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Estimating Production of Brewery and Distillery Spent Grains in Tennessee and Identifying Sustainable Uses

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ABSTRACT

Brewery and distillery spent grains (BDSG) are a by-product of the fermentation process and consists of various grains, hops, and flavor additives. Large breweries and distilleries can establish and maintain marketing channels to dispose of BDSG typically as a livestock feed. However, small-scale businesses may lack the necessary resources and contacts to dispose of BDSG, thus creating the potential disposal of BDSG through a landfill or wastewater system. This study aims to estimate the production of BDSG by craft breweries and distilleries in the state of Tennessee and identify sustainable uses and marketing channels for the product, which includes use as animal feeds and composts, soil amendments, or fertilizers for traditional agriculture and urban agriculture.

The objectives of the study are: i) determine the quantity of BDSG being produced in Tennessee by craft breweries and distilleries; ii) determine current BDSG disposal practices; and iii) determine the cost-savings for farmers resulting from BDSG disposal by breweries and distilleries as a livestock feed. These objectives were accomplished by surveying craft breweries and distilleries in Tennessee regarding their production practices and developing a linear programming model to determine the value of BDSG as a livestock feed for beef cattle.

Results of the survey indicate that the majority of breweries and distilleries are disposing of their spent grains as a livestock feed, with 100 percent of breweries and 87 percent of distilleries indicating that they dispose of at least a portion of their spent grains in this manner. Conversely, few breweries and distilleries are disposing of their spent grains as a compost, soil amendment, or fertilizer with only 15 percent of breweries and eight percent of distilleries selecting this method of disposal. Average annual production of BSG and DSG per brewery and distillery in the survey was 65,800 pounds and 51,808 gallons. Results of the least-cost winter feed ration suggest that significant cost savings can be afforded to farmers by including spent grains at their average daily production rate of 7.2 pounds of BSG and 47.1 pounds of DSG.

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CHAPTER I: INTRODUCTION AND OVERVIEW

Background

History of Craft Brewing and Distilling

Brewery and distillery spent grains (BDSG) are a byproduct of the fermentation process and can consist of malt barley (*Hordeum vulgare*), corn (*Zea mays*), other grains, hops (*Humulus lupulus*), and flavor additives. Large breweries and distilleries currently have the ability to separate by-products into different components such as grains, yeast, and condensed solubles, while micro-breweries or -distilleries may not have this ability and instead discard spent grains through waste disposal (Westendorf and Wohlt 2002). Many established large-scale and small-scale brewers and distillers market their BDSG to livestock producers as a feed component (Westendorf and Wohlt 2002). However, given the recent dramatic increase in craft brewers, defined as producing 6 million barrels (1 barrel = 31 gallons) of beer or less annually (Brewers Association 2018c), and craft distillers, defined as producing fewer than 750,000 gallons annually (American Craft Spirits Association 2018), in Tennessee and the United States, there is limited information about current craft brewery and distillery disposal methods. Many of these small-scale craft breweries and distilleries may be unaware of the ability to use BDSG as an animal feed and are disposing of spent grains through waste water treatment facilities or landfills. Furthermore, investigation into the marketing and economics of BDSG disposal could assist craft brewers and distillers seeking to reduce cost or increase revenue through sustainable disposal methods.

By the end of the 1970s the American beer industry only had 44 brewing companies (Brewers Association 2018a). With the deregulation of home brewing in the United States in 1979, craft breweries began to emerge (Kain 2011). North America's first brewpub was established in 1982 with craft brewing annual volume growth increasing from 35 percent in 1991, to 58 percent in 1995, before slowing down from 1997 to 2003 and picking up again in 2004 (Brewers Association 2018a). There were only eight craft brewers in the United States in 1980. As of 2018, it is estimated that there are more than 6,000 craft breweries in the United States (Brewers Association 2018a).

The American distilling industry has had a similar resurgence since the 1970s, which saw a period in which vodka sales were higher than whiskey sales for the first time in America (Routley 2017). 1982 marked the emergence of the craft distilling industry in the United States when two craft distillers in California began operation (Kinstlick 2011). The number of craft distilleries increased from 24 in 2000 to 234 in 2011 (Kinstlick 2011). Kell (2016) estimated that there were 1,315 craft distillers in the United States in 2015 and that their market share of the spirit industry grew from 0.8 percent in 2010 to 2.2 percent in 2015. Additionally, the American Craft Spirits Association estimated that the craft distilling industry earned $2.4 billion in sales in 2015 with a compound annual growth rate of 27.4 percent in volume over the previous year (Kell 2016).

In 2016, craft brewers collectively produced 24.6 million barrels of beer, which was a six percent increase in volume over the previous year. Microbreweries (small-scale breweries with limited production) and brewpubs (a restaurant that brews beer onsite) accounted for 90 percent of growth in the craft brewer industry (*Steady Growth* 2017). In addition, the number of operating breweries in the United States increased by 16.6 percent, which totals to 5,301 breweries, 3,132 of which are microbreweries (*Steady Growth* 2017). The state of Tennessee has also had a substantial increase in number of operating craft breweries, from 24 in 2011 to 66 in

2016, a 275 percent increase in just five years (Brewers Association 2018b), with approximately 104 breweries identified as either being in operation or in the planning stages as of January 2019 based on data from the Tennessee Department of Agriculture, the Tennessee Brewers Association, and internet searches.

Based on the same data sources, the estimated number of distilleries in Tennessee was 34, in January 2019, which includes large distilleries such as Jack Daniels, and George Dickel's, which account for the majority of state production with the former having by far the largest share. The fast-paced growth of the craft distilling industry globally means there is limited information as to how these small, new businesses are disposing of their spent grains. Combining these factors with younger generations making sustainability a shopping priority (Nielsen 2015), there is potential for sustainability to become prevalent marketing strategy in the alcoholic beverage industry. The environmental and financial challenges presented by craft beer and liquor production and BDSG disposal has the potential to become a rising issue as industry growth continues. Additionally, sustainable BDSG disposal has the potential to reduce costs or generate additional revenue for brewers and distillers.

Challenges Posed by BDSG Disposal

The brewing industry is a large industrial user of water and despite technological advancements over the last twenty years, water consumption, wastewater, and solid waste are still major challenges faced by the industry due to the high moisture content of spent grains (Olajire 2012; Blanpain-Avet, et al. 2005).The average moisture content of wet brewers grains is approximately 74 percent (NASEM 2016) and the average moisture content of wet distillers grains is 91 percent (Moorehead 2018). Spent grains are the largest source of waste for most brewery operations (Mussatto 2014), accounting for 85 percent of total by-products. The amount of BDSG being produced in Tennessee is growing due to the increased number of breweries. Since BDSG can be used as an animal feed (Ben-Hamed 2012; Crickenberger and Johnson 1982; Dooley 2008; Mussatto 2014; Mussatto, Dragone, and Roberto et al. 2006; Ojowi et al. 1997; Preston, Vance, and Cahill 1973; Thomas et al. 2016; Trenkle 1998; Westendorf and Wohlt 2002; Widyaratne and Zijlstra 2006), soil amendment (Ben-Hamed 2012; Boydston, Collins, and Vaughn 2008; Gagnon and Berrouard 1993; Mbagwu and Ekwealor 1990; Nnadi, et al. 2013; Qian, et al. 2011), or compost (Awopetu, Bakare, and Odeyemi 2015; Stocks, Barker, and Guy 2002), there is an economic and environmental opportunity to improve BDSG disposal methods for brewers, distillers, and farmers. However, micro-breweries and -distilleries face challenges regarding developing networks and methods to dispose of spent grains, other than landfilling or waste water treatment, and the information regarding use of distillery spent grains (DSG) is much sparser than information regarding brewery spent grains (BSG).

BSG is rich in sugars, proteins, and minerals, but exact chemical composition can vary greatly depending on how the grains were grown and processed (Mussatto 2014). The primary utilization of BSG for animal feed has been for cattle because it can be fed to cattle wet or dry. When combined with urea, BSG can provide all essential amino acids for cattle and can increase milk production in dairy cattle without negatively impacting fertility (Mussatto, Dragone, and Roberto 2006). However, BSG has also been added to poultry, swine, and fish feed where body weight gain was reported as an effect of supplementing the diet with BSG (Mussatto 2014).

As the craft beer and spirit industries grow in Tennessee, so does the need for collection of data on BDSG disposal and analysis of marketing systems. There is currently little available information regarding industry disposal practices in the craft markets, nearly all of which is coming from international data. While it is well-known that BDSG can be used as a feedstock and has been in Europe for centuries, it has yet to be determined if it is economically viable for small-scale Tennessee producers to also utilize this disposal practice. The limited amount of BSG produced by craft breweries and lack of proximity to livestock operations can provide hurdles to BSG disposal. Further, while it seems that BDSG has potential to become a valuable soil amendment or component in compost more research is needed to determine its value in traditional or urban agriculture.

Potential marketing systems for BDSG could include channels such as cooperatives, brokers, and private contracts. Transporting efficiency (through drying) of BDSG could increase the potential market boundary, the distance BDSG could be cost effectively hauled, and provide additional disposal alternatives for brewers and distillers. Drying costs and travel distance present obstacles for BDSG disposal for small scale operations; however, these issues have not been systematically analyzed. Farmers can also benefit economically from the disposal of BDSG as livestock feed or as soil amendments/components in composts, especially since it is typically either very low cost or free for the farmer to obtain (Mussatto, Dragone, and Roberto 2006).

Disposing of BDSG through sustainable channels could also provide a marketing opportunity for brewers and distillers for a public that is increasingly aware of the environmental impact and sustainability of production practices and consumption habits. According to a study by Nielsen (2015), 66 percent of respondents to a global survey about sustainability purchasing drivers indicated that they were willing to pay more for products and services acquired from companies who are committed to having positive social and environmental impacts, an increase from 55 percent in 2014 and 50 percent in 2013. The fourth highest sustainability purchasing driver is that the product is from a company known for being environmentally friendly (Nielsen 2015). This opportunity presented by consumers' rising concern about sustainability could be used in marketing beer and liquor to possibly obtain a price premium that could offset potential increased costs associated with the sustainable disposal of BDSG.

Objectives

The general goal of this research is to quantify the size of the craft brewing and distilling industries in Tennessee, determine current disposal methods for BDSG, and determine the economic value of disposing BDSG as a livestock feed for cow-calf (*Bos taurus*) operations in Tennessee. This will be achieved through the following specific objectives:

i. Determine the quantity of BDSG being produced in Tennessee by craft breweries and distilleries;
ii. Determine current BDSG disposal practices; and
iii. Determine the cost-savings for farmers resulting from BDSG disposal by breweries and distilleries as a livestock feed.

To complete objectives i and ii, a survey of craft breweries and distilleries in Tennessee was conducted. Objective iii will be accomplished by sampling BDSGs to determine nutrient content and then developing a cost minimizing linear programming model for small scale cow-calf operations in Tennessee. For the least-cost feed ration, multiple calving scenarios will be examined to determine how winter-feeding costs vary with the inclusion of BDSG as a feedstock.

Study Overview

To complete the objectives of this study, a survey of Tennessee brewers and distillers was developed and distributed, and a linear programing model was developed. The development of the survey and survey results are discussed in Chapter II. Chapter III develops a linear programing model and examines three calving season scenarios for cow-calf operations that are reflective of the Tennessee beef cattle industry. BDSG is included as an alternative by-product feed in the linear programing model. Study conclusions, limitations, and recommendations are discussed in Chapter IV.

CHAPTER II: SURVEY OF TENNESSEE BREWERS AND DISTILLERS

Abstract

A survey of Tennessee brewers and distillers was conducted to determine the quantity of beer and liquor being produced by craft brewers and distillers, the quantity of BDSG being produced, and the methods being utilized to dispose of BDSG. 96 breweries and 34 distilleries were identified as the populations, with sample sizes of 72 and 22. Results of the survey indicated that production levels vary widely between businesses and that the majority of brewers and distillers that completed the survey are currently disposing of BDSG as a livestock feed, as opposed to sending BDSG to a landfill, water treatment facility, or using BDSG as a component in compost or a soil amendment.

Introduction

This chapter discusses the development, distribution, and results of an industry survey completed by Tennessee brewers and distillers, which seeks to accomplish the first and second objectives of the study. To reiterate, the objectives of this study are to:

i. Determine the quantity of BDSG being produced in Tennessee by craft breweries and distilleries;
ii. Determine current BDSG disposal practices; and
iii. Determine the cost-savings for farmers resulting from BDSG disposal by breweries and distilleries as a livestock feed.

First, a literature review of BDSG disposal surveys and survey methods are presented. Next, the survey data and methods are discussed, followed by the survey results. The chapter is concluded with a summary of key findings and implications for the craft brewing and distilling industries in Tennessee.

Literature Review of BDSG Used in Animal Feeds

Mussatto (2014), Westendorf and Wohlt (2002), and Mussatto, Dragone, and Roberto (2006) all mention the possibility of utilizing BSG as a livestock feed in their reviews of BSG applications. Mussatto's (2014) article includes an analysis of the chemical composition of BSG and compared results to other studies in which BSG was tested. They indicate that the use of BSG as an animal feed promotes weight gain and milk production in dairy cattle. Westendorf and Wohlt (2002) took the review of the BSG analysis one step further than Mussatto (2014) by breaking their analysis of BSG into different components such as dried BSG, wet BSG, brewery dried yeast, malt sprouts, and dried spent hops. Their results indicate that BSG can meet a significant proportion of the protein required in livestock diets, but that product variability can influence usefulness.

Mussatto's (2014) research also indicates that the primary use for BDSG as a livestock feed is for dairy cattle, but it has also been fed to pigs, sheep, poultry, and beef cattle. Feeding BDSG to dairy cattle may be challenging for craft brewers and distillers depending on the size of the brewery or distillery. Dairy rations must be consistent to maximize milk production. As such, for smaller quantities it may be more beneficial to feed BDSG to cow-calf or stocker cattle. Mussatto, Dragone, and Roberto (2006) come to some of the same conclusions as in Mussatto (2014) and include results of similar testing regarding nutrient content.

Thomas et al. (2016) discusses nutrient content of wet BSG and considers them a good source of protein for animals. However, they disagree with Westendorf and Wohlt (2002) that wet BSG would be a suitable supplement for both ruminants and non-ruminants because of the high protein and fiber concentrations. Thomas et al. (2016) recommends that feed for mature cows be limited to 30 to 50 pounds of wet BSG per cow per day (7.8-13 pounds of dry matter), and that feed for calves should be limited to nine to 20 pounds of wet BSG per calf (2.3-5.2 pounds dry matter) per day based on the findings of previous nutrient content analyses of wet BSG. It is also recommended that wet BSG be mixed with other dry feedstuffs to reduce total water content in diets.

Preston, Vance, and Cahill (1973) and Crickenberger and Johnson (1982) each conducted studies regarding the use of BSG as a component of livestock feed. Ajanaku, Dawodu, and Siyanbola's (2010) Nigerian study was based on BSG as a feed for rats, but the nutrient analysis of the grains is still beneficial. Preston, Vance, and Cahill (1973) conducted their study in Ohio with 108 steer calves. Calves were fed rations containing: i) no BSG; ii) 25 percent dried BSG; iii) 25 percent dried BSG that contained five percent brewery yeast; and iv) 50 percent dried BSG. The other components of the feed were corn, urea, which was only used in the corn-only feed, and a mineral supplement. The percent corn in the 25 percent BSG ration was 65 percent and the percent corn in the 50 percent BSG ration was 40 percent. The remaining percentage was the mineral supplement.

After being fed for either 188 or 219 days, results indicated that feeding either 25 percent or 50 percent dried BSG significantly increased the rate of gain when compared to cattle that were fed a ration containing 95 percent corn. Preston, Vance, and Cahill (1973) determined that BSG is a valuable feed for cattle and that both feedlot performance and carcass quality were acceptable at either inclusion rates. They hypothesize that the positive results could be due to the elimination of rumen keratosis and liver abscesses in the cattle that were fed dried BSG.

Crickenberger and Johnson's (1982) North Carolina study used wet BSG as a feed source for 36 Angus heifers for a winter feeding trial. Three feeds were used in the trial and were: i) corn silage with no protein supplement; ii) corn silage plus 33.8 percent of the diet dry matter from wet BSG; and iii) wet BSG, corn, and fescue (*Festuca*) hay at 62.2, 26.1, and 10.8 percent of diet dry matter. After being fed for 112 days, the estimated average daily gains for each of the three feeds were 0.50, 0.73, and 0.56 kilograms (1.10, 1.61, and 1.23 pounds) per head. The differences between the first and second feeds were statistically significant at the five percent alpha level. It should be noted that the first feed was designed to be protein-deficient but that the wet BSG was sufficient to overcome the nutrient deficiencies.

Dooley (2008), Trenkle (1998), and Ojowi et al. (1997) each conducted studies regarding utilizing DSG as cattle feed. However, Dooley's (2008) and Trenkle's (1998) analyses were both based on DSG from the production of corn ethanol and Ojowi et al.'s (1997) study compared the use of dried DSG from wheat-based (*Triticum*) ethanol to wet BSG. Widyaratne and Zijlstra (2006) conducted a study regarding the nutritional value of wheat and corn DSG from ethanol production for use in pig feed, but the nutrient analysis of the grains is still useful. No research was discovered on the use of DSG specifically from liquor production.

Dooley's (2008) study focuses on the market potential of DSG from ethanol production as an addition to cattle feed in Indiana. His dried distillers' grains inclusion rates were adapted from Berger and Good (2007) and a 2007 NASS report about current feeding practices of DSG and are summarized in Table 1. He states that the most likely upper bound of dried DSG consumption for all animals in the state of Indiana is 755,600 tons annually. However, 2.9

million tons of dried DSG is produced each year in the state, meaning that most of it will be shipped out-of-state.

Trenkle (1998) conducted a feeding trial at Iowa State University with 940-pound yearling steers that were fed rations with percentages of wet DSG. Wet DSG was used as a replacement for corn and urea on a percentage dry matter basis. The three diets contained: i) zero percent wet DSG; ii) 20 percent of dry matter replaced with wet DSG; and iii) 40 percent of dry matter replaced with wet DSG. It was found that the 20 percent ration increased gains without increasing feed intake and the 40 percent ration decreased feed intake without affecting gains. Trenkle (1998) also tested whether suddenly switching the cattle from wet to dry DSG negatively impacted the cattle and found that switching had no impact assuming intake was managed. Trenkle (1998) concludes that wet DSG has a high energy value when compared to cracked corn.

In contrast, Ojowi et al.'s (1997) study focuses on the use of wheat-based DSG as a feed component for feedlot cattle, where they compared the nutrient value and degradability characteristics of wet DSG to wet BSG. For the feedlot growth and finishing trial, 120 yearling steers were divided into three feed groups, which were a control containing barley concentrate, alfalfa/brome hay, and barley straw; treatment one which contained wet BSG; and treatment two which contained wet DSG. The two treatments were formulated to contain the same energy and protein levels as the control and both contained the barley-based concentrate, hay, and straw. However, these amounts differed according to the nutrient differences in the wet BSG and DSG. Results of the study indicate that the cattle fed with rations containing wet DSG and wet BSG performed at least as well as the cattle fed the control feed and there were no adverse effects on carcass composition. This research indicates that if wet DSG can be provided to feedlots or cattle farmers at a lower cost than traditional feedstocks, it may be beneficial to utilize wet DSG as replacement for a portion of the feed ration.

Literature Review of BDSG Used in Composts

Awopetu, Bakare, and Odeyemi (2015) conducted a study regarding formulating compost from a base of BSG that was collected from International Breweries Limited in Nigeria. Seven compost piles that contained varied quantities of poultry manure, soybean meal, cattle manure, and groundnut (*Arachis hypogaea*) husks were formulated using BSG as the bulk material, with BSG alone being the control. The BSG was air-dried until it reached a moisture content of 60 percent, and once the piles were created they were turned mechanically every four days for the first 35 days of the composting process. Moisture amendment was conducted every eight days throughout the entire 50-day process.

After the composting process was complete, the mature composts were converted to pellets before the effects of the composts were tested on drought-resistant corn and soybeans. Results of the germination for soybeans indicated that all seven of the composts were deemed mature because the mean root and shoot lengths were greater than 90 percent of those in the control, which is soil only (Awopetu, Bakare, and Odeyemi 2015). The mean yield for corn was highest in the BSG, poultry manure, and soybean meal plot (BSGPS), with the mean yields all composts except the BSG and cattle manure (BSGC) and control (BSG) plots being higher than the untreated corn plots. The BSGPS plot also had a higher grain yield than the NPK fertilizer treated plot. Overall, the BSG that was mixed with both poultry manure and soybean meal resulted in the largest plant-yield.

Alternatively, brewery sludge, which is what is left over from the filtering treatment of the effluent coming from the brewery, has also been tested as a compost. While this process may be more involved, it could provide a disposal method for waste that may not be considered a big factor regarding disposal problems. Stocks, Barker, and Guy (2002) conducted a composting trial utilizing brewery sludge as a component in the United Kingdom. This sludge was collected from a treatment plant that was dedicated solely to the treatment of brewery wastewater. However, the practice of composting sludge is not wide spread in Europe, with only 0.5 percent of the total sludge produced being composted (Stocks, Barker, and Guy 2002).

After the sludge was dewatered, it was combined with BSG, shredded office paper and straw to produce a mix of 34 percent by weight dried solids. Temperature was controlled throughout the study and the rise in temperature at the beginning of the composting process indicated that the brewery wastes provide the necessary nutrients to produce an active composting pile. Plant growth trials on tomatoes (*Solanum lycopersicum*) and geraniums (*Pelargonium*) were then conducted using four different growing media where the compost was used as a peat (*Sphagnum*) replacement. The rate of successful germination for geraniums in the brewery compost were similar to the control, but the brewery compost used for tomato germination outperformed the two store-bought peat-based growing media. Further growth results indicated, however, that the younger plants grown in the brewery compost grew less than the ones in the store-bought growing media, but that as the plants got older the brewery compost began to once again out-perform the store-bought media. Stocks, Barker, and Guy (2002) hypothesizes that this may be due to the poorer water retention and high ammonia concentration qualities of the compost, which may make it unsuitable for young plants.

It should be noted that there is little literature regarding the composting of BDSG overall, and virtually none regarding this process in the United States and for DSG specifically. Further research needs to be conducted to determine the nutrient variability in domestically produced BDSG and the willingness of producers to participate in alternative disposal methods of their by-product.

Literature Review of BDSG Used as a Soil Amendment

In contrast to composting, utilizing BDSG as a soil amendment requires less time and storage because it can be applied directly to the soil with little to no further processing. Using BDSG as a soil amendment could save time and money for brewers and distillers who wish to sustainably dispose of their BDSG, but do not have connections to farmers. Instead of being used as a component of an animal feed ration or being composted, both of which would require more time and potentially transportation costs, the BDSG could be used as a soil amendment for landscaping or community gardens as urban agriculture becomes a growing trend in larger metropolitan areas (Palmer 2018). Given the large concentration of small brewers and distillers in urban areas in the state of Tennessee (Figures 1 and 2), this could provide an outlet for brewers and distillers to engage with the community and further market their product.

Nnadi et al. (2013) collected fresh BSG from a commercial brewer in the United Kingdom and added it to untreated, organic soil in different proportions of percent volume-to-volume. Plant growth effects were then collected on plots of leeks (*Allium ampeloprasum*) throughout a 17-week period by measuring leaf lengths of both plants and the stem diameters of the leeks. Results of the study indicate that leeks grown with 40 percent by volume BSG had significantly longer leaves than those in the control, especially in the later stages of growth, but that growth was inhibited somewhat in the earlier stages. They hypothesizes that the growth inhibition could be due to the initial high acidity of the BSG, but that as the BSG degrades the availability of nutrients increases, particularly for nitrogen and phosphorus.

Mbagwu and Ekwealor (1990) conducted a study comparing BSG to complete fertilizer in Nigeria for the purpose of improving productivity of corn for two soil types. The BSG was collected from a disposal site and had been air-dried at room temperature and sieved through a two-millimeter mesh. There was then a control, with no amendment, various levels of BSG application, combined fertilizer and BSG application, and fertilizer application, which were equivalent to the locally recommended rates. Once the soils were mixed with their appropriate applications, they were then incubated at field capacity for three weeks before the corn was planted. Results of the study indicate that a 2.5 percent application rate of BSG outperformed all other treatments regarding plant height and dry-matter yield. However, given the acidity of the BSG, they suggest that liming more acidic soil types would be necessary if BSG is applied. Alternatively, they found that increasing the rates of application for BSG increased the organic matter, aggregate stability, moisture content, and available water capacity for both soil types.

Gagnon and Berrouard (1993), Qian, et al. (2011), and Boydston, Collins, and Vaughn (2008) conducted studies regarding using DSG as soil amendments. Gagnon and Berrouard (1993) used DSG from whiskey production as an organic fertilizer for tomato transplants that were added to a soil that contained one-part compost and three parts peat. The compost was made of cow and chicken (*Gallus gallus domesticus*) manure, peat, and bark that was composted for 18 months. One of 13 organic fertilizers was then applied to the tomato transplants. These fertilizers were blood meal, feather meal, meat meal, crab-shell (*Brachyura*) meal, fish-meal, fish-scale meal, canola (*Brassica napus*) meal, cottonseed meal (*Gossypium*), soybean meal, dried DSG, wheat bran, alfalfa meal, dried whey sludge, and a control that did not contain any organic fertilizer. The fertilizers were analyzed for the nitrogen, phosphorus, and potassium (NPK) content and applied to the compost mixture at a constant rate of 0.67 grams (.024 ounces) of nitrogen. The dried DSG had an NPK of 4.3-0.9-1.1, while the dried whey sludge had an NPK of 5.3-2.5-0.9. The plants were harvested and dried 35 days after planting to compare the shoot dry weights. All fertilizers performed better than the control, which had a shoot dry weight of 10.3 grams (.36 ounces). The dried DSG trial had a shoot dry weight of 14.5 grams (.51 ounces), while the dried whey sludge trial had a shoot dry weight of 18.3 grams (.65 ounces). The highest shoot dry weight was achieved by the crab-shell meal at 18.8 grams (.66 ounces), which was not significantly different at the five percent level from the dried whey sludge.

Boydston, Collins, and Vaughn (2008) and Qian et al. (2011) conducted similar studies, but instead used DSG that was a by-product of ethanol production as opposed to liquor production. Boydston, Collins, and Vaughn (2008) added dried DSG from corn ethanol production at various rates as an amendment to potting soil and applied to the surface. The soil amendment trials were divided into dried DSG and methanol-extracted dried DSG. Results indicated that dried DSG were phytotoxic to transplanted rose (*Rosa*), phlox (*Phlox*), and coreopsis (*Coreopsis*), as well as to seeded annual bluegrass (*Poa annua*) and chickweed (*Stellaria media*) at application rates that were greater than or equal to ten percent by weight.

Qian et al. (2011) used dried DSG that was a product of wheat ethanol production. Dried DSG with solubles and wet DSG without solubles were added so that they had the same rates of nitrogen as urea for comparison. The nitrogen content of the dried DSG with solubles was 6.31 percent and the nitrogen content of the wet DSG was 3.65 percent. In contrast to the overall negative results from Boydston, Collins, and Vaughn's (2008) study, the DSG did not have detrimental effects to plant growth of canola. Canola yield increased as the application rate of dried DSG with solubles increased from 100 to 400 kilograms (220.46 to 881.85 pounds) per hectare, but only the highest rate of 400 kilograms (881.85 pounds) was significantly different from the same urea application at the five percent level. Canola yield also increased as the application rate of wet DSG increased, but none of the trials for which the wet DSG had a higher yield were significantly different from the urea applications. However, it should be noted that Qian et al. (2011) found that germination and emergence of canola seedlings that were planted with a high rate of dried DSG or wet DSG were reduced and appeared to be similar to the appearance of plants affected by excessive fertilizer in the seed row. There is, again, a considerable gap in the literature regarding BDSG as a soil amendment and benefit could be seen by analyzing the variability of BDSG in the state of Tennessee to provide further guidance on its uses.

Literature Review of Similar Surveys and Techniques

Overall, previous survey-based research on the production and disposal of craft breweries and distilleries is limited, with only two relevant studies identified. In Kerby and Vriesekoop's (2017) study of 90 craft breweries in Great Britain using an online survey, respondents were asked to estimate production volume, size of a typical batch, and how they disposed of their BSG. Breweries were categorized as small (producing less than 1,000 liters (264.17 gallons) per batch), medium, producing between 1,000 (264.17 gallons) and 2,000 liters (528.34 gallons) per batch, and large, producing more than 2,000 liters (528.34 gallons) per batch. Breweries were also categorized as either rural or urban, but this method of categorization was not further discussed.

Forty urban (nine small, 19 medium, and 12 large) and 50 rural (10 small, 20 medium, and 20 large) craft breweries participated in the survey. All 40 rural and the 12 large, urban based breweries disposed of their BSG as animal feed. However, the nine small urban breweries disposed of the BSG as compost and fertilizer, with some also opting to use a landfill disposal method in addition to disposing of the BSG as an animal feed.

In regard to cost for disposal, the majority of all breweries incurred no cost for disposal, but no small or medium urban breweries received payment for disposal. However, 25 percent of large urban breweries, ten percent of small rural breweries, five percent of medium rural breweries, and 5.2 percent of large rural breweries did receive payment for the BSG disposal. Alternatively, even though the large urban breweries contained the highest percentage of those who were paid for their BSG, none of them facilitate the disposal, where the costs incurred by the brewery included man hours and fuel to haul the grains. The study's summary of incurred costs is shown in Table 2.

Ben-Hamed (2012) conducted a survey by phone, personal interview, and questionnaire of 84 breweries in the Northeast United Kingdom. These breweries ranged in size of production from 320 liters to 6,400 liters (84.54-1,690.70 gallons) per batch, where they produced between one and five batches per week and one to 10 tons of spent grains per week. 64 percent of all breweries surveyed were considered "small", with sizes ranging from small, medium, and large.

A small brewery was defined as producing up to one ton of BSG per week, a medium brewery produces one to three tons of BSG per week, and a large brewery produces three to 10 tons of BSG per week.

The study had several goals, including determining the economic value of BSG as a soil amendment and cattle feed ration, and the estimation of average transportation cost of BSG. Ben-Hamed (2012) used a linear regression, with small breweries as the base group, to investigate the relationship between the distance between a brewery and a farm and the average transportation cost per ton of wet BSG. The ORWARE Model (ORganic WAste REsearch), which is a tool used for analysis of waste management, was then used to further develop the Spent Grain Costing Model used in the rest of the study.

Results of the study indicate that most of the vehicles used to transport wet BSG had between a one- and six-ton loading capacity and the average distance traveled from the breweries to farms was five miles. Three vehicle classes were used in the estimation and were one-ton, three-tons, and six-tons. The average transport cost per ton of wet BSG was £10.11 ($23.33), £5.20 ($6.86), and £3.27 ($4.31) (GBP/USD 1.31794, XE Corporation 2018), by vehicle class and a distance of five miles. For every additional mile beyond five miles, transportation cost increases by £1.99 ($2.62), £1.31 ($1.73), and £0.45 ($0.59) (GBP/USD 1.31794, XE Corporation 2018) by vehicle class.

Survey Data and Methods

Regarding survey design and implementation, Dillman, Smyth, and Christian (2014) indicate that single-mode surveys are important in many situations but can often lead to inadequate results. In contrast, mixed-mode surveys, where more than one method of contacting survey respondents is used, will likely be more successful than single-mode surveys. However, mixed-mode surveys might be more time consuming in some cases; where, for example, an email survey is first distributed, and a phone survey is used to follow-up on those who did not complete the survey by email.

Dillman, Smyth, and Christian (2014) claim that implementing a mixed-mode survey can actually lower the total cost of survey implementation because researchers can start with the less expensive survey mode, and then move to more expensive modes. This again can be illustrated through a mixed-mode survey that implements both email and phone surveys, where researchers begin with the less time-consuming, and thus cheaper mode of email distribution, before moving to phone surveys, which require more manpower and have a higher cost. Additionally, mixed-mode surveys can reduce coverage error and improve response rates, but attention should be paid to designing the initial questionnaire for the possibility of mixed-mode data collected by, in part, utilizing the same question format and wording across modes (Dillman, Smyth, and Christian 2014).

Thus, two surveys were designed to obtain information from craft breweries and distilleries in Tennessee. Our analysis used a mixed-mode survey method. Email surveys were initially distributed before phone surveys were conducted to try to reach individuals who did not respond to the survey via email. The goals of the surveys were to collect data about characteristics of the craft brewing and distilling industries, estimate the amount of BDSG being produced, determine how craft brewers and distillers dispose of their BDSG, and obtain data regarding the factors that influence their disposal decisions. Copies of the survey instruments are provided in Appendices C and D.

Brewery Survey Data and Methods

A list of craft breweries in Tennessee was obtained from the Tennessee Department of Agriculture, Tennessee Brewers Association, and through an internet search. This yielded 104 craft brewers in the state of Tennessee. The contact list developed included websites, email addresses, phone numbers, and mailing addresses. After removing duplicates of breweries that operated in multiple locations, this number was decreased to 96. Then by removing those that had no available contact information, those not currently in operation, or were operating outside the state of Tennessee, the sample size was decreased to 72.

The brewery survey was initially distributed on October 9, 2018 by email through Qualtrics. A follow up email was sent on October 15, 2018 to those who did not respond to the first request. The email survey yielded 18 responses from breweries. From December 5, 2018 to January 3, 2019, phone surveys were conducted to reach businesses that had not responded to the survey via email. The phone surveys resulted in 16 additional brewery responses. Thus, the total number of breweries that responded to the survey was 34, a response rate of 47 percent.

The brewery survey had five sections:

i. The first section of the survey focused on business characteristics. Respondents were asked to describe their business as either a brewery, brewery with bar, brewery with restaurant and bar, or other (please specify), with the purpose being to further define what operations the business conducts. The respondent was then asked what role they play in the business (marketing, master brewer, owner/investor, or other). Additionally, respondents were asked how many employees their business employs, whether their business offers tours plus the cost of tours, the value of their gross alcoholic beverage sales, how much they expect their sales to increase over the next five years, and what factors may have a negative impact on the growth of their business.
ii. The second section of the survey focuses on the purchase of hops. The respondents were asked whether they purchase Tennessee grown hops, if they would be interested in purchasing Tennessee grown hops in the future, whether they are interested in only purchasing pelletized hops, how many pounds of hops they purchase annually, and which varieties they currently purchase.
iii. In the third section of the survey, grain purchases were the focus. The questions included how many pounds of malt barley, or other grains are purchased annually, how many days of onsite storage were available for grains, and whether the grains were known to be grown in and purchased from Tennessee sources (why or why not). Additionally, brewers were asked whether they have an interest in purchasing barley from a Tennessee malting house and the price premium they would be willing to pay for a local product.
iv. The fourth section focused on production levels of the business's primary product including number of gallons produced annually for the current fiscal year and

previous fiscal year, production in pounds of BSG, and how many batches/gallons per batch were produced per week.

v. The fifth section of the survey focused on BSG disposal. Respondents were asked whether they were aware BSG can be used as a livestock feed and/or source of nutrients for plant production, and how they dispose of their BSG. Additionally, they were asked if processing of BSG occurred on site, was BSG tested for nutrients or moisture, how many days BSG remained at the brewery, how the BSG is marketed to producers, what distance the BSG travels to producers, and whether this transaction provides their business with revenue, costs them money, or breaks even. If respondents indicated they did not dispose of BSG through composting they were asked whether they were aware of a compost facility in their area. Additionally, respondents were asked at what revenue point they would consider disposing of BSG as a livestock feed or compost as opposed to landfilling if their BSG is currently being sent to a landfill and what obstacles they face in disposing of spent grains. Finally, brewers were asked what the largest obstacles were for BSG disposal, and whether they would expect a price premium for using sustainable disposal practices.

Distillery Survey Data and Methods

A list of distilleries in Tennessee was obtained from the Tennessee Department of Agriculture, Tennessee Distillers Guild, and through an internet search. This yielded 34 distillers in the state of Tennessee. Two large distillers, George Dickel's and Jack Daniels, were excluded from the survey, due to their large size (i.e., they are not craft distilleries). This process resulted in 32 craft distilleries. After removing distilleries that had no available contact information, were bringing liquor from outside of Tennessee, and those not currently in operation, the sample size was decreased to 22.

The distillery survey was distributed through Qualtrics on October 9, 2018 with a reminder email sent on October 16, 2018. Seven responses to the distillery survey were received. From December 5, 2018 to January 3, 2019, phone surveys were conducted to reach businesses that had not responded to the survey via email. The phone surveys resulted in nine additional distillery responses. The total number of distilleries that responded was 16, a 73 percent response rate.

The distillery survey had four sections:

i. The first section of the survey focused on business characteristics. Respondents were asked to describe their business as either a distillery, distillery with bar, distillery with restaurant and bar, or other (please specify), with the purpose being to further define what operations the business conducts. The respondent was then asked what role they play in the business (marketing, master distiller, owner/investor, or other). Additionally, respondents were asked how many employees their business employs, whether their business offers tours plus cost of tours, the value of their gross alcoholic beverage sales, how much they expect their sales to increase over the next five years, and what factors may have a negative impact the growth of their business.

ii. In the second section of the survey, grain purchases were the focus. The questions included how many pounds of corn, or other grains are purchased annually, how many days of onsite storage were available for grains, and whether the grains purchased were grown in Tennessee (why or why not).
iii. The third section focused on production levels of the business's primary product including number of gallons produced annually for the current fiscal year and previous fiscal year, production in gallons of DSG, and how many batches/gallons per batch were produced per week.
iv. The fourth section of the survey focused on DSG disposal. Respondents were asked whether they were aware DSG can be used as a livestock feed and/or source of nutrients for plant production, and how they dispose of their DSG. Additionally, they were asked if processing of DSG occurred on site, was DSG tested for nutrients or moisture, how many days DSG remained at the distillery, how the DSG is marketed to producers, what distance the DSG travels to producers, and whether this transaction provides their business with revenue, costs them money, or breaks even. If respondents indicated they did not dispose of DSG through composting they were asked whether they were aware of a compost facility in their area. Additionally, respondents were asked at what revenue point they would consider disposing of DSG as a livestock feed or compost as opposed to landfilling/wastewater if their spent grains are currently being sent to a landfill/wastewater and what obstacles they face in disposing of DSG. To finish the survey, distillers were asked what the largest obstacles were for DSG disposal, and whether they would expect a price premium for using sustainable production practices.

Survey Results

The results of the Qualtrics and phone survey were aggregated to avoid identifying participants in the study. Results are presented for the brewery and distillery surveys separately, with table or figure depictions being displayed in Appendices A or B when appropriate.

Brewery Survey Results

Regarding business description, 37 percent of responses to the question indicated the business was a brewery with restaurant and bar, while 35 percent indicated their business was a brewery with bar, 21 percent indicated their business was a brewery, and seven percent selected "other" (Figure 3). 43 responses were gathered for this question which is larger than the number of survey responses (34), due to the fact that respondents were allowed to select more than one option. "Other" responses included "brewery and farm", "cans of beer available", and "brew pub".

43 percent of respondents indicated that they were master brewer, 35 percent indicated they were the owner/investor, eight percent were responsible for marketing, and 14 percent identified their role within the business as "other" (Figure 4). As with the previous question, 51 responses were recorded due to the fact that respondents were able to select more than one choice. "Other" responses included "owner/brewer", "manager", "head brewer", "general manager", "sales manager", and "assistant brewer/taproom manager". The number of employees

employed by the business's brewing operation ranged from one to 13 (n=34), with a frequency table of responses shown in Figure 5. The average number of employees was 4.1, with the most frequent response, or mode, being two employees. However, the standard deviation of responses was relatively high at 3.2.

In regard to gross alcoholic beverage sales for the last fiscal year, the distribution was relatively consistent across the response categories. The largest proportion of breweries (29 percent of respondents, n = 28) indicated they made between \$100,000 and \$250,000, while 18 percent of respondents selected \$0.00 to \$100,000, \$250,000 to \$500,000, and \$500,000 to \$1,000,000, or greater than \$1,000,000 (Figure 6). Additionally, 53 percent of breweries (n=32) expect their sales to increase by greater than 25 percent over the next five years (Figure 7), with a growth of five to 15 percent being the second most common selection with 28 percent of responses falling into this category. 13 percent of respondents selected less than five percent, and six percent selected 15 to 25 percent. Responses to this question varied significantly more than the previous question, indicating there is significant variation in optimism regarding growth of the business. Calculating the correlation coefficient between gross alcoholic beverage sales and expected increase in sales over the next five years yielded a value of -0.25. This correlation coefficient has a t-value of -1.33 and is not significant at the $p < 0.05$ level. All correlation coefficients should be assumed to be non-significant at the $p < 0.05$ level unless otherwise stated. This value indicates that there is a low, negative correlation between value of gross sales and anticipated sales increase. Thus, optimism regarding growth may be inversely linked to gross sales. In other words, as the gross sales of the company grew, they anticipated the growth of their sales over the next five years to be lower.

