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Invited Review: Using whole cottonseed and cotton harvest residue in southeastern US beef cattle diets: Quality, intake, and changes in feed characteristics*

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ABSTRACT

Purpose: Cotton (*Gossypium* sp.) is grown on over 4.5 million hectares in the United States annually. This article provides an overview of cotton industry changes and their influence on whole cottonseed and cotton residue quality and use in beef cattle operations in the southeastern United States.

Sources: Whole cottonseed may vary depending on cotton growing and harvest conditions, seed composition, and ginning technologies. Most cottonseed is hand fed to beef cattle at a set feeding rate to control fat intake. However, there is variation in the literature in on-farm cottonseed feeding strategies and potential use of whole cottonseed in beef bull diets. Cotton residues are often used as a roughage alternative. Strategies to expand the use of cotton residues include integrated crop-livestock systems, gin byproduct baling applications, and evaluation of chemical residues to determine feeding safety.

Synthesis: Periodic characterization of seed protein, fat, and gossypol can refine beef cattle feeding strategies. Grazing cotton field residue can reduce hay needs in beef cattle diets. There is limited information on animal growth performance, health, and safety of beef cattle fed cotton residues, which may potentially contain detectable levels of pesticides or herbicides.

Conclusions and Applications: Use of whole cottonseed and cotton residues benefits both the cotton and beef cattle industries. Future research to more closely mimic on-farm beef nutritional management strategies may expand the use of whole cottonseed as a supplement. Quality evaluation of cotton byproducts ensures greater accuracy in ration development and may help elucidate threshold values for establishing safety of use.

Key words: cotton byproducts, cotton stalks, cotton gin byproduct, cotton feed value

INTRODUCTION

Beef cow-calf and stocker producers in the southeastern United States have access to a variety of supplemental feed byproducts from multiple agricultural industries. Cotton (*Gossypium* sp.) production provides beef producers with a variety of byproducts that can be included in beef cattle diets such as whole cottonseed, cottonseed hulls, cottonseed meal, cotton stalks, and gin byproduct (often referred to as "gin trash" or "cotton burrs"). The USDA National Agricultural Statistics Service Crop Production Summary reported 3.5 million hectares of cotton harvested in 2020, generating approximately 14.4 million 218.2-kg bales of cotton and 4.0 million metric tons of whole cottonseed (USDA NASS, 2021), illustrating the relative amount of potential feed byproducts that can be generated from cotton production. Use of byproducts by the beef industry provides mutualistic value to both the cotton and beef operations, which warrants periodic review of cotton byproduct feed quality characteristics. This article will provide an overview of cotton industry changes and the potential use of whole cottonseed and cotton residues, primarily gin byproduct and cotton stalks, as byproduct feed resources for potential use in beef cow-calf systems in the South United States.

Cotton Industry Technologies and Effects on Cottonseed and Cotton Residue Quality

Cotton plant breeding efforts have primarily focused on increased lint yield, insect resistance, disease resistance, and tolerance to abiotic stressors, which can influence seed

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size, density, and quality (Zeng et al., 2018). Cotton breeders have conducted extensive work to produce vigorous and viable seed to help ensure adequate stand establishment in cotton crop production systems. Some parameters of interest for breeding programs for seed characteristics include, but are not limited to, seed constituents, seed size, and gossypol concentration. Seed constituents such as protein and oil reserves support the growth of the cotton plant until it is photosynthetically active (Turley and Chapman, 2010). The protein and oil reserves also influence the nutritive value of whole cottonseed when used as a supplement in livestock systems. Seed size is another focal point of many cotton breeders. Large seed size has been related to increased seedling vigor due to greater oil and protein reserves; however, smaller seeded cotton varieties have been selected to increase lint yield and lint percentage (Snider et al., 2016). Smaller seed size may also result in decreased mastication and seed digestibility when fed to cattle (Bertrand et al., 2005). Breeding efforts have also focused on reducing gossypol concentration in cottonseed to allow its safe use as a potential food source for both humans and animals (Vroh Bi et al., 1999).

