Feeding distillers grains supplements to improve amino acid nutriture of lambs consuming moderate-quality forages

S. L. Archibeque, H. C. Freetly and C. L. Ferrell

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Feeding distillers grains supplements to improve amino acid nutriture of lambs consuming moderate-quality forages[1,2]

S. L. Archibeque,[3] H. C. Freetly, and C. L. Ferrell[4]

USDA-ARS, US Meat Animal Research Center, Clay Center, NE 68933-0166

ABSTRACT: We hypothesized that providing dried distillers grains with solubles (DDGS) would improve the N retention and use of nutrients by wethers fed a moderate-quality bromegrass hay. Additionally, we hypothesized that treatment effects on nutrient fluxes would be similar after 3, 6, or 9 wk on treatment. Chronic indwelling catheters were surgically implanted in a mesenteric artery, mesenteric vein, hepatic vein, and portal vein of 9 Suffolk × Dorset wethers (initial BW ± SD = 57.4 ± 6.1 kg). Wethers had ad libitum access to moderate-quality bromegrass hay (8.44% CP, DM basis) and received 100 g/d of either a corn-based (Corn, n = 4) or a DDGS-based (n = 5) supplement. There was no difference in DMI (P = 0.85) or DM digestibility (P = 0.46) between the 2 groups. There was a numerically greater N intake (21.5 vs. 18.4 g/d; P = 0.14) and N retention (4.4 vs. 2.5 g/d; P = 0.15) when wethers were supplemented with DDGS instead of Corn. Wethers fed DDGS had a greater (P = 0.008) release of α-amino N from the portal-drained viscera (PDV, 37.9 mmol/h) than those fed Corn (14.1 mmol/h). Similarly, there was a shift (P = 0.004) from a net splanchnic uptake to a net release of α-amino N in wethers fed DDGS (9.1 mmol/h) compared with those fed Corn (–9.6 mmol/h). However, there was no difference in ammonia release from the PDV (P = 0.49) or hepatic release of urea-N (P = 0.19) between the 2 treatments. There were very limited interactions between nutrient fluxes and the length of time after the initiation of treatments. However, there was a tendency (interaction, P = 0.07) for the PDV release of α-amino N to be greater at 6 and 9 wk after the initiation of the treatments than after 3 wk on treatment for wethers fed DDGS, although there was no difference over time for wethers fed the Corn supplement. Additionally, there were changes in numerous nutrient fluxes between 3 and 6 wk after the initiation of treatments regardless of treatment. These data indicate that DDGS is a viable supplement to enhance the nutriture of ruminants consuming moderate-quality forages. Additionally, these data indicate that the effects are discernible after 3 wk on treatment, with modest alterations in nutrient flux after additional time on treatment.

Key words: balance, distillers grain, metabolism, wether

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INTRODUCTION

Forage quality varies with locale and season and at times is not of adequate quality to provide the necessary nutriture to support the desired productivity of grazing ruminants. There are often improvements in weight gain or decreases in weight loss when ruminants consuming low-quality forages receive supplemental protein (Owens et al., 1991). Ruminally degradable intake protein supplementation is generally considered necessary to improve forage digestibility and intake in ruminants consuming low-quality forages (Swanson et al., 2004). However, there have been mixed results with the response to ruminally undegradable intake protein (**UIP**) supplementation (Schloesser et al., 1993; Alderton et al., 2000; Bohnert et al., 2002). Moreover, there is limited data identifying the adaptation of the splanchnic flux of nutrients over a prolonged range of time, greater than 28 d, after the initiation of dietary treatments to appropriately differentiate relative differences between experimental treatments.

With recent increases in ethanol production, distillers grains are increasingly available for livestock feed.

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

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[3]Present address: Department of Animal Science, Colorado State University, Ft. Collins, CO 80523-1171.

[4]Corresponding author: Cal.Ferrell@ars.usda.gov

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This feedstuff provides a substantial amount of energy, UIP, and P and may serve well as a supplement for ruminants consuming low-quality forages. However, there has been relatively little research focused on the use of distillers grains as a supplement for forage-fed ruminants.

Thus, the objectives of this study were to evaluate the potential of dried distillers grains with solubles (**DDGS**) as a supplement for wethers consuming moderate-quality forages and to quantify possible subsequent alteration over extended periods of time in nutrient fluxes when wethers were supplemented with DDGS, to determine the most adequate time frame that these studies should encompass.

MATERIALS AND METHODS

Animals and Experimental Procedures

The US Meat Animal Research Center Animal Care and Use Committee approved these experimental procedures.

Nine Dorsett-Suffolk wether lambs (initial BW ± SD = 57.4 ± 6.1 kg) from the US Meat Animal Research Center flock were surgically fitted with chronic indwelling catheters in the abdominal aorta, a mesenteric vein, the portal vein, and a hepatic vein (Ferrell et al., 1991). The wethers were housed in individual 1.17-m × 1.17-m pens at 20°C with a 14:10 h light:dark cycle. The wethers were used in a previous experiment (Archibeque et al., 2007), and 9 of the remaining wethers were selected based on patency of the catheters at the termination of the previous experiment.

The wethers had previously consumed a high-corn diet and were switched to an alfalfa pellet diet for 35 d before the initiation of this experiment. Throughout the study, wethers were allowed ad libitum access to chopped bromegrass hay (87% DM, 8.44% CP, and 0.10% P, on a DM basis). The wethers were stratified by weight and assigned to receive either a daily supplement of a corn-based supplement (Corn; Table 1, n = 4) or DDGS (n = 5) so that the initial BW was as similar as possible between the 2 groups. The supplements were formulated to provide similar amounts of energy (Corn = 0.328 and DDGS = 0.311 Mcal of ME/d), and 100 g/d was offered at 0800 to supply the amounts of supplement comparable to those in a grazing sheep scenario. However, the DDGS supplement contained slightly less energy due to the increased inclusion of limestone; this was necessary to avoid possible urinary calculi problems that may arise due to the greater P concentration in the DDGS.

