2021

Management and Dietary Strategies to Mitigate Environmental Stressors in Northern Plains Cattle Feeding Systems

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MANAGEMENT AND DIETARY STRATEGIES TO MITIGATE ENVIRONMENTAL STRESSORS IN NORTHERN PLAINS CATTLE FEEDING SYSTEMS

BY

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A dissertation submitted in partial fulfillment of the requirements for the

Doctor of Philosophy

Major in Animal Science

South Dakota State University

2021

DISSERTATION ACCEPTANCE PAGE

Warren Carl Rusche

This dissertation is approved as a creditable and independent investigation by a candidate for the Doctor of Philosophy degree and is acceptable for meeting the dissertation requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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I am dedicating this to family. To my children, Jordan and Matthew, I hope that I have managed to pass along some lessons that will serve you well as you prepare to take on the world. I could not be prouder of both of you. To my wife April, any degree of success that I have managed to achieve is because you have been always my biggest supporter. None of this would have happened without you. Thank you and I love you!

ACKNOWLEDGEMENTS

This dissertation marks one of the final steps on what has been a five-year journey. Not surprisingly, the list of people who I need to thank for helping me along the way is long. I sincerely hope that I have not left someone off the list.

I would first like to thank my advisor and supervisor, Dr. Joe Cassady, I greatly appreciate your willingness to take a leap of faith with me on this quite unconventional journey. I have appreciated all of your words of wisdom and particularly your leadership over these last five years. He has always been quick to ask, “What do you need from me?” which I have greatly appreciated.

I owe a special debt of gratitude to Dr. Zach Smith. His enthusiasm is contagious and in just a few short years has developed a solid research program. I feel fortunate to have had the opportunity to participate in the early phase of what I am confident will be a distinguished research career. I am looking forward to collaborating with him further in the years to come.

I have been fortunate to work with a great graduate committee that complements my advisors well. Dr. Julie Walker and I have worked together on a number of Extension projects, and I appreciate her commonsense perspective to research questions. I have enjoyed the chance to work with Dr. Kristin Hales and especially her contributions in improving my writing. Dr. Peter Sexton offers a great systems perspective on research questions and agricultural issues, and I appreciate his ability to encourage me to look at situations from different points of view.

I also need to thank Dr. Rebecca Brattain and KWS Cereals USA, LLC for their financial support of the rye feeding project and for her assistance and input during and after the study. The hybrid rye feeding project has been one of the most interesting professional experiences of my career and that would not have happened if she had not approached us about collaborating on the study.

Conducting two cattle feeding experiments 100 miles away from campus is not possible without outstanding people at the research station making certain everything is done correctly. Fortunately, we have that person with Mr. Scott Bird at the Southeast Research Farm. He and the rest of the team at Beresford did a superb job of caring for the cattle and helping collect the data. In my opinion we have the opportunity to do some great things for the cattle feeding industry in South Dakota through what we can learn at the Southeast Farm, and the people there are a big reason why.

One of the best parts of graduate school is the opportunity to work with your fellow graduate students. I have been privileged to learn alongside some really great people who have accepted me as the “grandpa” of the group. I need to recognize Wes Gentry, Ethan Blom, Wyatt Smith, Dathan Smerchek, Ellie Buckhaus, and Katie Miller for their help with one of more of the research projects that make up this dissertation. I also need to recognize Jason Griffith for all he did to assist with lab analysis and for our conversations about SD high school basketball.

I am blessed to have some of the best co-workers anyone could ask for, namely the people with SDSU Extension and the Department of Animal Science. I thank you for your words of encouragement and your tolerance for the multiple occasions when I have needed to say “no” or “not yet” for one request or another. I am looking forward to when

I have one or two fewer irons in the fire that need tending. Special thanks go to the women who make the Animal Science function, namely Cheryl Beste, Brenda Bjorklund, Judy Carlson, Bev French, and Terese Van Ravenswaay. Their cheerfulness and "can do" attitude are part of what has made this Department a great place to work, and I appreciate all the things they have done to help me along the way.

Finally, there are two additional individuals that deserve acknowledgement. Dr. Barry Dunn planted the seed of an idea that starting a PhD program in my 40's was not only possible, but something I needed to seriously consider. Journeys begin with a first step; his was the nudge to start me down this path. Last, but undoubtedly not least, is my wife April. These words are a poor attempt at expressing just how important she has been through this entire process. She is the unseen, and otherwise uncredited presence throughout this dissertation. She is my biggest cheerleader, and without her none of this would have been possible.

CONTENTS

ABBREVIATIONS

12SIL	12% DM silage inclusion
24SIL	24% DM silage inclusion
ADF	acid detergent fiber
ADG	average daily gain
AFBW	adjusted final body weight
BF	back fat
BMR	brown mid-rib
BRSV	bovine respiratory syncytial virus
BVD	bovine viral diarrhea
BW	body weight
CCI	comprehensive climate index
CI	confidence interval
cm	centimeter
CMS	cytoplasmic male sterility
CO	Colorado
CON	conventional
CP	crude protein
d	day

DM	dry matter
DMI	dry matter intake
DOF	days on feed
DP	dressing percentage
DRC	dry rolled corn
EBF	empty body fat
EG	energy gain
EM	maintenance energy
ENO	Enogen Feed Corn
FBW	final body weight
G:F	gain to feed ratio
g	gram
GDD	growing degree days
GMD	geometric mean diameter
GMDSD	geometric mean diameter standard deviation
h	hour
ha	hectare
HCW	hot carcass weight

HS	heat stress
IA	Iowa
IBR	infectious bovine rhinotracheitis
IL	Illinois
IN	Indiana
kg	kilogram
KPH	kidney, pelvic, and heart fat
KS	Kansas
L	liter
LAB	lactic acid bacteria
LM	longissimus muscle
m	meter
Mcal	Megacalories
MCP	microbial crude protein
MDGS	modified distillers grains plus solubles
mg	milligram
ME	metabolizable energy
MI	Michigan

min	minute
MN	Minnesota
MO	Missouri
MP	metabolizable protein
NDF	neutral detergent fiber
NE	Nebraska
NEg	net energy for gain
NEm	net energy for maintenance
OK	Oklahoma
OY	open yard facility
pa	performance adjusted
PC	partially covered facility
PI	processing index
PI3	parainfluenza-3 virus
ppb	parts per billion
ppm	parts per million
QG	Quality Grade
RDP	rumen degradable protein

rpm	revolutions per minute
RUP	rumen undegradable protein
RY	retail yield
SAS	Statistical Analysis Systems
S_D	standard deviation
SEM	standard error of the mean
SERF	Southeast Research Farm
TBC	total barn confinement
TDN	total digestible nutrients
THI	temperature humidity index
TX	Texas
USDA	United States Department of Agriculture
W	weight
WI	Wisconsin
WY	Wyoming
YG	Yield Grade

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ABSTRACT

MANAGEMENT AND DIETARY STRATEGIES TO MITIGATE ENVIRONMENTAL STRESSORS IN NORTHERN PLAINS CATTLE FEEDING SYSTEMS

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Three studies were undertaken to examine strategies to mitigate environmental stress faced by Northern Plains cattle feeders. In the first study, 46 feedlot managers from SD (n = 21), MN (n = 6), and NE (n = 19) were surveyed on use and perceptions of heat stress (HS) mitigation strategies. All respondents avoided cattle handling during heat stress events and incorporated some method of HS mitigation. Buildings or shades were perceived as the most successful strategy (60.9%) and were most commonly named as strategies managers would like to employ (63% for shades and 17.4% for buildings).

Increasing dietary corn silage inclusion is a method to deal with challenging weather either by expanding the harvest window or to salvage weather stressed crops. One hundred ninety steers [initial BW 420 kg (SD 24.7)] were used in a randomized complete block design to evaluate the effects of feeding two types of silage germplasm at two inclusion rates. A 2 × 2 factorial treatment arrangement was used with either a conventional hybrid or a hybrid with increased expression of alpha-amylase (Syngenta Enogen Feed corn, Syngenta Seeds, LLC) fed at either 12% or 24% of diet DM. No hybrid by inclusion rate interactions were detected for live growth performance ($P \geq$

0.15). Growth performance was unaffected by silage hybrid ($P \geq 0.35$). Feeding 24% silage reduced ADG and G:F ($P \leq 0.05$), but increased beef produced per ha ($P = 0.05$).

Hybrid cereal rye offers agronomic benefits as a rotational crop, but knowledge is lacking regarding feeding value in finishing beef diets. Two hundred and forty steers (initial BW 404 ± 18.5 kg) were used in a finishing experiment to evaluate the effect of hybrid rye (KWS Cereals USA, LLC, Champaign, IL) as a replacement for dry-rolled corn (DRC). Four treatments were used in a completely randomized design where DRC was replaced by rye (DRC:rye, 60:0, 40:20, 20:40, 0:60). Increased rye inclusion linearly decreased final BW, ADG, and G:F. Estimated NEm and NEg values for rye when fed at 60% of DM were 1.90 and 1.25 Mcal/kg, respectively.

CHAPTER I: REVIEW OF LITERATURE

INTRODUCTION

Cattle feeding is a highly competitive, narrow-margin enterprise (Lawrence et al., 1999). The greatest source of profit variability in cattle feeding arises from market risk for both feeder and slaughter cattle; however, weather can be a significant source of risk (Belasco et al., 2015). This is especially true in the Northern Plains of the United States, a region that commonly experiences weather extremes for both temperature and precipitation (Wienhold et al., 2018). These challenges will likely increase with changing global climate conditions (Gaughan and Cawdell-Smith, 2015; Wienhold et al., 2018; Walsh et al., 2020).

One of the more obvious influences of extreme weather conditions is on health, mortality, and feed efficiency of feedlot cattle. Cold stress and winter weather conditions are not uncommon events in the Northern Plains, but heat stress events have become more prevalent and of greater concern (Mader, 2012; Walsh et al., 2020). Heat stress events increase the risk of cattle mortality (Busby and Loy, 1997; Mader et al., 2001), negatively affect cattle welfare, and reduce cattle performance and efficiency (Hahn, 1999; Silanikove, 2000; Lees et al., 2019).

The effects of environmental stress on crop production affect cattle feeding risk by altering the supply and price dynamics of feedstuffs, particularly of corn grain. Corn is the primary feed ingredient in cattle finishing diets across the United States (Samuelson et al., 2016) and as such plays a significant role in the cost of gain during the feeding period. Weather challenges during the growing season ranging from excessive moisture delaying planting, insufficient precipitation limiting crop development, or early frost prematurely ending plant growth can all interfere with traditional marketing channels. The ability to integrate crops with a livestock enterprise provides harvest flexibility to mitigate changing environmental and economic conditions (Rotz et al., 2003), particularly in the case of corn silage. Understanding the value of corn silage in cattle diets and effects of corn hybrid characteristics and varying inclusion rates on cattle performance and system economics is important to optimizing resources in integrated systems.

The standard crop production system in recent decades in the Midwest has centered upon corn production often paired with soybeans (Wienhold et al., 2018) with a reduction in crop species diversity (Aguilar et al., 2015). Increasing diversity of such systems would offer benefits in resiliency to changing climate conditions (Lemaire et al., 2014; Gaudin et al., 2015; Bowles et al., 2020) and reduce peak labor requirements (Hoagland et al., 2010). Winter cereal grains such as winter wheat or rye have been proposed as possible additions to a corn-soybean rotation. Hybrid cereal rye germplasm from Europe is an intriguing option because of increased yield potential and reduced resource footprint compared to other crops (Hansen et al., 2004). Additional knowledge for the value of cereal rye in livestock diets is needed for increased adoption as livestock feeding is often the market of last resort when higher-value markets become saturated or if grain does not meet market specifications (Laidig et al., 2017).

Objectives of this research work were to study three different strategies that Midwest cattle feeders could employ to mitigate risk caused by changing environmental conditions: heat stress mitigation strategies used by Midwestern cattle feeders, corn silage inclusion and corn silage hybrid differences in finishing cattle diets, and evaluation of a novel cereal rye hybrid as a replacement for corn in finishing cattle. Previous work in these three areas will be reviewed in greater detail in the remainder of this chapter.

HEAT STRESS IN FEEDLOT CATTLE

Heat stress is detrimental to all livestock production, including beef cattle. Losses to the U. S. beef industry caused by heat stress (mortality plus lost production) were estimated to be $369 million in 2003 (St-Pierre et al., 2003). Those estimates are likely low given that cattle values and feed costs have increased over time. Economic losses can be manifested not only in lost performance (Lawrence et al., 1999; Belasco et al., 2015), but also in increased mortality, particularly during extreme heat stress conditions (Busby and Loy, 1997; Mader et al., 2001).

The thermoneutral zone has traditionally been viewed as temperature ranges where minimal regulatory efforts are required to maintain normal body temperature (Ames, 1980; Brown-Brandl, 2018). Temperatures outside that zone (hot or cold) cause animals to experience thermal stress. Environmental conditions interact with animal characteristics to influence thermal balance, animal well-being, and physiological responses (Lees et al., 2019).

Environmental factors contributing to heat stress

Environmental temperature is the most obvious external factor affecting thermal load in livestock. It has been well recognized that increases in external temperatures affect livestock productivity (Brody, 1945; Kleiber, 1961; Ames, 1980). Air temperatures greater than 25 ^{o}C have been associated with decreased feed intake and consequently reduced daily gains in finishing cattle fed high-concentrate diets (Hahn, 1995; 1999). Increased dry-bulb temperatures have also been positively correlated with increased respiration rate in cattle (Eigenberg et al., 2005). Increased respiration removes body heat via evaporation and thus is a key indicator of thermal stress (Hahn, 1999; Brown-Brandl et al., 2005). Both the daily maximum and minimum temperatures during heat events are important, as the lack of nighttime cooling can exacerbate heat stress responses (Fuquay, 1981; Hahn, 1999).

Ambient temperature cannot be considered alone without also discussing relative humidity. Primary mechanisms for cattle to dissipate excess body heat are through evaporation, either by sweating or panting (Gaughan and Mader, 2014). One of the earliest indexes to quantify heat stress is the Temperature Humidity Index (THI) which combines the effects of temperature and humidity (Thom, 1959). Regional differences within the U. S. in relative humidity have been indicated as a possible reason for greater degrees of heat stress for cattle in the Western Cornbelt and Midwest compared to the Southern Plains. Daytime temperatures are greater in the Southern Plains, but because of lower relative humidity, there are increased opportunities for cattle to dissipate accumulated heat load during nighttime hours (Mader, 2003b).

Because the primary mechanisms for heat load dissipation in cattle involve evaporation, amount of airflow influences heat lost to the environment. When finishing cattle were fed in the summer in sheltered pens with less airflow bodyweight gains were reduced compared to unprotected pens (Mader et al., 1997). In similar summertime studies conducted over three consecutive years, researchers noted that providing shade was beneficial to cattle fed in pens with wind barriers but had no effect when airflow was not restricted (Mader et al., 1999a). The use of fans to enhance airflow in completely shaded facilities also improved cattle performance and reduced maintenance energy requirements (Castro-Pérez et al., 2020). Insufficient airflow has also been associated with increased cattle mortality during extreme heat events (Mader et al., 2001).

Solar radiation independent of ambient temperature also influences the degree of heat load experienced by finishing beef cattle. Evidence of this effect can be shown by observed differences between shaded and unshaded pens. Protecting cattle through the use of shades has been proven to be highly effective in the desert regions of southern California (Garrett et al., 1960; Barajas et al., 2013) as well as in the southern High Plains (Mitlöhner et al., 2001; Mitlöhner et al., 2002). More consistent results to shade use have been observed in hot-arid regions compared to hot-humid climates (Mader et al., 1999a).

In order to quantify effects of these environmental factors on well-being, several different indexes have been proposed. Early efforts focused on relationships between temperature and relative humidity on heat stress indicators for humans (Rothfusz, 1990), or domestic livestock (Thom, 1959). More recent indexes combine temperature and relative humidity with wind speed (Gaughan et al., 2008b), or wind speed plus solar radiation (Mader et al., 2010). This comprehensive climate index (CCI) has the advantage of describing both cold and heat stress conditions, making this tool particularly useful as a method to communicate environmental risks to livestock managers.

Animal factors contributing to heat stress

Environmental factors alone do not explain all of the differences observed between animals experiencing increased ambient temperatures. Metabolic heat load, or heat generated by tissue metabolism and digestive tract fermentation, can account for one-third or more of the total heat load experienced by an animal under hot conditions (Fuquay, 1981; Blackshaw and Blackshaw, 1994). Animals with a greater production potential for either milk or growth also have a greater metabolic heat load (Mader, 2003b; Gaughan and Cawdell-Smith, 2015). Metabolic heat is also related to amount of metabolizable energy (ME) intake. During summer conditions, body temperature of steers increased linearly with increased ME intake (Arias et al., 2011). Heifers fed diets with increased ME had greater body temperatures as well as increased respiration rate (Brosh et al., 1998). Steers that were fed *ad libitum* amounts of a high-concentrate diet had increased body temperatures compared to cattle fed the same diet with intakes restricted to 90% (Mader et al., 1999b).

Differences in diet composition have also been proposed as a factor in differing animal responses to heat stress. Diets with reduced fiber and increased fat concentrations would seem to be plausible approaches to reducing metabolic heat load by reducing heat increment (Fuquay, 1981; Beede and Collier, 1986). However, feeding increased roughage to steers resulted in reduced respiration rate and body temperature, which researchers attributed to reduced ME intake (Mader et al., 1999b). Feeding increased concentrations of dietary fat has been found to reduce heat load in some studies using dairy cows (West, 1999), but mixed results have been reported when fat concentrations were increased in feedlot diets with improvements noted in some studies (Gaughan et al., 2008a), but not in others (Gaughan and Mader, 2009).

Various feed additives have been proposed as methods to mitigate effects of heat stress by supporting DMI and enhancing the animal's coping mechanisms. Blends of essential oils have demonstrated tendencies to improve, but not completely negate, physiological and behavioral impacts of heat stress (Diaz et al., 2018; Silva et al., 2019). Feeding increased concentrations of potassium to compensate for Na and K losses during periods of high ambient temperatures had no effect on gain or efficiency of Holstein steers (Pacheco et al., 2018). Dry matter digestibility was improved by feeding an active dry yeast supplement under thermoneutral, but not heat stress conditions (Crossland et al., 2018).

Characteristics of cattle themselves can play a role in how they respond to elevated thermal heat loads. Heavier cattle have been shown to be more sensitive to excessive heat load likely caused by changes in surface area to mass (Dikmen et al., 2011) as well as increased subcutaneous fat impairing thermal transfer to the environment (Mader, 2003b). During extreme heat events heavier cattle have also been shown to be at greater risk for mortality (Busby and Loy, 1997; Mader et al., 2001).

Coat color also plays a role in degree of heat stress experienced by an animal. Darker coat colors would absorb more solar radiation and consequently those animals would be expected to have increased environmental heat load. Research conducted in Nebraska has convincingly demonstrated that dark-hided cattle exhibited greater degrees of heat stress compared to cattle with red or white coats (Mader et al., 2002; Davis et al., 2003; Mader et al., 2006). Black cattle were also reported to be at greater risk of mortality during extreme heat events (Busby and Loy, 1997; Mader et al., 2001).

Genetic differences beyond coat color also influence how well cattle adapt to heat stress conditions. *Bos indicus* genetics were developed in the tropics and have been shown to be much more adaptable to excessive heat loads compared to *Bos taurus* breeds (Blackshaw and Blackshaw, 1994; Gaughan et al., 2010). Under extreme conditions *Bos indicus* cattle have demonstrated exponential increases in sweat output with increased body temperature whereas sweat output of *Bos taurus* cattle plateaued at a reduced amount (Blackshaw and Blackshaw, 1994). Unfortunately, *Bos indicus* genetics can have reduced growth performance compared to less adapted breeds (Gaughan and Cawdell-Smith, 2015). Other approaches such as selecting for earlier shedding of winter hair coats should improve the ability of *Bos taurus* breeds to adapt to challenging environmental conditions (Gray et al., 2011).

Physiological and behavioral responses to heat stress

Once heat load on the animal from all sources (environmental plus metabolic) exceeds a threshold level (Brown-Brandl et al, 2006), a series of physiological processes and hormonal signals are initiated to dissipate excess heat. The intricacies of regulatory mechanisms involved in maintaining homeostasis under excessive heat load conditions are beyond the scope of this review. However, in broad terms these mechanisms collectively signal the animal to reduce feed intake, increase sweating and respiration rate, and seek out features of their physical environment that could dissipate heat or at least prevent additional heat accumulation (Silanikove, 2000; Brown-Brandl, 2018; Lees et al., 2019; Edwards-Callaway et al., 2021).

Initial responses to increased environmental temperatures are to increase heat loss through evaporation. Sweating increases first in response to increased temperature, followed by increased respiration rate (Hahn, 1999; Silanikove, 2000). Both mechanisms use latent heat of evaporation of moisture from either the skin surface or the respiratory tract to reduce heat load in the body (Brown-Brandl, 2018; Edwards-Callaway et al., 2021). Respiration rate has been shown to peak shortly after peak solar radiation and either just before (Brown-Brandl et al., 2005; Eigenberg et al., 2005) or 0 to 3 h after peak ambient temperature (Hahn, 1999). Initially panting behavior is characterized by increased respiration rate, but with the mouth closed. As heat load increases cattle will open their mouth, extend their necks and tongues, and produce more drool. In extreme stress conditions cattle will shift to deeper, slower breaths (Blackshaw and Blackshaw, 1994; Gaughan and Mader, 2014). Maintenance energy costs have been estimated to increase by 7 to 25%, depending upon the severity of panting, because of the work involved with increased respiration rates (Beede and Collier, 1986; NASEM, 2016; Lees et al., 2019).