Within-season growing conditions and harvest management can further affect seed composition and cotton residue quality. Once a cotton crop has grown to maturity, the cotton boll is separated from its stalks through harvest. High harvesting efficiency that leaves as little seed cotton in the field as possible is a priority for cotton growers (Wanjura et al., 2010). Grazing field residue following cotton harvest represents a way to integrate row crop and beef production. However, the quality and number of grazing days provided through this system may be influenced by improvements in cotton harvest technologies.

Cotton harvesters generally fall into 1 of 2 categories: cotton stripper-type harvesters and cotton spindle pickers. Cotton spindle pickers remove the cotton from the bolls using finger-like spindles, and the burr and parts of the boll are left behind. Spindle pickers are capable of harvesting 95 to 98% of cotton produced, but field harvest losses may be greater (up to 20%) with this type of machine than with cotton strippers (Willcutt et al., 2010). Wanjura et al. (2015) noted that picker harvesters are more mechanically complex than strippers, and maximizing picking efficiency requires careful attention to cultural practices related to cotton establishment; management; and harvester setup, operation, and maintenance. Cotton strippers are designed to remove the entire boll and are capable of harvesting 95 to 98% of cotton produced (Wanjura et al., 2010). This equipment has a more indiscriminate harvest action than spindle-type pickers and can remove up to 99% of seed cotton from the plant (Wanjura et al., 2015). The greater the efficiency of field harvest, the more likely the remaining field residue is lower in total biomass and nutritional value for potential postharvest grazing by beef cattle. Postharvest biomass primarily consists of stalks, leaves, and partial boll material including burrs, some lint, and seed. Harvest-aid chemicals continue to be developed that create a "cleaner" cotton stalk to further facilitate harvest efficiency. These products help cotton plants open bolls, drop leaves, and desiccate plants before harvesting, which facilitates earlier stripper harvesting, greater yields, and improved lint quality. After picking, 3 methods of handling picked cotton are available, which prepare cotton for transport to cotton ginning facilities and processing. These systems include a basket-based system, which unloads cotton into a boll buggy followed by a module builder, or a half-module, or round-module, system. The half-module system eliminates the need for module builders and boll buggies. The round-module system rolls a cylinder of cotton and wraps each cylinder with plastic film before discharging from the module. Each of these methods has varying bale capacities of seed cotton, packing density, and potential exposure to additional environmental variables after baling (Willcutt et al., 2010).

In the last 2 decades, there has been significant consolidation of cotton gins in the United States, which has led to larger gins with the ability to process greater volumes of cotton. Combined with increased use of high-yielding cotton cultivars, the total number of bales of cotton ginned annually has either increased or remained stable, despite fluctuations in annual number of hectares planted in the United States. Technological advances at cotton gins have improved cotton fiber ginning efficiency through increased automation and accuracy of fiber separation. Handling capacity of postginning waste products, such as cotton gin byproduct, has also changed. Some gins have the capacity to compress or bale gin byproduct, making this a more compact resource that eases transport due to increased bulk density. These technology advancements can enhance or alter cotton byproduct quality, availability, and use by beef cattle operations.

Whole Cottonseed

It is estimated that more than 50% of the annual supply of whole cottonseed in the United States is consumed by dairy cattle (Wedegaertner, 2010). Whole cottonseed is also widely used as a source of supplemental protein and energy in southeastern US beef cow-calf diets. Most whole cottonseed in the southeastern United States is sold by gins and transported to dairies located in the North or West United States, where it is incorporated into TMR. This contributes toward fluctuations in price and availability of whole cottonseed for beef producers in the southeastern US region.

