THE EFFECT OF YEAST (*SACCHAROMYCES CEREVISIAE*) CULTURE IN A FREE-CHOICE MINERAL MIX ON INTAKE, DIGESTIBILITY, AND MILK PRODUCTION FOR BEEF CATTLE ON FESCUE-BASED PASTURE

A Thesis

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ABSTRACT

Yeast cultures are commonly used in the animal industry as feed supplements. Frequently found in the dairy industry, yeast cultures may enhance intake, digestibility, and milk production. There is little research examining the efficacy when given to beef cows exclusively on a pasture. Yeast (Saccharomyces cerevisiae) culture (YC) was provided in a free-choice vitamin-mineral mix. The effects of YC on organic matter intake (OMI), apparent organic matter digestibility (OMD), neutral detergent fiber degradability (NDFD) and in-situ NDF were examined over three periods (winter, early summer and late summer). There were no differences between the two groups for winter and early summer. OMI (kg/d) was higher (P=0.04) in the YC group (5.69 kg/d) compared to the control group (4.79 kg/d) in late summer. In addition, when intake was corrected for weight, OMI was also higher (P=0.02) for the YC group (11.6 g/kg BW) compared to the control group (9.0 g/kg BW). Similar to OMI, OMD was higher (P=0.04) in the YC group (27.2 %) compared to the control group (21.1%) late summer. NDFD was also higher (P=0.03) in the YC group (39.2 %) compared to the control group (32.3%) late summer. No changes were found in the in-situ degradability of NDF. There was no difference in milk production 60 days in milk (DIM) over two years. However, YC supplemented cows had (P=0.06) higher (5.6 kg) vs. (4.3 kg) 120 DIM estimated milk
production in the first year and also had (P=0.05) higher (6.3 kg.) vs. (5.0 kg.) 120 DIM estimated milk production in the second year. No changes were found in calf weight (per day of age), birth weights, or weaning weights. Yeast culture supplements are shown here to have positive production responses to beef cattle on a fescue-based pasture. The responses are focused in the late summer compared to early summer and winter months.
Dedicated to my parents
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CHAPTER 1

INTRODUCTION

Yeast are single-cell, microscopic fungi, about 5-10 microns in size. They are facultative anaerobes, able to survive and grow with or without oxygen. With over 1000 different species of yeast identified, few species are used commercially. The most commonly used species is *Saccharomyces cerevisiae*, also known as "baker’s yeast.” Yeast is most commonly used in bread making and alcoholic beverage production. Although its beneficial effects have been established for centuries, the inclusion of yeast and yeast products in animal diets has only occurred in recent years.

One of the first experiments reporting the use of yeast (*S. cerevisiae*) in animal diets was in 1925. Today, research continues to evaluate the use and benefits of supplemental yeast and yeast products in animal diets. In general, the majority of the reports of using supplementing yeast are positive with virtually no reports of harmful effects. The objective of this experiment was to investigate the efficacy of feeding a commercially available yeast culture product to beef cattle on pasture. We tested the hypothesis that yeast culture would increase intake, digestibility and milk production when provided in a free-choice mineral mix.
CHAPTER 2

LITERATURE REVIEW

Yeasts have been used throughout the centuries. Earlier civilizations used these organisms before beginning to understand the true nature of their function. In ancient Babylon, around 6000 B.C., a kind of beverage was prepared from germinating cereals (39). The beverage became fermented in the warm environment, acquiring a pleasant flavor and ‘heady’ quality. The fermented beverage was most likely the predecessor to modern day beer. Wine making was discovered later in Assyria around 3500 BC, and ancient Rome had over 250 bakeries making leavened bread by 100 BC.

The word yeast spans different cultures and languages, all containing common references (39). In French, yeast is called levere, based on the Latin term lever, meaning to lift. In German, yeast is called hefe, which stems from the verb heben also meaning to lift. The English word “yeast” and the related word "gist" in Dutch are derived from the Greek term zestos, meaning boiled. All listed root meanings reference the bubbling foam caused by yeast. We now know the process is fermentation and the bubbling gas is carbon dioxide. When the word “yeast” is mentioned, it usually brings to mind
fermentation. Both yeast and fermentation have been closely associated throughout their history.

Around 1665, Antonie van Leeuwenhoek created a crude microscope in which he was able to view yeast as well as other microorganisms. He observed globular, round and oval bodies in a drop of fermenting beer (61). He described the organisms as "little living animalcules". To him, yeast cells probably looked like small animal-like creatures.

In 1864, Louis Pasteur published his works *Estudes sur la Biere* and *Estudes sur le Vin* explaining the presence of these organisms was essential to the fermentation process, which he called "la fermentation est la vie sans air" (61). He postulated the fermentative process of the microorganisms (including both bacteria and yeast) living under anaerobic conditions constituted a substitute for the respiratory process of aerobic organisms. By the end of the 19th century, it was clear these microorganisms, living in the absence of oxygen, were able to covert sugar to carbon dioxide and alcohol. He noted that, without yeast, fermentation did not occur. In addition, if other morphologically different organisms were present, desirable fermentation did not occur and the wine or other fermented beverage was spoiled.

The following equations are a modern representation of the aerobic and anaerobic metabolism of yeast cells (40):

**Aerobic growth:**

1 glucose + 6 O₂ = 6 CO₂ + 6H₂O (686 kcal free energy)
Anaerobic fermentation:

$$1 \text{ glucose} = 2 \text{ CO}_2 + \text{CH}_3\text{CH}_2\text{OH} + 2 \text{ ethanol} (54 \text{ Kcal free energy})$$

Under aerobic conditions yeast can produce enough free energy, converting sugar and oxygen into carbon dioxide and water, in order to propagate and grow. Compared to aerobic conditions, yeast under anaerobic conditions produce less energy when converting sugar into carbon dioxide and ethyl alcohol. Therefore, the anaerobic metabolic process, when compared to aerobic metabolic process, is much less energy efficient, resulting in slower growth.

Around the same time Louis Pasteur was postulating the mechanisms of yeast metabolism, Eduard Buchner was able to achieve cell-free alcohol fermentation by extracting the enzyme responsible for fermentation (61). He called the enzyme zymase. Enzyme is a word derived from Greek, meaning "in yeast". We know today that yeast have a complex mixture of enzymes. By the beginning of the twentieth century, long after humans first started using yeast, the true nature of these organisms started to become clear.

