Journal of Economic Entomology, XX(XX), 2019, 1–9
doi: 10.1093/jee/toz013
Research

Cow-Calf Producers' Willingness to Pay for Bulls Resistant to Horn Flies (Diptera: Muscidae)

Lettie McKay,[1] Karen L. DeLong,[1] Susan Schexnayder,[2] Andrew P. Griffith,[1] David B. Taylor,[3] Pia Olafson,[4] and R. T. Trout Fryxell[5,6]

[1]Agricultural and Resource Economics, University of Tennessee, Knoxville, TN 37996, [2]Forestry, Wildlife and Fisheries, University of Tennessee, Knoxville, TN 37996, [3]USDA-ARS Midwest Livestock Insects Research Laboratory, Department of Entomology, University of Nebraska, Lincoln, NE 68583, [4]USDA-ARS, Knipling-Bushland U.S. Livestock Insects Research Laboratory, 2700 Fredericksburg Road, Kerrville, TX 78028, [5]Entomology and Plant Pathology, University of Tennessee, Knoxville, TN 37996, and [6]Corresponding author, e-mail: RFryxell@utk.edu

Subject Editor: Alec Gerry

Received 8 October 2018; Editorial decision 5 January 2019

Abstract

Horn flies (*Haematobia irritans* (L.)) have long posed animal health and welfare concerns. Economic losses to the cattle and dairy industries from their blood-feeding behavior include decreased weight gain, loss in milk productivity, and transmission of bacteria causing mastitis in cattle. Horn fly management strategies are labor intensive and can become ineffective due to the horn fly's ability to develop insecticide resistance. Research indicates that for some cattle herds, genetically similar animals consistently have fewer flies suggesting those animals are horn fly resistant (HFR) and that the trait is heritable; however, it is currently unknown if cattle producers value this trait. Tennessee and Texas cow-calf producers were surveyed to estimate their willingness to pay for HFR bulls and to identify the factors affecting their decision to adopt a HFR bull in their herds. Results indicate that Tennessee and Texas cow-calf producers were willing to pay a premium of 51% and 59% above the base price, respectively, for a HFR bull with the intent to control horn flies within their herd. Producer perceptions of horn fly intensities and the HFR trait, along with their pest management practices, were factors that affected Tennessee and Texas producer willingness to adopt a HFR bull. In Texas, demographics of the producers and their farms also had a role. Knowing producers are willing to pay a premium for the HFR bull indicates that producers value the HFR trait and warrants additional research on the development, implementation, and assessment of the trait.

Key words: horn fly resistance, contingent valuation, willingness to pay, cattle producer survey

Horn flies (*Haematobia irritans* (L.)) are ectoparasites that negatively affect animal welfare and the profitability of livestock operations. Horn flies are a recognized and chronic problem in the cattle industry. Flies blood feed from their host more than 30 times per day causing direct damage through blood loss, indirect damage via introduction of pathogens, and decreased feeding/weight gains, and peripheral damage such as decreased profits (Arther 1991). Horn flies also contribute to health problems in cattle including *Staphylococcus aureus* mastitis, bovine teat atresia and hide damage (Gillespie et al. 1999, Guglielmone et al. 1999, Edwards et al. 2000). Increasing fly counts are associated with decreased milk production and reduced weight gain in calves (Clutter and Nielsen 1987, Mays et al. 2014). These effects were observed across cattle breeds, cattle with fewer horn flies had larger calves than those with more flies (Steelman et al. 1991).

Gordon et al. (1984) estimated the economic threshold of horn flies to be between 10 and 230 flies per animal depending on cattle value and environmental conditions. The most recent estimate of loss to the industry is $876 million a year (Kunz et al. 1991). Common practices used to control horn flies include fly traps, manure manipulation, boluses, and topical insecticides such as ear tags, sprays, and dusts (Foil and Hogsette 1994). Importantly, many studies have demonstrated that managing horn flies can result in increased weight gains in cattle and positive returns to producers (Campbell 1976; Harvey and Brethour 1979; Haufe 1982, 1986; Kunz et al. 1984; DeRouen et al. 1995, 2003; Sanson et al. 2003). For example, up to 17% increased weight gain in cattle has been attributed to horn fly control (Haufe 1982, DeRouen et al. 1995). Unfortunately, current management practices are not without limitations. Some management practices are labor intensive such as herding cattle, bringing them into a chute or stall, and applying a fly treatment (e.g., ear tag or applying a pour-on insecticide). Other treatments are simply not efficient for the beef industry; for example, an electronic walk-through fly trap was developed for use with dairy animals as they move in and out of milking facilities (Watson et al. 2002, Denning et al. 2014). While these automated traps effectively reduced horn fly numbers, they also required electricity, which makes them difficult to use in pastures (Watson et al. 2002, Denning et al. 2014).

Possibly the greatest concern managing horn flies is their ability to develop resistance to insecticides (Quisenberry et al. 1984, Sheppard 1984, Sparks et al. 1985, Cilek et al. 1991, Byford et al. 1999, Barros et al. 2001). Horn flies can develop resistance to a chemical in as little as 2 yr (Quisenberry et al. 1984, Sheppard 1984) with complete product failure in 4 yr (Byford et al. 1999), while cross-resistance to different insecticides has also been reported (Sheppard 1984, Cilek et al. 1991). With the threat of horn flies developing resistance to insecticides, it is essential to develop new, noninsecticidal, horn fly management practices.

Selection for horn fly resistance in cattle has been proposed as an alternative that is environmentally safe and manages insecticide-resistant horn flies (Brown et al. 1992, Steelman et al. 2003). Variation in horn fly counts among hosts can be associated with breed (Steelman et al. 1994, Guglielmone et al. 2000), host color (Schreiber and Campbell 1986), frame size (Steelman et al. 1996), and hair density (Steelman et al. 1997). Individual cattle within breeds can be higher carriers than others (Steelman et al. 1991, 1993; Pruett et al. 2003; Jensen et al. 2004). Cattle that consistently carry fewer flies than other cattle with the same environmental and treatment conditions are often considered to be resistant to horn flies. For this study, we define a 'horn fly resistant' (HFR) animal as one that has lower fly counts in comparison with other animals in the herd (Pruett et al. 2003, Untalan et al. 2006). We provide a definition of the HFR trait in our survey design (below).

While breeding cattle for horn fly resistance has been proposed, no studies have examined producers' acceptance of the concept. Therefore, the goal of this study is to determine producers' attitude toward HFR cattle. To accomplish this, a survey of Tennessee and Texas cow-calf producers was conducted to estimate their willingness to pay (WTP) for a HFR bull and to determine the factors affecting their decision to adopt a HFR bull. These results will inform future research into identifying HFR traits in cattle and integrating HFR bulls into cattle herds.

Materials and Methods

Survey Design

In September 2017, cattle producers participating in the Tennessee Agriculture Enhancement Program (TAEP) were e-mailed invitations to participate in an online Qualtrics (www.qualtrics.com) survey regarding their preferences for HFR cattle. Second and third invitations were sent to nonrespondents in early and late October 2017, respectively. The Texas and Southwestern Cattle Raisers Association (TSCRA) issued e-mail invitations to its Texas and Oklahoma cattle producers in late November and sent a reminder to nonrespondents in early December. For the remainder of this manuscript, TAEP respondents are referred to as Tennessee producers and TSCRA respondents are referred to as Texas producers, although it is important to note that 5.5% of TSCRA respondents were farms operated in Oklahoma. The survey had full University of Tennessee Institutional Review Board approval prior to distribution (UTK IRB-17-03931-XM). Producers were required to be 18 yr or older to complete the survey. Eleven percent (464) of the 4,028 Tennessee producers and 8% (317) of the 3,882 Texas producers that were contacted responded to the survey. Prior to the survey being disseminated, the survey was pretested by Tennessee cow-calf producers. Producers who pretested the survey did not participate in the full launch of the survey.

All producers completing the survey were informed that a horn fly resistant (HFR) animal was defined as 'an animal with few to minimal horn flies present, noticeable, or feeding on the animal. It also means that other traits you select for would be unaffected by the addition of the horn fly resistance trait, so that the horn fly-resistant cattle and your current cattle are the same weight and have IDENTICAL muscling, gains, health, and other traits'. We wrote this in a way to be similar to current horn fly management options, such as ear tags. Following this definition of HFR, Tennessee and Texas cattle producers were asked a single-bounded dichotomous choice contingent valuation question to determine their preferences for HFR cattle. This method has been used previously for valuation of agricultural products and technology (e.g., Miller and Lindsay 1993; Dobbs et al. 2016; Chen et al. 2018a,b). The specific contingent valuation question asked was dependent upon the producers' defined primary segment of the cattle industry. Approximately 75% of producers surveyed managed cow-calf operations and were asked a contingent valuation question regarding their preferences for HFR bulls.

Tennessee cow-calf producers were asked if they would purchase a bull at a base price of $3,000 or a HFR bull at one of four prices: $3,000, $3,500, $4,000, or $4,500. Texas cow-calf producers were asked if they would purchase a bull at a base price of $5,000 or a HFR bull at one of four prices: $5,000, $5,500, $6,000, or $6,500. Price points were based on the average market prices of bulls in Tennessee and Western states at the time of the survey, and the specific price range for the HFR bull was based on the range of bull prices in the regions examined (Gardiner Angus Ranch 2017, Tri State Livestock News 2017; University of Tennessee Bull Test 2017).

In order to determine how information about the horn fly and its effects on cattle impacted producer preferences for the HFR trait, an Information Treatment was included in the survey prior to the contingent valuation question. Half of the producers received horn fly information (Information Treatment) and the other half did not receive this information. The Information Treatment provided was as follows:

> ABOUT HORN FLIES AND CATTLE
>
> Horn flies are a pest of cattle that inflict painful bites to draw 20–30 blood meals per day and have the following effects:
>
> - Animals' defensive behaviors interrupt adequate rest and food consumption.
> - Calves protected from horn flies have weaning weights 10–50 pounds more than unprotected calves with 200 or more flies.
> - Stockers and replacement heifers protected from horn flies have weight 16–18% above unprotected animals.
> - Horn flies can transmit bacteria that cause mastitis.

Econometric Model and Conceptual Framework

Producers are assumed to maximize profits. Similar to McFadden (1974) random utility theory, a producer, i, would choose the HFR bull rather than a non-HFR bull if his or her expected profit for the HFR bull, represented by $E(\Pi_{iHFR})$, was greater than the expected profit from purchasing the typical bull $E(\Pi_{iB})$; i.e., $E(\Pi_{iHFR}) > E(\Pi_{iB})$. The probability (Pr) that a producer expects the profit from a HFR bull to be greater than the expected profit from the alternative bull yields the probability to choose a HFR bull. Therefore,

$$\Pr[y_{iHFR}=1]=\Pr[E(\Pi_{iHFR})>E(\Pi_{iB})] \\ =\Pr[\boldsymbol{x}'\boldsymbol{\beta}+\varepsilon>0\,|\,x]=F(\boldsymbol{x}'\boldsymbol{\beta}) \quad (1)$$

where $\boldsymbol{x}'\beta$ represents observable elements of the difference of the two expected profit functions, ε is the difference between the two random elements, and *F* is the distribution function (Greene 2012). The factors hypothesized to impact a producer's decision to adopt a HFR bull is represented by the vector, $\boldsymbol{x}$. These factors include the *HFR Bull Price*, and whether or not participants saw the *Information Treatment*. Also included were producer and farm demographics such as *Education*, *Age*, *Income*, *Sole Proprietorship* status, *Herd Size*, and cattle breeds (*Angus*, *Charolais*) on their farm. Current horn fly perceptions and management practices were also considered to impact a producer's decision regarding a HFR bull and included producers' perceived *Horn Fly Intensity* in their cattle herds, *Use of Insecticides* to manage horn flies, *Use of Ear Tags* to manage horn flies, *Insecticide Effectiveness*, agreement that *Labor is Burdensome* in addressing horn flies, and use of *Extension* services for horn fly management. Finally, producer perceptions of incorporating horn fly resistance into their herd were considered to impact a producer's HFR bull decision and included *Expected Weight Gain* given their entire herd was resistant to horn flies and their evaluation of how important the HFR trait was given it was possible.

The specific names and definitions of the variables in these categories appear in Table 1. The latent regression model is represented by

$$y^*_{iHFR}=\boldsymbol{x}'\boldsymbol{\beta}+\varepsilon \quad (2)$$

where

$$y_{iHFR}=\begin{cases}1 & \text{if } y^*_{iHRFB}>0\\ 0 & \text{otherwise}\end{cases} \quad (3)$$

because only the decision to purchase the HFR bull is observed, not the actual expected profit. Maximum likelihood was estimated using two probit models, one for Tennessee using Tennessee bull prices, and another for Texas using Texas bull prices. Log likelihood ratio tests were conducted to assist in determining appropriate variables. The function for a probit model is the standard normal cumulative distribution function (Greene 2012):

$$\Pr[y_{iHFR}=1]=F(\boldsymbol{x}'\boldsymbol{\beta})=\int_{-\infty}^{\boldsymbol{x}'\boldsymbol{\beta}}\phi(z)dz=\Phi(\boldsymbol{x}'\boldsymbol{\beta}), \quad (4)$$

and the maximum likelihood estimation procedure is (Greene 2012):

$$\ln L=\sum_{r=1}^{N}[y_{iHFR}\ln\Phi(\boldsymbol{x}_r'\boldsymbol{\beta})+(1-y_{iHFR})\ln\{1-\Phi(\boldsymbol{x}_r'\boldsymbol{\beta})\}]$$

Following (Wooldridge 2002), the associated marginal effects were also calculated.

Differences in means of descriptive statistics between the two states were evaluated using *t*-tests using the *ttest* command in *STATA* (StataCorp 2017). The *STATA* command *probit* was used to estimate

Table 1. Names and definitions of dependent and independent variables in the Tennessee and Texas models

Variable	Description
Dependent variable	
Horn fly resistant (HFR) bull	% of respondents choosing the HFR bull
Price and Information Treatment	
HFR Bull Price	HFR bull prices: \$3,000, \$3,500, \$4,000, or \$4,500 for Tennessee; \$5,000, \$5,500, \$6,000, and \$6,500 for Texas
Information Treatment	1 if the Information Treatment was seen, 0 otherwise
Producer and farm demographics	
Education	Highest level of the producer's education[a]
Age	Age of the producer
Income	Level of total household income[b]
Sole Proprietorship	1 if business structure is sole proprietorship, 0 otherwise
Herd Size	Number of animals in the herd (bulls, cows, and calves)
Charolais	1 if the producer has Charolais-influenced cattle, 0 otherwise
Angus	1 if the producer has Angus-influenced cattle, 0 otherwise
Texas	1 if the producer was in Texas, 0 otherwise[c]
Current horn fly perceptions and management practices	
Horn Fly Intensity	Level of intensity of fly problem on back and withers[d]
Use of Insecticides	1 if the producer applies insecticides (e.g., pour-on) to animals to manage horn flies, 0 otherwise
Use of Ear Tag	1 if the producer uses ear tags to manage horn flies, 0 otherwise
Insecticide Effectiveness	Level of effectiveness of horn fly insecticides today compared to 5 yr ago[e]
Labor is Burdensome	Level of agreement that additional labor needed to address horn flies is burdensome[f]
Extension	1 if the producer gained information about horn flies from extension services, 0 otherwise
Perceptions of incorporating horn fly resistance into their herds	
Expected Weight Gain	Estimated percentage weight gain change given the entire herd were resistant to horn flies
HFR Trait Importance	Assuming horn fly resistance was a possible trait, how would you evaluate its importance?[g]

[a]1 = less than high school, 2 = high school graduate, 3 = some college or technical school/associate's degree, 4 = college degree or higher.

[b]1 = less than \$10,000; 2 = \$10,000–\$29,999; 3 = \$30,000–\$49,999; 4 = \$50,000–\$99,999; 5 = \$100,000–\$149,999; 6 = \$150,000–\$199,999; 7 = \$200,000–\$249,999; 8 = \$250,000–\$499,999; 9 = \$500,000 or greater.

[c]Only included in the Texas model.

[d]1 = no problem, 2 = minor problem, 3 = moderate problem, 4 = serious problem, 5 = very intense problem.

[e]1 = much less, 2 = somewhat less, 3 = slightly less, 4 = as effective, 5 = slightly more, 6 = somewhat more, 7 = much more.

[f]1 = strongly disagree, 2 = somewhat disagree, 3 = somewhat agree, 4 = strongly agree.

[g]1 = not important, 2 = slightly important, 3 = moderately important, 4 = very important.

the probit models and the associated marginal effects were calculated using the *margins* command. Variance inflation factors (VIFs) and condition index tests were used to determine if multicollinearity was present in either model using the *vif* and *coldiag2* commands, respectively (Belsley et al. 1980, Gujarati and Porter 2009; StataCorp 2017). Estimated coefficient significance levels are discussed using $P < 0.01$, $P < 0.05$, and $P < 0.10$ since previous survey research has also used these significance levels to discuss results (McFadden and Lusk 2015; DeLong et al. 2017, 2018; Bernard et al. 2018; McLeod et al. 2018). Of the 464 Tennessee and 317 Texas respondents to the survey, 254 answered all questions included in the Tennessee model, and 119 answered all questions included in the Texas model.

WTP Calculations

Results from the probit models were used to estimate producers' average WTP for a HFR bull with the formula

$$\widehat{WTP}_{iHFR} = -\frac{\hat{\beta}_0 + z'\hat{\boldsymbol{\beta}}_{-p}}{\hat{\beta}_p} \quad (6)$$

where $\hat{\beta}_0$ is the estimated intercept, $\hat{\boldsymbol{\beta}}_{-p}$ is a vector of estimated parameters excluding the price coefficient, z is the vector of independent variables excluding price, and $\hat{\beta}_p$ is the estimated parameter for the price of a HFR bull. Average WTP was estimated by calculating the mean of the WTP of each individual producer in the sample (Dobbs et al. 2016).

Results

Survey Descriptive Statistics

Dependent and independent variable means, standard deviations, and *t*-tests results for differences in survey statistics between Tennessee and Texas producers are presented in Table 2. Overall, 83% of producers chose the HFR bull rather than the non-HFR bull. Specifically, 81% of Tennessee respondents and 89% of Texas respondents chose the HFR bull (Table 2). The percentage of Texas producers who chose the HFR bull was significantly greater than the percentage of Tennessee producers who chose the HFR bull (T = –2.20; df = 285; P = 0.03) despite Texas producers receiving higher bull price levels than Tennessee producers. Texas producers received higher bull price levels than Tennessee producers since bulls are more expensive in the Western region of the country than in Tennessee (Gardiner Angus Ranch 2017, Tri State Livestock News 2017, University of Tennessee Bull Test 2017). Note that Satterthwaite's degrees of freedom are used since we are conducting a *t*-test between two samples with different sample sizes (Satterthwaite 1946).

Figure 1a shows the percentage of Tennessee producers who chose the HFR bull at each of the different price levels compared to a non-HFR bull at a base price of $3,000. To exemplify, when the HFR bull was the same price as the non-HFR bull, 100% of producers in the Information Treatment chose the HFR bull and 97% of producers without information chose the HFR bull. The Information Treatment only resulted in a significantly different percentage of producers who chose the HFR bull at $4,000 price level ($T$ = –2.14; df = 45; P = 0.03) (Fig. 1a). At this price level, producers who received the information were less likely to choose the HFR bull.

Similarly, Fig. 1b shows the percentage of Texas producers who chose the HFR bull at the different price levels compared to a non-HFR bull at a base price of $5,000. Similar to the Tennessee producers, a majority of Texas producers chose the HFR bull. Producers who were in the Information Treatment did not choose the HFR bull significantly more than those who did not see the horn fly information prior to the contingent valuation question (P > 0.10 for all price levels).

In terms of producer and farm demographics, the average producer from both states had some level of college or technical school

Table 2. Dependent and independent variable means (standard deviations) and differences of means for Tennessee and Texas respondents

Variable	Tennessee (n = 254)	Texas (n = 119)	*t*-test statistic state difference	Satterthwaite's degrees of freedom	*P*-value
Dependent variable					
HFR Bull	0.81 (0.40)	0.89 (0.31)	–2.20**	285.64	0.028
Price and Information Treatment					
HFR Bull Price	3,767.72 (558.07)	5,789.92 (580.38)	–31.75***	222.87	0.000
Information Treatment	0.47 (0.50)	0.55 (0.50)	–1.84*	159.39	0.067
Producer and farm demographics					
Education	3.38 (0.78)	3.61 (0.63)	–3.12***	282.30	0.002
Age	57.32 (11.79)	62.31 (11.0)	–3.99***	245.84	0.000
Income	4.81 (1.45)	5.87 (1.74)	–5.74***	196.95	0.000
Sole Proprietorship	0.81 (0.40)	0.76 (0.43)	1.09	213.82	2.778
Herd Size	110.99 (118.89)	202.34 (307.22)	–3.14**	134.83	0.002
Charolais	0.21 (0.41)	0.14 (0.35)	1.60	264.34	0.111
Angus	0.87 (0.33)	0.65 (0.48)	4.66***	172.96	0.000
Texas	NA	0.91 (0.29)	NA	NA	NA
Current horn fly perceptions and management practices					
Horn Fly Intensity	3.20 (0.81)	3.68 (0.75)	–5.63***	247.73	0.000
Use of Insecticides	0.92 (0.28)	0.92 (0.27)	–0.24	239.07	0.814
Use of Ear Tag	0.57 (0.50)	0.39 (0.49)	3.14**	233.21	0.002
Insecticide Effectiveness	4.09 (1.61)	4.20 (1.61)	–0.64	230.76	0.522
Labor is Burdensome	3.22 (0.82)	3.26 (0.74)	–0.47	254.16	0.640
Extension	0.75 (0.44)	0.70 (0.46)	1.00	219.07	0.316
Perceptions of incorporating horn fly resistance into their herds					
Expected Weight Gain	21.26% (12.90%)	23.13% (13.96%)	–1.24	215.25	0.217
HFR Trait Importance	3.06 (0.63)	3.24 (0.65)	–2.47**	225.04	0.014

*P < 0.1, **P < 0.05, ***P < 0.01.

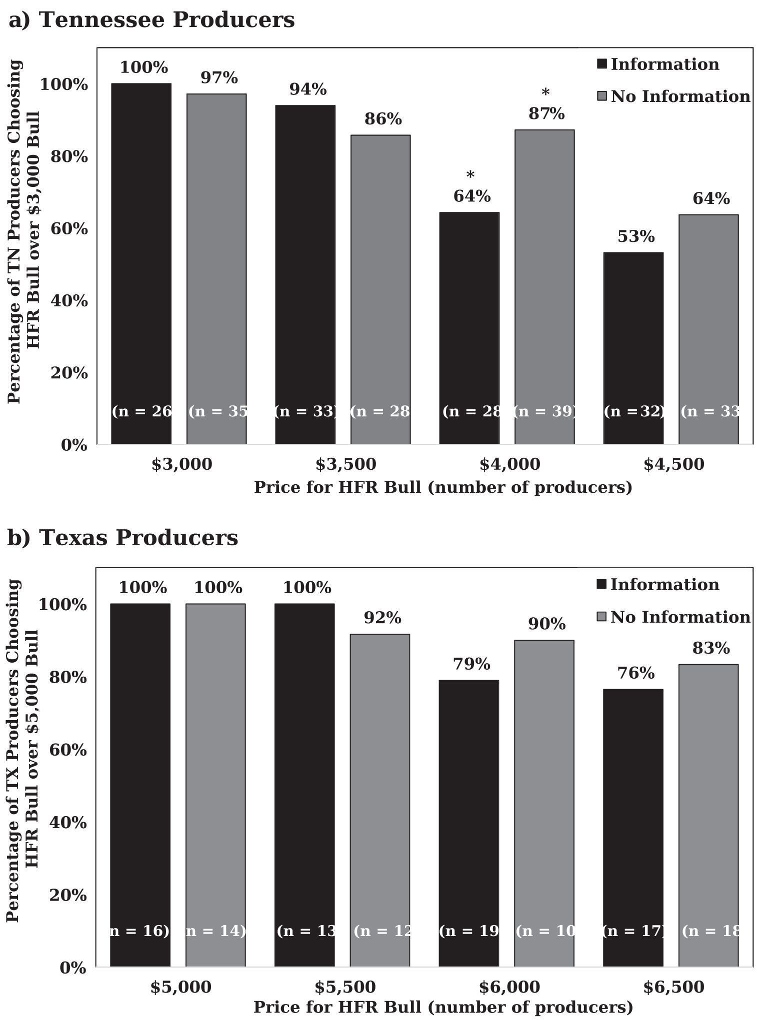

Fig. 1. Percent of Tennessee (a) and Texas (b) producers who chose a HFR bull over a $3,000 bull in Tennessee and a $5,000 bull in Texas. The only significant difference for the Information Treatment was at the $4,000 price level for Tennessee producers (T = 2.14; df = 45; P = 0.04). 'Information' refers to respondents who saw the Information Treatment and 'No Information' refers to respondents who did not see the Information Treatment.

education. The mean *Age* of Tennessee and Texas producers was 57 and 62 yr, respectively. While Texas respondents were significantly older than those from Tennessee (T = –3.99; df = 246; P < 0.01). Producers from both states were consistent with the average age of farmers in the United States of 58 yr (United States Department of Agriculture (USDA), National Agricultural Statistics Service (NASS) 2012a). On average, Tennessee producers reported earning $50,000 to $99,999/yr which is significantly lower than Texas producers reported earnings of $100,000 to $149,999/yr ($T$ = –5.74; df = 197; P < 0.01); average U.S. household income for farms is $119,880 (Schnepf 2017). Eighty-one percent of Tennessee and 76% of Texas producers operated under a sole proprietorship. Average cattle herd sizes were 111 head in Tennessee and 202 head in Texas, indicating Texas has significantly larger herd sizes (T = –3.14; df = 134; P = 0.002). State averages for beef cattle herd sizes is 47 in Tennessee and 74 in Texas (USDA, NASS 2012b,c); thus, the producers in our survey originated from larger than average cattle farms for their respective states. Fourteen percent of Texas producers and 21% of Tennessee producers owned Charolais-influenced cattle. Eighty-seven percent of Tennessee producers owned Angus-influenced cattle which is significantly more than in Texas where 65% of Texas producers owned Angus-influenced cattle (T = 4.66; df = 173; P < 0.01). Finally, a dummy variable was included in the Texas model (*Texas*) to control for producers who were located outside the state. Only 9% of farms in the 'Texas' model were located outside of Texas with 10 farms located in Oklahoma and one farm located in an 'other' southwestern state.

In terms of current horn fly perceptions and management practices, on average, producers considered the level of *Horn Fly Intensity* on their cattle a moderate to serious problem, in both states. In both states, 92% of producers used insecticides (e.g., pour-on, back-rubbers). Significantly more Tennessee producers (57%) used ear tags to control for horn flies than producers in Texas (39%) (T = 3.14; df = 233; P = 0.002). On average, producers from both states perceived horn fly insecticides 'as effective' today as they were 5 yr ago. On average, producers in both states 'somewhat agreed' that the additional labor needed to address horn flies was burdensome. Seventy-five percent of Tennessee producers and 70% of Texas producers received information about horn flies from Extension services.

With respect to perceptions of incorporating horn fly resistance in their herds, Tennessee and Texas producers expected a 21% and 23%, respectively, increase in cattle weight gains (*Expected Weight Gain*) if their entire herds were resistant to horn flies. In both states, producers considered a HFR trait as 'moderately important'.

Tennessee and Texas Probit Model Results

Results of the Tennessee and Texas probit models are reported in Table 3. The VIFs were all less than 10, and the mean VIF was 1.11 and 1.21 for the Tennessee and Texas model, respectively. The condition indexes using the coldiag2 code in *STATA* were all less than 34 (StataCorp 2017). Thus, multicollinearity was not a concern with the models.

The *HFR Bull Price* negatively impacted producers' choice to purchase a HFR bull. With each $100 increase in price, Tennessee and Texas producers were 1% (P = 0.006) less likely to choose the HFR bull, respectively. Note that marginal effects are interpreted as a one-unit increase in the independent variable, ceteris paribus, will increase/decrease the probability the producer will choose the HFR bull over the other bull by the magnitude of the marginal effect coefficient. Thus, for a $1 increase in the HFR bull price, the associated probability decrease in purchasing the HFR bull is 0.0003 (Table 3). To make this easier to interpret, we multiplied this coefficient by 100; thus, a $100 increase in the HFR bull price is associated with a decrease in probability of purchasing the HFR bull by 0.03 (or 3%). In Tennessee, producers who received the *Information Treatment* were 8% less likely to choose the HFR bull (P = 0.03). The *Information Treatment* was not significant in the Texas model.

Producer and farm demographics affected a producer's willingness to purchase a HFR bull in Texas, but not in Tennessee. As Texas producers were 1 yr older, they were 1% more likely to choose the HFR bull (P < 0.01). As household income increased by each category, Texas producers' likelihood of choosing the HFR bull increased by 3% (P = 0.02). Texas producers were 9% less likely to choose the HFR bull if they were sole proprietors (P = 0.08), and these respondents with Angus cattle were 10% more likely to choose the HFR bull (P = 0.04). As Texas producers' herds increased by 100 head, they were 3% more likely to choose the HFR bull (P = 0.07).

Current horn fly perceptions and management practices of producers were significant in both Tennessee and Texas. Tennessee producers were 8% more likely to choose the HFR bull when they indicated *Horn Fly Intensity* was more of a problem (P = 0.002). In Texas, a producer was 5% less likely to choose the HFR bull if they indicated that *Horn Fly Intensity* was more of a problem (P = 0.03). Producers who *Use Insecticide* to manage horn flies were 12% and 14% more likely to choose the HFR bull in Tennessee (P = 0.47) and Texas (P = 0.04), respectively. In Texas, producers who *Use Ear Tags* to manage horn flies were 12% more likely to choose the non-HFR bull instead of the HFR bull (P < 0.02). The more Tennessee producers agreed that *Labor Is Burdensome* in treating horn flies, they were 6% more likely to choose the non-HFR bull (P = 0.02); however, Texas producers who were in greater agreement that the horn fly management *Labor Is Burdensome* were 12% more likely to choose the HFR bull (P < 0.01). Use of *Extension* services was not significant in either Texas or Tennessee.

In both states perceptions of incorporating the HFR trait into their herds played a role in their decision of bull. With each 1% increase in *Expected Weight Gain*, producers were 1% more likely to choose the HFR bull (P < 0.01). As producers more greatly valued *HFR Trait Importance*, they were 7% and 5% more likely to choose the HFR bull in Tennessee (P = 0.04) and Texas (P < 0.03), respectively.

WTP Estimates

Overall, producers in Tennessee had an average WTP for a HFR bull of $4,652 ($4,621 median). This is a premium of $1,652 (59%)

Table 3. Tennessee and Texas probit model coefficients and marginal effects

	Tennessee		Texas	
Variable	Coef. (SE)	Marginal effects (SE)	Coef. (SE)	Marginal effects (SE)
Price and Information Treatment				
HFR Bull Price	−0.002 (0.00)***	−0.0003 (0.00)***	−0.002 (0.00)***	−0.0001 (0.00)***
Information Treatment	−0.46 (0.22)**	−0.08 (0.04)**	0.21 (0.43)	0.02 (0.04)
Producer and farm demographics				
Education	0.01 (0.15)	0.001 (0.03)	−0.47 (0.53)	−0.04 (0.04)
Age	−0.01 (0.01)	−0.002 (0.00)	0.11 (0.03)***	0.01 (0.00)***
Income	0.10 (0.08)	0.02 (0.01)	0.31 (0.14)**	0.03 (0.01)**
Sole Proprietorship	−0.09 (0.27)	−0.02 (0.05)	−1.09 (0.63)*	−0.09 (0.05)*
Herd Size	0.001 (0.00)	0.0002 (0.00)	0.004 (0.00)*	0.0003 (0.00)*
Charolais	−0.41 (0.26)	−0.07 (0.05)	0.07 (0.62)	0.01 (0.05)
Angus	0.13 (0.33)	0.02 (0.06)	1.14 (0.55)**	0.10 (0.04)**
Texas	NA	NA	−0.19 (0.71)	−0.02 (0.06)
Current horn fly perceptions and management practices				
Horn fly intensity	0.44 (0.14)***	0.08 (0.03)***	−0.58 (0.27)**	−0.05 (0.02)**
Use of Insecticide	0.67 (0.34)**	0.12 (0.06)**	1.68 (0.81)**	0.14 (0.07)**
Use of Ear Tags	0.23 (0.23)	0.04 (0.04)	−1.37 (0.53)***	−0.12 (0.05)***
Insecticide Effectiveness	−0.06 (0.07)	−0.01 (0.01)*	0.02 (0.13)	0.002 (0.01)
Labor is Burdensome	−0.33 (0.14)**	−0.06 (0.02)**	1.41 (0.38)***	0.12 (0.03)***
Extension	0.34 (0.24)	0.06 (0.04)	0.55 (0.53)	0.05 (0.04)
Perceptions of incorporating horn fly resistance into their herds				
Expected Weight Gain	0.04 (0.01)***	0.01 (0.002)***	0.08 (0.03)***	0.01 (0.00)***
HFR Trait Importance	0.38 (0.20)**	0.07 (0.03)**	0.64 (0.33)**	0.05 (0.03)**
Constant	4.27 (1.34)***		−2.36 (3.99)	
Observations	254		119	
Pseudo-R^2	0.337		0.553	
Wald χ^2	61.05***		39.76***	

*P < 0.1, **P < 0.05, ***P < 0.01.

above the $3,000 base price for a bull. In Texas, producers' average WTP for a HFR bull was $7,949 ($7,708 median), a premium of $2,949 (55%) above the $5,000 base price of a bull.

Discussion

The goal of this study was to determine cow-calf producers' WTP for a HFR bull and evaluate the factors that may be influencing their decision to integrate the HFR trait into their herds. Cow-calf producers, primarily from Tennessee and Texas, were surveyed concerning horn fly resistance. These two states account for approximately 17% of U.S. cow-calf production (USDA, NASS 2018). Producers chose the HFR bull rather than the non-HFR bull and were willing to pay a premium for the HFR bull. In both states, the decision to adopt a HFR bull was affected by management practices and the perceived impact of horn fly resistance; additionally, in Texas, demographic factors affected the decision to adopt a HFR bull. In both states, as the HFR bull price increased, producers were less willing to purchase the HFR bull.

When Tennessee producers received specific information about the specific damages horn flies cause, they were less likely to choose the HFR bull. A possible explanation for this is that producers who did not receive the additional horn fly information were already familiar with the damages horn flies cause. This is especially possible since over 70% of producers in both states indicated they received information from Extension services about horn flies (Table 2).

The role of producer and farm demographics in explaining producers' decisions to adopt a HFR bull was not the same in both states. Here, older producers in Texas were more likely to choose the HFR bull. Since older producers are often considered less willing to change (Weiss and Maurer 2004), this result may be reflective of older producers remembering horn flies before current management options (e.g., ear tags), their larger self-reported herd size, and/or their desire to use less labor-intensive methods of controlling for flies. Additionally, Texas producers were more likely to choose the HFR bull as they were wealthier. This could be reflective of producers with greater reported levels of income being more able to purchase more expensive HFR bulls because they have a greater amount of funds available to spend on a bull and/or make untested risk with a potential for great benefit. It was also found that Texas producers owning Angus-influenced cattle were more likely to choose the HFR bull. This is consistent with expectations since Angus is not a breed known for horn fly resistance (Steelman et al. 1991). Texas producers with larger herds were more likely to choose the HFR bull, which may be explained by larger farmers having more incentive to adopt this practice to control horn flies.

Tennessee producers were more likely to choose the HFR bull if they indicated that horn fly intensity was more of a problem. This result is consistent with expectations since it is likely producers would be interested in alternative horn fly management options if they have an observable horn fly problem and/or have not been successful at controlling horn flies. However, the opposite result was found in Texas, which could be explained by Texas producers finding current control methods effective as compared to previous years and the few Texas producers that chose the non-HFR bull. It was also found that Tennessee and Texas producers recognize the damage caused by horn flies and are attempting to manage their populations since producers in both states who use insecticides to manage horn flies were also more likely to purchase a HFR bull. In Texas, producers who use ear tags to manage horn flies were more likely to choose the non-HFR bull instead of the HFR bull. It is possible that these producers are already experiencing effectiveness at treating horn flies through the use of ear tags. Tennessee producers were less likely to choose the HFR bull as they considered labor more burdensome; in Texas, the opposite was true. Since a HFR herd would result in less labor from implementing other horn fly management practices, it was assumed producers in both states would choose the HFR as the labor required to manage horn flies was considered to be more burdensome.

In both states, as producer perceptions of incorporating the HFR trait into their herds was greater (both in terms of expected weight gain and the importance of a possible HFR trait), they were more likely to choose the HFR bull. These results are expected since producers with more positive perceptions of incorporating HFR bulls into their herds are more likely to adopt the HFR bull.

A possible explanation for differences in results between Tennessee and Texas cow-calf producers is that they differ across several demographics (see Table 2). Tennessee cow-calf producers that participated in the survey were current members of the TAEP. TAEP provides a cost share to producers for long-term investments that increase their likelihood of maximizing farm profits, adapting to changing markets, improving safety, increasing efficiency, and making positive economic impacts in their communities. For a producer to be eligible to participate in TAEP at the 35% cost share level, the producer must have a minimum of 30 head of any class of cattle and be Beef Quality Assurance certified. Producers completing the University of Tennessee Extension Advanced Master Beef Producer program qualify for a 50% cost share up to the TAEP program maximum. Thus, it is possible TAEP producer and farm demographics were more similar than those respondents for Texas as participants receive funding from the state and many participate in similar educational opportunities which shape production, management, and marketing decisions.

This study is not without limitations. It should be noted that while 83% of producers chose the HFR bull over the other bull, they did not actually purchase the bull. Thus, hypothetical bias could be present in these estimates (Cummings and Taylor 1999). Further, if we had used higher price points for the HFR bull extending more than $1,500 beyond the initial price point, the percentage of producers who selected the HFR would be expected to be much lower.

Overall, the results of this survey indicate that producers are willing to pay a premium for the HFR bull. Thus, the HFR trait is valued and should be evaluated as an additional management tactic for horn fly control. Understanding producer preferences adds to the motivation for advancing the research, evaluating the HFR trait, and initiates discussions on how to incorporate the trait. Before the trait is integrated into herds, it is first necessary to identify the genomic regions associated with the HFR trait, the frequency of the trait in geographically and genetically distinct animals, linked traits, procedures for verifying the trait that do not involve genetic procedures, and the potential profitability and sustainability of developing the trait. This is especially important since some producers may be unwilling to lose specific traits or integrate breeds into a herd, like Australian producers were unwilling to integrate Zebu cattle into their British cattle herds for tolerance of *Babesia* and *Rhipicephalus (Boophilus)* tick management (Wharton 1974). This study warrants continued research regarding the development and assessment of the HFR trait, and indicates that continued research into HFR is warranted and supported by producers.

Acknowledgments

We acknowledge the insightful survey contributions and collaborations provided by Drs. John Keele and Larry Kuehn with USDA-ARS Meat Animal Research Center; Dr. Kristina Friesen with the USDA-ARS Midwest Livestock Insects Research Laboratory; Dr. Meg Staton with University of Tennessee Institute of Agriculture, Dr. Wes Watson with North Carolina State University, Dr. Brandon Smythe with New Mexico State University, Dr. Eric Psota with University of Nebraska, and Drs. Charles Rosenkranz and Kelly Loftin with the University of Arkansas. We are particularly grateful for the cooperation of Texas and Southwestern Cattle Raisers Association (TSCRA) for reviewing the survey and administering it to its members. We thank the producers participating in the Tennessee Agriculture Enhancement Program (TAEP) and the TSCRA for completing the survey. Also, we are extremely grateful for the producers and research center directors for providing valuable comments and fantastic feedback on earlier drafts of the survey: Robert Simpson and Brandon Beavers (East Tennessee Research and Education Center, UTIA). We also want to acknowledge the effort provided to us by the reviewers as they not only provided a critical review of the manuscript, but also provided interesting comments and discussion for future research endeavors. This project was supported with funding from the UTIA AgResearch Innovation Grants Program. Personnel on the project are supported by USDA-ARS, and USDA National Institute of Food and Agriculture Multistate Hatch Projects S1076 (Fly management in animal and agriculture systems and impacts on animal health and food safety).