Water intake is critically important because of increased amounts lost through evaporative cooling mechanisms and consequently water requirements increase during periods of increased environmental heat load (NASEM, 2016). In a series of experiments over multiple seasons where water intakes were measured, daily water consumption was positively correlated with both daily minimum temperature as well as THI (Arias and Mader, 2011). Those researchers also reported that cattle fed in the summer drank 87% more water per day than cattle fed during the winter.

If increased respiration rates are insufficient to achieve thermal balance the animal will then reduce feed intake to reduce metabolic heat load (Hahn, 1995; 1999; Silanikove, 2000). Threshold temperature for reduced feed intake to occur in cattle is approximately 25 ºC with a 3 to 4 day lag from when ambient temperature increase until changes in feed intake are observed (Hahn, 1999). Meal events become more frequent with smaller amounts consumed during each meal while cattle are acclimating to increased heat loads (Hahn, 1995).

If the previously described set of physiological and behavioral adaptations are not capable of dissipating the excessive heat load, the animal's body temperature will begin to dramatically increase and enter an acute phase of heat stress (Silanikove, 2000). This stage induces maximal panting and sweating in the animal triggering increased heat production because of accelerated biological processes and the energetic costs of severe panting. A vicious circle sets in and death will occur unless heat load can be alleviated quickly.

These adaptation mechanisms provide cattle with the capability to acclimate to increased heat load with the result of a shifting in upper critical temperature (Lees et al., 2019). In some cases once cattle became acclimated to increased temperatures they were able to compensate for thermal stress occurring early in the feeding period (Mader et al., 1999a), while in other studies the negative impact of heat stress persisted and compensatory growth did not occur (Mitlöhner et al., 2001). Transition from one season to another in temperate climates is critically important as early summer heat stress events can be more detrimental to animal welfare and production than mid- or late-summer events with increased temperatures (Hahn, 1995; Nienaber and Hahn, 2007).

Mitigation strategies

Multiple mitigation strategies have been proposed and extensively reviewed as methods to reduce the impact of heat stress on welfare and performance of finishing beef cattle (Brown-Brandl, 2018; Lees et al., 2019; Edwards-Callaway et al., 2021). These strategies can be classified into two broad approaches: reducing effects of external heat load through facility design or modification or reduce metabolic heat load by manipulating diet or management. Each of these strategies have positive and negative aspects; understanding these factors can help guide management decisions more likely to succeed within the resource limitations and particular environmental conditions of an individual feedlot (Brown-Brandl, 2018).

Water application

Water application strategies rely on the latent heat of evaporation to cool the animal (Brown-Brandl, 2018) and have the advantage of not requiring a temperature gradient between cattle and environment to be effective, although insufficient airflow and high humidity can limit effectiveness (Mader, 2003b; Gaughan et al., 2008a). It has been noted that water application can improve cattle welfare indicators (Davis et al., 2003; Gaughan et al., 2008a), but the timing of sprinkler application is less clear. In environmental chambers steers sprinkled during the evening had lower respiration rates than did steers cooled during the day (Gaughan et al., 2008a); however, body temperatures were reduced (Davis et al., 2003) and feed efficiency tended to be improved (Mader and Davis, 2004) when feedlot pen surfaces were wetted in the AM compared to PM application. Heat conducts 20 times more effectively through water compared to air (Brody, 1945), thus water application should create a cooler pen surface and offer increased opportunity to dissipate heat through conduction to the ground before peak environmental heat load (Mader, 2012).

To maximize effectiveness of sprinkling, the animal needs to be saturated to the skin surface and allowed to dry completely (Brown-Brandl, 2018). Fine mists that do not penetrate completely may form a barrier reducing thermal transfer and may actually produce poorer results than not applying water (Mitlöhner et al., 2001). Other challenges with sprinkling are that animals cooled in such a manner may have limited adaptation capabilities (Mader et al., 2007; Gaughan et al., 2008a) and that sprinkling increases daily feedlot water usage 2- to 3-fold (Mader, 2012).

Shade

Shade providing structures have a key advantage of water application in that animals can use the shaded area voluntarily without daily decision making required by feedlot managers (Lees et al., 2019). In a meta-analysis evaluating 15 publications evaluating shade usage in feedlots, providing shade improved ADG and feed efficiency (Edwards-Callaway et al., 2021). A closer examination of the research results shows that there are regional differences in predictability of response to shade. Positive results from shade use have been reported in hot arid regions with greater solar radiation such as the Southern Plains or California (Mitlöhner et al., 2001; Mitlöhner et al., 2002; Barajas et al., 2013), while observations from regions with more humidity have been less consistently positive. Providing shade has improved measures of animal welfare such as body temperature and respiration rate (Brown-Brandl et al., 2005; Eigenberg et al., 2005) but not necessarily performance over the entire feeding period (Mader et al., 1999a; Hagenmaier et al., 2016). In the study conducted by Mader and co-workers (1999a), shades did provide performance benefits in pens with limited airflow for the first 56 d on feed; however, unshaded cattle acclimated to environmental conditions so that there was no difference by the end of the feeding period.

Shades can provide important benefits other than performance differences. Mitlöhner et al., (2002) observed that cattle provided shade had higher quality grades because of fewer dark cutters than did unshaded cattle. They also noted that shaded cattle displayed less agonistic and buller behavior, which should reduce both cattle injury and dust generation. Shade provision was also associated with reduced cattle mortality during extreme heat events in the Midwest (Busby and Loy, 1997; Mader et al., 2001).

A specialized form of shade provision is partial or total confinement barn facilities. These structures have become more common in parts of the Midwest and Northern Plains (Cortus et al., 2021), in part because they provide protection from both cold and heat stress. A comparison of three different housing systems (open yard without shelter, a partially covered yard, and full confinement) at the same location in SD and under the same management showed that shelter during summer reduced respiration rate and body temperature compared to cattle housed in open yards (Gaughan et al., 2009).

As mentioned earlier, sufficient airflow is important for evaporative cooling to be effective. Lack of airflow combined with high temperature and humidity has been associated with increased cattle mortality (Busby and Loy, 1997; Mader et al., 2001). Providing additional airflow by using fans in completely shaded facilities increased cattle performance and efficiency and tended to reduce maintenance energy requirements in cattle fed under tropical conditions (Castro-Pérez et al., 2020). Cattle fed in feedlot pens with shelterbelts or windbreaks gained more slowly and less efficiently in the summer compared to cattle in pens without protection (Mader et al., 1997).

Bedding

Measures that reduce potential for thermal transfer from the ground to the animal are another potential avenue for heat stress mitigation (Silanikove, 2000). The use of water applications to cool soil temperatures was discussed earlier. Providing bedding material could reduce environmental heat load by insulating the animal from increased soil temperatures. Bedding materials are typically lighter in color than the soil surface, so there should be less potential for solar radiation gain. Applying bedding to a dirt-surface reduced pen surface temperature by 14 ^{o}C when ambient temperature averaged 36 ^{o}C, but it is unknown if this difference would improve animal welfare or cattle performance (Rezac et al., 2012).

Adaptive management strategies

Not every mitigation strategy requires alterations to the feedlot physical environment. Adjusting management practices to reduce metabolic heat load experienced by cattle can help reduce risk and be particularly useful while transitioning from spring to summer. Two factors that would have the greatest impact are managing feed deliveries and minimizing additional heat load caused by animal handling (Brown-Brandl, 2018).

Feed delivery alteration

Altering the amount of feed offered is one method that can be used to reduce metabolic heat load. As discussed earlier in this chapter, ME intake is directly related to amount of metabolic heat contributed to total heat load. There is a 3 to 4 day lag between when environmental heat load begins to increase until the animal is able to reduce metabolic heat load through reduced dry matter intake (Hahn, 1995). Sustained extreme conditions during the period before ME intake has adjusted increases mortality risk.

Managing feed intake prior to onset of heat stress conditions can be an effective tool for heat stress risk mitigation. Managing feed intake, either through limit-feeding or by using bunk management strategies designed to ensure that bunks are devoid of feed for part of the day have been successful in assisting cattle in coping with increased environmental heat loads compared to cattle allowed to consume diets ad libitum (Davis et al., 2003; Holt et al., 2004; Mader and Davis, 2004).

Shifting time of feed deliveries to later in the day so that peak metabolic heat load does not coincide with peak heat load from the environment (Mader, 2012). Limit-fed Holstein steers fed in the summer gained 18% faster when fed in the evening compared to the morning with similar dry matter intake (Reinhardt and Brandt, 1994). Heat production for heifers fed in the afternoon was less than that observed in morning fed contemporaries (Brosh et al., 1998). Results of these experiments conducted using growing cattle agree with experiments conducted with cattle fed higher concentrate finishing diets where shifting all or part of the feed deliveries to afternoon resulted in improved measures of cattle welfare and/or improvements in growth efficiency (Davis et al., 2003; Mader and Davis, 2004; Barajas et al., 2013).

Animal handling

Imposing an additional heat load on the animal by movement associated with processing or shipping adds to the risk of loss if conducted during heat stress events. Moving cattle during either winter or summer months increased body temperature (Mader, 2003a). Cattle moved in June or August at 0900 h in those studies required approximately 3 h to return to a baseline body temperature. If cattle handling does not occur early enough in the AM, increased heat associated with movement would coincide with ambient temperature increases potentially resulting in total heat loads that cannot be dissipated by normal adaptive responses. Proactively avoiding unnecessary cattle handling when forecasted conditions are expected to be extremely high would be a prudent risk management strategy. Sprinkling cattle during handling events that cannot be postponed, such as shipping dates, would be another proactive measure to reduce risk (Brown-Brandl, 2018).

All of the mitigation measures discussed with the exception of building either confinement barns or shade structures require implementation decisions by management. Relying solely upon visual indicators of animal stress or feed consumption patterns eliminates the opportunity to proactively implement strategies to assist cattle in adapting to changing weather conditions. Because feed intake is a lagging indicator, by the time those changes are noted cattle may already be at risk if extreme conditions persist (Hahn, 1995; Mader et al., 2001). Increased adoption of indexes and early warning systems which encompass all environmental factors associated with heat stress would provide additional tools to improve cattle welfare and reduce the risk of losses (Mader et al., 2010).

CORN SILAGE AS PART OF BEEF CATTLE PRODUCTION SYSTEM

Corn silage is the entire corn plant harvested, processed, and preserved through fermentation. There are multiple advantages to harvesting corn as silage. Corn silage harvest results in greater quantities of forage dry matter per unit of land than most annual or perennial forage species, thereby freeing land resources to produce more feed or crops to sell (Allen et al., 2003). Harvesting as corn silage provides additional harvest flexibility by allowing managers freedom to tailor the amount of roughage and grain harvested to match requirements of their livestock and objectives of their business. Corn silage harvest occurs before grain harvest; therefore, corn silage expands the harvest window for the crop and reduces weather risk. Silage harvesting can be used as a method to salvage a corn crop that was damaged because of adverse weather conditions. Finally, because the crop is chopped as part of the harvest process before being placed into storage, silage requires no additional steps after removal from storage before feeding.

There also are some challenges associated with harvesting corn as silage. Soil quality and organic matter concentration can decline over time if silage is repeatedly harvested from the same field (Allen et al., 2003; Jokela et al., 2009). Corn silage is bulky and high in moisture content, both of which pose marketing barriers when livestock producers are not located near fields or storage facilities. Finally, problems during ensiling or storage can result in reduced feed value, excessive dry matter losses or both (Allen et al., 2003).

Agronomic practices to optimize yield

For an integrated crops livestock system, generic measure of efficiency would be units of animal protein (meat, milk, or fiber) per unit of land. Efficiency in that context would be determined by the interaction between nutritive value of the feedstuff and quantity of dry matter produced. Because dry matter yield is an important component to overall efficiency measures, a brief discussion of factors influencing yield is appropriate.

Corn for silage should be planted as early as possible provided that seed bed conditions are acceptable for maximum yield potential. Delayed planting reduces dry matter yield potential because of reduced growing degree days (GDD) accumulation and increases risk of yield loss caused by premature frost (Sulc et al., 1996; Allen et al., 2003). Hybrids intentionally selected for silage production should be slightly higher maturity rating than would normally be grown for grain at that geographic location (Garcia, 2016). If poor weather conditions delay planting, hybrid maturity may need to be adjusted so as to reduce risk of frost injury (Guyader et al., 2018).

Most agronomic practices for corn to be harvested as silage would be the same as those used for corn harvested for grain (Allen et al., 2003). Because the entire crop is removed, additional crop nutrient may need to be supplied. Applying manure from livestock being fed the corn silage would help bridge the gap between nutrients removed at harvest with typical fertilizer requirements of corn grain production. In fact, having corn silage in an integrated crops and livestock system could alleviate some challenges with unacceptably high soil nutrient concentrations associated with repeated manure application (Allen et al., 2003). Increased incorporation of cover crops, particularly fall-seeded winter annuals such as cereal rye, would also help address soil health concerns and prevent nutrient losses to the environment (Jokela et al., 2009; West et al., 2020).

Practices to improve feed value of silage for beef production

An important component of optimally producing any feedstuff is quality evaluation in the context of required attributes in the animal's diet. Some attributes differ in corn silage depending upon class of cattle being fed. Dairy cows are fed diets comprising 40 to 60% forage on a DM basis and intake is generally limited by rumen fill (Owens et al., 2018). Under those conditions practices that increase rate of NDF digestibility and DMI would be advantageous (Garcia, 2016; Grant and Ferraretto, 2018). On the other hand, diets fed to feedlot cattle typically contain more starch resulting in decreased ruminal pH and NDF digestion (Owens et al., 1995; NASEM, 2016; Owens et al., 2018). In addition, ruminal fill generally does not limit intake in cattle fed high-concentrate feedlot diets, but may be a limiting factor with lighter-weight growing cattle fed diets with greater roughage concentration (NASEM, 2016; Owens et al., 2018). Consequently, extrapolating research results from dairy to beef cattle feeding, especially finishing diets, could resulting in misleading conclusions (Owens et al., 2018). This section of the literature review will rely as much as possible on data collected with growing and finishing beef cattle.

Harvest moisture and maturity

A critical control point for silage quality and feed value is stage of maturity and moisture content at harvest. The traditional recommendation has been to chop corn for silage at 30 to 35% DM at the one-half to two-thirds milk line stage (Allen et al., 2003;

MacDonald, 2016). However, harvest at that growth stage sacrifices starch content and DM yield compared to harvesting when the plant is more mature (Owens et al., 2018). Modern corn genetics allow for photosynthesis, and consequently the deposition of carbohydrates, to continue longer because of improvements in late-season plant health (Mahanna et al., 2017). Delaying harvest until ¾ to full milk line, might increase economic value of corn silage by increasing the amount of beef produced per unit of cropland and improving cattle performance, although DM content greater than 40% complicates packing (Owens et al., 2018).

Researchers have observed that digestibility of NDF decreases with increased whole plant DM (Andrae et al., 2001; Burken et al., 2017a; Hilscher et al., 2019). However, whole plant DM yield per hectare also increased with delayed harvest (Burken et al., 2017a; Hilscher et al., 2019). Percentage of corn grain in the whole plant increased with later, but not earlier maturity corn, but TDN yield increased as harvest was delayed regardless of hybrid maturity (Burken et al., 2017a). Hilscher and co-workers (2019) noted increased starch content of later harvested silage. These results support the conclusion that delaying silage harvest results in greater total energy yield per hectare.

Cattle response to differing harvest moisture and maturities appears to depend upon inclusion rate or size of cattle being fed. Feeding corn silage harvested at a more advanced maturity (Chamberlain et al., 1971) or increased DM content (Hilscher et al., 2019) negatively affected performance and feed efficiency of growing cattle fed 70% or greater inclusions of corn silage on a DM basis. However, there were no differences in performance between harvest dates when finishing cattle were fed the same silages at less than 45% of DM. It is not clear if responses differ because harvest maturity effects are masked by low inclusions, or if reduced NDF digestibility seen in drier silages are the cause of poorer performance when diets with increased inclusions of silage are fed to growing cattle.

Kernel processing

Kernel processing or use of counter-rotating rolls mounted on silage harvesting equipment, first became popular in Europe with acceptance in North America beginning in the 1990's (Mahanna et al., 2017; Ferraretto et al., 2018). Increased interest in kernel processing has been linked to increased kernel dry matter, a trend towards longer length of cut, increased corn silage inclusion in dairy diets, and increased grain prices (Mahanna et al., 2017; Ferraretto et al., 2018). The objective of kernel processing is to break up kernels to increase starch digestibility, and to crush stalks and cobs (Allen et al., 2003; Owens et al., 2018). A related method of corn silage processing, termed shredlage, uses cross-grooved processing rolls designed to simultaneously produce longer chopped particles with greater physically effective NDF and greater surface area to enhance microbial digestion (Garcia, 2016; Ferraretto et al., 2018).

Results from kernel processing beef cattle diets have been mixed. Processing corn silage increased *in vivo* starch digestibility and tended to be more effective with drier silages in some studies (Andrae et al., 2001), with no effect in other experiments (Rojas-Bourrillon et al., 1987; ZoBell et al., 2002). Responses to kernel processing in growing and finishing studies are also variable, with no differences noted in some growing cattle experiments (Rojas-Bourrillon et al., 1987; ZoBell et al., 2002), with other researchers observing increased ADG and G:F in growing cattle (Brinton et al., 2020). Modest improvements from kernel processing was observed in finishing diets where corn silage comprised 40% of diet DM (Ovinge et al., 2018). Feeding shredlage to yearling steers increased ADG, G:F, and HCW and decreased DMI compared to conventional corn silage (Conroy et al., 2020). The greatest advantage to processing corn silage may be from reducing corn cob disks in silage and the quantity of whole corn kernels appearing in fecal material (Allen et al., 2003; Owens et al., 2018). Reduced diet sorting and refusals were noted when processed silage was fed (Andrae et al., 2001).

Influence of genetic traits on silage feed value

One of the corn hybrid options marketed to dairy and cattle producers have been those containing the brown midrib (BMR) trait. These hybrids have reduced lignin compared to conventional hybrids and consequently increased *in vitro* NDF digestibility (Mahanna et al., 2017; Owens et al., 2018). Feeding BMR corn silage, especially when offered *ad libitum*, generally results in greater DMI, and may improve efficiency and production if intake is limited by rumen fill (Allen et al., 2003; Owens et al., 2018). In steers fed a growing diet containing 86% corn silage, BMR increased DMI with no effect on ADG, resulting in 6.9% poorer G:F (Tjardes et al., 2000). In contrast, growing cattle fed 49% (Saunders et al., 2015) or finishing cattle fed 40% (Ovinge et al., 2018) BMR silage gained faster and more efficiently compared to controls.

Corn hybrids with an increased expression of alpha-amylase enzyme (Enogen Feed Corn, Syngenta Seeds, LLC; Minnetonka, MN) have been marketed as a method to enhance starch digestibility when fed either as corn grain or silage. Positive results to feeding Enogen Feed Corn have been reported in experiments with finishing cattle, with gain more consistently enhanced when fed concurrently with corn gluten feed (Jolly-Breithaupt et al., 2018). Silage made from Enogen Feed Corn supported increased ADG and improved feed efficiency in some growing cattle experiments (Johnson et al., 2019) but not others (Brinton et al., 2020). Feed efficiency in finishing diets improved with inclusion of Enogen Feed Corn silage but not when Enogen Feed Corn grain was fed, even though silage comprised a much smaller proportion of the diet (Baker et al., 2019). Silage from Enogen Feed Corn had a more rapid decrease in pH and improved aerobic stability in experimental silos, suggesting that alpha amylase expression may offer benefits in silage preservation (Baker and Drouillard, 2018).

Practices to optimize fermentation and minimize storage losses

Silage, unlike dry forage or grain, must undergo a fermentation process prior to being fed to livestock. Excessive losses negate many of the advantages of silage and reduce competitiveness of the associated livestock enterprise (Rotz et al., 2003). Some losses during fermentation and storage are unavoidable, but others can be minimized through the adoption of better management practices (Borreani et al., 2018).

The ensiling process can be divided into four phases: initial aerobic phase, primary fermentation phase, stable phase, and the feed-out period (Pahlow et al., 2003). The initial aerobic phase lasts as long as there is oxygen trapped within the packed forage. Oxygen allows biological and chemical processes that consume nutrients to proceed, producing heat as one of the by-products (Borreani et al., 2018). Dry matter losses increase with increased temperature and prolonged periods of heat exposure leads to greater degree of protein damage. Rapid silo filling, increased packing intensity of bunkers or piles, and covering bunkers of piles as quickly as possible minimizes oxygen exposure and aerobic phase length (Borreani et al., 2018; Brüning et al., 2018).