*Saccharomyces cerevisiae* is one of the few species used commercially, commonly for bread and alcohol (ale) production. Yeast may be further classified by sub-species or strain. Each sub-species or strain may potentially influence a product's qualities, such as aroma and flavor. The individual strains are often isolated and patented by manufacturers in order to produce proprietary beer, wine, and other food products (5).
With beer production, by-products or wastes (known as brewer's grains and brewer's yeast) are produced (54). Brewer's grains contain barley, corn grit, rice and hops. Yeast is added after the grains are removed from the production process, so brewer's grains may not have active yeast cells. Residual yeast from brewing operations, were recovered after the beer was fermented and dried at high temperatures to kill the yeast. By the 1930's, brewing residuals as well as baker's yeast were dried and sold to the human and animal feed industry as sources of vitamins, minerals, and protein. (36).

The use of residual products from the brewing and baking industry eventually promoted interest in direct supplementation of yeast and yeast products into animal diets. In 1925, one of the first experiments including live yeast in the diet of dairy cattle was reported (24). Supplemental active dried yeast was provided in the diet, and differences in amount of milk and butterfat generated daily were measured. The conclusion was that the addition of active dried yeast in the diet did not increase the milk or butterfat yield. Although the initial examination of yeast supplementation did not appear to be beneficial, the research continued and so did understanding. Over the years, yeast and similar microbial additives have been studied for their effectiveness as supplemental feeds in animal diets.

Active dried yeast (used in the fore-mentioned experiment) is one of the predominant viable yeast products available to the feed industry. It is approximately 95% dry matter and can be used to manufacture many yeast fermented products (63). Today, yeasts are
the producers of four leading fermentation products in terms of tons/year worldwide (25). These are beer (60 million tons), wine (30 million tons), single cell protein and fodder (800,000 tons), and bakers yeast (600,000 tons). A fifth product is citric acid (500,000 tons) also made by yeasts and molds.

Active dry yeast is produced using aerobic fermentors or bioreactors. The yeast is fed nutrients allowing them to reproduce exponentially. Yeast are asexual, and reproduction is accomplished by "budding". The "mother" yeast cell will form a bud and once mature, the bud will break off, forming a new "daughter" cell (40). Once the broth has a sufficient concentration of new cells, the broth is centrifuged, creating a yeast cream and then yeast cake. This cake is formed into wet yeast-noodles and slowly dried as to not affect the yeast's fermentative activity. The drying process is the most critical part in manufacturing of a yeast product. With few common drying processes in the industry, "fluid-bed drying" is the most widely used, causing the least amount of damage to the yeast cell, resulting in higher viability counts (63). Fluid bed drying is conducted at relatively low temperatures (32° to 55°C) and over a longer period of time (1 to 2 ½ hours) compared to conventional methods (> 55°C, 15-30 minutes) (36).

The final product consists of dried yeast cells, with industry viability counts ranging from 15 to 25 billion live colony forming units (cfu) per gram (63). Viability counts now depend on processing and storage conditions. The stability of dry yeast is dependent on how the product is packaged. The greatest stability is normally achieved when yeast is sealed in a package purged with nitrogen or carbon dioxide gas to displace any oxygen.
There are other yeast products commercially manufactured and available for use. One example is yeast culture (YC), defined as a fermented yeast product designed to provide fermentative metabolites resulting from a unique fermentative process (21). Yeast cultures are currently being supplemented in animal diets. The primary difference between yeast culture and active dry yeast is that yeast culture does not rely solely on the viability of yeast in its final product (63). Yeast culture is made from a specific starting growth media inoculated with live yeast cells and allowed to ferment under specific, proprietary conditions. After fermentation, the entire culture (yeast and media) is dried. The final media contain active yeast, the metabolic by-products produced by the yeast during the fermentation process, and the intracellular and extra-cellular metabolites of the fermentation. The metabolites produced will depend on the strain of yeast used for inoculation and the composition and conditions of the fermentation media. Yeast culture is a fermented product containing a unique and largely unknown profile of nutrients (22). Similar to beer and wine production, the strain of yeast and the metabolites from the fermentation process ultimately will affect the final product.

Besides active dry yeast and yeast culture, there are a variety of other microbial supplemental feeds. The terminology used to describe or categorize these supplements can be confusing and at times misleading. In the past, the term "probiotic" was often used to describe a microbial feed supplement. A probiotic is defined as "a live microbial feed supplement [that] beneficially affects the host animal by improving intestinal microbial balance" (64). Many researchers began to use the term “probiotic” loosely, to mean a
selected and concentrated viable count of lactic acid bacteria" (43). In 1989, the United States Food and Drug Administration (FDA) required manufacturers to use the term "Direct Fed Microbial" (DFM) rather than probiotic (64). The FDA defines DFM as a "source of live (viable) naturally occurring microorganisms" that includes bacteria, fungi, and yeast (64). The use of DFM instead of probiotic came as a result of unwarranted beneficial health claims. A DFM can include active dry yeast (e.g. *S. cerevisiae*), fungi (e.g. *Aspergillus oryzae*), and bacteria (e.g *Lactobacillus acidophilus* and *Streptococcus faecium*).

There is a wide selection of DFM's and related products available to the consumer. Each manufacturer reports its own claims as to the usefulness of its product. It is difficult for a consumer to compare products and manufacturer information about their product because each product may differ greatly. Diamond V Mills, Cedar Rapids IA; Alltech Biotechnology Inc., Nicholasville, KY; Amaferm, St. Joseph, MO; Chr. Hansen BioSystems, Inc., Milwaukee, WI; Trans Agra International, Inc. Storm Lake, IA are some of the many manufacturers of DFM or other ‘natural’ supplements. Each company has its own unique product line and its own theory on how its products work.

The majority of the work using yeast, YC, and DFM supplements is focused in the dairy industry. The focus is probably due to the popularity of using such supplements in commercial dairy rations. Typically supplemental feeds are relatively cheap and can be easily included in a total mixed ration (TMR). Although the majority of the research is
focused in the dairy industry, these supplemental feeds have also been examined for use in beef cattle and to a lesser extent in swine, sheep, and poultry (37, 38, 44, 53).

With the growing public concern over the use of antibiotics and other growth stimulants in animal production, there is an increasing interest in the use of alternate and natural feed supplements. There is a substantial collection of research reporting positive or neutral effects of these commercially available products, with virtually no reports of detrimental effects. Unfortunately, a large portion of the research with yeast, YC and other DFM’s is non-peer reviewed, with unsubstantiated claims. The focus of this review will be based on published material and divided up into two categories: the work conducted to measure production responses (e.g. intake, milk production, digestibility) and work trying to identify the underlying reason for a production response (e.g. stimulation of rumen microbes, changes in the rumen environment).