55 percent of breweries (n=33) offered tours with tour prices ranging from \$0.00 to \$12.00 and an average of \$3.81 (n=16), which indicates tours may be an additional source of revenue for some Tennessee breweries (Figure 8). The most frequently charged price for a tour was \$0.00, but the sample had a standard deviation of \$4.80. By assigning a value of one to breweries that did not offer tours and a value of two to those that did offer tours, a correlation coefficient was calculated between tours and gross alcoholic beverage sales to determine whether brewery size was a factor in whether or not tours were offered. The correlation coefficient between the two variables was 0.11 ($t = 0.58$), which indicates a low, positive correlation between gross sales and whether tours are offered. This indicates that while the correlation is low, as breweries increase sales, they are slightly more likely to offer tours.

When asked about what economic factors could have a negative impact on their business's growth, respondents indicated through a ranking system (one is most important, seven is least important) that industry saturation was the biggest threat (Table 3, n=31). Industry saturation had an average response value of two, indicating that more respondents selected this option as being "most important". Coming in second were government regulations and profitability, both with average response values of 3.1. Unexpectedly, waste disposal had the lowest level of importance at an average ranking of 5.5, other than the "other" category, which was fill-in-the-blank. "Other" responses included "poor quality, high maintenance equipment companies" and "breweries that don't know what they're doing".

Moving to the hops section of the survey, 47 percent of breweries indicated they would be "very interested" in purchasing Tennessee-grown wet hops (n=30), while 37 percent indicated they would be "very interested" in purchasing Tennessee-grown dry or pelletized hops (Figure

9). It should be noted that dry hops have a longer shelf-life, but require additional costs (drying, pelletizing, and packaging), while wet hops are fresh and need to be used quickly. Additionally, when asked to indicate their level of agreement with the statement "I am only interested in using pelletized hops with one being complete disagreement and five indicating complete agreement", 20 percent (n=30) indicated that they completely agree, while only seven percent completely disagree (Figure 10). The respondents' agreement with this statement is further solidified with their use of wet versus dry hops on an annual basis. The average number of pounds of wet hops being used was 46 pounds (n=29), while the average number of pounds of dry hops was 2,301 (n=27). The number of pounds of wet hops being used ranged from zero to 500, while the number of pounds of dry hops ranged from 100 to 16,500 pounds (Table 4). Regarding the varieties of hops being used by Tennessee craft brewers, the top five varieties of hops being used by frequency of responses were Cascade, Citra, Mosaic, Amarillo, Centennial, Hallertau, Magnum, and Simco, with Amarillo, Centennial, Hallertau, Magnum all tying for fourth place (n=26).

Tennessee brewers used an average of 78,760 pounds of malt barley during the last fiscal year, with a minimum of 1,500 and a maximum of 600,000 pounds (Table 5, n=24). Other types of grains being used included wheat, corn, oats, rye, rice, and buckwheat. 88 percent (Figure 11, n=26) of respondents indicated they do not purchase Tennessee-grown grain, with 48 percent (n=23) indicating lack of available supply as their reason for not purchasing, 22 percent indicating Tennessee grain had a higher price or was too expensive, nine percent indicating insufficient quantity or product consistency, and 22 percent indicating some other reason for not purchasing (Figure 11). Only one respondent indicated what percentage of purchased grain was Tennessee-grown, and it was only five percent.

However, 19 percent of respondents (n = 26) indicated they would pay a 10 to 25 percent price premium for Tennessee-produced malt barley, while 38 percent of respondents indicated they would pay an up to 10 percent price premium for Tennessee-produced malt barley, but 27 percent selected no price premium, and 15 percent selected unsure (Figure 12). Barley must be malted before it is used in beer production so that the starch can be used in the fermentation process ("Malt" 2019). Currently, no commercial malting facilities are located in Tennessee. Four percent of respondents (n = 26) indicated that their business has less than one days use of onsite storage available for grain, while 19 percent selected one to 10 days use, 12 percent selected 11 to 20 days use, 46 percent selected 21 to 30 days use, and 19 percent selected greater than 30 days use (Figure 13).

Regarding the production of beer, the average number of gallons of beer produced by Tennessee brewers in the last fiscal year was 46,580, with a minimum of 900 and a maximum of 384,000 gallons (Table 6, n=19). Their predicted production for the following year averaged 50,425 gallons, with a minimum of 275 and a maximum of 400,000 gallons (Table 6, n=24). This equates to an average increase in predicted production of approximately 8.3 percent. It should be noted that the minimum for the predicted production is lower than the minimum for actual production because response values of zero were not included in the summary statistics for either year.

Spent grain production follows a similar pattern to beer production with Tennessee brewers producing an average of 65,800 pounds of BSG in the last fiscal year, with a minimum of 3,500 and a maximum of 230,000 pounds being produced (Table 7, n=13). The total number of pounds being produced by all respondents during the last fiscal year was 855,400. Predicted production of BSG for the following year averaged 85,382 pounds, with a minimum of 4,200 and a maximum of 320,000 pounds and totaled to 1,451,500 pounds (Table 7, n=17). Calculating the correlation coefficient between gallons of beer produced during the last fiscal year and the pounds of BSG produced during the last fiscal year showed a correlation 0.90. This indicates that there is a high, positive correlation between the number of gallons of beer produced and the number of pounds of BSG produced. This correlation coefficient has a t-value of 7.4 and is significant at the $p < 0.001$ level. Calculating the correlation coefficient for predicted production also yielded a value of 0.90. This correlation coefficient has a t-value of 7.8 and is significant at the $p < 0.001$ level. This both indicates that reporting is consistent across the questions and ensures some level of internal validity within the survey.

It should be noted that because not all breweries responded to the survey, average values for BSG could be higher or lower based on the sizes of the non-responding breweries. Additionally, the total number of pounds of BSG being produced by craft breweries in Tennessee is higher for this same reason. As with the beer production summary statistics, response values of zero were not included in the BSG summary statistics.

When asked to break these numbers down into batch sizes, brewers indicated an average of 2.65 batches being produced per week with a minimum of 0.25 and a maximum of 7 batches (Table 8, n=26). Additionally, the average number of gallons of beer produced per batch was 1,873, with a minimum of 10 and a maximum of 36,000 gallons (Table 8, n=26). BSG produced per batch averaged to 2,720 pounds, with a minimum of 75 and a maximum of 36,000 pounds (Table 8, n=21). Calculating the correlation coefficient between gallons of beer produced per batch and pounds of BSG produced per batch yielded a value of 0.99, indicating that the two value have a very strong, positive correlation. This correlation coefficient has a t-value of 33.0 and is significant at the $p < 0.001$ level. The correlation coefficient in this scenario is slightly higher than in the annual production of beer and BSG question, but still indicates validity within the survey.

Moving to the BSG processing and disposal section of the survey, 100 percent of Tennessee brewers (n=26) indicated they were aware that BSG could be used as a livestock feed, while 96 percent (n=26) indicated they were aware that BSG could be used as a compost or source of nutrients for plant production. Additionally, 96 percent indicated they do not dry or process BSG onsite (n=26) and 100 percent indicated they have not tested the nutrient content of their BSG (n=26).

Regarding the moisture content of the BSG when it exits their facility, seven percent of respondents (n = 15) selected less than 15 percent, seven percent selected 15 to 25 percent, 13 percent selected 25 to 35 percent, seven percent selected 35 to 45 percent, and 67 percent indicated that the moisture content of their BSG is greater than 85 percent when it exits their facility (Figure 14). No responses were recorded for the categories between 45 percent and 85 percent. It should be noted that these values do not necessarily reflect the findings of NASEM (2016), where 3,921 samples of wet BSG were analyzed and the average value for dry matter was found to be 25.96 percent. However, with a standard deviation of 6.24 percent, samples may vary quite significantly. 54 percent (n=26) of respondents also indicated that their BSG spends less than one day at their facility (Figure 15), indicating that BSG is being removed rather rapidly. Due to the high moisture content of BSG, it spoils quickly, so if being used for animal feed it is important that it is used within a reasonably quick time frame. Currently, there is no information on how long BSG remain viable as a livestock feed.

Focusing on the disposal of BSG as a livestock feed, 100 percent of brewers indicated that their BSG is disposed of as a livestock feed (n=26), and 79 percent indicated they are marketing their BSG by giving it away to a predetermined producer or set of producers (Table 9, n=29). It should be noted that respondents were able to select more than one method of marketing. The BSG is travelling an average of 27.69 one-way miles to the livestock producers, with a minimum of 0.2 and a maximum of 60 miles (Figure 16, Table 9 n=25) The most frequent mileage response was 25 miles, and the sample had a standard deviation of approximately 15 miles. Transportation distances and costs are important when utilizing BSG as an animal feed to ensure that the costs are not exceeding the feed value of the grain. This concept is further discussed in the following chapter.

One-way miles traveled were only provided for the given away (to a predetermined producer or set of producers) and given away (first come, first serve) marketing methods by survey respondents (n = 25). By assigning a value of 1 to given away (to a predetermined producer or set of producers) and a value of 2 to given away (first come, first serve), a correlation coefficient was calculated to determine if there was a correlation between marketing method and one-way miles traveled. Results of the test indicated a correlation coefficient of -0.18 (t = -0.9), which illustrates a low, negative relationship. In terms of the marketing methods, this means that lower mileage is associated with the given away (first come, first serve) marketing method. However, this correlation is relatively low.

Additionally, 96 percent of brewers indicate that the transaction of marketing their BSG to livestock producers neither costs their business money nor provides it with revenue (Table 9, n=25). However, one respondent indicated that this transaction provides revenue of $100 per week. This respondent indicated in a previous question that their brewery makes 3.5 batches per week, with a production of 450 pounds of spent grains per batch. This totals to 1,575 pounds of spent grains produced per week. At a rate of $100 per week, the spent grains can be assumed to be sold at a rate of $15.75 per pound.

Regarding the disposal of BSG as a source of plant nutrients, only 15 percent of brewers indicated that they dispose of their BSG as a compost, soil amendment, or fertilizer (n=26) and 86 percent were unaware of a compost facility in their area (Table 10, n=22). Of those that are marketing their BSG as a compost, soil amendment, or fertilizer 50 percent are giving them away to a predetermined producer or set of producers, while 33 percent indicated they are marketing them to producers on a first come, first serve basis (Table 10, n=6). As with the livestock feed questions, brewers were allowed to select more than one option for the marketing question.

Similar to the distance travelled to livestock producers, BSG travelled an average of 25.60 one-way miles to the producer, with a minimum of one and a maximum of 52 miles (Figure 17, Table 10, n=5). Because there were only five responses to this question, and the responses were all different, there was no mode for the sample, but the standard deviation of the sample was 21 miles. Of the four respondents who indicated whether there was a transaction cost associated with disposing of their BSG as a compost, soil amendment or fertilizer, 75 percent indicated this transaction neither costs their business money nor provides it with revenue (Table 10, n=4). However, the one respondent that indicated that the transaction provides their business with revenue was not sure how much revenue it was providing.

When asked to describe how they dispose of their spent grains, 22 of the 26 respondents indicated that between 91 and 100 percent of their BSG was disposed of as a livestock feed. Additionally, only one of the 26 responding breweries used a landfill to dispose of their BSG, and only two percent of their total BSG production was disposed of in this manner (Figure 18). However, when asked to estimate the percent price premium they would expect from marketing beer as using sustainable production practices, such as non-land fill disposal of BSG, 64 percent (n=25) said they would expect to see no change in prices (Figure 19).

When asked about the biggest obstacles they face in regard to BSG disposal, respondents (n=20) indicated through a ranking system, where one was considered most important and six was considered least important, that on-site drying and processing was the biggest obstacle (Table 11). Unlike the previous ranking question regarding economic growth, the answers to this question were not as skewed, with onsite drying and processing having an average ranking value of 3.12, quantity produced having a value of 3.22, and market access/no contacts having a value of 3.32. Three respondents indicated in the comments that there are no obstacles at all to disposing of BSG, which could explain why there is little polarity in the results. “Other” obstacles listed by respondents included government regulations and storage.

Implications of Brewery Survey Results

Responses from this survey help accomplish the objective of determining the quantity of BSG being produced in Tennessee. With a response rate of 47 percent, it is fairly representative of the population. Unexpectedly, results indicate that most breweries are disposing of their BSG as a livestock feed, with 100 percent of this sample disposing of at least a portion of their BSG in this manner. However, very few selected composting, soil amendments, and fertilizers as a disposal method. These disposal results in particular indicate that further research regarding BSG as a livestock feed in Tennessee may be more useful than research on BSG as a compost, soil amendment, or fertilizer. There were several larger Tennessee craft breweries that did not respond to the survey, which means that average BSG production numbers could be larger than indicated by survey results. Using the average annual production of BSG in survey responses total production of BSG in Tennessee is estimated at 6,843,200 pounds (average annual production (65,800 pounds) multiplied by number of breweries (104)), but this assumes that the sample is representative of the population.

Distillery Survey Results

Regarding business description, 48 percent of total responses to the question indicated the business was a distillery, while 26 percent indicated their business was a distillery with bar, nine percent indicated their business was a distillery with restaurant and bar, and 17 percent selected “other” (Figure 20). However, 23 responses were gathered for this question which is larger than the number of survey responses (16), due to the fact that respondents were allowed to select more than one option. “Other” responses included “tastings”, “gift shop, tours and events” and “retail”.

Additionally, 48 percent of respondents indicated that they were master distiller, 30 percent indicated they were the owner/investor, 13 percent were responsible for marketing, and nine percent identified their role within the business as “other” (Figure 21). As with the previous question, 23 responses were recorded due to the fact that respondents were able to select more than one choice. “Other” responses included “general manager” and “wearing all hats”. The number of employees ranged from two to 30, with the full distribution of responses located in Figure 22. The average number of employees was 8.8, with the most frequent response, or mode, being three employees. However, the standard deviation of responses was relatively high at 8.6 employees.

In regard to gross alcoholic beverage sales for the last fiscal year, the largest proportion of respondents (33 percent, n = 9) distilleries indicated they made between $0.00 and $100,000, while 22 percent of respondents selected $250,000 to $500,000 and greater than $1,000,000. 11 percent indicated that their business had gross alcoholic beverage sales in the last fiscal year of $100,000 to $250,000 and $500,000 to $1,000,000 (Figure 23). Unlike the brewery survey, it appeared that respondents to this survey were more hesitant to answer financial questions, evidenced by the low response rate to the question. More survey respondents were willing to answer a question regarding the anticipated growth of their business, with 38 percent of distilleries (n=16) expecting their sales to increase by greater than 25 percent over the next five years. However, answers to this question varied significantly (Figure 24). Calculating the correlation coefficient between gross sales and anticipated growth yielded a value of 0.11 ($t = 0.3$). All correlation coefficients should be assumed to be non-significant at the $p < 0.05$ level unless otherwise stated. This indicates that there is a very small, but positive correlation between alcoholic beverage sales and anticipated growth of the company. This is in contrast to the brewery survey, which saw a correlation coefficient of -0.25. 94 percent of distilleries (n=16) offered tours with tour prices ranging from $0.00 to $12.00 and an average of $5.43 (n=14) (Figure 25), which indicates tours may be an additional source of revenue for some Tennessee distilleries. The most frequently charged price for tours was $0.00, but the standard deviation of the sample was $4.80. Because all of the distilleries who answered the question pertaining to gross alcoholic beverage sales indicated that they offer tours, a correlation coefficient could not be calculated. However, calculating a correlation coefficient between the price charged for tours and the gross alcoholic beverage sales yielded a value of -0.66 ($t = -2.3$). This indicates that as gross alcoholic beverage sales increase, the price for tours decreases.

When asked about what economic factors could have a negative impact on their business’s growth, respondents indicated through a ranking system (one is most important, seven is least important) that government regulations were the biggest threat (Table 12, n=15). Government regulations had an average response value of 2.6, indicating that more respondents selected this option as being “most important”. However, industry saturation came in a very close second place with an average response value of 2.7. As with the brewery survey, waste disposal was again the lowest ranked category, other than the “other” category, with an average response value of 5.1.

Tennessee distillers used an average of 89,009 pounds of corn during the past fiscal year, with a minimum of 7,500 and a maximum of 208,000 pounds (Table 13, n=11). Other types of grains being used included malted barley, rye, and wheat. Additionally, 64 percent (n=14) of respondents indicated that they purchased Tennessee-grown grains, while 29 percent indicated they do not purchase Tennessee grown grains, and seven percent were unsure. Of those that purchase Tennessee-grown grain, 63 percent indicated that 100 percent of their purchased grain is Tennessee-grown (Figure 26, n=8). By comparing pounds of grain purchased to the percentage of purchased grain that is Tennessee-grown, it is found that those eight distilleries are purchasing

512,750 pounds of Tennessee-grown grains. Additionally, 54 percent (n=13) of distillers indicated they have onsite grain storage available for one to ten days' use (Figure 27).

Regarding the production of whiskey, the average number of gallons of whiskey produced by Tennessee distillers in the past fiscal year was 16,624, with a minimum of 2,500 and a maximum of 78,000 gallons (n=10). Their predicted production for the following year averaged 31,948 gallons, with a minimum of 3,250 and a maximum of 156,000 gallons (n=7) (Table 14). Other liquors being produced included moonshine, gin, vodka, and rum, (Table 14). Comparing the two averages, this indicates that distillers are expecting whiskey production to increase by approximately 92 percent over the course of the year.

Spent grain production follows a similar pattern to liquor production with Tennessee distillers producing an average of 51,808 gallons of DSG in the past fiscal year, with a minimum of 1,248 and a maximum of 200,160 gallons being produced (Table 15, n=7). Assuming one gallon of DSG is equal to 8.3 pounds (Moorehead 2018), this equates to an average of 430,009 pounds, with a minimum of 10,358 and a maximum of 1,661,328. Predicted production of DSG for the following year averaged 78,620 gallons (652,548 pounds), with a minimum of 1,622 (13,463 pounds) and a maximum of 270,720 gallons (2,246,976 pounds) (Table 15, n=7). Total DSG production from this sample of distillers during the last fiscal year totaled 362,658 gallons (3,010,061 pounds), and predicted production for the next fiscal year totals 550,342 gallons (4,567,839 pounds) (Table 15).

Calculating the correlation coefficient between gallons of whiskey produced and gallons of DSG produced during the most recent fiscal year yield a value of 0.42 ($t = 1.0$). Similarly, the correlation coefficient was 0.48 ($t = 1.2$) for predicted production for the next fiscal year. This indicates a moderate correlation between gallons of whiskey produced and gallons of DSG produced. This is dissimilar to the correlation coefficient that was calculated for the same question in the brewery survey, which saw a very high, positive correlation between gallons of beer produced and pounds of DSG produced. This could indicate a problem with how the survey question was interpreted/quantified or be partially explained by the fact that distillers were more likely to produce multiple types of liquor.

Distillers indicated an average of 2.88 batches being produced per week with a minimum of 0.50 and a maximum of 6 batches (Table 16, n=13). Additionally, the average number of gallons of liquor produced per batch was 215.83, with a minimum of 30 and a maximum of 1,000 gallons (Table 16, n=12). DSG produced per batch averaged to 506.36 gallons, with a minimum of 35 and a maximum of 1,590 gallons (Table 16, n=11). Calculating the correlation coefficient between gallons of whiskey/spirits per batch and gallons of DSG per batch yielded a value of 0.16 ($t = 0.5$), indicating a small, but positive correlation between the two variables. This is even lower than the correlation coefficient calculated for gallons of whiskey and DSG produced during the most recent fiscal year. This is again starkly different than the value calculated for the same question in the brewery survey and is further evidence of possible internal validity problems regarding the spent grain production questions in the distillery survey.

Moving to the DSG processing and disposal section of the survey, 100 percent of Tennessee distillers (n=12) indicated they were aware that DSG could be used as a livestock feed, while 92 percent (n=12) indicated they were aware that DSG could be used as a compost or source of nutrients for plant production. Additionally, 92 percent indicated they do not dry or process DSG onsite (n=12) and 100 percent indicated they have not tested the nutrient content of their DSG (n=12). Further, 71 percent (n=7) indicated that the moisture content of their DSG is greater than 85 percent when it exits their facility (Figure 28) and 33 percent (n=12) indicated that the DSG spends one or two days at their facility (Figure 29). It should be noted that it is unlikely that any DSG would have a moisture content of less than 85 percent when exiting the facility if the spent grains had not been dried or further processed. DSG will typically have a moisture content level of around 91 percent (Moorehead 2018). This could simply indicate that some respondents to the moisture content question are actually unaware of the moisture content of their DSG.

Focusing on the disposal of DSG as a livestock feed, 83 percent of distillers indicated that their DSG is disposed of as a livestock feed (Table 17, n=12), and 73 percent of responses indicate that they are marketing their DSG by giving them away to a predetermined producer or set of producers (Table 17, n=11). It should be noted that respondents were able to select more than one method of marketing for the previously mentioned question. The DSG is travelling an average of 21.09 one-way miles to the livestock producers, with a minimum of one and a maximum of 50 miles (Figure 30, Table 17, n=11). The most frequently reported mileage, or mode, was 10 miles. However, the standard deviation of the sample was relatively large at 15.6 miles. 90 percent of distillers also indicate that this transaction neither costs their business money nor provides it with revenue (Table 17, n=10).

To compare the correlation coefficients between one-way miles traveled and disposal methods between the brewery and distillery surveys, miles traveled for the given away (to a predetermined producer or set of producers) and given away (first come, first serve) marketing methods by distillery survey respondents (n = 10) are compared. Mileage was only provided for one other marketing method in the distillery survey. By again assigning a value of 1 to given away (to a predetermined producer or set of producers) and a value of 2 to given away (first come, first serve), a correlation coefficient was calculated to determine if there is a correlation between marketing method and one-way miles traveled. Results of the test indicated a correlation coefficient of 0.60 (t = 2.1), which illustrates a moderate, positive relationship. In terms of the marketing methods, this means that higher mileage is associated with the given away (first come, first serve) marketing method. This is in contrast to the brewery survey, which saw a low, negative correlation for the same test.

Regarding the disposal of DSG as a source of plant nutrients, only eight percent of distillers indicated that they dispose of their DSG as a compost, soil amendment, or fertilizer (Table 18, n=12) and 73 percent were unaware of a compost facility in their area (Table 18, n=11). 100 percent are marketing their DSG as a source of plant nutrients by giving them away to a predetermined producer or set of producers (Table 18, n=1). DSG travels 15 one-way miles to the producer using them for the purposes of providing nutrients to plants (Table 18, n=1). Additionally, this transaction neither cost their business money nor provided it with revenue (Table 18, n=1).

When asked to describe how they dispose of their DSG, 10 of the 11 respondents indicated that between 91 and 100 percent of their DSG was disposed of as a livestock feed. Additionally, only one of the 11 responding distilleries used a landfill to dispose of their DSG, but 100 percent of their total DSG production was disposed of in this manner (Figure 31). However, when asked to estimate the percent price premium they would expect from marketing beer as using sustainable production practices, such as non-land fill disposal of DSG, 50 percent (n=12) said they would expect to see no change in prices (Figure 32).

When asked about the biggest obstacles they face in regard to DSG disposal, respondents (n=12) indicated through a ranking system (one is most important, six is least important) that market access/no contacts was the biggest obstacle (Table 19). Market access/no contacts had an average value of 2.6. However, on-site drying and processing and quantity produced, both came in close second with average ranking value of 2.8. Considering the moisture content of DSG is approximately 91 percent (Moorehead 2018), it makes sense that drying and processing is one of the biggest obstacles faced regarding DSG disposal. It should be noted that responses seemed to be relatively consistent across categories, with averages ranging from 2.6 to 3.6. Limited access to capital was the least important category other than the "other" fill-in-the-blank category. "Other" obstacles listed by respondents included government regulations and owning farmland.

Implications of Distillery Survey Results

Responses from this survey help accomplish the objective of determining the quantity of DSG being produced in Tennessee. With a response rate of 73 percent, it is representative of the population in regard to size. As with the brewery survey, results indicate that most distilleries are disposing of their DSG as a livestock feed, with 83 percent of this sample disposing of at least a portion of their DSG in this manner. Very few are selecting composting, soil amendments, and fertilizers as a disposal method. These disposal results in particular indicate that further research regarding DSG as a livestock feed may be more useful in Tennessee. This disposal method is likely due to a vibrant well distributed cattle industry in the state, thus making it easier for distilleries to dispose of DSG as a cattle feed than other locations. There are two large distilleries (non-craft) in the state of Tennessee, Jack Daniels and George Dickel's, and both dispose of DSG as cattle feed. In both circumstances extensive cattle operations have been developed around the distilleries due to the low cost of obtaining DSG. The craft distilling industry has lower volumes of production but can draw upon the expertise of the larger distilleries in the state. Using the average annual production of DSG in survey responses total production of DSG in Tennessee is estimated at 14,620,306 pounds (average annual production (430,009 pounds) multiplied by number of distilleries (34)), but this assumes that the sample is representative of the population.

Unlike the brewery survey, a larger proportion of respondents in this survey were not receptive to answering some of the financial questions in the survey. As indicated by the calculated correlation coefficients, there seems to be discrepancies between the amount of primary product reportedly being produced and the amount of DSG reportedly being produced. As such, more caution should be taken when interpreting the results of the distillery survey.

Summary of Survey of Tennessee Brewers and Distillers

35 percent of the 96 identified breweries and 47 percent of the 34 identified distilleries in Tennessee participated in the p survey either through email or phone. Of those that responded, the vast majority indicated that their business is already disposing of BDSG as a livestock feed to a predetermined set of producers and that this transaction does not cost their business money. Additional investigation into the potential value of BDSGs as a livestock feed and transportation costs/logistics is warranted. Due to supply constraints, quantities (as a percent of total ration) of

BDSG may be a limiting factor. In the next chapter, sustainable methods of BDSG disposal are discussed and information gathered from the survey is utilized to determine the potential amount of BDSG incorporated into a feed ration for cow-calf operations using a linear programming model. Other information gathered from the survey will be used to help determine market boundaries for BDSG disposal as a livestock feed in Tennessee, however this is not included in this thesis.

CHAPTER III: USE OF BDSG AS A LIVESTOCK FEED COMPONENT

Abstract

A linear programming model was developed to estimate a least-cost winter-feed ration using BDSG for lactating beef cows on fall, spring, and year-round calving schedules. The winter-feeding period was defined as November through March, where purchased hay was assumed to be the primary feedstock. BDSG was assumed to be added to the feed ration to reduce feeding costs. Alternative by-product feedstocks were included in the linear programing model to meet dietary needs of the lactating cows and included corn gluten feed, cottonseed meal, soybean (*Glycine max*) hulls, and soybean meal (high protein) in addition to either BSG or DSG. Five-year average prices from the USDA Agricultural Marketing Service were used as prices for the by-product feeds in the model. BDSG prices were listed as $0.00 in all scenarios based on the 2018 Tennessee Craft Brewers and Distillers survey results discussed in Chapter II. Nutrient requirements for the lactating beef cows are from National Academies of Sciences, Engineering, and Medicine (NASEM) (2016). Results indicated that increasing the portion of BDSG in the ration to around 30 percent of the total dry matter by weight decreases the total winter-feed costs by approximately 30 percent in all calving scenarios. Feeding BDSG at the average daily production rate for surveyed breweries and distilleries decreases winter feed costs by about 11 percent for BSG and 20 percent for DSG across scenarios.

Introduction

This chapter begins with a review of linear programming models to develop least cost feed rations for different classes of beef cattle. Following the literature review, the results of the BDSG nutrient content analyses are presented and survey results used in the linear programing model are stated. Next, the linear programming model and results are discussed. The results of this chapter will accomplish the third objective of the study. The study objectives are:

i. Determine the quantity of BDSG being produced in Tennessee by craft breweries and distilleries;
ii. Determine current BDSG disposal practices; and
iii. Determine the cost-savings for farmers resulting from BDSG disposal by breweries and distilleries as a livestock feed.

The chapter is concluded with a summary and implications for cattle producers and craft breweries and distilleries.

Literature Review of Feed Ration Analysis Through Linear Programming

The potential use of BDSG as an animal feed has been well established. To determine the price point at which it would be advantageous to use BSG and DSG in cow-calf production, linear programming models are used to determine least cost livestock feed rations. By minimizing total feed costs while meeting minimum nutrient requirements for the livestock, we can determine when it would be cost effective to include BSG and DSG in a feed ration.

Nabasirye, et al. (2011) created a linear programming model that seeks to minimize the total cost of a feed ration. The article illustrates a general model that is an example of how feed ration linear programming models should be constructed. The model minimizes the sum of the cost of each ingredient times the quantity of each ingredient, subject to the constraint of meeting the nutrient requirements of the animal. Under this linear programming model, prices, nutrient composition, and nutrient requirements are fixed, meaning that the sensitivity analysis for the model is an important component in determining how sensitive the optimal answer is to changes in key assumptions (Nabasirye, et al. 2011).

More specifically, Tozer (2000) and Rotaru et al. (2017) created least-cost ration formulations using linear programming for Holstein dairy heifers and lactating cows. Rotaru et al. (2017) placed constraints on the model regarding dry matter, nutritional units, digestible protein, calcium, phosphorus, carotene, and salt. Fodder resources were Lucerne hay, corn silage, beets, and wheat bran, where the nutrients provided by each and their respective costs were used as the coefficients for the model. Each nutrient had a minimum and maximum weight requirement with the total ration being no more than 40 kilograms (88.18 pounds). The linear programming model was run twice by maximizing income and then again by minimizing costs. While the two simulations resulted in different solutions, both provided optimal solutions based on the specified constraints of the model.

Tozer (2000) created four linear programming models to formulate rations for large breed replacement dairy heifers in 11 different weight classes. A base model was used, and then three additional models were developed to account for variability in the crude protein content of the ration ingredients, which included 20 different formulations. These formulations included four types of hay, five types of silage, five energy feeds, such as high moisture ear corn, and five protein feeds, which included dried distillers' grains. Variability was addressed by introducing a safety margin to the model, making right-hand side adjustments, and using stochastic programming. Results indicate that the linear programming model had the smallest total feed cost, while the stochastic programming, right-hand side adjustment, and safety margin models had greater costs in that particular order. However, this was to be expected given that these models account for the variability in crude protein, while the linear programming model assumes that the ingredients of the ration contain the average amount of crude protein found in the samples (Tozer 2000).

Jernej et al. (2013) conducted a study to optimize the feed rations for sport horses (*Equus caballus*) using both a linear programming model and two weighted-goal programming models. The input data for both models were the same with the exception of the fact that the costs calculated in the linear programming model were then used in the weighted-goal programming models, with the goals being to meet various nutrient requirements such as dry matter or metabolizable protein, or to minimize costs. Feeds used in this study included hay, grass silage, grain maize, barley, oats (*Avena sativa*), wheat, and Endurix Cavalor (a commercial horse feed).

Prisenk et al. (2013) took a similar approach, creating a linear programming model and two additional weighted-goal programming models also for the purpose of optimizing feed rations for sport horses. Feeds used in this study were the same as those used in Jernej et al.'s (2013) study. Both articles came to similar conclusions, in which the linear programming model was cheaper than at least one of the goal programming models, but that the feed rations created by the weighted-goal programming models were more stable.

BDSG Sample Analysis

Samples of BDSG were collected and analyzed by the Cumberland Valley Analytical Services to determine nutrient content. Bags and containers were distributed to brewers and distillers with instructions regarding how to gather and store samples before they were then collected by researchers to ensure uniformity in collection procedures. A copy of the sampling procedure instruction sheet that was distributed to the businesses is attached in Appendix E. Four BSG samples were collected from two breweries and were sent for analysis by Cumberland Valley Analytical Services. Results of the nutrient content analysis were used in the linear programming model. Nutrient values for DSG used in the linear programming model were provided by Moorehead (2018).

BDSG Sample Analysis Results

Results of the sample analyses have been aggregated to avoid identifying participants in the study. A summary of results for dry matter (DM), total digestible nutrients (TDN), net energy for maintenance (NEm), net energy for gain (NEg), and crude protein (CP) for BSG is provided in Table 20.

Least-Cost Feed Ration Linear Programming Data and Methods

Data requirements for the livestock feed ration linear programming model included: i) the nutritional requirements for lactating beef cattle on spring, fall, and year-round calving schedules; ii) the nutritional content of BSG and DSG samples; iii) the nutritional content of comparable feeds utilized in Tennessee; and iv) the average prices of those comparable feeds. A least-cost ration linear programming model was utilized to determine a value for BDSG as a feedstock when compared to other readily available feedstocks for the winter feeding season, defined as November through March (Smith 2019). Only winter feeding costs are calculated as hay (assumed to be purchased in this scenario) is the primary feed source during this time period, whereas pasture is the primary feeding source in all other months.

Results from the survey indicate that the majority of breweries and distilleries do not charge farmers who use their BDSG as a livestock feed component. Thus, BSG and DSG will be initially priced at $0.00 in the linear programming model. Additionally, average production of BSG from the survey is 65,800 pounds and average production of DSG is 430,009. This equates to an average daily production of 180.3 pounds of BSG and 1,178.1 pounds of DSG. To illustrate a per head upper bound constraint for BDSG consumption, herd size is assumed to be 25 head based on the recommendation from an industry expert (Smith 2019) that indicated this is a typical herd size for a part-time operation in Tennessee. This brings the average daily per head production of BSG to 7.2 pounds and the average daily per head production of DSG to 47.1 pounds, which will be used as upper bounds in the linear programming model.

To derive demand curves for BDSG, the same starting price of $0.00 is used in the model. However, the upper bound of BDSG will be adjusted to a value equal to approximately 30 percent of weight of the daily feed ration on a dry matter basis. This is the same as the upper bound limit for by-product feeds as suggested by Smith (2019). This equates to 25.2 pounds of BSG and 83.5 pounds of DSG. From there, allowable increases in price are used from the sensitivity reports to derive demand curves.

Nutritional Requirements of Lactating Beef Cows

Constraints in the least-cost feed ration were, in part, based on the nutrient requirements of lactating beef cows in a cow-calf operation. The daily nutrient requirements of a 1,200-pound shrunk body weight mature lactating beef cow at approximately 20 pounds of peak milk production per day (NASEM 2016) are provided in Table 21. Spring, fall, and year-round calving seasons are the three different scenarios analyzed with the linear programming model (Table 22).

Nutritional Content and Prices of BDSG and Other Feed Components

Data collected from the BDSG sample analysis were used in the livestock feed linear programming model to provide comparisons between BSG and DSG as feed ration components to other readily available by-product feeds. BSG and DSG are separated in the linear programming model due to the physical properties of the by-product. Other components of the ration include fescue hay, corn gluten feed, cottonseed meal, soybean hulls, and soybean meal (high protein). Summaries of the nutrient contents of all feedstocks are displayed in Table 23. Additionally, the estimated prices of the feedstocks are in Table 24. It should be noted that the prices assumed in the model for BSG and DSG are $0.00 based on the findings of the survey, which indicate that the majority of breweries and distilleries do not charge farmers for their BDSG. All prices are assumed to be at the point of purchase and do not include transportation costs.

Least-Cost Feed Ration Linear Programming Formulation

A daily per-cow least-cost ration was formed by utilizing linear programming techniques, where previously described nutrient contents of various feedstocks common to Tennessee are used to meet the daily nutrient requirements (Table 21) of a 1,200-pound lactating beef cow on three calving schedules (Table 22). Additionally, upper bound constraints were placed on the maximum number of pounds of feed that could be fed to each cow per day and the maximum level of contribution to total DM that the by-product feedstocks could provide to the daily ration (Smith 2019). The winter feeding season (November to March) and upper bound constraints (weight in dry matter pounds of the ration and a maximum 30 percent of total ration to be composed of by-product feedstocks on a dry matter basis) are based on recommendations by an extension beef cattle specialist at the University of Tennessee Institute of Agriculture (Smith 2019).

Upper bound constraints were imposed for BDSG inclusion in the daily feed ration due to supply constraints as indicated by the surveys discussed in Chapter II. Average production values of BSG (65,800 pounds) and DSG (430,006 pounds) from the survey are used as upper bound constraints., Through methods described previously, this equates 7.2 pounds of BSG available per head per day and 47.1 pounds of DSG available per head per day.

In the feed ration model, the feedstocks are represented by i =1 to 7 and the animal category and production phase are represented by j =1 to 15. The least-cost feed ration (Equation 1) was estimated for each animal category multiple times, once with BSG being included, once with DSG being included, and once with neither included (base). It was assumed that farmers would not have the infrastructure to feed both BSG and DSG in the same ration. This assumption was due to the increased costs and infrastructure requirements of the feeds, which could include specialized feed troughs, trucking equipment, and likelihood of proximity to both a brewer and distiller.

(1) $$Minimize\ C_{ij} = \sum_{i=1}^{7} Q_{ij} P_i$$

Subject to:

i. $Q_{ij} \geq 0$ (non-negativity)

ii. $\sum_{i=1}^{7} Q_{ij}X_{ij} \geq D_j$ (DMI requirement; NASEM 2016)

iii. $\sum_{i=1}^{7} Q_{ij}X_{ij}Y_{ij} \geq T_j$ (TDN requirement; NASEM 2016)

iv. $\sum_{i=1}^{7} Q_{ij}Z_{ij} \geq N_j$ (NE requirement; NASEM 2016)

v. $\sum_{i=1}^{7} Q_{ij}X_{ij}U_{ij} \geq E_j$ (CP requirement; NASEM 2016)

vi. $\sum_{i=1}^{7} Q_{ij}X_{ij}A_{ij} \geq M_j$ (MP requirement; NASEM 2016)

vii. $Q_6 \leq 7.2$ (BSG upper limit; survey results)

viii. $Q_7 \leq 47.1$ (DSG upper limit; survey results)

ix. $\frac{\sum_{i}^{7} Q_{ij}X_{ij}}{W_j} \leq 2.5\%$ (Constrains weight of total feed to ≤ 2.5% of the animal's body weight; Smith 2019)

x. $\left(\frac{\sum_{i=2}^{7} Q_{ij}X_{ij}}{\sum_{i=1}^{7} Q_{ij}X_{ij}}\right) \leq 30\% \ \forall\, j$ (Constrains by-product feeds to ≤ 30% of total ration; Smith 2019)

The variables are defined as:

Feedstocks (*i* = 1 to 7):
1 = Fescue Hay
2 = Corn Gluten Feed
3 = Cottonseed Meal
4 = Soybean Meal (high protein)
5 = Soybean Hulls
6 = BSG
7 = DSG

Animal Production Phases (*j*=1 to 15):
1 = Spring Calving Lactating Beef Cow in Production Phase: November
2 = Spring Calving Lactating Beef Cow in Production Phase: December
3 = Spring Calving Lactating Beef Cow in Production Phase: January
4 = Spring Calving Lactating Beef Cow in Production Phase: February
5 = Spring Calving Lactating Beef Cow in Production Phase: March
6 = Fall Calving Lactating Beef Cow in Production Phase: November
7 = Fall Calving Lactating Beef Cow in Production Phase: December
8 = Fall Calving Lactating Beef Cow in Production Phase: January
9 = Fall Calving Lactating Beef Cow in Production Phase: February
10 = Fall Calving Lactating Beef Cow in Production Phase: March
11 = Year-Round Calving Lactating Beef Cow in Production Phase: November
12 = Year-Round Calving Lactating Beef Cow in Production Phase: December
13 = Year-Round Calving Lactating Beef Cow in Production Phase: January
14 = Year-Round Calving Lactating Beef Cow in Production Phase: February
15 = Year-Round Calving Lactating Beef Cow in Production Phase: March

Quantity, Price, and Cost:
C_{ij} = Cost per cow per day of the feedstock *i* for animal in production phase *j*
Q_{ij} = Quantity in pounds of chosen feedstock *i* for animal in production phase j
P_i = Price in dollars per pound of feedstock *i*
X_i = Percent DM of feedstock *i*
Y_i = TDN provided in pounds by feedstock *i*
Zi = Total NE provided in Mcals./pound by feedstock *i*
U_i = Total CP in pounds provided by feedstock *i*
A_i = Total MP in pounds provided by feedstock *i*
W_j = Weight of animal in production phase *j*

Constraints:
D_j = DMI requirement in pounds/day for animal in production phase *j*
T_j = TDN requirement in pounds/day for animal in production phase *j*
N_j = NE requirement in Mcals./day for animal in production phase *j*
E_j = CP requirement in pounds/day for animal in production phase *j*
M_j = MP requirement in pounds/day for animal in production phase *j*

Derived Demand Curves for BDSG

To illustrate how quantity demanded of BDSG changes as price changes, the allowable increases from the sensitivity report of the linear programming model are utilized. Instead of running the model with the average daily per head supply of BDSG, weight values that are approximately equal to 30 percent of the feed ration on a dry matter basis are used as the starting point for the analysis. This is done because including by-product feeds at a rate of greater than 30 percent on a dry matter basis can cause harm to the animal (Smith 2019). Because the inclusion of BDSG at a rate of greater than 30 percent on a dry matter basis is not recommended, it is not included in the analysis. Thus, the upper limit (30 percent of the ration) of BSG is 25.2 pounds and 83.5 pounds of DSG, as opposed to the average daily per head supply rate used in Equation 1. Price is again assumed to be \$0.00. From there, the allowable increases are used as proxies for price to determine how quantity demanded changes as price changes.

Cost Savings for an Entire Herd

To illustrate cost savings for a herd over the course of the entire winter-feeding season, the previously described herd size of 25 head is used. Daily costs for the herd are aggregated by month into a winter-feeding cost, and changes from the base scenario are illustrated for each calving season.

Least-Cost Feed Ration Results

The per cow per day results of the least-cost feed ration linear programming model are discussed for each of the spring, fall, and year-round calving schedules. First, per cow, per day costs are described for the base scenario (no BDSG inclusion), and then per cow, per day costs are described for the inclusion of average daily supply of BDSG (BSG = 7.2 pounds, DSG = 47.1 pounds). Next, demand curves are constructed for BSG and DSG beginning at an initial supply rate that is equal to approximately 30 percent of the daily feed on a dry matter basis which is 25.2 pounds of BSG and 83.5 pounds of DSG. Tables and figures displaying results are located in Appendices A and B.

Per Cow Per Day Results for Spring Calving Schedule

For the base model, which included no BDSG, only hay was included in the ration for the entire winter-feeding season, which was defined as November through March. Cost per head per day ranged from $1.12 to $1.17 (Table 25). Between 27 and 30 pounds of hay are consumed per cow, per day in months November through March, with reduced costs being zero for hay. Reduced costs are lowest for corn gluten feed, the second cheapest feed after soybean hulls, at $0.014 per cow per day, and highest for soybean meal, the most expensive feed, at $0.135 per cow per day (Table 26). In each month of the spring calving base scenario, the minimum TDN requirement is the binding constraint and has a shadow price ranging from $0.072 to $0.080 per cow per day. All other nutrients have shadow prices of zero and are not binding (Table 27).

The inclusion of BSG at average daily production levels for craft breweries in Tennessee of 7.2 pounds (as determined by the craft brewery survey) decreased daily costs for all months by approximately 11 percent when compared to the base scenario (Table 25). While 7.2 pounds of feed is being added to the ration across all months, it does not decrease the final value of hay by 7.2 pounds. This is due to the differences in nutrients between the two feeds on a dry matter basis. Final values for hay now fall between 24 and 27 pounds and 7.2 pounds of BSG is utilized each day in every month (Table 28). As with the base, the reduced cost for hay is zero, but the reduced cost for BSG is -$0.013 per head per day. This is because loosening the upper bound constraint on BSG, which is free to add to the ration, would decrease the total ration cost. Dissimilar to the base, reduced costs are lowest for soybean hulls, the cheapest feed, at $0.028 per cow per day, and highest for soybean meal, the most expensive feed, at $0.149 per cow per day (Table 28). Dissimilar from the base, DMI is now the binding constraints in all months with the inclusion of BSG at its average daily rate of production. The shadow price for DMI is consistent across months at $0.045 per head per day. All other nutrients have shadow prices of zero and are not binding (Table 29).

The inclusion of DSG at its average daily production level of 47.1 pounds (as determined by the craft distillery survey) again decreased daily costs for all months, but percent change from the base scenario was much higher than in the average supply of BSG scenario at approximately 19.7 percent (Table 25). As with the BSG inclusion, including DSG at a rate of 47.1 pounds does not substantially reduce the amount of hay being included in the ration. Final values for hay now fall between 22 and 24 pounds and 47.1 pounds of DSG is utilized each day in every month (Table 28). As with the base, the reduced cost for hay is zero, but the reduced cost for DSG is -$0.004 per head per day. This is because loosening the upper bound constraint on DSG, which is free to add to the ration, would decrease the total ration cost. However, this reduced cost is smaller than with BSG due to the high moisture content of DSG. Similar to the BSG inclusion scenario, reduced costs are again lowest for soybean hulls, the cheapest feed, at $0.028 per cow per day, and highest for soybean meal, the most expensive feed, at $0.149 per cow per day (Table 28). Dissimilar from the base, DMI is now the binding constraints in all months with the inclusion of DSG at its average daily rate of production. The shadow price for DMI is consistent across months at $0.045 per head per day. All other nutrients have shadow prices of zero and are not binding (Table 29).

As stated in the methods, the base price of $0.00 and a weight of BSG and DSG that is equal to approximately 30 percent of the ration on a dry matter basis were used as starting points to derive demand curves for BDSG. The 30 percent upper bound is based on recommendations by an animal science expert (Smith 2019) and these weights are 25.2 pounds of BSG and 83.5 pounds of DSG. The monthly demand curves for BSG are displayed in Figure 33 and quantity demanded based on the price ranges from the demand curves is displayed in Table 30. It should be noted that the demand curves share similarities in that the maximum allowable weight of BSG is included at the price of $0.00 and continues to be included at the maximum allowable rate until a price higher than $25.95 per ton is reached across all months. From there, some variation is present across months. Rates of inclusion vary from 6.49 pounds to 6.83 pounds per head per day at a price range of $25.96 per ton to $35.68 per ton. All months see no inclusion of BSG at a price of $35.69 per ton.

Dry matter remains the binding constraint until the price of $35.69 is reached, at which point TDN becomes the binding constraint, which is similar to the base scenario. The shadow price for DMI remains consistent at $0.045 per head per day as the price moves from $0.00 per ton to $25.96 per ton. At $35.69 per ton, TDN has a shadow price of $0.077 (Table 31). However, variability in nutrient content and product consistency could vary each presented demand curve if changed.

Monthly spring calving demand curves for DSG are displayed in Figure 34 and quantity demanded based on the price ranges from the demand curves are displayed in Table 32. As with the BSG demand curves, these demand curves share similarities in that the maximum allowable weight of DSG is included at the price of $0.00 and continues to be included at the maximum allowable rate until a price higher than $8.09 per ton is reached across all months. Between the prices of $8.10 per ton and $11.80 per ton, quantity demanded varies from 17.04 pounds per head per day to 17.94 pounds per head per day. All months see no inclusion of DSG at a price of $11.81 per ton.

As with BSG, dry matter remains the binding constraint until the price of $11.81 is reached, at which point TDN becomes the binding constraint. Again, the shadow price for DMI remains at $0.045 per head per day until TDN becomes the binding constraint, which has a shadow price of $0.077 per head per day (Table 33). As with BSG, variability in nutrient content and product consistency could vary each presented demand curve if changed.

Per Cow Per Day Results for Fall Calving Schedule

For the base model, which included no BDSG, corn gluten feed was included in the ration for November, December, and January. Cost per head per day ranged from $1.16 to $1.30 (Table 34). It should be noted that cost per head per day is significantly higher in some months in the fall calving schedule than in the other two calving schedules. This is due to the increased protein requirements of the cattle during the winter months because of the change in calving schedule. This change is further illustrated by the change in binding constraints discussed later in this section and the higher variability in the demand curves for BDSG. Final values for per head per day hay consumption fell between 27 and 30 pounds, with corn gluten feed being included at a rate of 2.8 pounds per head per day in November, 2.3 pounds per head per day in December, and 0.4 pounds per head per day in January (Table 26). Hay had a reduced cost of $0.00 in each month and corn gluten feed also had a reduced cost of $0.00 during the months in which it was included (November through January). Dissimilar to the other two calving schedules, DMI and MP are binding constraints in November, TDN and MP are binding constraints in December and January, and TDN is the sole binding constraint in February and March (Table 27).

The inclusion of BSG at average daily production levels for craft breweries in Tennessee of 7.2 pounds decreased daily costs for all months by approximately 11 percent when compared to the base scenario (Table 34). However, cost savings were much higher in months November and December due to the inclusion of corn gluten feed. Final values for hay now fall between 25 and 28 pounds, but the inclusion of corn gluten feed was limited to 0.70 pounds per head per day in November and 0.25 pounds per head per day in December (Table 35). 7.2 pounds of BSG is utilized each day in every month (Table 35). As with the base, the reduced cost for hay and corn gluten feed (during the months it is included) is zero, but the reduced cost for BSG is -$0.013 per head per day. Reduced costs for cottonseed meal and soybean hulls are $0.021 in months when corn gluten feed is included (November and December), before reduced costs begin to differ again between the two in the following months (Table 35). Similar to in the spring calving schedule, the inclusion of BSG causes the reduced cost to be highest for soybean meal, the most expensive feed, at $0.054 when corn gluten feed is included and $0.149 per cow per day in every other month (Table 35). For months November through January both DMI and MP are binding constraints, and in February and March only DMI is the binding constraint (Table 36).

The inclusion of DSG at its average daily production level of 47.1 pounds again decreased daily costs for all months, but percent change from the base scenario was much higher than in the average supply of BSG scenario at approximately 19 percent (Table 34). As with the BSG inclusion, including DSG at a rate of 47.1 pounds has a higher cost reduction over the base in months November and December, when the most corn gluten feed is being utilized. Dissimilar from the BSG scenario, corn gluten feed is not utilized in the ration in any month with average daily production of DSG being included in the ration. Final values for hay now fall between 23 and 26 pounds and 47.1 pounds of DSG is utilized each day in every month (Table 35). As with the base, the reduced cost for hay is zero, but the reduced cost for DSG is -$0.004 per head per day, which is again similar to the spring calving schedule. Reduced costs are lowest for soybean hulls at $0.028 per cow per day, and highest for soybean meal at $0.149 per cow per day (Table 35). The only binding constraint across all months with DSG inclusion is DMI and has a shadow price of $0.045. All other nutrients have shadow prices of zero and are not binding (Table 36).

As previously stated, derived demand curves for the fall calving schedule are slightly more varied and complex than in the other two calving scenarios. Allowable increases in price were not necessarily the same across months as they were in the other scenarios, which is illustrated by the demand curves. The base price of $0.00 and a weight of 25.2 pounds of BSG and 83.5 pounds of DSG were used as starting points to derive demand curves for BDSG. The monthly demand curves for BSG under the fall calving schedule are displayed in Figure 35 and quantity demanded based on the price ranges from the demand curves are displayed in Table 31. It should be noted that the demand curves share similarities in that the maximum allowable weight of BSG is included at the price of $0.00 and continues to be included at the maximum allowable rate until a price of $25.96 per ton is reached across all months. This is similar to in the other scenarios. From there, there is more variation in allowable price increases across months. Allowable increases vary in the next iteration from prices of $42.74 per ton in November and December, to $35.68 per ton in January through March, with inclusion rates varying from 6.77 pounds to 9.64 pounds of BSG. At a price above $42.74 no BSG is included in November, and at a price of above $35.68 no BSG is included in February and March. December and January have final price points of $43.52, where 1.22 pounds is being included per head per day in December and 1.44 pounds per head per day is included in January. Above a price of $43.53, no BSG is included in December and January.

Dry matter remains the binding constraint until the price of $35.69 is reached, at which point TDN becomes the binding constraint, which is similar to the other calving schedules. The shadow price for DMI remains consistent at $0.045 per head per day as the price moves from $0.00 per ton to $25.96 per ton. At $35.69 per ton, TDN has a shadow price of $0.077 (Table 37). At a price of $42.75 per ton, DMI and MP become binding constraints with shadow prices of $0.022 and $0.382 during months November and December. More variation is seen in binding constraints and shadow prices at the highest price point of $43.52, with DMI and MP being binding constraints in November, TDN and MP being binding constraints in December, and only TDN being the binding constraints in the remaining months (Table 37). However, variability in nutrient content and product consistency could vary each presented demand curve if changed.

Monthly fall calving demand curves for DSG are displayed in Figure 36 and quantity demanded based on the price ranges from the demand curves are displayed in Table 32. As with the BSG demand curves, there is more variability in the fall calving season. The maximum allowable weight of DSG is included in all months until a price higher than $8.09 per ton is reached. Months December through March have an allowable price increase that reaches $11.80 per ton, and between the price of $8.10 per ton and $11.80 per ton the inclusion of DSG ranges from 17.78 pounds per head per day to 18.99 pounds per head per day. At a price greater than $11.80 no DSG is included in February and March. December and January have a third price range with an upper limit of $15.44 per ton, where 18.08 pounds per day is included in December, but only 3.1 pounds per day is included in January. November has the highest allowable price at $15.48 per pound, at which point 21.92 pounds of DSG is still included in the ration. This is again due to the higher nutrient requirements for this calving schedule and November in particular.

Dry matter again remains the binding constraint until a price of $11.81 per ton is reached, at which point TDN becomes the binding constraint, with a shadow price of $0.077 (Table 38). At a price of $15.45 per ton the binding constraints are both TDN and MP, and at a price of $15.49, DMI and MP are binding constraints (Table 38). However, variability in nutrient content and product consistency could vary each presented demand curve if changed.

Per Cow Per Day Results for Year-Round Calving Schedule

For the base model, which included no BDSG, only hay was included in the ration for the entire winter-feeding season, which was defined as November through March. This is similar to in the spring calving schedule, but dissimilar to the fall calving schedule. Cost per head per day ranged from $1.15 to $1.18 (Table 39). Between 28 and 30 pounds of hay are consumed per cow, per day in months November through March, with reduced costs being zero for hay. Reduced costs are lowest for corn gluten feed, the second cheapest feed after soybean hulls, at $0.014 per cow per day, and highest for soybean meal, the most expensive feed, at $0.135 per cow per day (Table 26), which is the same as in the spring calving schedule. In each month of the year-round calving base scenario, the minimum TDN requirement is the binding constraint and has a shadow price of $0.077 per cow per day. All other nutrients have shadow prices of zero and are not binding (Table 27).

The inclusion of BSG at average daily production levels for craft breweries in Tennessee of 7.2 pounds decreased daily costs for all months by approximately 11 percent when compared to the base scenario (Table 39). Final values for hay now fall between 25 and 27 pounds and 7.2 pounds of BSG is utilized each day in every month (Table 40). As with the base, the reduced cost for hay is zero, but the reduced cost for BSG is -$0.013 per head per day. Similar to in the spring calving schedule, the inclusion of BSG causes the reduced cost to be lowest for soybean hulls, with a value of $0.028 per cow per day, and highest for soybean meal, the most expensive feed, at $0.149 per cow per day (Table 40). Dissimilar from the base, DMI is now the binding constraint in all months with the inclusion of BSG at its average daily rate of production. The shadow price for DMI is consistent across months at $0.045 per head per day. All other nutrients have shadow prices of zero and are not binding (Table 41).

The inclusion of DSG at its average daily production level of 47.1 pounds again decreased daily costs for all months, but percent change from the base scenario was much higher than in the average supply of BSG scenario at approximately 19 percent (Table 39). As with the BSG inclusion, including DSG at a rate of 47.1 pounds does not substantially reduce the amount of hay being included in the ration. Final values for hay now fall between 23 and 24 pounds and 47.1 pounds of DSG is utilized each day in every month (Table 40). As with the base, the reduced cost for hay is zero, but the reduced cost for DSG is -$0.004 per head per day, which is again similar to the spring calving schedule. Similar to the BSG inclusion scenario, reduced costs are again lowest for soybean hulls at $0.028 per cow per day, and highest for soybean meal at $0.149 per cow per day (Table 40). Dissimilar from the base, but similar to the BSG inclusion scenario, DMI is now the binding constraints in all months with the inclusion of DSG at its average daily rate of production. The shadow price for DMI is consistent across months at $0.045 per head per day. All other nutrients have shadow prices of zero and are not binding (Table 29).

As stated in the methods, the base price of $0.00 and a weight of 25.2 pounds of BSG and 83.5 pounds of DSG were used as starting points to derive demand curves for BDSG. The monthly demand curves for BSG are displayed in Figure 37 and quantity demanded based on the price ranges from the demand curves are displayed in Table 32, and results are similar to those seen in the spring calving scenario. It should be noted that the demand curves share similarities in that the maximum allowable weight of BSG is included at the price of $0.00 and continues to be included at the maximum allowable rate until a price higher than $25.95 per ton is reached across all months. From there, some variation is present across months. Rates of inclusion vary from 6.72 pounds to 6.89 pounds per head per day at a price range of $25.96 per ton to $35.68 per ton. All months see no inclusion of BSG at a price of $35.69 per ton.

Dry matter remains the binding constraint until the price of $35.69 is reached, at which point TDN becomes the binding constraint, which is similar to the base scenario. The shadow price for DMI remains consistent at $0.045 per head per day as the price moves from $0.00 per ton to $25.96 per ton. At $35.69 per ton, TDN has a shadow price of $0.077 (Table 42). However, variability in nutrient content and product consistency could vary each presented demand curve if changed.

Monthly spring calving demand curves for DSG are displayed in Figure 38. As with the BSG demand curves, these demand curves share similarities in that the maximum allowable weight of DSG is included at the price of $0.00 and continues to be included at the maximum allowable rate until a price higher than $8.09 per ton is reached across all months. Between the prices of $8.10 per ton and $11.80 per ton, quantity demanded varies from 17.64 pounds per head per day to 18.09 pounds per head per day. All months see no inclusion of DSG at a price of $11.81 per ton.

As with BSG, dry matter remains the binding constraint until the price of $11.81 is reached, at which point TDN becomes the binding constraint. Again, the shadow price for DMI remains at $0.045 per head per day until TDN becomes the binding constraint, which has a shadow price of $0.077 per head per day (Table 43). As with BSG, variability in nutrient content and product consistency could vary each presented demand curve if changed.

Summary of Total Winter-Feeding Costs by Calving Season under an Assumed Herd Size of 25 Head

Per cow, per day feeding costs are aggregated to show total winter-feeding costs for a 25 head herd. Including BSG at its average daily supply decreases total winter-feeding costs by $474.06 in the spring calving schedule, $525.40 in the fall calving schedule, and $477.16 in the year-round calving schedule (Table 44). Including DSG at its average daily supply decreases total winter-feeding costs by $841.13 in the spring calving schedule, $913.35 in the fall calving schedule, and $844.22 in the year-round calving schedule (Table 44). With both BSG and DSG, the highest savings per herd are seen in the fall calving schedule. This is again due to the increase in nutrient requirements in the winter months for this calving schedule. If year-long feeding costs were examined with hay as the basis, it is likely that the spring and fall calving schedules would share similar costs.

Table 45 displays total winter-feeding costs with BSG and DSG being included at their highest possible inclusion rates of 25.2 pounds of BSG and 83.5 pounds of DSG, which is equal to approximately 30 percent of the feed per head per day on a dry matter basis. Savings from the inclusion of the two feeds at similar rates on a dry matter basis presents similar levels of savings. At the high rate of BSG inclusion, costs decreased by $1,355.81 for the spring calving schedule, $1,428.04 for the fall calving schedule, and $1,358.91 for the year-round calving schedule (Table 45). Including DSG at the high rate of supply decreased costs by $1,397.38 for the spring calving schedule, $1,469.61 for the fall calving schedule, and $1,400.48 for the year-round calving schedule (Table 45). This indicates that on a dry matter basis, the feeds can provide similar cost savings, but on an as-fed basis, BSG is more valuable per pound than DSG is. However, DSG is much more difficult to transport on an as-fed basis due to its incredibly high moisture content, and custom-built tanker trucks are often used to transport the feed (Moorehead 2018). Additionally, special feeding equipment is often required to feed DSG for this same reason. Because of this, the cost of feeding DSG is likely higher than is the cost of feeding BSG, which should be taken into consideration.

Implications of Least-Cost Feed Ration Results

Results of the linear programming model indicate that the inclusions of BDSG as a feedstock component has the potential to dramatically decrease the costs of winter feed rations for lactating beef cows in all three calving scenarios keeping transportation costs at zero. However, the fall calving schedule was costlier and required the use of additional feedstock even with the inclusion of BDSG in some cases. It is important to note that the value of the feed is at farm-gate so transportation costs would need to be considered when evaluating the value of feed for individual cow-calf operations. This can, in part, be done by utilizing the demand curves that were constructed under the 25-head herd assumption to determine the maximum allowable transportation costs for the feed before quantity demanded decreases. These maximum allowable transportation costs can also be used to determine a market boundary for the by-products. However, feed consistency, quality, and its potential to spoil quickly could greatly impact quantity demanded, allowable transportation costs, and market boundaries.

Given the size of the Tennessee craft brewing and distilling industries, there is potential for spent grain production to provide a considerable decrease in feeding costs. Respondents of the survey indicated that they produced 855,400 pounds of BSG and 3,010,061.4 pounds of DSG during the last fiscal year. This is a daily production of 2,343.6 pounds of BSG and a daily production of 8,246.7 pounds of DSG. If consumed at the average daily production rates of 7.2 pounds of BSG and 47.1 pounds of DSG as used in the linear programming model, this sample of breweries could feed approximately 325 lactating beef cows for the winter-feeding season and this sample of distilleries could feed approximately 175 lactating beef cows for the winter-feeding season. Since not all breweries and distilleries responded to the survey, production levels are inevitably larger, and number of cows fed could be increased or decreased depending on the amount of BDSG included in their rations.

Summary of Identifying Sustainable Uses of BDSG and its Value as a Livestock Feed

While some research has been done regarding the use of BDSG as a compost or soil amendment, results of trials vary, and results of the survey of Tennessee brewers and distillers do not support the notion that it is a main-stream practice. This least-cost feed ration analysis shows that BDSG can be cost effectively included in lactating beef cow rations. Prices producers are willing to pay will be determined by transportation costs from a brewery to their farm and competition for the feed.

This least-cost feed ration model illustrates one of many viable scenarios that could occur on a Tennessee cow-calf operation. Availability of feeds, transportation costs, and calving schedules are a few variables that, if changed, could dramatically alter the outcome of the model. Thus, it should be noted that the use of a least-cost feed ration model should be individualized such that it meets the requirements of each individual farm.

In this particular illustration of cow-calf operations on three separate calving schedules, holding transportation costs across purchased feeds at zero, the inclusion of BSG at the average daily production level decreased winter feed costs by 11.1 percent for the spring calving schedule 11.3 percent for the fall calving schedule, and 10.8 percent for the year-round calving schedule when compared to the base scenario. Similarly, the inclusion of DSG at the average daily production level decreased winter feed costs by 19.6 percent for the spring calving schedule 19.7 percent for the fall calving schedule, and 19.1 percent for the year-round calving schedule when compared to the base scenario. Additional analysis would be required to determine the prices producers would be willing to pay in year-round feeding systems for cow-calf producers and whether BDSG has the potential to be fed during other seasons as a replacement for summer grasses. However, finishing and stocker operations could illustrate year-round demand for the by-products.

CHAPTER IV: CONCLUSIONS AND RECCOMENDATIONS

Introduction

This chapter addresses the objectives of the study and how they were achieved. The objectives of this study were to:

i. Determine the quantity of BDSG being produced in Tennessee by craft breweries and distilleries;
ii. Determine current BDSG disposal practices; and
iii. Determine the cost-savings for farmers resulting from BDSG disposal by breweries and distilleries as a livestock feed.

This is followed by the conclusions of the research and how the results can be applied. Finally, the recommendations and limitations of the research are discussed.

Study Overview and Conclusions

The objectives of this research were to quantify the amount of BDSG being produced by craft brewers and distillers in Tennessee, determine current BDSG disposal methods being utilized by craft brewers and distillers, and determine the potential cost-savings associated with of disposing BDSG as a livestock feed for cow-calf operations in Tennessee.

To quantify the amount of BDSG being produced in Tennessee, lists of Tennessee breweries and distilleries were constructed from information from the Tennessee Department of Agriculture, the Tennessee Distillers Guild, and the Brewers Association. This effort produced an estimated population of 104 breweries and 34 distilleries. After removing large operations, those that were not in production, and those without contact information, the sample sizes decreased to 72 breweries and 22 distilleries. Next, surveys were distributed through Qualtrics by email. This survey distribution method yielded 18 responses from breweries and seven responses from distilleries. Follow-up phone surveys added an additional 16 responses from breweries and nine from distilleries. The survey response rate for breweries was 47 percent and 73 percent for distilleries.

Results from the survey indicated that the responding breweries and distilleries produced an average of 65,800 and 430,009 pounds of BDSG during the last fiscal year, respectively. The total number of pounds of BDSG being produced by all survey respondents was 855,400 for BSG and 3,010,061.4 for DSG. Additionally, 100 percent of responding breweries and 83 percent of responding distilleries dispose of at least a portion of their BDSG as a livestock feed. Only 15 percent of responding breweries and eight percent of responding distilleries dispose of at least a portion of their BDSG as a soil amendment, compost, or fertilizer. This indicated that determining the value of BDSG as a livestock feed may be more beneficial than determining its value as a compost, soil amendment, or fertilizer.

To determine the cost-savings resulting from utilizing BDSG as a livestock feed for cow-calf operations in Tennessee, a linear programming model was used to create a least-cost feed ration for spring, fall, and year-round calving schedules. Because pasture is the primary source of feed during spring, summer, and fall, the model was used to calculate winter feeding costs during months November through March, with purchased hay being the base feed in the ration. Through this model it was determined that feeding BSG at the average daily production rate for surveyed breweries decreases winter feed costs by 11.1 percent for the spring calving schedule, 11.3 percent for the fall calving schedule, and 10.8 percent for the year-round calving schedule when compared to the base scenario. Similarly, the inclusion of DSG at the average daily production level decreased winter feed costs by 19.6 percent for the spring calving schedule 19.7 percent for the fall calving schedule, and 19.1 percent for the year-round calving schedule when compared to the base scenario. Increasing the portion of BDSG to around 30 percent of the total ration on a dry matter basis decreases the total winter feed costs by approximately 30 percent in all calving scenarios. Additionally, derived demand curves can be utilized to determine allowable transportation costs and market boundaries for BDSG.

Recommendations and Limitations

Regarding the survey of breweries and distilleries, while response rates were relatively high at 47 percent for breweries and 73 percent for distilleries, whether the sample is truly representative of the population is unknown. Production of primary product, BDSG, and disposal practices could vary between what was indicated by the sample and what is true of the population.

Given the high concentrations of breweries (Figure 1) and distilleries (Figure 2) in metropolitan areas, sustainable distribution of waste to rural areas may be an obstacle faced by both breweries and distilleries, as well as the farmers who may be using BDSG as a component of a feed ration. Thus, the cost of substitutes in feed ration mixes and transportation costs are important and the demand curves derived from the linear programming model should be used in combination with transportation costs to determine market boundaries. This will illustrate at which point utilizing BDSG as a feed ration component is no longer financially beneficial to livestock producers.

The linear programming model only provides a few scenarios that could occur on Tennessee beef cattle farms. To be completely accurate it would have to be completed on a per farm and per brewery or distillery basis to determine accurate timelines, prices and transportation costs. Additionally, nutrient variability of Tennessee-produced BDSG may influence the market boundary. Thus, after the BDSG sampling is completed by researchers, scenarios which vary the nutrient contents of the feedstock should be added to the least-cost feed ration model.

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APPENDICES

Appendix A: Tables

Table 1. Current Inclusion Rates for Dried Distillers Grains (DDG) in Animal Feed[1]

	Annual DDG Rate (pounds/year/head)	
Class of Livestock	Current Practice[2]	Upper Limit[3]
Dairy cows	1,002.00	1,642.50
Beef cows	396.00	720.00
Other cattle	346.50	630.00
Cattle on feed	916.00	2,555.00
Breeding swine	105.53	372.00
Market swine	51.77	182.50
Broilers	0.33	1.16
Layers	3.37	11.87
Pullets	1.03	3.63
Turkeys	1.80	6.35

[1]Dooley 2008
[2]Current practice of Midwestern farmers of pounds fed per head per year by animal as found by NASS (2007).
[3]Suggested upper limit of pounds fed per head per year as found by Berger and Good (2007)

Table 2. Percentages of Breweries Surveyed in Great Britain That Incur Costs for Removal of Spent Grains[1]

Brewery; Location and Size	Brewery Incurs No Cost	Brewery Facilitates Disposal	Brewery Incurs All Costs	Brewery Receives Payment
Urban-Small	55.6%	44.4%	0.0%	0.0%
Urban-Medium	89.5%	10.5%	0.0%	0.0%
Urban-Large	75.0%	0.0%	0.0%	25.0%
Rural-Small	70.0%	20.0%	0.0%	10.0%
Rural-Medium	90.0%	5.0%	0.0%	5.0%
Rural-Large	73.7%	10.5%	0.0%	5.2%

[1]Kerby and Vrieskoop 2017

Table 3. Average Brewery Response Values for Factors Affecting Growth of Business, 1 Being Most Important, 7 Being Least Important – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries

	Economic Downturn	Government Regulations	Industry Saturation	Profitability	Quality of Labor	Waste Disposal	Other[1]
Breweries	3.5	3.1	2.0	3.1	4.5	5.5	6.7

n=31
[1]Comments listed in the "other" category included: "Poor quality product", "high maintenance equipment companies", and "breweries that don't know what they're doing".

Table 4. Pounds of Wet or Dry Hops Used Annually by Tennessee Craft Breweries – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries

	Wet Hops, n = 29	Dry/Pelletized Hops, n = 27
Average	46	2,301
Mode	0	4,000
Max	500	16,500
Min	0	100
Standard Deviation	102	4,072
Total	1,335	62,125

Table 5. Pounds of Grain Purchased Annually by Breweries – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries

	Pounds of Malt Barley, n = 24	Pounds of Other Grains[1], n = 30
Average	78,760	3,020
Mode	20,000	300
Min	1,500	100
Max	600,000	40,000
Standard Deviation	132,375	7,324
Total per Grain	1,890,250	90,600
Total Grain Purchased	1,980,850	

[1]Other grains include wheat, corn, wheat, corn, oats, rye, rice.

Table 6. Gallons of Beer Produced by Tennessee Craft Breweries[1] – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries

	Last Fiscal Year, n = 9	Current Fiscal Year, n = 19
Average	46,580	74,176
Max	384,000	400,000
Min	900	24
Standard Deviation	87,362	85,309
Total	885,014	1,210,199

[1]Summary statistics do not include values of zero for breweries that were not currently in production.

Table 7. Pounds of Spent Grains Produced by Tennessee Breweries[1] – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries

	Last Fiscal Year, n = 13	Current Fiscal Year, n = 17
Average	65,800	83,907
Max	230,000	320,000
Min	3,500	3,500
Standard Deviation	81,445	106,979
Total	855,400	1,451,500

[1]Summary statistics do not include values of zero for breweries that were not currently in production.

Table 8. Batches of Beer Produced by Tennessee Craft Breweries – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries

	Number of Batches per Week, n = 26	Gallons per Batch, n = 26	Pounds of Spent Grains per Batch, n = 21
Average	2.6	1,873	2,720
Mode	2	220	400
Max	7	36,000	36,000
Min	0.25	10	75
Standard Deviation	1.4	6,993	7,736

Table 9. Summary of Brewery BSG Disposal as a Livestock Feed – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries

Are your spent grains disposed of as a livestock feed?	
	Breweries, n=26
Yes	100%
No	0%
How are your spent grains marketed to livestock producers?	
	Breweries, n=29
Broker	0%
Private contract	3%
Affiliated or subsidiary entity	0%
Given away (first come first serve)	14%
Given away (to a predetermined producer or set of producers)	79%
Other[1]	3%
What is the average distance (one-way miles) that the spent grains travel to the livestock producers?	
	Breweries, n=25
Average	27.69
Minimum	0.2
Maximum	60
Does the disposal of your spent grains as a livestock feed provide your business with revenue or cost you money?	
	Breweries, n=25
Provides revenue[2]	4%
Costs money	0%
Breaks-even	96%

[1]Comments listed in the “other” category for marketing included: “MTSU dairy farmer”.
[2]Respondent indicated it provides revenue of “$100 per week”.

Table 10. Summary of Brewery BSG Disposal as a Source of Plant Nutrients – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries

Are your spent grains disposed of as a compost/fertilizer/soil amendment?	
	Breweries, n=26
Yes	15%
No	85%
Are you aware of a compost facility in your area?	
	Breweries, n=22
Yes	14%
No	86%
How are your spent grains marketed to producers using them as a compost/fertilizer/soil amendment?	
	Breweries, n=6
Broker	0%
Private contract	0%
Affiliated or subsidiary entity	17%
Given away (first come first serve)	33%
Given away (to a predetermined producer or set of producers)	50%
Other	0%
What is the average distance (one-way miles) that the spent grains travel to producers using them as a compost/fertilizer/soil amendment?	
	Breweries, n=5
Average	25.60
Minimum	1
Maximum	52
Does the disposal of your spent grains as a compost/fertilizer/soil amendment provide your business with revenue or cost you money?	
	Breweries, n=4
Provides revenue[1]	25%
Costs money	0%
Breaks-even	75%

[1]Respondent indicated they were "not sure, but not losing money on it".

Table 11. Average Brewery Response Values for Factors Affecting Disposal of Spent Grains, 1 Being Most Important, 6 Being Least Important – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries

	Quantity Produced	Market Access/No Contacts	Limited Knowledge	On-Site Drying/Processing	Limited Access to Capital	Other[1]
Breweries	3.0	3.1	4.1	2.9	3.6	4.1

n=22
[1]Comments listed in the “other” category included: "None of these are significant issues. Giving away grain is easy", "regulations", "none", "federal regulations" (2), "no issues at all", and "storage".

Table 12. Average Distillery Response Values for Factors Affecting Growth of Business, 1 Being Most Important, 7 Being Least Important – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries

	Economic Downturn	Government Regulations	Industry Saturation	Profitability	Quality of Labor	Waste Disposal	Other[1]
Distilleries	2.9	2.6	2.7	3.7	4.1	5.1	6.7

n=15
[1]Comments listed in the "other" category included: "local specialty grain availability".

Table 13. Pounds of Grain Purchased Annually by Tennessee Craft Distilleries – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries

	Pounds of Corn, n = 11	Pounds of Other Grains[1], n = 11
Average	89,009	26,482
Mode	50,000	15,000
Min	7,500	3,000
Max	208,000	93,350
Standard Deviation	74,097	30,208
Total per Grain	979,100	291,300
Total Grain Consumption	1,270,401	

[1]Other grains included barley, rye, and wheat.

Table 14. Gallons of Product Produced by Tennessee Craft Distilleries – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries

	Most Recent Fiscal Year		Next Fiscal Year	
	Whiskey, n = 10	Other Spirits[1], n = 4	Whiskey, n = 7	Other Spirits[1], n = 4
Average	16,624	1,234	31,948	5,313
Mode	2,500	No Mode	No Mode	No Mode
Max	78,000	2,600	156,000	20,000
Min	2,500	229	3,250	0.05
Standard Deviation	23,564	1,163	56,163	9,796
Total	166,244	4,934	223,638	21,250

[1]Other spirits include vodka, moonshine, gin, and rum.

Table 15. Spent Grains Produced by Tennessee Craft Distilleries – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries

	Most Recent Fiscal Year, n = 7		Next Fiscal Year, n = 7	
	Gallons	Pounds[1]	Gallons	Pounds[1]
Average	51,808	430,006	78,620	652,548
Max	200,160	1,661,328	270,720	2,246,976
Min	1,248	10,358	1,622	13,463
Standard Deviation	69,810	579,426	97,055	805,556
Total	362,658	3,010,061	550,342	4,567,939

[1]1 gallon of DSG = 8.3 pounds (Moorehead 2018)

Table 16. Batches of Liquor Produced by Tennessee Craft Distilleries – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries

	Number of Batches per Week, n = 13	Gallons per Batch, n = 12	Gallons of Spent Grains per Batch, n = 11	Pounds of Spent Grain per Batch, n = 11
Average	2.9	216	506	4,203
Mode	3	50	250	2,075
Max	6	1,000	1,590	13,197
Min	0.5	30	35	291
Standard Deviation	1.7	268	529	4,387

Table 17. Summary of Distillery DSG Disposal as a Livestock Feed – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries

Are your spent grains disposed of as a livestock feed?	
	Distilleries, n=12
Yes	83%
No	17%
How are your spent grains marketed to livestock producers?	
	Distilleries, n=11
Broker	0%
Private contract	0%
Affiliated or subsidiary entity	0%
Given away (first come first serve)	18%
Given away (to a predetermined producer or set of producers)	73%
Other[1]	9%
What is the average distance (one-way miles) that the spent grains travel to the livestock producers?	
	Distilleries, n=11
Average	21.09
Minimum	1
Maximum	50
Does the disposal of your spent grains as a livestock feed provide your business with revenue or cost you money?	
	Distilleries, n=10
Provides revenue	10%
Costs money	0%
Breaks-even	90%

[1]Comments listed in the "other" category for marketing included: "own cattle, onsite farm".

Table 18. Summary of Distillery DSG Disposal as a Source of Plant Nutrients – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries

Are your spent grains disposed of as a compost/fertilizer/soil amendment?	
	Distilleries, n=12
Yes	8%
No	92%
Are you aware of a compost facility in your area?	
	Distilleries, n=11
Yes	27%
No	73%
How are your spent grains marketed to producers using them as a compost/fertilizer/soil amendment?	
	Distilleries, n=1
Broker	0%
Private contract	0%
Affiliated or subsidiary entity	0%
Given away (first come first serve)	0%
Given away (to a predetermined producer or set of producers)	100%
Other	0%
What is the average distance (one-way miles) that the spent grains travel to producers using them as a compost/fertilizer/soil amendment?	
	Distilleries, n=1
Average	15
Minimum	15
Maximum	15
Does the disposal of your spent grains as a compost/fertilizer/soil amendment provide your business with revenue or cost you money?	
	Distilleries, n=1
Provides revenue	0%
Costs money	0%
Breaks-even	100%

Table 19. Average Distillery Response Values for Factors Affecting Disposal of Spent Grains, 1 Being Most Important, 6 Being Least Important – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries

	Quantity Produced	Market Access/No Contacts	Limited Knowledge	On-Site Drying/Processing	Limited Access to Capital	Other[1]
Distilleries	3.0	2.6	3.4	2.8	3.6	5.4

n=12
[1]Comments listed in the "other" category included: "owning farmland ourselves", government regulations", and "contacts".

Table 20. Sample Results for Nutrient Content Analysis of BSG from Two Craft Breweries in Tennessee[1]

	DM (% AF)	TDN (% DM)	Nem (Mcal/lb)	Neg (Mcal/lb)	CP (% DM)
Average	0.29	0.80	0.88	0.59	0.21
Standard Deviation	0.050	0.035	0.042	0.038	0.035
Sample Size	4	4	4	4	4

[1]Nutrient content analysis completed by Cumberland Valley Analytical Services
(DM = dry matter, AF = as fed, TDN = total digestible nutrients, NEm = net energy for maintenance, NEg = net enegery for gain, CP = crude protein)

Table 21. Daily Nutrient Requirements of a 1,200 Pound Shrunk Body Weight Mature Lactating Beef Cow by Month after Calving[1]

	Months Since Calving											
Requirement	1	2	3	4	5	6	7	8	9	10	11	12
DMI (lb./day)	26.7	27.3	26.9	26.2	25.6	25.1	24.7	24.5	24.3	24.0	24.0	25.4
TDN (lb/day)	16.0	16.4	16.1	15.7	15.3	15.1	14.8	14.7	14.6	14.4	14.4	15.2
Total NE (Mcal/day)	15.3	16.2	15.7	14.7	13.7	12.9	12.4	12.3	12.6	13.4	14.8	16.9
MP (lb./day)	1.72	1.87	1.78	1.61	1.45	1.32	1.23	1.18	1.17	1.22	1.34	1.53

[1]NASEM 2016
(DMI = dry matter intake, TDN = total digestible nutrients, Total NE = total net energy, MP = metabolizable protein)

Table 22. Percent Calves Born per Month based on Three Common Calving Seasons

	Month											
Calving Season	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Spring[1]	-	0.25	0.50	0.25	-	-	-	-	-	-	-	-
Fall[1]	-	-	-	-	-	-	-	0.25	0.50	0.25	-	-
Year-Round[12]	0.12	0.15	0.19	0.12	0.08	0.05	0.03	0.03	0.05	0.07	0.06	0.06

[1]Units are displayed as percent of cows calving in each month. Each season totals to 1.
[2]USDA APHIS 2009

Table 23. Nutrient Content of Common Feed Ration Components for Beef Cattle[1]

	Feedstock						
	Fescue Hay	Cottonseed Meal	Corn Gluten Feed, Dry	Soybean Meal High CP	Soybean Hulls	Brewers Grains, Wet[2]	Distillers Grains, Wet[3]
DM (% AF)	0.889	0.886	0.889	0.917	0.900	0.289	0.314
TDN (% DM)	0.583	0.696	0.800	0.811	0.626	0.802	0.980
NE (Mcal/lb)	0.875	1.197	1.470	1.501	1.007	1.468	1.910
CP (% DM)	0.092	0.450	0.226	0.465	0.124	0.211	0.306
MP (% DM)	0.059	0.288	0.145	0.298	0.079	0.135	0.196

[1]NASEM 2016
[2]Results from Cumberland Valley Analytical Services BDSG sample analysis
(DM = dry matter, AF = as fed, TDN = total digestible nutrients, NE = net energy, CP = crude protein, MP = metabolizable protein (1 lb. CP = .64 lb. MP))
[3]Moorehead 2016, used as a proxy for wet distiller's grains produced by distilleries in Tennessee

Table 24. Prices of Common Cattle Feed Components in Tennessee

Feedstuff	Price per Ton	Price per Pound
Fescue Hay[1]	$80.00	$0.04
Cottonseed Meal[2]	$276.37	$0.14
Corn Gluten Feed[2]	$138.35	$0.07
Soybean Meal, High CP[2]	$379.15	$0.19
Soybean Hulls[2]	$136.63	$0.07
BSG[3]	$0.00	$0.00
DSG[3]	$0.00	$0.00

[1]Griffith and Bowling 2019
[2]5-Year Average Prices of from USDA-AMS, 2019.
[3]Assumed to be $0.00 based on survey results that indicated the majority of breweries and distilleries were giving away BDSG.

Table 25. Cost Savings for Spring Calving Cow-Calf Producers from Including 7.2 Pounds of BSG or 47.1 Pounds of DSG at a Cost of $0.00 per Ton[1]

	Cost/Cow/Day		
Month	**Base Scenario**	**Average BSG Supply Scenario[2,3]**	**Average DSG Supply Scenario[2,4]**
November	$1.13	$1.01 (-11.1%)	$0.91 (-19.7%)
December	$1.12	$1.00 (-11.2%)	$0.90 (-19.8%)
January	$1.12	$0.99 (-11.2%)	$0.89 (-19.9%)
February	$1.13	$1.00 (-11.1%)	$0.91 (-19.7%)
March	$1.17	$1.05 (-10.8%)	$0.95 (-19.1%)

[1]Only hay and BSG or hay and DSG were selected to be used in the ration for each month across all scenarios.
[2]Percent change from base located in parenthesis.
[3]Average supply of BSG is 7.2 pounds as indicated by a 2018 University of Tennessee survey of craft breweries and distilleries.
[4]Average supply of DSG is 47.1 pounds as indicated by a 2018 University of Tennessee survey of craft breweries and distilleries.

Table 26. Final Values in Pounds/Cow/Day or Megacalories/Cow/Day and Reduced Costs in Dollars/Cow/Day for Feedstocks with No BDSG Inclusion for Each Calving Schedule

		Spring Calving		Fall Calving		Year-Round Calving	
Month	Feedstock	Final Value	Reduced Cost[1]	Final Value	Reduced Cost[1]	Final Value	Reduced Cost[1]
November	Fescue Hay	28.325	-	27.662	-	28.881	-
	Corn Gluten Feed, Dry	-	0.014	2.774	-	-	0.014
	Cottonseed Meal	-	0.091	-	0.021	-	0.091
	Soybean Meal, High CP	-	0.135	-	0.054	-	0.135
	Soybean Hulls	-	0.025	-	0.021	-	0.025
December	Fescue Hay	28.070	-	27.911	-	28.860	-
	Corn Gluten Feed, Dry	-	0.014	2.301	-	-	0.014
	Cottonseed Meal	-	0.091	-	0.042	-	0.091
	Soybean Meal, High CP	-	0.135	-	0.077	-	0.135
	Soybean Hulls	-	0.025	-	0.021	-	0.025
January	Fescue Hay	27.878	-	29.825	-	28.941	-
	Corn Gluten Feed, Dry	-	0.014	0.394	-	-	0.014
	Cottonseed Meal	-	0.091	-	0.042	-	0.091
	Soybean Meal, High CP	-	0.135	-	0.077	-	0.135
	Soybean Hulls	-	0.025	-	0.021	-	0.025
February	Fescue Hay	28.197	-	29.664	-	29.181	-
	Corn Gluten Feed, Dry	-	0.014	-	0.014	-	0.014
	Cottonseed Meal	-	0.091	-	0.091	-	0.091
	Soybean Meal, High CP	-	0.135	-	0.135	-	0.135
	Soybean Hulls	-	0.025	-	0.025	-	0.025
March	Fescue Hay	29.345	-	29.090	-	29.585	-
	Corn Gluten Feed, Dry	-	0.014	-	0.014	-	0.014
	Cottonseed Meal	-	0.091	-	0.091	-	0.091

Table 26. Continued.

		Spring Calving		Fall Calving		Year-Round Calving	
Month	Feedstock	Final Value	Reduced Cost[1]	Final Value	Reduced Cost[1]	Final Value	Reduced Cost[1]
March	Soybean Meal, High CP	-	0.135	-	0.135	-	0.135
	Soybean Hulls	-	0.025	-	0.025	-	0.025

[1]Displayed as per cow/per day.
(CP = crude protein)

Table 27. Final Values in Pounds/Cow/Day or Megacalories/Cow/Day and Shadow Prices in Dollars/Cow/Day for Nutrients with No BDSG Inclusion for Each Calving Schedule

		Spring Calving		Fall Calving		Year-Round Calving	
Month	Nutrient	Final Value	Shadow Price[1]	Final Value	Shadow Price[1]	Final Value	Shadow Price[1]
November	DMI (lbs.)	25.189	-	27.066	0.022	25.683	-
	TDN (lbs.)	14.685	0.077	16.315	-	14.973	0.077
	NE (Mcal)	24.796	-	28.293	-	25.283	-
	MP (lbs.)	1.486	-	1.809	0.382	1.516	-
December	DMI (lbs.)	24.962	-	26.867	-	25.665	-
	TDN (lbs.)	14.553	0.080	16.108	0.052	14.963	0.077
	NE (Mcal)	24.573	-	27.816	-	25.265	-
	MP (lbs.)	1.473	-	1.761	0.251	1.514	-
January	DMI (lbs.)	24.792	-	26.874	-	25.737	-
	TDN (lbs.)	14.454	0.080	15.744	0.052	15.005	0.077
	NE (Mcal)	24.406	-	26.689	-	25.336	-
	MP (lbs.)	1.463	-	1.616	0.251	1.519	-
February	DMI (lbs.)	25.076	-	26.381	-	25.950	-
	TDN (lbs.)	14.619	0.072	15.380	0.077	15.129	0.077
	NE (Mcal)	24.685	-	25.969	-	25.546	-
	MP (lbs.)	1.480	-	1.557	-	1.531	-
March	DMI (lbs.)	26.097	-	25.870	-	26.310	-
	TDN (lbs.)	15.215	0.080	15.082	0.077	15.339	0.077
	NE (Mcal)	25.690	-	25.467	-	25.900	-
	MP (lbs.)	1.540	-	1.527	-	1.552	-

[1]Displayed as per cow/per day.
(DM = dry matter, TDN = total digestible nutrients, NE = net energy, MP = metabolizable protein)

Table 28. Final Values in Pounds/Cow/Day and Reduced Costs in Dollars/Cow/Day for Feedstocks at Average BSG and DSG Inclusion for Spring Calving[1]

		BSG		DSG	
Month	**Feedstock**	**Final Value**	**Reduced Cost[2]**	**Final Value**	**Reduced Cost[2]**
November	Fescue Hay	25.186	-	22.756	-
	Corn Gluten Feed, Dry	-	0.029	-	0.029
	Cottonseed Meal	-	0.098	-	0.098
	Soybean Meal, High CP	-	0.149	-	0.149
	Soybean Hulls	-	0.028	-	0.028
	BSG	7.200	-0.013	47.100	-0.004
December	Fescue Hay	24.938	-	22.508	-
	Corn Gluten Feed, Dry	-	0.029	-	0.029
	Cottonseed Meal	-	0.098	-	0.098
	Soybean Meal, High CP	-	0.149	-	0.149
	Soybean Hulls	-	0.028	-	0.028
	BSG	7.200	-0.013	47.100	-0.004
January	Fescue Hay	24.753	-	22.322	-
	Corn Gluten Feed, Dry	-	0.029	-	0.029
	Cottonseed Meal	-	0.098	-	0.098
	Soybean Meal, High CP	-	0.149	-	0.149
	Soybean Hulls	-	0.028	-	0.028
	BSG	7.200	-0.013	47.100	-0.004
February	Fescue Hay	25.062	-	22.632	-
	Corn Gluten Feed, Dry	-	0.029	-	0.029
	Cottonseed Meal	-	0.098	-	0.098
	Soybean Meal, High CP	-	0.149	-	0.149
	Soybean Hulls	-	0.028	-	0.028
	BSG	7.200	-0.013	47.100	-0.004
March	Fescue Hay	26.178	-	23.747	-
	Corn Gluten Feed, Dry	-	0.029	-	0.029
	Cottonseed Meal	-	0.098	-	0.098
	Soybean Meal, High CP	-	0.149	-	0.149
	Soybean Hulls	-	0.028	-	0.028
	BSG	7.200	-0.013	47.100	-0.004

[1]Average daily production is 7.2 pounds of BSG and 47.1 pounds of DSG.
[2]Displayed as per cow/per day.
(CP = crude protein)

Table 29. Final Values in Pounds/Cow/Day or Megacalories/Cow/Day and Shadow Prices in Dollars/Cow/Day for Nutrients at Average BSG and DSG Inclusion for Spring Calving[1]

		BSG		DSG	
Month	**Nutrient**	**Final Value**	**Shadow Price[2]**	**Final Value**	**Shadow Price[2]**
November	DMI (lbs.)	24.476	0.045	24.476	0.045
	TDN (lbs.)	14.724	-	15.401	-
	NE (Mcal)	32.615	-	94.839	-
	MP (lbs.)	1.603	-	1.899	-
December	DMI (lbs.)	24.255	0.045	24.255	0.045
	TDN (lbs.)	14.595	-	15.272	-
	NE (Mcal)	32.398	-	94.622	-
	MP (lbs.)	1.590	-	1.886	-
January	DMI (lbs.)	24.090	0.045	24.090	0.045
	TDN (lbs.)	14.499	-	15.176	-
	NE (Mcal)	32.235	-	94.459	-
	MP (lbs.)	1.580	-	1.877	-
February	DMI (lbs.)	24.365	0.045	24.365	0.045
	TDN (lbs.)	14.659	-	15.337	-
	NE (Mcal)	32.507	-	94.730	-
	MP (lbs.)	1.596	-	1.893	-
March	DMI (lbs.)	25.358	0.045	25.358	0.045
	TDN (lbs.)	15.238	-	15.915	-
	NE (Mcal)	33.483	-	95.707	-
	MP (lbs.)	1.655	-	1.952	-

[1]Average daily production is 7.2 pounds of BSG and 47.1 pounds of DSG.
[2]Displayed as per cow/per day.
(DM = dry matter, TDN = total digestible nutrients, NE = net energy, MP = metabolizable protein)

Table 30. Monthly Demand for BSG with Varying Prices

	Spring Calving Schedule		**Fall Calving Schedule**		**Year-Round Calving Schedule**	
Month	Price Range ($/Pound)	Pounds Demanded	Price Range ($/Pound)	Pounds Demanded	Price Range ($/Pound)	Pounds Demanded
November	$0.00 - $25.95	25.20	$0.00 - $25.95	25.20	$0.00 - $25.95	25.20
	$25.96 - $35.68	6.59	$25.96 - $42.74	9.64	$25.96 - $35.68	6.72
	> $35.68	0.00	> $42.74	0.00	> $35.68	0.00
December	$0.00 - $25.95	25.20	$0.00 - $25.95	25.20	$0.00 - $25.95	25.20
	$25.96 - 35.68	6.53	$25.96 - $42.74	8.05	$25.96 - 35.68	6.72
	> $35.68	0.00	$42.75 - $43.52	1.22	> $35.68	0.00
			> $43.52	0.00		
January	$0.00 - $25.95	25.20	$0.00 - $25.95	25.20	$0.00 - $25.95	25.20
	$25.96 - 35.68	6.49	$25.96 - 35.68	7.07	$25.96 - 35.68	6.74
	> $35.68	0.00	$35.69 - $43.52	1.44	> $35.68	0.00
			> $43.52	0.00		
February	$0.00 - $25.95	25.20	$0.00 - $25.95	25.20	$0.00 - $25.95	25.20
	$25.96 - 35.68	6.56	$25.96 - 35.68	6.90	$25.96 - 35.68	6.79
	> $35.68	0.00	> $35.68	0.00	> $35.68	0.00
March	$0.00 - $25.95	25.20	$0.00 - $25.95	25.20	$0.00 - $25.95	25.20
	$25.96 - 35.68	6.83	$25.96 - 35.68	6.77	$25.96 - 35.68	6.89
	> $35.68	0.00	> $35.68	0.00	> $35.68	0.00

Table 31. Final Values in Pounds/Cow/Day or Megacalories/Cow/Day and Shadow Prices in Dollars/Cow/Day of Nutrients in the Spring Calving Schedule with BSG Inclusion at Varying Prices[1]

		Price Charged per Ton[2]					
		$0.00		$25.96		$35.69	
Month	**Nutrient**	**Final Value**	**Shadow Price[3]**	**Final Value**	**Shadow Price[3]**	**Final Value**	**Shadow Price[3]**
November	DMI (lbs.)	24.476	0.045	24.476	0.045	25.189	-
	TDN (lbs.)	15.860	-	14.685	-	14.685	0.077
	NE (Mcal)	53.918	-	31.897	-	24.796	-
	MP (lbs.)	1.998	-	1.589	-	1.486	-
December	DMI (lbs.)	24.255	0.045	24.255	0.045	24.962	-
	TDN (lbs.)	15.731	-	14.553	-	14.553	0.077
	NE (Mcal)	53.701	-	31.609	-	24.573	-
	MP (lbs.)	1.985	-	1.575	-	1.473	-
January	DMI (lbs.)	24.090	0.045	24.090	0.045	24.792	-
	TDN (lbs.)	15.635	-	14.454	-	14.454	0.077
	NE (Mcal)	53.538	-	31.394	-	24.406	-
	MP (lbs.)	1.975	-	1.564	-	1.463	-
February	DMI (lbs.)	24.365	0.045	24.365	0.045	25.076	-
	TDN (lbs.)	15.795	-	14.619	-	14.619	0.077
	NE (Mcal)	53.810	-	31.753	-	24.685	-
	MP (lbs.)	1.992	-	1.582	-	1.480	-
March	DMI (lbs.)	25.358	0.045	25.358	0.045	26.097	-
	TDN (lbs.)	16.374	-	15.215	-	15.215	0.077
	NE (Mcal)	54.786	-	33.046	-	25.690	-
	MP (lbs.)	2.050	-	1.646	-	1.540	-

[1]Value of BSG included varies as illustrated by associated demand curves (Figure 33).
[2]Prices change based on allowable increases from sensitivity report.
[3]Displayed as per cow/per day. (DM = dry matter, TDN = total digestible nutrients, NE = net energy, MP = metabolizable protein)

Table 32. Monthly Demand for DSG with Varying Prices for Each Calving Schedule

	Spring Calving Schedule		**Fall Calving Schedule**		**Year-Round Calving Schedule**	
Month	Price Range ($/Pound)	Pounds Demanded	Price Range ($/Pound)	Pounds Demanded	Price Range ($/Pound)	Pounds Demanded
November	$0.00 - $8.09	83.50	$0.00 - $8.09	83.50	$0.00 - $8.09	83.50
	$8.10 - $11.80	17.32	$8.10 - $15.48	21.92	$8.10 - $11.80	17.65
	> $11.80	0.00	> $15.48	0.00	> $11.80	0.00
December	$0.00 - $8.09	83.50	$0.00 - $8.09	83.50	$0.00 - $8.09	83.50
	$8.10 - $11.80	17.16	$8.10 - $11.80	18.99	$8.10 - $11.80	17.64
	> $11.80	0.00	$11.81 - $15.44	18.08	> $11.80	0.00
			> $15.44	0.00		
January	$0.00 - $8.09	83.50	$0.00 - $8.09	83.50	$0.00 - $8.09	83.50
	$8.10 - $11.80	17.04	$8.10 - $11.80	18.56	$8.10 - $11.80	17.69
	> $11.80	0.00	$11.81 - $15.44	3.10	> $11.80	0.00
			> $15.44	0.00		
February	$0.00 - $8.09	83.50	$0.00 - $8.09	83.50	$0.00 - $8.09	83.50
	$8.10 - $11.80	17.24	$8.10 - $11.80	18.13	$8.10 - $11.80	17.84
	> $11.80	0.00	> $11.80	0.00	> $11.80	0.00
March	$0.00 - $8.09	83.50	$0.00 - $8.09	83.50	$0.00 - $8.09	83.50
	$8.10 - $11.80	17.94	$8.10 - $11.80	17.78	$8.10 - $11.80	18.09
	> $11.80	0.00	> $11.80	0.00	> $11.80	0.00

Table 33. Final Values in Pounds/Cow/Day or Megacalories/Cow/Day and Shadow Prices in Dollars/Cow/Day of Nutrients in the Spring Calving Schedule with DSG Inclusion at Varying Prices[1]

		Price Charged per Ton[2]					
		$0.00		$8.10		$11.81	
Month	**Nutrient**	**Final Value**	**Shadow Price[3]**	**Final Value**	**Shadow Price[3]**	**Final Value**	**Shadow Price[3]**
November	DMI (lbs.)	24.476	0.045	24.476	0.045	24.476	-
	TDN (lbs.)	16.276	-	16.276	-	16.276	0.077
	NE (Mcal)	149.512	-	149.512	-	149.512	-
	MP (lbs.)	2.251	-	2.251	-	2.251	-
December	DMI (lbs.)	24.255	0.045	24.255	0.045	24.255	-
	TDN (lbs.)	16.147	-	16.147	-	16.147	0.077
	NE (Mcal)	149.295	-	149.295	-	149.295	-
	MP (lbs.)	2.238	-	2.238	-	2.238	-
January	DMI (lbs.)	24.090	0.045	24.090	0.045	24.090	-
	TDN (lbs.)	16.051	-	16.051	-	16.051	0.077
	NE (Mcal)	149.132	-	149.132	-	149.132	-
	MP (lbs.)	2.229	-	2.229	-	2.229	-
February	DMI (lbs.)	24.365	0.045	24.365	0.045	24.365	-
	TDN (lbs.)	16.211	-	16.211	-	16.211	0.077
	NE (Mcal)	149.403	-	149.403	-	149.403	-
	MP (lbs.)	2.245	-	2.245	-	2.245	-
March	DMI (lbs.)	25.358	0.045	25.358	0.045	25.358	-
	TDN (lbs.)	16.790	-	16.790	-	16.790	0.077
	NE (Mcal)	150.380	-	150.380	-	150.380	-
	MP (lbs.)	2.303	-	2.303	-	2.303	-

[1]Value of DSG included varies as illustrated by associated demand curves (Figure 34).
[2]Prices change based on allowable increases from sensitivity report.
[3]Displayed as per cow/per day. (DM = dry matter, TDN = total digestible nutrients, NE = net energy, MP = metabolizable protein)

Table 34. Cost Savings for Fall Calving Cow-Calf Producers from Including 7.2 Pounds of BSG or 47.1 Pounds of DSG at a Cost of $0.00 per Ton

	Cost/Cow/Day		
Month	**Base Scenario[1]**	**Average BSG Supply Scenario[245]**	**Average DSG Supply Scenario[346]**
November	$1.30	$1.14 (-11.9%)	$1.03 (-20.9%)
December	$1.28	$1.12 (-12.1%)	$1.02 (-20.3%)
January	$1.22	$1.09 (-10.9%)	$0.99 (-18.9%)
February	$1.19	$1.06 (-10.7%)	$0.96 (-18.9%)
March	$1.16	$1.04 (-10.9%)	$0.94 (-19.2%)

[1]Corn gluten feed was included in the ration in addition to hay for months November, December, and January.
[2]Corn gluten feed is included in months November and December in addition to hay and BSG.
[3]Only hay and DSG are included in the ration each month.
[4]Percent change from base located in parenthesis.
[5]Average supply of BSG is 7.2 pounds as indicated by a 2018 University of Tennessee survey of craft breweries and distilleries.
[6]Average supply of DSG is 47.1 pounds as indicated by a 2018 University of Tennessee survey of craft breweries and distilleries.

Table 35. Final Values in Pounds/Cow/Day and Reduced Costs in Dollars/Cow/Day for Feedstocks at Average BSG and DSG Inclusion for Fall Calving[1]

		BSG		DSG	
Month	**Feedstock**	**Final Value**	**Reduced Cost[2]**	**Final Value**	**Reduced Cost[2]**
November	Fescue Hay	27.399	-	25.669	-
	Corn Gluten Feed, Dry	0.701	-	-	0.029
	Cottonseed Meal	-	0.021	-	0.098
	Soybean Meal, High CP	-	0.054	-	0.149
	Soybean Hulls	-	0.021	-	0.028
	BSG	7.200	-0.021	47.100	-0.004
December	Fescue Hay	27.607	-	25.421	-
	Corn Gluten Feed, Dry	0.245	-	-	0.029
	Cottonseed Meal	-	0.021	-	0.098
	Soybean Meal, High CP	-	0.054	-	0.149
	Soybean Hulls	-	0.021	-	0.028
	BSG	7.200	-0.021	47.100	-0.004
January	Fescue Hay	27.170	-	24.739	-
	Corn Gluten Feed, Dry	-	0.029	-	0.029
	Cottonseed Meal	-	0.098	-	0.098
	Soybean Meal, High CP	-	0.149	-	0.149
	Soybean Hulls	-	0.028	-	0.028
	BSG	7.200	-0.013	47.100	-0.004
February	Fescue Hay	26.488	-	24.057	-
	Corn Gluten Feed, Dry	-	0.029	-	0.029
	Cottonseed Meal	-	0.098	-	0.098
	Soybean Meal, High CP	-	0.149	-	0.149
	Soybean Hulls	-	0.028	-	0.028
	BSG	7.200	-0.013	47.100	-0.004
March	Fescue Hay	25.930	-	23.499	-
	Corn Gluten Feed, Dry	-	0.029	-	0.029
	Cottonseed Meal	-	0.098	-	0.098
	Soybean Meal, High CP	-	0.149	-	0.149
	Soybean Hulls	-	0.028	-	0.028
	BSG	7.200	-0.013	47.100	-0.004

[1]Average daily production is 7.2 pounds of BSG and 47.1 pounds of DSG.
[2]Displayed as per cow/per day.
(CP = crude protein)

Table 36. Final Values in Pounds/Cow/Day or Megacalories/Cow/Day and Shadow Prices in Dollars/Cow/Day for Nutrients at Average BSG and DSG Inclusion for Fall Calving[1]

		BSG		DSG	
Month	**Nutrient**	**Final Value**	**Shadow Price[2]**	**Final Value**	**Shadow Price[2]**
November	DMI (lbs.)	27.066	0.022	27.066	0.045
	TDN (lbs.)	16.369	-	16.912	-
	NE (Mcal)	35.582	-	97.389	-
	MP (lbs.)	1.809	0.382	2.052	-
December	DMI (lbs.)	26.846	0.022	26.846	0.045
	TDN (lbs.)	16.153	-	16.783	-
	NE (Mcal)	35.094	-	97.172	-
	MP (lbs.)	1.761	0.382	2.039	-
January	DMI (lbs.)	26.240	0.045	26.240	0.045
	TDN (lbs.)	15.752	-	16.429	-
	NE (Mcal)	34.352	-	96.575	-
	MP (lbs.)	1.707	0.000	2.004	-
February	DMI (lbs.)	25.633	0.045	25.633	0.045
	TDN (lbs.)	15.398	-	16.076	-
	NE (Mcal)	33.755	-	95.978	-
	MP (lbs.)	1.671	-	1.968	-
March	DMI (lbs.)	25.137	0.045	25.137	0.045
	TDN (lbs.)	15.109	-	15.787	-
	NE (Mcal)	33.266	-	95.490	-
	MP (lbs.)	1.642	-	1.939	-

[1]Average daily production is 7.2 pounds of BSG and 47.1 pounds of DSG.
[2]Displayed as per cow/per day.
(DM = dry matter, TDN = total digestible nutrients, NE = net energy, MP = metabolizable protein)

Table 37. Final Values in Pounds/Cow/Day or Megacalories/Cow/Day and Shadow Prices in Dollars/Cow/Day of Nutrients in the Fall Calving Schedule with BSG Inclusion at Varying Prices[1]

		Price Charged per Ton[2]									
		$0.00		$25.96		$35.69		$42.75		$43.53	
Month	Nutrient	Final Value	Shadow Price[3]	Final Value	Shadow Price[3]	Final Value	Shadow Price[3]	Final Value	Shadow Price[3]	Final Value	Shadow Price[3]
November	DMI (lbs.)	27.066	0.045	27.066	0.045			27.066	0.022	27.066	0.022
	TDN (lbs.)	17.370	-	16.388	-			16.315	-	16.315	-
	NE (Mcal)	56.469	-	38.049	-			28.293	-	28.293	-
	MP (lbs.)	2.151	-	1.809	-			1.809	0.382	1.809	0.382
December	DMI (lbs.)	26.846	0.045	26.846	0.045			26.846	0.022	26.867	-
	TDN (lbs.)	17.242	-	16.159	-			16.108	-	16.108	0.052
	NE (Mcal)	56.251	-	35.956	-			29.039	-	27.816	-
	MP (lbs.)	2.138	-	1.761	-			1.761	0.382	1.761	0.251
January	DMI (lbs.)	26.240	0.045	26.240	0.045	26.240	-			26.849	-
	TDN (lbs.)	16.888	-	15.744	-	15.744	0.077			15.744	0.077
	NE (Mcal)	55.655	-	34.196	-	34.196	-			28.131	-
	MP (lbs.)	2.102	-	1.704	-	1.704	-			1.616	-
February	DMI (lbs.)	25.633	0.045	25.633	0.045	26.381	-			26.381	-
	TDN (lbs.)	16.534	-	15.380	-	15.380	0.077			15.380	0.077
	NE (Mcal)	55.058	-	33.405	-	25.969	-			25.969	-
	MP (lbs.)	2.066	-	1.664	-	1.557	-			1.557	-
March	DMI (lbs.)	25.137	0.045	25.137	0.045	25.870	-			25.870	-
	TDN (lbs.)	16.245	-	15.082	-	15.082	0.077			15.082	0.077
	NE (Mcal)	54.569	-	32.759	-	25.467	-			25.467	-
	MP (lbs.)	2.037	-	1.632	-	1.527	-			1.527	-

[1]Value of BSG included varies as illustrated by associated demand curves (Figure 35).

[2]Prices change based on allowable increases from sensitivity report; not all months had the same allowable increases.
[3]Displayed as per cow/per day.
(DM = dry matter, TDN = total digestible nutrients, NE = net energy, MP = metabolizable protein)

Table 38. Final Values in Pounds/Cow/Day or Megacalories/Cow/Day and Shadow Prices in Dollars/Cow/Day of Nutrients in the Fall Calving Schedule with DSG Inclusion at Varying Prices[1]

		Price Charged per Ton[2]									
		$0.00		$8.10		$11.81		$15.45		$15.49	
Month	Nutrient	Final Value	Shadow Price[3]	Final Value	Shadow Price[3]	Final Value	Shadow Price[3]	Final Value	Shadow Price[3]	Final Value	Shadow Price[3]
November	DMI (lbs.)	27.066	0.045	27.066	0.045					27.066	0.022
	TDN (lbs.)	17.786	-	16.306	-					16.315	-
	NE (Mcal)	152.062	-	59.561	-					28.293	-
	MP (lbs.)	2.404	-	1.809	-					1.809	0.382
December	DMI (lbs.)	26.846	0.045	26.846	0.045	26.846	-	26.867	-		
	TDN (lbs.)	17.658	-	16.108	-	16.108	0.077	16.108	0.052		
	NE (Mcal)	151.845	-	54.954	-	54.954	-	27.816	-		
	MP (lbs.)	2.391	-	1.768	-	1.768	-	1.761	0.251		
January	DMI (lbs.)	26.240	0.045	26.240	0.045	26.240	-	26.874	-		
	TDN (lbs.)	17.304	-	15.744	-	15.744	0.077	15.744	0.052		
	NE (Mcal)	151.248	-	53.712	-	53.712	-	26.689	-		
	MP (lbs.)	2.355	-	1.728	-	1.728	-	1.616	0.251		
February	DMI (lbs.)	25.633	0.045	25.633	0.045	25.633	-				
	TDN (lbs.)	16.951	-	15.380	-	15.380	0.077				
	NE (Mcal)	150.652	-	52.471	-	52.471	-				
	MP (lbs.)	2.320	-	1.688	-	1.688	-				
March	DMI (lbs.)	25.137	0.045	25.137	0.045	25.137	-				
	TDN (lbs.)	16.661	-	15.082	-	15.082	0.077				
	NE (Mcal)	150.163	-	51.456	-	51.456	-				
	MP (lbs.)	2.290	-	1.655	-	1.655	-				

[1]Value of DSG included varies as illustrated by associated demand curves (Figure 36).
[2]Prices change based on allowable increases from sensitivity report; not all months had the same allowable increases.

[3]Displayed as per cow/per day.
(DM = dry matter, TDN = total digestible nutrients, NE = net energy, MP = metabolizable protein)

Table 39. Cost Savings for Year-Round Calving Cow-Calf Producers from Including 7.2 Pounds of BSG or 47.1 Pounds of DSG at a Cost of $0.00 per Ton[1]

	Cost/Cow/Day		
Month	**Base Scenario**	**Average BSG Supply Scenario[2,3]**	**Average DSG Supply Scenario[2,4]**
November	$1.16	$1.03 (-10.9%)	$1.03 (-19.4%)
December	$1.15	$1.03 (-10.9%)	$1.03 (-19.4%)
January	$1.16	$1.03 (-10.9%)	$1.03 (-19.3%)
February	$1.17	$1.04 (-10.8%)	$1.04 (-19.2%)
March	$1.18	$1.06 (-10.7%)	$1.06 (-19.0%)

[1]Only hay and BSG or DSG were selected to be used in the ration for each month across all scenarios.
[2]Percent change from base located in parenthesis.
[3]Average supply of BSG is 7.2 pounds as indicated by a 2018 University of Tennessee survey of craft breweries and distilleries.
[4]Average supply of DSG is 47.1 pounds as indicated by a 2018 University of Tennessee survey of craft breweries and distilleries.

Table 40. Final Values in Pounds/Cow/Day and Reduced Costs in Dollars/Cow/Day for Feedstocks at Average BSG and DSG Inclusion for Year-Round Calving[1]

		BSG		DSG	
Month	**Feedstock**	**Final Value**	**Reduced Cost[2]**	**Final Value**	**Reduced Cost[2]**
November	Fescue Hay	25.726	-	23.296	-
	Corn Gluten Feed, Dry	-	0.029	-	0.029
	Cottonseed Meal	-	0.098	-	0.098
	Soybean Meal, High CP	-	0.149	-	0.149
	Soybean Hulls	-	0.028	-	0.028
	BSG	7.200	-0.013	47.100	-0.004
December	Fescue Hay	25.707	-	23.276	-
	Corn Gluten Feed, Dry	-	0.029	-	0.029
	Cottonseed Meal	-	0.098	-	0.098
	Soybean Meal, High CP	-	0.149	-	0.149
	Soybean Hulls	-	0.028	-	0.028
	BSG	7.200	-0.013	47.100	-0.004
January	Fescue Hay	25.785	-	23.354	-
	Corn Gluten Feed, Dry	-	0.029	-	0.029
	Cottonseed Meal	-	0.098	-	0.098
	Soybean Meal, High CP	-	0.149	-	0.149
	Soybean Hulls	-	0.028	-	0.028
	BSG	7.200	-0.013	47.100	-0.004
February	Fescue Hay	26.018	-	23.587	-
	Corn Gluten Feed, Dry	-	0.029	-	0.029
	Cottonseed Meal	-	0.098	-	0.098
	Soybean Meal, High CP	-	0.149	-	0.149
	Soybean Hulls	-	0.028	-	0.028
	BSG	7.200	-0.013	47.100	-0.004
March	Fescue Hay	26.411	-	23.980	-
	Corn Gluten Feed, Dry	-	0.029	-	0.029
	Cottonseed Meal	-	0.098	-	0.098
	Soybean Meal, High CP	-	0.149	-	0.149
	Soybean Hulls	-	0.028	-	0.028
	BSG	7.200	-0.013	47.100	-0.004

[1]Average daily production is 7.2 pounds of BSG and 47.1 pounds of DSG.
[2]Displayed as per cow/per day.
(CP = crude protein)

Table 41. Final Values in Pounds/Cow/Day or Megacalories/Cow/Day and Shadow Prices in Dollars/Cow/Day for Nutrients at Average BSG and DSG Inclusion for Year-Round Calving[1]

		BSG		DSG	
Month	**Nutrient**	**Final Value**	**Shadow Price[2]**	**Final Value**	**Shadow Price[2]**
November	DMI (lbs.)	24.956	0.045	24.956	0.045
	TDN (lbs.)	15.004	-	15.681	-
	NE (Mcal)	33.088	-	95.311	-
	MP (lbs.)	1.631	-	1.928	-
December	DMI (lbs.)	24.938	0.045	24.938	0.045
	TDN (lbs.)	14.993	-	15.671	-
	NE (Mcal)	33.070	-	95.294	-
	MP (lbs.)	1.630	-	1.927	-
January	DMI (lbs.)	25.008	0.045	25.008	0.045
	TDN (lbs.)	15.034	-	15.711	-
	NE (Mcal)	33.139	-	95.363	-
	MP (lbs.)	1.634	-	1.931	-
February	DMI (lbs.)	25.215	0.045	25.215	0.045
	TDN (lbs.)	15.155	-	15.832	-
	NE (Mcal)	33.343	-	95.567	-
	MP (lbs.)	1.646	-	1.943	-
March	DMI (lbs.)	25.564	0.045	25.564	0.045
	TDN (lbs.)	15.358	-	16.036	-
	NE (Mcal)	33.687	-	95.911	-
	MP (lbs.)	1.667	-	1.964	-

[1]Average daily production is 7.2 pounds of BSG and 47.1 pounds of DSG.
[2]Displayed as per cow/per day.
(DM = dry matter, TDN = total digestible nutrients, NE = net energy, MP = metabolizable protein)

Table 42. Final Values in Pounds/Cow/Day or Megacalories/Cow/Day and Shadow Prices in Dollars/Cow/Day of Nutrients in the Year-Round Calving Schedule with BSG Inclusion at Varying Prices[1]

		Price Charged per Ton[2]					
		$0.00		$25.96		$35.69	
Month	**Nutrient**	**Final Value**	**Shadow Price[3]**	**Final Value**	**Shadow Price[3]**	**Final Value**	**Shadow Price[3]**
November	DMI (lbs.)	24.956	0.045	24.956	0.045	25.683	-
	TDN (lbs.)	16.140	-	14.973	-	14.973	0.077
	NE (Mcal)	54.391	-	32.523	-	25.283	-
	MP (lbs.)	2.027	-	1.620	-	1.516	-
December	DMI (lbs.)	24.938	0.045	24.938	0.045	25.665	-
	TDN (lbs.)	16.129	-	14.963	-	14.963	0.077
	NE (Mcal)	54.373	-	32.500	-	25.265	-
	MP (lbs.)	2.025	-	1.619	-	1.514	-
January	DMI (lbs.)	25.008	0.045	25.008	0.045	25.737	-
	TDN (lbs.)	16.170	-	15.005	-	15.005	0.077
	NE (Mcal)	54.442	-	32.591	-	25.336	-
	MP (lbs.)	2.030	-	1.624	-	1.519	-
February	DMI (lbs.)	25.215	0.045	25.215	0.045	25.950	-
	TDN (lbs.)	16.291	-	15.129	-	15.129	0.077
	NE (Mcal)	54.646	-	32.861	-	25.546	-
	MP (lbs.)	2.042	-	1.637	-	1.531	-
March	DMI (lbs.)	25.564	0.045	25.564	0.045	26.310	-
	TDN (lbs.)	16.494	-	15.339	-	15.339	0.077
	NE (Mcal)	54.990	-	33.316	-	25.900	-
	MP (lbs.)	2.062	-	1.660	-	1.552	-

[1]Value of BSG included varies as illustrated by associated demand curves (Figure 37).
[2]Prices change based on allowable increases from sensitivity report.
[3]Displayed as per cow/per day. (DM = dry matter, TDN = total digestible nutrients, NE = net energy, MP = metabolizable protein)

Table 43. Final Values in Pounds/Cow/Day or Megacalories/Cow/Day and Shadow Prices in Dollars/Cow/Day of Nutrients in the Year-Round Calving Schedule with DSG Inclusion at Varying Prices[1]

		Price Charged per Ton[2]					
		$0.00		$8.10		$11.81	
Month	**Nutrient**	**Final Value**	**Shadow Price[3]**	**Final Value**	**Shadow Price[3]**	**Final Value**	**Shadow Price[3]**
November	DMI (lbs.)	24.956	0.045	24.956	0.045	25.683	-
	TDN (lbs.)	16.556	-	14.973	-	14.973	0.077
	NE (Mcal)	149.985	-	51.085	-	25.283	-
	MP (lbs.)	2.280	-	1.643	-	1.516	-
December	DMI (lbs.)	24.938	0.045	24.938	0.045	25.665	-
	TDN (lbs.)	16.545	-	14.963	-	14.963	0.077
	NE (Mcal)	149.967	-	51.048	-	25.265	-
	MP (lbs.)	2.279	-	1.642	-	1.514	-
January	DMI (lbs.)	25.008	0.045	25.008	0.045	25.737	-
	TDN (lbs.)	16.586	-	15.005	-	15.005	0.077
	NE (Mcal)	150.036	-	51.192	-	25.336	-
	MP (lbs.)	2.283	-	1.647	-	1.519	-
February	DMI (lbs.)	25.215	0.045	25.215	0.045	25.950	-
	TDN (lbs.)	16.707	-	15.129	-	15.129	0.077
	NE (Mcal)	150.240	-	51.615	-	25.546	-
	MP (lbs.)	2.295	-	1.660	-	1.531	-
March	DMI (lbs.)	25.564	0.045	25.564	0.045	26.310	-
	TDN (lbs.)	16.911	-	15.339	-	15.339	0.077
	NE (Mcal)	150.584	-	52.330	-	25.900	-
	MP (lbs.)	2.316	-	1.683	-	1.552	-

[1]Value of DSG included varies as illustrated by associated demand curves (Figure 38).
[2]Prices change based on allowable increases from sensitivity report.
[3]Displayed as per cow/per day. (DM = dry matter, TDN = total digestible nutrients, NE = net energy, MP = metabolizable protein)

Table 44. Estimated Total Winter-Feeding Costs for a 25 Head Herd on Varying Calving Schedules with Average Supply of BDSG[1]

Calving Schedule	Base Scenario (No BDSG)	Average BSG Supply (7.2 lbs.)	Average DSG Supply (47.1 lbs.)
Spring	$4,283.35	$3,809.29 (-11.1%)	$3,442.22 (-19.6%)
Fall[2]	$4,640.47	$4,115.07 (-11.3%)	$3,727.12 (-19.7%)
Year-Round	$4,392.44	$3,915.28 (-10.9%)	$3,548.22 (-19.3%)

[1]Percent change from base located in parenthesis.
[2]Fall base scenario includes corn gluten feed in months November through January and fall average supply of BSG includes corn gluten feed in November and December.

Table 45. Estimated Total Winter-Feeding Costs for a 25 Head Herd on Varying Calving Schedules with High Supply of BDSG[1]

Calving Schedule	Base Scenario (No BDSG)	High BSG Supply (25.2 lbs.)	High DSG Supply (83.5 lbs.)
Spring	$4,283.35	$2,927.54 (-31.7%)	$2,885.97 (-32.6%)
Fall	$4,640.47	$3,212.43 (-30.8%)	$3,170.86 (-31.7%)
Year-Round	$4,392.44	$3,033.53 (-30.9%)	$2,991.96 (-31.9%)

[1]Percent change from base located in parenthesis.

Appendix B: Figures

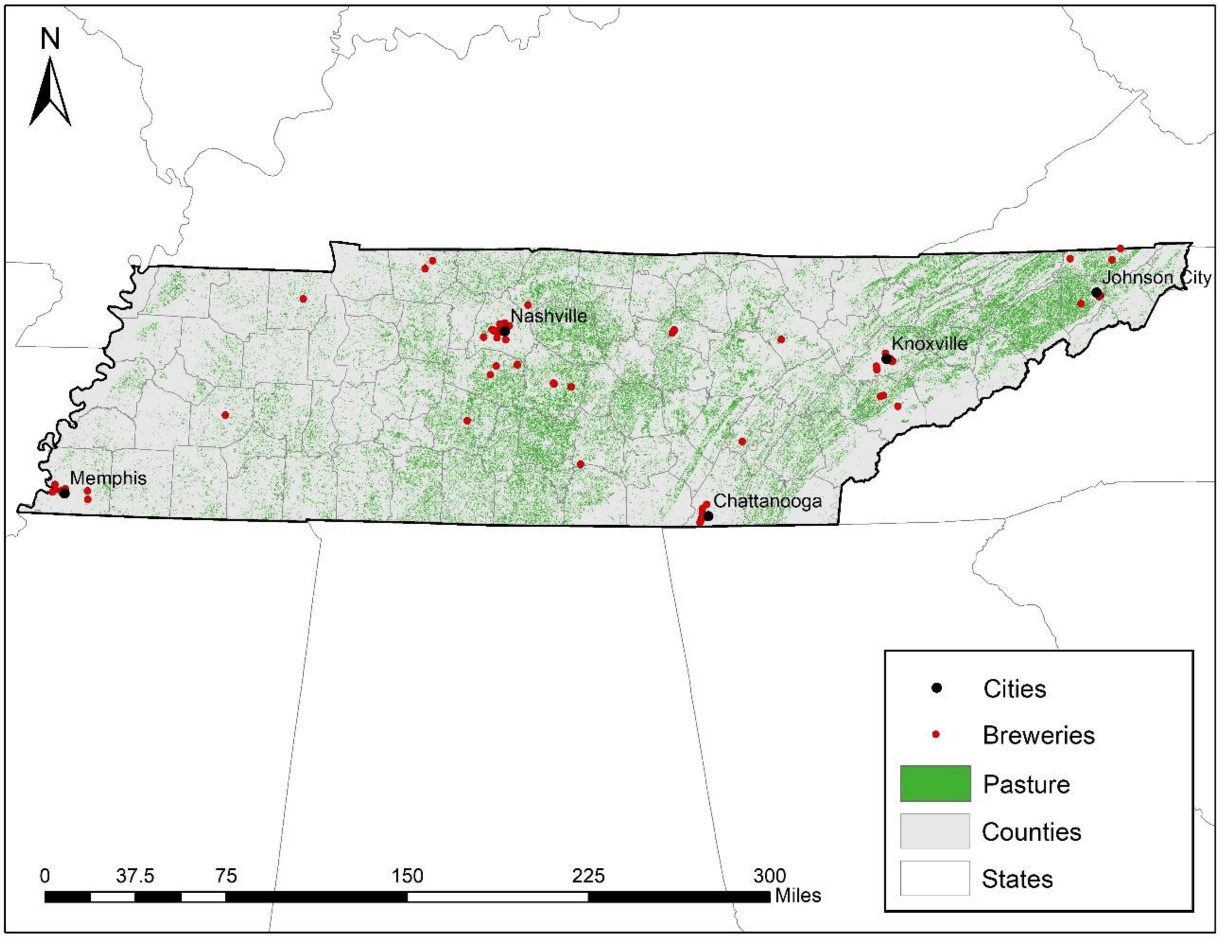

Figure 1. Map of 96 Identified Breweries in Tennessee with Pasture Layer

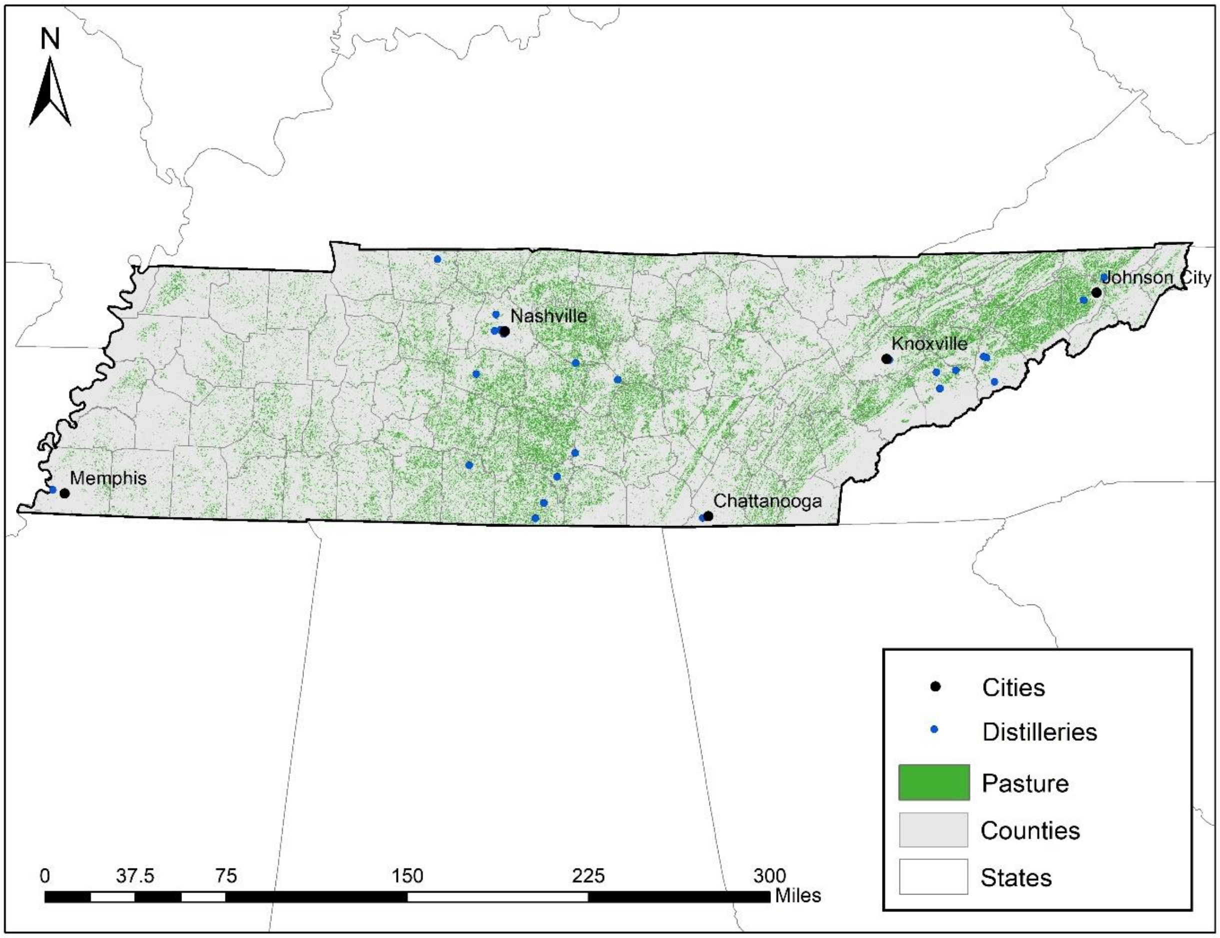

Figure 2. Map of 34 Identified Distilleries in Tennessee with Pasture Layer

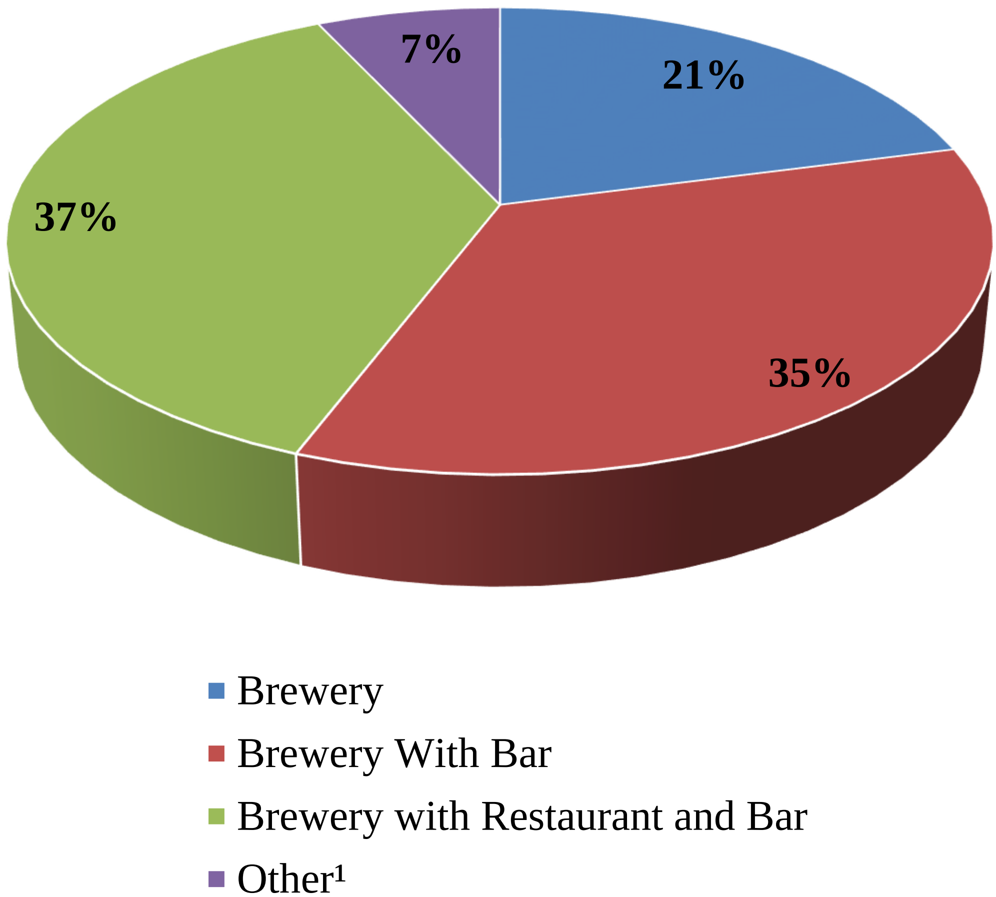

Figure 3. Brewery Business Descriptions – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n = 43
[1]Comments listed in the "other" category included: "brewery and farm", "cans of beer available", and "brew pub".

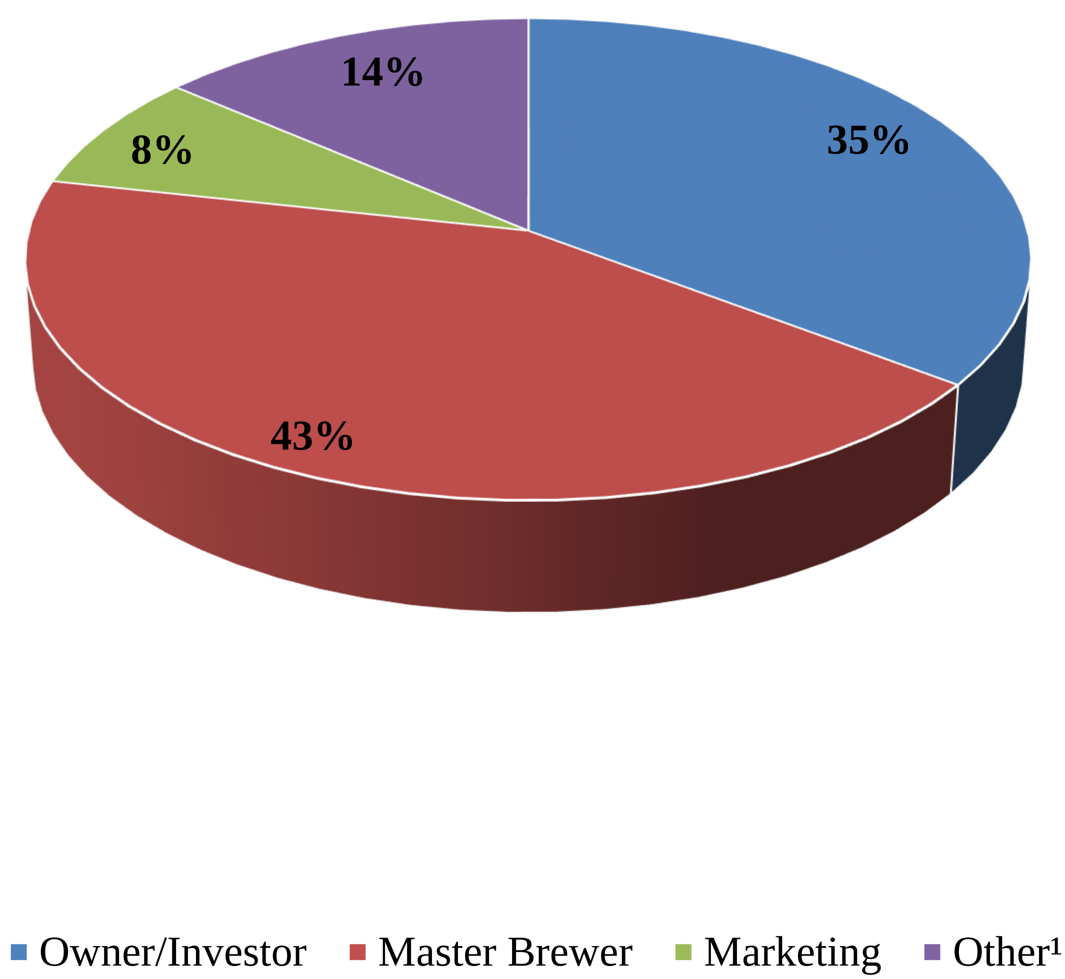

Figure 4. Brewery Survey Respondents' Business Roles – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n = 51
[1]Comments listed in the "other" category included: "owner/brewer", "manager", "head brewer", "general manager", "sales manager", and "assistant brewer/taproom manager".

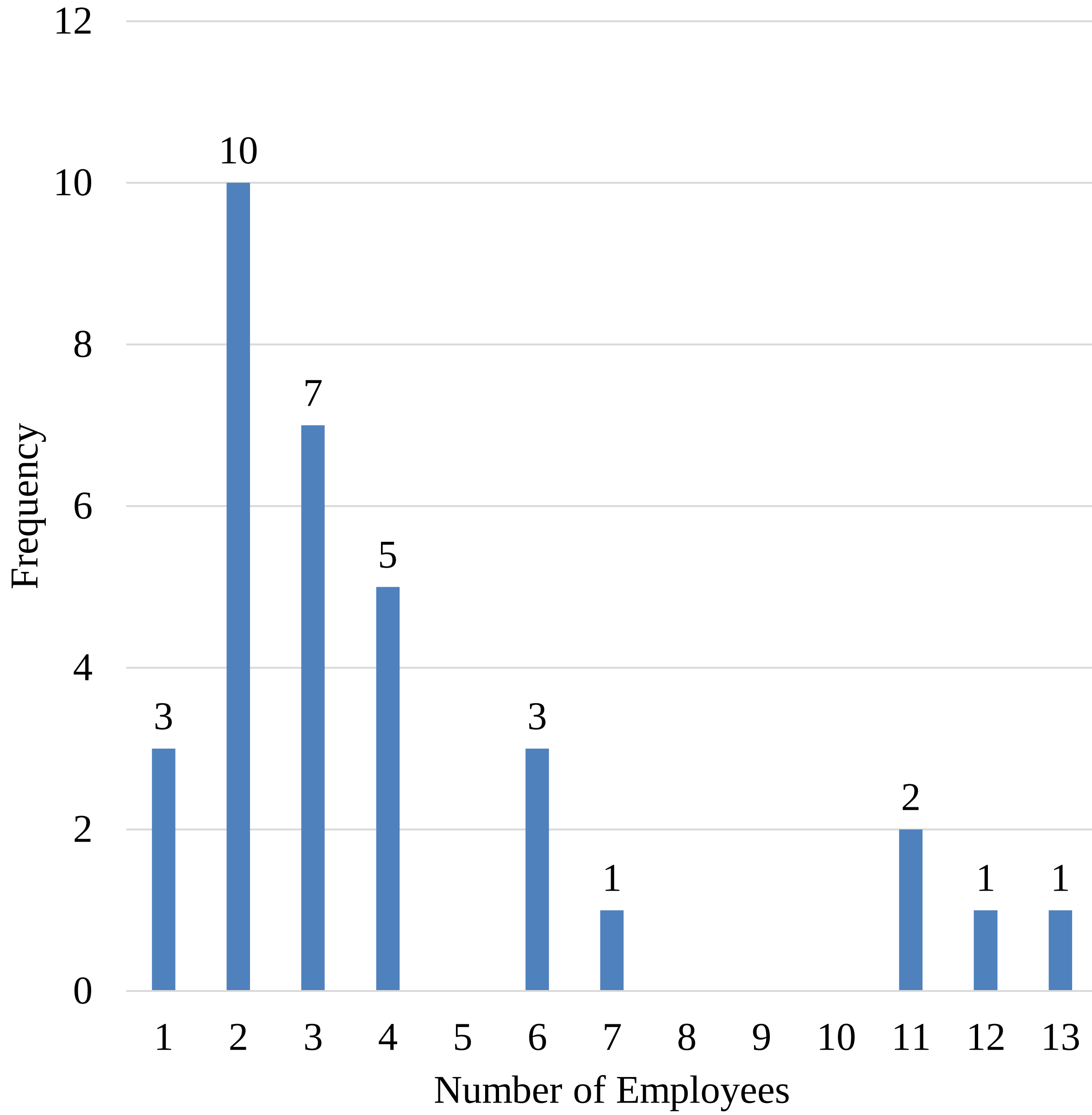

Figure 5. Number of Employees Employed by the Brewing Operation – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n=34

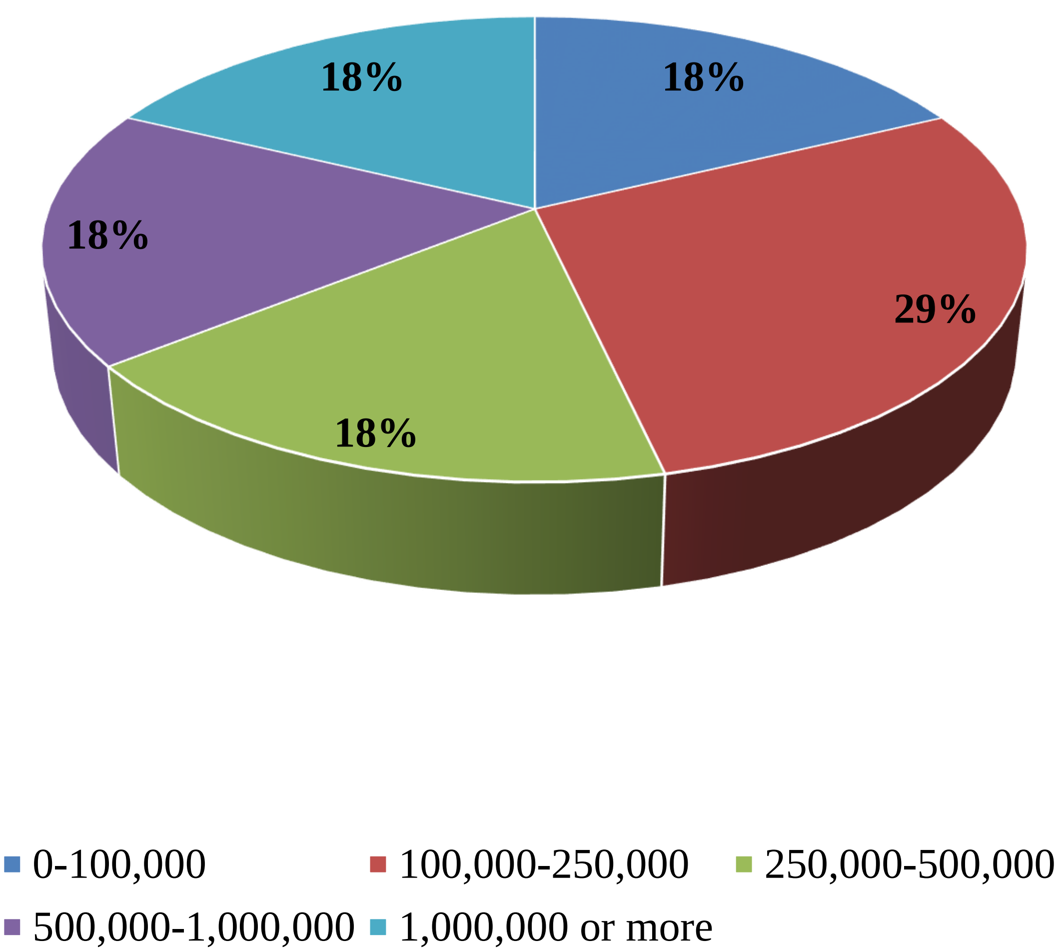

Figure 6. Brewery Annual Gross Alcoholic Beverage Sales During the Last Fiscal Year – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n=28

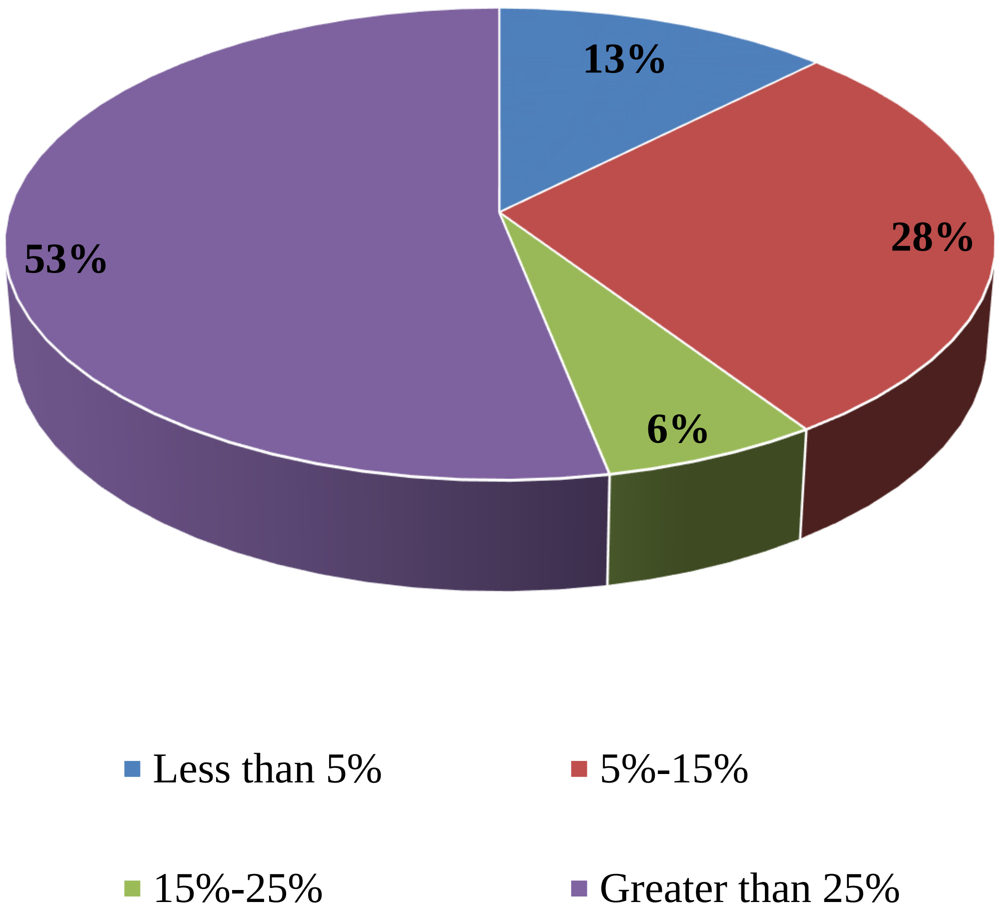

Figure 7. Brewery Expected Sales Increase Over the Next Five Years – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n=32

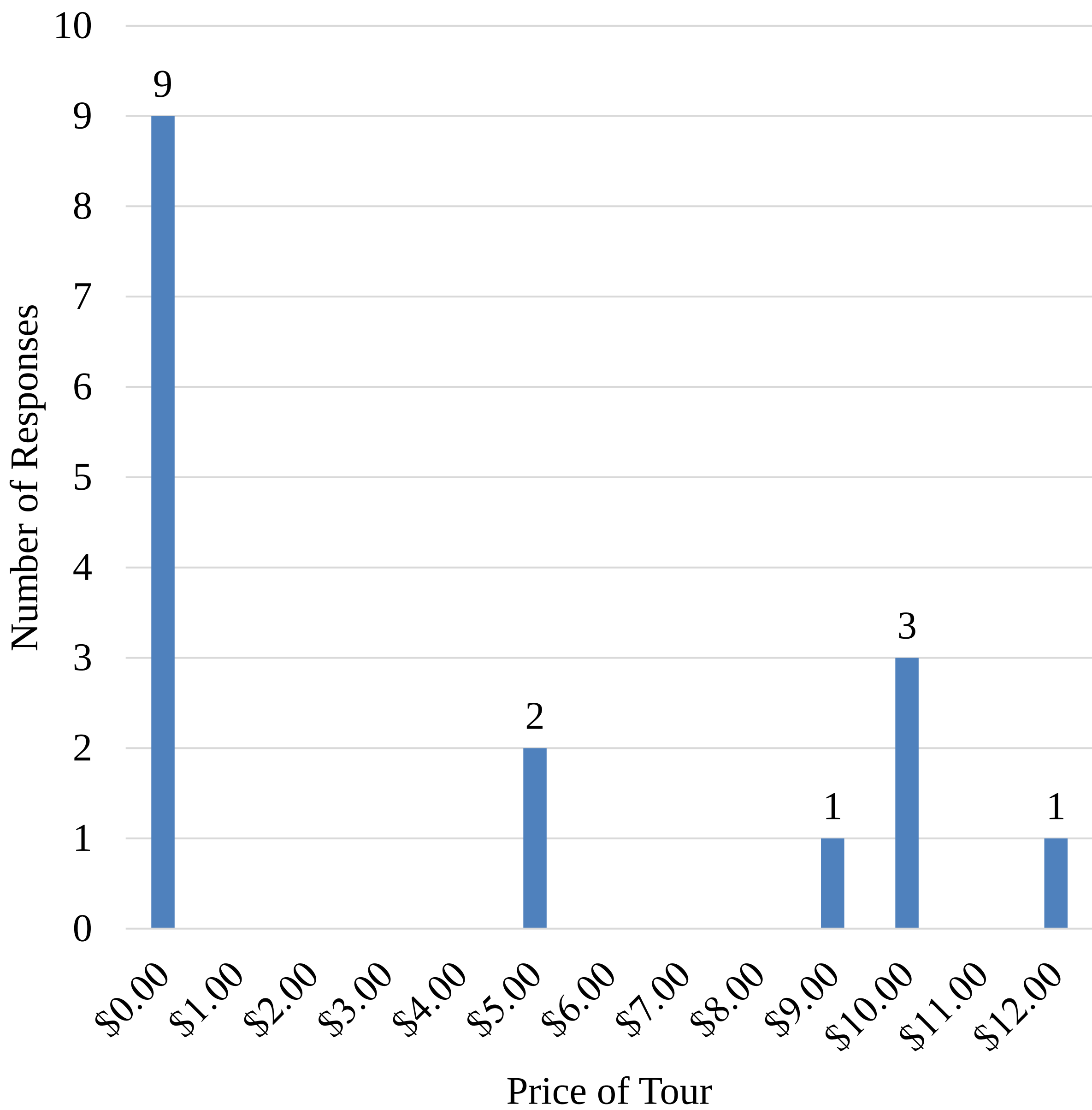

Figure 8. Prices Charged by Breweries for Tours – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n = 16

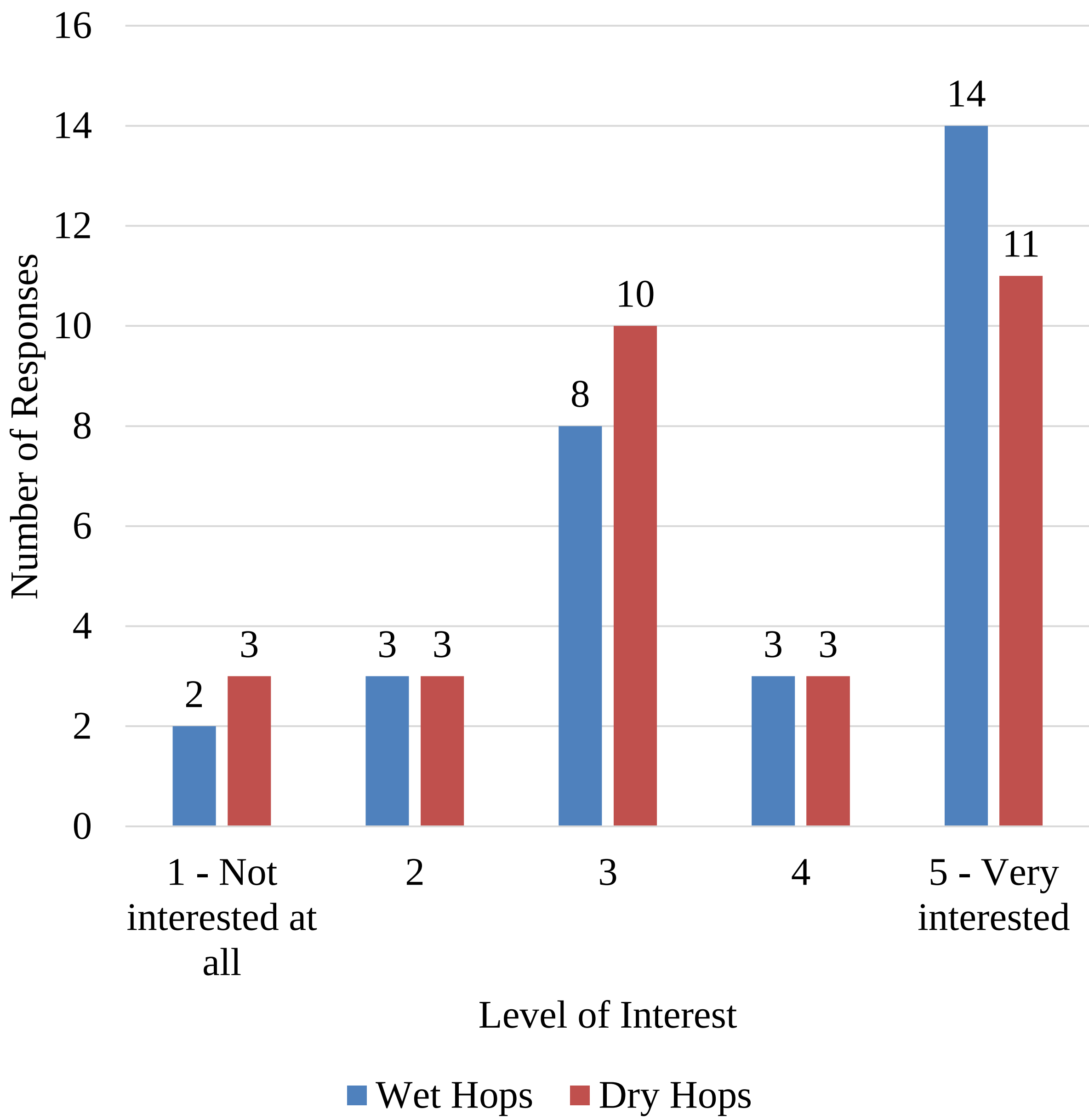

Figure 9. Brewery Interest in Purchasing Tennessee-Grown Hops (With 1 Being Not Interested at all and 5 Being Very Interested) – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n=30

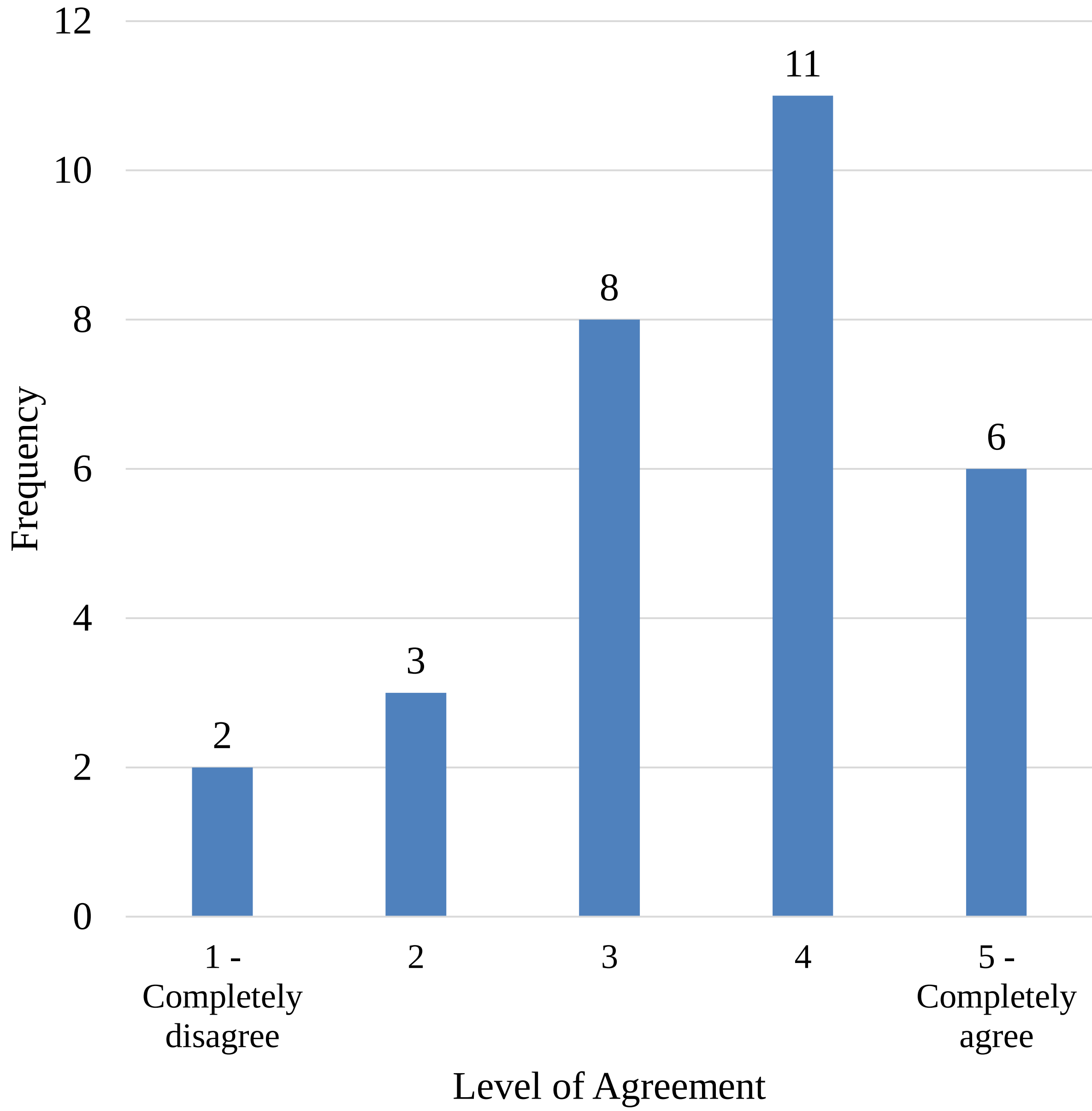

Figure 10. Brewery Frequency of Responses When Asked Whether They Are Only Interested in Using Pelletized Hops (With 1 Indicating They Completely Disagree With the Statement "I am Only Interested in Using Pelletized Hops, and 5 Indicating They Completely Agree With the Statement) – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n=30

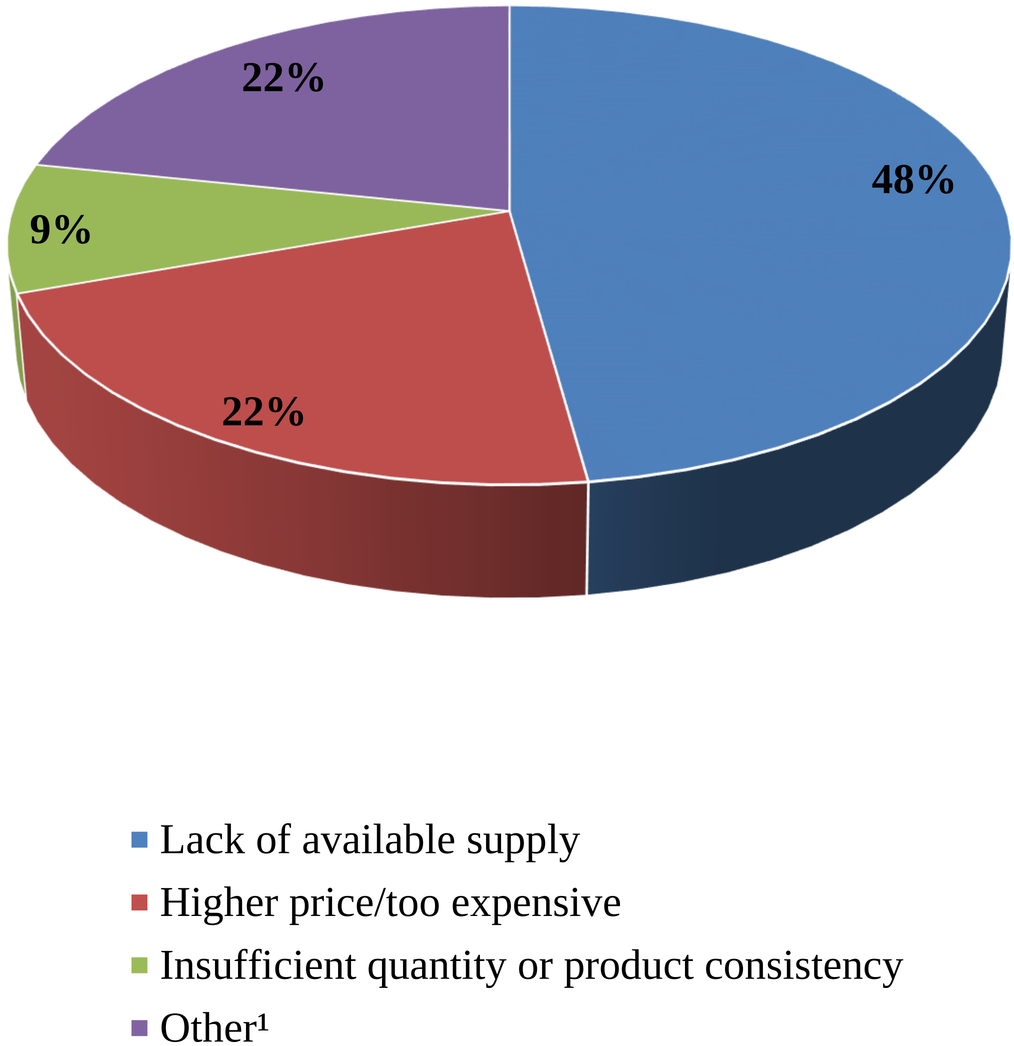

Figure 11. Brewery Reasons for Not Purchasing Tennessee Grains – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n=23
[1]Comments listed in the "other" category included: "required varieties not available", "never been approached", "quality concerns", "not looked into it", and "no control over purchasing his own hops; determined by corporate".

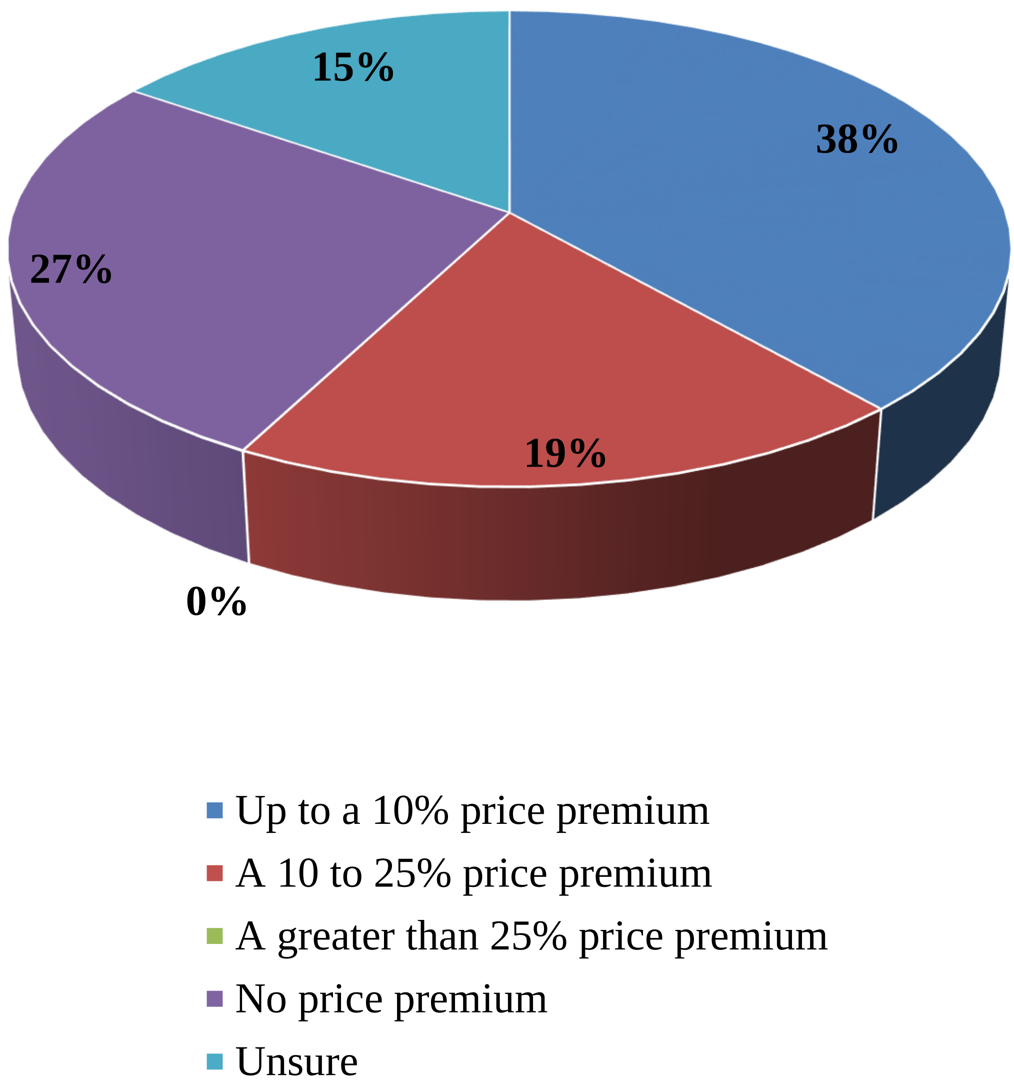

Figure 12. Brewery Willingness to Pay a Price Premium for a Tennessee Malting House Using Tennessee-Grown Barley – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n=26

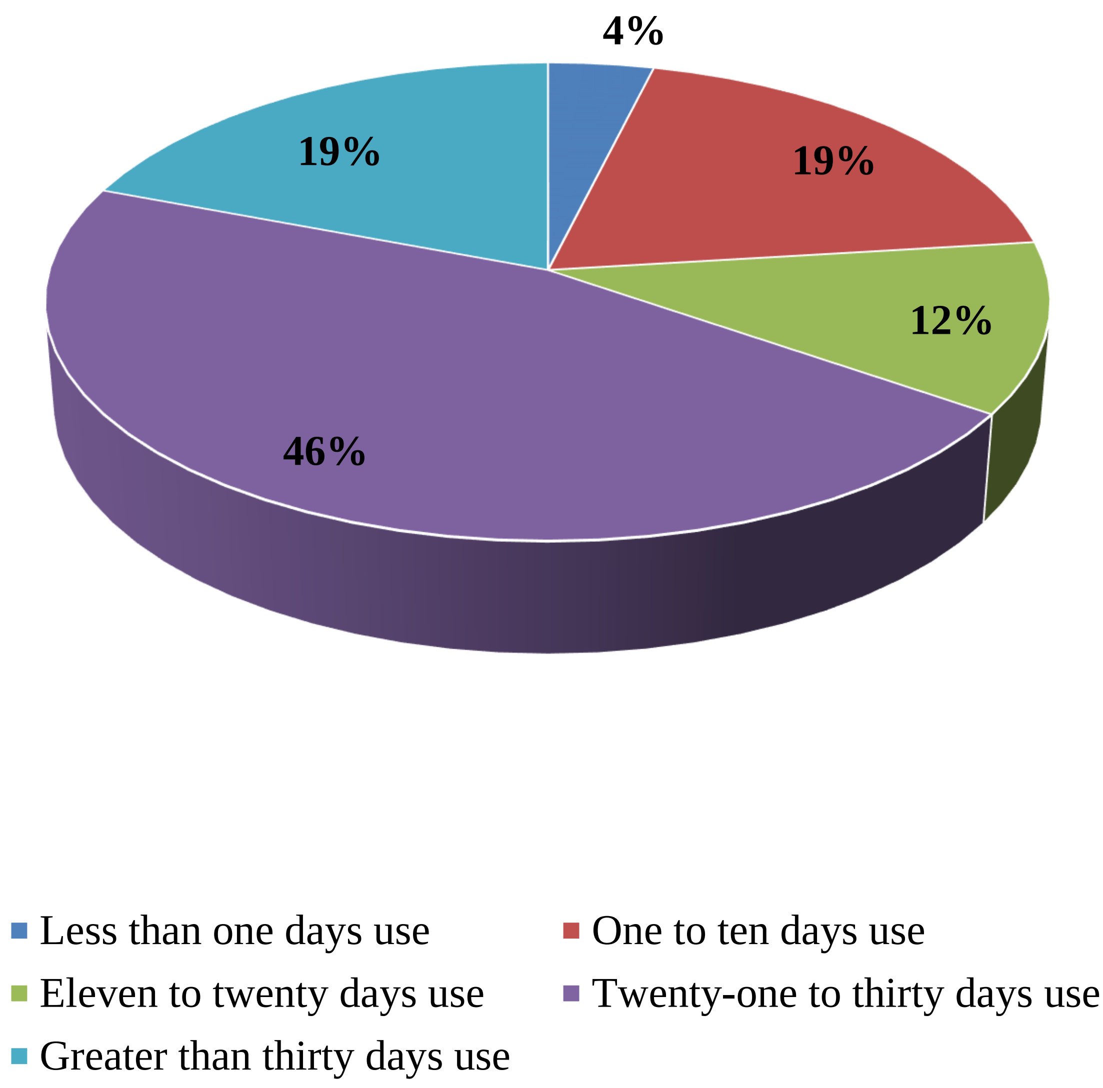

Figure 13. Number of Days Breweries Have Available for Onsite Storage of Barley and Other Grains – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n=26

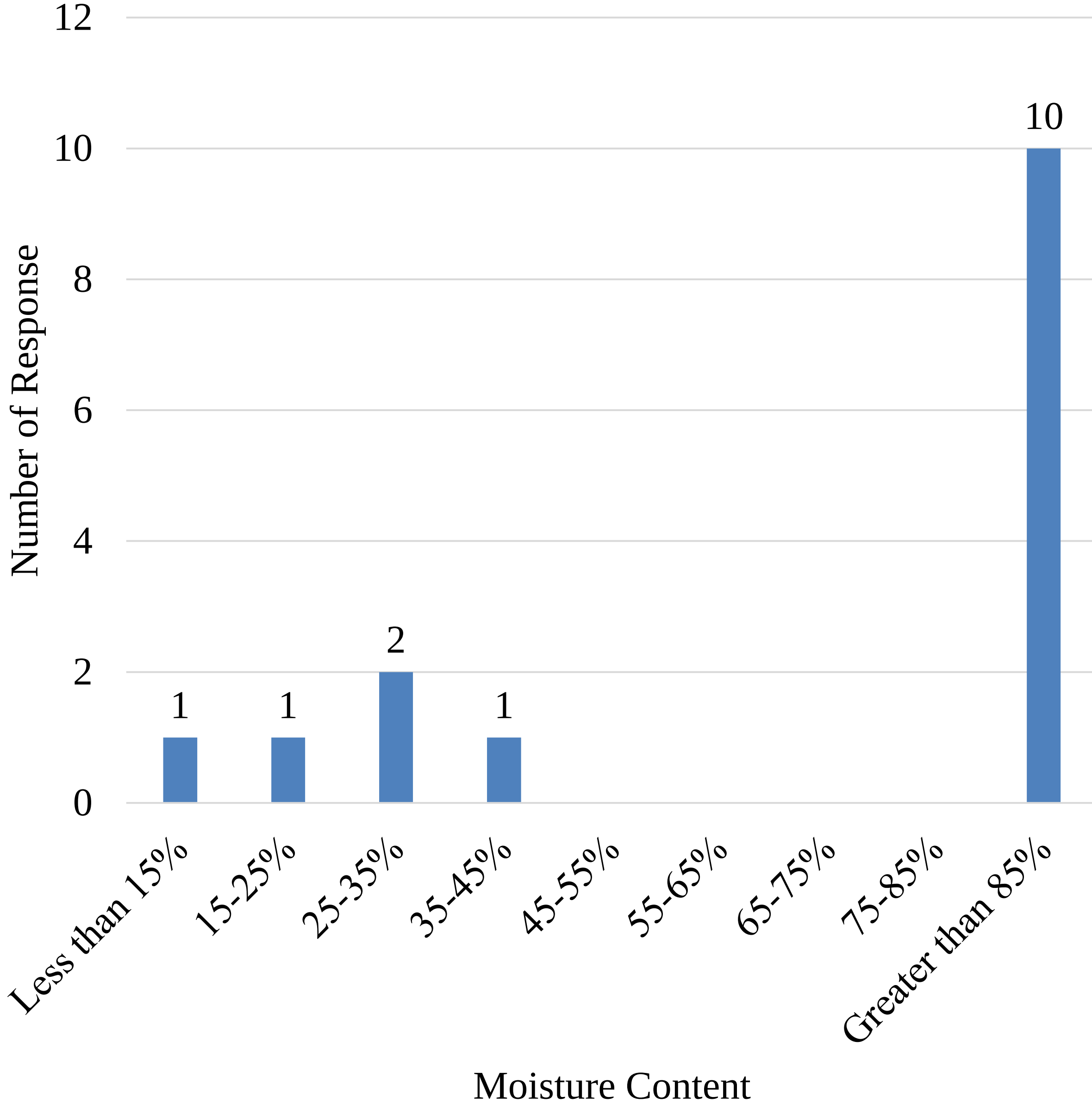

Figure 14. Moisture Content of BSG When It Exits Facility – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n=15

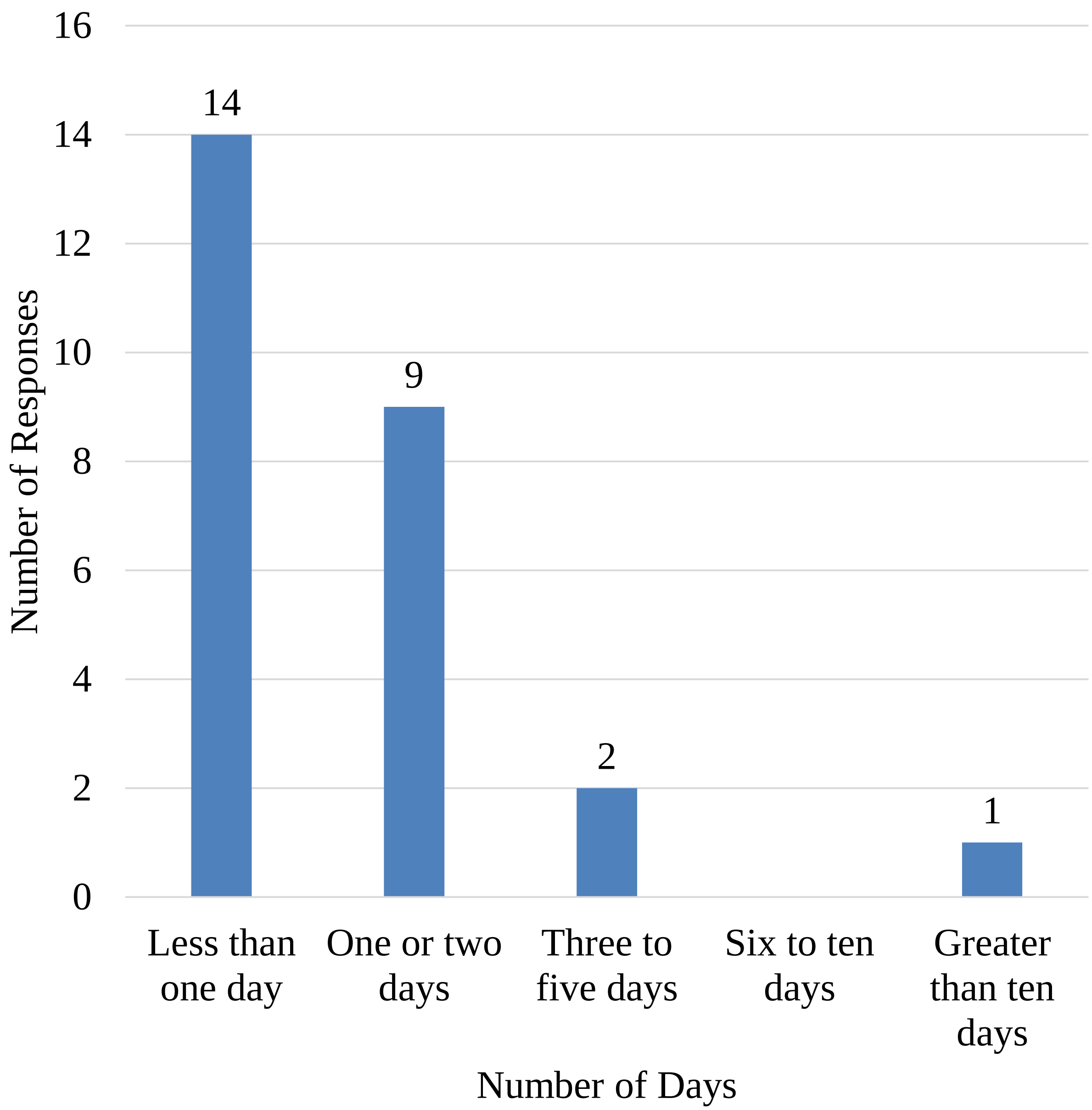

Figure 15. Number of Days BSG Spends at Facility – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n=26

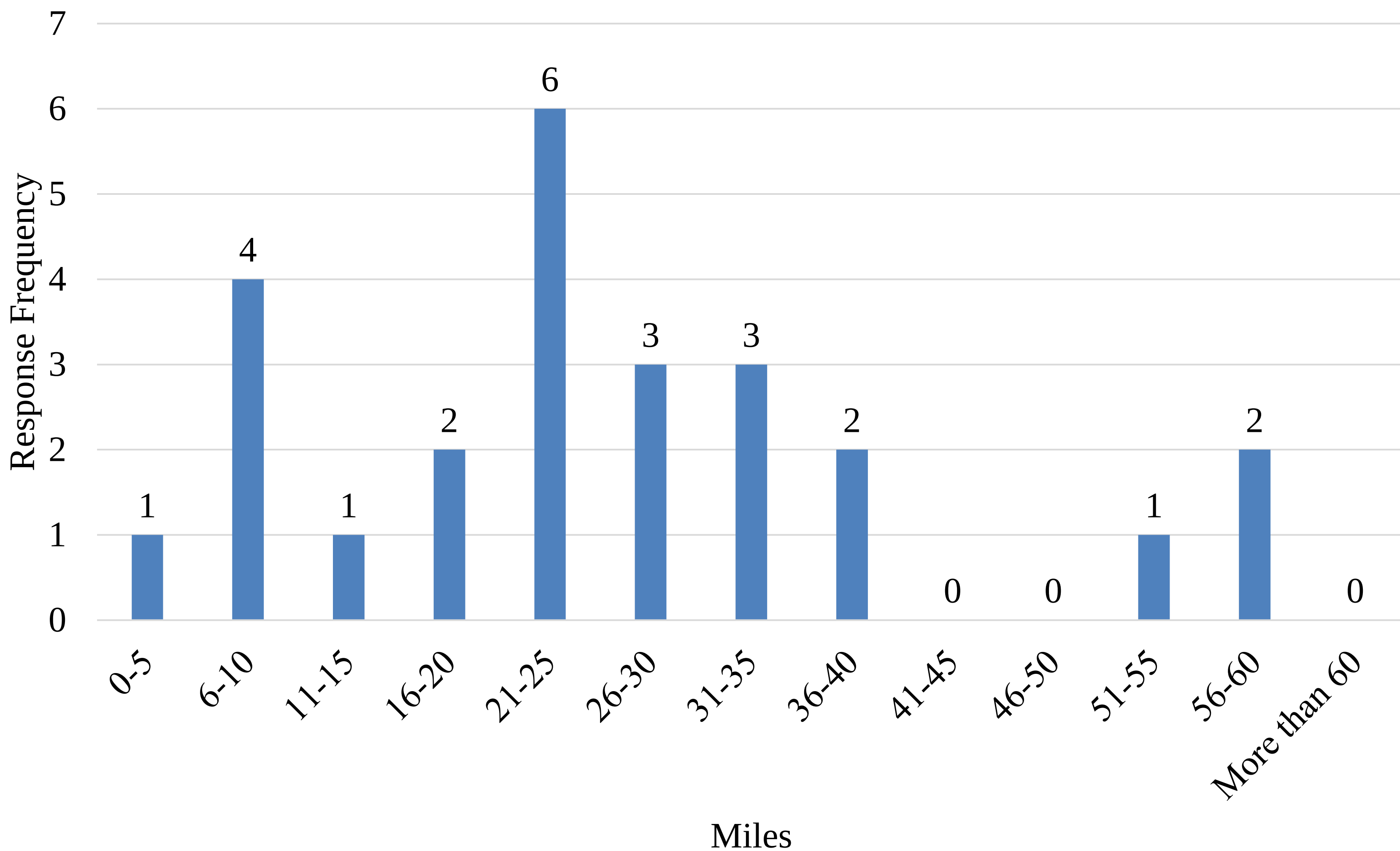

Figure 16. Miles BSG Travels from the Brewery to a Livestock Facility – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n = 25

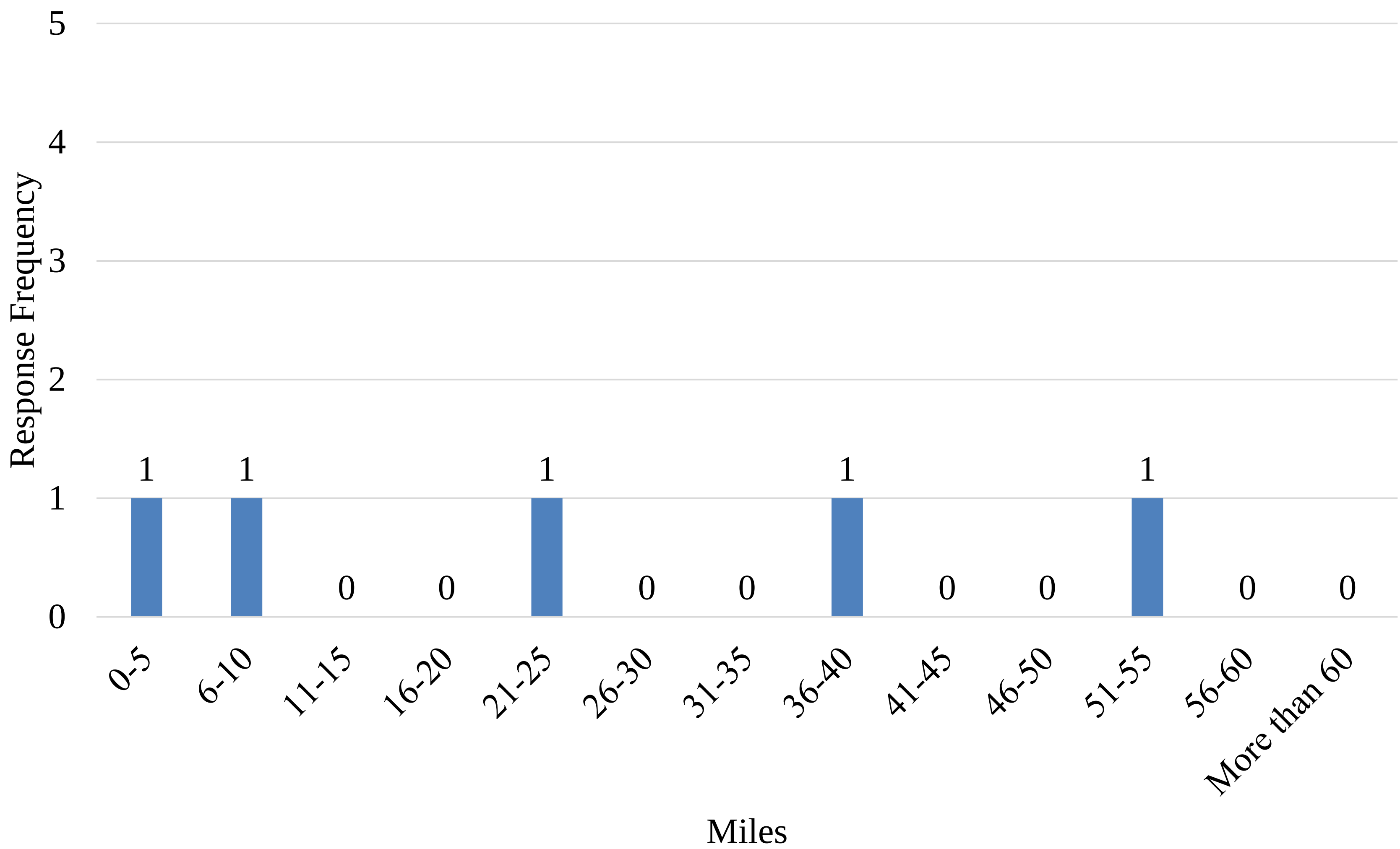

Figure 17. Miles BSG Travels from the Brewery to a Producer Utilizing BSG for Composting/Soil Amendments/Fertilizers – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n = 5

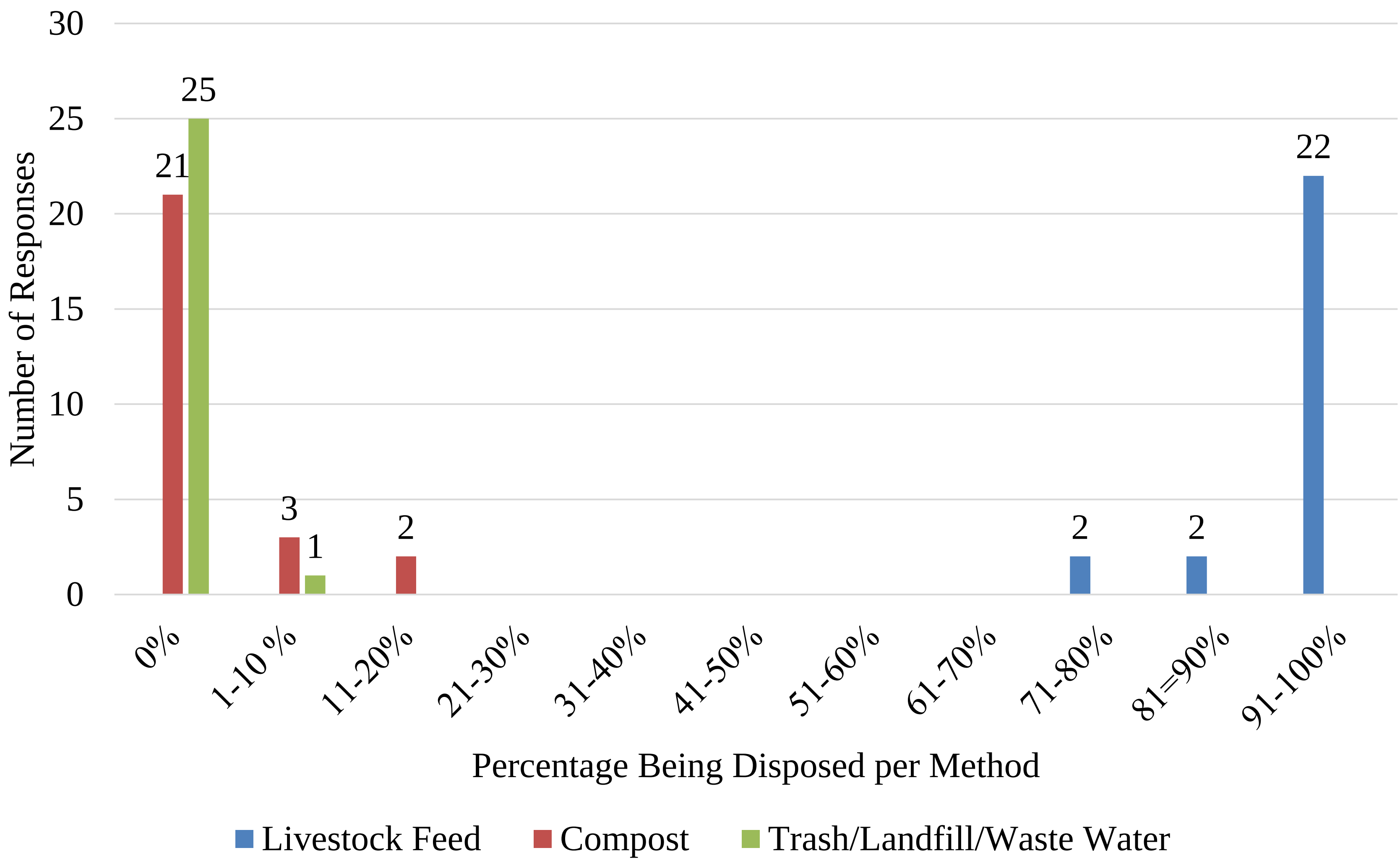

Figure 18. Percentage of Spent Grains Being Disposed of Through Each Method by Breweries – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n=26

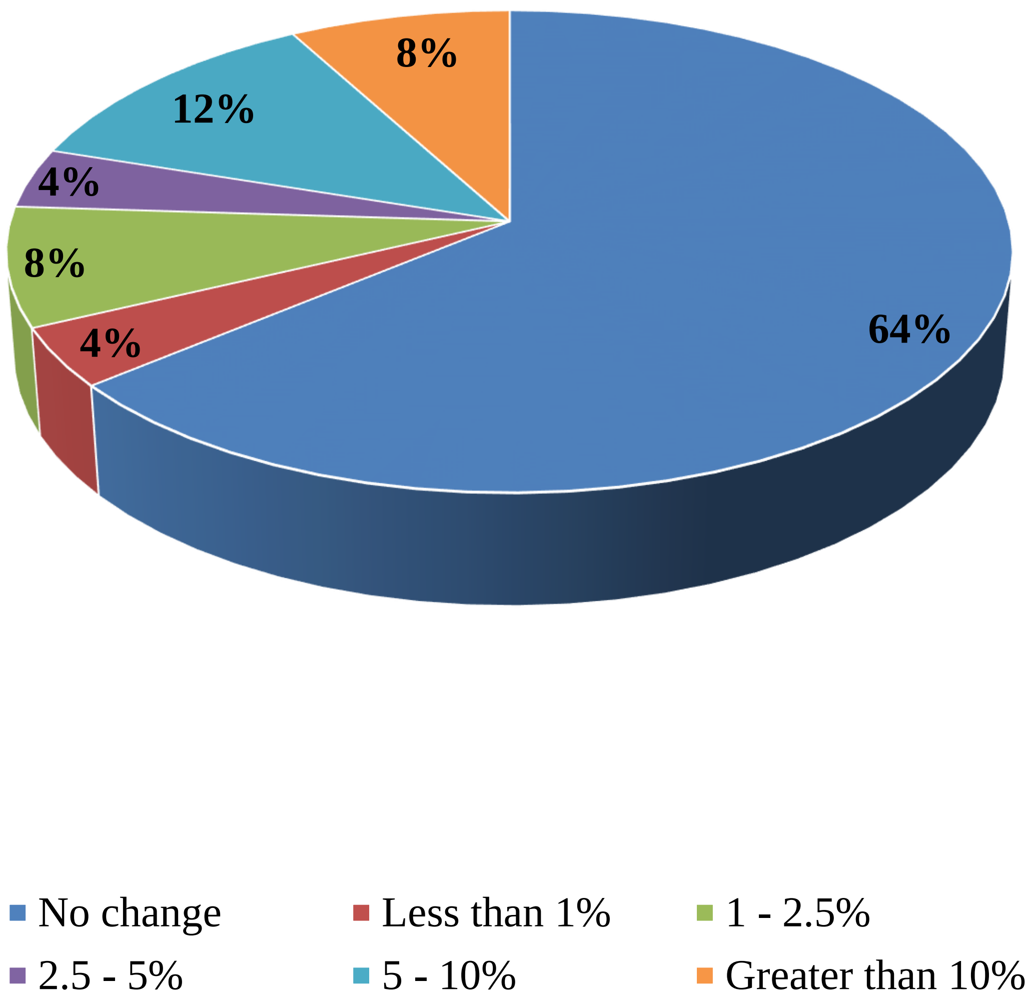

Figure 19. Expected Price Premium by Breweries from Sustainable Marketing – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n=25

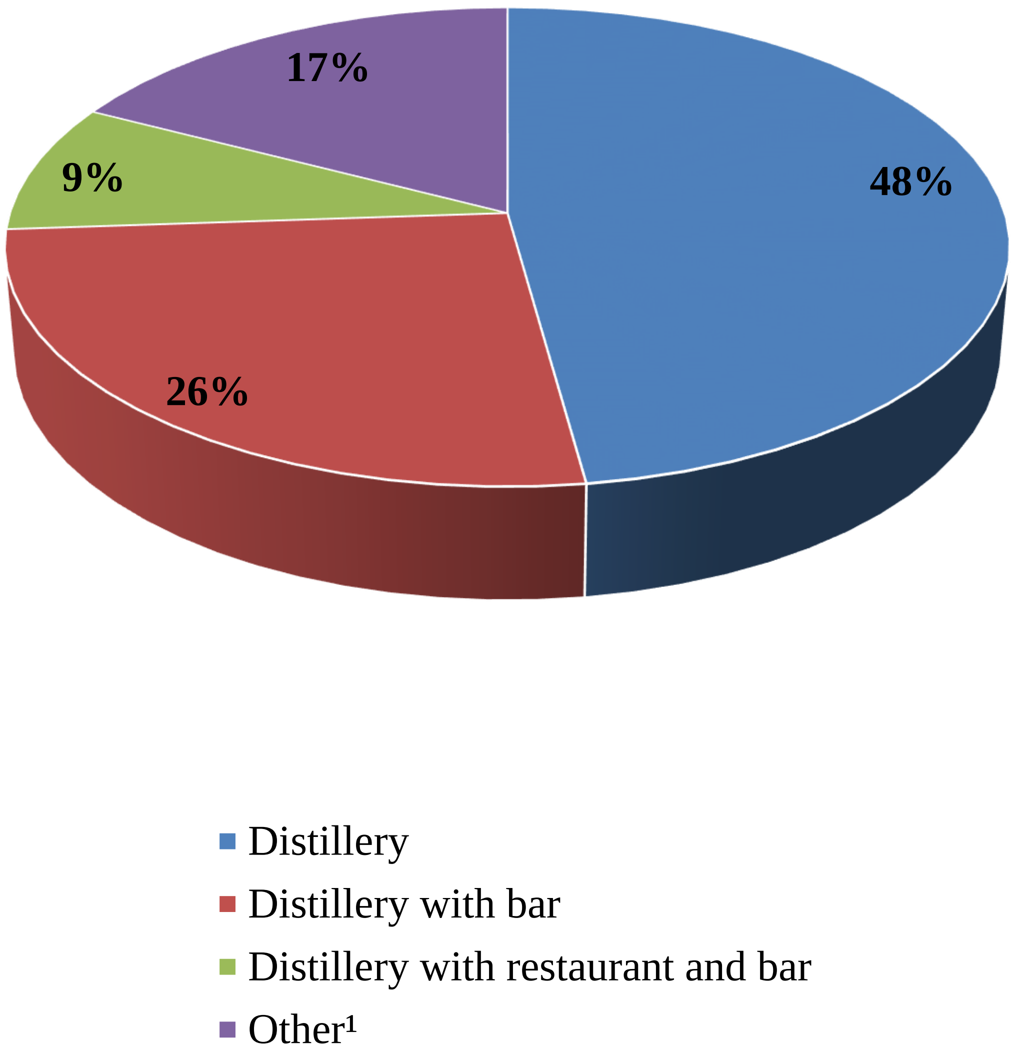

Figure 20. Distillery Business Descriptions – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n = 23
[1]Comments listed in the "other" category included: "tastings", "gift shop, tours and events" and "retail".

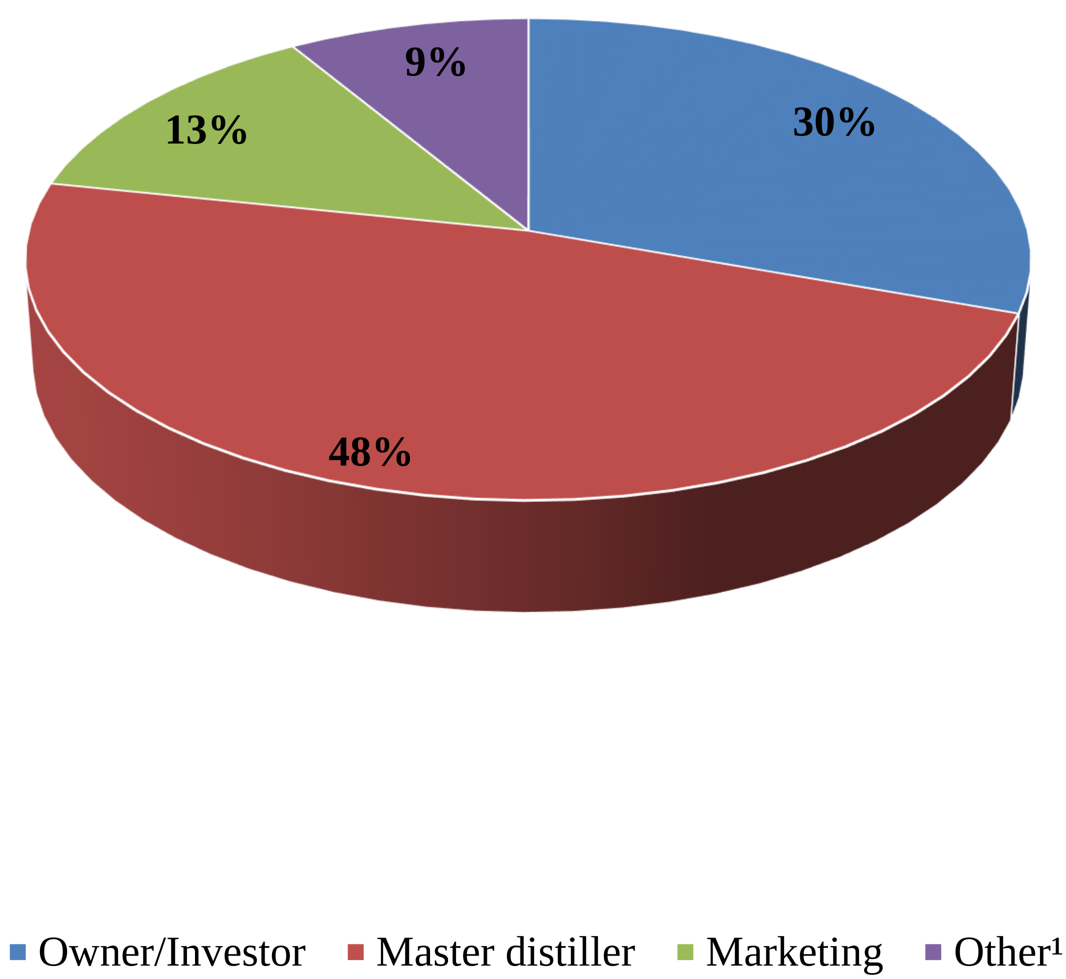

Figure 21. Distillery Survey Respondents' Business Roles – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n = 23
[1]Comments listed in the "other" category included: "general manager" and "wearing all hats".

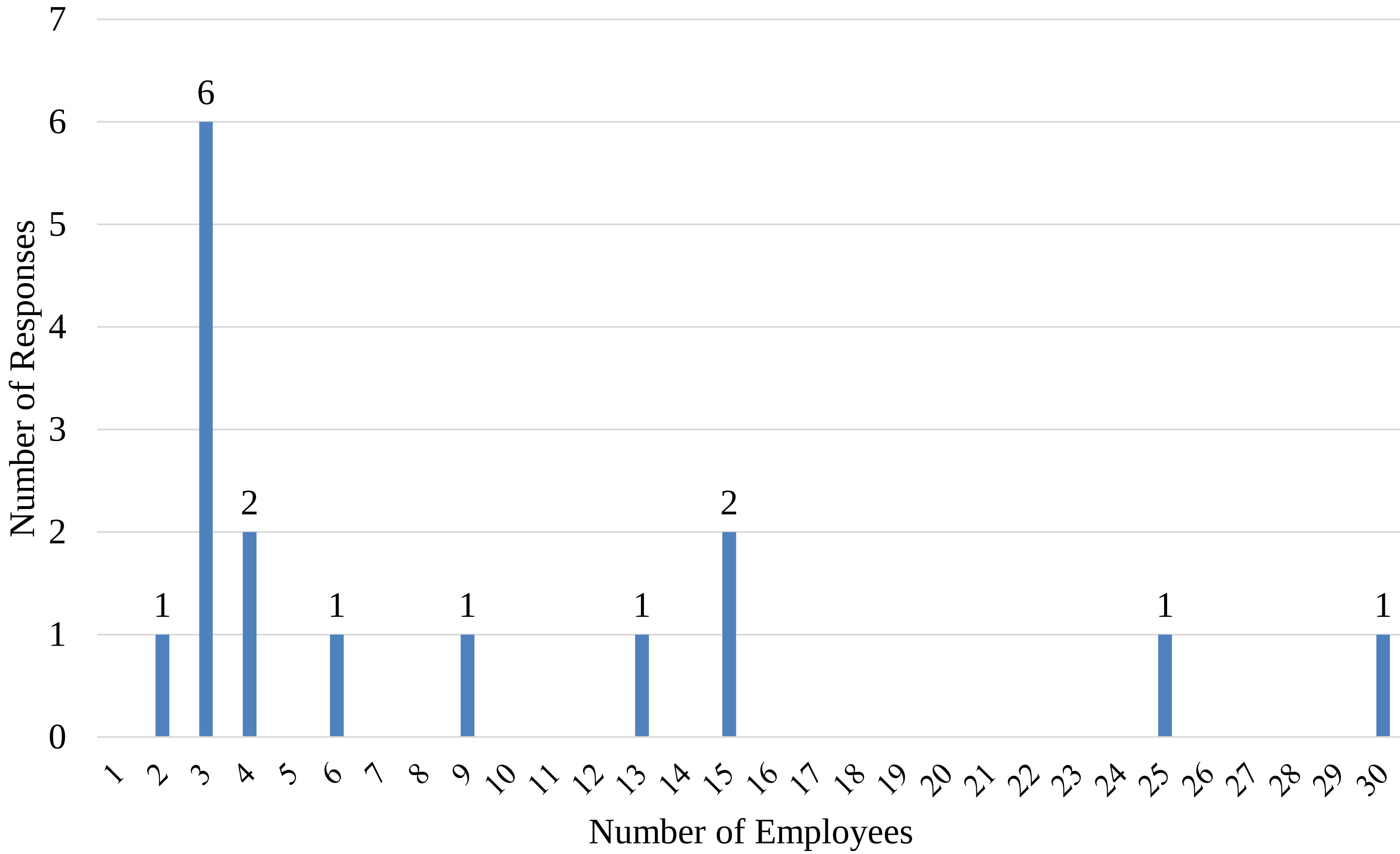

Figure 22. Number of Employees Employed by the Distilling Operation – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n=16

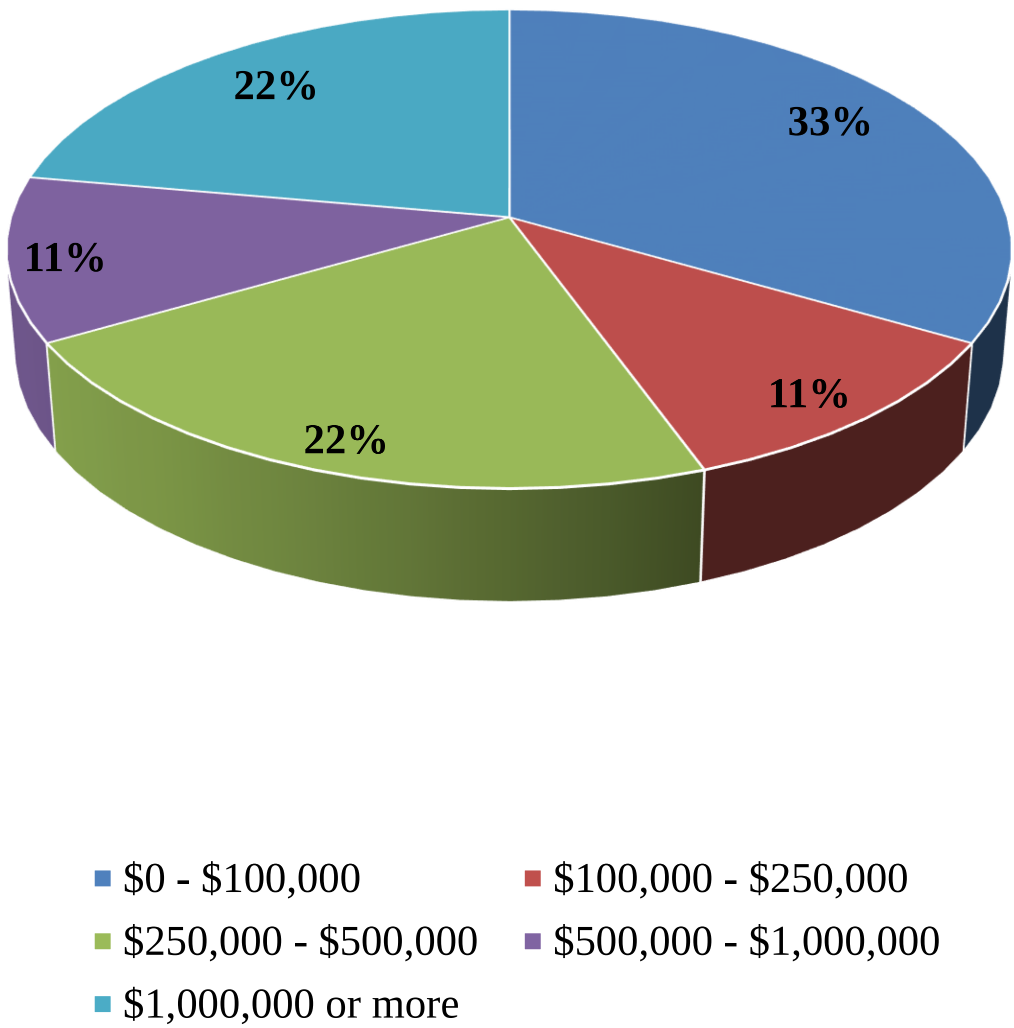

Figure 23. Distillery Annual Gross Alcoholic Beverage Sales During the Last Fiscal Year – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n=9

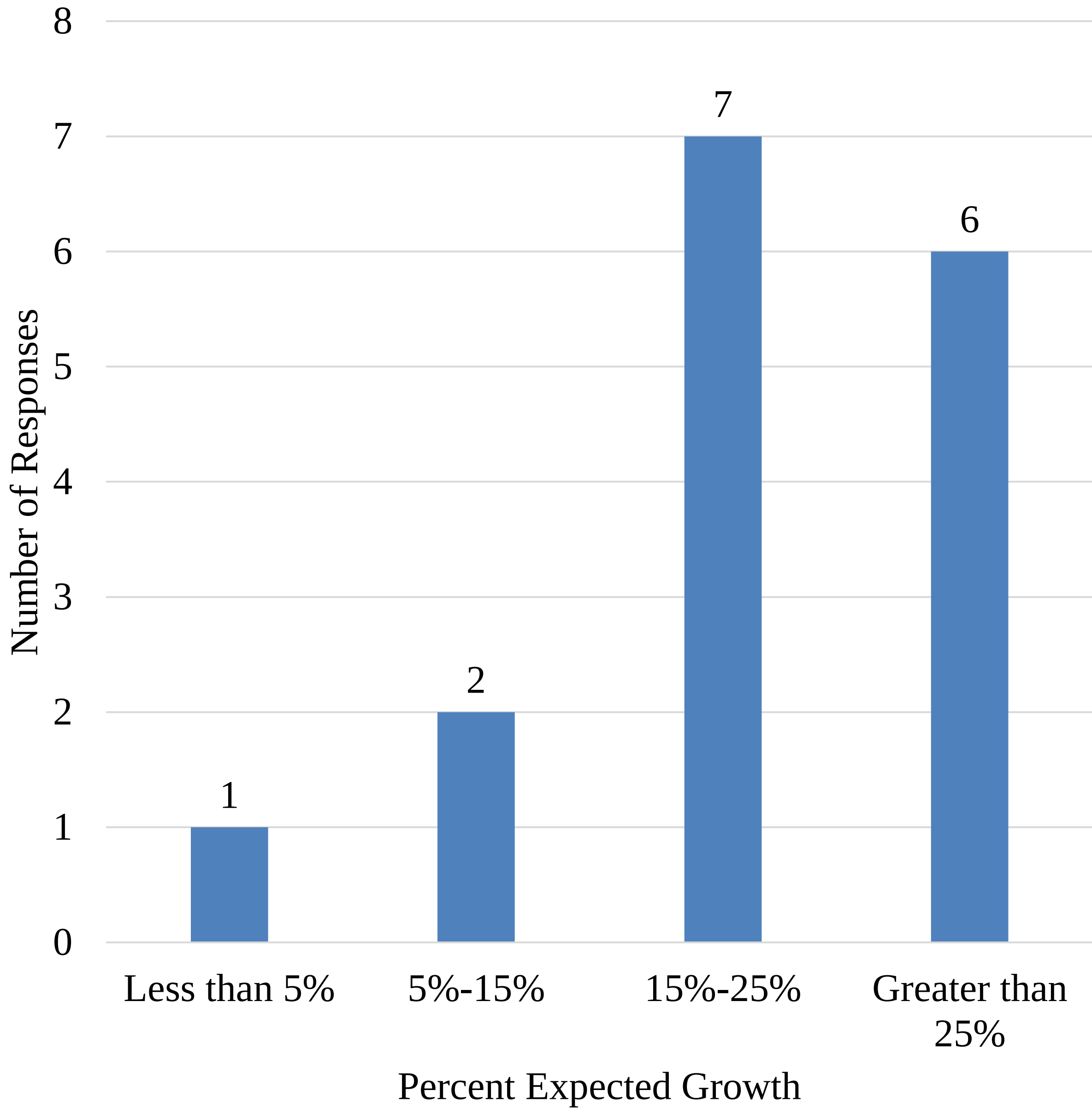

Figure 24. Distillery Expected Sales Increase Over the Next Five Years – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n=16

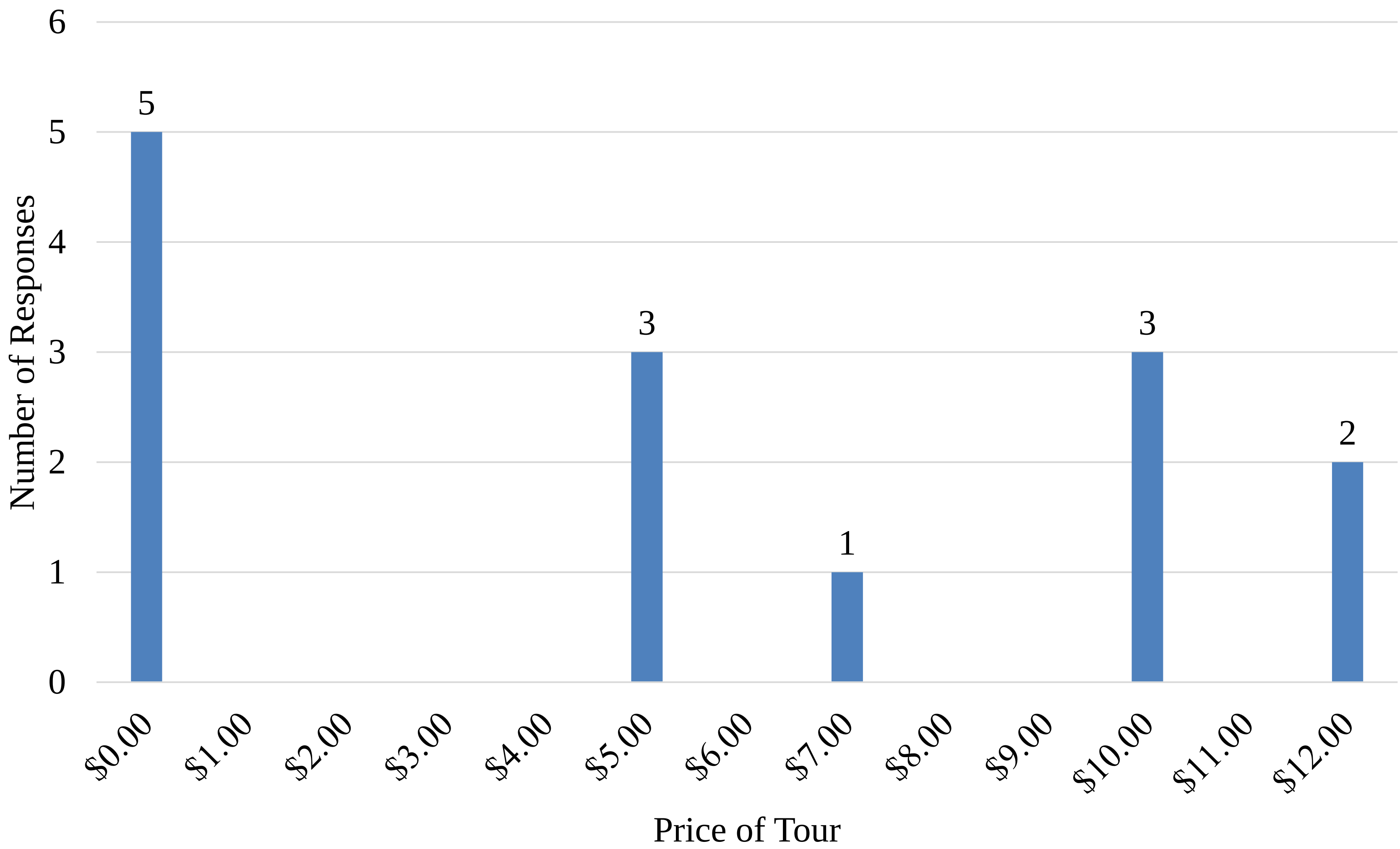

Figure 25. Prices Charged by Distilleries for Tours – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n = 14

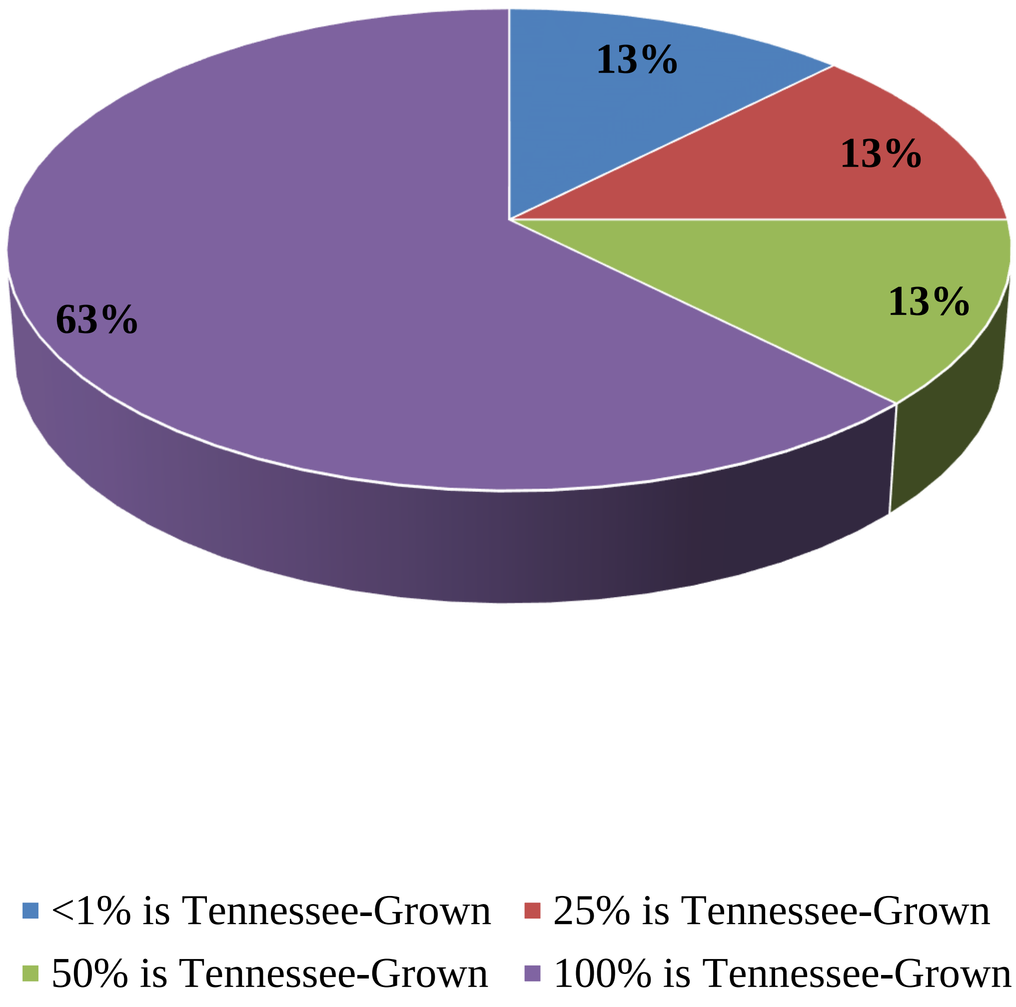

Figure 26. Percentage of Purchased Grain That is Tennessee-Grown – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n = 8

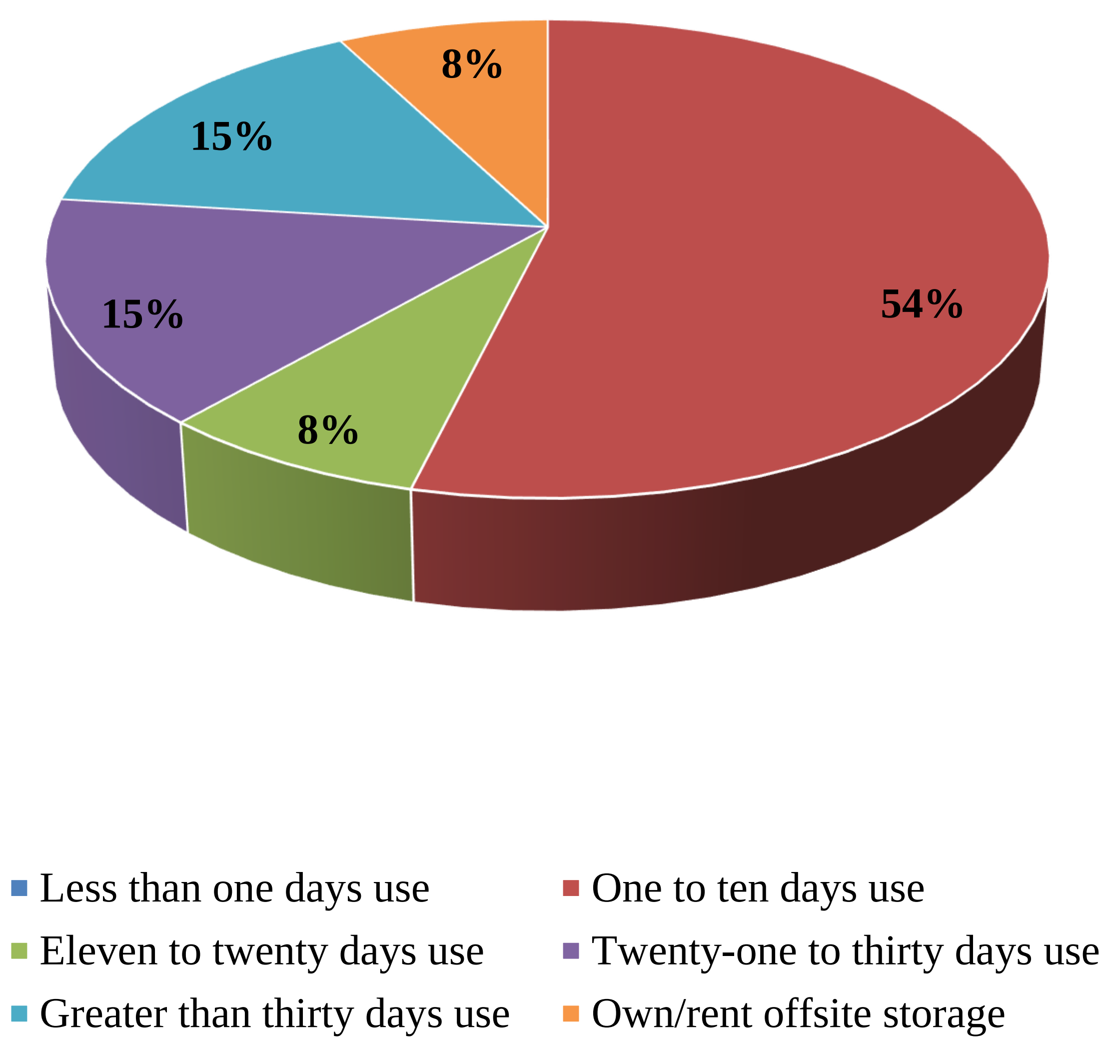

Figure 27. Number of Days Distilleries Have Available for Onsite Storage of Corn and Other Grains – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n=13

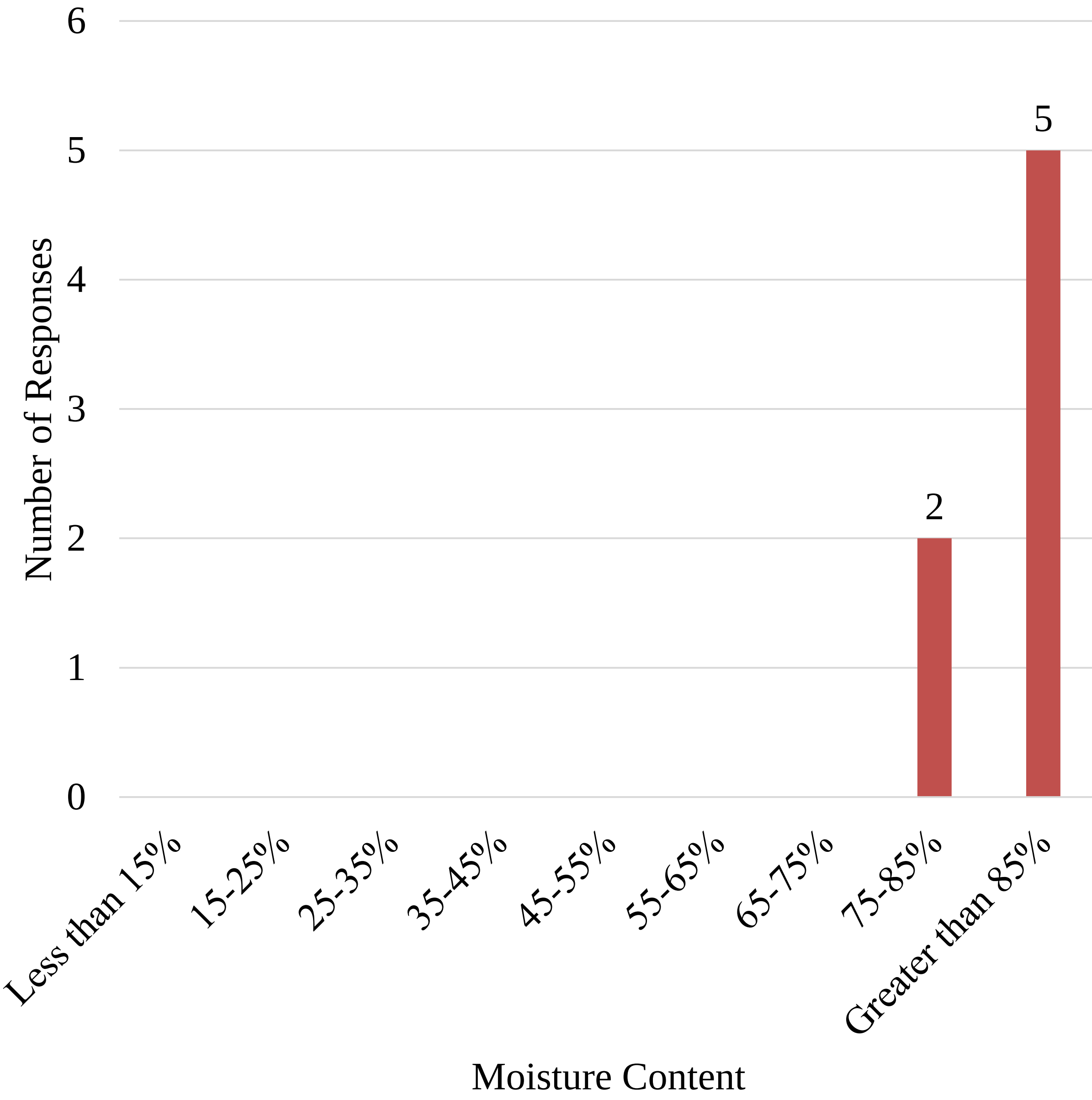

Figure 28. Moisture Content of DSG When it Exits Facility – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n=7

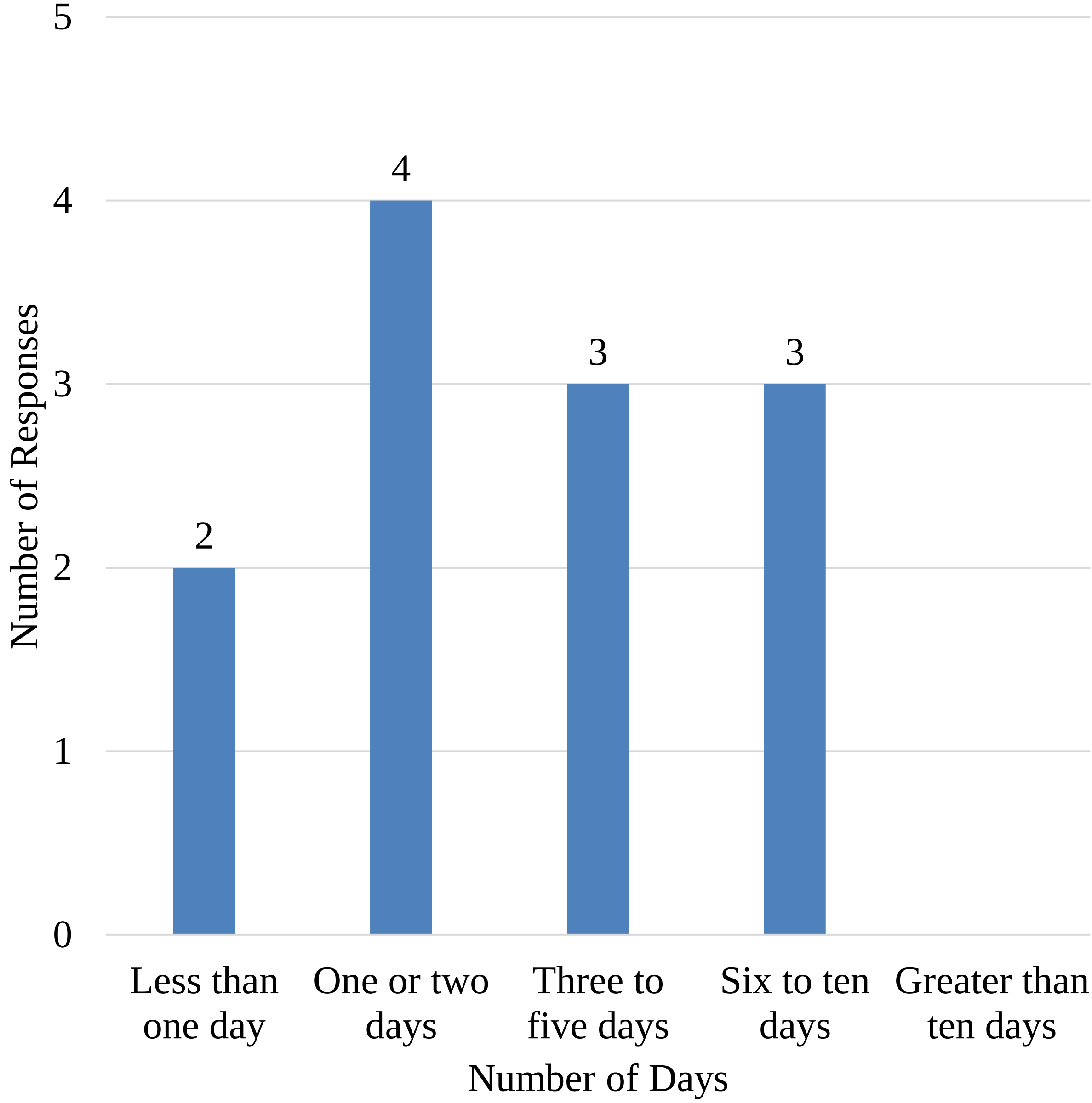

Figure 29. Number of Days DSG Spends at Facility – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n=12

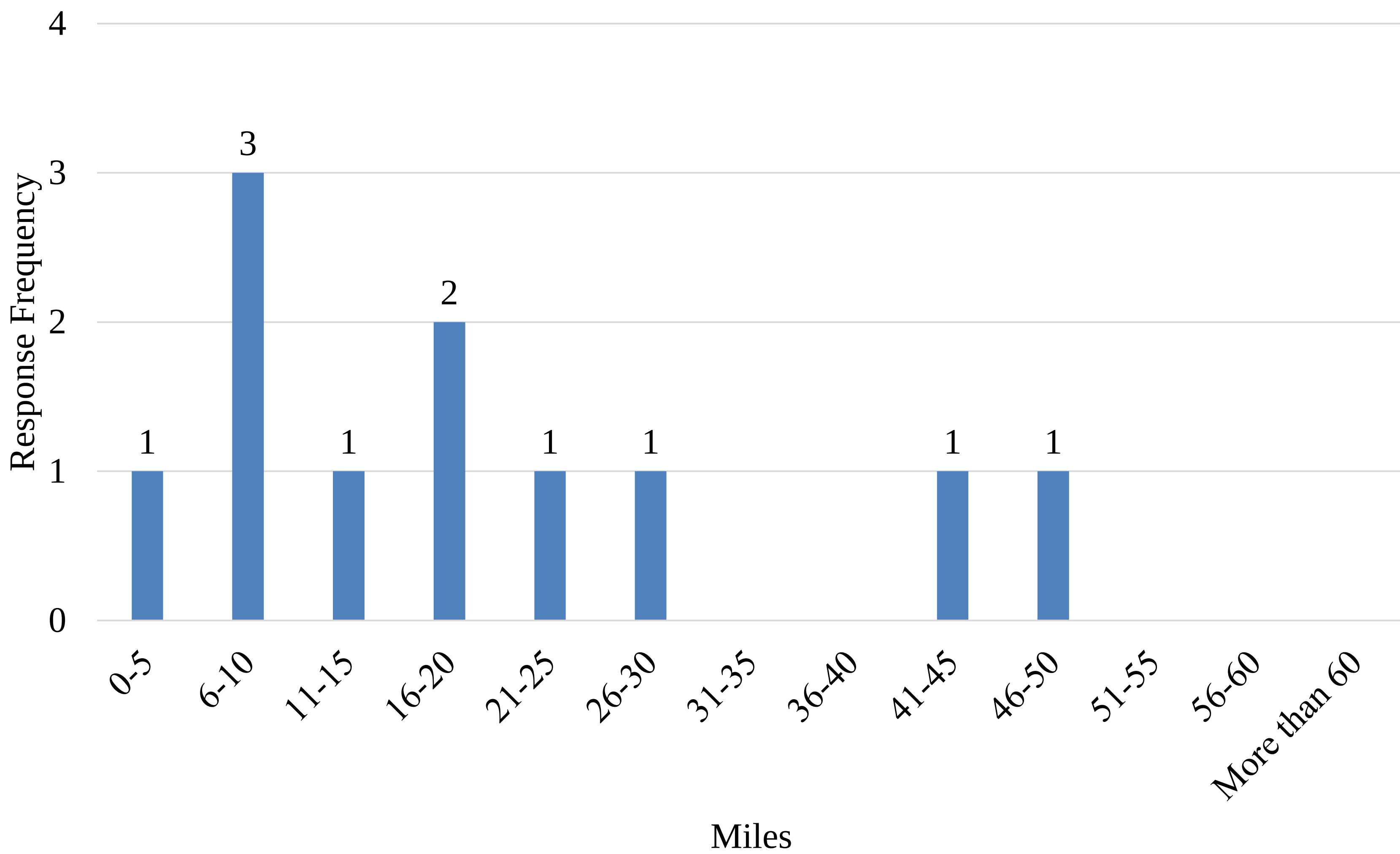

Figure 30. Miles DSG Travels from the Distillery to a Livestock Facility – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n = 11

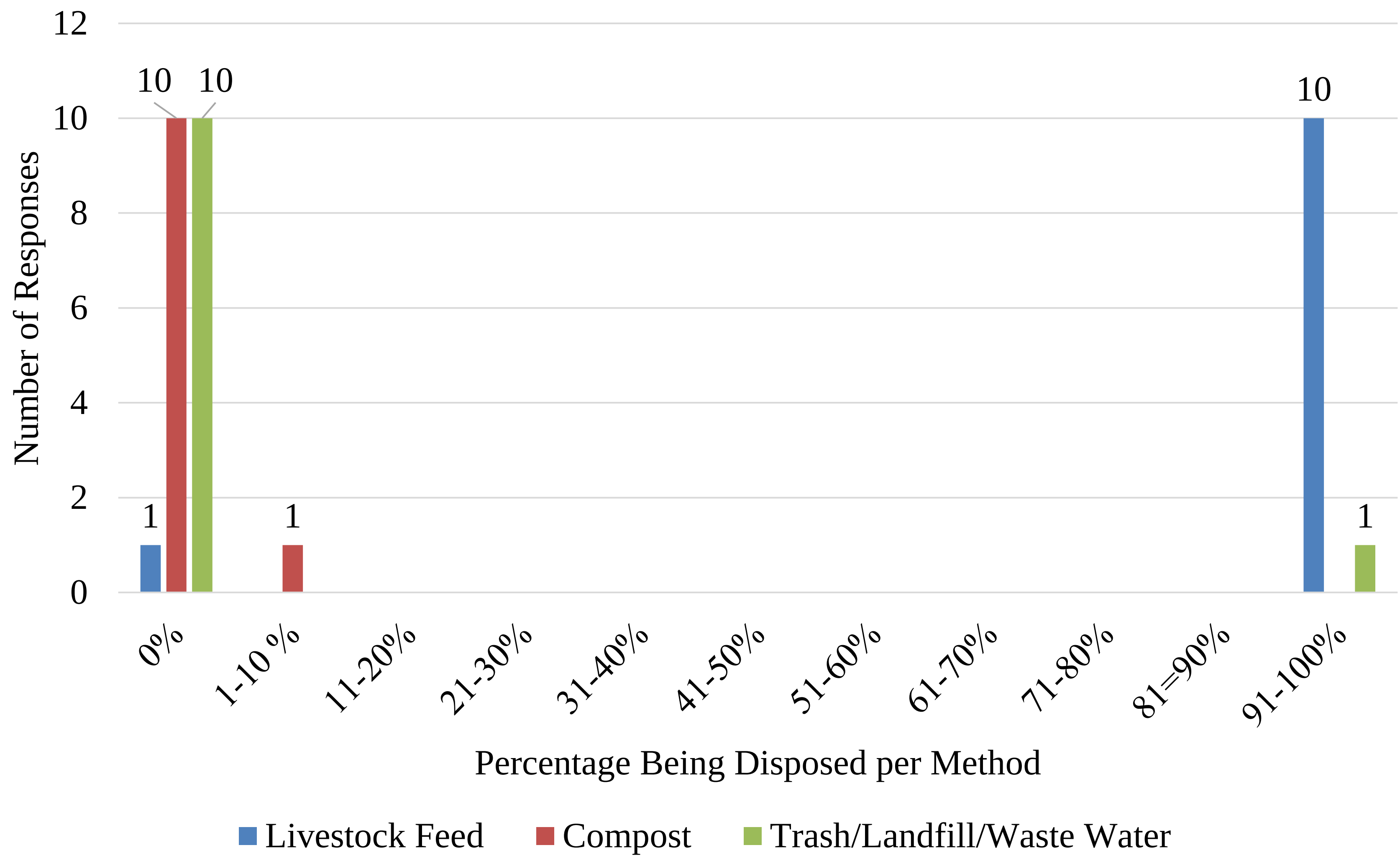

Figure 31. Percentage of Spent Grains Being Disposed of Through Each Method by Distilleries – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n=11

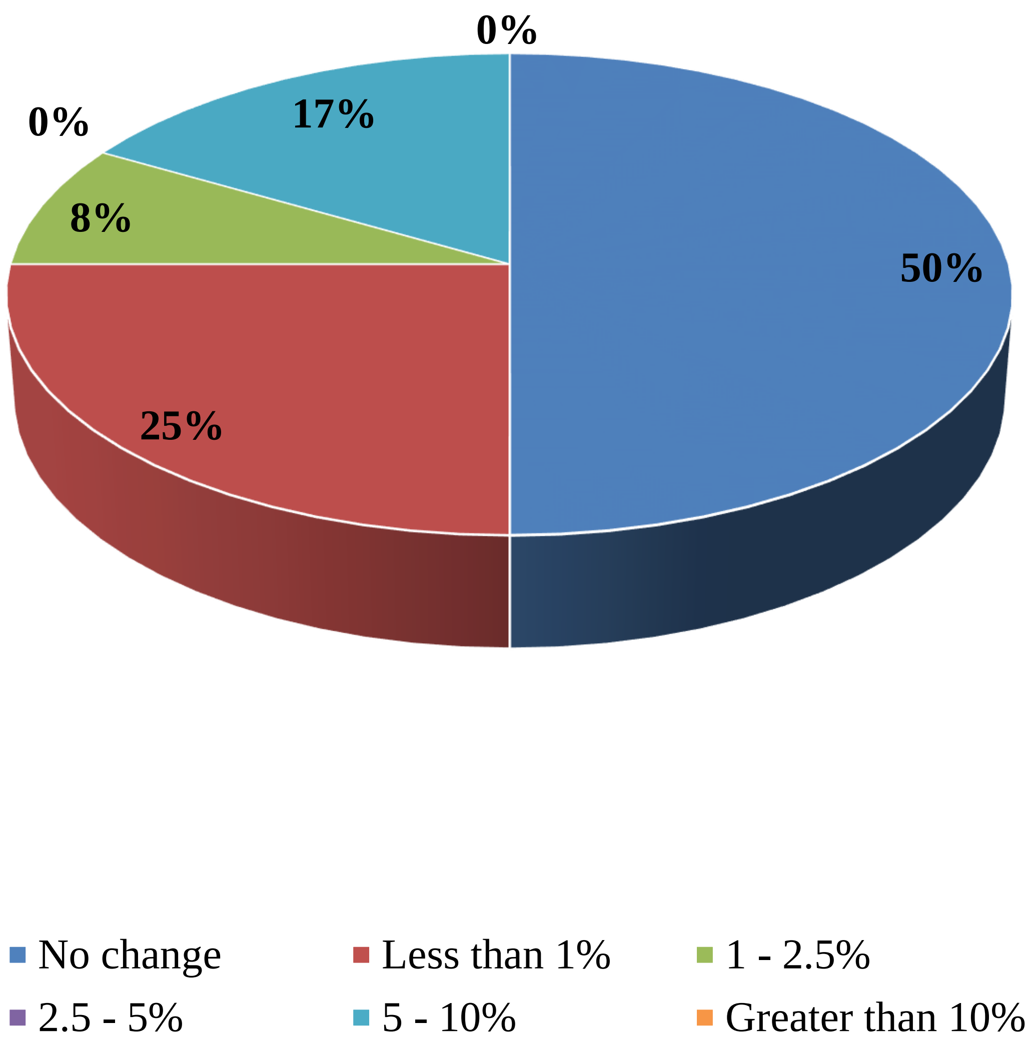

Figure 32. Expected Price Premium by Distilleries from Sustainable Marketing – Results of a 2018 Survey of Tennessee Craft Breweries and Distilleries
n=12

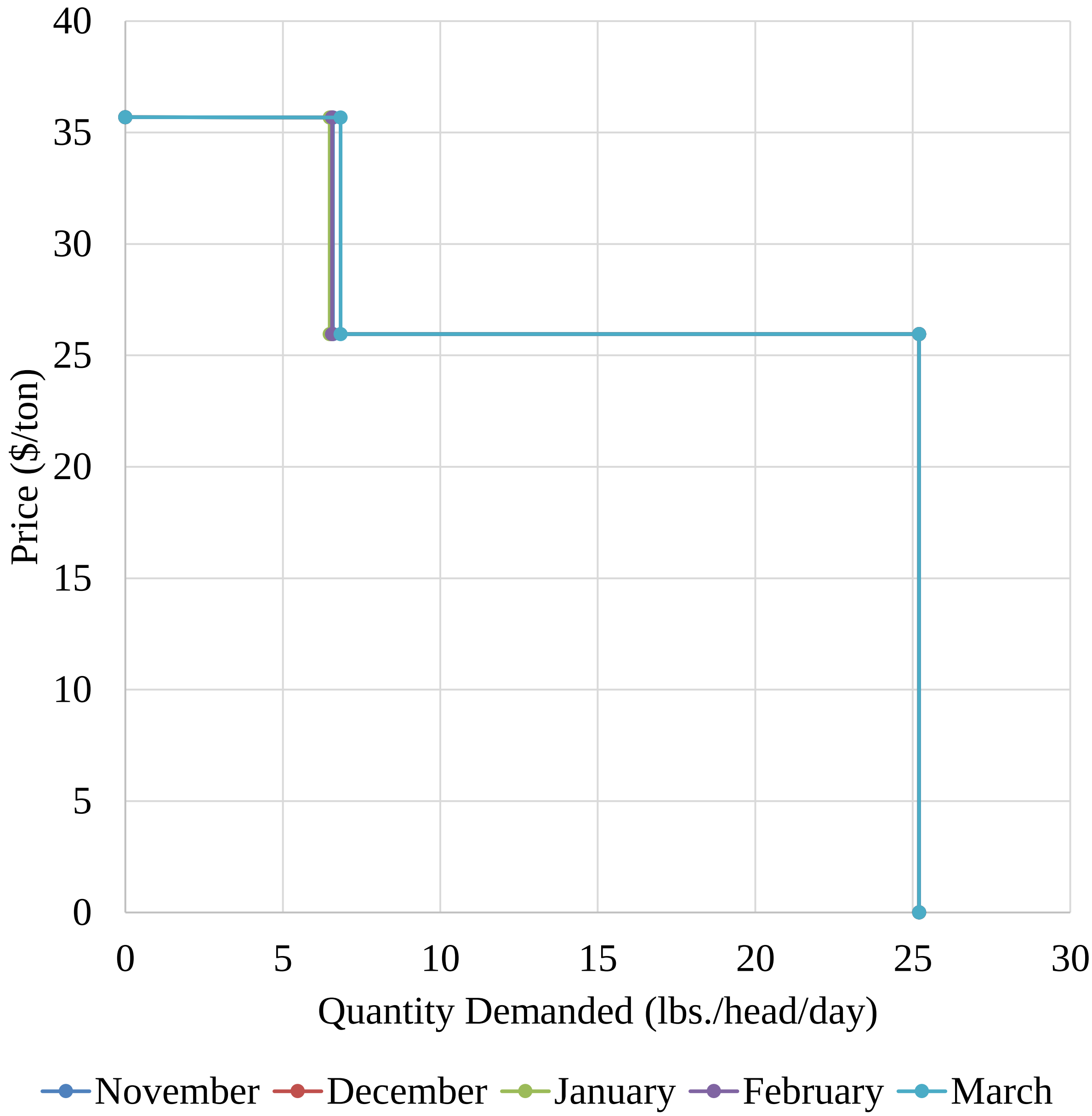

Figure 33. Monthly BSG Demand Curves for the Spring Calving Schedule[1]
[1]Demand curves are displayed for all months. Overlapping illustrates consistency in demand across months.

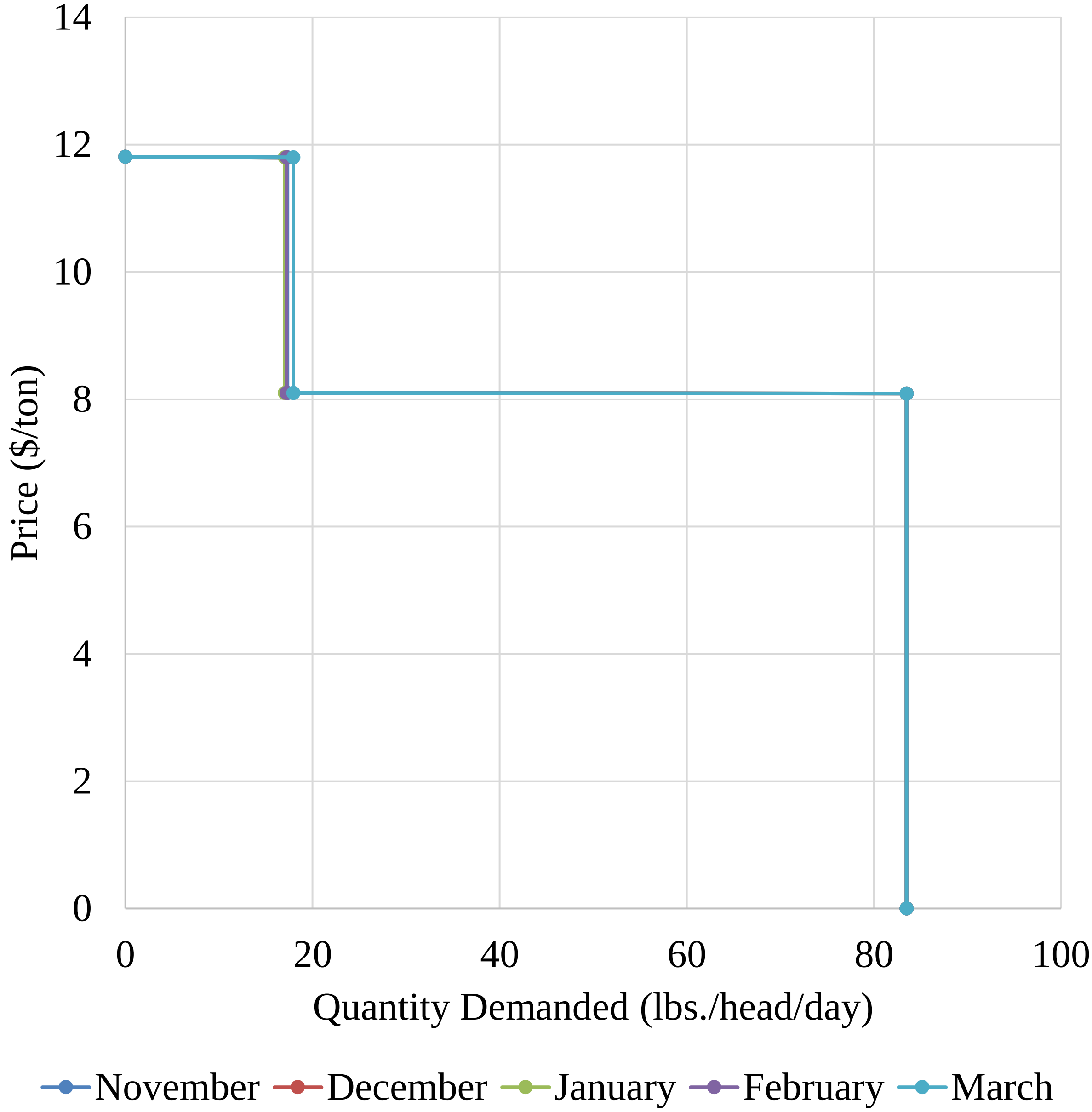

Figure 34. Monthly DSG Demand Curves for the Spring Calving Schedule[1]
[1]Demand curves are displayed for all months. Overlapping illustrates consistency in demand across months.

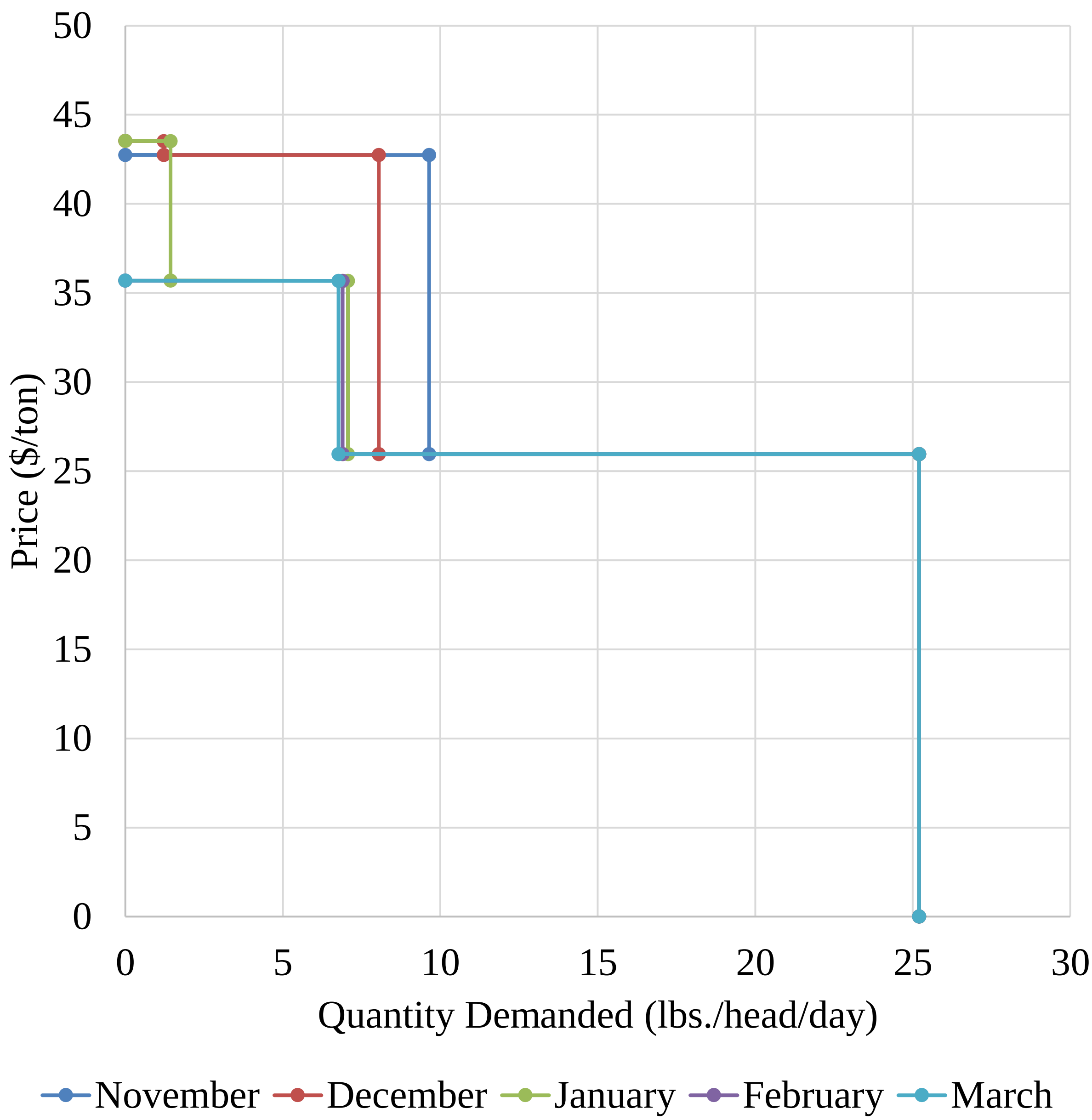

Figure 35. Monthly BSG Demand Curves for the Fall Calving Schedule[1]
[1]Demand curves are displayed for all months. Overlapping illustrates consistency in demand across months.

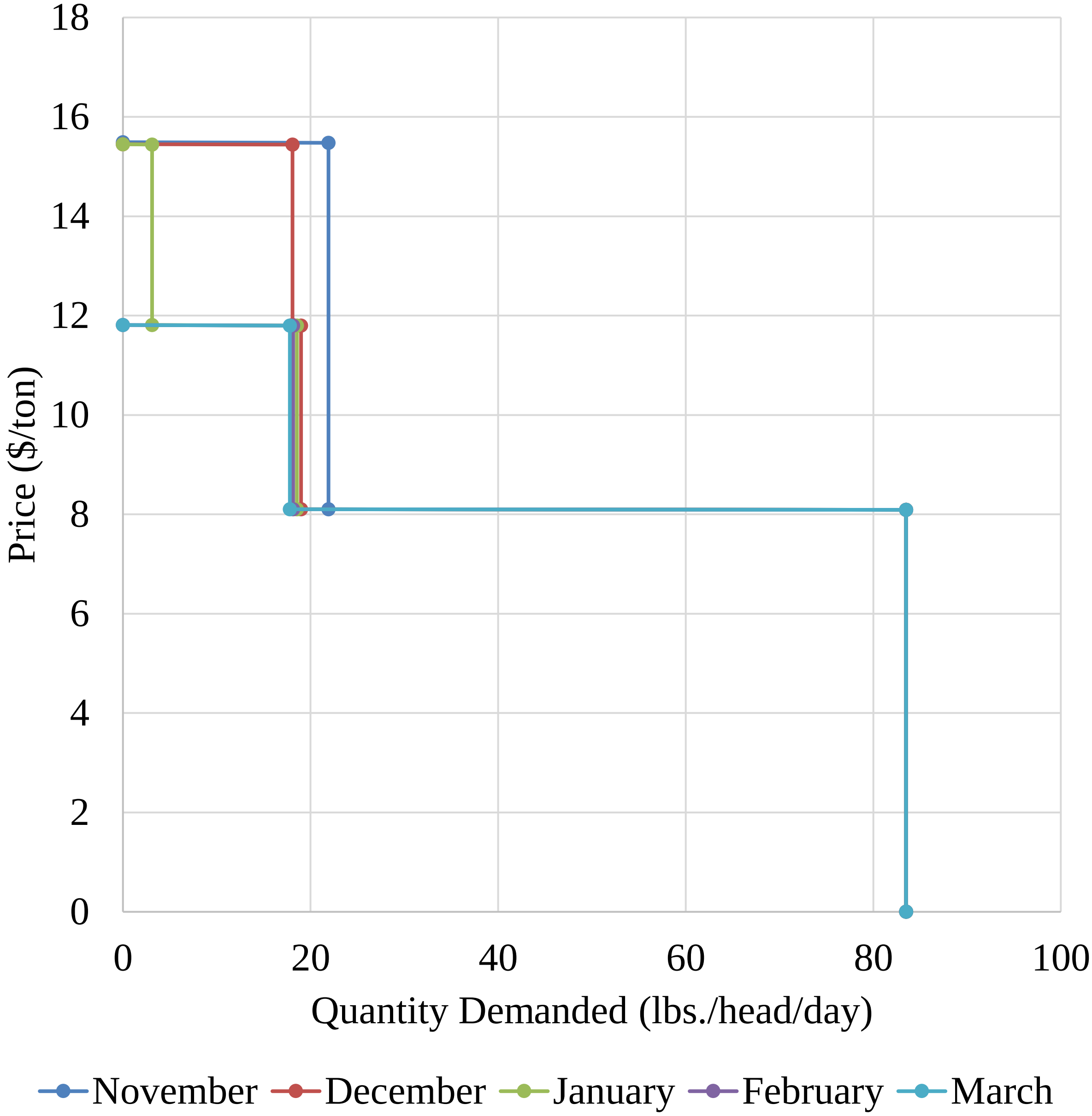

Figure 36. Monthly DSG Demand Curves for the Fall Calving Schedule[1]
[1]Demand curves are displayed for all months. Overlapping illustrates consistency in demand across months.

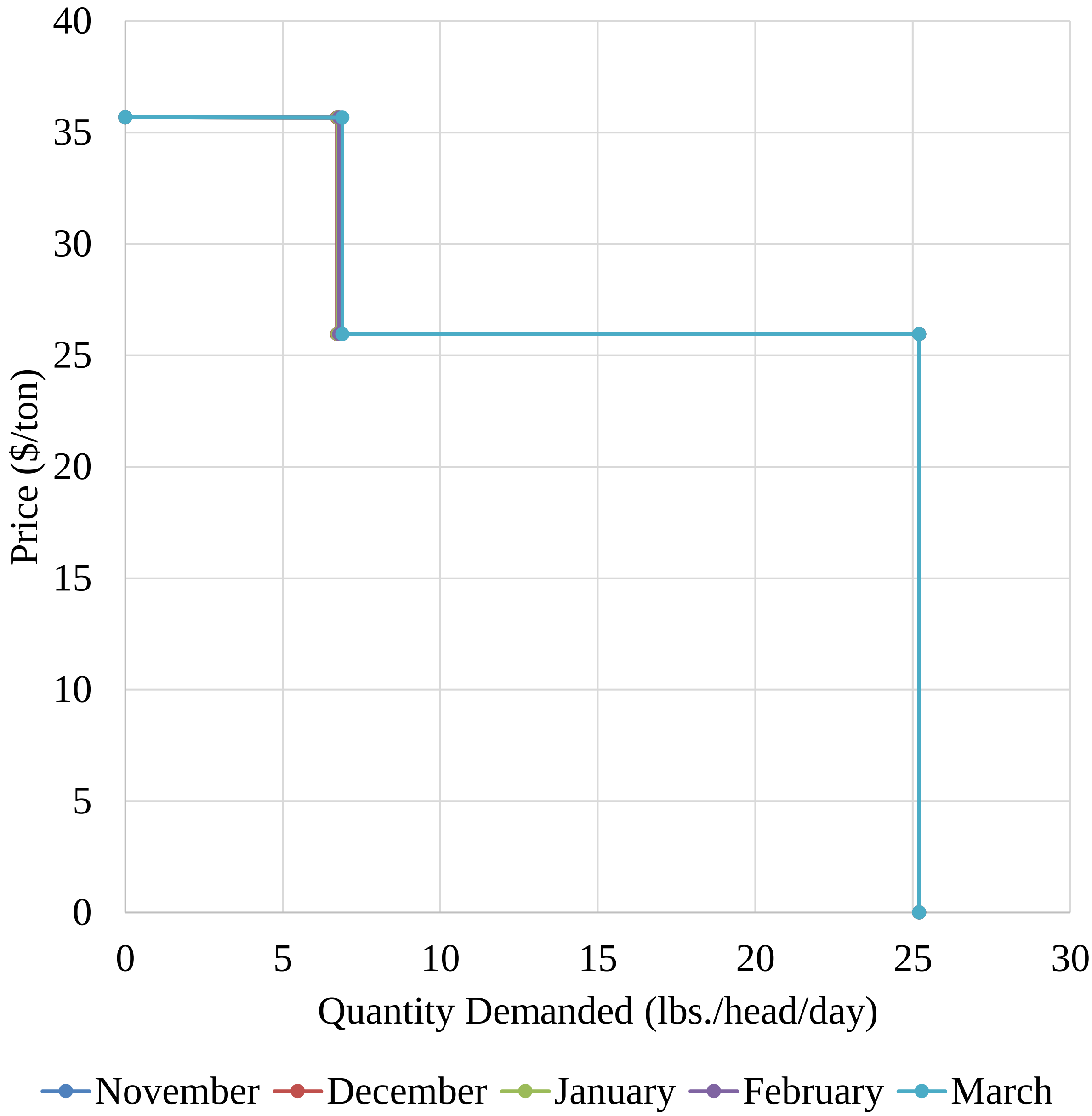

Figure 37. Monthly BSG Demand Curves for the Year-Round Calving Schedule[1]
[1]Demand curves are displayed for all months. Overlapping illustrates consistency in demand across months.

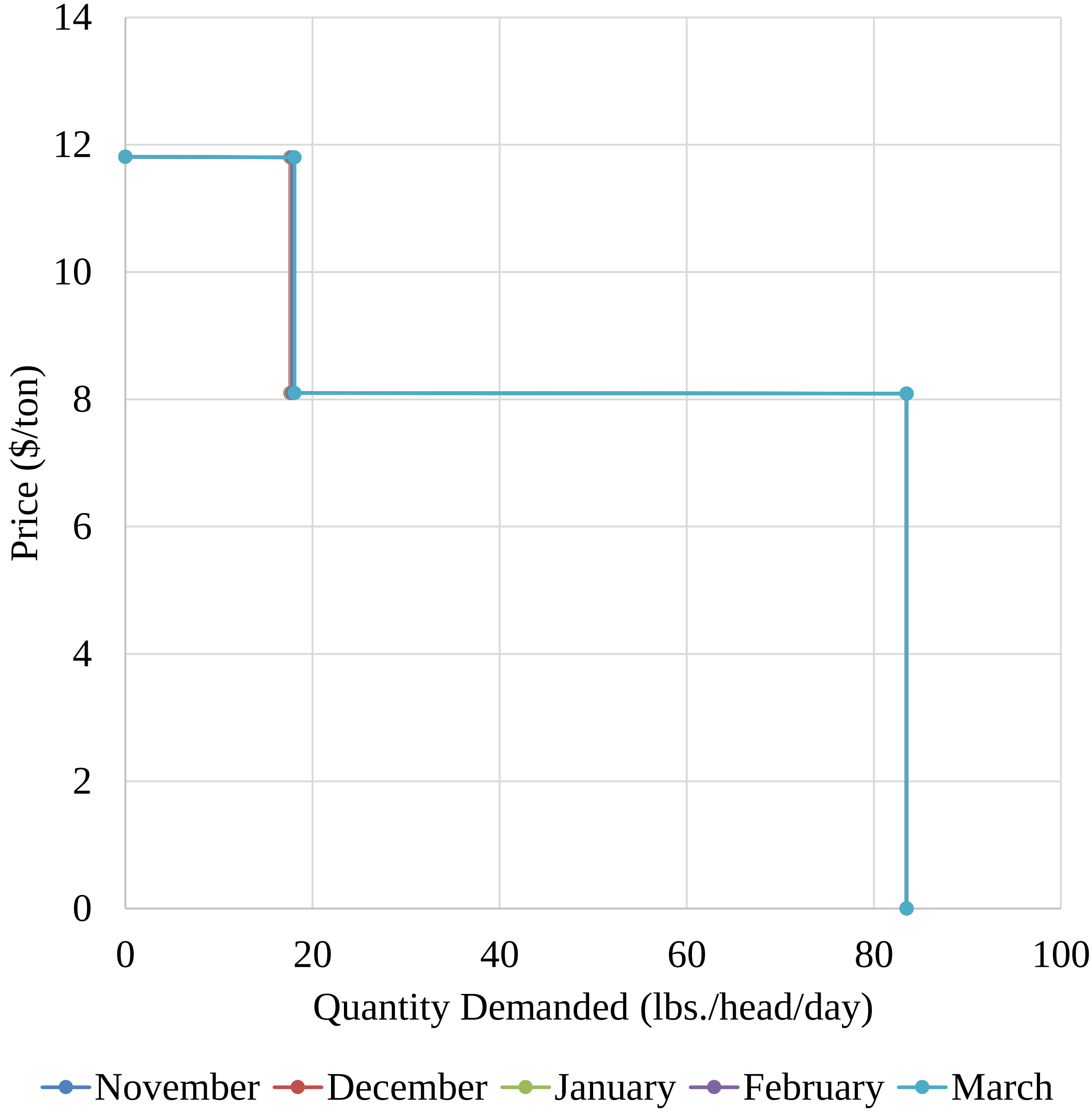

Figure 38. Monthly DSG Demand Curves for the Year-Round Calving Schedule[1]
[1]Demand curves are displayed for all months. Overlapping illustrates consistency in demand across months.

Appendix C: Copy of Brewery Survey

Before you begin…

We invite you to participate in a study conducted by University of Tennessee Institute of Agriculture researchers. Information from this study will be helpful for understanding the inputs used in breweries and uses, disposal, and market potential for craft brewery spent grains in your region. We are also interested in understanding the issues and information that your craft breweries need in order to improve production and management decisions, increase firm profits and foster expansion of this growing industry in Tennessee.

Please have the firm's primary decision maker answer the survey. The survey should take about 10 minutes to complete.

If you answer these questions you will be voluntarily participating in a research project. Any information you provide will not be associated with your name or your company's name. Data will be stored securely and made available only to researchers conducting the study. We'll release information only as summaries. There's no known risk to you for participating in this research, nor are there direct benefits. You can skip any question you don't want to answer and withdraw from the study anytime without penalty, in which case the data you provide will be destroyed.

If you have questions about your rights as a survey participant, contact the UT Institutional Review Board Staff at utkirb@utk.edu or (865) 974-7697. Please contact us if you have any other questions about the survey. Thank you for taking time out of your busy schedule to help us!

Thank you!

S. Aaron Smith
Assistant Professor, Department of Agricultural and Resource Economics
University of Tennessee Institute of Agriculture
325B Morgan Hall, 2621 Morgan Circle
Knoxville, TN 37996-4518
Ph: (865) 974-7476
Email: aaron.smith@utk.edu

CONSENT

Clicking the "next" button below indicates you have read the above information and consent to participate in the survey.

Q1 Please enter the name of your craft brewery.

____

Q2 Check the boxes that best describe your business (more than one box can be checked).

- ☐ Brewery
- ☐ Brewery with bar
- ☐ Brewery with restaurant and bar
- ☐ Other (please specify): ____________________________________

Q3 What is your role or position in the business (check all that apply)?

- ☐ Owner/Investor
- ☐ Master brewer
- ☐ Marketing
- ☐ Other (please specify): ____________________________________

Q4 How many employees does your brewery employ (this does not include employees involved with the restaurant aspect of your business such as bartenders, waiters, cooks, busboys, etc.)?

____

Q5 Does your craft brewery offer public tours? If yes, indicate the cost per person.

- ○ Yes ____
- ○ No

Q6 What was the value of your gross alcoholic beverage sales in the last fiscal year?

- ○ $0 - $100,000
- ○ $100,000 - $250,000
- ○ $250,000 - $500,000
- ○ $500,000 - $1,000,000
- ○ $1,000,000 or more

Q7 How much do you expect your sales to increase over the next five years?

- ○ Less than 5%
- ○ 5%-15%
- ○ 15%-25%
- ○ Greater than 25%

Q8 Rank in order of importance factors that may have a negative impact on the anticipated growth of your craft brewery (1 is most important, 7 is least important).

	Rank (1-7)
Economic downturn	
Government regulations	
Industry saturation	
Profitability	
Quality of labor	
Waste disposal	
Other (specify):	

Q9 Please indicate your level of interest in the following with 1 as not interested at all and 5 as very interested:

	1	2	3	4	5
Purchasing Tennessee grown hops for a wet-hops beer					
Purchasing Tennessee grown hops (dry or pelleted) for beer production					

Q10 Please indicate your level of agreement with the following statement (1 indicating completely disagree and 5 indicating completely agree):

	1	2	3	4	5
"I am only interested in using pelletized hops with one being complete disagreement and five indicating complete agreement."					

Q11 How many pounds of the following categories of hops does your brewery use annually?

	Pounds per year
Wet hops	
Pelletized (or dry) hops	

Q12 Please list the varieties of hops used at your brewery in order of the largest quantity used to the smallest quantity used (if you are unsure please indicate "unsure" in line 1)

____

____

____

____

____

Q13 In the last fiscal year, how many pounds of malt barley or other grains did your brewery purchase?

	Pounds
Malt barley	
Other (please specify):	
Other (please specify):	
Other (please specify)	

Q14 Were the malt barley or other grains purchased by your brewery grown in Tennessee?

- ◯ Yes
- ◯ No
- ◯ Unsure

Skip To: Q14-Y If "Were the malt barley or other grains purchased by your brewery grown in Tennessee?" = Yes

Skip To: Q15 If "Were the malt barley or other grains purchased by your brewery grown in Tennessee?" = Unsure

---

Q14-N If no, why?

- ◯ Lack of available supply
- ◯ Higher price/too expensive
- ◯ Insufficient quantity or product consistency
- ◯ Other: ____

Skip To: Q15 If "If no, why?" = Lack of available supply

Skip To: Q15 If "If no, why?" = Higher price/too expensive

Skip To: Q15 If "If no, why?" = Insufficient quantity or product consistency

Skip To: Q15 If "If no, why?" = Other:

Skip To: Q15 If "If no, why?(Other:)" Is Not Empty

Q14-Y If yes, what percent of total malt barley and other grains were purchased from Tennessee producers (enter %)?

____

Q15 If a commercial malting house using Tennessee malting barley was available in Tennessee, would you pay a price premium (compared to your current supplier) for malt barley of....

- Up to a 10% price premium
- A 10 to 25% price premium
- A greater than 25% price premium
- No price premium
- Unsure

Q16 How many days of onsite storage is available for malt barley and other grains?

- Less than one days use
- One to ten days use
- Eleven to twenty days use
- Twenty-one to thirty days use
- Greater than thirty days use

Q17 Please provide your estimated production in gallons of primary product (beer, other) for the last fiscal year and predicted production for the current fiscal year.

	Last fiscal year	Current fiscal year
Beer (in gallons)		
Other - please specify (in gallons):		

Q18 Please provide your estimated production in pounds of spent grain/mash for the last fiscal year and predicted production for the current fiscal year.

	Last fiscal year	Current fiscal year
Brewery spent grains (in pounds)		
Other (in pounds):		

Q19 In the last fiscal year, how many batches did you produce per week? And what was the average batch size?

- ○ Number of batches per week ____
- ○ Gallons per batch ____
- ○ Spent grains per batch (pounds) ____________________________________

Q20 Are you aware that spent brewery grains can be used as feed for livestock?

- ○ Yes
- ○ No

Q21 Are you aware that spent grains can be used in compost or as a source of nutrients for plant production?

- ○ Yes
- ○ No

Q22 Did your facility dry or otherwise process spent grains on site?

- ○ Yes
- ○ No

Q23 Have you tested the nutrient content of your spent grains?

- ○ Yes
- ○ No

Q24 What is the estimated moisture content of the spent grains when it exits your facility (leave blank if unknown)?

- ○ Less than 15%
- ○ 15-25%
- ○ 25-35%
- ○ 35-45%
- ○ 45-55%
- ○ 55-65%
- ○ 65-75%
- ○ 75-85%
- ○ Greater than 85%

Q25 How many days are spent grains stored at your facility?

◯ Less than one day

◯ One or two days

◯ Three to five days

◯ Six to ten days

◯ Greater than ten days

Q26 Are your spent grains disposed of through local producers to be used as a component of livestock feed rations?

◯ Yes

◯ No

Skip To: Q27 If "Are your spent grains disposed of through local producers to be used as a component of livestock..." = No

---

Q26A How are the spent grains marketed to livestock producers (you may select more than one answer)?

▢ Broker

▢ Private contract

▢ Affiliated or subsidiary entity

▢ Given away (first come first serve)

▢ Given away (to a predetermined producer or set of producers)

▢ Other (specify): ____

Q26B What is the average distance (one-way miles) that spent grains travel to the livestock producer from your facility through the following mechanisms:

- ◯ Broker ____
- ◯ Private contract ____
- ◯ Affiliated or subsidiary entity ____
- ◯ Given away (first come first serve) _____________________________________
- ◯ Given away (to a predetermined producer or set of producers) _______________
- ◯ Other ____

Q26C Indicate whether disposing of spent grains as a component of livestock feed rations provides your business with revenue, costs your business money, or breaks-even. Also, include cost or revenue per ton if applicable.

- ◯ Provides revenue; estimated revenue per ton ($/ton): _______________________
- ◯ Costs money; estimated cost per ton ($/ton): ____________________________
- ◯ Breaks-even (no cost or revenue)

Q27 Are your spent grains disposed of through composting/soil amendments/fertilizers?

- ◯ Yes
- ◯ No

Skip To: Q27A-Y If "Are your spent grains disposed of through composting/soil amendments/fertilizers?" = Yes

Q27A-N Are you aware of a composting facility in your area?

○ Yes

○ No

Skip To: Q28 If "Are you aware of a composting facility in your area?" = Yes

Skip To: Q28 If "Are you aware of a composting facility in your area?" = No

Q27A-Y How are the spent distillers grains marketed to producers using them for composting/soil amendments/fertilizer (you may select more than one answer)?

▢ Broker

▢ Private contract

▢ Affiliated or subsidiary entity

▢ Given away (first come first serve)

▢ Given away (to a predetermined producer or set of producers)

▢ Other (specify): ____

Q27B What is the average distance (one-way miles) that the spent grains travel to producers from your facility for composting/soil amendments/fertilizer through the following mechanisms:

- ○ Broker ____
- ○ Private contract ____
- ○ Affiliated or subsidiary entity ____
- ○ Given away (first come first serve) ____________________________________
- ○ Given away (to a predetermined producer or set of producers) _______________
- ○ Other ____

Q27C Indicate whether disposing of spent grains for composting/soil amendments/fertilizer provides your business with revenue, costs your business money, or breaks-even. Also, include cost or revenue per ton if applicable.

- ○ Provides revenue; estimated revenue per ton ($/ton): _____________________
- ○ Costs money; estimated cost per ton ($/ton): ________________________
- ○ Breaks-even (no cost or revenue)

Q28 In the last fiscal year, indicate the percent of spent grains/mash that were disposed of using the following methods (answers should total to 100%)?
Livestock feed : _______
Composting/soil amendment/fertilizer : _______
Trash/landfill : _______
Other (specify) : _______

Total : ________

Skip To: Q29 If "In the last fiscal year, indicate the percent of spent grains/mash that were disposed of using th..." = Trash/landfill

---

Q28A If you are currently disposing of spent grains in a landfill, at what revenue point would you consider disposing of spent grains using an alternative other than trash/landfilling?

- ◯ A loss of greater than $50/ton
- ◯ A loss of $49/ton to $25/ton
- ◯ A loss of $24/ton to $0/ton
- ◯ A gain of $1/ton to $24/ton
- ◯ A gain of greater than $25/ton

Q29 Rank in the order of importance the biggest obstacles in disposing of spent grains (1 is most important, 6 is least important).

	Rank (1-6)
Quantity produced	
Market access/no contacts	
Limited knowledge of livestock or cropping uses	
On-site drying/processing	
Limited access to capital	
Other (specify):	

Q30 Estimate the percent price premium you would expect from marketing beer as using sustainable production practices, such as non-land fill disposal of brewery spent grains.

- ◯ No change
- ◯ Less than 1%
- ◯ 1 - 2.5%
- ◯ 2.5 - 5%
- ◯ 5 - 10%
- ◯ Greater than 10%

Q31 Comments or areas of future research that would assist your business or the craft beer industry in Tennessee.

____

____

____

____

____

End of Block: Default Question Block

Appendix D: Copy of Distillery Survey

Before you begin…

We invite you to participate in a study conducted by University of Tennessee Institute of Agriculture researchers. Information from this study will be helpful for understanding issues faced by craft distilleries in Tennessee. We are also interested in data and information that is required by your craft distillery that could improve production and management decisions, increase profits and foster expansion of this growing industry in Tennessee.

Please have the craft distillery's primary decision maker answer the survey. The survey should take about 10 minutes to complete.

If you answer these questions you will be voluntarily participating in a research project. Any information you provide will not be associated with your name or your company's name. Data will be stored securely and made available only to researchers conducting the study. We'll release information only as aggregated summaries. There's no known risk to you for participating in this research, nor are there direct benefits. You can skip any question you don't want to answer and withdraw from the study anytime without penalty, in which case the data you provide will be destroyed.

If you have questions about your rights as a survey participant, contact the UT Institutional Review Board Staff at utkirb@utk.edu or (865) 974-7697. Please contact us if you have any other questions about the survey. Thank you for taking time out of your busy schedule to help us!

Thank you!

S. Aaron Smith
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Ph: (865) 974-7476
Email: aaron.smith@utk.edu

CONSENT

Clicking the "next" button below indicates you have read the above information and consent to participate in the survey.

Q1 Please enter the name of your craft distillery.

____

Q2 Check the boxes that best describe your business (more than one box can be checked).

- ☐ Distillery
- ☐ Distillery with bar
- ☐ Distillery with restaurant and bar
- ☐ Other (specify): ____

Q3 What is your role or position in the craft distillery (check all that apply)?

- ☐ Owner/Investor
- ☐ Master distiller
- ☐ Marketing
- ☐ Other (please specify): ____

Q4 How many employees does your distillery employ (this does not include employees involved with the restaurant aspect of your business such as bartenders, waiters, cooks, busboys, etc.)?

____

Q5 Does your craft distillery offer public tours? If yes, indicate the cost per person.

- ○ Yes ____
- ○ No

Q6 What was your gross sales from alcoholic beverages in the past fiscal year?

- ○ $0 - $100,000
- ○ $100,000 - $250,000
- ○ $250,000 - $500,000
- ○ $500,000 - $1,000,000
- ○ $1,000,000 or more

Q7 How much do you expect your sales to increase over the next five years?

- ○ Less than 5%
- ○ 5%-15%
- ○ 15%-25%
- ○ Greater than 25%

Q8 Rank in order of importance factors that may have a negative impact on the anticipated growth of your craft distillery (1 is most important, 7 is least important).

	Rank (1-7)
Economic downturn	
Government regulations	
Industry saturation	
Profitability	
Quality of labor	
Waste disposal	
Other (specify):	

Q9 In the past fiscal year, how many pounds of corn or other grains did your distillery purchase?

	Pounds
Corn	
Other grains (please specify):	
Other grains (please specify):	
Other grains (please specify):	
Other grains (please specify):	

Q10 Were the corn or other grains purchased by your craft distillery grown in Tennessee?

- ○ Yes
- ○ No
- ○ Unsure

Skip To: Q10-Y If "Were the corn or other grains purchased by your craft distillery grown in Tennessee?" = Yes

Skip To: Q11 If "Were the corn or other grains purchased by your craft distillery grown in Tennessee?" = Unsure

Q10-N If no, why?

- ◯ Lack of available supply
- ◯ Higher price/too expensive
- ◯ Insufficient quality or product consistency
- ◯ Other: ____

Skip To: Q11 If "If no, why?" = Lack of available supply

Skip To: Q11 If "If no, why?" = Higher price/too expensive

Skip To: Q11 If "If no, why?" = Insufficient quality or product consistency

Skip To: Q11 If "If no, why?(Other:)" Is Not Empty

Q10-Y If yes, what percent of total corn and other grains were purchased from Tennessee farmers (enter percent of total calendar year use)?

____

Q11 How many days of onsite storage is available for corn and other grains?

- ◯ Less than one days use
- ◯ One to ten days use
- ◯ Eleven to twenty days use
- ◯ Twenty-one to thirty days use
- ◯ Greater than thirty days use

Q12 In the past fiscal year, how many batches did you produce per week? And what was the average batch size?

- ◯ Number of batches per week ____
- ◯ Gallons of whiskey/spirits per batch ___________________________________
- ◯ Spent grains per batch (gallons) ______________________________________

Q13 Please provide your estimated production in gallons of primary product (whiskey/spirits, other) for the most recent fiscal year and predicted production for the next fiscal year.

	Most recent fiscal year	Next fiscal year
Whiskey (in gallons)		
Other spirits - please specify (in gallons):		
Other spirits - please specify (in gallons):		
Other spirits - please specify (in gallons):		

Q14 Please provide your estimated production in gallons of spent distillers grain/mash for the most recent fiscal year and predicted production for the next fiscal year.

	Most recent fiscal year	Next fiscal year
Distillery spent grains (in gallons)		
Other - please specify (in gallons):		

Q15 Are you aware that spent distillers grains can be used as feed for livestock?

◯ Yes

◯ No

Q16 Are you aware that spent distillers grains can be used in compost or as a source of nutrients for plant production?

◯ Yes

◯ No

Q17 Did your facility dry or otherwise process spent distillers grains on site?

- Yes
- No

Q18 Have you tested the nutrient content of your spent distiller grains?

- Yes
- No

Q19 What is the estimated moisture content of the spent grains when it exits your facility (leave blank if unknown)?

- Less than 15%
- 15-25%
- 25-35%
- 35-45%
- 45-55%
- 55-65%
- 65-75%
- 75-85%
- Greater than 85%

Q20 How many days are spent distillers grains stored at your facility?

- ◯ Less than one day
- ◯ One or two days
- ◯ Three to five days
- ◯ Six to ten days
- ◯ Greater than ten days

Q21 Are your spent distillers grains disposed of through local farmers to be used as a component of livestock feed rations?

- ◯ Yes
- ◯ No

Skip To: Q22 If "Are your spent distillers grains disposed of through local farmers to be used as a component of l..." = No

---

Q21A How are the spent distillers grains marketed to livestock producers (you may select more than one answer)?

- ☐ Broker
- ☐ Private contract
- ☐ Affiliated or subsidiary entity
- ☐ Given away (to a predetermined producer or set of producers)
- ☐ Given away (first come first serve)
- ☐ Other (specify): ____

Q21B What is the average distance (one-way miles) that spent grains travel to the livestock producer from your business through the following mechanisms (number of miles; leave blank if uncertain):

- ○ Broker ____
- ○ Private contract ____
- ○ Affiliated or subsidiary entity ____
- ○ Given away (first come first serve) ____________________________________
- ○ Given away (to a predetermined producer or set of producers) _______________
- ○ Other ____
- ○ Unknown ____

Q21C Indicate whether disposing of spent grains as a component of livestock feed rations provides your business with revenue, costs your business money, or breaks-even. Also, include an estimated cost or revenue per ton if applicable.

- ○ Provides revenue; estimated revenue per ton ($/ton): _______________________
- ○ Costs money; estimated cost per ton ($/ton): _____________________________
- ○ Breaks-even (no cost or revenue)

Q22 Are your spent distillers grains disposed of through composting/soil amendments/fertilizers?

- ○ Yes
- ○ No

Skip To: Q22A-Y If "Are your spent distillers grains disposed of through composting/soil amendments/fertilizers?" = Yes

Q22A-N Are you aware of a composting facility in your area?

- ○ Yes
- ○ No

Skip To: Q23 If "Are you aware of a composting facility in your area?" = Yes

Skip To: Q23 If "Are you aware of a composting facility in your area?" = No

Q22A-Y How are the spent distillers grains marketed to farmers using them for composting/soil amendments/fertilizer (you may select more than one answer)?

- ▢ Broker
- ▢ Private contract
- ▢ Affiliated or subsidiary entity
- ▢ Given away (first come first serve)
- ▢ Given away (to a predetermined producer or set of producers)
- ▢ Other (specify): ____

Q22B What is the average distance (one-way miles) that the spent grains travel to farmers from your business for composting/soil amendments/fertilizer through the following mechanisms (number of miles or leave blank if uncertain):

- ◯ Broker ____
- ◯ Private contract ____
- ◯ Affiliated or subsidiary entity ______________________________________
- ◯ Given away (first come first serve) ____________________________________
- ◯ Given away (to a predetermined producer or set of producers) _______________
- ◯ Other ____

Q22C Indicate whether disposing of spent grains for composting/soil amendments/fertilizer provides your business with revenue, costs your business money, or breaks-even. Also include cost or revenue per ton if applicable.

- ◯ Provides revenue; estimated revenue per ton ($/ton): ______________________
- ◯ Costs money; estimated cost per ton ($/ton): ____________________________
- ◯ Breaks-even (no cost or revenue)

Q23 In the most fiscal year, indicate the percent of spent distillers grains/mash that were disposed of using the following methods (answers should total to 100%)?
Livestock feed : _______
Composting/soil amendment/fertilizer : _______
Trash/landfill/waste water : _______
Other (specify) : _______

Total : ________

Skip To: Q24 If "In the most fiscal year, indicate the percent of spent distillers grains/mash that were disposed..." = Trash/landfill/waste water

---

Q23A If you are currently disposing of spent grains in the landfill or wastewater, at what revenue point would you consider disposing of spent grains using an alternative other than trash/wastewater/landfilling?

- ○ A loss of greater than $50/ton
- ○ A loss of $49/ton to $25/ton
- ○ A loss of $24/ton to $0/ton
- ○ A gain of $1/ton to $24/ton
- ○ A gain of greater than $25/ton

Q24 Rank in the order of importance the biggest obstacles in disposing of spent grains (1 is most important, 6 is least important).

	Rank (1-6)
Quantity produced	
Market access/no contacts	
Limited knowledge of livestock or cropping uses	
On-site drying/processing	
Limited access to capital	
Other (specify):	

Q25 Estimate the percent price premium you would expect from marketing whiskey/spirits as using sustainable or environmentally conscience production practices, such as non-waste water or landfill disposal of spent grains.

- ◯ No change
- ◯ Less than 1%
- ◯ 1 - 2.5%
- ◯ 2.5 - 5%
- ◯ 5 - 10%
- ◯ Greater than 10%

Q26 Comments or areas of future research that would assist your business or the craft distillery industry in Tennessee.

____

____

____

____

____

End of Block: Default Question Block

Appendix E: BDSG Sampling Instructions

Recommended procedures for sampling wet brewer's or distiller's grains

When taking samples of wet brewer's or distiller's grains, it is critical to ensure that all samples are collected in a similar fashion in order to maintain consistency. Below are the recommended methods for collecting and labeling samples to assure a uniform collection process.

When collecting a sample of wet brewer's or distiller's grains, be sure that the sample is a sufficient representation of the entire brewing/distilling by-product. In order to obtain a homogenous representation, collect the sample as soon as possible following batch production, and obtain subsamples throughout various portions of the product. Place these into a container that is large enough to allow adequate mixing (such as a bucket). Once all subsamples have been collected (target 4 – 6 subsamples), mix thoroughly. Once mixed, fill the sample submission container completely, but without prohibiting closure, and fill out the sample label. Once the container has been filled and sealed, and the label completed, freeze it immediately. Avoid thawing and re-freezing samples.

Please label the sample container with the following information:

- Name of the brewery or distillery
- Name and contact information of the employee who collected the sample
- Description of the type of product that was brewed or distilled. If multiple products were brewed or distilled to result in a mixed batch of by-product, please specify that.
- Date(s) the sample batch was produced
- Date the sample was collected

VITA

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