The primary fermentation phase begins shortly after harvest when oxygen supplies have been depleted. Ideally fermentation would be entirely by lactic acid bacteria (LAB) that convert water soluble carbohydrates into lactic acid (Pahlow et al., 2003; Mahanna et al., 2017). This reduces pH until silage enters the stable phase when few changes occur, provided that the silo remains sealed and oxygen is excluded (Pahlow et al., 2003). In reality other problematic microbial species are also present in silage competing with LAB and causing less desirable fermentation end products (Mahanna et al., 2017). Yeast populations increase if filling is prolonged or sealing is delayed, and then proliferate when exposed to oxygen, resulting in greater DM loss and poorer aerobic stability (Pahlow et al., 2003). *Clostridial* species are associated with excessively wet forage or soil contamination, and typically result in foul-smelling silage with butyrate formation which reduces palatability and DMI (Mahanna et al., 2017).

Silage inoculants containing LAB have been developed as a method to improve silage value by overwhelming the population of undesirable microbes (Mahanna et al., 2017). Inoculants containing *Lactobacillus buchneri* have become widely adopted because of yeast inhibiting activity and improved aerobic stability on feed out (Muck et al., 2018). A weakness of *L. buchneri* inoculants has been that 1-2 months are required to see differences in aerobic stability. Newer inoculants with *L. buchneri* combined with other microbial species such as *Pediococcus pentosaceus* and *Lactobacillus plantarum* have been more successful at rapidly improving stability while also enhancing DM recovery (Muck et al., 2018).

Opening the silo for feeding ends the stable phase and begins the final phase of ensiling. Silage is unavoidably exposed to oxygen at this time, and thus at risk for loss of nutrients associated with aerobic oxidation. In fact, up to 50% of all DM losses occur during feed-out (Mahanna et al., 2017). Managing feed-out rate to keep the face of a bunker or pile as fresh as possible minimizes the time silage is exposed to oxygen and reduces DM loss (Borreani et al., 2018). Feed out rates less than 0.5 m/week in winter and 0.8 m/week in summer have been associated with severe deterioration of feed quality, with faster rates improving aerobic stability (Borreani et al., 2018). Using a pile facer to shave the silage face or a front-end bucket to peel back silage horizontally is preferred over lifting the bucket from the bottom to the top to reduce the depth of oxygen infiltration (Mahanna et al., 2017). Spoiled silage should be segregated and removed rather than blended into cattle diets. Feeding diets with spoiled silage to steers resulted in decreased DMI and digestibility compared to diets containing normal silage (Whitlock et al., 2000).

Safety around silage should also be addressed, particularly around bunkers and piles. Increased farm size has led to larger piles with greater peak heights. Consequently, the risk of avalanche or collapse increases which could result in feeding equipment damage, or most tragically, injury or death (Mahanna et al., 2017; Bolsen, 2018). Care also needs to be taken during filling and packing as rollover risks increase if pile slopes are not monitored carefully (Bolsen, 2018).

Silage use in beef cattle diets

Corn silage is a versatile feed for beef cattle and functions as a high-energy forage source to supplement poorer quality roughage for beef cow diets. Because corn silage is intermediate in net energy content compared to grains and most roughage sources common to the Midwest (NASEM, 2016), it can be included in various proportions in growing diets to meet performance objectives within constraints of feedstuff availability and cost. Including ensiled feed reduced sorting behavior in growing calves compared to dry or wetted hay (Blom et al., 2020). These characteristics help explain the widespread adoption of corn silage by integrated crops – beef cattle enterprises, with corn silage production reported by 42 and 60% of Northern Plains (ND, SD, and NE) and Midwest (IL, IN, IA, MI, MN, MO, and WI) cattle feeders, respectively (Asem-Hiablie et al., 2016). Average dry matter inclusions for growing diets in that survey ranged from zero to 78% in the Northern Plains and from zero to 67% in the Midwest, indicating that corn silage is used in a variety of ways depending upon resources at individual feedlots.

Crude protein provided by corn silage alone is not sufficient to meet the needs of growing beef calves. More specifically, with corn silage alone there is insufficient metabolizable protein supply (MP), which is the sum of microbial crude protein (MCP) and rumen undegradable protein (RUP) compared to the animal's requirements (NASEM, 2016). Young growing cattle require additional RUP beyond that supplied by MCP to meet their needs (Klopfenstein, 1996). Extensive proteolysis occurs during fermentation resulting in a high proportion of rumen degradable protein (RDP; Weiss et al., 2003). When supplements containing distillers grains or soybean meal were fed in diets containing 79% corn silage and formulated to be isonitrogenous and isocaloric, growing calves had greater DMI, increased ADG, and improved feed efficiency compared to calves fed urea-based supplements (Felix et al., 2014). In separate experiments with growing cattle fed diets containing > 80% of DM from corn silage, increased supply of RUP linearly increased ADG and G:F (Hilscher et al., 2019; Oney et al., 2019). These results support the conclusion that providing supplemental RUP to corn silage-based diets fed to growing cattle is important to optimize feed value.

Finishing diets typically contain only a limited percentage of roughage as a method to help prevent digestive upsets (Galyean and Defoor, 2003). Corn silage inclusion rates in finishing beef diets have been extensively studied with clear evidence that feeding increased amounts of corn silage negatively affects performance and efficiency of finishing cattle (Goodrich et al., 1974; Preston, 1975; Gill et al., 1976; DiCostanzo et al., 1997; DiCostanzo et al., 1998). Gains declined primarily because net energy for gain (NEg) content of corn silage is less than that of corn or other concentrate being replaced (Preston, 1975; Owens et al., 2018). The negative effect of corn silage inclusion on performance in finishing diets is more pronounced at greater inclusion rates (Goodrich et al., 1974; Owens et al., 2018).

The previously cited experiments (Goodrich et al., 1974; Preston, 1975; Gill et al., 1976; DiCostanzo et al., 1997; DiCostanzo et al., 1998) were conducted prior to widespread availability and adoption of corn processing co-products, such as distillers grains, in cattle finishing diets. Distillers grain inclusion has been shown to increase DMI and increased concentrations of RUP compared to urea or oilseed-based protein supplements (Klopfenstein et al., 2008). Researchers at the University of Nebraska – Lincoln conducted a series of experiments to examine if feeding these co-products affected the influence of corn silage inclusion on finishing cattle gain and feed efficiency. In one experiment, finishing steers were fed increasing amounts of corn silage (15, 30, 45, and 55% of DM, respectively) in diets containing 40% of DM as modified distillers grains with solubles (Burken et al., 2017a). They observed that as corn silage inclusion increased there were linear decreases in ADG, G:F, and calculated NEg content. They also reported that G:F was reduced 5.0% by increasing corn silage from 15 to 45% compared to an approximately 15% reduction reported by Goodrich et al. (1974) for the same inclusion rates. These researchers speculated that because of distillers grains inclusion the negative effects of corn silage on finishing cattle efficiency were lessened. Increased inclusions of corn silage reduced ADG and G:F in similar experiments where either 40% (Burken et al., 2017b; Hilscher et al., 2019), or 20% distillers grains (Burken et al., 2017b) on a DM basis were fed. Feeding an increased amount of silage for the same number of days on feed resulted in lighter carcasses with less fat (Burken et al., 2017a; Burken et al., 2017b; Hilscher et al., 2019). Increasing number of days on feed for cattle fed increased inclusions of corn silage resulted in HCW similar to (DiCostanzo et al., 1997) or greater than (Ovinge et al., 2019) cattle fed lesser amounts of silage.

Economics of increased corn silage inclusion in cattle finishing diets

Evaluating the economics of silage begins with determining correct value per 1,000 kg of corn silage. Pricing corn silage is complicated by the challenge of representative sampling for DM content and in determining the appropriate proportion of dry corn per 1,000 kg of harvested silage (Owens et al., 2018). The correct reference price for dry corn also needs to be identified. Silage is harvested in the fall which corresponds with increased likelihood of seasonally low corn prices (Welch et al., 2011). Prices typically rise until late spring or early summer, making that time period more attractive as a pricing point for farmers contracting corn silage acres. However, capturing seasonally high corn prices requires incurring storage costs. If corn silage is priced in the field, the purchaser of the silage would pay all storage costs; consequently, corn silage should be priced using harvest prices rather than some price point later in the year (Klopfenstein and Hilscher, 2018). Harvest costs for silage and for dry grain, risks for DM loss from delaying harvest, expenses to dry corn to 85% DM, and silage shrink all need to be considered in correctly determining silage value (Klopfenstein and Hilscher, 2018; Owens et al., 2018).

Degree of integration between crops and livestock enterprises play a role in whether or not increased silage inclusion is economically viable. When corn silage, earlage, or high-moisture corn were compared to dry-rolled, corn silage was more efficient than dry-rolled corn when measured on a metabolizable energy (ME) or gain per ha basis (Johnson et al., 2016; Owens et al., 2018). Integrated enterprises that can more effectively use manure as an asset to reduce commercial fertilizer expenses or also incorporate cover crops for additional forage could more easily justify increasing corn silage harvest and use (Klopfenstein and Hilscher, 2018). Business plans of feeders need to be considered as lots managed to be kept full all year would be less able to increase silage use if that required greater days on feed and reduced yard turnover per year (Goodrich et al., 1974). Ovinge et al. (2019), concluded that feeding 45% corn silage and increasing days on feed was more profitable than feeding 15% corn silage. Determining optimal inclusion of corn silage is a complex process. Relying on a single parameter, such as differences in feed efficiency, may very well lead to incorrect or misleading conclusions.

RYE GRAIN AS AN ALTERNATIVE TO CORN

Corn is considered the “gold standard” in terms of a feed grain for livestock, including beef cattle. Corn is widely grown across large portions of the United States, and is produced in increasingly larger quantities because of advancements in cultural practices and genetic selection for increased stress tolerance (Duvick, 2005). Given that corn is widely available and is a predictable source of dietary starch (energy), it is not surprising that corn is the most commonly used feed grain in US feedlots (Samuelson et al., 2016).

However, modern corn production in the US is not without challenges and critics. Concerns surrounding corn production include water use and run-off of crop nutrients, soil degradation, and reduced biodiversity (Sandhu et al., 2020). Those concerns will undoubtedly increase, creating a need to modify production practices to reduce environmental impact. At the same time, climate change will likely lead to more variable and extreme weather conditions (Wienhold et al., 2018; Walsh et al., 2020), increasing crop production (and feed supply) risk. Introducing greater cropping diversity into row-crop systems would at least partially mitigate these concerns. Increasing cropping system diversity improves resiliency to changing weather conditions (Gaudin et al., 2015; Bowles et al., 2020), particularly when paired with livestock (Lemaire et al., 2014).

Hybrid rye production

Rye is a winter annual planted in autumn. It requires freezing temperatures to vernalize and initiate reproductive development the following spring (Oelke et al., 1990). Winter rye (*Secale cereale*) is a promising candidate to be added to corn-soybean system.

Winter annuals reduce peak labor requirements compared to corn and soybean production (Hoagland et al., 2010). Rye improves the environmental footprint of corn-soybean production by reducing amount of crop nutrients leaving the system and providing additional cover during winter fallow periods (Feyereisen et al., 2006; Karlen et al., 2006; West et al., 2020). Winter rye also has been effective as an additional method to suppress weed populations that have become resistant to widely used herbicides (Cornelius and Bradley, 2017). Rye also offers a wide array of harvest options, particularly for operations with livestock, as it can be grazed, harvested for forage, or allowed to mature to be harvested for grain (Oelke et al., 1990).

Yield advantages of hybrid rye

Relatively poor grain yields of rye compared to other cash crops led to reduced plantings with more than 50% of rye used for forage or cover crop purposes. Of the portion that is harvested in the US, about half is used for livestock feed or exported with the balance used for distilling, milling, or seed (Oelke et al., 1990). New hybrid germplasm could make cereal rye production more attractive. Hybrid rye was first released in Europe in 1984 and today represents a majority of rye planted in Germany (Laidig et al., 2017), likely because of the 10 to 20% greater yield compared to population genetics (Hansen et al., 2004; Laidig et al., 2017). Yield differences in the US have been even greater, for instance test plot results from southeast South Dakota showing that hybrid rye out-yielded population varieties by 72% (Sexton et al., 2020).

Ergot in cereal rye

Ergot infection of cereal rye has been another obstacle to greater adoption of the crop. Ergot in cereal rye is caused by the fungal species *Claviceps purpurea* (Coufal-Majewski et al., 2016). Unfertilized ovaries on the rye seed head are infected by ascospores released from ergot bodies (sclerotia) produced in a previous growing season and overwintered or from secondary inoculum arising from infected susceptible grasses near cultivated fields (Miedaner and Geiger, 2015). The infected ovary hardens and is replaced by a purplish colored ergot body that either falls before harvest to infest later plantings or is harvested along with the grain (Coufal-Majewski et al., 2016). Ergot results in yield losses of 5 to 10%, but the primary economic loss is caused by discounts for contaminated grain (Miedaner and Geiger, 2015; Coufal-Majewski et al., 2016). Ergot bodies produce ergot alkaloids which have a wide array of physiological effects in humans, including hallucinogenic properties and vasoconstrictive effects that can lead to dry gangrene (Miedaner and Geiger, 2015). Vasoconstriction can also occur in livestock resulting in losses of tail switches or hooves ("fescue foot") or more subtle responses such as hyperthermia, loss of production, and depressed feed intake (Klotz, 2015).

Cultural practices can help reduce the incidence of ergot. Planting clean seed, controlling wild, weedy grasses within or near fields, and rotating with non-susceptible crops are practices that would reduce infection risk. Chemical fungicides have been used to prevent infection in Kentucky bluegrass seed production fields, but these options are generally uneconomical for cereal production (Schumann and Uppala, 2000). Sclerotia bodies can be removed using either gravity tables or optical-electronic color sorters;

however, these are only practical for large-scale mills or seed production facilities (Miedaner and Geiger, 2015).

Allowable limits of ergot for livestock feed or human use are not globally uniform. The United States requires that grain destined for livestock feed have less than 0.3 ppm ergot, compared to 0.1 ppm for the European Union and 0.001ppm for the United Kingdom (Miedaner and Geiger, 2015; Coufal-Majewski et al., 2016). Further complicating matters is that in most cases legislated limits for ergot or ergot alkaloid contamination are not based on toxicological studies with livestock (Coufal-Majewski et al., 2016).

Genetic selection holds promise to reduce ergot infection. Rye is an open pollinator, meaning that it is more susceptible to ergot infection compared to self-pollinators such as wheat or barley (Coufal-Majewski et al., 2016). In rye, susceptibility is related to the length of time when flowers are open for infection. Late flowers from extended tillering period increased risk as does a reduced amount of pollen resulting in less competition with ergot spores (Miedaner and Geiger, 2015). Hybrid rye cultivars are created using an inbred cytoplasmic-male sterility (CMS) line that is first crossed with an inbred line that produces pollen. The resulting plants are crossed with an additional line that carries a restorer gene to enable fertility of the resulting hybrid rye seed. Initial rye hybrids introduced in 1985 shed less pollen than did population cultivars, resulting in increased ergot susceptibility. Genes (*Rfp1* and *Rfp2*) with greater restorative capability were found in germplasm from Iran and Argentina resulting in greater pollen production, a shorter pollination period, and reduced risk of ergot infection (Miedaner and Geiger, 2015; Miedaner et al., 2017). Hybrids with these *Rfp1* gene (PollenPlus®; KWS Cereals USA, Champaign, IL) have since been introduced to the marketplace.

Incorporation of rye into ruminant diets

Nutrient composition

Rye is a small grain and as such has composition relatively similar to other small grains fed to beef cattle such as barley or wheat. According to NASEM (2016), nutrient composition of rye grain most closely resembles barley, with CP, starch, NDF and ADF percentages of 11.3, 58.0, 15.4, and 7.5%, respectively, compared to 12.8, 56.7, 18.3, and 7.0% respectively for barley. Wheat has a higher concentration of starch and CP and less NDF and ADF compared to rye. In contrast, reported composition values for corn CP, starch, NDF, and ADF are 8.8, 72.0, 9.7, and 3.6% respectively. These values are comparable to chemical composition of rye and corn (maize) used in digestibility and ruminal fermentation experiments conducted in Poland (Rajtar et al., 2020a; Rajtar et al., 2020b). A portion of the increased NDF concentration can be explained by greater concentrations of non-starch polysaccharides, particularly arabinoxylans and β-glucans (Hansen et al., 2004; Jürgens et al., 2012). Arabinoxylan concentration can negatively affect nutrient digestibility in monogastrics, but are typically fermented by ruminal microbes similarly to NDF (NASEM, 2016).

Ruminal degradability

Starch in rye is degraded more rapidly and to a greater extent in the rumen than that of barley (Krieg et al., 2017) or of corn (Rajtar et al., 2020a; Rajtar et al., 2020b). When rye that was processed to increasing degrees (whole grain, coarsely rolled, ground through 4 mm screen, or 1.5 mm screen), *in situ* ruminal starch degradability increased from 18.3% for whole rye to 92.5, 85.5, and 96.0%, respectively. In contrast, when corn was processed in the same manner, in situ ruminal starch degradability was 4.6, 36.9, 50.5, and 57.5%, respectively. Total tract starch digestibility was greater with rye compared to corn for all processing methods except ground through 1.5 mm screen (Rajtar et al., 2020a). Acidosis risk and negative effects of NDF digestion may be increased with rye; however, as ruminal pH was lower when rye was fed to sheep compared to corn (Rajtar et al., 2020b).

Crude protein degradability in the rumen followed a pattern like that of starch, with increased rate and extent of ruminal crude protein degradability in rye compared to corn (Rajtar et al., 2020a). Estimated RUP values derived from in situ experiments were 19.6% of CP for rye compared to 24.6, 28.3, and 77.3% for barley, wheat, and corn, respectively (Benninghoff et al., 2015).

Differences in ruminal starch degradability can be exploited in finishing diets by feeding rapidly fermentable grains in combination with grains where starch is degraded more slowly. Combining wheat, a grain with rapid ruminal starch degradability, with corn resulted in a positive associative effect where cattle fed blended diets gained 4% faster and 4.4% more efficiently compared to the average of cattle fed either 100% corn or wheat (Kreikemeier et al., 1987). Positive associative effects were also observed when steam-flaked grain sorghum was fed in combination with either high-moisture or dry-rolled corn (Huck et al., 1998).

The extent of ruminal degradability of crude protein from rye suggests that additional RUP may be required, particularly when fed to fast growing calves. As previously discussed, feeding increasing amounts of RUP in a diet very high in RDP improved gain and feed efficiency. In spite of the greater CP content of rye, additional RUP supplementation may be required if MP supply is inadequate.

Ergot alkaloid toxicity

Because rye is susceptible to ergot infection, the impact of ergot alkaloids on cattle needs to be considered when evaluating including rye in cattle diets. Ergot alkaloids associated with endophyte infected fescue have been studied much more extensively compared to those produced by *Claviceps pupurea*, although toxicosis and ergo-peptide alkaloids from the two sources do share similarities (Evans et al., 2004). Acute toxicity symptoms were discussed earlier, but much of the loss associated with ergot alkaloid toxicity is related to loss of production from chronic exposure. One of the challenges of determining the effects of ergot alkaloid exposure is highly variable responses between animals (Klotz, 2015). Reduced DMI has been noted in steers fed hay with ergot alkaloid concentrations of 120 ppb (Matthews et al., 2005) while in another experiment Holstein-Friesian bulls were fed diets with as much as 421 ppb ergot alkaloid concentration with no effect on feed intake or growth (Schumann et al., 2007). Lambs fed diets containing 433 ppb ergot alkaloids had reduced ADG and G:F compared to those fed diets containing 169 ppb with similar DMI (Coufal-Majewski et al., 2017). Despite differences in responses observed in individual experiments, it is generally accepted that primary cause of reduced performance in cattle consuming ergot alkaloids is reduced feed intake (Klotz, 2015; Koontz et al., 2015).

Ergot alkaloids can mimic signs of heat stress because of vasoconstriction, reducing the animal's ability to diffuse heat to the environment (Klotz, 2015). Sheep fed endophyte infected fescue seeds were more sensitive to heat stress compared to sheep not fed additional ergot alkaloids (Hannah et al., 1990). Signs of heat stress and ergot alkaloid exposure overlap (depressed feed intake, increased body temperature, elevated respiratory rate), which can pose a challenge in determining causes of observed animal differences when both factors are present (Klotz, 2015).

Experimental feeding results in cattle

Data from actual experiments feeding rye grain to cattle is limited. Researchers in South Dakota in the 1930s compared feeding rye to feeding corn to steers with access to free-choice alfalfa hay. They reported that palatability was reduced for rye and speculated that blending rye with other grains might increase grain intake (Wilson and Wright, 1932). Early researchers also noted challenges with ergot infested rye grain fed to beef cattle (Dinusson et al., 1971). For these reasons the standard recommendation for rye grain was to limit inclusion to 25 to 50% of total grain in beef diets (Matsushima, 1979).

More recent work has examined the potential for rye to substitute for other cereal grains. Young Holstein calves were fed from birth to 18 weeks of age 0, 30, 60, or 80% rolled rye in their diets, replacing rolled barley (Sharma et al., 1981). They reported no differences between treatments in growth or feed intake measures for the first 6 weeks, but from week 7 through 18 increased inclusions of rye reduced DMI and ADG with no effect on feed efficiency. Interestingly, an additional treatment in that experiment of 80% whole roasted rye supported equivalent gains and DMI as the rolled rye control diet. The authors did not speculate why roasted rye supported increased growth performance, but heat treatment may have increased RUP in the rye grain and thus increased MP supply to the calf.