Nutrient flux across the portal-drained viscera (**PDV**), hepatic, and total splanchnic tissues was measured during 3 periods, which were 3, 6, or 9 wk after the initiation of treatments. During each sampling period, blood was collected from 2 wethers on each treatment during the first day, 1 wether on each treatment during the second day, and the remaining 3 wethers during the third day of the period. During blood sampling, wethers were placed in portable crates (0.40-m wide × 1.2-m long × 1.17-m high) and allowed ad libitum access to the bromegrass hay and water. The supplement was offered at least 10 min before the first sampling of the day and was consumed by all wethers before any sampling occurred.

Table 1. Dry matter and chemical composition of the experimental supplements fed to mature wethers[1]

	Percentage of diet DM	
Item	Corn	DDGS[2]
Ingredient		
Ground corn	94.4	—
DDGS[2]	—	93.4
Molasses (dry)	5	5
Limestone	0.6	1.6
Nutrient content, DM basis		
DM,[3] %	88.0	90.1
CP,[3] %	10.13	29.50
DIP,[4] %	4.53	7.44
UIP,[4] %	5.60	22.06
ME,[4] Mcal/kg	3.28	3.11
Ca,[4] g/kg	2.9	7.0
P,[3] g/kg	2.9	6.0

[1]Wethers were fed 100 g of supplement/d in addition to chopped bromegrass hay (87% DM, 8.44% CP, and 0.10% P, on a DM basis), which was fed to appetite.
[2]DDGS = dried distillers grains with solubles.
[3]Measured values of balance trial composites.
[4]Calculated using tabular values (NRC, 1985).

A primed (15 mL), continuous infusion (0.8 mL/min) of paraaminohippuric acid (3% wt/vol) through a 0.22-μm sterile filter into the mesenteric vein was begun at 0700. Blood was drawn (4.5 mL) in heparinized syringes simultaneously from the mesenteric arterial, portal venous, and hepatic venous catheters at 0800 and then at hourly intervals for 6 h. Blood samples were immediately placed on ice. Within 4 h, 0.666 mL of blood was mixed with 1.998 mL of water for analysis of paraaminohippuric acid (Harvey and Brothers, 1962), α-amino N (**AAN**; Palmer and Peters, 1969), urea-N (Marsh et al., 1965), and ammonia-N (Huntington, 1982) using a Technicon Autoanalyzer System (Technicon Autoanalyzer Systems, Tarrytown, NY), and blood flows and net nutrient flux were calculated (Ferrell et al., 1999). An additional sample of blood from each vessel was drawn anaerobically into a 1-mL heparinized syringe, placed on ice, and analyzed within 10 min for hemoglobin and percentage oxygen saturation of hemoglobin (Hemoximeter, model OSM 1, Radiometer, Copenhagen, Denmark). Blood oxygen concentrations were calculated as described by Burrin et al. (1989). The blood in this 1-mL syringe was also immediately analyzed for glucose, L-lactate, glutamine, and glutamate using an immobilized enzyme system (model 2700 YSI, Yellow Springs Instrument, Yellow Springs, OH).

The wethers were allowed to recover from the final blood sampling for at least 11 d, after which total col-

lections of urine, feces, and orts were conducted for 4 d in the previously mentioned portable crates. Hay and supplements were sampled (100 g) daily during the 4 d of sample collection and composited for nutrient analysis. Urine was collected in plastic bottles containing 100 mL of 6 *M* HCl. Feces were collected by the use of a fecal bag. Orts, feces, and urine were collected daily and weighed, and an aliquot (100% of orts, 20% of feces, and 20% of urine daily output) was retained. Urine pH was measured with pH-sensitive paper before collection of aliquots to assure a pH < 4. Aliquots were pooled within wether and kept frozen at <–17°C until analyzed.

Composited feed, ort, and fecal samples were weighed, dried in a forced-air oven (55°C), weighed again, and then ground with a Wiley Mill (Arthur Thomas Co., Philadelphia, PA) fitted with a 1-mm screen. A subsample of feed, orts, and feces was dried at 70°C for determination of DM. Concentrations of N (LECO CN-2000 carbon/nitrogen analyzer, LECO Corporation, St. Joseph, MI) and P (HNO_3 digestion and subsequent color development using the Fiske chemical method; Fiske and Subbarow, 1925) were determined for feed, orts, feces, and urine for nutrient balance. Urinary urea-N was measured (Marsh et al., 1965) using a Technicon Autoanalyzer (Technicon Autoanalyzer System, Tarrytown, NY). Metabolic fecal N was calculated as 0.55 g of metabolic fecal N/100 g of DMI (Harris and Mitchell, 1941).

Statistical Analysis

The MIXED procedure (SAS Inst. Inc., Cary, NC) was used for statistical analysis of the data. The model for the nutrient flux data included treatment, period, and the treatment × period interaction as fixed effects and lamb(treatment) as a random effect. Period was treated as a repeated measure with an AR(1) error structure and lamb(treatment) as the subject. Two single degrees of freedom contrasts were used to test for differences due to period effects when there was a significant period effect ($P < 0.05$). The 2 contrasts were as follows: 3 wk vs. 6 wk on treatment and 6 wk vs. 9 wk on treatment. The model for balance trial data included treatment as a fixed effect. When treatment effects were significant ($P < 0.05$), a difference was determined, and a tendency for treatment to elicit a response was noted when $P < 0.10$.