References Cited

Arther, R. 1991. Management of horn fly resistance. Mobay Animal Health, Shawnee, KS.

Barros, A. T., J. Ottea, D. Sanson, and L. D. Foil. 2001. Horn fly (Diptera: Muscidae) resistance to organophosphate insecticides. Vet. Parasitol. 96: 243–256.

Belsley, D., E. Kuh, and R. Welsch. 1980. Regression diagnostics. Wiley, New York, NY.

Bernard, T., M. Hidrobo, A. Le Port, and R. Rawat. 2018. Nutrition-based incentives in dairy contract farming in Northern Senegal. Am. J. Agric. Econ. In press. doi:10.1093/ajae/aay036

Brown, A. H., C. D. Steelman, Z. B. Johnson, C. F. Rosenkrans, and T. M. Brasuell. 1992. Estimates of repeatability and heritability of horn fly resistance in beef cattle. J. Anim. Sci. 70: 1375–1381.

Byford, R. L., M. E. Craig, S. M. DeRouen, M. D. Kimball, D. G. Morrison, W. E. Wyatt, and L. D. Foil. 1999. Influence of permethrin, diazinon and ivermectin treatments on insecticide resistance in the horn fly (Diptera: Muscidae). Int. J. Parasitol. 29: 125–135.

Campbell, J. B. 1976. Effect of horn fly control on cows as expressed by increased weaning weights of calves. J. Econ. Entomol. 69: 711–712.

Chen, K., P. Tozer, S. Galinato, and T. L. Marsh. 2018a. Biotechnology to sustainability: consumer preferences for food products grown on biodegradable mulches. Food Res. Int. In press. doi:10.1016/j.foodres.2018.08.013.

Chen, X., Z. Gao, M. Swisher, L. House, and X. Zhao. 2018b. Eco-labeling in the fresh produce market: not all environmentally friendly labels are equally valued. Ecol. Econ. 154: 201–210.

Cilek, J. E., C. D. Steelman, and F. W. Knapp. 1991. Horn fly (Diptera: Muscidae) insecticide resistance in Kentucky and Arkansas. J. Econ. Entomol. 84: 756–762.

Clutter, A. C., and M. K. Nielsen. 1987. Effect of level of beef cow milk production on pre- and postweaning calf growth. J. Anim. Sci. 64: 1313–1322.

Cummings, R. G., and L. O. Taylor. 1999. Unbiased value estimates for environmental goods: a cheap talk design for the contingent valuation method. Am. Econ. Rev. 89: 649–665.

DeLong, K. L., D. M. Lambert, S. Schexnayder, P. Krawczel, M. Fly, L. Garkovich, and S. Oliver. 2017. Farm business and operator variables associated with bulk tank somatic cell count from dairy herds in the southeastern United States. J. Dairy Sci. 100: 9298–9310.

DeLong, K. L., K. L. Jensen, A. P. Griffith, and E. McLeod. 2018. Beef cattle farmers' marketing preferences for selling local beef. Agribusiness. 1–15. doi:10.1002/agr.21579.

Denning, S. S., S. P. Washburn, and D. W. Watson. 2014. Development of a novel walk-through fly trap for the control of horn flies and other pests on pastured dairy cows. J. Dairy Sci. 97: 4624–4631.

Derouen, S. M., L. D. Foil, J. W. Knox, and J. M. Turpin. 1995. Horn fly (Diptera: Muscidae) control and weight gains of yearling beef cattle. J. Econ. Entomol. 88: 666–668.

DeRouen, S. M., L. D. Foil, A. J. MacKay, D. E. Franke, D. W. Sanson, and W. E. Wyatt. 2003. Effect of horn fly (*Haematobia irritans*) control on growth and reproduction of beef heifers. J. Econ. Entomol. 96: 1612–1616.

Dobbs, L. M., K. L. Jensen, M. B. Leffew, B. C. English, D. M. Lambert, and C. D. Clark. 2016. Consumer willingness to pay for Tennessee beef. J. Food Dist. Res. 47: 38–61.

Edwards, J. F., S. E. Wikse, R. W. Field, C. C. Hoelscher, and D. B. Herd. 2000. Bovine teat atresia associated with horn fly (*Haematobia irritans irritans* (L.))-induced dermatitis. Vet. Pathol. 37: 360–364.

Foil, L. D., and J. A. Hogsette. 1994. Biology and control of tabanids, stable flies and horn flies. Rev. Sci. Tech. 13: 1125–1158.

Gardiner Angus Ranch. 2017. Sale Results. http://www.gardinerangus.com/sale-results/index.html.

Gillespie, B. E., W. E. Owens, S. C. Nickerson, and S. P. Oliver. 1999. Deoxyribonucleic acid fingerprinting of *Staphylococcus aureus* from heifer mammary secretions and from horn flies. J. Dairy Sci. 82: 1581–1585.

Gordon, D. V., W. D. Haufe, and K. K. Klein. 1984. Determination of economic thresholds for horn fly control in Western Canada: a farm level simulation approach. Can. J. Agric. Econ. 32: 399–421.

Greene, W. H. 2012. Econometric analysis, 7th ed. Prentice Hall, Boston, MA.

Guglielmone, A. A., E. Gimeno, J. Idiart, W. F. Fisher, M. M. Volpogni, O. Quaino, O. S. Anziani, S. G. Flores, and O. Warnke. 1999. Skin lesions and cattle hide damage from *Haematobia irritans* infestations. Med. Vet. Entomol. 13: 324–329.

Guglielmone, A. A., E. Curto, O. S. Anziani, and A. J. Mangold. 2000. Cattle breed-variation in infestation by the horn fly *Haematobia irritans*. Med. Vet. Entomol. 14: 272–276.

Gujarati, D. N., and D. Porter. 2009. Basic econometrics, 5th ed. McGraw-Hill Irwin, Boston, MA.

Harvey, T. L., and J. R. Brethour. 1979. Effect of horn flies on weight gains of beef cattle. J. Econ. Entomol. 72: 516–518.

Haufe, W. O. 1982. Growth of range cattle protected from horn flies (*Haematobia irritans*) by ear tags impregnated with fenvalerate. Can. J. Anim. Sci. 62: 567–573.

Haufe, W. O. 1986. Productivity of the cow-calf unit in range cattle protected from horn flies, (*Haematobia irritans*) (L.), by pesticidal ear tags. Can. J. Anim. Sci. 66: 575–589.

Jensen, K. M. V., J. B. Jespersen, M. A. Birkett, J. A. Pickett, G. Thomas, L. J. Wadhams, and C. M. Woodcock. 2004. Variation in the load of the horn fly, *Haematobia irritans*, in cattle herds is determined by the presence or absence of individual heifers. Med. Vet. Entomol. 18: 275–280.

Kunz, S. E., A. J. Miller, P. L. Sims, and D. C. Meyerhoeffer. 1984. Economics of controlling horn flies (Diptera: Muscidae) in range cattle management. J. Econ. Entomol. 77: 657–660.

Kunz, S. E., K. D. Murrell, G. Lambert, L. F. James, and C. E. Terrill. 1991. Estimated losses of livestock to pests, pp. 68–69. *In* D. Pimental (ed.), CRC handbook of pest management in agriculture, vol. 1. CDC, Boca Raton, FL.

Mays, A. R., M. A. Brown, D. L. von Tunglen, and C. F. Rosenkrans. 2014. Milk production traits of beef cows as affected by horn fly count and sire breed type. J. Anim. Sci. 92: 1208–1212.

McFadden, D. 1974. Conditional logit analysis of qualitative choice behavior, pp. 105–142. *In* P. Zarembka (ed.) Frontiers in economics. Academic Press, New York, NY.

McFadden, B. R., and Lusk, J. L. 2015. Cognitive biases in the assimilation of scientific information on global warming and genetically modified food. Food Policy. 54: 35–43.

McLeod, E., K. Jensen, A. P. Griffith, and K. L. DeLong. 2018. Tennessee beef producers' willingness to participate in a state branded beef program. J. Agric. Appl. Econ. 50: 579–601.

Miller, J. D., and B. E. Lindsay. 1993. Willingness to pay for a state gypsy moth control program in New Hampshire: a contingent valuation case study. J. Econ. Entomol. 86: 828–837.

Pruett, J. H., C. D. Steelman, J. A. Miller, J. M. Pound, and J. E. George. 2003. Distribution of horn flies on individual cows as a percentage of the total horn fly population. Vet. Parasitol. 116: 251–258.

Quisenberry, S. S., J. A. Lockwood, R. L. Byford, H. K. Wilson, and T. C. Sparks. 1984. Pyrethroid resistance in the horn fly, *Haematobia irritans* (L.) (Diptera: Muscidae). J. Econ. Entomol. 77: 1095–1098.

Sanson, D. W., A. A. DeRosa, G. R. Oremus, and L. D. Foil. 2003. Effect of horn fly and internal parasite control on growth of beef heifers. Vet. Parasitol. 117: 291–300.

Satterthwaite, F. E. 1946. An approximate distribution of estimates of variance components. Biomet. Bull. 2: 110–114

Schnepf, R. 2017. U.S. Farm Income Outlook for 2017. Congressional Research Service. https://fas.org/sgp/crs/misc/R40152.pdf

Schreiber, E. T., and J. B. Campbell. 1986. Horn fly (Diptera: Muscidae) distribution on cattle as influenced by host color and time of day. Environ. Entomol. 15: 1307–1309.

Sheppard, D. C. 1984. Fenvalerate and flucythrinate resistance in a horn fly population. J. Agric. Entomol. 1: 305–310.

Sparks, T. C., S. S. Quisenberry, J. A. Lockwood, R. L. Byford, and R. T. Roush. 1985. Insecticide resistance in the horn fly *Haematobia irritans*. J. Agric. Entomol. 2: 217–233.

StataCorp. 2017. Stata Statistical Software, version, 15th ed. StataCorp, College Station, TX.

Steelman, C. D., A. H. Brown, Jr., E. E. Gbur, and G. Tolley. 1991. Interactive response of the horn fly (Diptera: Muscidae) and selected breeds of beef cattle. J. Econ. Entomol. 84: 1275–1282.

Steelman, C. D., E. E. Gbur, G. Tolley, and A. H. Brown, Jr. 1993. Individual variation within breeds of beef cattle in resistance to horn fly (Diptera: Muscidae). J. Med. Entomol. 30: 414–420.

Steelman, C. D., R. W. McNew, M. A. Brown, G. Tolley, and J. M. Phillips. 1994. Efficacy of Brahman breeding in the management of insecticide-resistant horn flies (Diptera: Muscidae) on beef cattle. J. Econ. Entomol. 87: 7–14.

Steelman, C. D., C. J. Brown, R. W. McNew, E. E. Gbur, M. A. Brown, and G. Tolley. 1996. The effects of selection for size in cattle on horn fly population density. Med. Vet. Entomol. 10: 129–136.

Steelman, C. D., M. A. Brown, E. E. Gbur, and G. Tolley. 1997. The effects of hair density of beef cattle on Haematobia irritans horn fly populations. Med. Vet. Entomol. 11: 257–264.

Steelman, C. D., R. W. McNew, R. B. Simpson, R. W. Rorie, J. M. Phillips, and C. F. Rosenkrans, Jr. 2003. Evaluation of alternative tactics for management of insecticide-resistant horn flies (Diptera: Muscidae). J. Econ. Entomol. 96: 892–901.

Tri State Livestock News. 2017. Mangen Angus Ranch 45th Annual Bull Sale. https://www.tsln.com/market-reports/sale-reports/mangen-angus-ranch-45th-annual-bull-sale/.

University of Tennessee Bull Test. 2017. Bull Testing Program. https://ag.tennessee.edu/AnimalScience/Pages/ BullTestProgram.aspx.

Untalan, P. M., J. H. Pruett, H. N. Atteberry, and C. D. Steelman. 2006. Thrombostasin isoform frequency in a Central Texas field population of the horn fly, *Haematobia irritans*. Vet. Parasitol. 142: 359–366.

U.S. Department of Agriculture, National Agricultural Statistics Service. 2012a. 2012 Census of Agriculture Preliminary Report, state data. https://www.nass.usda.gov/Publications/AgCensus/2012/.

U.S. Department of Agriculture, National Agricultural Statistics Service. 2012b. Tennessee beef cow herd size by inventory and sales: 2012 Census of Agriculture, state data. https://www.nass.usda.gov/Publications/AgCensus/2012/Full_Report/Volume_1,_Chapter_1_State_Level/Tennessee/.

U.S. Department of Agriculture, National Agricultural Statistics Service. 2012c. Texas beef cow herd size by inventory and sales: 2012 Census of Agriculture, state data. https://www.nass.usda.gov/Publications/AgCensus/2012/Full_Report/Volume_1,_Chapter_1_State_Level/Texas/.

U.S. Department of Agriculture, National Agricultural Statistics Service. 2018. Statistics by state. https://www.nass.usda.gov/Statistics_by_State/index.php.

Watson, D. W., S. M. Stringham, S. S. Denning, S. P. Washburn, M. H. Poore, and A. Meier. 2002. Managing the horn fly (Diptera: Muscidae) using an electric walk-through fly trap. J. Econ. Entomol. 95: 1113–1118.

Weiss, E. M., and T. J. Maurer. 2004. Age discrimination in personnel decisions: a reexamination1. J. Appl. Soc. Psych. 34: 1551–1562.

Wharton, R. H. 1974. Ticks with special emphasis on *Boophilus microplus*, pp. 35–52. *In* R. Pal **and** R. H. Wharton (eds.), Control of arthropods of medical and veterinary importance. Plenum Press, New York, NY.

Wooldridge, J. M. 2002. Introduction to econometrics. Southwest Press Publishing, New York, NY.