. 1 was 92% of SFC. Finally, dressing percent was reduced by feeding WDGS, probably by effects on gut fill and weight of splanchnic tissue. Data from Exp. 2 deviates slightly from findings in Exp. 1, which may be largely explained by the relative grain composition of the WDGS fed. Animals fed 15% WDGS in Exp. 2 gained faster by consuming more feed. The lower energy value of the WDGS, compared with SFC (82%) in Exp. 2 substantiates the dilution of energy observed. Differences across experiments beyond the WDGS fed might be attributed to environmental conditions and differences in BW of cattle in both studies. Data from both experiments suggest that between 1.50 and 2.25% NPN may be needed in SFC-based diets containing 15% WDGS made from a blend of corn and sorghum; however, no supplemental NPN appears to be needed in diets containing 30% WDGS. Further research is required to elucidate the effects of distiller's grains derived from different blends of cereal grains on cattle performance and their interaction with ruminally degraded protein requirements. Additionally, possible deleterious effect of WDGS on dressed yield needs to be explored.

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