RESULTS

The supplements in this study were designed to provide similar amounts of energy, although the DDGS supplement would provide additional protein to near-mature wethers consuming moderate-quality forage. The maturity of the wethers was reflected by the limited increase ($P = 0.001$; Figure 1) in BW. Dry matter intake increased in time ($P = 0.001$; Figure 2) while wethers were in the 1.17 m × 1.17-m pens. The calculated ME concentration (Table 1) was slightly lower for the DDGS supplement, and it had a greater measured concentration of both CP and P than the Corn supplement. Similar to the supplement concentrations, there was a numerically greater ($P = 0.14$) N intake (Table 2) when wethers were fed the DDGS supplement instead of the Corn supplement. Assuming that the nutritional needs of these wethers were similar to nonpregnant, nonlactating ewes in maintenance of a simi-

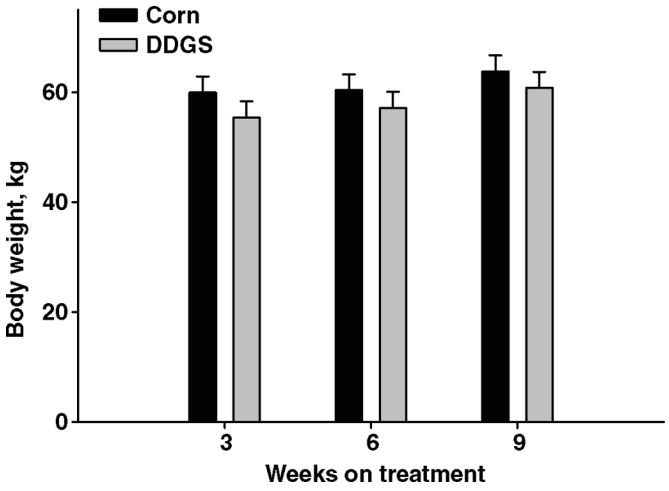

Figure 1. Body weight of wethers (SEM = 2.90) fed moderate-quality bromegrass hay and either a Corn (n = 4) or dried distillers grains with solubles (DDGS, n = 5) supplement after 3, 6, or 9 wk (period) of each treatment. There were no treatment ($P = 0.43$) or treatment × period effects ($P = 0.27$), yet there was a period effect ($P = 0.001$) on BW.

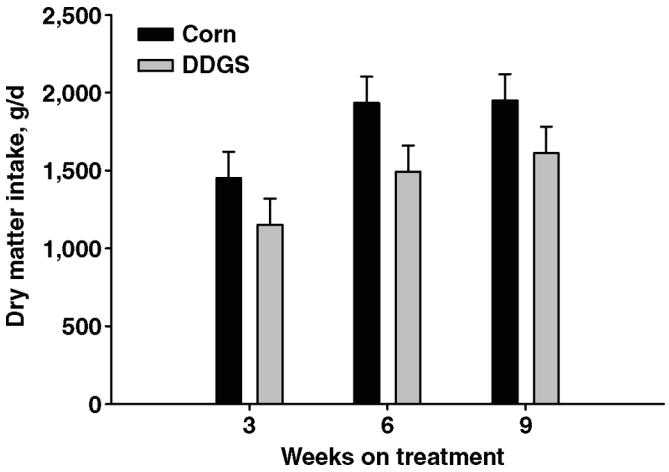

Figure 2. Average 3-d DMI (SEM = 169) of wethers fed moderate-quality bromegrass hay and either a Corn (n = 4) or dried distillers grains with solubles (DDGS, n = 5) supplement after 3, 6, or 9 wk (period) of each treatment. There were no treatment ($P = 0.16$) or treatment × period effects ($P = 0.75$), yet there was a period effect ($P = 0.001$) on DMI.

Table 2. Nutrient intake, digestion, and retention in 9 wethers fed moderate-quality bromegrass hay and either a Corn (n = 4) or a dried distillers grains with solubles (DDGS; n = 5) supplement during a nutrient balance trial

	Treatment			
Item	Corn	DDGS	SEM	*P*-value
DMI, g/d	1,376	1,349	102	0.85
DM digestibility, %	51.59	54.43	2.61	0.46
N				
N intake, g/d	18.41	21.46	1.38	0.14
Feces N, g/d	9.64	9.49	0.70	0.87
Urine N, g/d	6.23	7.52	0.61	0.16
Urine urea-N, g/d	2.52	3.79	0.35	0.03
N digestibility, %	47.23	55.90	2.64	0.04
N retained, g/d	2.54	4.45	0.79	0.15
P				
P intake, g/d	1.57	1.83	0.10	0.10
Feces P, g/d	1.40	1.46	0.11	0.72
Urine P, mg/d	10.02	10.27	0.59	0.76
P digestibility, %	10.66	20.57	4.26	0.13
P retained, g/d	0.16	0.36	0.06	0.05
Manure N:P[1]	11.24	11.57	0.19	0.23

[1]Manure N:P = (fecal N + urine N)/(fecal P + urine P).

lar size, then N intakes were near or slightly above requirements (NRC, 1985). There was an improvement ($P = 0.04$) in N digestibility, which was accompanied by a modest increase ($P = 0.03$) in urinary urea-N excretion when wethers were supplemented with DDGS, as compared with those fed the Corn supplement. Ultimately, the numerical increase of 3.06 g of N intake/d resulted in a numerical increase ($P = 0.15$) in N retention from 2.54 to nearly double (4.45 g/d) when wethers were fed DDGS. Similar to the changes in N use, P intake tended ($P = 0.10$) to be greater in wethers fed the DDGS than those fed Corn, which led to an increased ($P = 0.05$) P retention. These simultaneous alterations in N and P use and excretion from wethers fed either Corn (15.87 g of N, 1.50 g of P) or DDGS (17.01 g of N, 1.47 g of P) did not alter ($P = 0.23$) the ratio of N:P, an indicator of the potential value of the manure as a fertilizer, in the excreta of wethers fed either supplement.