**Milk Production.**

Yeast, YC and other DFM’s are commonly claimed to enhance milk production. As mentioned earlier, Eckles and Williams (24) reported including a "dried yeast preparation" at the rate of 25 grams per pound of milk produced in a common dairy ration. The inclusion of the yeast supplement did not increase milk or butter fat yield. The nature of the “dried yeast preparation”, the feeding practices, and data collecting procedures such as milk yield estimates were unclear. Although it captures an interest of
including yeast and other fermented products in animal diets in the early part of the 20th century, it may not have produced comparable results to today's product lines.

**Alltech Yea-Sacc.** Yea-Sacc, manufactured by Alltech, is one of the commercially available yeast culture products. Several studies have examined its ability to enhance milk production. Adams et. al. (1) included YC (*S. cerevisiae*, Yea-Sacc; Alltech, Inc., Nicholasville, KY) at the rate of 10 g/d to dairy cows in four forage treatments: 1) 45.0% corn silage 2) 33.75% corn silage plus 11.25% alfalfa hay; 3) 33.75% corn silage plus 11.25% bermudagrass hay; or 4) 33.75% corn silage plus 11.25% cottonseed hulls on a DM basis fed to dairy cows. The diets also varied in fat content: no added fat, 12.5% whole cottonseed, or 2.5% tallow. The remaining content of each of the diets was grain and were formulated to be iso-nitrogenous (approximately 17% CP). Cows with YC included in their ration had higher milk yield in the forage supplemented groups without fat added. The effects were negative with whole cottonseed and neutral with tallow. In another experiment, Holstein cows in a commercial Florida dairy were fed 10 g/d continuously for 60 days. Cows receiving the dietary yeast supplementation produced milk with a higher (P = 0.09) percentage of milk fat.

Putnam et. al. (52) included YC (*S. cerevisiae*, Yea-Sacc; Alltech Inc. Lexington, KY) at the rate of 10 g/d with different levels of dietary crude protein (16.1% vs. 18.8% of dry matter) in 44% forage fed to dairy cows. Yields of fat and 4% fat-corrected milk were increased by yeast culture supplementation in the low protein (16.1% crude protein) diet. Similar tendencies were noted for yields of milk and milk protein.
Williams et. al. (72) included YC (S. cerevisiae, Yea-Sacc. Alltech Biotechnology Center, Nicholasville, KY) at the rate of 10 g/d in multiparous Freisian dairy cows on 4 different dairy rations 1) 50% Concentrate, 50% Hay-based 2) 50% Concentrate, 50% Straw-based (ammonia) 3) 60% Concentrate, 40% Hay-based 4) 60% Concentrate, 40% Straw-based (ammonia). Supplementation with YC increased milk yield by 1.4 liters/d (corrected to 4% butter fat; P ≤ .05). They also found an interaction between diet composition and YC. The effects of YC were greatest in the 60:40 (concentrate:forage) ratio.

Dann et. al. (19) included YC (S. cerevisiae, Yea-Sacc; Alltech, Inc., Cedar Rapids, IA) at the rate of 60 g/d to Jersey dairy cows for approximately 21d prepartum and 140 d postpartum in a TMR. The prepartum TMR consisted of 47.4% corn silage, 28.4% chopped alfalfa hay, 16.9% ground shelled corn, and 5.4% soybean meal. The postpartum TMR consisted of 21.7% corn silage, 21.6% chopped alfalfa hay, 31.2% ground shelled corn, and 13.1% soybean meal, 48% CP. Total milk production did not differ between the two groups the first 140 d of lactation. However, a significant interaction of treatment by day indicated that cows supplemented with YC reached peak milk production sooner than non-supplemented cows. Concentrations of fat, protein, lactose, total solids, and urea N in milk as well as somatic cell count were not significantly affected by YC supplementation. Including “Yea-Sacc” YC at the rate of 10 g/h/d in 40-50 % forage-based diets, increased or tended to increase milk yield and/or fat percentage.
**Diamond V XP Yeast Culture.** XP Yeast Culture by Diamond V is another commercially available yeast culture with reports of enhanced milk production. Shaver et al. (59) included YC (*S. cerevisiae*, Diamond V XP yeast culture; Diamond V Mills, Cedar Rapids, IA) at a rate of 57 g/hd over a 30-d period to the TMR of dairy cows on 11 commercial dairies. Dietary yeast cultures increased *(P < 0.001)* actual and 150-d adjusted milk yields 0.9 kg/d. Milk fat content was lower *(P < 0.001)* and milk fat protein content was lower *(P < 0.05)* for cows given YC. Milk fat yield was similar and milk protein yield was higher *(P < 0.01)* for cows fed YC.

Robinson et al. (56) included YC (*S. cerevisiae* - containing $4 \times 10^7$ cfu/g, XP yeast culture, Diamond V Mills Inc., Cedar Rapids, IA) at the rate of 57 g/h/d to pre and post-partum pregnant, multiparous and primiparous Holstein cow diets of corn silage and timothy silage. The YC supplemented cows had numerically higher milk yield and milk components, but these effects were not significant.

Arambel et al. (3) included YC (*S. cerevisiae* - containing $2.0 \times 10^6$ cfu/g, XP yeast culture, Diamond V Mills Inc., Cedar Rapids, IA) at the rate of 90 g/h/d (top-dressed) to Holstein dairy cows in early to mid lactation for 10 weeks. The diet consisted of 18.7 % chopped alfalfa hay, 11.8 % alfalfa haylage, 7.3 % corn silage, and concentrate (rolled barley, whole cotton seed, dried brewers grains etc.). Milk yield and composition were not significantly affected by treatment.
Higginbotham et. al. (33) included YC (*S. cerevisiae*; XP yeast culture, Diamond V Mills Inc., Cedar Rapids, IA) at the rate of 56 g/h/d and a fermentative extract (*S. cerevisiae* (Diamond V Mills Inc., Cedar Rapids, IA) at a rate of 3g/d to Holstein dairy cows in early lactation. The TMR contained alfalfa silage, alfalfa hay, corn silage, rolled barley, rolled corn, whole cottonseed, wet citrus pulp, molasses supplement, and minerals. The combination of both supplements had no effect on actual milk yield, milk fat or protein percentages.

Wang et. al. (69) included YC (*S. cerevisiae*; "XP" Yeast Culture, Diamond V Mills, Cedar Rapids, IA) at a rate of 60 g/h/d beginning d 21 prepartum and extending to d 140 postpartum in Holstein Cows. Cows were group fed a prepartum diet with or without yeast culture. After parturition, cows were individually fed one of five treatments: 1) 21% NDF without YC 2) 21% NDF with YC 3) 17% NDF without YC 4) 17% NDF with YC 4) 25% NDF with YC for 30 d and then switched to treatment 4 for 110 d. During the first 30 d in milk (DIM), dry matter intake, milk yield, and milk protein yield increased for the 21% forage NDF with YC group. From 31 to 140, yeast culture tended to increase milk fat percentage and appeared to have positive effects on milk yield and milk fat yield when supplemented to 21% NDF diets. Feeding 17% vs. 21% forage NDF increased milk protein percentage from 31 to 104 DIM.