Sharma et al., (1981) also conducted an experiment where rolled rye replaced one-third, two-thirds, or all rolled barley in lactating cow diets. Grain was offered separately from forage in that experiment. The authors reported that grain intake was similar across treatments, but that intake of grass silage was reduced with increasing inclusions of rye grain. These researchers also observed that cows fed rye as the sole grain source consumed their daily ration more slowly, which they speculated might be related to observed differences in silage intake. Inclusion of rye had no effect on milk production or composition.

Other researchers feeding limited amounts of rye grain to lactating cows have observed little to no effect on milk output with varying effects on feed intake. Feeding lactating Holstein cows 36% of diet DM as rye grain depressed DMI, but had no effect on milk yield or composition (Spiece, 1986). In that experiment, heat treating rye by either roasting or extruding had no effect on DMI or milk production compared to dry rolled rye. In a more recent experiment with lactating cows replacing ground wheat with ground rye had no effect on milk production or DMI (Pieszka et al., 2015). However, inclusion rates of rye reported were considerably less than previous research, with only 10.6 and 15.3% rye fed in two separate experiments.

Published results from experiments in growing or finishing beef cattle are quite limited. Spiece (1986) reviewed older beef cattle research reports from Canada in the 1970s with some researchers reporting no negative effects of up to 60% rye inclusion in beef finishing diets with others noting slight reductions in gain and efficiency when rye grain was substituted for barley. Rye grain replaced barley in diets fed to growing and finishing dairy bulls with rye inclusions of 0, 7.5, 15, and 22.5%, respectively

(Huuskonen and Pesonen, 2018). Treatment had no effect on DMI, nor on measures of gain and efficiency on either a live- or carcass-adjusted basis. It should be noted that grain processing methods were not specified in that study.

The lack of published data indicates a need for additional research to more fully explore how to best utilize hybrid cereal rye in beef cattle diets. Research questions include determining the correct degree of grain processing for rye and the effect that rapid ruminal starch degradability associated with rye grain might have on feeding behavior, feed intake, and acidosis risk. Additional work regarding RUP needs would be warranted, especially for rapidly growing calves during backgrounding. Characterizing ergot alkaloid concentrations in commercial hybrid rye production and improved understanding of ergot alkaloid tolerances for various classes of beef cattle will also be important as hybrid rye usage increases.

SUMMARY

At first glance heat stress, silage use in beef diets, and evaluation of hybrid rye feeding in beef finishing diets appear to be quite unrelated. That conclusion could be justified based on a superficial examination. However, when viewed through the context of risk mitigation these seemingly unrelated topics in several areas can be connected as parts of potential solutions to deal with environmental stress in the Northern Plains.

Integration of crops and livestock systems adds resiliency not only at the individual farm level, but also on a regional level. Heat stress increases risk of not only catastrophic losses, but also from noticeable decreases in production and efficiency. The most effective mitigation strategies require additional capital investment (shades, structures, or sprinkler systems), but lower cost management adaptations are also effective measures to reduce risk, either alone or in combination with facility modifications. For instance, reducing dietary energy concentration by increasing corn silage inclusion should result in cattle that acclimate more rapidly to greater environmental heat loads. Straw from rye grain harvest could be used as a method to reduce heat transfer from pen surfaces to cattle.

South Dakota weather conditions also increase crop production and feed supply risk. Alternative crops, such as winter rye, that are planted and harvested at different time points compared to corn reduce the risk of adverse weather preventing critical agronomic practices or negatively affecting yield. Flexibility to harvest corn for silage reduces risk of adverse weather delaying harvest of corn grain and the potential expense of drying corn to 85% DM for storage. Silage harvest expands windows of opportunity for other farm operations such as manure application. Silage production also allows for greater opportunity to plant fall-seeded crops, which would improve soil health and nutrient cycling compared to a winter fallow system. Winter rye, one of the fall-seeded options, offers multiple opportunities for livestock feed including grazing, harvested forage, and rye grain.

Traditional row-crop based agriculture in South Dakota requires additional options and strategies in order to respond to new challenges in a sustainable manner. The topics explored in this review of scientific literature offer potential solutions that could be used to enhance resiliency of rural South Dakota.

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CHAPTER II: HEAT STRESS MITIGATION STRATEGIES USED BY MIDWESTERN CATTLE FEEDERS

ABSTRACT

The objective of this survey was to obtain descriptive data regarding facilities and heat stress (HS) mitigation strategies, and to determine cattle feeders' perceptions of the effectiveness and preferences of HS mitigation practices. Feedlot managers (n = 46 total) from SD (n = 21), MN (n = 6), and NE (n = 19) were surveyed about facilities and management, perceptions of HS mitigation success or failure, and strategies they would like to employ. Open yards (OY) were the most common system (62%), followed by total barn confinement (TBC; 23%) and partial barn confinement (PC; 14%) with 15 respondents (33%) reporting multiple systems. Modifications were made to all OY (55% shades, 52% water application, and 25% bedding). Buildings were the sole adaptation for 79% of the TBC and PC facilities. Feed delivery adjustments and feed additives to mitigate HS were used by 33% and 35% of respondents, respectively. All respondents avoided cattle handling and 67% adjusted shipping schedules during HS events. Initiation of mitigation steps was triggered by observed weather conditions (56%), visual indicators of cattle HS (39%), HS alerts (26%), and calendar triggers (6%). Buildings or shades were perceived as the most successful (61%) heat stress mitigation strategy, followed by water application (50%), additional water space during HS (33%), and bedding (24%). Strategies perceived as less successful included water application (24%), feed additives (22%), and bedding (17%). Of respondents dissatisfied with water application, 64% specifically cited mud. Shade structures (63%) and confinement buildings (17%) were strategies respondents most wanted to implement with barriers being cost, time, and

perceived need (72, 22, and 11% of all respondents, respectively). Midwest cattle feeders use multiple approaches to mitigate HS with those providing shade on cattle perceived to be most successful.

INTRODUCTION

Heat stress (HS) can be a significant source of risk when feeding cattle. Hyperthermia not only increases the risk of mortality, but also can result in growth performance losses, and detrimental effects on animal welfare. Evidence is accumulating that HS risk has increased over time, in part because of increased nighttime temperatures and increased humidity (Walsh et al., 2020). Mitigation of HS may become more critical in geographical regions not traditionally associated with HS risk such as the Midwest.

While factors contributing to and the physiological responses to HS have been extensively studied and reviewed (Mader, 2003; Brown-Brandl, 2018; Lees et al., 2019; Edwards-Callaway et al., 2021), less work has been done in examining what mitigation steps are most likely to be adopted by producers and their perceptions of potential success or failure. Outreach and information transfer efforts that take into account attitudes of potential adopters are more likely to be successful (Rehman et al., 2007; Ritter et al., 2017). Edwards-Callaway et al. (2021) concluded that understanding producer perception of HS mitigation value and quantifying mitigation practices currently in use were critical areas of focus to improve cattle welfare and reduce risk of economic loss. The objective of this survey was to obtain descriptive data regarding management practices and facility design pertaining to HS mitigation, identify practices perceived by producers to be more useful, and to obtain insight on where to focus outreach efforts to assist cattle feeders.

MATERIALS AND METHODS

Institutional Animal Care and Use Committee approval was not required for this study because no animals were used. The Institutional Review Board at South Dakota State University granted approval to conduct this survey (IRB – 1507004 – EXM).

Survey participants were invited using mailing lists compiled by Extension personnel and from industry professionals. Candidate feedlot locations were identified by HS risk zones characterized by typical number of days with temperature-humidity index (THI) greater than 80 (Rothfusz, 1990; High Plains Regional Climate Center, 2020). Prospective participants were first contacted by telephone, and if willing to participate, were visited by a trained individual to conduct survey interview and to observe feedlot characteristics including facility type, location of windbreaks, and presence of shade structures or sprinkler systems. Participants were asked to answer questions about types of cattle fed, types of facilities used with specific questions for open yards (OY), covered confinement barns (TBC), and partially covered pens (PC). They were also asked open-ended questions about their perceptions of HS mitigation strategy success and what strategies they would like to implement (See APPENDIX). There were 46 total cooperating feedlots, 19, 21, and 6 from NE, SD, and MN, respectively. Because MN and SD participants had similar characteristics and because of comparatively fewer responses from MN, SD and MN data were combined (MN/SD) for the purposes of analysis.

Response data from the survey were entered into a Microsoft Excel (Microsoft, Redmond, WA) spreadsheet for summarization. Confidence intervals for feedlot capacity for NE and MN/SD were determined using the TTEST procedure of SAS 9.4 (SAS Inst. Inc., Cary, NC) with an alpha of 0.05. Participants could provide multiple responses for the open-ended questions, consequently the number of responses to a particular question is expressed as a percentage of the number of individual feedlots or facility types within a particular category.

RESULTS AND DISCUSSION

Descriptive statistics

Descriptive data for state location, placement mix, and finishing diet energy concentration are presented in Table 2.1. Mean cattle capacity for NE feedlots was greater ($P < 0.001$) than for MN/SD (NE; mean 7,832 cattle, 95% CI [5,341, 10,322], MN/SD; mean 3,029 cattle, 95% CI [1,971, 4,086]; Figure 2.1). Feedlots in NE placed a higher proportion of yearlings (67.5%) and cattle with *Bos indicus* influence (5.5%) compared to MN/SD (44 and 0.2%, respectively).

Participants were asked about previous losses caused by HS. All of the respondents indicated that they had experienced losses from previous HS events with 87% of feedlots perceived and described their losses as “minor” and 13% as “moderate” (data not shown). Participating feedlots were classified into zones for summer heat stress risk (Figure 2.2; High Plains Regional Climate Center, 2020) based on the number of days with THI (Rothfusz, 1990) greater than 80. The resulting zones and heat index values were Red, > 70 d; Orange, 60 to 70 d; and Yellow, 50 to 60 d. Feedlots in NE were at greater risk for HS with 42, 58, and 0% of feedlots in the Red, Orange, and Yellow zones, respectively, compared to 0, 41, and 59% for MN/SD (Table 2.2).

General heat stress mitigation practices

Open yards were the most reported facility type with 100% of NE respondents reported this facility type with only two reporting managing a TBC facility in addition to an OY (Table 2.2). In contrast, MN/SD feedlots reported a more diverse mix of facility types with OY, TBC, and PC facilities representing 49, 30, and 21% of all facility types, respectively. A survey of Iowa feedlot operators showed that 73% of cattle in that state were fed in facilities that offered some form of shelter and that 50% of new expansion for the previous 5 years was in the form of confinement barns (Schulz et al., 2015). Midwestern (IA, MI, MN, IL, WI and IN) cattle feeders surveyed reported that open facilities were used by 47% of operations, compared to 61 and 20% for bedded pack and slatted floor facilities, respectively (Asem-Hiablie et al., 2016).

Feed was delivered two or more times by 100% of NE feedlots compared to 78% of MN/SD (Table 2.2). Seasonal shifts of feeding to deliver a greater proportion of the daily diet to afternoon or evening was reported by 37 and 30% of respondents from NE and MN/SD, respectively. Feeding a greater proportion of DM later in the day has been proposed as a method to shift metabolic heat load to coincide more closely with nighttime cooling and consequently help cattle cope with heat stress (Brosh et al., 1998; Mader and Davis, 2004; Barajas et al., 2013).

Feeding increased amounts of dietary fat is another management intervention during HS because of lower heat increment and greater caloric value compared to carbohydrates and protein which in turn can aid in maintaining performance in the face of decreased DMI (Beede and Collier, 1986; Gaughan and Mader, 2009). In this survey, 26% of NE feedlots reported feeding added dietary fat as opposed to none of the MN/SD feedlots (Table 2.2).

Various blends of essential oils, electrolytes, and direct fed microbials have also been proposed to support DMI and to enhance cattle's ability to cope with elevated heat loads (Kern et al., 2013; Diaz et al., 2018; Silva et al., 2019). Feed additives for HS were reported by 32 and 37% of NE and MN/SD feedlots, respectively (Table 2.2). Specific additives mentioned included Hydro-Lac (Form-A-Feed, Inc; Stewart, MN), Beef Abate (PMI Nutritional Additives, Arden Hills, MN) as well as essential oil blends of capsaicin and/or cinnamaldehyde.

Limiting cattle handling during heat events to early mornings or preferably avoiding handling altogether is a standard recommendation to avoid increased body temperature post-handling (Brown-Brandl et al., 2010; Brown-Brandl, 2018). In this survey 100% of producers from both NE and MN/SD reported avoiding cattle handling during heat events and shipping schedules were adjusted to minimize heat load experienced by market-ready cattle by 68 and 67% of NE and MN/SD producers, respectively (Table 2).

Open yard specific mitigation practices

All of the OY facilities in NE were earthen surfaced with concrete aprons compared to 86% in MN/SD (Table 2.3). Space allowances per animal in earthen surfaced OY facilities were 32.2 and 27.0 m^2 for NE and MN/SD, respectively. Four of the MN/SD feedlots with OY managed pens that were completely concrete surfaced with a mean space allotment of 7.0 m^2 per animal.

Windbreaks were present in 42% of NE but 95% of MN/SD feedlots (Table 2.3). Windbreaks, whether from tree shelterbelts or constructed, are useful in reducing winter cold stress but increase the risk of HS by restricting airflow and thus evaporative cooling (Mader, 2003). The NE results in the current survey are consistent with findings from a survey of feedlot managers in the High Plains (TX, OK, KS, CO, WY, and NE) where 43% reported using windbreaks (Simroth et al., 2017). Respondents in this study from more northerly latitudes appear to have prioritized cold stress mitigation and management of snow accumulation. Mounds were reported in 90% of the OY with 100% of NE and 82% from MN/SD. Mounds in OY are important for HS mitigation as greater wind speeds have been reported at the mound peak compared to lower elevations within a pen (Mader et al., 1997).

All NE respondents reported that some or all the waterers were located in the middle of OY they managed compared to 57% of MN/SD (Table 2.3). Fewer NE respondents indicated that waterers were shared between pens compared to MN/SD (21 and 52%, respectively). Inadequate access to water can lead to crowding around waterers and has been purported as a contributing factor to high mortality events during HS (Mader et al., 2001). Providing ample quantities of water and ensuring that waterer space is not limiting is important during HS events because of the amount of water lost through evaporation (skin and respiratory) as the animal attempts to maintain an appropriate body temperature (Mader and Davis, 2004; NASEM, 2016).

Shades were used in OY by 79 and 32% of NE and MN/SD, respectively (Table 2.3). The present survey shows a considerably greater adoption rate of shades compared to other published results. A survey of consulting nutritionists servicing 14,000,000 feedlot cattle annually reported that 17% of their clientele used shades in their feedlots (Samuelson et al., 2016). That survey encompassed a broad geographical cross section of the U. S. and did not specify if consultants in the Midwest or Northern Plains observed an increased shade usage by their clients. Similarly, a survey of feedlot managers in the High Plains reported 17% using shade in feedlot pens, although that utilization rate increased to 50% in hospital pens (Simroth et al., 2017). This difference is surprising considering NE and particularly MN/SD are less likely to observe performance benefits from shades because of fewer hours with temperatures exceeding 29.4 ºC (Brown-Brandl, 2018).

Sprinklers use was reported by 90% of participating feedlots (100 and 86% for NE and MN/SD, respectively; Table 2.3). Overall, 68% of participants using sprinklers reported applying water to cattle and 62% to the pen surface with 28% applied water to both cattle and pen surfaces. Time of sprinkling initiation was mixed with greater percentages indicating their earliest start time in the AM or mid-day (44 and 53%, respectively) compared to 8% reporting that they did not start to use sprinklers until later in the day. Sprinkler use has been shown to be an effective method of relieving HS (Mader, 2003; Mader and Davis, 2004).

Applying bedding such as straw or cornstalks has been proposed as a HS mitigation strategy by reducing pen surface temperature and the potential for heat transfer to the animal (Rezac et al., 2012). Bedding was used by 21 and 27% of NE and MN/SD feedlots with OY, respectively (Table 2.3).

Covered and partially covered facilities

Confinement structures, whether completely or partially covering the cattle, offer a method to reduce solar radiation load on the animal. In a comparative case study examining OY, PC, and TBC facilities under a single management system, cattle in PC and TBC with similar access to shade had reduced panting scores and tympanic temperature compared to cattle fed in OY without shelter (Gaughan et al., 2009). The majority of TBC facilities in this survey were bed pack systems (72%) compared to 28% slatted floor facilities (Table 2.4). Monoslope barns were the most reported (67%), followed by hoop barns (22%) and gable-roof structures (11%). Space allowances per animal for bed pack and slatted floor facilities were 4.0 and 2.6 m^2, respectively. Waterers were located along the fence lines in 94% of barns represented in this survey and were shared with an adjacent pen in 50% of barns. Feedlot owners using TBC facilities relied on the provision of shade from the structures themselves as their primary HS mitigation strategy with only one of 16 reporting applying water in emergencies. Powered fans were reported in two of 16 TBC facilities.

Partially covered facilities were defined as those where the feed bunk and a loafing area were located under a building with an attached open pen. The only respondents indicating that they managed PC facilities were in MN/SD and comprised 33% of reported facilities from that region (Table 2.5). One-third of the PC facilities had mounds in the outside pen, and 56% were protected by windbreaks. Waterers were in the fence lines in 67% and shared with another pen in 44% of PC facilities in this survey. Much like the TBC facilities in this survey, the overhead shelter provided was the primary HS mitigation enhancement used with only two of nine reporting emergency water application.

Mitigation strategy triggers

Participants were asked what criteria they used to begin preparing for HS and also to initiate HS mitigation practices. Decisions to begin preparing for HS were most commonly made based upon calendar schedules (90 and 52% for NE and MN/SD, respectively; Table 2.6). Mitigation strategy implementation was most commonly in response to observed weather (56%) or cattle conditions (39%). Comparatively fewer (26%) of feedlots in this survey used some form of HS alert system to initiate steps to proactively manage HS. Increased adoption of alert systems that could provide advance warning of HS events, particularly those that encompass multiple risk factors such as the comprehensive climate index (Mader et al., 2010) would allow feedlot managers greater opportunity to mitigate HS before cattle reach threshold levels where mortality is more likely (Hahn, 1999; Mader et al., 2001).

Perceptions of successful and less successful mitigation strategies

Management adaptations were perceived to be the most successful HS mitigation strategy by respondents (63%; Table 2.7). Management adaptations included pen or bed pack maintenance, feed delivery or diet adjustments, pen stocking or usage adjustments based upon airflow, altering market timing, fly control, reducing numbers of dark-hided cattle fed during summer months, and close observation of cattle. Shades or buildings were named as a successful mitigation strategy by 59% of respondents and water application was listed by 50%. Providing additional water tanks, providing bedding, and using feed additives were named by 33, 24, and 17% of respondents, respectively. Managers based success upon maintaining feed intake, mortality rate, and indications of cattle comfort (74%, 56%, and 17%, respectively, data not shown).

Water application was the most common response from participants when asked which strategy was least successful (24%; Table 2.8). Of those respondents, 64% specifically indicated that issues with additional mud in pens caused by water application at least partially outweighed perceived benefits. Degree of pen surface mud caused by water application may be influenced by several factors including timing of application, rainfall amount, and evaporation rate. Feed additives, bedding, and shade were viewed as unsatisfactory by 22, 17, and 11% of respondents, respectively.

Desired mitigation strategies and barriers to implementation

Participating feedlots were most interested in building some form or structure to reduce the impact of solar gain. Shade structures for OY were named by 63% and building confinement barns were named by 17% of all respondents (Table 2.9). No other mitigation strategy was named by more than 10% of participants. Implementing shades or building confinement barns do require additional capital, so it was not surprising that cost was named as the primary barrier to adoption (72%; Table 2.10). Time requirements for adoption of additional strategies were mentioned by 22% of participants. For four respondents, HS was not perceived to be a critical issue that needed to be addressed. All four of these participants were from MN/SD and three managed TBC facilities, which may have affected their perception of the urgency of implementing additional HS mitigation measures.

Increased adoption and interest in using shades in the cattle feeding region covered by this survey is interesting compared with the lesser adoption rate for feedlots in geographical regions with increased daytime ambient temperatures (Samuelson et al., 2016; Simroth et al., 2017). Performance responses alone are unlikely to be the reason for increased interest in shades. Authors of a meta-analysis conducted as part of a review of shade studies in feedlot cattle concluded that shades had a positive effect on gain and feed efficiency (Edwards-Callaway et al., 2021). Most of the positive responses have occurred in geographic regions with increased solar radiation (Mitlöhner et al., 2001; Mitlöhner et al., 2002; Barajas et al., 2013); however, conclusions from experiments conducted in the northern portions of the U.S. have been mixed. While several studies have shown positive effects on animal comfort measures (Brown-Brandl et al., 2005; Gaughan et al., 2009), definitive benefits on performance measures have been variable. Some researchers have reported no effect of shade on cattle performance or efficiency (Boyd et al., 2015; Melton et al., 2018). Potential reasons for differing responses include degree of actual heat stress, shade area, air flow, or pen factors such as mud or fly pressure. Other studies have demonstrated positive responses while cattle were acclimating to increasing temperatures, but those differences largely disappeared by the end of the feeding period as unshaded cattle compensated for earlier performance depression (Mader et al., 1999).