The NASEM feed composition tables (NASEM, 2016; Table 18-1, p. 316) describe the nutritional content of whole cottonseed as containing 22.8% CP, 19.5% fat, 93% TDN, 47.8% NDF, 0.53% P, and 0.22% Ca. These values were derived from a summary with a minimum of 92 observations per variable. Table 1 presents the chemical composition of whole cottonseed obtained from samples submitted to Cumberland Valley Analytical Services (Waynesboro, PA) from March of 2012 to March 2022 (Cumberland Val-

Table 1. Average analysis of whole cottonseed and gin byproduct samples submitted to Cumberland Valley Analytical Services (Waynesboro, PA) from March 2012 to March 2022

	Whole cottonseed			Gin byproduct		
Item (% of DM unless otherwise noted)	No. of samples	Mean	SD	No. of samples	Mean	SD
DM	2,304	89.9	4.0	435	86.9	8.9
CP	1,607	23.0	3.5	407	12.3	4.2
Adjusted CP[1]	1,550	22.8	3.5	402	11.2	4.4
ADF	1,405	35.0	5.8	397	49.2	13.2
NDF	1,480	44.6	6.7	390	57.7	12.7
Lignin	713	10.6	2.5	232	16.7	5.8
Starch	424	0.8	1.0	127	1.09	1.5
Crude fat	1,101	18.7	2.9	253	5.4	5.3
Ash	1,277	4.7	1.3	383	12.2	6.7
TDN[2]	1,124	88.9	8.6	247	48.3	16.4
NE_l[2] (Mcal/kg)	1,055	2.11	0.22	244	1.06	0.42
NE_m (Mcal/kg)	1,055	2.20	0.26	244	0.84	0.57
NE_g (Mcal/kg)	1,055	1.52	0.35	244	0.28	0.64
Calcium	1,268	0.23	0.15	379	1.7	1.93
Phosphorus	1,268	0.63	0.11	379	0.31	0.20
Magnesium	1,266	0.41	0.06	378	0.35	0.03
Potassium	1,266	1.26	0.13	378	1.96	0.86
Sulfur	336	0.27	0.06	141	0.42	0.29
Sodium	1,267	0.03	0.09	378	0.08	0.11
Chloride	327	0.08	0.05	139	0.47	0.43
Iron (mg/kg)	1,267	103	158	378	774	955
Manganese (mg/kg)	1,267	22.4	18.3	378	62.8	44
Zinc (mg/kg)	1,267	42.4	26.7	3,768	33.5	186
Copper (mg/kg)	1,267	11.0	8.16	379	9.91	62

[1]Crude protein corrected for insoluble CP.

[3]The TDN and NE estimates were calculated using the OARDC Summative Energy Equation (Weiss, 1998).

ley Analytical Services, 2022). These samples represent submissions from livestock operations, cotton gins, and industry partners for feed quality assessment. Many of these samples are submitted for characterization of feedstuffs before marketing or for on-farm decision making regarding supplementation strategies. The largest variation is represented by TDN, NDF, and ADF. This is likely partially explained by differences in field harvest efficiency, cotton variety, and pre- and postharvest processing conditions.

Feeding whole cottonseed provides a similar nutritive response as feeding an equal amount of cottonseed hulls, meal, and oil (Moore et al., 1986). Rogers et al. (2002) stated that the CP in whole cottonseed is primarily used for supplementing high-forage diets. The protein in whole cottonseed is primarily located in the heart of the seed, encased in the hull, and mixed with fat, which slows its release into the rumen. Data on protein degradability characteristics of whole cottonseed are not as readily available. A review by Arieli (1998) reported a rumen CP degradability value of 70% (DM basis) for whole cottonseed from 3 separate studies. As a result of cotton breeding selection pressures, seed characteristics and constituents have been altered, potentially changing protein concentration and protein digestibility characteristics (Bertrand et al., 2005). Jacobs et al. (2022a) observed that whole cottonseed samples from 88 cotton ecotypes of Upland-type cotton had a range of 36.0 to 73.9% degradable intake protein (**DIP**), illustrating a range of potential values based on seed composition. Sixty-five percent of samples analyzed were between 45 and 55% DIP. There are no values for DIP or undegradable intake protein listed for whole cottonseed in the NASEM (2016) feed composition tables; however, the NASEM (2000) lists DIP of whole cottonseed (black seed; Appendix Table 1, p. 196) as 69.6% on a DM basis. Variation in protein composition of seed demonstrates the need for further analysis if whole cottonseed is used for strategic supplementation of DIP or undegradable intake protein, which may be especially applicable in growing or development of rations in beef systems.