Yeast products from Alltech Inc. and Diamond V. Mills Inc., although different, appear to produce similar beneficial response in milk production. Including “Yea-Sacc” YC at the rate of 10 g/h/d in 40-50% forage-based diets, increased or tended to increase milk
yield and fat percentage (1,52,69,72). It also appears that “XP” YC at 57 g/h/d in forage-based diets increased milk yield (56, 59). Some exceptions were also noted (3, 19, 33). Inconsistencies in results may be explained by differences in experimental conditions and/or diet. The possible mechanisms of yeast supplementation effects will be discussed later.

**Chr. Hansen Biosystems Inc. Biomate Yeast Plus.** Besides “Yea-Sacc” and “XP” yeast cultures, there are several other commercially available DFM’s available including Biomate Yeast Plus (a liquid yeast supplement). Kung et al. (42) included YC (S. cerevisiae, Biomate Yeast Plus®; Chr. Hansen BioSystems, Inc., Milwaukee, WI) in two separate experiments. The first experiment included 20 multiparous Holstein Cows that were provided the YC top-dressed at a rate of 10 g/d in a 5% chopped alfalfa hay diet, 45% corn silage and 50% concentrate. The supplement had no effect on milk production or milk composition. The second experiment included 18 multiparous Holstein cows in early lactation and provided a similar diet to the previous experiment and given YC at the rate of 0, 10 or 20 g/d. The addition of yeast to the diet tended (P < 0.11) to increase milk production in cows provided 10 g/d compared with the controls and higher dose animals. The cows also tended (P < 0.07) to produce more fat-corrected milk. Although the researchers did not explain the theory on why the lower (10 g/d) dose group had a higher return than the higher dose (group), they did speculate that top-dressing may not be as effective way to feed use because data from a continuous culture experiment suggested yeast may wash out of the rumen when not mixed in with the diet. In addition, one may speculate that too high a concentration, perhaps at 20 g/d, may result in settling of the
yeast. The results from the 20 g/d group were numerically higher than the control group but were not significant.

Wohlt et. al. (74) examined the effect of feeding a YC product (Biomate Yeast Plus®; 5 x 10⁹ cfu; Chr. Hansen BioSystems, Inc., Milwaukee, WI) beginning 30 d prepartum and continuing through wk 4 postpartum in Holstein cows at the rate of 10 g/d. From wk 5 to wk 18 postpartum, cows were divided into three more groups fed 0, 10, or 20 g/d of yeast. Prepartum diet consisted a total mixed ration of mixed grass and legume hay (25%), corn silage (45%) and grain mix (28%). Postpartum diet consisted of a total mixed ration of mixed grass and legume hay (3%), corn silage (44%) and grain mix (50%). Yeast supplementation during early lactation improved (P < 0.05) milk yield prepartum compared to control. In addition, numerical increases in milk yield postpartum (from wk 5 – wk 18) were greater for cows fed 20 g/h/d yeast than for cows fed 10 g/d, but the results were not significant.

Soder et. al. (60) examined the effects of feeding a YC product (Biomate Yeast Plus®; Chr. Hansen BioSystems, Inc., Milwaukee, WI) beginning 28 d prepartum and continuing through wk 13 postpartum in Holstein cows. Biomate Yeast Plus® is a yeast culture (5 x 10⁹ cfu of S. cerevisiae/g) and the following enzymes: 100 units (U)/g of protease, 9 U/g of lipase, and 100 U/g of α-amylase. The treatment consisted of 1) whey control, 10 g/d of YC 2) enzyme 10 g/d 3) yeast 15 g/d 4) Biomate Yeast Plus® (yeast and enzyme); 20 g/d). The prepartum diet consisted of a total mixed ration containing chopped grass hay (28%), corn silage (35%) and grain and mineral pellet. The postpartum diet consisted of a
total mixed ration containing corn silage (25%), legume haylage (18%), chopped legume hay (4%), and grain and mineral pellet. Yeast cultures with or without enzymes had no effect on milk yield or composition.

**Other DFM's.** Products such as Yea Sacc, Diamond V XP and Biomate have all been shown to enhance milk production. However other researchers have used a combination of DFM’s and examined changes in milk production. Herring et al. (31) included a DFM (*S. cerevisiae, Enterococcus faecium, Lactobacillus acidophilus, Bacillus subtilis, A. oryzae*) at a rate of 28.4 g/d per cow to lactating Angus cows from d 53 to 123 of lactation in a hay-based diet (alfalfa, wheat or rye) with supplemental grain. There was no change in milk yield, protein percent, or somatic cell count in those cows receiving the DFM. However, those receiving the DFM had a higher (P<0.05) percentage of fat than the control group.

Using mixed microbial cultures may not elicit a positive production response compared to the fore-mentioned pure products. The other three manufacturers discussed used *S. cerevisiae* exclusively in their product. If *S. cerevisiae* is a responsible for enhanced milk production, its effect was most likely diluted.

**Organoleptic Characteristics.** Other researchers examined the possible effects of DFM supplementation on milk organoleptic characteristics. Organoleptic can be defined as effecting or employing one or more of the organs of special sense (e.g. smell, taste). Besong et. al. (8) included a liquid Y product (Zea Gen Inc. Wichester, KY) added to a
basal TMR 45:55 ratio of mixed concentrate and chopped alfalfa hay at DM rate of 0, 3, 7.5 and 15.5 %. The basal TMR plus 15.5% had severely depressed feed intake, so it was discontinued. There was no difference in milk yield or milk protein yield. There was a tendency (P = 0.11) for Y to increase milk fat %. Milk was also evaluated for its organoleptic characteristics. Milk from the Y supplemented cows had higher acceptability scores, based on a taste panel, than the milk from the control cows. The researchers observed the milk from cows fed 3 % and 7.5 % dietary Y was yellowish, suggesting that riboflavin was likely transferred to the milk. This suggests riboflavin did not have any detrimental effects on milk flavor characteristics. Furthermore, it may suggest that riboflavin has a protective, perhaps anti-oxidant effect in milk. Considering that different yeast strains influence taste of beer and bread products, the milk of a yeast supplemented dairy cow may have more desirable taste. Steckley, et. al. (62) included a yeast slurry (Molsons Brewery (Ontario) Limited, Barrie, Ontario plant) with soybean meal, both included at 6 and 12 % of dry matter to increase crude protein from 13% to 15 and 17%. Milk yield and milk components were higher on supplemental diets. No changes in organoleptic quality of milk from each ration were observed.