Investing in shade structures could be viewed as a reasonable precaution against catastrophic weather conditions. There were a series of well-publicized HS events in the 1990’s and 2000’s with documented mortality approaching 5,000 cattle in each event (Busby and Loy, 1997; Mader, 2012). Severe HS episodes require rapid emergency responses that can be challenging to implement successfully. An analysis of losses associated with a HS event in western Iowa revealed that shaded lots experienced a 0.2% mortality rate compared to 4.8% in lots without shade (Busby and Loy, 1997) with the greatest susceptibility in heavier cattle.

Shades also would have an advantage over other mitigation investments such as sprinkler systems in that there would be little daily decision making required once shades were in place. Sprinkler usage requires a series of daily decisions whether or not to apply water, when to initiate application, and how much to apply so as to positively affect cattle without creating additional mud or contributing to increased humidity in pen micro-climates. Simplicity of operational management may be a compelling draw to favor shades over other effective mitigation measures.

APPLICATIONS

Midwest cattle feeders employ a variety of HS mitigation strategies specific to the unique features of their location and management practices. Mitigation measures that reduce solar load such as confinement barns or shade structures appear to be viewed most positively in this region. Increased use of site-specific HS alert tools and a greater number of weather monitoring stations would allow for increased opportunity to mitigate HS before critical stress thresholds are reached. Research and outreach efforts should take producer perceptions of HS mitigation strategies and barriers to implementation into account to increase impact of HS mitigation on cattle welfare and feedlot performance.

ACKNOWLEDGMENTS

This work is supported by AFRI-CARE, grant # 2015-67029-23654/project accession no. 1006426 from the USDA National Institute of Food and Agriculture. The authors wish to acknowledge Dr. Matt Luebbe, Dr. Anna Taylor, and Dr. Dennis Todey for their efforts in writing the funding proposal. The authors would also like to thank Alison Van Der Wal, Tom Winders, and Larry Howard for their assistance with data collection.

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TABLES

Table 2.1. Cooperating feedlot descriptive statistics for a heat stress survey conducted in NE, MN, and SD.

Item	NE	MN/SD
Number	19	27
Cattle demographics, average % of cattle fed by participating feedlots		
Calf-fed	32	56
Yearlings	68	44
Steers	67	70
Heifers	33	30
Bos indicus influence	5.5	0.2
Feedlot turnover, %	200	170
Finishing diet NEg, Mcal/kg	1.49	1.38

Table 2.2. Heat stress zone, facility, and husbandry characteristics of cooperating feedlots that participated in a heat stress survey conducted in NE, MN, and SD.[1]

	NE		MN/SD		Overall	
Item	Number	%	Number	%	Number	%
Cooperating feedlots	19		27		46	
Heat stress risk zone[2]						
Yellow	0	0	16	59	16	35
Orange	11	58	11	41	22	48
Red	8	42	0	0	8	17
Facility type, percentage of facilities reported						
Open	19	90	21	49	40	62
Covered	2	9	13	30	15	23
Partially covered	0	0	9	21	9	14
Feed deliveries/day, summer						
One	0	0	6	22	6	13
Two	17	90	19	70	36	78
Three	2	10	2	7	4	9
Seasonally adjusted feeding	7	37	8	30	15	33
Added dietary fat	5	26	0	0	5	11
Feed additive usage						
Ionophores	19	100	26	96	45	98
Beta-agonists	15	79	14	52	29	63
Tylosin	4	21	2	7	6	13
Heat stress abatements[3]	6	32	10	37	16	35
Animal husbandry adaptations during heat events						
Cattle handling avoidance	19	100	27	100	46	100
Altered shipping schedule	13	68	18	67	31	67

[1]Multiple responses were provided by some feedlots for some categories. Percentages are of the total for each region and overall.
[2]Heat risk zones categorized by number of days exceeding heat index threshold of 80: Yellow, 50 to 60 d; Orange, 60 to 70 d; Red, > 70 d (Rothfusz, 1990; High Plains Regional Climate Center, 2020).
[3]Includes Hydro-Lac (Form-A-Feed, Stewart, MN), Beef Abate (Land O'Lakes, Arden Hills, MN), capsicum, or cinnamon.

Table 2.3. Characteristics of open yard feedlots from NE, MN, and SD that participated in a heat stress survey.[1]

	NE		MN/SD		Overall	
Item	Number	%	Number	%	Number	%
Number, percent of total	19	100	21	78	40	87
Pen surface type						
Concrete	0	0	4	19	4	10
Earthen	19	100	18	86	37	90
Area per animal, m^2						
Concrete	NA		7.0			
Earthen	32.2		27.0			
Mounds in pens	19	100	18	82	37	90
Windbreak present	8	42	20	95	28	70
Pen waterer location						
Fenceline	3	16	15	71	18	45
Middle of pen	19	100	12	57	31	78
Shared between pens	4	21	11	52	15	38
Shade structures	15	79	7	32	22	54
Sprinkler utilization	19	100	18	86	36	90
Where applied, percentage of open yards using sprinklers						
Cattle	18	95	10	48	27	68
Pen surface	8	42	16	76	25	62
Timing of sprinkling initiation, percentage of open yards using sprinklers						
AM	8	37	8	44	16	44
Mid-day	11	58	8	44	19	53
PM	1	5	2	11	3	8
Bedding application	4	21	6	27	10	24

[1]Multiple responses were provided by some feedlots for some categories. Percentages are of the number of feedlots reporting open lots unless otherwise noted.

Table 2.4. Characteristics of covered facilities in NE, MN, and SD as part of a heat stress survey.[1]

	NE		MN/SD		Overall	
Item	Number	%	Number	%	Number	%
Number, percentage of total responses						
	2	10	14	52	16	35
Pen surface type, percentage of covered facilities						
Bed pack	1	50	12	75	13	72
Slatted floor	1	50	4	25	5	28
Building type, percentage of covered facilities						
Hoop	1	50	3	19	4	22
Monoslope	1	50	11	69	12	67
Gable	0		2	12	2	11
Area per animal, m^2						
Bed pack	4.1		4.0		4.0	
Slatted	4.2		2.2		2.6	
Waterer location, percentage of covered facilities						
Fenceline	2	100	15	94	17	94
Middle of pen	0	0	3	19	3	17
Shared between pens	2	100	7	44	9	50
Additional heat stress mitigation measures, percentage of covered facilities						
Water application	0	0	1	6	1	6
Fans	0	0	2	12	2	11

[1]Multiple responses were provided by some feedlots for some categories. Percentages are of the number of covered or partially covered facilities reported, unless otherwise noted.

Table 2.5. Characteristics of partially covered facilities in NE, MN, and SD as part of a heat stress survey.[1]

	NE		MN/SD		Overall	
Item	Number	%	Number	%	Number	%
Number, percentage of total responses						
	0	0	9	33	9	20
Pen surface type, percentage of partially covered facilities						
Concrete	0	0	7	78	7	78
Earthen	0	0	2	22	5	22
Area per animal, m^2						
Concrete surface	NA	-	7	-	-	-
Earthen surface	NA	-	20	-	-	-
Mounds, percentage of partially covered facilities						
	NA	-	3	33	3	33
Windbreaks, percentage of partially covered facilities						
	NA	-	5	56	5	56
Waterer location, percentage of partially covered facilities						
Fenceline	NA	-	6	67	6	67
Middle of pen	NA	-	3	33	3	33
Shared between pens	NA	-	4	44	4	44
Additional heat stress mitigation measures, percentage of partially covered facilities						
Water application	NA	0	2	22	2	22

[1]Multiple responses were provided by some feedlots for some categories. Percentages are of the number of covered or partially covered facilities reported, unless otherwise noted.

Table 2.6. Triggers to initiate mitigation strategy triggers as reported by feedlot managers from NE, MN, and SD who participated in a heat stress survey.[1]

	NE		MN/SD		Overall	
Item	Number	%	Number	%	Number	%
Mitigation strategy preparation triggers[2]						
Calendar	17	90	14	52	31	67
Forecast	8	42	9	33	17	37
Mitigation strategy implementation trigger[2]						
Heat stress alerts	7	37	5	18	12	26
Weather conditions	15	79	11	41	26	56
Cattle conditions	11	58	7	26	18	39
Calendar	0	0	3	11	0	6

[1]Percentage of respondents.

[2]Multiple responses were provided by some feedlots for some categories. Percentages are of the total number of feedlots.

Table 2.7. Heat stress mitigation strategies perceived to be successful by feedlot managers from NE, MN, and SD in a heat stress survey.[1]

	NE		MN/SD		Overall	
Item	Number	%	Number	%	Number	%
Management adaptations[2]	10	53	19	70	29	63
Structures (shades or buildings)	12	63	15	56	27	59
Water application	6	32	17	63	23	50
Additional water tanks during heat events	2	10	13	48	15	33
Bedding	4	21	7	26	11	24
Feed additives[3]	4	21	4	15	8	17

[1]Multiple responses were provided by some feedlots for some categories. Percentages are of the total number of feedlots.
[2]Responses included pen maintenance, dietary or feed delivery alterations, changing pen stocking density, avoiding certain pens based on airflow, managing marketing timing, and close observation of cattle.
[3]Includes Hydro-Lac (Form-A-Feed, Stewart, MN), Beef Abate (Land O'Lakes, Arden Hills, MN), capsicum, or cinnamon.

Table 2.8. Heat stress mitigation strategies perceived to be less successful by feedlot managers from NE, MN, and SD in a heat stress survey.[1]

	NE		MN/SD		Overall	
Item	Number	%	Number	%	Number	%
Water application	6	32	5	18	11	24
Dissatisfaction caused by mud, percent of those listing water application						
	4	67	3	60	7	64
Feed additives[2]	2	10	8	30	10	22
Bedding	6	32	2	7	8	17
Shade	2	10	3	11	5	11
Other[3]	2	10	2	7	4	9
Inaction	1	5	2	7	3	6

[1]Multiple responses were provided by some feedlots for some categories. Percentages are of the total number of feedlots.
[2]Includes Hydro-Lac (Form-A-Feed, Stewart, MN), Beef Abate (Land O'Lakes, Arden Hills, MN), capsicum, or cinnamon.
[3]Includes using bunk blower to create wind, extra water tanks, and dietary changes.

Table 2.9. Strategies that feedlot managers from NE, MN, and SD would like to implement as reported in a heat stress survey.[1]

	NE		MN/SD		Overall	
Item	Number	%	Number	%	Number	%
Install shade structures	12	63	17	63	29	63
Build confinement barn	3	16	5	18	8	17
Automated sprinkler system	4	21	0	0	4	9
Additional concrete	2	10	0	0	2	4
Bedding	0	0	1	4	1	2
Increase water capacity	0	0	1	4	1	2
Change diet or feed delivery	0	0	1	4	1	2

[1]Multiple responses were provided by some feedlots for some categories. Percentages are of the total number of feedlots.

Table 2.10. Barriers to implementing desired heat stress mitigation strategies as reported by feedlot managers from NE, MN, and SD in a heat stress survey.[1]

	NE		MN/SD		Overall	
Item	Number	%	Number	%	Number	%
Cost	18	95	15	56	33	72
Time limitations	4	21	6	22	10	22
Not perceived to be a critical need	0	0	5	18	5	11

[1]Multiple responses were provided by some feedlots for some categories. Percentages are of the total number of feedlots.

FIGURES

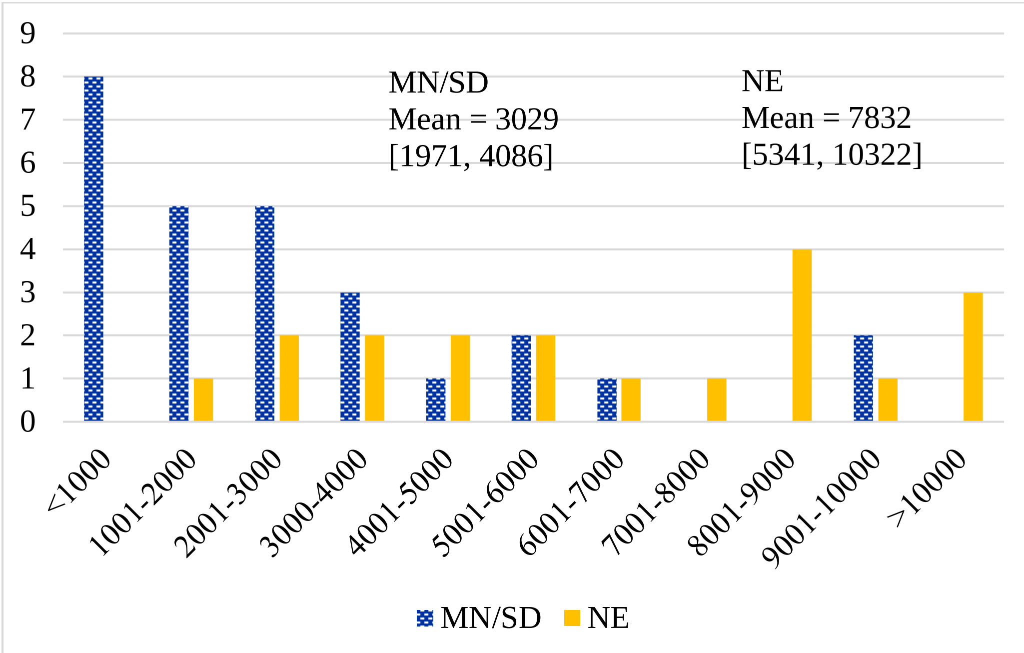

Figure 2.1. Histogram depicting the distribution of feedlot capacities reported by survey participants from MN/SD and from NE. Mean reported capacity for MN/SD was 3,029 cattle with a 95% confidence interval of [1,971, 4,086] and mean reported capacity for NE participants was 7,832 with a 96% CI of [5,341, 10,322].

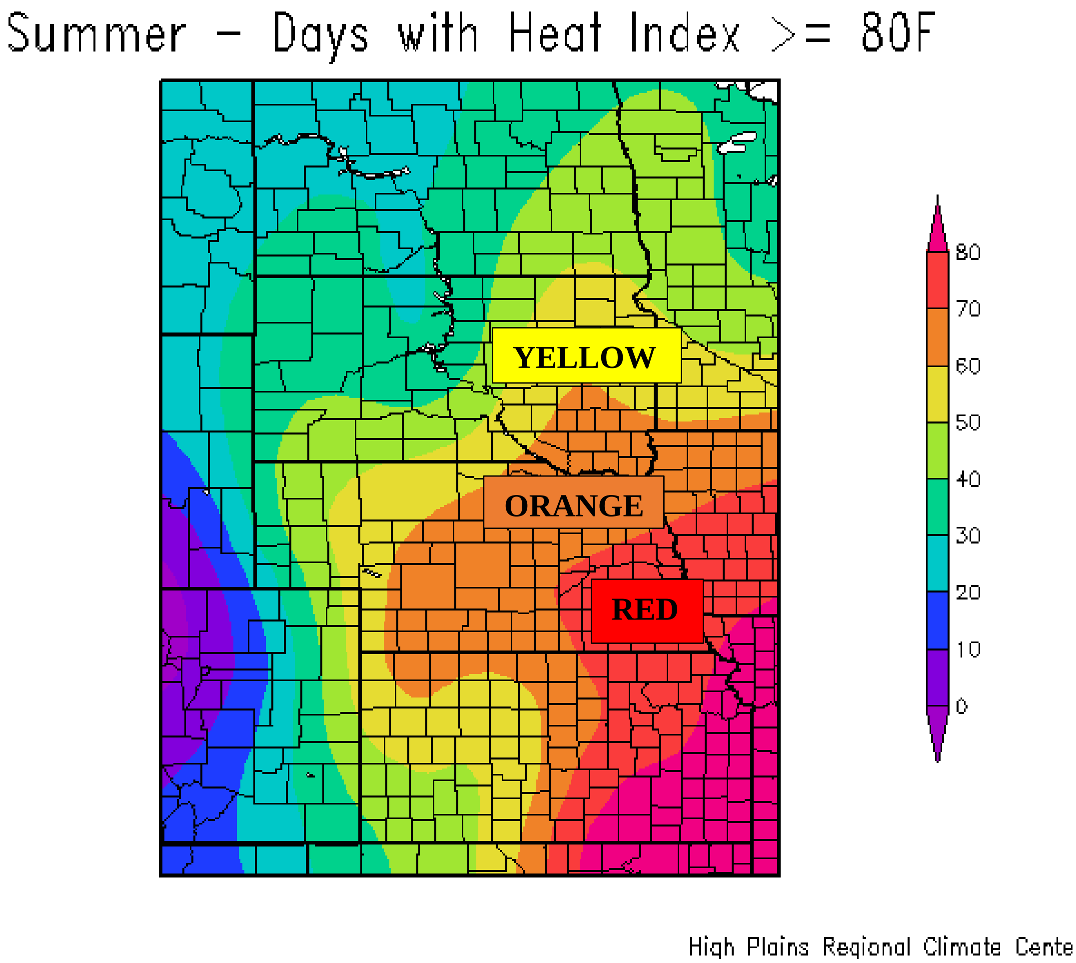

Figure 2.2. Map of SD, MN, and NE categorized by the number of days during the summer where the Heat Index exceeded 80: Yellow, 50 to 60 d; Orange, 60 to 70 d; Red, > 70 d (Rothfusz, 1990; High Plains Regional Climate Center, 2020).

CHAPTER III: EFFECT OF INCLUSION RATE OF SILAGE WITH OR WITHOUT α-AMYLASE TRAIT ON FINISHING STEER GROWTH PERFORMANCE, CARCASS CHARACTERISTICS, AND AGRONOMIC EFFICIENCY MEASURES

ABSTRACT

One hundred ninety-two Continental × British steers [initial BW 420 kg (S_D 24.7)] were used in a randomized complete block design finishing study to evaluate the effects of feeding two types of silage germplasm at two inclusion rates. A 2 × 2 factorial arrangement of treatments was used with either a conventional hybrid (Golden Harvest G07B39-311A, Syngenta Seeds LLC, Minnetonka, MN; CON) or a hybrid with increased expression of alpha-amylase (Syngenta Enogen Feed corn, Golden Harvest E107B3-3011A-EVT5, Syngenta Seeds, LLC; ENO) fed at either 12% (12SIL) or 24% (24SIL) of diet DM. Steers were blocked by source and location (source 1; first 3 pen replicates, n = 10 steers per pen with a fourth pen replicate of six steers per pen, and source 2; one pen replicate, n = 12 steers per pen) and assigned randomly within block to treatments, resulting in five pens and 48 steers per treatment. Steers were harvested after 126 (12SIL) or 140 (24SIL) days on feed (DOF). There were no silage hybrid by inclusion rate interactions detected for live growth performance ($P \geq 0.15$). Silage hybrid did not affect average daily gain (ADG), gain-to-feed ratio (G:F), or final BW (FBW; $P \geq 0.35$). Feeding 24% silage reduced ADG ($P = 0.04$) and increased G:F ($P = 0.01$) but increased FBW ($P = 0.02$) because of greater DOF compared to 12SIL. A hybrid by inclusion rate interaction was detected ($P = 0.04$) for calculated yield grade (YG) with steers fed 24SIL having increased YG within CON but not ENO. Hot carcass weight and

backfat were unaffected by silage hybrid ($P \geq 0.81$) but were increased by feeding 24SIL ($P = 0.03$ and $P = 0.02$, respectively). Feeding increased amounts of silage increased beef produced per ha ($P = 0.05$). Source of silage did not affect feedlot growth performance of cattle, but because of slight differences in estimated silage yield, conventional silage produced more kg of beef per ha ($P < 0.01$). Feeding increased amounts of silage reduced G:F on both a live and carcass-adjusted basis, but increased kg of beef produced per unit of land which is paramount to cattle feeders who grow their own feedstuffs.

INTRODUCTION

Corn silage is a cornerstone feed ingredient for beef production in the Midwest. It is a versatile source of readily digestible energy and NDF and can be an effective option for marketing home-raised feedstuffs through cattle. The most effective use of corn silage is in growing cattle diets. In finishing diets corn silage is typically limited to the minimum amount required for sufficient scratch factor to maintain ruminal health (Samuelson et al., 2016). However, farmer feeders may desire to increase the utilization of silage for several reasons including weather conditions, workload demands, or market signals. Increased inclusion rates of corn silage in finishing diets may be economically beneficial, depending upon the business and marketing strategies of the enterprise, and the degree of integration between crops and livestock (Goodrich et al., 1974; DiCostanzo et al., 1997; Klopfenstein and Hilscher, 2018). Measuring efficiency of beef production both on a unit of cropland and on a per animal basis is important in an integrated crop-livestock system.

Hybrid selection affects the amount of beef produced per ha of cropland as a result of differences in both yield and nutrient digestibility. Recently, corn hybrids with an increased expression of an alpha-amylase enzyme have been marketed as a method to enhance starch digestion either when fed as grain or as corn silage. Others have noted that silages from these hybrids have increased feed efficiency in growing (Johnson et al., 2019) and finishing cattle diets (Baker et al., 2019). The objective of this study was to evaluate the effects of levels of corn silage inclusion (on a DM-basis) with or without alpha-amylase on the growth performance and carcass characteristics of finishing yearling steers and to determine differences in efficiencies as measured on both a per animal and per unit of cropland basis.