Fat concentration of whole cottonseed is a source of energy and is considered the primary factor in limiting supplementation rate of whole cottonseed in beef cattle diets

(Moore et al., 1986; Rogers et al., 2002). Bertrand et al. (2005) reported nutrient composition of seed from conventional or genetically modified cotton varieties, including fat concentration. Total fat percentage of these varieties ranged from 15.7 to 17.4% on a DM basis (SEM = 0.2; n = 58 samples). Fatty acid composition was characterized by seed type in this study. Linoleic acid (56.1%; C18:2), palmitic acid (24.0%; C16:0), and oleic acid (15.2%; C18:1) were present in the greatest quantities across all cotton varieties, illustrating a mix of both saturated and unsaturated fatty acids present in whole cottonseed. The authors noted a 13% decrease in total seed fat concentration in this study compared with fat percentage for whole cottonseed reported in the NASEM (2000) feed composition tables (17.5% DM basis). Mean fat percentage reported by Cumberland Valley Analytical Services was 18.7% ± 2.9 across a larger number of samples (n = 11,011) and is slightly lower than that reported by the NASEM (2016; Table 18-1, p. 316; mean 19.45% ± 2.59, n = 534 samples on a DM basis). Variation in fat concentration of seed may be related to cotton breeding selection pressures to increase or decrease seed oil content, field growing conditions, and mixing of cotton varieties during the ginning process.

Reports of fat digestion response in the rumen and relative tolerance of fat inclusion in ruminant diets differ within the literature. Zinn and Plascencia (1993) suggested that there is extensive hydrogenation of whole cottonseed within the rumen in a study with beef steers fed at up to 20% inclusion rate in the diet, with seed containing a high percentage of PUFA. In contrast, Sklan et al. (1992) noted that whole cottonseed fed to dairy cattle did not cause marked changes in VFA in the rumen, which indicates that fat in seed may be released slowly or leave the rumen still enclosed within seed. Rogers et al. (2002) reported whole cottonseed should be limited to no more than 0.5% of BW or 20% of the total diet for mature cattle, which corresponds to about 4% fat in the total ration. This is based on a study by Moore et al. (1986) that noted that this is the maximum amount of fat that can be fed without negatively affecting rumen function in forage-based diets. Hill et al. (1999) evaluated nonlactating, nonpregnant cows receiving 0.25% of BW, 0.5% BW, or free-choice whole cottonseed supplement for 63 and 70 d in yr 1 and 2, respectively. The study demonstrated that mature cows allowed free-choice access to whole cottonseed may consume almost twice the amount of the recommended daily hand-fed rate (0.5% of BW), which may negatively affect forage digestion and rumen health because of increased fat intake (Stewart and Rossi, 2010). However, no negative animal performance responses were observed for cows on the free-choice whole cottonseed diet during the short-term feeding study. It is likely that some of this intake response is associated with seed degradation patterns in the rumen, rate of seed passage, and its influence on fat escaping degradation in the rumen, although there are no published studies that have evaluated this in beef cattle. This illustrates a potential knowledge gap in how seed composition changes due to cotton selection pressures may alter beef cattle feeding recommendations of whole cottonseed based on fat percentage. Allowing free-choice access to whole cottonseed by beef cattle can also result in increased feed waste. Many beef cattle producers may feed whole cottonseed directly on the ground or in open feed troughs, which may increase wastage due to trampling or rain. Based on observed greater-than-recommended free-choice intake (Hill et al., 2000) and potential waste, this may lead to increased supplementation costs for whole cottonseed; however, it is still a practice used by many beef cow-calf operations as a way to reduce labor (Mason et al., 2021).

Hand-feeding whole cottonseed at 0.33% of animal BW per day is recommended for growing cattle based on limiting seed supplementation to 20% of the total diet (Rogers et al., 2002). A study by Poore et al. (2006) evaluated beef heifer supplementation strategies using whole cottonseed while grazing stockpiled tall fescue. Heifers were either supplemented with (1) whole cottonseed at 0.33% of BW and 0.2 kg of a corn and soybean meal mix per day to ensure complete cottonseed consumption or were (2) allocated to graze stockpiled tall fescue with no supplementation. Heifers supplemented with whole cottonseed had a greater ADG and BCS than heifers only grazing stockpiled tall fescue. By supplementing heifers grazing stockpiled tall fescue with whole cottonseed, adequate gains were achieved to reach targeted BW and condition (Poore et al., 2006).

Another limiting factor affecting the inclusion of whole cottonseed into cattle supplementation programs is gossypol. Gossypol is a yellow pigmented, polyphenolic aldehyde produced by glands throughout the cotton plant to help protect itself from predation (Zhang et al., 2007). Gossypol in seed is found in 2 isomers, the (−) isomer, or free gossypol, and (+) isomer, or bound gossypol, and is a highly reactive compound that easily binds to AA. Free gossypol is the more biologically active and toxic form, whereas bound gossypol is attached to an AA and is considered nontoxic for ruminants (Gadelha et al., 2014). Nonruminants and preruminants are more susceptible to gossypol than functioning ruminants (Randel et al., 1992). Whole cottonseed has been observed to have greater rumen retention time than other cotton-based byproducts, such as cottonseed meal, and ruminal microbes are able to at least partially detoxify free gossypol in seed by binding it to proteins (Nunes et al., 2010). Gossypol toxicosis typically results from prolonged exposure to high levels of free gossypol that overload the detoxifying capacity of the rumen, causing free gossypol to be directly absorbed by the animal in the small intestine.

Gossypol concentration in cotton is influenced by several factors including weather conditions, cotton species, and cotton variety within species (Nunes et al., 2010). The most common species of cotton planted in the United States are Pima (*Gossypium barbadense*) and Upland cotton (*Gossypium hirsutum*). Pima cotton generally has greater concentrations of free gossypol than cottonseed from Upland varieties (Broderick et al., 2013; Knutsen et al., 2017). Whole cottonseed free gossypol concentration varies among cotton varieties, with a reported range from 0.02 to 6.64% (Gadelha et al., 2014). Jacobs et al. (2002a) observed a range of 0.2 to 1.4% free gossypol across 88 breeding lines or commercial varieties of Upland cotton. The USDA Crop Acreage Report (USDA NASS, 2021) notes that the vast majority of cotton grown in the United States is Upland-type cotton, with Pima cotton representing less than 80,000 ha in 2020.

The effects of gossypol toxicosis are more prominent in male ruminants, mainly affecting sperm production and motility by decreasing testosterone concentrations and damaging spermatogenic epithelium (Randel et al., 1992). Gadelha et al. (2014) reported that negative effects of gossypol on male ruminant reproductive parameters have been observed at as little as 6 mg of free gossypol per kilogram of animal BW per day. Hassan et al. (2004) reported that peripubertal bulls fed a ration containing gossypol at levels of 8 mg of free gossypol per kilogram of animal BW per day had increased primary and secondary sperm abnormalities over a 60-d feeding period. These effects were observed for 4 wk after the end of gossypol feeding; however, continued observation of sperm abnormalities were not detected after this time period, illustrating the reversibility of deleterious reproductive effects of gossypol after feeding. It is generally recommended to not feed bulls whole cottonseed 60 to 90 d before the start of a breeding season as a precaution, although potential fertility effects of gossypol toxicosis often take several months to develop (Myer et al., 2018). Many beef cattle producers are hesitant to use whole cottonseed as a winter supplement in cow-calf operations due to perceived risks associated with bulls consuming this supplement during the breeding season and potentially having negative reproduction effects. Davis et al. (2022b) fed 2-yr-old bulls 3 levels of whole cottonseed for 60 d. The feeding period was based on the time for total duration of spermatogenesis in bulls (61 d; Staub and Johnson, 2018). Additionally, this represents the potential overlap in winter supplementation of a cow herd that includes whole cottonseed and the breeding season when bulls may be exposed to whole cottonseed. Bulls were fed 1 of 3 isonitrogenous diets that included 0, 1.6, or 3.2 kg/d of whole cottonseed to represent a control and 50% and 100% of the maximum recommended daily intake for whole cottonseed based on fat content. Breeding soundness exams were administered on d 0, 30, and 60. These authors reported no differences in normal morphology, proximal droplets, or coiled or folded tails among treatments at the end of the feeding period. Additionally, there were no differences in the number of bulls that passed the breeding soundness exam. These data indicate that whole cottonseed can be included in a ration up to 3.2 kg/d over a 60-d period without affecting bull fertility. Hassan et al. (2004) suggested that varying results in bull feeding recommendations for whole cottonseed may be in part due to variation among rations and feeding protocols used by different researchers in published trials. Additional research associated with feeding whole cottonseed to bulls to mimic supplementation strategies in beef cattle herds before and during the breeding season would update recommendations according to industry changes in cotton seed characteristics and potentially enhance the adoption of whole cottonseed feeding in beef operations.

COTTON RESIDUES

Cotton Gin Byproduct

Cotton gin byproduct is considered an alternative roughage source for beef cattle or as a replacement or partial replacement for low- to medium-quality hay and is often sourced more by beef producers in times of drought or hay shortage (Myer, 2008; Stewart and Rossi, 2010; Jacobs et al., 2020). The ginning byproduct consists of fragments of cotton stems, leaves, burrs, lint, seed fragments, immature seed, and soil residue. Nutrient composition of cotton gin byproduct is highly variable, and the associated feed value is influenced by cotton harvest conditions, gin processing, and storage of gin byproduct after ginning. Cotton gin byproduct feed composition is reported by the NASEM (2016; Table 18-1 listed as “cotton gin trash,” p. 316, minimum n = 259 per parameter listed) as 90.8% DM, 48.5% TDN, 12.3% CP, 1.57% Ca, and 0.24% P on a DM basis. Table 1 presents the chemical composition of cotton gin byproduct submitted to Cumberland Valley Analytical Services (Cumberland Valley Analytical Services, 2022) from March 2012 through March 2022. Nutritive value parameters from Cumberland Valley Analytical Services with the 3 greatest SD were DM, TDN, and ash of gin byproduct. Cotton DM percentage may vary depending on field harvest conditions, and many gins spray gin byproduct piles postprocessing with water to reduce dust and speed up decomposition (Rankins, 2002). As gin byproduct is stacked or baled, moisture may cause heating of the product, which influences nutrient availability and digestibility. Additionally, harvest methods, field conditions, and soil type influence ash value found in cotton gin byproduct and can alter feed digestibility and palatability characteristics (Kennedy, 2006). A summary report of gin byproduct analyses from 26 cotton gins in Georgia reported moisture ranging from 8 to 60%, 2 to 16% CP, and 16 to 62% TDN (Stewart et al., 1998). Because of the varying nutrient characteristics of gin byproduct, it is most often used in beef cattle rations for animals with low energy requirements such as nonlactating cows.

Inclusion rate in beef cattle diets ranges from 5 to 40%, depending on the stage of production of animals being fed, with use in growing beef cattle diets being more restricted by the low energy concentration (Kennedy, 2006; Myer, 2008). Sagebiel and Cisse (1984) evaluated the effects of feeding cotton gin byproduct to pregnant beef cows across

2 studies. In the first trial, 90 cows in mid-gestation were fed (1) 100% cotton gin byproduct, (2) 30% cotton gin byproduct and 70% sorghum silage, or (3) 100% sorghum silage. Cows on the 100% gin byproduct diet lost weight during the 90-d feeding period, whereas those on the diets containing sorghum silage maintained or gained weight. The authors noted that cows fed the 100% cotton gin byproduct diet did not consume enough of this roughage source to meet their daily TDN requirements, but they did exceed their protein requirement by 38%. Hill et al. (2000) conducted a trial feeding gin byproduct to dry, nonpregnant beef cows fed free-choice gin byproduct or free-choice gin byproduct and 1.36 kg/d corn. Cows supplemented with corn maintained or gained BW during the trial, but cows on gin byproduct alone lost BW and condition. The authors reported that the nutritive value of gin byproduct cannot maintain beef cows without adequate energy supplementation but was generally adequate in protein, which is similar to the observations of Sagebiel and Cisse (1984). Use of cotton gin byproduct in growing and finishing beef cattle diets is generally more limited (5 to 10% inclusion rates), and gin byproduct is viewed as a way to provide roughage value while decreasing overall ration costs (Stewart and Rossi, 2010).

For each 218-kg bale of cotton, a range of 70 to 90 kg of gin byproduct is generally produced (Stewart and Rossi, 2010). Gin byproduct is generally considered a relatively low-value byproduct, with transportation commonly being the greatest cost associated with use in beef cattle diets due to its low bulk density. Because of the low monetary value and amount produced by the ginning process, many gins pile the gin byproduct outside where it is exposed to weather, which can lead to mold, reduced palatability, and decomposition (Rogers et al., 2002; Stewart and Rossi, 2010). Some gins have begun baling gin byproduct (Adams and Morgan, 2015). The baling process compacts the gin byproduct using a module press, which increases the bulk density and makes it easier to handle and store, potentially preserving nutritive value if stored inside. Baled gin byproduct may be more readily accessible by smaller cow-calf operations because it can be transported in small loads using a trailer, whereas loose gin byproduct is generally hauled to operations using a tractor trailer (Adams and Morgan, 2015).

Cotton Stalks

Crop residues have the potential to serve as a winter feed for cattle to greatly reduce feed cost. Cotton is typically mowed soon after harvest, in part to comply with boll weevil eradication programs (Lu et al., 2010). However, substantial material remains on the cotton plant after harvest such as cottonseed, cotton lint, leaves, and burrs. The type of harvester likely affects the amount and content of residue left in field. Spindle-type pickers are more commonly used, and these harvesters can have greater field harvest losses than stripper-type pickers. Picking efficiency has improved over time, so this can decrease cotton biomass remaining after harvest.

Minimal research has been conducted to evaluate the use of cotton crop residue as a feedstuff for cattle. Nutritionally, cotton residue is similar to cotton gin byproduct (Table 1). The energy and protein is adequate to support a nonlactating cows; however, some supplementation would be needed for lactating beef cows. Rossi (2006) compared nonlactating cow performance on postharvest cotton residue versus Coastal bermudagrass (*Cynodon dactylon* L.). In this study, the authors estimated that 1 ha of cotton stalk residue would support a nonlactating cow for 108 d (44 d/acre). Additionally, cows consuming hay gained 21.8 kg over the period compared with 6.8 kg grazing cotton residue. The author noted that the cows maintained a BCS of 5 or greater over the 84-d trial during this study. A similar trial was conducted by Davis et al. (2022a) over a 3-yr period to evaluate standing cotton residue as a partial replacement for hay during winter supplementation. In this trial, nonlactating cows were fed bermudagrass hay only or cotton residue with access to free-choice bermudagrass hay beginning 2 wk after grazing. The authors indicated that the 1 ha of cotton residue would support a nonlactating beef cow for 74 d (30 d/acre) with hay offered after 2 wk, reducing the amount of hay fed in the cotton residue–hay system by 65%. Additionally, the authors reported no difference in BW gain for cattle on hay only versus cotton residue (24 and 18 kg, respectively). These studies illustrate the potential use of cotton crop residues as a way to integrate crop-livestock systems, reduce winter hay needs, and extend the grazing season in the southeastern United States.

Chemical Residue

Chemical residues are a concern when feeding gin byproduct or grazing cotton stalks. Several of the chemicals used in cotton production are not labeled for consumption by food animals. The chemicals that are most likely to be present are cotton harvest aids (e.g., defoliants) and pesticides commonly applied soon before harvest. Table 2 list the residual tolerance concentration values of some commonly used harvest-aid chemicals in cotton (Code of Federal Regulations, 2022). Stewart et al. (1998) collected samples of gin byproduct from gins throughout southern Georgia. The only chemical detected was tribufos. The average level found was 4.5 mg/kg, well below the tolerance level. Similar observations were reported by Jacobs et al. (2022b) in an evaluation of loose and baled gin byproduct for feeding nonlactating cows, with tribufos being the only residue detected. Davis et al. (2022a) conducted a chemical screen of residue before cattle grazed cotton stalks. These authors reported the average and greatest individual sample concentration of 4 detected chemicals. These included 2,4-dichlorophenoxyacetic acid (i.e., 2,4-D; 0.0018 and 0.0020 mg/kg, respectively), glyphosate (0.13 and 0.21 mg/kg, respectively), thidiazuron (0.03 and 0.05

mg/kg, respectively), and tribufos (2.8 and 8.0 mg/kg, respectively). These concentrations were well below the thresholds indicated in Table 2. Some state departments of agriculture provide chemical screens, as well as several private laboratories. Chemical residue screens should be conducted before using cotton gin byproduct or grazing cotton residue. Following continued screening and characterization of cotton residue use in livestock diets, label tolerances for residues can be updated as products are registered or reregistered. Revised tolerance levels for feeding gin waste in beef cattle and dairy systems are desired by both the animal science and cotton industry communities.

Table 2. Federal tolerances for chemicals commonly used before harvest in cotton[1]

Chemical name	Cotton gin byproduct (mg/kg)	Un-delinted cottonseed (mg/kg)
2,4-Dichlorophenoxyacetic acid	1.5	0.08
Glyphosate	210	NL[2]
Pendimethalin	3	0.1
Thidiazuron	24	0.3
Tribuphos	40	4
Trifluralin	0.05	NL
Ethephon	180	6
Cyclanilide	25	0.6

[1]Adapted from Tolerances and Exemption for Pesticide Chemical Residues in Food (Code of Federal Regulations, 2022).

[2]NL = no tolerance listed for un-delinted cottonseed.

EDUCATION AND AWARENESS OF COTTON BYPRODUCT USE IN SOUTHEASTERN BEEF COW-CALF SYSTEMS

Periodic research evaluations of byproduct feeds are necessary to update and validate industry feeding recommendations. With rapid advances in plant breeding and mechanization of cotton harvest and ginning, changes in byproduct feed characteristics may alter feeding strategies for beef cow-calf operations. Before this review, most published research with cotton byproduct feed quality and use in beef cow-calf operations was conducted before 2000 or is only reported in regional extension bulletins or thesis or dissertation projects. Many states in the Southeast region have feedstuff decision-aid tools tht allow producers to compare feed ingredients based on nutrient composition and costs. These resources can be a useful demonstration tool to showcase the application of byproduct feeds in beef cattle diets. Regional efforts to incorporate updated values into these tools may offer a way for animal scientists and industry partners to provide more accurate information to clientele. Partnership with analytical service laboratories, either private or public, would provide annual estimates of byproduct quality more reflective of in-season management for making feeding recommendations.

Collaboration among animal scientists with cotton researchers and cotton industry partners can help promote the use of cotton byproducts in beef operations. Cotton gins represent a local source of cotton byproducts at the community level and serve as a point of outreach on the use of cotton byproducts. Communication and outreach through animal scientists, cotton ginning associations, cotton boards, and growers can provide gins with educational resources for clients who may be seeking information on cotton byproducts. Many gins partner with row crop extension and industry to offer educational programs before the start of the ginning season, which provides a potential opportunity for partnered educational initiatives.

CONCLUSIONS AND APPLICATIONS

Although cotton industry changes affect the composition of cotton byproducts, cotton byproducts remain a viable source of nutrients for beef cattle producers. Whole cottonseed, gin byproduct, and grazed cotton residue can be used effectively in beef cow-calf operations; however, it is imperative to follow the feeding recommendations set forth for each product and obtain a chemical analysis (both nutritional and residual chemical) to ensure proper use and safety. Additionally, although the current review focuses on specific cotton products and their use in beef cow-calf systems in the southeastern United States, these practices may be applicable to other parts of the country and across the world where cotton is commonly grown. In the future, continuing research is crucial to track the effects of changing practices associated with cotton production to maintain proper feeding practices for cattle.

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