There is some evidence (8) yeast products may add a desirable flavor to milk through an unknown protective function or from the flavors generated and transferred from the yeast itself. Yeast products do not appear to have a detrimental effect on flavor, however, we cannot assume all yeast products will improve the organoleptic characteristics of milk (62). It is difficult to make a generalization since Besong et. al (8) and Steckley et. al. (62) used different yeast-based products.
Feed Intake and Weight Change.

Dry matter intake is a commonly measured variable in animal production. DFM supplementation may increase DMI and is one the possible explanations for increased milk production and weight gain. Adams et. al. (1) found that cows receiving YC had higher (P = 0.069) DMI than controls. In addition they found a correlation (r = .568) between DMI and milk production. Although the effect of YC supplementation on milk yield was greatest in the corn silage and alfalfa hay diet. In contrast, they did not find any significant difference in DMI for YC supplemented cows from commercial dairies.

Putnam et. al. (52) reported that YC tended to increase DMI and consequently increased intakes of organic matter, crude protein, NDF, ADF, and NSC. DMI increased 0.9 kg/d with YC supplementation. The authors concluded the primary way that YC appeared to stimulate milk yield was through a increase in DMI. In addition, the increase in milk yield and DMI only showed a tendency in the low protein group. Williams et. al. (72) reported that cows supplemented with YC increased (P ≤ .062) DMI by a mean of 1.2 kg/d. The authors concluded the increased intake was most likely responsible for the increase in milk yield. Dann et. al. (19) had reported that cows fed YC had an increased dry matter intake both the last 7 d prepartum (9.8 vs. 7.7 kg.) and during the first 42 d of lactation (13.7 vs. 11.9 kg.). Although milk production did not differ, YC supplemented cows did reach peak milk production quicker.
Mir et. al. (45) included YC (S. cerevisiae, 5 x 10⁹ organisms/g of Yea-Sacc, Alltech Biotechnology Center, Nicholsville, KY) at the rate of 10 g/day in three growing and finishing Hereford steer diets: 1) 75% alfalfa silage and 25% barley 2) 96% corn silage and 4% soybean meal or 3) 75% dry rolled barley and 25% alfalfa hay. The study was conducted over two years with different weaned steers. YC was given as a total mixed diet in yr 1 and top-dressed in yr 2. Although YC supplementation did not increase average daily gain, there were numerical increases in daily dry matter intake (g/kg BW).

Using ‘XP’ YC, Robinson et. al. (56) found cows of both parities supplemented with YC had numerically higher DMI. This finding may explain why the YC supplemented cows had numerically higher milk yield and milk components that were significant. The milk production values for the primiparous cows approached statistical significance. Arambel et. al. (3) found no mean daily DMI differences in those cows supplemented with yeast. This was consistent with the finding of milk yield and composition not being significantly affected by treatment. Wang et. al. (69) found during the first 30 DIM, DMI increased in the 21% forage NDF with YC group. From 31 to 140 DIM, YC had positive effects on DMI in the 21% forage NDF with the YC group. Feeding 17% vs. 21% forage NDF tended to increase DMI from 31 to 140 DIM. Olson et. al. (49) ruminally dosed 28.4 g/d YC (XP Yeast Culture, Diamond V Mills, Cedar Rapids, IA) to beef steers grazing from late June to early November on a mixed grass prairie. Organic matter intake was greater by YC-supplemented steers in June.
Although Kung et al. (42) reported some difference in milk yield after YC supplementation, DMI was not effected in either experiment. Soder et. al. (60) reported that yeast cultures with or without enzymes had no effect on DMI, which is consistent with no change finding in milk yield and composition. Wohlt et. al. (74) found significant increases in DMI during early lactation corresponding to increases in milk yield and numerical increases in DMI corresponding to numerical increases in milk yield post-partum. The increases were greater in the cows fed 20 g/d versus 10 g/d.

Besong et. al. (8) reported severely depressed feed intake in the basal TMR plus 15.5% liquid Y product and was discontinued. Even though they found some change in milk fat percent and a better milk acceptability score when the yeast supplement was provided at rate of 3%, there was no increase in DMI over the non-supplemented group. In fact, there was a linear effect of decreased (P < 0.001) DMI at the 7.5% level. This may confirm a possible 3% inclusion limit of this supplement. Although Herring et al. (31) found there was no change in milk yield or milk composition, supplemented cows receiving the DFM lost less weight (P<0.05) than control.

Varel et. al. (66) included a fermentative extract (A. oryzae, Amaferm, BioZyme, St. Joseph, MO) at a rate of 3 g/d in non-pregnant, non-lactating beef cows provided an alfalfa (13% CP) bromegrass (6% CP) hay diets. The extract was mixed with a soybean supplement. The fermentative extract did not affect (P > .10) feed intake. The lack of response may have been a lack of response from the extract to cause a change in intake. Another possibility is the product may have been more effective with another diet or at a
higher dose level. Most of the other products mentioned provided the supplement at a rate of 57 or 90 g/day. Similar results were found by Kreikemeier et al. (41), who included a fermentative extract (A. oryzae, Amaferm, BioZyme, St. Joseph, MO) at a rate of 2 g/d to steers fed a 53% corn stalk, 40%wheat middlings, and 5% sunflower meal diet. There was no change (P>0.22) in DMI in supplemented animals over control.

Coffey et. al. (15) included a fermentative extract (A. oryzae, Amaferm, BioZyme, St. Joseph, MO) to Angus and Angus-Hereford steers in order to see if the extract prevented the symptoms of fescue toxicosis. The steers received either Acremonium coenophilum fescue or bromegrass seed screening at a rate of 2.0 kg/d. In addition, they received a soybean hull supplement containing the fermentative extract provided at a rate of 2 g/d. The extract did not affect gain, DMI, or feed conversion. In addition, increases in body temperature due to fescue toxicosis, was un-affected by the fermentative extract supplementation.

Caton et al. (14) ruminally dosed A. oryzae (Amaferm; Biozyme, St. Jospeh, MO) at 2g/d to cannulated steers grazing cool-season pasture during June, July and August. Eighteen days of adaptation to the supplement and 7 days for collection were used. Forage OM intake was greater (9.7 g/kg BW vs. 7.7 g/kg BW) (P < 0.10) in supplemented steers.

Higginbotham et al. (32) included L. Acidophilus (Fast Start®; Trans Agra International, Inc. Storm Lake IA, 10 x 10^8 non viable cells/mL) at a rate of 6mL/d in their milk to new-born Holstein dairy calves. In another trial, Holstein calves were given one of three
treatments: 1) Control 2) *L. Acidophilus* and *Streptococcus faecium* (All-Lact 20®, 1 x 10⁹ viable cells; Alltech, Inc., Nicholasville, KY) at a rate of 1 g/d or 3) *L. Acidophilus* (Fast Start®; Trans Agra International, Inc. Storm Lake IA, 1 x 10⁸ non viable cells/mL) at a rate of 6 mL/d. Calves in both trials had access to a starter mix (19.06% crude protein, 5.88% crude fiber, and 2.4% ether extract on a DM basis) at d 2 of life. Trial 1 revealed no differences in average daily gain or calf starter intake between supplemented and unsupplemented groups. Trial 2 revealed calves tended to have higher gains in early stages of growth. Starter diet intake was higher for the nonviable fermentative product group than for controls.

**Digestibility, rumen volatile fatty acid (VFA) production, pH Changes and microbial stimulation.**

Much of the measurable changes in milk production, intake, gain etc. during DFM supplementation are due to underlying changes in the rumen environment. Some of the commonly examined mechanisms are the ability of a DFM to stimulate bacteria responsible for fiber digestion, buffer pH, and/or alter VFA concentration or ratios.

**Alltech Yea-Sacc.** Williams et. al. (72) found the extent of DM degradation of hay incubated in the rumen of steers fed the hay and rolled barley diet was increased (P < .05) in the presence of YC at 12 h of incubation, but degradation was similar in all treatments. There was also an increase (P < .05) in ruminal pH four hours after being fed to a YC supplemented steer provided a hay, barley (50:50) diet. The elevation was probably due
to a reduction ($P \leq .01$) in the concentration of L-lactate in the rumen. Steers supplemented with YC had no effect in VFA concentration, but acetate to propionate ratio was reduced ($P \leq .01$) from 3.3:1 to 2.8:1 in steers given YC. Using the same product, Putnam et. al. (52) found that the cows supplemented with yeast culture had no effects on ruminal pH, NH$_3$, and VFA. YC tended to increase the concentration of isobutyrate in the low CP diet and decrease the concentration of isobutyrate in the high CP diet. Mir et. al. (45) found yeast supplemented diets did not reveal any changes in DM digestibility or degradability, corresponding to no significant increases in daily gain or intake. There was also no change in VFA concentration or ratios.

Amaferm. Varel et. al. (66) reported that no effects on fiber degradation in situ, organic matter or fiber digestion and on VFA concentrations, pH, or NH$_3$ ($P > .10$). The DFM did not effect ($P > .10$) the total number of cellulolytic bacteria in cows fed either diet. However it did increase the proportion of *Ruminococcus albus* isolates from 21.7 to 33.3 % of the total cellulolytics. Amaferm increased ($P < .10$) the number of ruminal bacteria in cows fed brome grass but not those fed alfalfa. Using the same DFM, Firkins et al. (27) found supplementation tended to increase acetate:propionate ratios in the rumen and no effect on the extent of digestion. Kreikemeier et al. (41) reported that the enumeration of ruminal bacteria showed greater counts of cellulolytic bacteria. There were no changes in VFA and NH$_3$ concentrations, but isobutyrate was greater in steers supplemented with AO. Caton et al. (14) found in vitro DM digestibility was greater (65.2% vs. 59.3%) in supplemented steers. Ruminal total tract NDF and ADF digestibilities were greater in July in supplemented steers. Total, essential, and non-essential amino acid flows were
increased by supplementation and there was no effect on ruminal pH. Changes also seem to vary with season. Amaferm appears to stimulate cellulolytic organisms (41, 52, 72). Cellulose breakdown could increase total digestibility in the rumen and possibly stimulate more intake.

**Diamond V XP Yeast Culture.** Wiedmeier et al. (70) used *S. cerevisiae* culture (XP yeast culture, Diamond V Mills Cedar Rapids, IA) and *A. Oryzae* culture (Amaferm, Biozyme Enterprises, Inc. St. Joseph, MO) in three treatments: 1) basal diet (50& concentrate) 2) basal diet (plus *S. cerevisiae*); 2) basal diet (plus *A. Oryzae*) 4) basal diet plus both *S. cerevisiae* and *A. Oryzae*. Digestibility was increase by *A. Oryzae* and combination treatments. Increases of cellulolytic organisms were found in all extracts. Olson et. al. (50) found YC-supplemented steers had a greater in-vitro OM diaparance throughout the grazing season. Although there was some scattered evidence of increased NDF disappearance in YC-supplemented steers, overall NDF disappearance rate and lag time were not different from control. Supplementation with YC increased true ruminal OM digestion in late June and late July. Harrison et al. (30) added a live yeast culture supplement (Diamond V Mills Inc. Cedar Rapids, IA) to diets of lactating cows on 40% corn silage and 60% concentrate. Concentration of anaerobic bacteria concentrations and cellulolytic bacteria were higher in cows fed yeast and no changes were found in pH or VFA concentrations. Callaway et. al. (13) tested the effect of yeast culture (*S. cerevisiae*, XP yeast culture, Diamond V Mills, Cedar Rapids, Iowa) on lactate utilization and cellulose digestion. Yeast culture increased the concentrations of propionate and total VFA produced from *Selenomonas ruminantium*. *Megasphaera elsdenii* had no effect on
VFA production. Treatment with yeast culture increased the initial rate of cellulose degradation by *Fibrobacter succinogenes* and *Ruminococcus flavefaciens*. Yeast culture may provide soluble growth factors (i.e., organic acids, B vitamins, and amino acids) stimulating growth of ruminal bacteria that utilize lactate and degrade cellulose. Yoon et al. (75) added supplemental yeast (*S. cerevisiae*, Diamond V XP yeast culture, Diamond V Mill, Cedar Rapids IA) and fungal (*A. oryzae* extract; Diamond V Mills Inc.) cultures to cows fed a basal diet containing 32.5% corn silage, 17.5% alfalfa hay, 35.3% corn grain, 12.7% soybean meal, and 2% vitamin and mineral mixture. Treatment were divided into four groups: 1) basal diet, 2) basal diet + SC (57g/d), 3) basal diet + AO (3g/d), and 4) basal diet + SC + AO. The SC increased ruminal OM and CP digestibility and AO stimulated proteolytic and cellulolytic bacterial counts. Robinson et al. (55) included a YC (*S. cerevisiae* - containing $4 \times 10^7$ cfu/g, XP yeast culture, Diamond V Mills Inc., Cedar Rapids, IA) and found no treatment differences in prepartum or postpartum dry matter intake. The extent and rate of depression were also not different. There was a higher net energy intake than expected, which might be a result of increased digestibility.