MATERIALS AND METHODS

All procedures involving the use of animals in this experiment were approved by the South Dakota State University Institutional Animal Care and Use Committee (IACUC, approval number 19-008E). The experiment was conducted at the South Dakota State University Southeast Research Farm (SERF) located near Beresford, SD.

Experimental design and treatments

A randomized complete block design was used to evaluate animal performance, carcass traits, and beef produced per ha. Treatments were arranged in a 2 × 2 factorial with the factors of silage hybrid (conventional silage, CON, Golden Harvest G07B39-311A, Syngenta Seeds LLC, Minnetonka, MN) or (Syngenta Enogen Feed corn silage, ENO, Golden Harvest E107B3-3011A-EVT5, Syngenta Seeds, LLC) and corn silage inclusion at either 12% (12SIL) or 24% (24SIL) of diet DM. The two corn hybrids were genetically similar except for the expression of the alpha-amylase trait. Both hybrids were planted on May 9, 2018 at a population of 74,132 plants per ha. Plots received the same amounts of commercial fertilizer and identical herbicide treatments during the growing season. Silage harvest occurred on September 10, 2018 (CON) and September 11, 2018 (ENO). Silage was stored in oxygen impermeable bags using two bags for each hybrid.

Animals, initial processing, and study initiation

A total of 192 [initial BW 420 kg (S_D 24.7)] steers were used in this study. Steers were sourced from two different consignments at one South Dakota sale barn and delivered to the SERF. Source 1 steers (n = 144 steers; first 3 pen replicates, n = 10 steers per pen with a fourth pen replicate of six steers per pen) and source 2 steers (n = 48 steers; pen replicate 5; 12 steers per pen) were received on March 25, 2019. Cattle were processed on March 28, 2019, body weight (BW) was collected, a unique identification tag was applied to each steer, and vaccinated against respiratory pathogens: infectious bovine rhinotracheitis (IBR), bovine viral diarrhea (BVD) types 1 and 2, parainfluenza-3 virus (PI3), and bovine respiratory syncytial virus (BRSV) (Bovi-Shield Gold 5, Zoetis, Parsippany, NJ) and clostridial species (Ultrabac 7/Somubac, Zoetis). On April 2, 2019, steers were administered pour-on moxidectin (Cydectin, Bayer, Shawnee Mission, KS), administered a steroidal implant (200 mg trenbolone acetate and 28 mg estradiol benzoate; Synovex Plus, Zoetis), BW collected, and the study was initiated.

Diet and intake management

Steers were fed once daily in the morning. Bunks were managed to be slick at 0800 h most mornings. Steers were stepped up to their final diet over a 21-d period with three step-up diets utilized. Feed intake and diet formulations were summarized at weekly intervals. Actual DM composition of the finishing diets are shown in Table 3.1. Steers that died during the trial or that were removed from the study were assumed to have consumed feed equal to the pen mean DMI up to the point of removal or death. Three steers (two from the ENO-12SIL and one from the CON-12SIL treatments, respectively) died during the study from issues unrelated to dietary treatment thus all data are reported on a deads and removals excluded basis.

Ingredient samples were collected weekly, and DM calculated after drying in a forced air oven at 60 ºC. Weekly DM values for each ingredient were used to calculate DMI and actual DM ingredient inclusions. Bunk samples were also collected weekly and stored in a freezer at -20 ºC until nutrient analyses were completed. After DM determination (method no. 935.29; AOAC, 2012), weekly samples from the final step for each treatment were composited into a monthly sample of the diets. The monthly composite samples of the finishing diets were analyzed for nutrient composition (N, method no. 968.06; AOAC, 2016; Rapid Max N Exceed; Elementar; Mt. Laurel, NJ; NDF and ADF, Van Soest et al., 1991; and ash, method no. 942.05; AOAC, 2012).

Cattle management and data collection

Steer BW was recorded at the time of study initiation, d 28 (pen BW), d 63, d 126, and on d 140 (24SIL only) for the calculation of live growth performance. Body weights were measured before the morning feeding. A 3% pencil shrink was applied to final BW and carcass adjusted performance was calculated using HCW adjusted to a common dressing percentage of 62.5%.

Cattle were shipped when they were visually appraised to have 1.27 cm of backfat (BF). Cattle were shipped on two different dates; August 6, 2019 (12SIL) after 126 DOF and on August 20, 2019 (24SIL) after 140 DOF and harvested the following day at Tyson Fresh Meats in Dakota City, NE. Video image data was obtained from the plant for LM area, BF, calculated USDA Yield Grade (YG) and USDA marbling scores. Dressing percentage was calculated as HCW/(final BW × 0.97). Carcass measurements were used to calculate empty body fat percentage (EBF; Guiroy et al., 2002), adjusted final BW at 28% EBF (AFBW), and proportion of closely trimmed boneless retail cuts from carcass round, loin, rib, and chuck (Retail Yield, RY; Murphey et al., 1960).

Performance adjusted NE (paNE) was calculated from daily energy gain (EG; Mcal/d): EG = $ADG^{1.097} \times 0.0557W^{0.75}$, where W is the mean equivalent shrunk BW [shrunk BW × (478/AFBW), kg; (NRC, 1996)]. Maintenance energy required (EM; Mcal/d) was calculated by the following equation: EM = $0.0077BW^{0.75}$ (Lofgreen and Garrett, 1968) where BW is the mean shrunk BW from the trial. Using the estimates required for maintenance and gain the performance adjusted (pa) NE_m and NE_g values (Owens and Hicks, 2019), of the diet were generated using the quadratic formula: $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2c}$, where x = NE_m, Mcal/kg, a = -0.41EM, b = 0.877EM + 0.41DMI + EG, c = -0.877DMI, and NE_g was determined from: $0.877NE_m - 0.41$ (Zinn and Shen, 1998; Zinn et al., 2008).

Beef production per ha of cropland was calculated from DMI of corn silage and dry rolled corn for each pen using the weekly diet compositions and DMI records. Actual corn silage yield observed at the Southeast Research Farm in September 2018 was 45.7 and 42.1 metric ton/ha for CON and ENO, respectively (P. Sexton, personal communication). Corn yield (kg/ha) was estimated using the formula: Corn yield (kg/ha) = Silage yield (as-is, metric ton/ha) × 224 (Lauer, 2006). Cropland required was the sum of kg consumed/yield for both corn and corn silage. Beef production (kg/ha) was then calculated as: (carcass adjusted final BW – Initial BW)/ha.

Statistical analysis

Growth performance and carcass traits were analyzed as a randomized complete block design using the GLIMMIX procedure of SAS 9.4 (SAS Inst. Inc., Cary, NC) with pen as the experimental unit. The model included fixed effects of block, silage hybrid, inclusion rate and the interaction of silage hybrid × inclusion rate. Least squares means were generated using the LSMEANS statement of SAS. Data means were separated and denoted to be different using the pairwise comparisons PDIFF and LINES option of SAS when a significant preliminary F-test was detected. An α of 0.05 or less determined significance and tendencies are discussed from 0.05 to 0.10.

RESULTS

Steer performance results are reported in Table 3.2. There were no silage × inclusion interactions ($P \geq 0.15$) detected for any live or carcass adjusted growth performance traits. Silage hybrid did not affect final live or carcass adjusted BW, ADG, DMI, or G:F ($P \geq 0.35$). Silage hybrid had no influence on paNE values ($P \geq 0.55$) or observed/expected NE values ($P \geq 0.49$).

Final live and carcass-adjusted BW were 1.8 and 2.1% greater, respectively, for 24SIL compared to 12SIL ($P \leq 0.03$). However, 24SIL steers required an additional 14 d on feed to reach a similar compositional endpoint as the 12SIL steers translating into a poorer ($P = 0.04$) live basis ADG for the 24SIL steers. Daily DMI did not differ ($P = 0.86$) between 12SIL and 24SIL. Steers fed 12SIL had greater live ($P = 0.01$) and carcass adjusted ($P = 0.03$) G:F compared to the 24SIL steers. Steers fed 24SIL tended to have smaller ($P \leq 0.07$) paNE values compared to 12SIL steers and observed/expected NE values did not differ ($P \geq 0.37$) between silage inclusion level.

There were no silage × inclusion interactions detected for carcass traits except for YG (*P* =0.04; Table 3.3). Silage hybrid did not affect dressing percentage, HCW, LM area, BF, marbling scores, KPH percentage, estimated EBF, AFBW, YG, or retail yield ($P \geq 0.19$). No differences were detected between 12SIL and 24SIL for dressing percentage, LM area, marbling score, KPH percentage, or final BW at 28% EBF ($P \geq 0.56$). Silage hybrid interacted with inclusion rate (*P* =0.04) with steers fed 24SIL having increased YG within the CON but not ENO treatments (Fig. 3.1). Feeding 24SIL did increase ($P \leq 0.03$) HCW, BF, YG, and retail yield and tended (*P* = 0.06) to increase EBF compared to 12SIL.

There was no silage × inclusion rate interaction for beef production per ha of cropland (*P* = 0.34, Table 3.3). Because as-is silage yield of CON was greater than ENO, conventional silage did produce ($P < 0.01$) more beef per ha compared to ENO (2,121 vs. 1,974 ± 25.7 kg beef/ha, respectively). Feeding increased amounts of corn silage also resulted in greater production of beef per ha compared to 12SIL (*P* = 0.05, 2,008 vs. 2,087 ± 25.7 kg beef/ha cropland, respectively).

DISCUSSION

Effect of silage type

The lack of response in this experiment to silage expressing the alpha-amylase trait contrasts with the positive effects observed when Enogen Feed corn silage was fed to growing steers (Johnson et al., 2019) or finishing yearling steers (Baker et al., 2019). In the growing cattle study by Johnson et al. (2019) feeding Enogen silage at 40% of diet DM without a corn processing co-product increased ADG and tended to increase DMI resulting in greater G:F. Feeding Enogen silage at 8% of diet DM combined with Sweet Bran in finishing diets reduced DMI with no effect on ADG resulting in greater G:F compared to conventional silage (Baker et al., 2019). In contrast to the present experiment, neither of these studies utilized distillers grains as a source of supplemental protein. Both experiments also examined the effects of Enogen Feed corn as starch sources in the diets in a 2 × 2 factorial arrangement of treatments. Johnson et al. (2019) fed dry-rolled corn at 38.5% of diet DM while Baker et al. (2019) used steam-flaked corn at 74.5% of diet DM. Including Enogen Feed corn as grain either resulted in no effect on cattle performance (Johnson et al., 2019) or reduced G:F (Baker et al., 2019) compared to conventional corn sources.

Similar inconsistencies have been observed in experiments utilizing corn with the alpha-amylase trait in finishing cattle, particularly when distillers grains are concurrently fed. Schoonmaker et al., (2014) compared corn grain expressing alpha-amylase at three different inclusion rates in diets containing wet distillers grains. They observed no differences in DMI, performance measures, or carcass characteristics. When Enogen Feed Corn was used as the sole source of starch in finishing cattle diets, positive responses for ADG and G:F were observed when corn gluten feed was included in the diet but in only one of two experiments that included distillers grains (Jolly-Breithaupt et al., 2019). Taken together, these results suggest that feeding Enogen Feed Corn does not elicit a consistent response when combined with distillers grains in finishing diets.

Effect of silage inclusion rate

The results of this experiment align well with previous work reporting that increased inclusion rates of corn silage in finishing cattle diets result in reduced ADG and G:F (Goodrich et al., 1974; Gill et al., 1976; DiCostanzo et al., 1997, 1998; Burken et al., 2017a, 2017b; Hilscher et al., 2019). This would be expected when corn silage replaces corn grain such as in this experiment because of the lesser NE_g for corn silage compared to corn grain (Owens et al., 2018). In this experiment, increasing silage inclusion rate by 12% decreased G:F by 4.4% compared to 5.1% predicted using regression values published by Goodrich et al., (1974).

Providing increased amounts of corn silage did not affect DMI in the current experiment. This result was surprising considering that increased NDF supply from roughage is associated with increased DMI (Galyean and Defoor, 2003). In the current experiment, NDF as percent of DM was 4.5% greater in the 24SIL diet compared to 12 SIL. Assuming that this increase is a direct result of increased silage inclusion, predicted DMI should increase by approximately 0.6 kg per d for 24SIL based on the relationship between NDF supplied by forage and DMI from Galyean and Defoor (2003). In a review of feeding trials specifically evaluating corn silage inclusion, DMI was not markedly increased until inclusion rate exceeded 28% (Owens et al., 2018). Studies comparing silage inclusion rates at concentrations similar to those used in the present experiment noted increased DMI in some trials (Goodrich et al., 1974; Gill et al., 1976; DiCostanzo et al., 1997) but no differences in others (Brennen et al., 1987; DiCostanzo et al., 1998; Burken et al., 2017b; Hilscher et al., 2019). Thus, when corn silage is included at less than 30% dry matter, DMI is not consistently increased or decreased.

Another possible explanation for DMI results that are not consistent with previous literature is the warmer than normal temperatures experienced at Beresford, SD during the last 80 d of the feeding period for the 24SIL treatment group. During that time period the normal maximum heat index value was exceeded on 34 out of 80 d and the minimum observed heat index was greater than the normal minimum value on 44 out of 80 d (South

Dakota Mesonet, 2020). Excessive heat loads are associated with decreases in DMI (Mader, 2003), which may have limited the willingness of steers on the 24SIL treatment to increase voluntary feed intake in the current experiment.

Other studies have reported reduced final BW and HCW as a result of increased corn silage inclusion where days on feed were consistent between treatments (Burken et al., 2017a, 2017b; Hilscher et al., 2019). In this experiment, steers on the 24SIL treatment were fed an additional 14 d in an attempt to equalize final HCW with the expectation that increased silage would depress dressing percentage. Dressing percentage did not differ between 12SIL and 24SIL in the current experiment, consequently steers fed an increased amount of corn silage had heavier BW at trial completion with greater HCW and increased BF compared to 12SIL. Dressing percentage has been shown to decrease in response to increased dietary corn silage in some studies (Brennan et al., 1987; Burken et al., 2017a; Hilscher et al., 2019) but remained unchanged in others (Gill et al., 1976) with Burken et al. (2017b) reporting reduced dressing percentage in one experiment but no differences in the second experiment. The additional days on feed for the 24SIL treatment likely played a role in the increased BF and YG, reduced RY, and a tendency for increased EBF% observed in the current experiment. The additional HCW observed in the steers on the 24SIL treatment did not represent greater carcass weight associated with frame growth as evidenced by similar AFBW between the steers fed either 12SIL or 24SIL.

The interaction between silage type and inclusion rate for YG is not easily explained. Jolly-Breithaupt et al. (2019) observed increased BF and greater YG with

Enogen Feed Corn fed with distillers grains. In the present experiment, the authors suspect that there is little biological significance to the differing YG responses observed.

Beef produced per unit of cropland

Differences in beef produced per unit of cropland associated with feeding different silage types were entirely caused by different corn yields for the hybrids grown under these specific circumstances and not differences in growth performance or feed efficiency in the present study. Feeding increased amounts of silage resulted in greater amounts of beef produced per ha. Johnson et al. (2016) observed that harvesting corn as silage, earlage, high-moisture or dry corn did not affect gross return per ha of cropland when utilized for finishing beef cattle. The optimum corn crop utilization strategy likely depends upon the interactions between corn price, business model (seasonal placement and marketing patterns vs. continuous occupancy), and the ability to capture manure value as part of an integrated crops-livestock system (Goodrich et al., 1974; DiCostanzo et al., 1997; Klopfenstein and Hilscher, 2018).

These data indicate that silage hybrids had no effect on animal growth performance or carcass traits, but that choosing silage hybrids with greater yield does result in increased beef produced per ha. Feeding increased amounts of silage resulted in reduced ADG and feed efficiency on an individual animal basis, but increased HCW and beef produced per ha compared to a reduced silage inclusion rate when fed to equal backfat. Cattle feeders that raise their own feed may be able to increase the amount of beef produced from a fixed land base by increasing the inclusion rate of corn silage in cattle finishing diets.

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TABLES

Table 3.1. Actual diet formulations fed.[1]

	Finisher (d 22 to harvest)			
Silage[2]	CON		ENO	
Inclusion[3]	12	24	12	24
Dry rolled corn, %	65.1	52.9	65.0	52.7
MDGS, %[4]	19.3	19.7	19.3	19.6
Silage, %	11.5	23.3	11.6	23.5
Hay, %	--	--	--	--
Liquid Supplement, %[5]	4.1	4.1	4.1	4.2
Nutrient composition[6]				
DM, %	65.8	59.0	67.1	60.3
CP, %	12.4	13.2	12.8	13.2
NDF, %	15.3	20.9	15.9	19.6
ADF, %	6.3	9.7	7.1	9.5
Ash, %	4.6	5.7	4.7	5.0
NEm, Mcal/ kg	2.11	2.04	2.10	2.04
NEg, Mcal/kg	1.43	1.37	1.43	1.37

[1]All values except DM on a DM basis.
[2]Silage hybrid: CON, conventionally available corn silage without α-amylase trait; ENO, silage from Syngenta Enogen Feed Corn.
[3]Dietary DM inclusion: 12, 12% inclusion of diet DM as corn silage; 24, 24% inclusion of diet DM as corn silage.
[4]MDGS, modified distillers grains plus solubles.
[5]Provided 30 g/ton of monensin as well as vitamins and minerals to exceed requirements (NASEM, 2016).
[6]Tabular NE from (Preston, 2016) and actual nutrient compositions from monthly composite samples of the diets.

Table 3.2. Animal growth performance, carcass characteristics, and efficiency measures.[1]

Item	Silage Type (S)		Inclusion Rate (I)			*P* -Values		
	CON	ENO	12%	24%	SEM[2]	S	I	S × I
Pens, n	10	10	10	10				
Days on feed, d	133	133	126	140				
Initial BW, kg	421	420	421	420	0.5	0.24	0.80	0.49
Final BW, kg[3]	612	615	608	619	2.9	0.54	0.02	0.24
ADG, kg	1.44	1.47	1.49	1.42	0.021	0.35	0.04	0.17
DMI, kg	10.2	10.3	10.3	10.2	0.07	0.54	0.86	0.59
G:F	0.140	0.141	0.144	0.137	0.0016	0.45	0.01	0.15
Carcass Basis[4]								
Final BW, kg	634	633	627	640	3.5	0.99	0.03	0.37
ADG, kg	1.60	1.61	1.64	1.56	0.025	0.80	0.06	0.27
G:F	0.156	0.155	0.159	0.152	0.0020	0.93	0.03	0.29
paNE, Mcal/kg[5]								
Maintenance	1.96	1.97	1.98	1.94	0.015	0.55	0.07	0.21
Gain	1.31	1.32	1.33	1.29	0.013	0.55	0.07	0.22
Tabular trial NE, Mcal/kg[6]								
Maintenance	2.05	2.05	2.08	2.02				
Gain	1.37	1.37	1.39	1.34				
Observed/Expected NE[7]								
Maintenance	0.96	0.96	0.95	0.96	0.007	0.49	0.37	0.25
Gain	0.95	0.96	0.95	0.96	0.009	0.55	0.53	0.20

[1]Silage type: CON, conventional corn silage without α-amylase trait; ENO, silage from Syngenta Enogen Feed Corn. Dietary DM inclusion: (12), 12% inclusion of diet DM as corn silage; (24), 24% inclusion of diet DM as corn silage.
[2]Pooled SEM.
[3]Final BW shrunk 3% to account for digestive tract fill.
[4]Calculated from HCW/0.625.
[5]pa = performance adjusted (Owens and Hicks, 2019).
[6] Tabular NE value weighted for each diet fed.

[7]paNE/tabular trial NE.

Table 3.3. Carcass traits and beef production per ha of cropland.[1]

Item	Silage Type (S)		Inclusion Rate (I)			*P* - Values		
	CON	ENO	12%	24%	SEM[2]	S	I	S × I
Dressing percent, %[3]	64.67	64.38	64.47	64.50	0.191	0.30	0.70	0.83
HCW, kg	396	396	392	400	2.2	0.99	0.03	0.37
LM area, cm^2	84.8	85.0	85.2	84.6	0.72	0.86	0.57	0.22
BF, cm	1.37	1.37	1.32	1.45	0.046	0.81	0.02	0.25
KPH, %	1.80	1.76	1.79	1.77	0.025	0.19	0.56	0.91
YG	3.33	3.33	3.23	3.43	0.044	0.94	0.01	0.04
Retail Yield, %[4]	49.82	49.86	50.04	49.63	0.098	0.80	0.01	0.06
Estimated EBF. %	30.87	30.90	30.53	31.25	0.250	0.93	0.06	0.55
Final BW at 28% EBF (AFBW), kg	575	575	575	575	2.7	0.86	0.99	0.82
Marbling score[5]	532	510	519	522	12.7	0.25	0.85	0.39
Beef produced, kg/ha	2,121	1,974	2,008	2,087	25.7	<0.01	0.05	0.34

[1]Silage type: CON, conventionally available corn silage without α-amylase trait; ENO, silage from Syngenta Enogen Feed Corn. Dietary DM inclusion: (12), 12% inclusion of diet DM as corn silage; (24), 24% inclusion of diet DM as corn silage.
[2]Pooled SEM.
[3]HCW/final BW shrunk 3%.
[4]As a percentage of HCW.
[5]USDA Marbling Score 400 = $Small^0$ = Low Choice; 500 = $Modest^0$ = Average Choice.

