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Effects of increasing concentrations of wet distillers grains with solubles in steam-flaked, corn-based diets on energy metabolism, carbon-nitrogen balance, and methane emissions of cattle[1]

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ABSTRACT: The use of wet distillers grains with solubles (WDGS) in feedlot diets has increased in the Southern Great Plains as a result of the growing ethanol industry. Nutrient balance and respiration calorimetry research evaluating the use of steam-flaked corn (SFC)-based diets in conjunction with WDGS is limited. Therefore, the effects of increasing concentrations of WDGS in a SFC-based diet on energy metabolism, C, and N balance, and enteric methane (CH_4) production was evaluated in Jersey steers fed at 2 times maintenance, using respiration calorimetry chambers. Four treatments were used in two 4 × 4 Latin square designs, using 8 steers. Treatments consisted of: 1) SFC-based diet with 0% WDGS (SFC-0); 2) SFC-based diet with 15% WDGS (SFC-15); 3) SFC-based diet with 30% WDGS (SFC-30); and 4) SFC-based diet with 45% WDGS (SFC-45). Diets were balanced for degradable intake protein (DIP) by adding cottonseed meal to the SFC-0 diet. As a proportion of GE, fecal, urinary, and CH_4 energy increased linearly ($P < 0.03$) as WDGS concentration increased in the diet. In contrast, DE, ME, and retained energy decreased linearly ($P < 0.01$) as a proportion of GE as WDGS concentration increased. Increasing concentration of WDGS in the diet did not affect ($P > 0.78$) heat production as a proportion of GE. As a result of greater N intake, total N excretion increased linearly ($P < 0.01$) with increasing WDGS inclusion in the diet. Fecal C loss and CH_4–C respired increased linearly ($P < 0.01$) when WDGS concentration increased in the diet whereas CO_2–C respired decreased (linear, $P = 0.05$) as WDGS concentration increased. We conclude that CH_4 production as a proportion of GE increases linearly ($P < 0.01$) when WDGS concentration in the diet is increased; however, dietary inclusion of WDGS at up to 45% seems to have no effect ($P > 0.78$) on heat production as a proportion of GE. The reason for a linear decrease in retained energy as WDGS increased was likely because of increased fecal energy loss associated with feeding WDGS. Total N excretion, fecal C loss, and CH_4–C respired increased linearly with increasing concentration of WDGS in the diet. We determined NE_g values for WDGS to be 2.02, 1.61, and 1.38 Mcal/kg when included at 15%, 30%, and 45%, respectively, in a SFC-based diet. From these results we conclude that the energy value (NE_g) of WDGS in a finishing cattle diet based on SFC must be decreased as the inclusion increases.

Key words: cattle, distillers grains, methane, steam-flaked corn

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INTRODUCTION

Alternative uses of agricultural products traditionally used to feed livestock have resulted in alternative feed resources in which nutrient values are poorly defined. Distillers grains contain relatively high concentrations of oil, protein, NDF, and ADF, compared with other grains it replaces in feedlot diets (Klopfenstein et al., 2008). The growing ethanol industry has increased the

[1]Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the USDA. USDA is an equal opportunity provider and employer.

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use of distillers grains with solubles (**WDGS**) in cattle finishing diets (DiLorenzo and Galyean, 2010; Hales et al., 2012). Few studies have used steam-flaked, corn (**SFC**)-based diets typically used in the Southern Great Plains (Cole et al., 2006; 2009).

Dietary NE values are often estimated from animal performance (Zinn et al., 2003; Vasconcelos and Galyean, 2008). Based on performance response, wet distillers grains were reported to have a greater NE_g value than corn grain when fed in control diets without WDGS (Lodge et al., 1997; Al-Suwaiegh et al., 2002). Recently, NE_g values of WDGS derived using respiration calorimetry were reported to be 1.65 Mcal/kg, a value slightly greater than the NRC (1996)-estimated value of 1.50 Mcal/kg (Hales et al., 2012).

Methane (**CH_4**) losses from cattle fed a variety of diets are documented throughout the literature (Johnson and Johnson, 1995; Beauchemin and McGinn, 2005); however, effects of WDGS on CH_4 production in cattle are not well defined. Previous research results yielded conflicting evidence regarding the impact of feeding WDGS on CH_4 emissions. McGinn et al. (2009) reported a reduction, whereas Behlke et al. (2008) observed an increase and Hales et al. (2012) found no effect of WDGS on enteric CH_4 emissions. Our hypothesis was that at high concentrations in feedlot diets (>30% DM), WDGS will increase CH_4 production. Thus, our objectives were to measure the effects of WDGS inclusion in SFC-based diets on energy metabolism, C and N balance, and enteric CH_4 losses from cattle, and to quantify dietary NE value for WDGS.

MATERIALS AND METHODS

All procedures involving live animals were approved by and conducted within the guidelines of the Cooperative Research, Education, and Extension Team animal care and use committee (Texas Agrilife Research, USDA-ARS, West Texas A&M University).