**Other DFM’s.** Doreau et al. (23) examined the digestive effects of feeding Y (*S. cerevisiae*, CNCM I-1077, Institute Pasteur, Paris, France; produced by Santel Louverne, France) at a rate 0.5 g ($6 \times 10^8$ cfu/g) provided in a mineral and vitamin premix. The diet consisted of 60% corn silage, 24% concentrate, and 15% soybean meal. Digestive effects were measured for 12 days, with 23 days for adaptation. Total and ruminal
degradabilities of organic matter, ruminal protozoal numbers, pH, and volatile fatty acid concentrations were not modified by the addition of *S. cerevisiae*.

Other research includes the use or continuous cultures. Dawson et. al. (20) used continuous rumen cultures and in vivo feeding trials to examine the effects of two commercially available products on microbial stimulation. The supplement (Yea-Sacc) contained *Saccharomyces cerevisiae* (2.04 x 10^9 colony forming units [cfu]/g) and the other supplement (Lacto-Sacc) contained *S. cerevisiae, L. acidophilus*, and *Enterococcus faecium* (8.13 x 10^8 cfu/g, 1.3 x 10^8 cfu/g and 7.5 x 10^5 cfu/g, respectively). Concentration of viable yeast cells was increased in all continuous cultures and in the steers given a fescue-based diet. Concentrations of cellulolytic microorganisms in cultures and in steers received the yeast supplement were 5 to 50 times greater than those not receiving any supplement. Supplements that were heat-treated to inactivate the yeast cells did not alter the concentration of cellulolytic bacteria, suggesting the live yeast culture supplements stimulate the growth of cellulolytic microorganisms in the rumen. There were also no changes in relative concentrations of VFA in continuous cultures and in vivo. The pH tended (P = .13) to be greater in continuous cultures receiving yeast culture (Yea-sacc) in a fescue based diet. Using a different DFM (Biomate), Kung et al. (42) added YC to continuous cultures and found no effect on pH.

Newbold et al. (48) examined the use of different strains of *S. cerevisiae* (NCYC 240, NCYC 694, NCYC 1026, NCYC 1088 and Yea Sacc) on ruminal bacterial numbers in vitro and in the rumen of sheep. When grown in cultures, NCYC 240, NCYC 1026 and
Yea Sacc stimulated total and cellulolytic bacterial numbers. When in vivo (in canulated sheep), NCYC 1026 stimulated total bacterial numbers and NCYC 240 stimulated cellulolytic bacteria. Thus, differences do exist between different strains of *S. cerevisiae*. Strain 1026 appears to be the best at stimulating cellulolytic bacteria, which is one of the underlying mechanisms for increased digestibility and effectiveness of DFM supplementation.

Figure 2.1 is a summary of the proposed mechanisms for yeast culture responses in ruminant animals. Since yeast are facultative anaerobes, they can use oxygen within the rumen, thereby creating a more anaerobic environment. The anaerobic environment can stimulate the ruminal bacteria. The ruminal bacteria can work through three modes to enhance animal performance. First, it could stimulate the bacteria responsible for fiber digestion thereby increasing rumen flow, and possibly increasing intake. Second, by stimulating bacteria responsible for lactate utilization, yeast culture can increase and stabilize rumen pH. A review by Martin et al. (43) concluded that DFM supplementation also provides soluble factors that stimulate lactate utilization by *S. ruminantium*. Evidence was presented indicating that the malate concentration of *A. Oryzae* and *S. cerevisiae* culture may be involved in this stimulation. Third, stimulation of ruminal bacteria can lead to enhanced ammonia utilization and increased protein synthesis. Wallace (68) summarized the inclusion of live microbial cultures and their extracts (*S. cerevisiae* and *A. oryzae*) may increase bacterial viability by improving pH, changing VFA proportions, decreasing lactate production, stabilizing pH, increasing rate of cellulolysis, increasing microbial flow.
Carcass quality. There is some research examining DFM supplementation on carcass quality. As previously mentioned, Mir et. al. (45) included a yeast culture (*S. cerevisiae*, $5 \times 10^9$ organisms/g of Yea-Sacc, Alltech Biotechnology Center, Nicholasville, KY) at a rate of $10 \text{ g/day}$ in growing and finishing steers. Two separate experiment were conducted over two years. Supplementation with yeast culture did not alter carcass characteristics; however, carcasses of yeast fed steers were heavier than the controls in both years of the study. The grade fat (average fat over the 12th rib), loin area, and dressing percentage of YC fed steers were all consistently better in than those of control steers, but the effect was not significant. Unfortunately, research examining possible effects DFM supplementation on carcass quality is limited.

Health benefits. One major concern in beef cattle production is the stress that calves experience during transportation and placement in feedlots. Increases in stress can often lead to a greater likelihood of sick calves. Some research has focused on the potential for using DFM supplementation in preventive healthcare. Cole et. al. (16) included YC (*S. cerevisiae* - containing $2.0 \times 10^6$ cfu/g, XP yeast culture, Diamond V Mills Inc., Cedar Rapids, IA) in two experiments. The first included YC at a rate of 0 or .75% to steer calves provided a diet of 45% dry rolled corn, 29% cottonseed hulls, 5.0% alfalfa, and 14.0% cottonseed meal. Calves tended to maintain heavier weights and DMI when challenged with infectious bovine rhinotracheitis virus. Morbid calves fed yeast culture required fewer
(P < .05) days of antibiotic therapy. Higginbotham et al. (34) included 1.2 mL/d of a
direct fed microbial (Streptococcus faecium, L. acidophilus, S. cerevisiae, Bacillus
subtilis, and A. oryzae) - 8.8 x 10^8 cfu/g of lactic acid producing bacteria and 8.8 x 10^8
cfu/g of live yeast cells - Fastrak® Liquid Dispersible; Conklin Co., Inc. Shakopee, MN) in milk replacer for bull calves. There was no effect on Cryptosporidium parvum oocyst shedding, which is a common cause of neonatal diarrhea among calves.

DFM supplementation has also been examined in other situations in which health
problems arise. As previously mentioned, Coffey et al. (15) included a fermentative
extract (A. oryzae, Amaferm, BioZyme, St. Joseph, MO) at a rate of 2 g/d to Angus and
Angus-Hereford steers offered feedstuffs containing A. coenophialum. There was no
effect on the typical fescue toxicosis symptoms (i.e. higher temperatures) caused by the
fungus in a tall fescue based diet.