FIGURES

Figure 3.1. Interaction for calculated USDA Yield Grade between silage hybrid and inclusion rate. Corn silage was harvested from either a conventional hybrid (CON) or from a hybrid with increased α-amylase expression (Syngenta Enogen Feed Corn, Syngenta Seeds, LLC, Minnetonka, MN; ENO) fed at either 12 or 24% of diet DM (12SIL and 24SIL, respectively) in a randomized complete block design. For each of the four treatment combinations there were 48 steers housed in five pen replicates. Means with different superscripts differ $P < 0.05$.

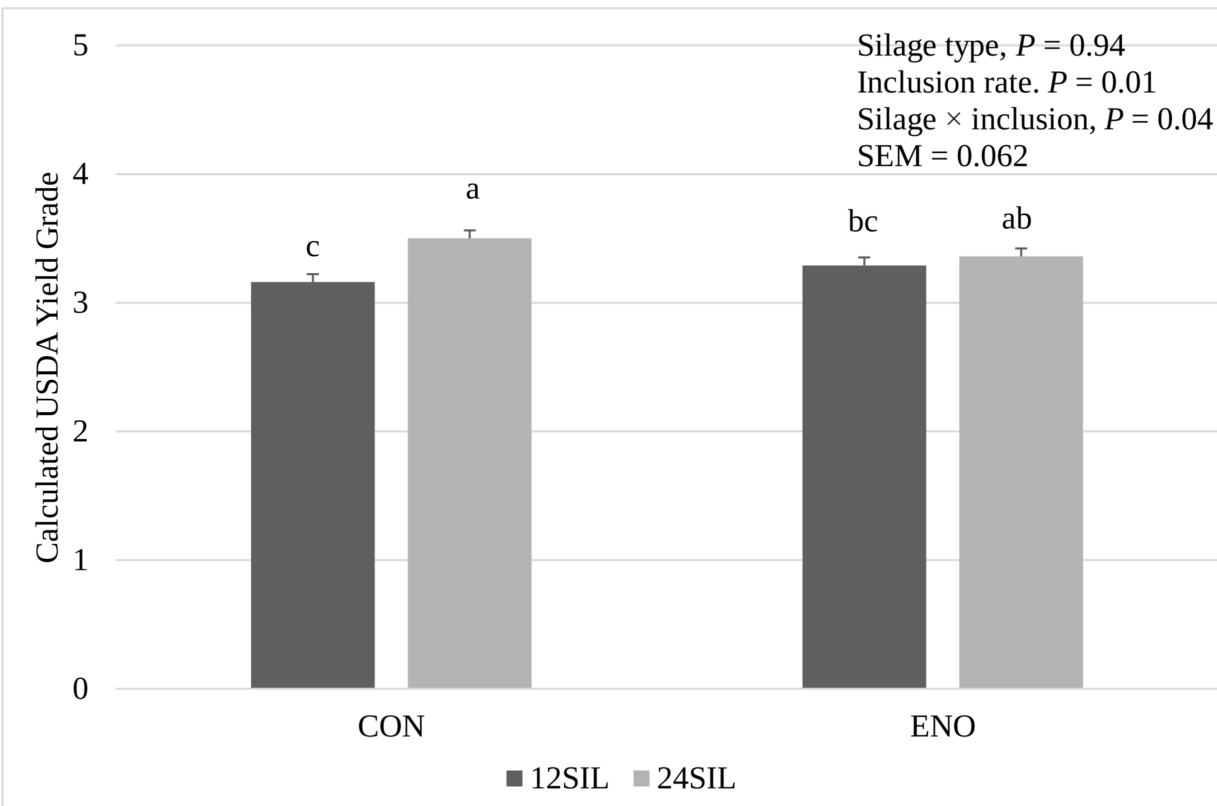

Figure 3.1.

CHAPTER IV: EVALUATION OF HYBRID RYE ON GROWTH PERFORMANCE, CARCASS TRAITS, AND EFFICIENCY OF NET ENERGY UTILIZATION IN FINISHING STEERS

ABSTRACT

Angus and crossbred steers with a high percentage of Angus ancestry (n = 240, initial shrunk bodyweight [BW], 404 ± 18.5 kg) were used in a 117-d feedlot experiment to evaluate the effect of hybrid rye (KWS Cereals USA, LLC, Champaign, IL; Rye) as a replacement for dry-rolled corn (DRC) on growth performance, carcass traits, and comparative net energy (NE) value in diets fed to finishing steers. Rye from a single hybrid (KWS Bono) with an ergot alkaloid concentration of 392 ppb was processed with a roller mill to a processing index (PI) of 78.8 ± 2.29. Four treatments were used in a completely randomized design (n = 6 pens/treatment, 10 steers/pen) where DRC (PI = 86.9 ± 4.19) was replaced by varying proportions of rye [DRC:Rye, DM Basis (**60:0**), (**40:20**), (**20:40**), and (**0:60**)]. Liver abscess scores and carcass characteristics were collected at the abattoir. Carcass-adjusted performance was calculated from HCW/0.625. Performance-adjusted NE was calculated using carcass-adjusted ADG, DMI, and mean equivalent shrunk BW with the comparative NE values for rye calculated using the replacement technique. Data were analyzed using the GLIMMIX procedure of SAS 9.4 (SAS Inst. Inc., Cary, NC) with pen as the experimental unit. Treatment effects were tested using linear and quadratic contrasts as well as between diets with and without Rye. Replacing DRC with Rye linearly decreased ($P \leq 0.01$) carcass-adjusted final BW, ADG, DMI and G:F. Feeding rye linearly decreased HCW and LM area ($P \leq 0.04$). Distributions of liver scores and USDA grades for quality and yield were unaffected by treatment ($P \geq 0.09$). Estimated replacement NEm and NEg values for rye when included at 60% of diet DM were 1.90 and 1.25 Mcal/kg, respectively. Rye can be a suitable feed ingredient in finishing diets for feedlot steers. Estimated replacement values of Rye when fed at 60% of diet DM closely agreed with current tabular standards, but when included at 20% of diet DM estimated NEm and NEg values of Rye were increased 9.5 and 12.8%, respectively. Net energy value of hybrid rye is approximately 84% compared to DRC, thus, complete replacement of DRC with rye depressed DMI, ADG, G:F, and carcass weight.

INTRODUCTION

Increasing crop-rotation diversity offers a number of benefits to an integrated crops-livestock production system, including greater yield resiliency and enhanced yield increases compared to a monoculture or two-crop rotation (Bowles et al., 2020). Diversified crop rotations, when combined with livestock production, also reduce month-to-month variation in labor requirements compared to a corn-soybean rotation with livestock (Poffenbarger et al., 2017).

Cereal rye offers several attributes that warrant consideration for inclusion as a component of an integrated crops-livestock system. Rye can be grazed, harvested for forage, or allowed to reach maturity for harvest of grain and straw. Furthermore, rye is harvested earlier than row crops, allowing for greater manure application flexibility or planting of short-season forage crops if conditions allow. Newer hybrid rye germplasms are particularly promising because of their enhanced yield potential and decreased ergot incidence compared to traditional open-pollinated rye cultivars (Hansen et al., 2004).

Multiple potential uses enhance the utility and acceptance of any crop by providing additional options and lessening the reliance on any one market channel. Cereal rye grain has not been traditionally thought of as a suitable cereal grain for finishing cattle. It has been recommended to only feed cereal rye to finishing cattle in limited amounts because of the negative effects of ergot ingestion and observed decreases in dry matter intake (Matsushima, 1979). However, those recommendations were made before development of novel hybrid rye germplasm with decreased ergot risk and in diets where corn processing co-products were not used.

Objectives of this experiment were to determine the effects of hybrid rye inclusion on dry matter intake, growth performance, and feed efficiency in finishing beef steers and to estimate net energy (NE) value. Our hypothesis was that cereal rye could be substituted for dry-rolled corn in finishing beef diets and that increased inclusion rates would decrease growth performance and feed efficiency with no negative effects on carcass characteristics or the severity and incidence of liver abscesses.

MATERIALS AND METHODS

All procedures involving use of animals in this experiment were approved by the South Dakota State University Institutional Animal Care and Use Committee (IACUC, approval number 19-047E). The experiment was conducted at the South Dakota State University Southeast Research Farm (SERF) located near Beresford, SD.

Experimental design and treatments

Four treatments were used in a completely randomized design to evaluate animal performance, carcass traits, and to estimate the NE value for hybrid rye. Hybrid rye (Rye) was substituted for dry-rolled corn (DRC) as follows: a basal finishing diet formulated (DM basis) with 60% corn grain (DRC:Rye, 60:0) and three additional diets formulated with increasing proportions of Rye (40:20, 20:40, and 0:60). All rye grain used was from the same hybrid (KWS Bono, KWS Cereals, LLC; Champaign, IL) and from a single source. Each truckload of Rye was sampled on arrival at SERF and composited for ergot alkaloid analysis. Total ergot alkaloid concentration from the composited sample was 392 ppb on a DM basis (Table 4.1; NDSU Veterinary Diagnostic Laboratory, Fargo, ND) and less than the recommended maximum ergot alkaloid concentration of 2 ppm for cattle diets (Coufal-Majewski et al., 2016).

Animals, initial processing, and study initiation

Angus and crossbred steers with a high percentage of Angus ancestry (n = 240, initial shrunk bodyweight [BW], 404 ± 18.5 kg) were used in this experiment. Steers were sourced from a single consignment at one South Dakota auction facility and delivered to SERF. Steers were fed in 24 dirt-surfaced pens, resulting in six replications per treatment and 60 steers per treatment (n = 10 steers/pen). The dirt surfaced pens had a 6.1 m concrete bunk apron, a continuous flow waterer on the fence line located 0.6 m from the bunk apron and provided 54.4 m^2 of pen space per steer and 61 cm of linear bunk space per steer. Cattle were processed on September 6, 2019, where BW was collected to be used for allotment purposes, a unique identification tag was applied to each steer, vaccines administered against respiratory pathogens: infectious bovine rhinotracheitis (IBR), bovine viral diarrhea (BVD) types 1 and 2, parainfluenza-3 virus (PI3), and bovine respiratory syncytial virus (BRSV) (Bovi-Shield Gold 5, Zoetis, Parsippany, NJ) and clostridial species (Ultrabac 7/Somubac, Zoetis), and administered pour-on moxidectin (Cydectin, Bayer, Shawnee Mission, KS). The experiment was initiated on September 10, 2019 with a 19-d adaptation period and a 98-d finishing period, resulting in a total experiment length of 117 d. On September 30, 2019 (d 19) steers were administered a steroidal implant (200 mg trenbolone acetate and 28 mg estradiol benzoate: Synovex Plus, Zoetis).

Diets and intake management

Steers were fed once daily. Steers were stepped up to the final diet over a 19-d period. From d 8 to d 14 Rye was introduced to the step-up diets at 40% of the ultimate inclusion rate (0, 8, 16, and 24%, respectively) with the final proportions of Rye fed in experimental diets from d 15 to d 19. The final diets fed (d 20 to 117) are presented in Table 4.2. Bunks were managed with the intention to be devoid of feed at 0800 h. Feed intake and diet formulations were summarized at weekly intervals. Steers that were removed from the study or that died during the study were assumed to have consumed feed equal to the pen mean DMI up to the point of removal or death. Two steers (one from 60:0 and one from 40:20) died or were removed from the study for reasons unrelated to dietary treatment, thus all data are reported on a deads and removals excluded basis.

Rye was processed by passing whole rye through a roller mill (Lone Star Enterprises, Lennox, SD). The rolls were 23 × 30 cm with 4.7 corrugations/cm in a round bottom v pattern and ran at 857.5 rpm at a 1:1 ratio. Corrugations in one roller were straight while the second roller was machined with a 12.7 cm spiral design. Rolls were adjusted so that the processing index (PI) for Rye was 78.8 ± 2.29 as described by (Yang et al., 2014), where PI was defined as the volume weight (g/L) of the grain (as is) after processing expressed as a percentage of the volume weight before processing. Rye samples (processed and un-processed) were analyzed for particle size distribution and geometric mean diameter at Ward Laboratories in Kearney, NE (Table 4.3). Samples were split using a riffle splitter, and a 100-g subsample was weighed and sieved through a set of 8 circular sieves (3,350 µm; 1,700 µm; 1,180 µm; 850 µm; 600 µm; 425 µm; 212 µm; 53 µm, and pan) using a sieve shaker for 10 min. After the sample was shaken, the weight of the material on each sieve was recorded. No agitators or dispersion agents were used in the analysis. Representative visual examples of degree of processing compared to whole rye are presented in Figure 4.1. Dry-rolled corn was processed similarly with a processing index of 86.9 ± 4.19. Ingredient samples were collected weekly, and DM calculated after drying in a forced-air oven at 60 ºC until no further weight change occurred. Weekly DM values for each ingredient were used to calculate DMI and actual DM ingredient inclusions. Weekly ingredient samples were stored in a freezer at -20 ºC until nutrient analyses were completed. After DM determination (method no. 935.29; (AOAC, 2012), weekly samples from each ingredient were analyzed for N (method no. 968.06; AOAC, 2016; Rapid Max N Exceed; Elementar; Mt. Laurel, NJ), and ash (method no. 942.05; AOAC, 2012). Modified distillers grains samples were analyzed for ether extract content using an Ankom Fat Extractor (XT10; Ankom Technology, Macedon, NY). Percentages of ADF and NDF were assumed to be 3 and 9 percent for corn and 9 and 19 percent for Rye, respectively (Preston, 2016). Analysis of ADF and NDF composition for all other feeds was conducted as described by Van Soest et al. (1991). Nutrient composition values for Rye and DRC are presented in Table 4.4. Dietary metabolizable protein supply and balance were determined post-hoc using the Beef Cattle Nutrient Requirements Model (NASEM, 2016) using observed performance variables; solution type was set at empirical calculations.

Cattle management and data collection

Steer BW were recorded at the time of study initiation, d 19, d 47, d 75, and the morning of study termination on d 117 for the calculation of growth performance. Body weights were measured before the morning feeding with a 4% pencil shrink applied to initial and final BW. Wet weather combined with temperatures generally greater than 0 ^{o}C during the final 40 d of this experiment resulted in greater than normal amounts of mud at harvest. Therefore, carcass-adjusted performance using HCW adjusted to a common dressing percentage of 62.5% was used to determine cumulative performance and efficiency measures with unshrunk BW used for interim performance measures.

Cattle were weighed off test when they were visually appraised to have 1.27 cm of fat at the 12th rib (BF). Cattle were shipped 48 h after final BW determination and harvested the next day at Tyson Fresh Meats in Dakota City, NE. Steers were commingled at the time of study termination and remained as such until 0700 h the morning after shipping. Prevalence of abscessed livers and abscess severity were determined by a trained technician using the Elanco system as Normal (no abscesses), A- (1 or 2 small abscesses or abscess scars), A (2 to 4 well organized abscesses less than 2.5 cm diameter), or A+ (1 or more large active abscesses greater than 2.5 cm diameter with inflammation of surrounding tissue). Video image data were obtained from the plant for LM area, BF, calculated USDA Yield Grade (YG), and USDA marbling scores. Dressing percentage was calculated as HCW/(final BW × 0.96). Estimated empty body fat (EBF) percentage and final BW at 28% EBF (AFBW) were calculated from observed carcass traits (Guiroy et al., 2002), and proportion of closely trimmed boneless retail cuts from carcass round, loin, rib, and chuck (Retail Yield, RY; (Murphey et al., 1960).

Performance-adjusted Net Energy (paNE) was calculated from daily energy gain (EG; Mcal/d): EG = (carcass-adjusted ADG from d 20 to 117)$^{1.097}$ × 0.0557W$^{0.75}$, where W is the mean equivalent shrunk BW [shrunk BW × (478/AFBW), kg; (NRC, 1996)] for the period from d 20 to 117. Maintenance energy required (EM; Mcal/d) was calculated by the following equation: EM = 0.077BW$^{0.75}$ (Lofgreen and Garrett, 1968) where BW is the mean shrunk BW (using the average of carcass-adjusted final BW and BW from d 20). Using the estimates required for maintenance and gain the pa NEm and NEg values (Owens and Hicks, 2019) of the diet were generated using the quadratic formula: $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2c}$, where x = NEm, Mcal/kg, a = -0.41EM, b = 0.877EM + 0.41DMI + EG, c = -0.877DMI, and NEg was determined from: 0.877NEm – 0.41 (Zinn and Shen, 1998; Zinn et al., 2008).

The comparative NEm values for rye were estimated using the replacement technique. Given that the NEm value of dry-rolled corn was 2.17 Mcal/kg (NASEM, 2016), the comparative NEm values for rye were estimated as follows (Estrada-Angulo et al., 2019): Rye NEm, Mcal/kg = [(test diet paNEm – control diet paNEm)/RYE_y] + 2.17, where RYE_y represents the inclusion of rye that replaced dry-rolled corn in the diet (0.1991, 0.3993, and 0.6004), respectively. The same was done for NEg, assuming the dry-rolled corn had a NEg value (Mcal/kg) of 1.49 (NASEM, 2016).

Statistical analysis

Growth performance, carcass traits, and efficiency of dietary energy utilization were analyzed as a completely randomized design using the MIXED procedure of SAS 9.4 (SAS Inst. Inc., Cary, NC) with pen as the experimental unit. The model included fixed effect of dietary treatment. Least squares means were generated using the LSMEANS statement of SAS and treatment effects were evaluated using orthogonal polynomials (Steel and Torrie, 1960). Dry matter intake was evaluated in the MIXED procedure of SAS 9.4, using repeated measures, the model included the fixed effects of treatment, day, and their interaction; day was included as the repeated variable; pen was considered the experimental unit. The covariance structure with the lowest Akaike information criterion was used. Distribution of USDA Yield and Quality grade, as well as liver abscess severity and prevalence data were analyzed as binomial proportions in the GLIMMIX procedure of SAS 9.4 with fixed effects in the model as described previously. An α of 0.05 or less determined significance and tendencies are discussed between 0.05 and 0.10.

RESULTS

Rye improved performance with linear increases in BW, ADG, DMI, and G:F (*P* = 0.01; Table 4.5) during the initial 19-d adaptation period (with Rye fed from d 8 to d 19). Some of those responses to Rye were maintained during the d 20 to d 47 period, with a quadratic increase in BW (*P* =0.03) and a tendency for increased ADG and G:F (*P* ≤ 0.07). However, increased Rye linearly decreased ADG (*P* = 0.01) and quadratically decreased BW (*P* ≤ 0.04) from d 48 to d 117. Dry matter intake decreased quadratically (*P* = 0.03) from d 48 to d 75 in the 0:60 treatment compared to treatments with lesser inclusion rates of Rye. Dry matter intake linearly decreased (*P* = 0.01) with increasing Rye inclusion from d 76 to d 117. Feed efficiency was linearly decreased by increased Rye (*P* = 0.05) from d 48 to d 75 but unaffected by treatment from d 76 to trial termination.

Using carcass-adjusted cumulative performance, Rye inclusion linearly decreased carcass-adjusted final BW, ADG, and G:F (*P* = 0.01; Table 4.6). There was an interaction (*P* < 0.0001) between DRC:Rye and days on feed, where DMI did not differ between treatments initially but diverged during the experiment, resulting in decreased DMI with increased Rye inclusion (*P* = 0.02, Figure 4.2). Using the period from when steers were on the final diet (d 20 to d 117; the energetics assessment period), rye inclusion linearly decreased paNE values (*P* = 0.01; Table 4.6) with no effect on observed/expected NE (*P* ≥ 0.31). Comparative NEm and NEg values for hybrid rye at 20, 40, and 60% inclusion levels were 2.08 and 1.41, 1.93 and 1.28, and 1.90 and 1.25 Mcal/kg for maintenance and gain, respectively.

Hot carcass weight (HCW) linearly decreased with increased Rye (*P* = 0.01; Table 4.7). Dressing percentage decreased quadratically with increased Rye inclusion (*P* = 0.02). Rib fat, KPH %, YG, RY, and estimated empty body fat % (EBF) were unaffected by treatment (*P* ≥ 0.14). Dietary treatment tended (*P* = 0.07) to affect marbling quadratically with reduced marbling in the 0:60 treatment compared to treatments with lesser inclusions of Rye. Longissimus muscle (LM) area decreased with increased Rye inclusion (*P* = 0.04), as did AFBW (*P* = 0.01). Dietary treatment did not affect distributions of USDA YG or QG or severity or prevalence of liver abscess scores (*P* ≥ 0.09).

DISCUSSION

The estimates for NEm and NEg (1.90 and 1.25 Mcal/kg, respectively) in the current experiment agree closely with previously published values for rye grain (1.97 and 1.32 Mcal/kg, NASEM, 2016; 1.90 and 1.23 Mcal/kg, Preston, 2016). Gain and efficiency differences observed in this experiment are consistent with dilution of NE caused by substitution of Rye for DRC. Other researchers have reported that limited inclusion levels of rye grain (< 30%) did not affect performance of growing Holstein calves (Sharma et al., 1981) or finishing dairy bulls (Huuskonen and Pesonen, 2018). Those researchers were substituting rye for barley, resulting in experimental diets that were nearly isocaloric to controls.