Cattle

Eight Jersey steers were used in the experiment. Steers were assigned to 1 of 2 Latin squares (maintenance intake or 2 times maintenance level of intake; each square was a 4 × 4, using 4 steers) and cattle began diet adaptation to target a maintenance or 2 times maintenance level of intake for 16 d. Maintenance intake was determined based on the NRC (1996) as 0.077 Mcal/kg of metabolic BW (**MBW**). Steers fed near maintenance were only used to measure heat production (**HP**) to aid in determining the energy value of WDGS. Steers were individually weighed before feeding (Trojan Livestock Equipment, Weatherford, TX; set on 4 electronic load cells; readability of ±0.45 kg; scale calibrated with 454 kg of certified weights before use), implanted with Ralgro (36 mg of zeranol; Merck Animal Health, Summit, NJ), and sorted to 8 fly-ash-surfaced outdoor individual pens (3.7 m × 3.7 m). All cattle were weighed before feeding at the start of the experiment (initial BW = 322 kg) and at the end of each experimental period to monitor either the maintenance of BW or BW gain. During each experimental period, cattle fed 2 times maintenance gained an average of 16.5 kg per animal, whereas cattle fed at maintenance gained or lost <3.6 kg per animal. The experiment was conducted from October 2010 through February 2011. Periods 1 and 2 were completed before mid-November of 2010 and then followed by a break in the experiment during December. Periods 3 and 4 were completed in January and February 2011, respectively. During the break in the experiment, cattle were maintained on a 75% concentrate diet at their respective intake level.

Treatment and Experimental Design

Treatments consisted of 1) SFC-based diet with 0% WDGS (**SFC-0**); 2) SFC-based diet with 15% WDGS (**SFC-15**); 3) SFC-based diet with 30% WDGS (**SFC-30**); and 4) SFC-based diet with 45% WDGS (**SFC-45**). All diets (Table 1) were formulated to contain a minimum of 8.0% degradable intake protein (**DIP**). Recent literature has indicated that feeding diets with <7.4% DIP adversely affected feedlot performance in cattle fed SFC-based diets, but DIP concentration >8.4% resulted in minimal improvement in performance (Wagner et al., 2010); thus, the target of 8.0% DIP was used during diet formulation. A commercial supplement formulated to provide a dietary DM concentration of 33 mg/kg monensin (Rumensin; Elanco Animal Health, Greenfield, IN) and 8.7 mg/kg tylosin (Tylan; Elanco Animal Health), and vitamins and minerals to meet or exceed NRC (1996) requirements was included at 2.5% of diet DM.

Digestion Collections

The indirect calorimetry system used throughout the study consisted of 4 chambers under negative pressure. Steers were adapted to living in the calorimetry chambers before the start of the experiment. Briefly, the external dimensions of each chamber were ~210 cm H × 244 cm L × 115 cm W and chambers were constructed with 5-cm pipe panels (W-W Livestock Systems, Weatherford, OK). The panel exterior was covered with clear Lexan. The flooring inside of each chamber was made up of plastic boards, with a high density polyethylene pan (66 cm length × 51 cm width × 15 cm height) for urine collection, placed underneath a plastic-coated metal grate in the center of each chamber. Outside air was pulled into each chamber through polyvinylchloride pipe and outgoing air from each chamber was pulled through a similar pipe to the gas sampling system. An air conditioning system (Fredrich Company, San Antonio, TX) was located inside each chamber to facilitate air circulation, remove humidity, and maintain the temperature within a thermoneutral range. The mean temperature across all chambers for the duration of the experiment was 18.8°C and the mean relative humidity was 60.7%. Each of the 4 periods in the Latin squares consisted of an initial 16-d diet adaptation, followed by 5 d of fecal, urine, and gas collections, resulting in 84 d for the experiment. Urine was collected daily by vacuum aspiration from a preacidified pan (urine was acidified with 150 mL of a 3*N* HCl solution) to ensure the pH of urine was <6 (using a combination electrode), thereby preventing N volatilization. Feces were collected from each steer in a nylon bag with a harness as described by Tolleson and Erlinger (1989). Diets, urine, and feces were weighed daily on a top-loading analytical balance (1.0 g readability; Sartorius L2200, Data Weighing Systems Inc., Elk Grove, IL). Aliquots (10%) of urine and feces were collected daily and stored at 4°C until completion of the collection period. After completion of each collection period, the daily aliquots from each steer were thoroughly mixed and subsamples were stored in plastic bags (feces) or polyethylene bottles (urine) at –5°C for laboratory analyses.

Table 1. Composition and analyzed nutrient content (DM basis) of diets based on steam-flaked corn (SFC) with 0%, 15%, 30%, and 45% wet distillers grains with solubles (WDGS)

	Treatment[1]			
Item	SFC-0	SFC-15	SFC-30	SFC-45
Ingredient, %				
SFC	73.00	69.25	56.00	41.65
WDGS[2]	–	15.00	30.00	45.00
Alfalfa hay	10.00	10.00	10.00	10.00
Cottonseed meal	5.60	–	–	–
Yellow grease	3.50	2.25	0.85	0.50
Molasses	4.50	–	–	–
Urea	0.90	1.00	0.65	0.35
Supplement[3]	2.50	2.50	2.50	2.50
Analyzed composition,[4] %				
DM	86.2	70.6	57.7	52.1
CP[5]	13.3	14.3	18.3	20.2
Starch	60.7	58.7	42.8	39.1
ADF	7.9	8.6	12.3	16.5
NDF	14.5	16.8	18.5	18.7
Ether Extract	5.9	5.8	7.4	8.3
Ca	0.9	0.9	0.9	0.8
P	0.3	0.3	0.4	0.4
S	0.2	0.2	0.4	0.4

[1]SFC-0, SFC-15, SFC-30, and SFC-45 = SFC (bushel weight 360g/L or 28 lb/bu)-based diet with 0%, 15%, 30%, and 45% WDGS on a DM basis, respectively.

[2]Average DM content of WDGS (Chief Ethanol; Hastings, NE) during the experiment was 34.92% and WDGS was produced solely from corn grain.

[3]Formulated to provide a dietary DM inclusion of 0.30% salt, 60 mg/kg Fe, 40 mg/kg Zn, 30 mg/kg Mg, 25 mg/kg Mn, 10 mg/kg Cu, 1 mg/kg I, 0.15 mg/kg Co, 0.10 mg/kg Se, 1.5 IU/g vitamin A, 0.15 IU/g vitamin D, 8.81 IU/kg vitamin E, 33 mg/kg monensin (Elanco Animal Health, Greenfield, IN), and 8.7 mg/kg tylosin (Elanco Animal Health).

[4]Samples were analyzed by Servi-Tech Laboratories, Amarillo, TX.

[5]The diets were formulated to provide a minimum degradable intake protein of 8.0% of DM.

Diets were mixed in 91-kg batches weekly in a portable mixer (Uebler Manufacturing Company, Vernon, NY) and stored in 132-L plastic barrels. Before mixing, each ingredient was weighed on a platform scale (90-kg capacity and 0.45-kg readability; Ohaus Corp., Pine Brook, NJ). Ingredients were added to the mixer and each diet was allowed to mix for ~15 min. Cleanout of the mixer unit was monitored to ensure that cross contamination of diets was minimized and any carryover debris was removed before each diet was mixed. All cattle were fed daily at ~0800 h and had ad libitum access to fresh water. During the collection periods, feed refusals were weighed daily and sampled for DM content to determine DMI. A subsample of each ort was also saved and analyzed for GE using bomb calorimetry, and any necessary adjustments in GE intake were made. The WDGS used throughout the experiment was purchased from a single plant in the Northern Plains (Chief Ethanol, Hastings, NE) and was 100% corn-based WDGS. The WDGS was delivered in a single load and stored in a silage bag. The WDGS quality was monitored weekly (by DM analysis) throughout the experiment.

Ingredient and mixed diet samples were collected weekly to determine DM content, using a forced-air oven at 55°C for ~48 h. Samples of mixed feed from each steer and all ingredients were collected weekly throughout the experiment and composited by treatment across the 4 periods. Composited samples of mixed diets and individual feed ingredients were analyzed for CP, ADF, NDF, ether extract (**EE**), starch, Ca, P, S, and K by a commercial laboratory (Servi-Tech Laboratories, Amarillo, TX, using methods from AOAC, 1990). Urinary N was also analyzed in the same laboratory, as well as fecal analyses of CP, NDF, EE, and starch.

Before gas measurements, the gas sampling system described by Hales et al. (2012) was calibrated for O_2 consumed and CO_2 produced by burning absolute ethanol with alcohol lamps. Oxygen and CO_2 recoveries averaged across all chambers were 99.96% (SD ± 1.61) for O_2 and 98.23% (SD ± 2.75) for CO_2. Before each gas exchange collection period, each gas analyzer (CO_2, CH_4, O_2) was calibrated with commercially prepared gas standards (Matheson Tri-Gas, Pasadena, TX). Respiration chambers were sealed ~22 h each day. A minimum of two 22-h runs was used to determine gaseous exchanges for each animal and, in turn, used to calculate HP, according to Brouwer (1965). A known quantity of a commercially prepared CH_4 standard was released in each chamber to ensure the CH_4 analyzer was working correctly. Recoveries averaged across all chambers were 97.22% (SD ± 1.98).

Laboratory Analyses

Feces and ingredients were analyzed for DM by drying to a constant weight at 55°C in a forced-air oven. Ingredient and fecal samples were ground to pass through a 2-mm screen. Total C and N in feed ingredients and feces were determined by combustion in a C-N analyzer (Elementar Vario MAX CN, Elementar Americas Inc., Mt. Laurel, NJ). Gross energy concentration in feces and dietary ingredients was determined using an automatic bomb calorimeter (Model 6400, Parr Instrument Company, Moline, IL). Urine energy was calculated as the quotient of the gross heat (2.3 kcal/g) of urea and urinary urea-N concentration, assuming all urinary N was urea. Urea was assumed to be the primary source of energy contained in the urine (Street et al., 1964).

Fasting Heat Production

Fasting heat production (**FHP**) was measured in late September 2010 (BW = 326 kg). Before and after the measurement, fasted steers were fed the SFC-0 diet. Steers fasted for 48 h but had ad libitum access to fresh water. After the fast, steers were placed in the respiration calorimetry chambers where gas, feces, and urine were collected for an additional 48 h. Heat production was then calculated, according to Brouwer (1965).

Calculations and Statistical Analyses

All data were analyzed as a Latin square design, using the Mixed procedure (SAS Inst. Inc., Cary, NC). Random effects were steer and period, and diet was included as a fixed effect in the model. Orthogonal contrast statements were used to separate linear and quadratic effects of WDGS inclusion in the diet. Effects were considered significant at *P*-value of ≤ 0.05, with tendencies declared at *P*-values between 0.05 and 0.10.

To calculate NE_g of each experimental diet, the within treatment retained energy (RE) per unit MBW was regressed on ME intake per unit MBW and fit with a quadratic equation. Maintenance ME intake was solved for RE = 0. Fasting heat production was estimated as the 0 intercept of the quadratic regression. To calculate partial efficiency of ME for maintenance (**k_m**), the FHP was divided by ME intake for maintenance. Net energy for maintenance was calculated as k_m times the average ME content of feed estimated from cattle fed near maintenance. To calculate partial efficiency of gain (**k_g**), the estimated RE was divided by the average ME intake when steers were fed 2 times maintenance divided by the increased ME intake above maintenance. Net energy of gain was calculated as k_g times the average ME intake at 2 times maintenance.

In calculating NE_m and NE_g of WDGS, the tabular NE values for each ingredient were adjusted for calorimetry-based calculations. For instance, if calorimetry-based data were ~95% of tabular values for NE_g in the SFC-0 diet, then tabular values for all non-WDGS ingredients in the SFC-0 diet were multiplied by this adjustment factor. The contribution was then subtracted from the calorimetry-based NE concentration for each diet, with the difference divided by the percentage of WDGS in the diet to calculate the NE concentration of WDGS. This technique has also been used for calculating NE_m and NE_g from performance, as described by May et al. (2011) and Hales et al. (2012).

RESULTS AND DISCUSSION

Throughout the experiment, 4 steers were fed at a maintenance level of intake to determine the NE value of WDGS; however, only data from cattle fed the target of 2 times maintenance intake are presented.

Diet Analyses

Chemical compositions of the dietary treatments are presented in Table 1. By feeding increasing concentrations of WDGS in the diets, we realized that our diets could not be isonitrogenous, so we formulated for equivalent DIP by adding urea. Similarly, we unsuccessfully attempted to balance for EE by adding fat to the control diet and minor concentrations to the diets containing WDGS; however, the resulting range of EE in the diets was from 5.9 to 8.3% of DM. There were greater ADF and NDF concentrations in our diets as WDGS increased. Dietary S concentration also increased with inclusion of WDGS and the greatest dietary S concentration was slightly greater than the maximum tolerable value reported in NRC (1996), but no adverse S toxicity effects were noted during the experiment.

Nutrient Digestibility

Digestibility of starch, NDF, and EE are presented in Table 2. As the concentration of WDGS increased in the diet, starch intake decreased (linear, $P < 0.01$), which was expected because the starch concentration in WDGS is less than that of corn. Even though starch intakes differed across treatments, fecal starch excretion was not affected

Table 2. Influence of feeding steam-flaked (SFC)-based diets with 0%, 15%, 30%, or 45% wet distillers grains with solubles (WDGS) on starch, NDF, and fat digestibility in cattle fed at an intake level twice that of maintenance[1]

	Treatment					Linear	Quadratic
Item	SFC-0	SFC-15	SFC-30	SFC-45	SEM[2]	*P*-value[3]	*P*-value
Starch							
Intake, g/d	3,921	3,730	2,701	2,241	150.35	<0.01	0.16
Fecal excretion, g/d	20.8	26.7	24.0	21.4	5.45	0.96	0.34
Apparent digested, g/d	3,900	3,703	2,678	2,220	151.18	<0.01	0.17
Apparent digestibility, % of intake	99.5	99.3	99.1	99.1	0.18	0.07	0.71
NDF							
Intake, g/d	939.0	1,063.4	1,169.6	1,076.8	51.30	0.02	0.02
Fecal excretion, g/d	630.1	752.3	991.7	917.5	56.98	<0.01	0.11
Digested, g/d	309.0	311.1	177.9	159.4	55.55	0.06	0.86
Digestibility, % of intake	32.9	29.1	19.6	14.9	4.10	<0.01	0.91
Ether extract							
Intake, g/d	380.7	368.9	465.4	473.9	20.92	<0.01	0.52
Fecal excretion, g/d	27.6	35.4	34.5	35.8	4.82	0.06	0.19
Apparent digested, g/d	353.0	333.5	430.9	438.1	18.58	<0.01	0.37
Apparent digestibility, % of intake	92.7	90.5	92.5	92.6	0.95	0.50	0.05

[1]Corn grain was processed by steam flaking and WDGS concentration was 0%, 15%, 30%, or 45% of dietary DM.

[2] Pooled SEM ($n = 4$).

[3]The observed significance level for the contrasts. Contrasts were linear and quadratic effects of increasing concentrations of WDGS.

($P > 0.34$) by diet. Similarly, Hales et al. (2012) reported no difference in fecal starch excretion between cattle fed 0% or 30% WDGS diets. Additionally, May et al. (2010) noted that total tract digestion of starch did not differ among cattle fed SFC-based diets with 0% or 15% corn or sorghum WDGS. Other research reported no differences in starch digestibility between cattle fed control diets and diets containing 40% wet distillers grains (Vander Pol et al., 2009) or between diets with 0% or 25% dried distillers grains with solubles (May et al., 2009). In the current experiment, grams of apparent starch digested decreased (linear, $P < 0.01$) as WDGS increased in the diet, in accordance with decreased starch intake. However, apparent starch digestibility as a proportion of intake also tended to decrease (linear, $P < 0.07$) as WDGS increased in the diet. Nevertheless, apparent starch digestibility exceeded 99% for all treatments.

Neutral detergent fiber intake increased as WDGS inclusion increased from 0 to 30% but decreased as WDGS inclusion increased from 30 to 45% in the diet (quadratic, $P = 0.02$). Subsequently, fecal excretion of NDF increased from 0 to 30% inclusion (linear, $P < 0.01$) and decreased from 30 to 45% inclusion. The reason for decreased NDF intake and excretion at the greatest (45%) WDGS inclusion was likely caused by the linear ($P = 0.04$) decrease in DMI in response to WDGS inclusion. Neutral detergent fiber digestibility decreased linearly ($P < 0.01$) as a percentage of NDF intake as the concentration of WDGS in the diet increased from 0 to 45% of DM. In a recent study by Hales et al. (2012), apparent NDF digestibility increased in cattle fed 30% vs. 0% WDGS in DRC or SFC diets. Likewise, Luebbe et al. (2011) noted an increase in NDF digestibility with increasing WDGS concentration in a SFC-based finishing diet. Conversely, others have reported no differences in NDF digestibility when feeding wet or dry distillers grains at up to 15% of DM in high concentrate diets (Depenbusch et al., 2009; Vander Pol et al., 2009; May et al., 2010).

When WDGS concentration in the diet increased from 15 to 45%, EE intake increased ($P < 0.01$), as expected, based on the analyzed composition of the diets (Table 1). Similarly, apparent EE digested (g/d) increased ($P < 0.01$) as the concentration of WDGS increased in the diet. There was a linear trend ($P = 0.06$) for increased EE excretion as the concentration of WDGS increased in the diet. No difference was detected ($P = 0.50$) for apparent digestibility as a proportion of EE intake.

Methane and Carbon Dioxide Emissions

Dry matter intake decreased linearly ($P < 0.04$; Table 3) as WDGS increased in the diet. Methane production (L/steer and Mcal/d) increased quadratically ($P = 0.03$) as WDGS increased in the diet. Furthermore, when expressed as L/kg of DMI and as a proportion of GE or DE, CH_4 production increased linearly ($P < 0.01$) with increasing concentrations of WDGS in the diet. Beauchemin and McGinn (2005) reported CH_4 losses as a proportion of GE of 2.8% when cattle were fed dry-rolled corn (**DRC**)-based diets and Hales et al. (2012) reported losses of 2.47% and 3.04% of GE for SFC- and DRC-based diets, respectively. The loss in GE as CH_4 reported in the current experiment (Table 3) was similar to the expected range of 2 to 4% reported for feedlot cattle

Table 3. Daily methane (CH_4) and CO_2 emissions from cattle fed steam-flaked (SFC)-based diets with 0%, 15%, 30%, or 45% wet distillers grains with solubles (WDGS) at an intake twice the level of maintenance[1]

Item	Treatment				SEM[2]	Linear *P*-value[3]	Quadratic *P*-value
	SFC-0	SFC-15	SFC-30	SFC-45			
DMI, kg	6.5	6.3	6.3	5.8	0.29	0.04	0.27
DMI, % of BW	1.97	1.96	1.97	1.78	0.057	0.05	0.37
CH_4 production							
L/steer	69.8	70.7	83.1	101.9	5.43	<0.01	0.03
L/kg of DMI	10.9	11.2	13.2	17.9	1.25	<0.01	0.07
% of GE	2.4	2.5	2.9	3.7	0.27	<0.01	0.10
% of DE intake	3.4	3.5	4.3	5.9	0.38	<0.01	0.06
Mcal	0.66	0.67	0.79	0.96	0.05	<0.01	0.03
CO_2 production							
L/steer	2,929	2,968	2,798	2,692	142.9	0.23	0.87
CO_2:CH_4 ratio	42.6	42.9	33.7	27.0	3.19	<0.01	0.05

[1]Corn grain was processed by steam flaking and WDGS concentration was 0%, 15%, 30%, or 45% of dietary DM.

[2]Pooled SEM (*n* = 4).

[3]The observed significance level for the contrasts. Contrasts were linear and quadratic effects of increasing concentrations of WDGS.

fed corn grain-based diets (Johnson and Johnson, 1995). The Intergovernmental Panel on Climate Change (**IPCC**) 2006 tier II model estimates enteric CH_4 production at 3% of GE for feedlot cattle. Based on our results, it seems that CH_4 emissions from feedlot cattle fed SFC-based diets with 30% WDGS or less are less than the value of 3.0% of GE used by IPCC. Using the sulfur hexafluoride tracer technique, Mc Geough et al. (2010) fed beef cattle wheat silages with varying grain concentrations and reported no differences in CH_4 production in response to increasing grain concentrations in silage. Additionally, Behlke et al. (2008) observed a linear decrease in CH_4 per mg of DM digested as dried distillers grains and solubles increased in an in vitro incubation system.

In the present experiment, there were no dietary effects ($P > 0.23$) on total CO_2 production; however, the CO_2:CH_4 ratio decreased quadratically ($P < 0.05$) as WDGS concentration increased in the diet. Similar to our results, McGinn et al. (2004) noted no differences in CO_2 production when cattle were fed treatments of barley silage-based diets that included a control diet and diets including monensin, sunflower oil, or a proteolytic enzyme. Additionally, McGinn et al. (2004) reported the total CO_2 emission was 3.4 kg per animal, whereas the average total daily CO_2 emission in the current experiment was 1.5 kg per animal. The reason for the greater CO_2 production noted by McGinn et al. (2004) is likely because of greater DMI.

Energy Losses

The GE is partitioned into its various components in Table 4. There were no differences in GE ($P > 0.37$) as WDGS concentration increased in the diet. In contrast, fecal and urinary energy loss (Mcal/d) increased linearly ($P < 0.02$) as WDGS concentration increased in the diet. Similarly, as WDGS increased in the diet, fecal energy, as a proportion of GE, increased linearly ($P < 0.01$). Cattle fed SFC- or DRC-based diets with 0% or 30% WDGS had no differences in fecal energy loss as a proportion of GE (Hales et al., 2012). However, urinary energy loss was greater when cattle were fed 30% WDGS (Hales et al., 2012). Greater urinary energy loss as WDGS increased in the diet is expected because the primary energetic constituent in urine is urea, which increases with increased dietary CP. In our experiment, when WDGS concentration in the diet increased, DE, ME, and RE decreased linearly as a proportion of GE ($P < 0.04$). It is likely that these decreases were primarily caused by the SFC-45 diet with the greatest concentration of WDGS and subsequently fiber. Unlike the present experiment, Hales et al. (2012) reported no differences in DE, ME, or RE as a proportion of GE when WDGS concentration in the diet increased from 0 to 30% of DM. The reason for the conflicting results could be that Hales et al. (2012) fed WDGS up to 30% of DM, whereas, in the current study, WDGS was included up to 45% of DM. In the present experiment, when expressed as Mcal/kg of DMI, DE, and CH_4, energy decreased ($P < 0.01$) linearly when WDGS concentration increased in the diet from 0 to 45% of DM. Likewise, ME (Mcal/kg of DMI and as a % of DE) decreased linearly ($P < 0.01$) as WDGS concentration in the diet increased. As WDGS concentration increased in the diet, HP was not different ($P > 0.78$) when expressed as a proportion of GE.

Net Energy for Maintenance and Gain

Through feeding cattle near maintenance and at 2 times maintenance, we determined the NE_m values for WDGS to be 2.54, 2.62, and 2.68 Mcal/kg when included at 15%, 30%, and 45% of dietary DM, respectively, in a SFC-based diet. In contrast, NRC (1996) reported

Table 4. Daily energy intake and losses from cattle fed steam-flaked (SFC)-based diets with 0%, 15%, 30%, or 45% wet distillers grains with solubles (WDGS) at an intake twice the level of maintenance[1]

	Treatment					Linear	Quadratic
Item	SFC-0	SFC-15	SFC-30	SFC-45	SEM[2]	*P*-value[3]	*P*-value
GE, Mcal	27.4	27.4	27.7	26.1	1.31	0.38	0.37
Fecal energy, Mcal	7.5	8.1	9.3	9.6	0.79	<0.01	0.68
Fecal energy, % of GE	27.3	29.4	33.6	36.7	1.71	<0.01	0.70
DE, Mcal	19.9	19.2	18.9	16.5	0.75	0.02	0.26
DE, Mcal/kg DMI	3.1	3.0	2.9	2.9	0.07	0.01	0.98
DE, % of GE	72.7	70.5	66.4	63.3	1.71	<0.01	0.70
Urinary energy, Mcal	0.2	0.4	0.4	0.4	0.05	0.02	0.52
Urinary energy, % of GE	0.9	1.3	1.3	1.7	0.22	0.03	0.78
Methane energy, Mcal/kg DMI	0.1	0.1	0.1	0.2	0.01	<0.01	0.07
ME, Mcal/kg DMI	3.0	2.9	2.8	2.6	0.07	<0.01	0.34
ME, % of GE	69.4	66.8	62.2	57.9	1.67	<0.01	0.57
ME, % of DE	95.8	95.0	94.3	91.9	0.64	<0.01	0.25
Heat production, Mcal	13.3	13.4	13.0	12.5	0.64	0.10	0.50
Heat production, % of GE	48.9	49.0	47.3	48.4	3.11	0.78	0.84
Retained energy, Mcal	5.7	4.7	4.3	2.6	0.97	0.06	0.64
Retained energy, % of GE	20.6	17.8	15.0	9.5	3.18	0.04	0.69

[1]Corn grain was processed by steam flaking and WDGS concentration was 0%, 15%, 30%, or 45% of dietary DM.

[2]Pooled SEM (*n* = 4).

[3]The observed significance level for the contrasts. Contrasts were linear and quadratic effects of increasing concentrations of WDGS.

a value for NE_m of WDGS at 2.18 Mcal/kg and we previously reported the NE_m value of WDGS at 2.39 or 2.27 Mcal/kg in SFC- or DRC-based diets at 30% inclusion (Hales et al., 2012). Values for NE_g of WDGS determined in the current experiment were 2.02, 1.61, and 1.38 Mcal/kg when included at 15%, 30%, or 45% of DM, respectively, in a SFC-based finishing diet. Once more, these NE_g values are greater than those reported in the NRC (1996) value of 1.50 Mcal/kg. The NE_g value for WDGS at 30% inclusion in this study is similar to the value determined using respiration calorimetry at the same location by Hales et al. (2012). Moreover, the NE_g value of WDGS in the current study was maximized at a lower concentration (15%) and appeared to have a deleterious effect on NE_g at the greatest inclusion concentration of 45% of DM. The partial efficiency of ME use for maintenance (k_m) did not differ across WDGS inclusion concentrations and ranged from 0.70 to 0.72 (SD ± 0.009). Furthermore, k_g responded in a similar manner and did not differ across inclusion of WDGS in the diet and was 0.38 (SD ± 0.002) for all diets. A probable explanation for the decreased NE_g as WDGS increased in the diet is likely because of the decreased ME:GE ratio, which was a result of the increased fiber present in WDGS, and a decreased fiber digestibility (presented in Table 4). This is likely because efficiency of ME use for maintenance and gain were not changed in response to increased WDGS inclusion. Interestingly, HP was not different across treatments and ME and DE responded in a similar manner, thus indicating that the primary factor causing the decrease in NE_g of WDGS was the decrease in DE.

Recently, May et al. (2011) determined dietary NE_m and NE_g for WDGS from performance data and these values ranged from 92 to 105% and 88 and 105% for NE_m and NE_g, respectively, when WDGS replaced a combination of SFC, cottonseed meal, and molasses in the diet, with differing concentrations of alfalfa hay. Inclusion of 20% or 40% WDGS in DRC and high moisture corn-based diets resulted in improvements in dietary NE_g of 2.5 and 6.8% (Vander Pol et al., 2009). In other work, when dietary NE_m and NE_g values were calculated from performance, NE_m and NE_g was greater in SFC- than DRC-based diets when WDGS replaced cottonseed meal, molasses, fat, urea, and SFC (Leibovich et al., 2009). Larson et al. (1993) reported a NE_g value of 2.53 Mcal/kg for yearling cattle and 1.95 Mcal/kg for WDGS in yearling cattle when DRC and molasses were replaced by wet distillers coproducts at 5.2%, 12.6%, and 40% of DM. In the present experiment, WDGS replaced SFC, cottonseed meal, and some proportion of urea and yellow grease.

Nitrogen Balance

Nitrogen balance is presented in Table 5. Intake of N increased linearly ($P < 0.01$) with increasing concentration of WDGS in the diet. This result was not surprising, because the CP concentration of WDGS is ~3 times greater than corn. Urinary N excretion increased linearly ($P < 0.02$) when WDGS concentration increased

Table 5. Influence of feeding steam-flaked (SFC)-based diets with 0%, 15%, 30%, or 45% wet distillers grains with solubles (WDGS) on N balance in cattle fed at an intake level twice that of maintenance[1]

Item	Treatment				SEM[2]	Linear *P*-value[3]	Quadratic *P*-value
	SFC-0	SFC-15	SFC-30	SFC-45			
N intake, g/d	138.3	143.5	177.5	179.0	7.91	<0.01	0.75
N excretion, g/d							
Urine	44.6	68.8	68.8	81.9	9.02	0.02	0.52
Feces	50.5	53.2	64.2	57.5	4.19	0.01	0.05
Total	95.2	122.0	133.0	139.5	9.72	<0.01	0.25
N excretion, % of total N excretion							
Urine	44.1	55.9	51.8	58.2	4.91	0.11	0.56
Feces	55.9	44.1	48.2	41.8	4.91	0.11	0.56
N excretion, % of N intake							
Urine	32.0	48.9	38.9	46.8	7.09	0.28	0.51
Feces	36.7	36.9	36.0	32.2	1.71	0.04	0.15
Apparent N digested,							
g/d	87.8	90.3	113.3	121.5	5.39	<0.01	0.57
% of N intake	63.3	63.1	64.0	67.8	1.71	0.04	0.15
N retained,							
g/d	43.2	21.4	44.5	39.5	11.56	0.81	0.48
% of N intake	31.3	14.2	25.2	21.0	7.29	0.54	0.38
% of digested N	48.9	23.3	39.3	30.2	11.14	0.41	0.45

[1]Corn grain was processed by steam flaking and WDGS concentration was 0%, 15%, 30%, or 45% of dietary DM.

[2]Pooled SEM ($n = 4$).

[3]The observed significance level for the contrasts. Contrasts were linear and quadratic effects of increasing concentrations of WDGS.

in the diet, likely as a result of the overall increase in N intake. Previous studies (Cole, 1999; Archibeque et al., 2007; Hales et al., 2012) reported a general increase in urinary N as dietary N intake increased in both sheep and cattle. In the present experiment, fecal N excretion increased quadratically ($P = 0.05$), whereas total N excretion increased linearly ($P < 0.01$) as WDGS concentration increased in the diet. These data are consistent with other reports of increased total N excretion as WDGS increased in a finishing cattle diet from 0 to 30% of DM (Hales et al., 2012). In the current experiment, increasing WDGS in the diet had no effect on the contributions of urinary or fecal N to total N excretion ($P > 0.11$) in urine or feces. As a proportion of N intake, fecal N excretion decreased linearly ($P < 0.04$) as WDGS increased in the diet, yet there was no effect on urinary N excretion ($P > 0.28$). Apparent N digestibility increased linearly ($P < 0.04$) as WDGS increased in the diet. Nitrogen retention (g/d, % of N intake, and % of N digested) were not affected ($P > 0.41$) by increased concentrations of WDGS in the diet. Both of these findings are in contrast with those of Hales et al. (2012), who reported greater N digestibility and greater N retention in response to 30% WDGS inclusion in both SFC- and DRC-based diets.

Carbon Balance

Carbon balance is presented in Table 6. Intake of C did not differ ($P > 0.25$) as WDGS increased from 0 to 45% of the diet DM. Increasing WDGS in the diet resulted in an increase (linear, $P < 0.02$) in urinary, fecal, and CH_4–C excretion, with excretion being least for cattle fed the SFC-0 diet. Hales et al. (2012) reported that cattle respired more CH_4–C when consuming DRC- than SFC-based diets. Likewise, in the current experiment, as a proportion of total C loss, increasing WDGS concentration in the diet caused an increase (linear, $P < 0.04$) in C excretion in urine and feces. Alternatively, a quadratic ($P < 0.04$) response was present in CH_4–C respired as a proportion of total C loss, with respired C being least for the diet without WDGS and greatest for the diet with 45% WDGS (DM basis). Carbon respired in the form of CO_2–C decreased (linear, $P < 0.01$) as a proportion of total C loss, when WDGS concentration increased in the diet, which differs from Hales et al. (2012) that reported no differences in CO_2–C respired for cattle consuming diets with 0% or 30% WDGS. As a proportion of C intake, urinary–, fecal–, and CH_4–C increased (linear, $P < 0.04$) as WDGS concentration increased in the diet. In contrast, increasing WDGS in the diet resulted in a linear decrease ($P < 0.01$) in the apparent C digested (g/d and % of C intake). No differences were detected ($P > 0.11$) in C retention (g/d, % of C intake, % of C digested) as WDGS increased in the diet, which is similar to Hales et al. (2012), who

Table 6. Influence of feeding steam-flaked (SFC)-based diets with 0%, 15%, 30%, or 45% wet distillers grains with solubles (WDGS) on C balance in cattle fed at an intake level twice that of maintenance[1]

Item	Treatment				SEM[2]	Linear *P*-value[3]	Quadratic *P*-value
	SFC-0	SFC-15	SFC-30	SFC-45			
C intake, g/d	2,770	2,736	2,813	2,581	131.7	0.25	0.29
C loss, g/d							
Urine	21	32	32	38	4.21	0.02	0.52
Feces	716	782	902	919	68.23	<0.01	0.50
CO_2–C	1,569	1,590	1,499	1,442	76.59	0.05	0.40
CH_4–C	38	38	45	55	3.17	<0.01	0.06
Total	2,343	2,443	2,478	2,452	106.87	0.15	0.25
C excretion, % of total C loss							
Urine	0.9	1.3	1.3	1.5	0.18	0.04	0.55
Feces	30.5	31.8	36.3	37.3	1.96	<0.01	0.69
CO_2–C	67.0	65.3	60.6	58.9	1.68	<0.01	0.98
CH_4–C	1.6	1.6	1.8	2.2	0.14	<0.01	0.04
C excretion, % of C intake							
Urine	0.6	1.2	1.2	1.5	0.19	0.03	0.83
Feces	25.8	28.4	32.0	35.5	1.36	<0.01	0.70
CO_2–C	56.9	58.3	53.7	56.4	3.36	0.66	0.83
CH_4–C	1.4	1.4	1.6	2.2	0.16	<0.01	0.11
Apparent C digested,							
g/d	2,054	1,954	1,912	1,665	78.0	<0.01	0.32
% of C intake	74.3	71.6	68.0	64.6	1.38	<0.01	0.74
C retained,							
g/d	427	293	336	129	103.2	0.11	0.73
% of C intake	15.3	10.7	11.6	4.5	3.67	0.10	0.74
% of C digested	20.6	14.9	16.9	6.8	5.30	0.15	0.70

[1]Corn grain was processed by steam flaking and WDGS concentration was 0%, 15%, 30%, or 45% of dietary DM.

[2]Pooled SEM ($n = 4$).

[3]The observed significance level for the contrasts. Contrasts were linear and quadratic effects of increasing concentrations of WDGS.

reported no differences in C retention, when WDGS was fed at 0% or 30% of diet DM.

Conclusions

We conclude that in SFC-based diets as a proportion of GE, CH_4 production increases when WDGS concentration is increased in the diet and RE decreases as WDGS increases. The reason for a linear decrease in RE as WDGS increased in the diet is likely because of the increased fecal energy loss associated with feeding WDGS. Moreover, dietary inclusion of WDGS at up to 45% had no effect on HP. As a result of greater N intake, total N excretion increased linearly with increasing WDGS inclusion in SFC-based diets. Fecal C loss and CH_4–C respired increased linearly with increasing dietary inclusion of WDGS. Carbon dioxide–C respired decreased as WDGS concentration increased, which was likely caused by decreased DMI with increased WDGS inclusion. We determined the NE_g values for WDGS to be 2.02, 1.61, and 1.38 Mcal/kg when included at 15%, 30%, and 45%, respectively, when added to a SFC-based diet. The results of this experiment are interpreted to suggest that the NE_g of WDGS in SFC-based finishing cattle diets must be discounted as the concentration increases.

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