Although supplementing DDGS instead of Corn resulted in few statistically significant alterations in the concentrations of nutrients within the various blood vessels (Table 3), the numerical differences and tendencies were consistent with increased provision of N to the wethers. For example, portal ammonia-N concentrations tended ($P = 0.08$) to be greater, and there was a numerical increase of at least 1.6 m*M* in the urea-N concentration of arterial ($P = 0.20$), portal venous ($P = 0.21$), and hepatic venous ($P = 0.19$) blood when wethers received the DDGS supplement instead of the Corn. Although there was a tendency ($P = 0.10$) for wethers fed DDGS to have a lower hepatic arterial blood flow (Table 4) than those fed Corn, there were no differences in portal ($P = 0.98$) or hepatic ($P = 0.62$) venous blood flows between the 2 treatment groups. There was a tendency (Figure 3A; treatment × period, $P = 0.07$) for PDV release of AAN to be greater for DDGS than for Corn after 3 wk of treatment. The PDV release of AAN for DDGS increased even further between 3 and 6 wk after the initiation of treatments and remained at an elevated rate 9 wk after the initiation of treatments, but there was no alteration throughout the 9-wk period in the PDV release of AAN when wethers were fed Corn. This increase in release of AAN from the PDV of DDGS-fed wethers between 3 and 6 wk of treatment was associated with a relatively unchanged ($P = 0.25$) hepatic AAN uptake (Figure 3B), which ultimately led to an alteration ($P = 0.004$) in total splanchnic flux from a net uptake when wethers were fed Corn to a net release in wethers fed DDGS (Figure 3C). Although there was no difference in glutamine PDV flux between the 2 treatments, there was a greater ($P = 0.02$) uptake of glutamine by hepatic tissues when wethers were supplemented with DDGS in lieu of Corn. This occurred concomitantly with no difference between treatments in ammonia flux from either the PDV ($P = 0.49$) or from hepatic tissues ($P = 0.46$), which may suggest that the glutamine was being used to transport excess N to the liver from the PDV for subsequent metabolism and removal from the system. There was a tendency (treatment × period, $P = 0.06$) for PDV uptake of glutamine to be increased 6 wk after the initiation of treatments compared with either 3 or 9 wk after the initiation of treatments when wethers were fed DDGS, yet there was no alteration throughout the 9-wk period in the PDV uptake of glutamine when wethers were fed Corn (Figure 3D). This alteration in PDV flux, coupled with a greater ($P = 0.02$) hepatic uptake of glutamine when wethers were fed DDGS instead of Corn, resulted in a similar (treatment × period, $P = 0.001$) alteration of total splanchnic flux of glutamine (Figure 3F). However, unlike glutamine, there was no change in PDV release ($P = 0.49$) and hepatic uptake ($P = 0.46$) of ammonia-N when wethers were supplemented with DDGS instead of Corn. There was numerically greater ($P = 0.19$) hepatic urea-N release by wethers fed the DDGS supplement rather than the Corn supplement. It is worth noting that the percentage of hepatic urea-N release accounted for by hepatic ammonia uptake was approximately 65% when wethers received the Corn supplement but only 58% in wethers that received the DDGS supplement.

As stated previously, the wethers used in this study were near their mature size during this study, which along with further adaptation to dietary treatments may explain a myriad of differences that were noted in blood nutrient concentrations (Table 5) and fluxes (Table 6) as time on treatment progressed. However, when wethers had received their dietary treatments for 6 wk, ammonia-N concentrations in the portal and hepatic vein were greater ($P = 0.04$ to 0.001) than after 3 or 9 wk on treatment. Similarly, urea-N concentrations after 6 wk on treatment were numerically greater

Table 3. Nutrient concentrations in the arterial, portal venous, and hepatic venous blood of 9 wethers fed moderate-quality bromegrass hay with either a Corn (n = 4) or a dried distillers grains with solubles (DDGS; n = 5) supplement

	Treatment			*P*-value		
Item	Corn	DDGS	SEM	Supplement (S)	Time (T)	S × T
α-Amino-N concentration, m*M*						
Artery	4.25	4.14	0.13	0.56	0.60	0.37
Portal vein	4.35	4.42	0.12	0.65	0.60	0.25
Hepatic vein	4.20	4.20	0.12	0.97	0.48	0.29
Ammonia-N concentration, m*M*						
Artery	0.055	0.073	0.008	0.11	0.02	0.13
Portal vein	0.230	0.275	0.016	0.08	0.001	0.18
Hepatic vein	0.050	0.066	0.007	0.15	0.01	0.12
Urea-N concentration, m*M*						
Artery	6.81	8.41	0.86	0.20	0.004	0.13
Portal vein	6.68	8.26	0.86	0.21	0.006	0.18
Hepatic vein	6.95	8.62	0.88	0.19	0.006	0.15
Glutamine concentration, m*M*						
Artery	0.306	0.314	0.024	0.82	0.001	0.54
Portal vein	0.242	0.244	0.022	0.97	0.001	0.23
Hepatic vein	0.252	0.240	0.023	0.70	0.001	0.03
Glutamate concentration, m*M*						
Artery	0.060	0.062	0.006	0.81	0.08	0.71
Portal vein	0.055	0.053	0.005	0.73	0.30	0.85
Hepatic vein	0.059	0.067	0.007	0.41	0.48	0.55
Glucose concentration, m*M*						
Artery	3.04	3.06	0.09	0.84	0.92	0.03
Portal vein	2.94	2.97	0.09	0.83	0.80	0.02
Hepatic vein	3.14	3.14	0.08	0.97	0.81	0.03
Lactate concentration, m*M*						
Artery	0.79	0.58	0.09	0.11	0.005	0.05
Portal vein	0.86	0.70	0.09	0.25	0.06	0.04
Hepatic vein	0.76	0.63	0.10	0.35	0.02	0.03
Oxygen concentration, m*M*						
Artery	5.64	5.37	0.15	0.23	0.12	0.14
Portal vein	4.28	4.00	0.15	0.18	0.19	0.14
Hepatic vein	3.41	3.10	0.15	0.15	0.38	0.28

(P = 0.14 to 0.16) in all vessels compared with those on treatments for 3 wk, and urea-N was greater at 6 wk (P = 0.02) than those on treatment for 9 wk. Conversely, there was an overall decrease in portal and hepatic venous glutamine concentrations at 6 wk on treatment (P = 0.003 to 0.001) when compared with the concentrations in these vessels at 3 or 9 wk on treatment.

During the study, it was noted that when wethers became agitated or moved around excessively, there was an elevation in lactate concentrations in all blood vessels, which would gradually decrease throughout the rest of the sampling times within that day. Additionally, this phenomenon was apparent in 7 wethers during the first sampling period, although it was largely absent during the final sampling period.

Although there appeared to be some vacillation in the concentrations of nutrients in the blood during this study, there was a greater consistency in the nutrient flux measurements (Table 6), with most changes in net flux across the splanchnic tissues occurring between 3 and 6 wk on treatment, although there were fewer changes between 6 and 9 wk on treatment. For example, despite a tendency (P = 0.06) for PDV release of ammonia to be increased between 3 and 6 wk on treatment, there was no further increase (P = 0.55) in PDV release of ammonia between 6 and 9 wk on treatment. Similar to PDV release of ammonia, hepatic uptake of ammonia increased (P = 0.04) between 3 and 6 wk but was unchanged (P = 0.57) between 6 and 9 wk on treatment. Accordingly, although there was no change in PDV uptake of urea-N across periods (P = 0.28 to 0.99), hepatic release of urea-N increased (P = 0.04) between 3 and 6 wk but was unchanged (P = 0.97) between 6 and 9 wk on treatment. This consistency, however, did not hold true for several other nutrient fluxes. Glutamine uptake by the PDV increased between 3 and 6 wk on treatment and then decreased by 9 wk on treatment. Additionally, although there was no difference (P = 0.85) in glucose uptake by the PDV between 3 and 6 wk on treatment, PDV uptake of glucose tended (P = 0.06) to be decreased at 9 wk on treatment. However, this change in glucose uptake

Table 4. Blood flow and net nutrient flux across splanchnic tissues of 9 wethers fed moderate-quality bromegrass hay with either a Corn (n = 4) or a dried distillers grains with solubles (DDGS; n = 5) supplement

	Treatment			*P*-value		
Item	Corn	DDGS	SEM	Supplement (S)	Time (T)	S × T
Blood flow, L/h						
Portal venous	141	140	10	0.98	0.002	0.67
Hepatic venous	171	162	13	0.62	0.008	0.15
Hepatic arterial	27	22	2	0.10	0.49	0.02
α-Amino-N net release,[1] mmol/h						
PDV[2]	14.1	37.9	4.9	0.008	0.004	0.07
Hepatic	–22.9	–28.8	3.6	0.25	0.84	0.50
Splanchnic	–9.6	9.1	3.3	0.004	0.16	0.76
Ammonia-N net release, mmol/h						
PDV	25.2	28.1	3.0	0.49	0.006	0.75
Hepatic	–26.2	–29.4	3.0	0.46	0.003	0.79
Splanchnic	–0.84	–1.22	0.17	0.13	0.86	0.14
Urea-N net release, mmol/h						
PDV	–19.7	–22.0	4.4	0.71	0.53	0.37
Hepatic	45.9	55.7	5.2	0.19	0.001	0.92
Splanchnic	27.0	33.7	5.2	0.36	0.001	0.35
Glutamine net release, mmol/h						
PDV	–9.3	–9.8	1.5	0.84	0.01	0.06
Hepatic	–0.14	–2.22	0.56	0.02	0.64	0.45
Splanchnic	–9.5	–12.1	1.6	0.27	0.001	0.001
Glutamate net release, mmol/h						
PDV	–0.73	–1.12	0.47	0.56	0.006	0.87
Hepatic	0.46	1.95	0.59	0.11	0.11	0.55
Splanchnic	–0.30	0.83	0.74	0.29	0.15	0.52
Glucose net release, mmol/h						
PDV	–12.5	–12.8	1.9	0.92	0.11	0.74
Hepatic	30.6	24.7	2.6	0.13	0.004	0.04
Splanchnic	17.4	11.9	1.9	0.06	0.01	0.92
Lactate net release, mmol/h						
PDV	8.2	8.7	1.0	0.72	0.48	0.11
Hepatic	–14.6	–8.6	3.0	0.18	0.001	0.82
Splanchnic	–6.4	0.0	3.4	0.20	0.001	0.94
Oxygen net release, mmol/h						
PDV	–189	–193	15	0.86	0.004	0.88
Hepatic	–183	–175	12	0.63	0.34	0.05
Splanchnic	–373	–367	26	0.87	0.04	0.36

[1]A positive number indicates net release, and a negative number indicates a net uptake.
[2]PDV = portal-drained viscera.

was paralleled by an unchanged ($P = 0.20$) PDV uptake of oxygen between 3 and 6 wk on treatment, followed by an increase ($P = 0.01$) by 9 wk on treatment.

DISCUSSION

With the considerable expansion of the ethanol industry (RFA, 2006) there is an increasing abundance of ethanol co-products available for use by the livestock industries, with 9 million metric tons of distillers grains produced in 2005 and estimates of 12 to 14 million metric tons to be produced annually by 2012. This increase in production will necessitate new uses and markets for these co-products. Distillers grains are relatively high in CP, ME, and P, which would make them an ideal supplement for ruminants consuming low- to moderate-quality forages, which typically are lacking in CP, ME, and P necessary for optimal performance. However, DDGS are relatively low in rumen-degradable protein (**DIP**; 27.2% of CP) and relatively high in UIP (72.8% of CP; NRC, 2000). When feeding low- to moderate-quality forages, it is common to have insufficient DIP, which in turn may limit ruminal NH_3 concentrations. Many of the cellulolytic bacteria prefer NH_3 as the source for N (Russell et al., 1992), and deficient ruminal N may, therefore, limit CP synthesis and growth of these cellulolytic bacteria. Subsequently, this limitation upon the cellulolytic bacteria could influence fiber fermentation, digesta outflow, and forage intake (Maeng et al., 1976; Egan, 1980; Gilbery et al., 2006). Ultimately, this alteration of bacterial functionality may affect the amount of energetic substrates (VFA) and AA available to the ruminant animal. The wethers in the current study were near

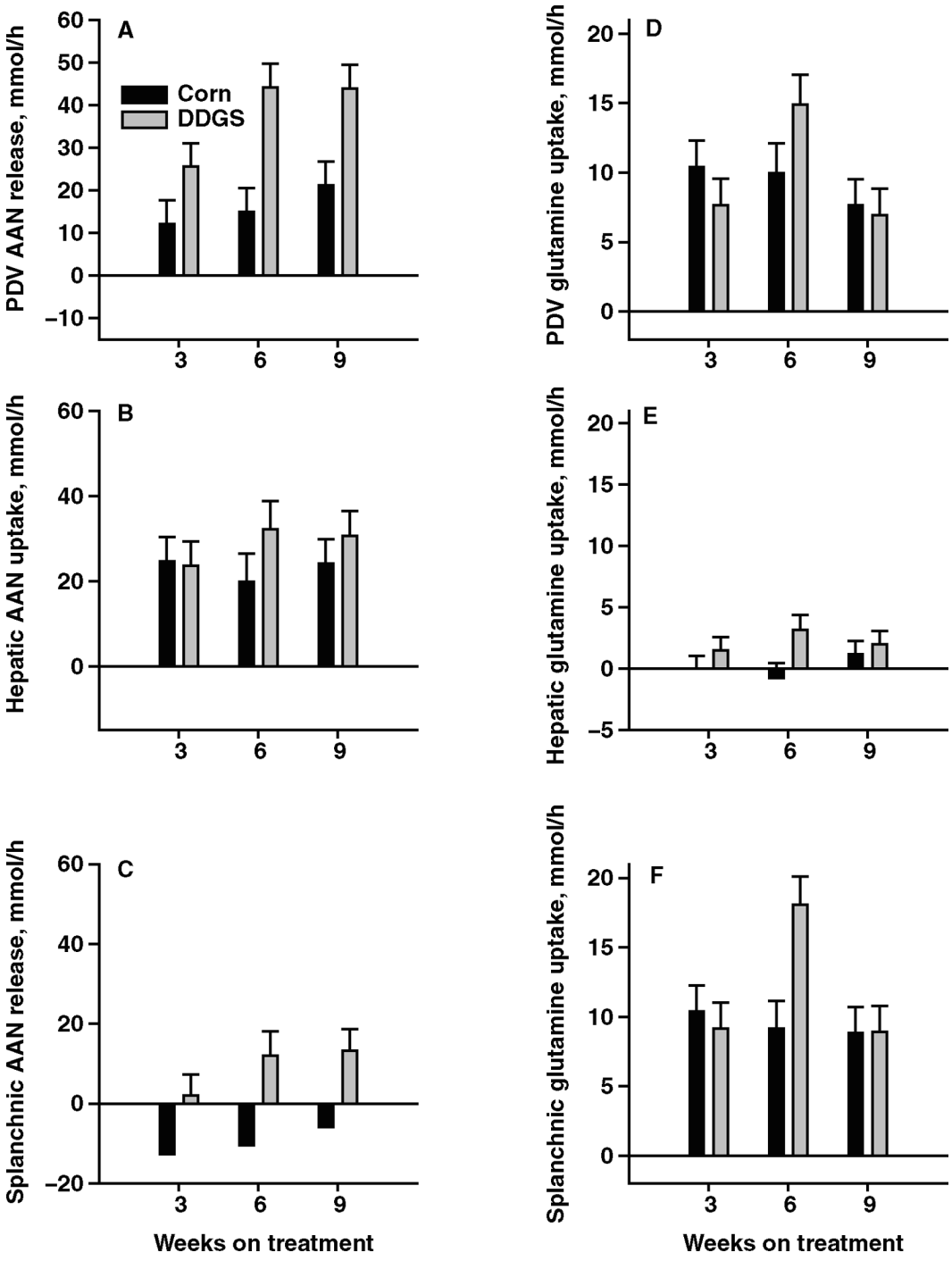

Figure 3. Net nutrient flux across portal-drained viscera (PDV), hepatic, and total splanchnic tissues of 9 wethers fed moderate-quality bromegrass hay with either a Corn (n = 4) or dried distillers grains with solubles (DDGS; n = 5) supplement. There was a tendency for a treatment × period effect ($P = 0.07$) for α-amino N (AAN) flux from PDV (A; $P = 0.07$; SEM = 5.57) but not for hepatic (B; $P = 0.50$; SEM = 5.75) or total splanchnic tissues (C; $P = 0.76$; SEM = 5.32). There was tendency for a treatment × period effect for glutamine flux from PDV (D; $P = 0.07$; SEM = 1.91) tissues, no treatment × period effect for hepatic tissues (E; $P = 0.45$; SEM = 1.07), and a significant treatment × period effect for total splanchnic tissues (F; $P = 0.001$; SEM = 1.89).

their mature size, and therefore, growth and deposition of lean tissue was minimal. Hence, these wethers would have a lower need for dietary AA than an ovine with a greater plane of productivity (i.e., pregnant-lactating ewes, rapidly growing lambs, etc.). This lower requirement and the low level of supplementation may explain why there was a limited effect upon N retention. Additionally, in some instances, UIP may indirectly supply DIP via urea recycling to increase ruminal N. This did not appear to be the case in the

Table 5. Nutrient concentrations in the arterial, portal venous, and hepatic venous blood of 9 wethers after 3, 6, or 9 wk of consuming a moderate-quality bromegrass hay with a supplement

	Weeks on treatment				*P*-value[1]	
Item	3	6	9	SEM	3 vs. 6	6 vs. 9
α-Amino-N concentration, m*M*						
Artery	4.23	4.09	4.26	0.13		
Portal vein	4.39	4.29	4.47	0.13		
Hepatic vein	4.21	4.10	4.30	0.12		
Ammonia-N concentration, m*M*						
Artery	0.061	0.084	0.048	0.008	0.07	0.01
Portal vein	0.251	0.284	0.223	0.013	0.02	0.001
Hepatic vein	0.054	0.077	0.043	0.008	0.04	0.004
Urea-N concentration, m*M*						
Artery	7.52	8.89	6.43	0.76	0.15	0.02
Portal vein	7.37	8.73	6.29	0.76	0.16	0.02
Hepatic vein	7.66	9.07	6.63	0.77	0.14	0.02
Glutamine concentration, m*M*						
Artery	0.363	0.279	0.288	0.018	0.001	0.52
Portal vein	0.293	0.191	0.244	0.018	0.001	0.003
Hepatic vein	0.299	0.201	0.239	0.016	0.001	0.001
Glutamate concentration, m*M*						
Artery	0.067	0.051	0.064	0.006		
Portal vein	0.050	0.055	0.059	0.005		
Hepatic vein	0.067	0.058	0.065	0.006		
Glucose concentration, m*M*						
Artery	3.03	3.07	3.05	0.08		
Portal vein	2.92	2.96	2.99	0.08		
Hepatic vein	3.10	3.15	3.15	0.08		
Lactate concentration, m*M*						
Artery	0.539	0.897	0.618	0.077	0.002	0.009
Portal vein	0.612	0.957	0.773	0.102		
Hepatic vein	0.472	0.893	0.717	0.105	0.005	0.18
Oxygen concentration, m*M*						
Artery	5.52	5.69	5.31	0.15		
Portal vein	4.15	4.31	3.95	0.16		
Hepatic vein	3.25	3.40	3.10	0.16		

[1]The probability of the single degree of freedom contrast of 3 vs. 6 wk or of 6 vs. 9 wk on treatment, when there was a significant ($P < 0.05$) effect of time on treatment.

current study, because there was no alteration in urea-N flux between the 2 dietary treatments.

However, with P intakes well below requirements, it was not surprising to see the substantial increase in retained P. Currently, a large proportion of DDGS is being fed to finishing beef cattle. As noted by Erickson et al. (1999, 2002), there is sufficient P in basal finishing diets for cattle. Therefore, by including high levels of DDGS in finishing rations, it is reasonable to assume that there would be considerable increases in the loss of P in excreta, unlike what was demonstrated in the forage-fed ruminants in the current study. Therefore, as the supply of DDGS expands, a more focused distribution of DDGS to forage-based production systems, which will need the nutrients in DDGS, must be made. Although the potential for supplementation of DDGS to forage-fed ruminants may be limited by the small quantity of DDGS that such supplementation may be able to utilize, or the quantity that may be transported to and stored at an operation, it provides a very promising outlet for the increased supply of DDGS.

Nutritional needs of the viscera comprise a substantial amount of the nutritional needs of a mammal. In a review of the literature, Ferrell (1988) estimated that the PDV and hepatic energy expenditures each comprise 20 to 25% of the total whole-animal energy expenditures. Ferrell (1988) also described, in detail, a myriad of physiological factors that may influence energy expenditures and the overall contribution of visceral expenditures to whole-animal expenditures. Glucose and glutamine are important metabolic fuels for gut tissue (Windmueller and Spaeth, 1980; Okine et al., 1995), and recent studies have focused on the importance and substitutive properties of these 2 fuels in nonruminants (Wu et al., 1995; Stoll et al., 1998; Wu, 1998) and ruminants (Okine et al., 1995; Oba et al., 2004). Oba et al. (2004) distinguished a "different extent of reliance on glutamine as an energy source between ruminant and nonruminant enterocytes." This was largely based on the sparing of glutamine oxidation in the presence of other metabolic substrates, and the extent of sparing may be concentration-dependent for some substrates, such as propio-

Table 6. Blood flow and net nutrient flux across splanchnic tissues of 9 wethers after 3, 6, or 9 wk of consuming a moderate-quality bromegrass hay with a supplement