Net energy dilution alone does not explain the increased ADG observed during the adaptation period and the lack of treatment effects on G:F from d 20 to 47 in the current experiment. Negative effects of increased Rye inclusion on DMI, growth response, and feed efficiency were not apparent until after d 47. Taken together, these observations support the conclusions that exposure to increased amounts of ingested Rye or exposure over a prolonged period, negatively affect growth and efficiency in finishing beef steers.

One explanation for differing DMI and ADG responses over time is ergot alkaloid exposure. Much more research has been conducted on the effects of alkaloids associated with endophyte-infected fescue compared to those produced by *C. pupurea* in ergot-infested grain; however, toxicosis and ergopeptide alkaloids are similar between the two sources (Evans et al., 2004). Dietary ergot alkaloid concentrations were 0, 78, 157, and 235 ppb for 60:0, 40:20, 20:40, and 0:60, respectively, based on total ergot alkaloid concentration in the hybrid cereal rye used in this experiment. (Matthews et al., 2005), observed decreased DMI of endophyte-infested fescue with ergot alkaloid concentration of 120 ppb. Growth and efficiency decreases have been observed with ergot alkaloids as low as 150 to 200 ppb (Evans et al., 2004; Klotz, 2015), suggesting that longer-term exposure to ergot alkaloids could cause receptor accumulation, leading to larger impacts on biological processes. In this experiment, as days on feed and DMI increased, increased inclusions of Rye could have caused DMI and performance decreases later in the feeding period, particularly in the 20:40 and 0:60 treatments.

Altered cattle feeding behavior could be another explanation for these differing responses over time. This experiment was not designed to quantify changes in feeding patterns; however, it was apparent by daily observation that pens assigned to treatments with greater inclusion of Rye took more time to consume their daily ration compared to 60:0 (S. Bird, personal communication). This agrees with experiments where steers fed endophyte-infested fescue seed ate more slowly compared to their pair-fed counterparts on a negative control diet (Ahn et al., 2020). Decreased rate of DMI with increased inclusions of Rye in this experiment could have provided an advantage by mitigating sub-acute acidosis risk during the early portion of the experiment but negatively affected DMI later in the experiment.

The degree of rye processing also may have contributed to decreased DMI. The PI for Rye chosen for this experiment was based upon suggested PI used for barley and wheat in finishing diets to minimize excess fines while enhancing ruminal starch degradability (Koenig and Beauchemin, 2011). Excessive fines created by increased grain processing can depress DMI (Zinn, 1993). Excessively processing the Rye in this experiment could have caused reduced DMI with increased inclusion rates of Rye. The lack of response during the adaption phase could be explained by increased amount of roughage fed during this period, mitigating effects of rapid ruminal starch degradation. Starch from rye grain was more degradable *in situ* than either barley (Krieg et al., 2017) or corn (Rajtar et al., 2020). In the latter experiment, degree of processing had less effect on rye compared to corn. Because of differences in starch degradability and response to grain processing, the optimal processing index for cereal rye may be less than that of other cereal grains such as barley or corn.

The decreased dressing percentages observed for all treatments in this experiment is consistent with results observed during the winter in the Midwest in cattle with similar mud scores (Pusillo et al., 1991; Busby and Strohbehn, 2008). The quadratic effect of Rye inclusion on DP could be related to increased concentrations of dietary NDF and ADF. However, increased concentrations of NDF and ADF caused by increased inclusions of dry-rolled barley substituting for DRC had no effect on dressing percentage

(Johnson et al., 2020). Feeding endophyte-infested fescue seed increased total weight of rumen contents (Ahn et al., 2020) which might explain dressing percentage changes observed in the current experiment as dietary ergot alkaloid intake increased. However, because of the unusually high mud scores in the current experiment and the correspondingly less than expected dressing percentages, in the authors' opinion any conclusions regarding effects of Rye inclusion on dressing percentage should be made cautiously.

Indicators of carcass fatness (BF, KPH %, RY, and YG) were all unaffected by treatment. However, LM area and AFBW both decreased with increased Rye inclusion, suggesting that Rye decreased muscling and frame size at increased inclusion rates. This result was unexpected and not easily explained. Greater substitution of rye grain for DRC decreased the energy density of the diet. This combined with the decreased DMI observed in the current experiment should have resulted in less fat deposition compared to the 60:0 diet. A metabolizable protein (MP) deficiency is consistent with decreased DMI and AFBW; however, MP supply was greater than requirements in this experiment (NASEM, 2016). Very little work has been done evaluating the impact of ergot alkaloid contamination in finishing cattle diets, however, it has been suggested that ergot alkaloids can negatively affect energy metabolism independent of DMI (Coufal-Majewski et al., 2016).

CONCLUSION

These data indicate that hybrid rye can be successfully fed to finishing beef steers. In this experiment the NE value of hybrid rye is approximately 84% compared to DRC. Blends of two-thirds DRC to one-third hybrid rye supported increased carcass-adjusted growth performance and DMI compared to increased inclusions of hybrid rye. Additional work is required to determine if the negative effects of increased rye inclusion on DMI and performance were caused by cereal rye *per se*, ergot alkaloid concentrations, or degree of grain processing.

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TABLES

Table 4.1. Hybrid cereal rye ergot alkaloid concentration (DM Basis).[1, 2]

Ergot Alkaloid	Concentration (ppb)
Ergosine	70
Ergotamine	25
Ergocornine	31
Ergocryptine	138
Ergocristine	47
Ergosinine	28
Ergotaminine	< 20
Ergocorinine	< 20
Ergocryptinine	32
Ergocristinine	21
Total	392

[1]North Dakota State University Veterinary Diagnostic Laboratory.
[2]Detection limit = 20 ppb.

Table 4.2. Composition of experimental finishing diets fed from d 19 to d 117 (DM basis).

	DRC[1]:Rye grain inclusion (DM basis)			
Item	60:0	40:20	20:40	0:60
Ingredient composition, %				
DRC[1]	60.34	40.33	20.22	0.00
Hybrid rye	0.00	19.91	39.93	60.04
MDGS[2]	18.90	18.95	19.00	19.05
Corn silage	16.84	16.89	16.93	16.97
Liquid supplement[3]	3.91	3.92	3.93	3.94
Nutrient composition[4]				
NEm, Mcal/kg	2.08	2.02	1.95	1.89
NEg, Mcal/kg	1.41	1.35	1.30	1.25
CP, %	12.78	13.62	14.47	15.32
NDF, %	18.90	20.91	22.94	24.98
ADF, %	9.88	11.10	12.32	13.54
Ash, %	4.83	4.92	5.01	5.09
EE, %	4.69	4.35	4.01	3.67

[1]DRC, dry rolled corn.
[2]MDGS, modified distillers grains plus solubles.
[3]Provided 30 g/907-kg of monensin as well as vitamins and minerals to exceed requirements (NASEM, 2016).
[4]Tabular NE from (Preston, 2016) and actual nutrient compositions from weekly assays of the ingredients.

Table 4.3. Whole and processed rye particle size distribution, geometric mean diameter (GMD), and geometric mean diameter standard deviation (GMDSD).

Item	Whole Rye (%, retained)	Processed Rye (%, retained)
Screen Size, µm		
3,350	0.0	0.0
1,700	96.1	78.1
1,180	3.9	17.8
850	0.0	2.7
600	0.0	0.6
425	0.0	0.3
212	0.0	0.4
53	0.0	0.1
Pan	0.0	0.0
GMD, µm	2,339	2,081
GMDSD	1.1	1.4

Table 4.4. Nutrient composition of Rye and dry-rolled corn (DM basis).

Item	Rye (n = 17)	Dry-Rolled Corn (DRC; n = 17)
Nutrient composition, %		
Dry matter (as-is basis)	88.83 ± 0.962	88.00 ± 2.149
Crude protein	11.58 ± 0.464	7.32 ± 0.321
Ash	2.00 ± 0.071	1.53 ± 0.168
Processing index[1]	78.8 ± 2.29	86.9 ± 4.19

[1]Processing index = (g/L processed grain/g/L unprocessed grain) × 100.

Table 4.5. Influence of replacing dry-rolled corn (DRC) with Rye grain on interim period steer growth performance.

	DRC:Rye grain inclusion, % DM basis					*P*-value[1]		
Item	60:0	40:20	20:40	0:60	SEM[2]	0 vs. Rye	L	Q
Allotment BW, kg [2, 3]	429	429	429	429	-	-	-	-
Initial BW, kg [4]	418	420	421	423	-	-	-	-
Initial to d 19								
BW d 19, kg	445	450	455	459	2.4	0.01	0.01	0.84
ADG, kg	1.40	1.54	1.78	1.90	0.121	0.02	0.01	0.94
DMI, kg	9.48	9.50	9.51	9.52	0.005	0.01	0.01	0.27
G:F	0.139	0.159	0.182	0.196	0.0128	0.02	0.01	0.66
d 20 to 47								
BW d 47, kg	524	532	536	534	2.2	0.01	0.01	0.03
ADG, kg	2.84	2.93	2.90	2.66	0.087	0.87	0.13	0.07
DMI, kg	11.05	11.05	11.04	11.05	0.001	0.01	0.01	0.01
G:F	0.256	0.265	0.261	0.239	0.0078	0.83	0.10	0.06
d 48 to 75								
BW d 75, kg	612	620	619	615	2.5	0.07	0.62	0.02
ADG, kg	3.14	3.13	2.97	2.88	0.064	0.07	0.01	0.51
DMI, kg	13.65	13.60	13.43	13.15	0.050	0.01	0.01	0.03
G:F	0.230	0.230	0.221	0.218	0.0046	0.23	0.05	0.78
d 76 to 117								
BW d 117, kg	704	713	704	689	5.4	0.83	0.05	0.04
ADG, kg	2.17	2.21	2.02	1.79	0.107	0.20	0.01	0.21
DMI, kg	14.63	14.27	13.84	13.33	0.184	0.01	0.01	0.68
G:F	0.145	0.155	0.145	0.133	0.0065	0.91	0.14	0.11

[1]0 v Rye = 60:0 v 40:20, 20:40, 0:60; L = Linear; Q = Quadratic.
[2]Pooled SEM.
[3]No shrink was applied to any BW measures.
[4]BW collected on September 6, 2020.
[5]Cattle were allotted using BW from September 6, 2019, bodyweight from September 10, 2019 was used as initial on-test BW.

Table 4.6. Effect of replacing dry-rolled corn (DRC) with hybrid Rye grain on carcass-adjusted growth performance of feedlot steers and dietary energy.

	DRC:Rye grain inclusion, % DM basis					*P* – value[1]		
Item	60:0	40:20	20:40	0:60	SEM[2]	0 v Rye	L	Q
Initial BW, kg[3]	401	404	405	406	-	-	-	-
Final BW, kg[4]	650	648	632	620	4.9	0.01	0.01	0.32
ADG, kg	2.12	2.09	1.94	1.83	0.030	0.01	0.01	0.36
DMI, kg	12.71	12.57	12.38	12.13	0.067	0.01	0.01	0.42
G:F	0.167	0.166	0.157	0.150	0.0030	0.02	0.01	0.38
Energetics assessment period (d 20 to 117)								
d 19 BW, kg[3]	427	432	437	441	2.3	0.01	0.01	0.84
Final BW, kg[4]	650	648	632	620	4.9	0.01	0.01	0.32
ADG, kg	2.27	2.20	1.99	1.83	0.053	0.01	0.01	0.40
DMI, kg	13.34	13.16	12.93	12.64	0.080	0.01	0.01	0.43
G:F	0.170	0.167	0.154	0.145	0.0034	0.01	0.01	0.39
MP balance[5], g/d	590	544	454	363	-	-	-	-
paNE, Mcal/kg[6]								
Maintenance	2.07	2.05	1.98	1.91	0.027	0.01	0.01	0.34
Gain	1.41	1.39	1.32	1.26	0.024	0.01	0.01	0.34
Observed/Expected dietary NE[7]								
Maintenance	0.99	1.02	1.01	1.01	0.014	0.31	0.65	0.36
Gain	1.00	1.03	1.02	1.01	0.018	0.35	0.73	0.35
Estimated NE value of Rye, Mcal/kg[8]								
Maintenance		2.08	1.93	1.90	-	-	-	-
Gain	-	1.41	1.28	1.25	-	-	-	-

[1]0 v Rye = 60:0 v 40:20, 20:40, 0:60; L = Linear; Q = Quadratic.
[2]Pooled SEM.

[3]Body weight (BW) was shrunk 4% to account for digestive tract fill.
[4]Carcass-adjusted using hot carcass weight (HCW)/0.625.
[5]Daily metabolizable protein balance determined using the NASEM Beef Cattle Nutrient Requirements Model (2016)
[6]paNE = performance adjusted Net Energy (Owens and Hicks, 2019).
[7]paNE/tabular trial NE.
[8]Net energy values for Rye derived using the replacement technique, assuming that net energy for maintenance and net energy of gain values of dry-rolled corn are 2.17 and 1.49 Mcal/kg, respectively (NASEM, 2016).

Table 4.7. Effect of replacing dry-rolled corn (DRC) with hybrid Rye grain on carcass traits and liver abscess prevalence in feedlot steers.

	DRC:Rye grain inclusion, % DM basis					*P* – value[1]		
	60:0	40:20	20:40	0:60	SEM[2]	0 v Rye	L	Q
HCW, kg	406	405	395	388	3.0	0.01	0.01	0.33
Dressing percent, %[3]	60.10	59.12	58.42	58.56	0.221	0.01	0.01	0.02
Rib fat, cm	1.30	1.30	1.30	1.24	0.036	0.78	0.46	0.55
LM area, cm^2	83.3	84.6	82.1	80.8	1.00	0.52	0.04	0.22
Marbling[4]	474	478	485	445	11.3	0.74	0.14	0.07
KPH, %	1.79	1.80	1.81	1.79	0.014	0.59	0.71	0.48
YG	3.40	3.32	3.37	3.32	0.063	0.43	0.54	0.85
Retail yield, %[5]	49.67	49.83	49.72	49.82	0.136	0.46	0.60	0.82
Estimated EBF, %	30.29	30.19	30.43	29.78	0.253	0.59	0.27	0.29
Final BW at 28% EBF (AFBW), kg	599	599	581	580	4.5	0.02	0.01	0.99
YG distribution							*P* - value	
YG 1, %	1.70	0.00	0.00	0.00	0.833		0.41	
YG 2, %	13.70	23.89	11.67	21.67	5.261		0.31	
YG 3, %	64.26	64.26	78.33	70.00	8.218		0.59	
YG 4, %	20.37	11.85	10.00	8.33	5.453		0.43	
QG distribution								
Prime, %	0.00	0.00	3.33	0.00	1.054		0.09	
Premium Choice, %[6]	29.07	34.07	30.00	21.67	6.517		0.60	
Choice, %	50.37	50.93	53.34	48.33	7.590		0.97	
Select, %	20.56	15.00	13.33	30.00	4.966		0.11	
Liver abscess scores								

Normal, %	69.44	74.63	65.00	70.00	4.909	0.60
A^-, %	13.52	5.00	13.33	13.33	4.419	0.46
A, %	8.52	10.00	6.67	6.67	3.360	0.87
A^+, %	8.52	10.37	15.00	10.00	4.365	0.75

[1]0 v Rye = 60:0 v 40:20, 20:40, 0:60; L = Linear; Q = Quadratic.
[2]Pooled SEM.
[3]HCW/final BW shrunk 3%.
[4]USDA Marbling Score 400 = Small^0 = Low Choice; 500 = Modest^0 = Average Choice.
[5]As a percentage of HCW.
[6]Average or High Choice Quality Grade.

FIGURES

A

B

Figure 4.1. Depicts unprocessed whole rye (A) and processed rye (B), processing index (PI) = 78.8 ± 2.29. Processing index is defined as: (g/L processed grain/g/L unprocessed grain) × 100.

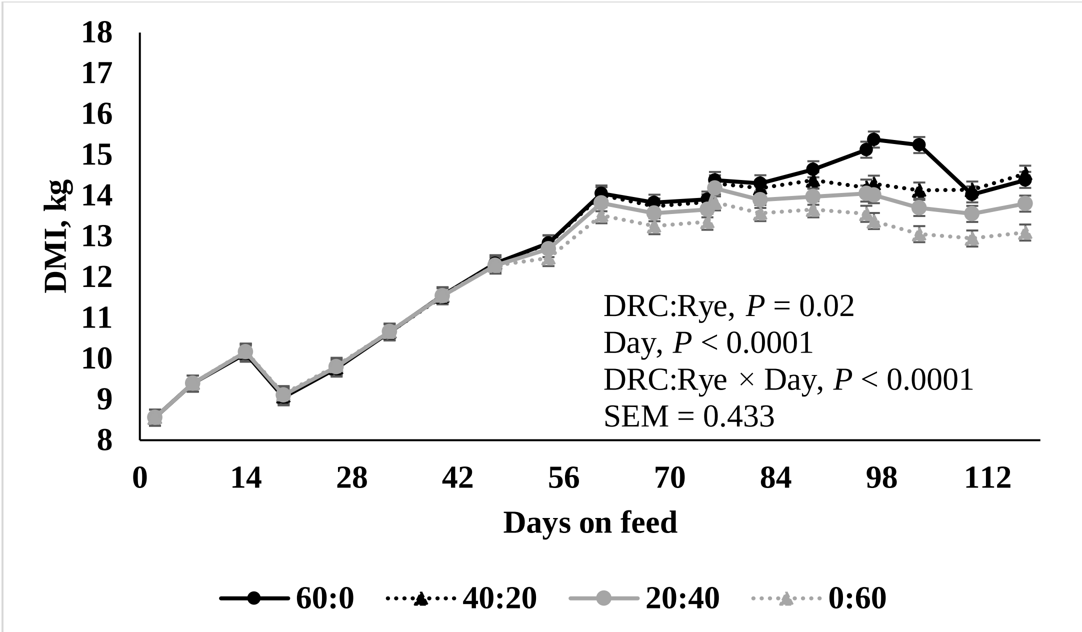

Figure 4.2. Effect of treatment on dry matter intake (DMI) over the experimental period. Hybrid rye (Rye) was substituted for dry-rolled corn (DRC) as follows: a basal finishing diet formulated (DM basis) 60% corn grain (DRC:Rye, **60:0**) and three additional diets formulated with increasing proportions of Rye (**40:20**, **20:40**, and **0:60**). For each of the four treatments there were 60 steers housed in six pen replicates. All rye grain used was from the same hybrid (KWS Bono, KWS Cereals, LLC; Champaign, IL) and from a single source. The experiment was analyzed as a completely randomized design using repeated measures.

APPENDIX

Feedlot and cattle management

1. One-time capacity?
2. Cattle demographics, % of one-time capacity?
    a. Calf-fed
    b. Yearlings
    c. Bos indicus influenced
    d. Steers
    e. Heifers
3. Number of placements per year?
4. Feed delivery and diet composition
    a. Feed deliveries per day?
    b. Proportion fed at each feeding?
    c. Does proportion fed differ at each feeding differ in summer compared to other seasons?
    d. Finishing diet NEg, Mcal/cwt?
    e. Percent added fat in finishing diet?
    f. Additives used?
        i. Ionophore
        ii. B-agonist
        iii. MGA
        iv. Hydro-Lac
        v. Other

Facility data

Multiple answers possible for each question

5. Facility type?
    a. Open
    b. Covered
    c. Partially covered
6. IF OPEN
    a. Pen surface?
        i. Earthen
        ii. Concrete
    b. Mounds? Yes or No
    c. Pen density, ft^2 per animal?
    d. Waterer location?
        i. Fence line? Yes or No
        ii. Middle of pen? Yes or No
        iii. Shared with another pen? Yes or No
    e. Windbreak present?
    f. Shade? Yes or No
    g. Water application during heat event?
        i. Water applied to:
            1. Cattle
            2. Pen surface
        ii. Time of day applied:

1. AM
2. Mid-day
3. PM/evening

7. IF COVERED (multiple answers possible if more than one type of confinement barn managed)
   a. Barn type?
      i. Monoslope
      ii. Hoop
      iii. Gable
   b. Floor type?
      i. Slatted
      ii. Bed pack
   c. Pen density, ft^2 per animal?
   d. Waterer location?
      i. Fence line? Yes or No
      ii. Middle of pen? Yes or No
      iii. Shared with another pen? Yes or No
   e. Water application during heat event?
8. IF PARTIALLY COVERED
   a. Covered surface?
      i. Earthen
      ii. Concrete
   b. Uncovered surface?

      i. Earthen
      ii. Concrete
   c. Mounds? Yes or No
   d. Waterer location?
      i. Fence line? Yes or No
      ii. Middle of pen? Yes or No
      iii. Shared with another pen? Yes or No
   e. Windbreak present? Yes or No
   f. Additional shade present in outside pen? Yes or No
   g. Water application during heat event?
      i. Water applied to:
         1. Cattle
         2. Pen surface
      ii. Time of day applied:
         1. AM
         2. Mid-day
         3. PM/evening

Open-ended questions

9. When do you start preparing for heat stress?
10. Triggers for mitigation strategies?
11. What mitigation strategies have worked well?
12. What criteria are used to determine successful mitigation?
13. Have you experienced losses?

   a. Minor
   b. Moderate
   c. Acute
   d. Context of loss:

14. What mitigation strategies have not worked well?
15. What mitigation strategies do you wish you could use?
16. What is the limitation to implementing those strategies?
17. What are your cattle handling procedures during heat stress (shipping, receiving, processing, etc.)?
18. Other comments: