FINAL REPORT

AN EVALUATION OF BIOFUEL FEEDSTOCK COPRODUCTS AND BLENDED COPRODUCTS COMPARED TO DE-OILED CORN DISTILLERS GRAINS IN FEEDLOT DIETS: EFFECTS ON CATTLE GROWTH PERFORMANCE, CARCASS CHARACTERISTICS, NUTRIENT DIGESTIBILITY, AND WATER USE ASSESSMENT OF FEEDSTOCK SOURCES

1401 USCP/TCFA

A cooperative project between:
Texas Tech University
United Sorghum Checkoff Program
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PROJECT INFORMATION

Title:
An evaluation of biofuel feedstock coproducts and blended coproducts compared to de-oiled corn distillers grains in feedlot cattle diets: effects on cattle growth performance, carcass characteristics, nutrient digestibility, and water use assessment of feedstock sources.

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ABSTRACT

Crossbred steers (British x Continental; n = 192; initial BW 391 ± 28 kg) were used to evaluate the effects of feeding ethanol coproducts on feedlot growth performance, carcass characteristics, apparent nutrient digestibility, and the relationship between crop yield, water input and animal performance. Steers were blocked by initial BW and assigned randomly to 1 of 6 dietary treatments within block. Treatments were replicated in 8 pens with 4 steers/pen. Treatments included: **1)** control, steam-flaked corn-based diet **(CTL)**; **2)** corn dried distillers grains with solubles (DGS; **DRY-C**); **3)** de-oiled corn dried DGS **(DRY-CLF)**; **4)** blended 50/50 dry corn/sorghum DGS **(DRY C/S)**; **5)** sorghum dried DGS **(DRY-S)**; and **6)** sorghum wet DGS **(WET-S)**. The inclusion rate of DGS was 25% (DM basis); DGS diets were isonitrogenous, whereas CTL was formulated for 13.5% CP. All diets were balanced for fat. Overall ADG (1.64 kg), and DMI (10 kg/d) did not differ ($P \geq 0.14$) among treatments. Means for G:F were identical (0.153) for DRY-C and DRY-CLF, which were similar to CTL, DRY C/S, and WET-S ($P \geq 0.30$). Gain efficiency was decreased 9.6% with DRY-S vs. CTL (0.142 vs. 0.157, respectively, $P < 0.01$), and was 7.2% les for DRY-S vs. DRY-C or DRY-CLF ($P < 0.05$), but tended ($P = 0.06$) to be 5.6% greater for WET-S vs. DRY-S. Diet did not affect HCW (400 kg) or dressing percent (62.4%; $P \geq 0.10$); however, yield grade tended ($P = 0.09$) to be less for DRY-CLF and DRY-S vs. other treatments. Digestibility of DM and OM did not differ among CTL, DRY-C, DRY-CLF, and WET-S ($P \geq 0.30$), and were least for DRY-S vs. other treatments ($P < 0.01$). Digestibility of DM and OM were greater for DRY-C/S vs. DRY-S ($P < 0.01$), and similar for DRY-C/S, and DRY-C ($P \geq 0.20$). Digestibility of NDF was greater ($P < 0.01$) for WET-S vs. other treatments, and least for DRY-S vs. other treatments ($P < 0.01$), but not different among DRY-C, DRY-CLF, and DRY-C/S ($P \geq 0.40$). Starch digestibility was the greatest and not different among CTL, DRY-C, DRY-CLF, and DRY-C/S ($P \geq 0.40$). Analysis of total crop water use for corn vs. grain sorghum relative to G:F for DRY-C, DRY-S, and WET-S diets revealed a greater coefficient for steer gain relative to grain yield as a function of water input at 280 mm of water for grain sorghum vs. corn. At a moderately high (25% dietary DM) inclusion, blending C/S or feeding WET-S resulted in similar cattle performance to CTL and corn-based coproducts.

INTRODUCTION

Legislative mandates continue to drive U.S. ethanol production, with corn being the most widely used feedstock. In the Texas High Plains, an increasing number of acres are being planted to grain sorghum because of its capability to produce with limited water resources; ethanol production is a potential consumer for grain sorghum in this region.

Volatile feed commodity prices have increased reliance and level of inclusion of coproducts, such as distillers grains with solubles (DGS), in feedlot diets. Challenges with feeding coproducts continue to persist. Variation between ethanol plants in processing techniques and changes in processing with advancing technologies alter the composition and consistency of resulting coproducts, warranting continued research.

Relative to the consistency of distillers coproducts, previous research has evaluated corn and sorghum as feedstocks with mixed results, varying with level of inclusion and DGS source. Al-Suwaiegh et al. (2002) fed wet corn or wet sorghum DGS to replace 30% dry-rolled corn and reported similar results for ADG, gain efficiency and carcass characteristics for corn and sorghum-based DGS. Similarly, source of DGS (sorghum vs. corn), included at 15% (DM basis), did not alter DMI, ADG, gain efficiency, or carcass characteristics, nor did physical form (wet or dry) affect performance responses (Depenbusch et al., 2009). Conversely, wet sorghum DGS included at 15% (DM basis) in dry-rolled or steam-flaked corn-based diets decreased ADG, gain efficiency, hot carcass weight and dressing percent, regardless of corn processing method (Leibovich et al., 2009). Vasconcelos et al. (2007) also reported decreased growth performance and carcass weight with increasing levels (up to 15% DM basis) of wet sorghum DGS. Nonetheless, in the same study, growth performance, gain efficiency, and hot carcass weight were similar for feeding 10% (DM basis) wet corn DGS or wet sorghum DGS. May et al. (2010) evaluated feeding 0%, 15%, or 30% of wet corn DGS, wet sorghum DGS or a 50:50 blend of wet corn and wet sorghum DGS. No influence of DGS source on ADG was noted; however, growth performance was more favorable for 15% inclusion of DGS vs. 30%, regardless of DGS source. It is important to note that the DGS for the Leibovich, Vasconcelos, and a portion of the May studies originated from a New Mexico plant that is no longer in operation. A current supply of sorghum DGS in the Texas Panhandle is from a newly renovated sorghum ethanol plant in Levelland, TX, in which no large-scale research has been conducted with this product in this region. In addition, research is needed to evaluate feeding coproducts from different biofuel feedstocks, processing methods and inclusion rates.

Although it is apparent that most of the previously conducted research favors moderate inclusion of DGS in diets for feedlot cattle, economic circumstances as well as availability of alternate feedstuffs in the cattle feeding industry are leading to higher inclusion rates of coproducts. Moreover, ethanol processing methods continue to evolve, thus a greater understanding of the feeding value of DGS products is warranted. To enhance the viability of capturing a locally produced product such as sorghum DGS, as well as to better understand challenges and opportunities of local coproducts, current research with the products produced in the Texas Panhandle is needed.

OBJECTIVES

1) To evaluate the effects of feeding wet and dry sorghum, and blended (dry) corn/sorghum DGS products, compared with dry corn and de-oiled dry corn DGS on feedlot cattle growth performance, carcass characteristics and total tract apparent nutrient digestibility.

2) To better understand the role of grain sorghum in beef production systems by evaluating crop yield, as a function of total water input, for corn and grain sorghum, as associated to differences in animal performance from the two grain sources.

MATERIALS AND METHODS

All experimental procedures were conducted in accordance with an approved Texas Tech University Animal Care and Use Protocol (Protocol # 13068-08).

Cattle Management: Crossbred steers (n = 200; British x Continental) were received to the Texas Tech University Burnett Center on 16 April 2014. Cattle were owned by a cooperating producer and were sourced from wheat pasture. Before wheat pasture turnout, the cattle were vaccinated for IBR, PI3, BRSV, BVD type I and II (Bovi-Shield Gold 5; Zoetis Animal Health, Florham Park, NJ), *Clostridium chauvoei, Clostridium septicum, Clostridium novyi, Clostridium sordellii, Clostridium perfringen*s types C & D (Ultrabac 7; Zoetis Animal Health), treated for internal parasites (Safe-Guard, Merck Animal Health, Summit, NJ), and implanted with Revalor-G (40 mg TBA, 8 mg E_2; Merck Animal Health). Cattle were re-treated once during the grazing period for internal parasites (Safe-Guard, Merck Animal Health).

On arrival to the Texas Tech University Burnett Center Research Center, cattle were housed in soil-surface pens (10 to 15 steers/pen) with access to long-stem hay, a 65% concentrate receiving diet, and water; cattle were processed 48 h after arrival. At processing, steers were individually weighed [(Silencer Chute, Moly Manufacturing, Lorraine, KS; mounted on Avery Weigh-Tronix load cells, Fairmount, MN; readability ± 0.45 kg); before each use, the scale was validated with 454 kg of certified weights], individually identified with numbered identification tags, treated for external parasites (Dectomax Pour-On; Zoetis Animal Health), administered an internal paraciticide (Safe-Guard), and vaccinated against *Mycoplasma bovis* bacterin (American Animal Health, Grand Prairie, TX). Following processing, cattle were returned to soil-surface pens and remained on a 65% concentrate receiving diet. An unshrunk sorting BW was obtained on 25 April 2014; 192 steers were selected for enrollment in the experiment based on BW uniformity, health status, and temperament. Enrolled steers were ranked by ascending BW, assigned to BW block (n = 8 blocks), and returned to soil-surface pens. On 30 April 2014, steers within block, steers were assigned randomly to pen (4 steers/pen), and pens within block were assigned randomly to one of six dietary treatments within block; thus, treatments were replicated in 8 pens. Steers were sorted into 48 concrete, partially slotted-floor pens (2.9 m wide x 5.5 m deep; 2.4 m of linear bunk space). Dietary treatments included: **1)** steam-flaked corn-based diet, control (**CTL**)**; 2)** corn dried distillers grains with solubles (DGS; **DRY-C**); **3)** de-oiled corn dried DGS (**DRY-CLF**); **4)** blended 50/50 dry corn/sorghum DGS (**DRY C/S**); **5)** sorghum dried DGS (**DRY-S**); and **6)** sorghum wet DGS (**WET-S**). For DGS diets, coproduct inclusion rate was 25% (DM basis). The coproduct diets were balanced for CP and crude fat, whereas the positive control diet was formulated to provide 13.5% CP and balanced for fat with other diets. A vitamin/trace mineral supplement was included in all diets to meet or exceed NRC (1996) recommendations and to provide 33 mg/kg monensin (Elanco Animal Health, Indianapolis, IN) and 9.9 mg/kg tylosin (Elanco Animal Health; DM basis). Composition of dietary treatments is shown in Table 1; and formulated dietary nutrient compositions are provided in Table 2.

Steers were allowed 6 d for adaptation to concrete pens. On 6 May 2014, steers were individually weighed to obtain initial BW, and each steer was implanted with Revalor-XS (200 mg TBA, 20 mg E_2, Merck Animal Health). At this time, feeding of respective experimental dietary treatments commenced, and steers were gradually transitioned from diets containing 65% concentrate to 90% concentrate finishing diet over a 21-d period.

Throughout the finishing period, pen weights were collected every 28-d using a platform scale (readability ± 2.3 kg; validated before each use with 454 kg of certified weights). Feed bunks were cleaned at each weigh day, and any remaining feed was weighed and analyzed for DM content in forced-air oven at 100^0C for 24 h. Unconsumed feed was accounted for at each weigh day. In addition, daily feed records were adjusted if feed was removed because significant rainfall or feed spoilage.

Diet Sampling and Feed Delivery. Feed bunks were read at 0700 to 0730 h daily to estimate the quantity of residual feed for each pen and the bunks were managed such that only traces of feed remained before the next feeding. A 1.27-m^3-capacity paddle mixer (Marion Mixers, Inc., Marion, IA) was used to mix diets; a drag-chain conveyor was used to move feed from the mixer to tractor-pulled mixer/delivery unit (Roto-Mix 84-8, Roto-Mix, Dodge City, KS; scale readability of ± 0.45 kg) for delivery of feed to the bunk. The mixer was visually inspected before each diet was produced to ensure adequate cleanout to decrease cross-contamination of diets. For WET-S diets, all ingredients were milled in the batching system, except for WET-S, which was directly added to the Roto-Mix, and the complete diet was mixed thoroughly before delivery.

Throughout the experiment, diets were sampled each week from each of the 8 pens/treatment, composited by treatment, and composited by 28-d weigh periods. Dietary composites were analyzed at the end of the study by Servi-Tech Laboratory, Amarillo, TX for DM, CP, ADF, ether extract, Ca, P, Mg, K, S, Zn, Fe, Mn, and Cu (Table 2).

Samples of coproducts were obtained throughout the study to monitor nutrient composition, and weekly samples were obtained for analysis of DM. Samples of other dietary ingredients were sampled every other week for determination of DM in a forced-air oven for ~15 h at 100^{o}C.

Optaflexx (Ractopamine-hydrochloride; Elanco Animal Health, Greenfield, IN) was administered the final 28-d of the finishing period at the rate of 300 mg/steer/daily. On the day that Optaflexx feeding commenced, pens starting Optaflexx were weighed individually, by previously described procedures. Steers within respective weight blocks were sent to a commercial slaughter facility on 3 dates (blocks 7-8, 15 September 2014; blocks 4-6, 30 September 2014; blocks 1-3, 21 October 2014). Steers were shipped the morning of each slaughter date, with an individual BW measurement obtained before shipping. A 4% pencil shrink was used for determination of final BW.

Steers were transported 220 km to a commercial slaughter facility (Tyson Fresh Meats Inc., Amarillo, TX). Carcass characteristics were evaluated 24 h after slaughter by trained personnel from West Texas A&M University for the final 2 slaughter dates. Because of logistical error, carcass data were not collected for the first slaughter group; thus, only data for 2 slaughter groups are presented. Dressing percent was calculated by dividing the HCW by the unshrunk final BW. Carcass-adjusted final BW was calculated for cattle in final 2 slaughter dates only and was tabulated using HCW divided by the average dressing percent of each slaughter group (61.67%, and 63.06% for slaughter dates 2 and 3, respectively) and adjusted by a 4% shrink. Carcass-adjusted final BW was used to calculate carcass-adjusted ADG using unshrunk initial BW and DOF; carcass-adjusted ADG divided by average DMI for the experiment was used to calculate carcass-adjusted G:F.

Management of Coproducts: Coproducts were received at the Texas Tech University Burnett Center on 4 April 2014 and bagged on arrival. Samples were obtained from the front, middle and end of each truck as it was unloaded, and composited for analysis of nutrient composition of each coproduct. Respective nutrient compositions of each coproduct were used for formulation of experimental diets. Coproducts were received from the following locations: corn dry DGS, Arkalon Ethanol, Liberal, KS; de-oiled corn dry DGS, Poet, Amarillo, TX; 50/50 corn/sorghum DDGS, Conestoga Energy, Levelland, TX; dry sorghum DGS, Conestoga Energy, Levelland, TX; and wet sorghum DGS, Levelland, TX. Two additional loads of wet sorghum DGS were received toward the end of the study because of a greater than estimated moisture content, storage losses and greater DM intake than expected by cattle consuming this product. Average nutrient composition of coproducts throughout the experimental period are presented in Table 3.

Apparent Diet Digestibility: Diet samples (1,200 g) were collected once daily (d 103 to 108 on feed) from the bunk immediately after delivery at approximately 0900; a subsample (approximately 200 g) of each diet sample was frozen at 20ºC for later analyses, and the reminder of the sample was used for determination of dietary DM. Diet subsamples were composited by treatment at the end of the 5-d digestion study. From d 104 to 109 of the feeding period, orts were collected, and their weight was recorded. Approximately 10% of orts remaining were subsampled and frozen at -20ºC. The remainder of the orts sample was used for determination of dietary DM; subsamples were composited by pen following the digestion period. Feces were collected twice daily at 0700 and 1600 from d 104 to 109 of the feeding period, and samples were homogenized by pen following each collection. A subsample (approximately 100 g) of homogenized feces from each collection was obtained and composited by pen and frozen following each collection period. Before laboratory analyses, frozen composited laboratory samples were dried at 60°C for 72 h. Diet, orts and fecal samples were ground in a Wiley mill (Thomas Scientific, Swedesboro, NJ) to pass a 1 mm screen.

Laboratory Analyses: Diet, orts, and fecal samples were analyzed for acid insoluble ash, DM, OM, NDF, ADF, ether extract and starch. Acid insoluble ash (AIA) concentrations were determined using 2*N* HCl analysis (Van Keulen and Young, 1977), in triplicate. All other sample analyses were conducted in duplicate, and corrected for laboratory DM, determined by drying samples at 100°C in forced-air oven for 24 h. Ash was evaluated for determination of OM by burning samples at 550°C for 4 h (AOAC, 1990). Neutral detergent fiber and ADF were determined using a fiber analyzer (Ankom Technology, Macedon, NY), with the addition of sodium sulfite and α-amylase for the NDF procedure. Hemicellulose was calculated as the difference between NDF and ADF. Crude protein was determined using a Leco CNS Nitrogen Analyzer (Leco CNS-200, St. Joseph, MI). Starch and ether extract were evaluated by a commercial laboratory (ServiTech, Amarillo, TX). Apparent total tract digestibility of DM, OM, CP, NDF, ADF, hemicellulose, ether extract, and starch was determined from the following equation: 100-100 x [(concentration of AIA in feed/concentration of AIA in feces) x (concentration of nutrient in feces/concentration of nutrient in feed)]. Orts were accounted for in nutrient concentration of feed by correcting nutrient concentrations by dividing the adjusted (for orts) nutrient composition of the nutrient consumed by the adjusted (for orts) quantity of DM consumed.

Statistical Analyses: Data for performance, carcass characteristics and diet intake and digestibility were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) in a randomized complete block design. Pen served as the experimental unit, dietary treatment was a fixed effect and block was a random effect. Binomial proportions were used to analyze quality grade and yield grade with the Glimmix procedure (SAS Inst. Inc.), with block included as a random effect. When the P-value for the F-statistic was ≤ 0.05, least squares means were separated and reported using the LSD procedure of SAS ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Cattle Performance: Cattle performance data are presented in Table 4. Live and carcass-adjusted final BW, ADG and overall DMI did not differ among treatments ($P > 0.10$). Means for gain efficiency were identical (0.153) for DRY-C and DRY-CLF, and did not differ from CTL, DRY-C/S and WET-S ($P > 0.08$). Gain efficiency was decreased 9.6% with DRY-S vs. CTL (0.142 vs. 0.157, respectively, $P < 0.01$) and was 7.2% lower for DRY-S vs. DRY-C or DRY-CLF ($P < 0.05$), but tended ($P = 0.06$) to be greater (5.6%) for WET-S vs. DRY-S. At a similar inclusion of DGS (25 to 30% DM basis), results for G:F are mixed; Al-Suwaiegh et al. (2002) reported an improvement compared with control, whereas others reported G:F was less than control (Depenbusch et al., 2008; May et al., 2010). Furthermore, at a lower DGS inclusion (15%, DM basis) than in present study, Depenbusch et al. (2009) reported no difference in feedlot performance for steers fed dried sorghum DGS, wet sorghum DGS, or dried corn DGS in steam-flaked corn based diets. Conversely, Leibovich et al. (2009) and Vasconcelos et al. (2007) each reported reduced growth performance and carcass weight with steers fed 15% (DM basis) wet-sorghum DGS. In addition, May et al. (2010) fed increasing levels (0%, 15%, or 30%) of wet corn DGS, wet sorghum DGS, or 50:50 blend wet corn and wet sorghum DGS and reported no influence of DGS source on ADG; however, growth performance was more favorable for 15% inclusion of DGS vs. 30%, regardless of DGS source. Furthermore, regarding differences from de-oiling and similar to our findings, Jolly et al. (2014) reported no difference in G:F for wet-corn DGS or de-oiled wet corn DGS in blended dry-rolled and high-moisture corn-based diets.

The methods of Vasconcelos and Galyean (2008) were used to calculate net energy values for each of the dietary treatments based on treatment means for cattle performance. Calculated energy values were the greater for CTL, DRY-C and DRY-CLF vs. other treatments ($P > 0.60$), but similar for WET-S, DRY C/S, DRY-CLF ($P > 0.20$). Calculated energy values for all of the diets were slightly lower than tabular values (Table 4 and Table 2, respectively).

Carcass Characteristics: Measured characteristics (Table 5) did not differ among treatments; however, because 2 pens of cattle for each treatment are missing from carcass data analysis as a result of failed collection at the plant, numerical trends merit mentioning. Carcasses for DRY-CLF and DRY-S had lower 12th-rib fat thickness ($P = 0.17$) and a lower USDA yield grade ($P = 0.09$). In contrast with our findings, others reported reduced HCW with increasing levels of wet sorghum DGS in steam-flaked corn-based diets (Vasconcelos et al., 2007; Leibovich et al., 2009; May et al., 2010).

Nutrient Intake and Apparent Diet Digestibility: Data for nutrient intake and apparent diet digestibility are presented in Table 6, and the dietary nutrient composition during the digestion study is presented in Table 7. Intake of DM, OM, CP, and EE was greater for DRY-C vs. other treatments ($P \leq 0.03$). Intakes of NDF and hemicellulose were greater for all DGS treatments vs. CTL ($P < 0.05$), and starch intake was greater for CTL vs. DGS treatments ($P < 0.05$), which reflects the nature of the differences in chemical composition of DGS diets vs. CTL. Greater intakes of CP and EE by DRY-C are driven by greater DMI for this diet compared to with other diets during the experimental phase, as well as slightly higher fat and CP contents of this diet during the collection phase.

Data for nutrient digestibility provide a complement to feedlot performance results. Digestibility of DM and OM did not differ for WET-S, CTL, DRY-C, and DRY-CLF ($P > 0.30$), and was least for DRY-S vs. other treatments ($P < 0.01$). Interestingly, DM and OM digestibility were greater for DRY-C/S vs. DRY-S (75.66% vs. 68.75% for DM and 76.89% vs. 70.77% for OM, respectively, $P < 0.01$). In addition, DM and OM digestibility did not differ ($P > 0.20$) for DRY C/S and DRY-C.

The fiber (NDF, ADF, and hemicellulose) fractions of WET-S were highly digestible and yielded greater digestibility coefficients than other treatments ($P < 0.01$); conversely, the same fiber fractions of DRY-S were lower in digestibility than other DGS diets ($P < 0.01$), and were 48.5%, 65.4%, and 36.2% lower for NDF, ADF, and hemicellulose, respectively, compared with WET-S. Interestingly, DRY-C/S resulted in similar digestibility of NDF, ADF, and hemicellulose compared to DRY-C and DRY-CLF ($P \geq 0.26$). Crude protein digestibility was the greatest, and similar for CTL, DRY-C and DRY-CLF vs. other treatments ($P \geq 0.20$); intermediate, and similar for DRY-C/S and WET-S ($P = 0.90$), and lowest for DRY-S ($P < 0.01$). Digestibility of EE was the greatest and similar for CTL and DRY-CLF ($P = 0.86$) and was least for DRY-S vs. other treatments ($P < 0.01$). The EE digestibility for DRY-C/S was greater than DRY-S ($P < 0.01$), and WET-S did not differ from DRY-C ($P = 0.09$). Starch digestibility was the greatest and similar for CTL, DRY-C, DRY-CLF, and DRY-C/S ($P \geq 0.40$); whereas DRY-S and WET-S did not differ ($P = 0.18$).

In diets where corn-DGS was included at 25% (DM basis) to replace a portion of steam-flaked corn, May et al. (2009) found similar results to our study with no decrease in apparent DM, OM, NDF, or starch digestibility for DGS compared to control. In contrast, Uwituze et al. (2010) reported decreased apparent DM, OM, starch and CP digestibility for corn-DGS compared with control. In addition, May et al. (2010) reported no difference in nutrient digestibility between wet-corn or wet-sorghum DGS, included at 15% (DM basis), in steam-flaked corn-based diets compared to control.

When diets were balanced for fat, no differences in performance were observed for DRY-C and DRY-CLF; however, digestibility of EE was greater for DRY-CLF vs. DRY-C (93.47% and 91.21%, respectively, $P < 0.05$). Digestibility of other nutrients did not differ between the two corn DGS products, indicating that the further processing by de-oiling did not significantly affect digestibility of nutrients with the product used in this study.

Animal Performance, Crop Water Use Relationship: As water resources continue to become more limited in the Texas High Plains and surrounding regions, areas that at one time had irrigation capacity to support corn production are no longer able to support this crop and are as a result, being transitioned to low water-use crops, such as grain sorghum. Dynamic, innate interactions between compounds and nutrients within grain sorghum can result in decreased nutrient availability for livestock feeding compared with corn. Nonetheless, grain sorghum is potentially a more sustainable crop than corn in semi-arid regions, where irrigation water is limited. Evaluating the relationship between crop yield as a function of total water input, relative to differences and tradeoffs in animal performance is important in better understanding the role of grain sorghum in beef production systems. The following descriptive analysis is the beginning of the development of an evaluation of interchanges between water use and animal performance.

Crop yield (kg/ha) as a function of total crop water (assuming rainfall + irrigation) were derived from historical production information (J. Weinheimer, personal communication). Figure 1 depicts the relationship between total water and respective estimated yields of grain sorghum and corn, assuming crops were grown within similar environmental and management conditions. The differences in how each crop responds in production to increasing water increments indicates greater production of grain sorghum with limited water and greater corn yields with increased availability of crop water. Figure 2 shows the ratio of grain sorghum yield to corn yield as a function of water applied. In this figure, a plateau near 300 mm of total water, indicates similar yields of grain sorghum or corn at this level.

Performance data from the current study showed a decrease in G:F for DRY-S vs DRY-C or DRY-CLF (0.142, 0.153, and 0.153, respectively, $P < 0.05$; Table 4), whereas this ratio did not differ ($P = 0.50$) for WET-S (0.15) vs. DRY-C and DRY-CLF. To combine the data for crop production in relation to water use and animal performance, we considered the following scenarios: if total crop water (rainfall plus irrigation) is 254 mm, respective yields of grain sorghum and corn are 7,029 kg/ha and 6,025 kg/ha. If 7,029 kg/ha of grain sorghum at 254 mm water application is multiplied by the G:F ratio for DRY-S (0.142) = 998, and the yield for corn (6,025 kg/ha) is multiplied by G:F for DRY-C (0.153) = 922. These calculations suggest greater gain (grain yield in relationship to animal performance) for sorghum when total crop water is 254 mm, and could be considered a "GAIN FACTOR" when comparing the performance of cattle fed corn or sorghum.

In an alternate scenario, where the crop receives 406 mm of water, respective yields of grain sorghum and corn are 9,853 and 11,422 kg/ha, respectively. If 9,853 kg/ha yield for grain sorghum is multiplied by the G:F ratio for DRY-S (0.142), the result is 1,409, corresponding to the gain factor. If corn yield (11,422 kg/ha) is multiplied by G:F ratio for DRY-C (0.153), resulting gain factor is 1,748, indicating greater gain efficiency for corn (grain yield in relationship to animal performance) when 406 mm of total crop water is available.

These scenarios, as well as the trend described in Figure 2, indicate that increasing water application results in greater gain efficiency in feedlot steers from corn vs. sorghum. The crossover from sorghum to corn occurs when:

$$S \times 0.142 = C \times 0.153$$

Where S and C are yields (kg/ha) of sorghum and corn, respectively. This is equivalent to:

$$C/S = 0.153/0.142 = 1.077$$

If the same calculation is applied to the gain efficiency results for WET-S that were observed in the study, the crossover from sorghum to corn occurs when:

$$S \times 0.150 = C \times 0.153$$

$$C/S = 0.153/0.150 = 1.02$$

Figure 3 shows the ratio of grain sorghum yield to corn yield as depicted in Figure 2, but with the inclusion of the critical crossover ratios of 1.077 and 1.02. Based on the intersects in Figure 3, it is evident that the crossover point occurs around 280 mm of water when gain efficiency of DRY-S is compared with DRY-C, and 304 mm of water when gain efficiency of WET-S is compared to DRY-C. Thus, in areas with limited water availability, greater steer gains, relative to crop yield might be realized for grain sorghum compared with corn.

IMPLICATIONS

Data from this study indicate at a moderately high (25% dietary DM) inclusion, blending dry corn/sorghum and feeding wet-sorghum DGS resulted in similar cattle performance to a steam-flaked corn-based control diet, and corn-based coproducts. Moreover, blending dry corn DGS and dry sorghum DGS at a 50:50 ratio allows for greater nutrient availability and digestibility compared with dry sorghum DGS alone, potentially attributed to a dilution of reduced nutrient availability of dry-sorghum DGS compared to corn coproducts, and/or a positive associative effect with the two grain types. Based on gain efficiency and digestibility of nutrients, the feeding value of wet-sorghum DGS was improved compared to dry-sorghum DGS, although reasons for this response are not clearly delineated in this study. Nutrient digestibility also did not differ for WET-S compared to corn products and the steam-flaked corn control diet. Tradeoffs in animal performance for corn vs. grain sorghum can be evaluated in relationship to reduced water requirements for grain sorghum compared with corn, these calculations show the value of grain sorghum in water-limited regions.

Table 1. Composition of experimental diets (DM basis).

	Treatment[1]					
Ingredient, %	CTL	DRY-C	DRY-CLF	DRY-C/S	DRY-S	WET-S
Steam-flaked corn	75.71	59.68	57.24	59.49	59.45	61.94
Corn DDGS[2]	--	25.00	--	--	--	--
De-oiled corn DDGS	--	--	25.00	--	--	--
Corn/sorghum DDGS	--	--	--	25.00	--	--
Sorghum DDGS	--	--	--	--	25.00	--
Wet sorghum DGS[3]	--	--	--	--	--	25.00
Cottonseed hulls	5.50	4.00	4.00	4.00	4.00	4.00
Alfalfa hay	5.50	4.00	4.00	4.00	4.00	4.00
Molasses	5.00	3.00	3.00	3.00	3.00	--
Supplement[4]	2.00	2.00	2.00	2.00	2.00	2.00
Tallow	3.11	--	2.33	0.39	1.25	0.79
Limestone	1.67	1.80	1.80	1.78	1.30	1.79
Urea	1.51	0.52	0.63	0.34	--	0.48

[1]CTL = steam-flaked corn-based diet; DRY-C = 25% (DM basis) inclusion of corn dried distillers grains with solubles (DGS); DRY-CLF = 25% (DM basis) inclusion of dried de-oiled corn DGS; DRY-C/S= 25% (DM basis) inclusion of blended corn/sorghum dried DGS; DRY-S = 25% (DM basis) inclusion of sorghum dried DGS; and WET-S = 25% (DM basis) inclusion of sorghum wet DGS.

[2]DDGS = dried distillers grains with solubles.

[3]DGS = distillers grains with solubles.

[4]Supplement contained (DM basis): 71.514% ground corn; 0.500% antioxidant (Endox, Kemin Industries, Des Moines, IA); 10.000% potassium chloride; 15.000% salt; 0.002% cobalt carbonate; 0.196% copper sulfate; 0.083% iron sulfate; 0.003% ethylenediamine dihydroiodide; 0.167% manganous oxide; 0.125% selenium premix (0.2% Se); 0.9859% zinc sulfate; 0.009% vitamin A (1,000,000 IU/g); 0.157% vitamin E (500 IU/g); 0.750% Rumensin (220.5 mg/kg monensin, Elanco Animal Health, Indianapolis, IN); 0.506% Tylan (97 mg/kg tylosin, Elanco Animal Health).

Table 2. Formulated and analyzed nutritional composition of finishing diets.

	Treatment[1]					
Item	CTL	DRY-C	DRY-CLF	DRY-C/S	DRY-S	WET-S
Formulated Composition[2]						
DM, %	90.0	90.0	90.0	90.0	90.0	90.0
CP, %	13.5	16.5	16.5	16.5	16.6	16.5
Crude fat, %	6.4	6.4	6.4	6.4	6.4	6.4
NEm, Mcal/kg	2.11	2.12	2.08	2.09	2.05	2.09
NEg, Mcal/kg	1.44	1.45	1.42	1.42	1.39	1.43
Ca, %	0.75	0.74	0.76	0.74	0.60	0.75
P, %	0.28	0.43	0.43	0.43	0.34	0.44
Mg, %	0.17	0.22	0.22	0.22	0.19	0.24
K, %	0.73	0.80	0.84	0.78	0.76	0.74
S, %	0.17	0.21	0.35	0.23	0.23	0.22
Na, %	0.15	0.19	0.20	0.19	0.16	0.17
Zn, mg/kg	76	86	89	88	83	86
Fe, mg/kg	135	142	145	149	180	196
Mn, mg/kg	33	35	34	38	37	40
Cu, mg/kg	19	17	18	17	18	16
Analyzed Composition[2,3]						
DM, %	81.3	83.3	83.2	82.9	83.5	63.8
CP, %	14.0	16.6	17.3	16.9	16.5	18.0
Crude fat, %	6.1	6.0	6.0	5.7	6.0	6.1
Ca, %	0.80	0.82	0.79	0.72	0.74	0.74
P, %	0.26	0.37	0.41	0.37	0.31	0.42
Mg, %	0.17	0.21	0.23	0.21	0.19	0.26
K, %	0.74	0.79	0.84	0.74	0.69	0.83
S, %	0.15	0.19	0.31	0.20	0.20	0.19
Na, %	0.13	0.17	0.18	0.15	0.14	0.16
Zn, mg/kg	79	76	81	77	78	87
Fe, mg/kg	181	176	155	156	186	312
Mn, mg/kg	27	27	27	31	32	42
Cu, mg/kg	11	12	11	11	13	14

[1]CTL = steam-flaked corn-based diet; DRY-C = 25% (DM basis) inclusion of corn dried distillers grains with solubles (DGS); DRY-CLF = 25% (DM basis) inclusion of dried de-oiled corn DGS; DRY-C/S= 25% (DM basis) inclusion of blended corn/sorghum dried DGS; DRY-S = 25% (DM basis) inclusion of sorghum dried DGS; and WET-S = 25% (DM basis) inclusion of sorghum wet DGS.

[2]Values, with the exception of DM, are expressed on DM basis.

[3]Dietary samples were collected weekly, composited by 28-d weigh period analyzed by Servi-Tech Laboratory, Amarillo, TX.

Table 3. Average nutrient composition of coproducts throughout experimental period.

	Coproduct Type				
Item	DRY-C	DRY-CLF	DRY-C/S	DRY-S	WET-S
Analyzed Composition[1], % DM					
DM, %	88.8 ± 0.68	88.8 ± 0.35	88.9 ± 0.40	89.4 ± 0.68	34.6 ± 1.03
CP, %	33.2 ± 0.15	31.6 ± 1.31	34.3 ± 1.68	39.6 ± 0.21	34.5 ± 1.69
Crude fat, %	15.2 ± 1.25	6.1 ± 0.56	12.6 ± 1.70	9.6 ± 0.44	14.4 ± 2.00
NDF, %	36.0 ± 1.01	32.2 ± 1.51	36.0 ± 2.21	42.2 ± 3.25	30.3 ± 2.80
ADF, %	18.1 ± 2.14	13.1 ± 1.06	21.6 ± 2.41	26.7 ± 1.94	20.0 ± 3.49
Ca, %	0.04 ± 0.00	0.06 ± 0.01	0.05 ± 0.01	0.12 ± 0.00	0.12 ± 0.40
P, %	0.87 ± 0.20	0.94 ± 0.06	0.85 ± 0.07	0.53 ± 0.05	0.97 ± 0.16
S, %	0.36 ± 0.01	0.94 ± 0.04	0.41 ± 0.04	0.42 ± 0.03	0.37 ± 0.07

[1]Analyzed composition from a commercial laboratory (Dairy One Forage Testing Laboratory, Ithaca, NY).

Table 4. Effects of type of coproduct on growth performance of feedlot steers

	Treatment[1]							
Item	CTL	DRY-C	DRY-CLF	DRY-C/S	DRY-S	WET-S	SE	*P*-value
No. of pens	8	8	8	8	8	8		
Avg. days on feed	149	149	149	149	149	149		
Initial BW, kg	390	391	392	391	391	391	8.60	0.83
BW, kg								
d 56	500	499	492	497	489	497	10.33	0.17
d 112	567	579	569	572	556	579	11.37	0.10
Pre-Optaflexx[4]	603	612	599	602	590	609	8.11	0.13
Final BW,[2] kg	620	627	619	619	602	623	9.32	0.19
Adj. final BW[3]	611	628	619	617	596	619	11.54	0.20
ADG, kg								
d 0 to 56	1.96	1.93	1.79	1.90	1.76	1.89	0.06	0.11
d 0 to Optaflexx[4]	1.73	1.80	1.69	1.71	1.61	1.77	0.05	0.08
d Optaflexx to end	1.56	1.48	1.63	1.53	1.35	1.44	0.14	0.69
d 0 to end[5]	1.53	1.57	1.51	1.51	1.40	1.54	0.05	0.14
Adj., d 0 to end[3]	1.46	1.57	1.51	1.50	1.36	1.51	0.06	0.23
DMI, kg								
d 0 to 56	9.72	10.05	9.91	10.06	9.81	9.93	0.20	0.46
d 0 to Optaflexx[4]	9.80	10.33	9.97	10.14	9.91	10.44	0.26	0.23
d Optaflexx to end	9.35	9.83	9.44	9.81	9.47	9.51	0.27	0.65
d 0 to end[5]	9.71	10.24	9.87	10.08	9.83	10.26	0.25	0.30
G:F								
d 0 to 56	0.201[a]	0.192[ab]	0.180[bc]	0.189[abc]	0.179[c]	0.191[abc]	0.005	0.02
d 0 to Optaflexx[4]	0.177	0.175	0.169	0.169	0.163	0.171	0.004	0.08
d Optaflexx to end	0.166	0.151	0.173	0.153	0.142	0.150	0.012	0.56
d 0 to end[5]	0.157[a]	0.153[a]	0.153[a]	0.150[ab]	0.142[b]	0.150[ab]	0.003	0.03
Adj., d 0 to end[3]	0.153	0.155	0.156	0.151	0.139	0.152	0.004	0.12
Calculated NE value[6]								
NEm, Mcal/kg of DM	2.03[ab]	2.04[a]	2.01[ab]	1.96[bc]	1.91[c]	1.95[bc]	0.031	0.03
NEg, Mcal/kg of DM	1.37[ab]	1.38[a]	1.35[ab]	1.30[bc]	1.27[c]	1.30[bc]	0.027	0.03

[1]CTL = steam-flaked corn-based diet; DRY-C = 25% (DM basis) inclusion of corn dried distillers grains with solubles (DGS); DRY-CLF = 25% (DM basis) inclusion of dried de-oiled corn DGS; DRY-C/S= 25% (DM basis) inclusion of blended corn/sorghum dried DGS; DRY-S = 25% (DM basis) inclusion of sorghum dried DGS; and WET-S = 25% (DM basis) inclusion of sorghum wet DGS.

[2]Data for d 0 to 56, d 0 to Optaflexx® (Elanco Animal Health, fed the final 28-d of finishing period at 300 mg/steer/d), Optaflexx to end were not shrunk; however, a 4% shrink was applied to final BW and adjusted final BW for calculation of ADG from d 0 to end and adjusted, d 0 to end. Body weights for initial BW, d 56, d 112, or pre-Optaflexx are non-shrunk.

[3]Adjusted final BW equaled HCW divided by the average dressing percent of each slaughter group, 61.67% and 63.06% for the second and third groups, respectively. Adjusted BW gain (d 0 to end) was calculated from the adjusted final BW and the initial BW, and DOF; adjusted G:F (d 0 to end) was calculated as the ratio of adjusted ADG to average DMI for the experimental period.

[4]Cattle in blocks 7-8, 4-6, 1-3 were started on Optaflexx at d 105, 120, 141, respectively.

[5]Cattle in blocks 7-8, 4-6, 1-3 were on feed for 132, 147, and 168 d, respectively.

[6]Dietary NE values were calculated from performance data using the methods of Vasconcelos and Galyean (2008), based on net energy equations (NRC, 1996).

[a,b,c]Means within rows that do not have a common superscript differ, $P < 0.05$.

Table 5. Effects of type of coproduct on carcass characteristics of feedlot steers.

	Treatment[1]							
Item	CTL	DRY-C	DRY-CLF	DRY-C/S	DRY-S	WET-S	SE	*P*- value
No. of pens	6	6	6	6	6	6		
HCW, kg	397	408	402	401	388	402	7.65	0.23
Dressing percent[2]	62.43	62.48	62.54	62.53	61.89	62.23	0.57	0.95
12th rib-fat, cm	1.35	1.53	1.23	1.55	1.34	1.50	0.10	0.17
LM area, cm^2	86.48	87.08	86.47	84.59	89.83	84.09	2.19	0.51
KPH, %	1.92	2.00	1.93	1.93	1.95	2.03	0.046	0.43
Yield grade	3.25	3.51	3.17	3.57	3.17	3.58	0.15	0.09
Yield grade 2.00-2.99, %	16.67	--	16.67	--	33.33	--	12.91	0.95
Yield grade 3.00-3.99, %	83.33	100.00	83.33	100.00	66.67	83.33	14.59	0.96
Yield grade 4.00-5.00, %	--	--	--	--	--	16.67	6.80	1.00
Marbling score[3]	408	418	386	407	379	417	17.35	0.41
Select, %	50.00	50.00	83.33	33.33	66.67	16.17	20.18	0.61
Low Choice, %	50.00	33.33	16.67	66.67	33.33	83.33	19.95	0.53
Upper 2/3 Choice, %	--	16.67	--	--	--	--	7.46	1.00

[1]CTL = steam-flaked corn-based diet; DRY-C = 25% (DM basis) inclusion of corn dried distillers grains with solubles (DGS); DRY-CLF = 25% (DM basis) inclusion of dried de-oiled corn DGS; DRY-C/S= 25% (DM basis) inclusion of blended corn/sorghum dried DGS; DRY-S = 25% (DM basis) inclusion of sorghum dried DGS; and WET-S = 25% (DM basis) inclusion of sorghum wet DGS.
[2]Dressing percent = HCW/unshrunk final BW.
[3]100 = practically devoid^{00}, 200 = traces^{00}, 300 = slight^{00}, 400 = small^{00}, 500 = modest^{00}, 600 = moderate^{00}.

Table 6. Effects of type of coproduct on intake and apparent digestibility of nutrients of feedlot steers

	Treatment[1]							
Item	CTL	DRY-C	DRY-CLF	DRY-C/S	DRY-S	WET-S	SE	*P* - value
No. of pens	8	8	8	8	8	8		
Intake, kg/d[2]								
DM	9.32[b]	10.52[a]	9.69[b]	9.37[b]	9.42[b]	9.42[b]	0.31	0.03
OM	8.96[b]	9.98[a]	9.19[b]	8.96[b]	8.96[b]	8.94[b]	0.30	0.04
NDF	1.33[c]	1.85[a]	1.67[b]	1.72[ab]	1.66[b]	1.78[ab]	0.06	< 0.01
ADF	0.56[d]	0.65[b]	0.60[cd]	0.65[bc]	0.62[bc]	0.71[a]	0.02	< 0.01
HEM	0.77[c]	1.20[a]	1.07[b]	1.08[b]	1.04[b]	1.06[b]	0.04	< 0.01
CP	1.28[c]	1.80[a]	1.51[b]	1.54[b]	1.50[b]	1.70[a]	0.06	< 0.01
EE	0.54[bc]	0.64[a]	0.57[b]	0.53[bc]	0.54[bc]	0.52[c]	0.02	< 0.01
Starch	5.17[a]	4.73[b]	4.56[b]	4.56[b]	4.45[bc]	4.13[c]	0.14	< 0.01
Fecal output, kg/d	1.99[c]	2.39[b]	2.11[bc]	2.29[bc]	2.95[a]	2.03[c]	9.61	< 0.01
Digestibility, %								
DM	78.7[a]	77.2[ab]	78.2[ab]	75.7[b]	68.8[c]	78.5[a]	0.95	< 0.01
OM	79.8[a]	78.4[ab]	79.5[ab]	76.9[b]	70.8[c]	79.7[a]	0.95	< 0.01
NDF	37.2[cd]	46.9[b]	44.4[bc]	43.8[bc]	32.6[d]	59.9[a]	2.73	< 0.01
ADF	27.8[c]	39.4[b]	38.8[bc]	35.8[bc]	19.0[d]	53.7[a]	3.00	< 0.01
HEM	44.1[bc]	51.1[b]	47.5[bc]	48.6[bc]	40.8[c]	64.0[a]	2.81	< 0.01
CP	71.4[a]	74.5[a]	74.3[a]	65.6[b]	50.7[c]	65.9[b]	1.88	< 0.01
EE	93.6[a]	91.2[b]	93.5[a]	89.2[c]	86.5[d]	89.7[bc]	0.62	< 0.01
Starch	95.6[ab]	95.5[ab]	96.3[a]	96.1[a]	93.3[c]	94.3[bc]	0.56	< 0.01

[1]CTL = steam-flaked corn-based diet; DRY-C = 25% (DM basis) inclusion of corn dried distillers grains with solubles (DGS); DRY-CLF = 25% (DM basis) inclusion of dried de-oiled corn DGS; DRY-C/S= 25% (DM basis) inclusion of blended corn/sorghum dried DGS; DRY-S = 25% (DM basis) inclusion of sorghum dried DGS; and WET-S = 25% (DM basis) inclusion of sorghum wet DGS.
[2]HEM = hemicellulose.
[a,b,c,d]Means within rows that do not have a common superscript differ, $P < 0.05$.

Table 7. Analyzed nutritional composition of diets during digestibility study

	Treatment[1]					
Item	CTL	DRY-C	DRY-CLF	DRY-C/S	DRY-S	WET-S
DM, % as fed-basis	82.96	83.36	83.60	83.97	83.83	63.55
Nutrients, % of DM[2]						
Ash	4.05	5.13	5.12	4.56	4.92	5.14
NDF	14.22	17.56	17.23	18.45	17.68	18.81
ADF	6.01	6.18	6.20	6.89	6.55	7.54
HEM	8.21	11.38	11.02	11.56	11.13	11.27
CP	13.79	17.14	15.59	16.71	16.08	18.09
Crude fat	5.90	6.10	5.90	5.70	5.70	5.50
Starch	55.30	44.90	47.10	48.00	47.00	43.80

[1]CTL = steam-flaked corn-based diet; DRY-C = 25% (DM basis) inclusion of corn dried distillers grains with solubles (DGS); DRY-CLF = 25% (DM basis) inclusion of dried de-oiled corn DGS; DRY-C/S= 25% (DM basis) inclusion of blended corn/sorghum dried DGS; DRY-S = 25% (DM basis) inclusion of sorghum dried DGS; and WET-S = 25% (DM basis) inclusion of sorghum wet DGS.
[2]HEM = hemicellulose.

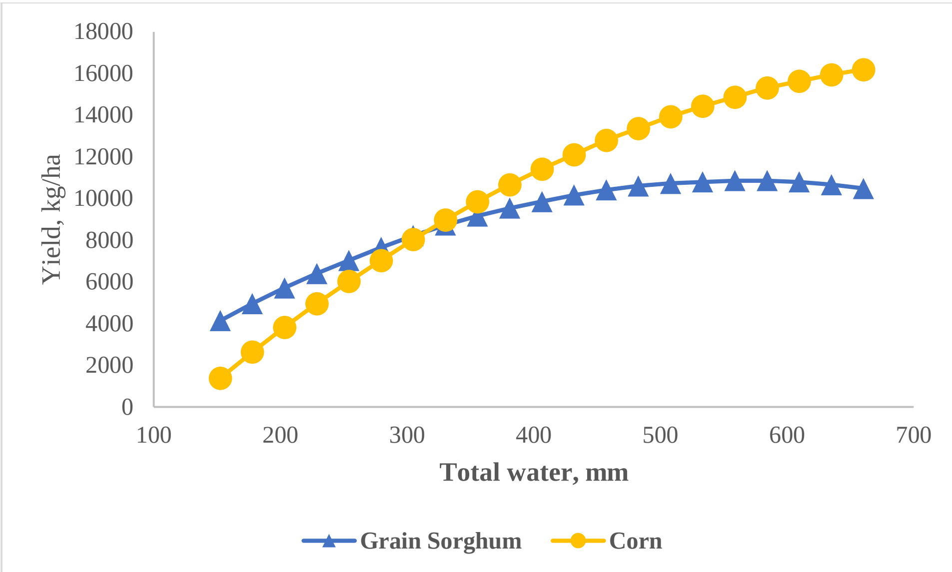

Figure 1: The relationship between grain yield (kg/ha) and total crop water (mm, assuming rainfall + irrigation)

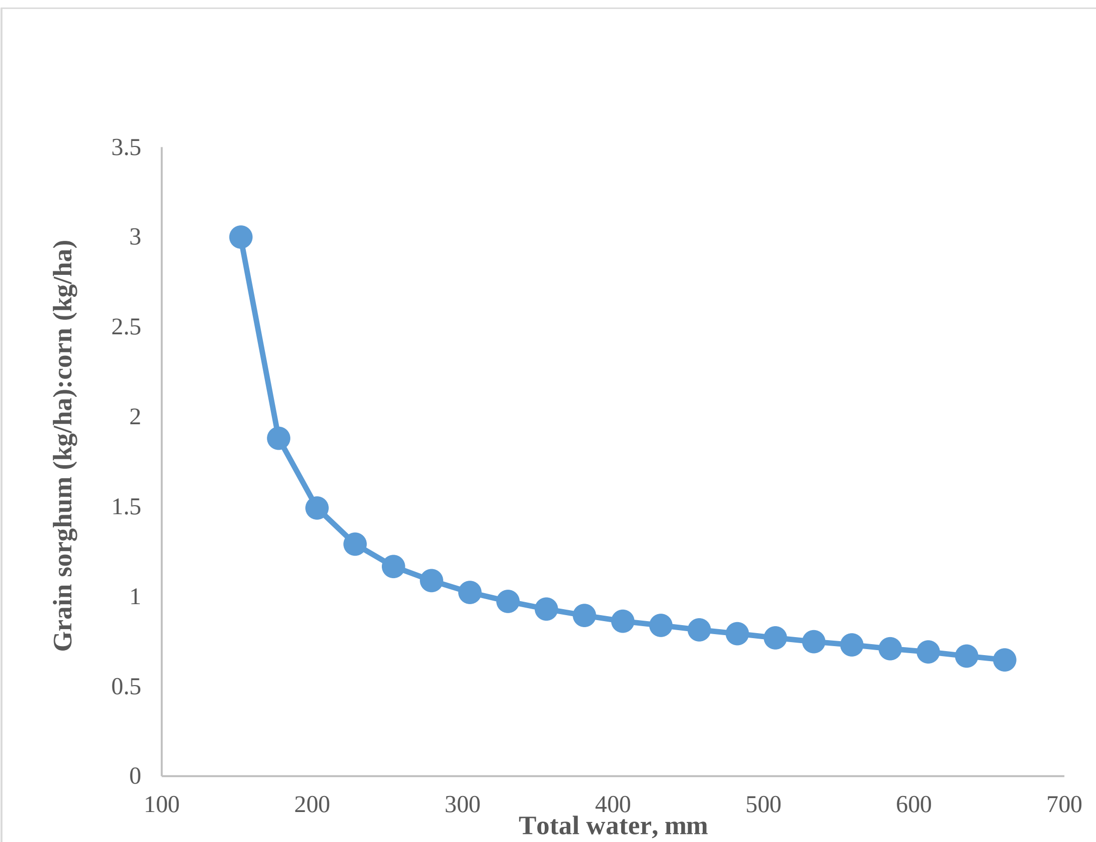

Figure 2: The ratio of grain sorghum yield to corn yield as a function of total crop water (rainfall + irrigation).

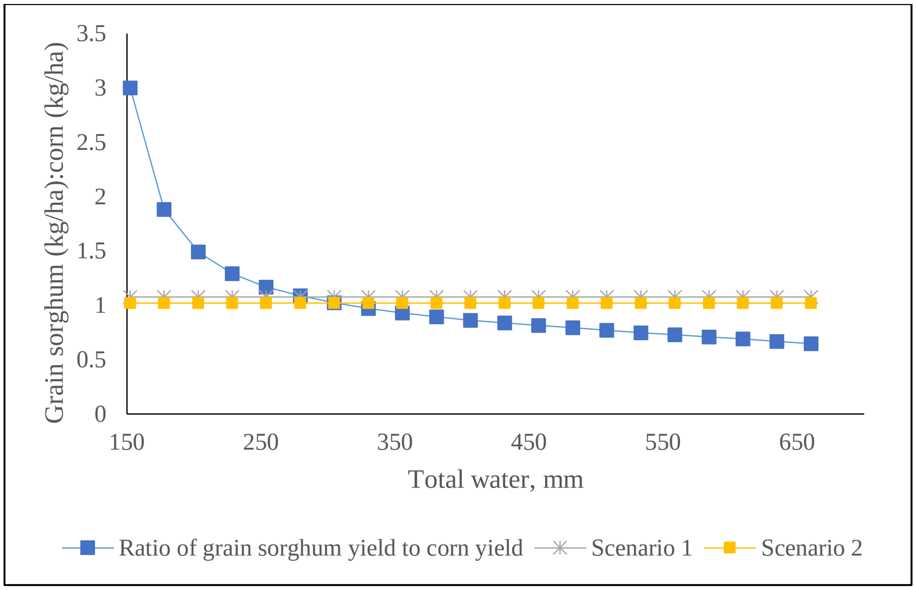

Figure 3: The ratio of grain sorghum yield to corn yield, as depicted in Figure 2, with the addition of the critical crossover point, as described by the ratio of gain efficiency for feedlot cattle consuming diets with 25% inclusion (DM basis) of either corn dried distillers grains with solubles (DRY-C), sorghum dried distillers grains with solubles (DRY-S) or sorghum wet distillers grains with solubles (WET-S). Scenario 1 shows the ratio as 0.153 (the mean gain efficiency for DRY-C) divided by 0.142 (the mean gain efficiency for DRY-S), equal to 1.077. Scenario 2 shows the ratio as 0.153 (the mean gain efficiency for DRY-C) divided by 0.150 (the mean gain efficiency for WET-S), equal to 1.02.

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