	Weeks on treatment				*P*-value[1]	
Item	3	6	9	SEM	3 vs. 6	6 vs. 9
Blood flow, L/h						
Portal venous	127	139	157	10	0.36	0.17
Hepatic venous	152	169	178	10	0.11	0.38
Hepatic arterial	26	26	21	3		
α-Amino-N net release,[2] mmol/h						
PDV[3]	18.8	28.1	31.1	4.2	0.06	0.50
Hepatic	–24.1	–26.0	–27.4	3.9		
Splanchnic	–5.3	0.81	3.7	3.9		
Ammonia-N net release, mmol/h						
PDV	24.0	28.7	27.3	2.4	0.06	0.55
Hepatic	–25.0	–29.8	–28.6	2.3	0.04	0.57
Splanchnic	–1.0	–1.0	–1.1	0.3		
Urea-N net release, mmol/h						
PDV	–18.9	–21.8	–21.8	3.4		
Hepatic	38.4	56.8	57.0	5.4	0.04	0.97
Splanchnic	19.5	36.2	35.3	5.5	0.06	0.91
Glutamine net release, mmol/h						
PDV	–9.03	–12.44	–7.29	1.37	0.04	0.004
Hepatic	–0.74	–1.21	–1.58	0.77		
Splanchnic	–9.77	–13.63	–8.87	1.31	0.04	0.001
Glutamate net release, mmol/h						
PDV	–2.19	–0.33	–0.92	0.50	0.003	0.09
Hepatic	2.02	0.71	0.89	0.57		
Splanchnic	–0.16	0.99	–0.03	0.62		
Glucose net release, mmol/h						
PDV	–14.1	–14.6	–9.2	2.0		
Hepatic	24.3	30.0	28.6	0.9	0.001	0.31
Splanchnic	10.2	14.4	19.3	2.1	0.12	0.07
Lactate net release, mmol/h						
PDV	8.9	7.8	8.6	0.9		
Hepatic	–18.5	–9.2	–7.1	2.5	0.002	0.41
Splanchnic	–9.6	–1.5	1.5	2.7	0.001	0.27
Oxygen net release, mmol/h						
PDV	–173	–186	–214	12	0.20	0.01
Hepatic	–171	–184	–183	10		
Splanchnic	–344	–371	–395	20	0.13	0.18

[1]The probability of the single degree of freedom contrast of 3 vs. 6 wk or of 6 vs. 9 wk on treatment, when there was a significant ($P < 0.05$) effect of time on treatment.
[2]A positive number indicates net release, and a negative number indicates a net uptake.
[3]PDV = portal-drained viscera.

nate. Additionally, this may spare other AA, which may be degraded to form glutamine or subsequent products derived from glutamine, such as Arg or NO. In a previous study in our lab (Archibeque et al., 2007), when wethers were fed a diet deficient in protein, they had a greater PDV uptake of glutamine than those receiving adequate amounts of dietary protein, which was likely due to an insufficient amount being absorbed from the lumen of the small intestine. However, Doepel et al. (2005) noted no improvement in either energy or protein metabolism across the gut of lactating dairy cows consuming a complete total mixed ration that was supplemented with 300 g of glutamine/d via abomasal infusions. This may indicate a specific need by the intestinal mucosa for a basal amount of glutamine, which was already supplied by the diets of these cows fed a standard dairy total mixed ration, allowing this excess to be metabolized for other purposes. Additionally, in the current study, there was no response in PDV uptake of glutamine when wethers were supplemented with DDGS; however, there was a substantial increase in net release of AAN across the PDV when wethers were fed DDGS. This implies that some of the high nutritional needs of the PDV were being met when supplemented with DDGS, which may have a greater potential to affect ruminants that are in a greater plane of productivity.

Numerous studies evaluating the dynamics of nutrient flux across splanchnic tissues have focused on acute effects due to various chronic treatments. Typically, after less than 28 d of adjustment to treatments, nutrient fluxes are measured. The current study evaluated possible interactions and alterations in nutrient fluxes 3, 6, or 9 wk after the initiation of treatment. Again, these wethers were mature and grew only modestly during the study, which may complicate interpre-

tation of the data, because alterations in growth patterns and nutritional needs may have also slightly changed during the course of the experiment. However, as previously mentioned, this may be similar to many sheep in production, particularly mature ewes, which may spend a substantial portion of the year in a nonproductive state (i.e., nonpregnant and nonlactating). In the current study, most nutrient fluxes were near a steady state after 3 wk on treatment, yet additional adjustments in nutrient flux, most notably AAN, occurred after 3 wk on treatment, with minor additional alterations after 6 wk on treatment. There was also a modest increase in average DMI across all treatments during this time as well. Irrespective of DMI, these results are similar to the results of Ferrell and Koong (1985), who determined that 21 to 42 d were required to attain constant organ weights in feed-restricted lambs. Moreover, Freetly et al. (1995) determined, using nutrient flux data, that hepatic tissue required 21 d and PDV required 29 d to be near equilibrium with nutrient fluxes measured up to 80 d after challenged with nutrient restriction, and Burrin et al. (1989) estimated that a steady state was achieved by 14 d based on nutrient flux data. Although the wethers in the current study were not feed-restricted, these data correspond with previous studies suggesting that although most alterations in nutrient flux will be near a steady-state, some nutrient fluxes may continue to adjust up to 6 wk after the initiation of treatments. However, it should be noted that many of these effects were similar to the pattern of DMI, which may have also contributed to these differences. For example, the previously described increase in PDV release of AAN between 3 and 6 wk when wethers were fed DDGS followed the increase over time in DMI. However, it is uncertain why a similar response was not detected in wethers supplemented with Corn, because they also had a similar increase in DMI between 3 and 6 wk on treatment.

Overall, these data suggest that DDGS are a viable supplement for forage-fed ruminants. Although, at the amounts provided in this study, DDGS may be limited in their ability to improve DM digestibility, supplementation of DDGS is capable of improving the absorption of AAN for use by the animal. Additionally, although most treatment effects upon nutrient flux are apparent 3 wk after the initiation of treatments, additional time on treatment, up to 6 wk, was necessary to limit further alterations in absolute nutrient fluxes.

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