**SUMMARY**

There is a large selection of commercially available DFM supplements as well as many
unique production systems in which they can be applied. The following inconsistencies
and differences are some of the reasons it is difficult to compare and standardize positive
research findings.

1. **DFM supplement inconsistencies and/or lack of complete information.** Due to the
   availability of a variety of DFM supplements, comparisons between products can be
difficult. Each supplement is unique and produced under specific conditions. More than 1,000 strains of *S. cerevisiae* alone are listed in the American Type Culture collection catalog (ATCC, 1990) (5). Differences between two studies can be simply justified by differences in the DFM tested. The majority of the researchers reported the exact product and supplier used. However, comparison is difficult because researchers provided only generic or vague description of the supplement they test as well as vague descriptions of the quantity of the supplement, dosing method, and/or time the supplement was provided. Providing as much information on the product and how it was used is an important part of comparing a specific product with a specific response.

2. **Inconsistency in diet.** Animal diet varies between experimental designs. Because diet may be partly responsible for the effectiveness of DFM supplementation, it is important to know what diet was provided at the time of supplementation. Most researchers provide dietary analysis however; in some instances (i.e., pasture research), diet may be harder to assess.

3. **Variability in production environment.** The production environment in which DFM supplementation was tested may be an important role of assessment. Reviewed research varied from dairy operations, feedlots, and pasture. There was also research exclusively in the laboratory (e.g., in vitro or continuous cultures).
4. **Variability in test species.** DFM supplementation in different species must be considered when making generalizations. Variables such as age and level of production must also be considered.

5. **Measurement of dependent variables.** Measurement of the dependent variable may have varied from study to study. For example, was intake may have been measured using total collection techniques or estimated using markers. The difference created by an experimental technique could play an important part in a reported response.

**HYPOTHESIS AND OBJECTIVES**

Considering the diversity of possible interactions, the most practical approach in deciding whether or not to use a DFM may be just to include it in a suitable fashion for a specific production environment. Olson et al (49, 50) was one of the more substantial projects conducted on pasture. The majority of their work used ruminally cannulated animals being ruminally dosed with yeast cultures. However, there is little or no work examining the use of yeast culture as a free-choice supplement for the grazing animal. Since yeast culture is a light, flaky product, environmental conditions may make it difficult to effectively supplement the animals. Weather protected feeders may help reduce supplement loss; however, combining yeast culture with another supplement may be the best solution. A base supplement, such as a mineral-mix, can "hold" the yeast culture so the animal can ingest it. According to the manufacturer yeast culture can strengthen a mineral program in three ways: improve the palatability of minerals, helps maximize the
ration's nutritional value, and increase forage digestibility (63). They concluded animals supplemented with yeast culture resulted in increase in dry matter intake, increased rumen pH, and stimulation of cellulolytic and other rumen microbes.

The following set of experiments examined the effects of a commercially available yeast (S. cerevisiae) culture when provided in a free-choice mineral mix to beef cattle on a fescue-based pasture grazing system. It was hypothesized that yeast (S. cerevisiae) culture included in a free-choice mineral-mix would have a beneficial effect on beef cattle performance by increasing intake and digestibility. The increases in intake and digestibility may subsequently increase milk production at different times in lactation.

Using internal and external markers to estimate organic matter intake, DM digestibility and NDF digestibilities for animals on pasture provided yeast culture supplement in a free-choice mineral mix. In addition, ruminal dosed cannulated steers were used to estimate NDF degradability in situ. Milk production was also examined using a weigh-suckle-weigh technique for animals on pasture provided yeast culture supplement in a free-choice mineral mix. The primary objectives of this experiment were to test the hypothesis that yeast culture would increase NDF digestibility, OMI and milk yield while:

- Maintaining a natural grazing environment.
- Using a slow-release chromium capsule as an external marker and indigestible acid detergent fiber as an internal marker to estimate intake and digestibility.
- Using traditional techniques (weigh-suckle weigh) to estimate milk production.
Figure 2.1: The proposed mechanisms for yeast culture responses in ruminant animals.
CHAPTER 3

Effect of Yeast (*Saccharomyces cerevisiae*) Culture Included In A Free-Choice Mineral Mix On Organic Matter Intake and Digestibility In Beef Cows and Steers on a Fescue-Based Pasture

INTRODUCTION

There are several reports of increased dry matter intake (1, 16, 49, 52, 56, 72) and increased digestibility (13, 14, 68, 75) in beef and dairy cattle supplemented with yeast, yeast culture or other direct fed microbials. The majority of this work was conducted in dairy cattle in which the supplement was combined in total mixed ration (TMR). In these settings, dry matter intake and fecal output can usually be accurately recorded. However, the task of assessing dry matter intake and fecal output for animals on pasture is more difficult.

The goal of this experiment was to examine changes in intake and digestibility in beef cattle on pasture, supplemented with yeast culture, without interfering with normal grazing behavior. The assessment was accomplished using internal and external marker technology to estimate fecal output and organic matter intake.
MATERIALS AND METHODS

Twenty Angus and Angus-Hereford cows were used to evaluate the effect of yeast (Saccharomyces cerevisiae) culture provided in a free-choice mineral mix. Cows had access to free-choice CONTROL or YEAST mineral mix detailed in Table 1-1. The CONTROL group was provided the base mineral mix. The YEAST group was provided the base mineral mix with yeast culture (Diamond V XP, Diamond V Mills Inc., Cedar Rapids, Iowa) added at a rate of 25%. The inclusion rate was based on a 1-yr pilot experiment that found animals provided mineral-mix with yeast culture added, consumed more mineral-mix than those provided mineral-mix alone. The supplement (CONTROL or YEAST) was available in a weather-protected feeder and was provided to each group on a free-choice basis. The mineral mix was weighed and placed in the mineral feeder on a weekly or bi-weekly basis, depending on the need. Any mineral mix not consumed was weighed back and deducted from the amount supplied. In addition, any supplement deemed unsuitable for consumption was weighed and removed. Mineral mix intake was calculated and reported as a monthly average consumed per animal. Organic matter intake, organic matter intake (corrected for body weight), organic matter digestibility, and neutral detergent fiber (NDF) digestibility were measured and/or calculated. In addition, four ruminally cannulated Angus steers were used to evaluate In-situ NDF degradability. There were three 21-d experimental periods. One was conducted in winter (December) and two were conducted in summer (June and August). Mineral intake was also measured during and between the experimental periods. An additional experiment was also conducted to verify the release rate of the chromic oxide capsules.
Pre-Experimental Period.

The four Angus steers were surgically fitted with rumen cannulas. Cannulation techniques were approved by The Ohio State University Animal Care and Use Committee and were performed by a board certified veterinarian. All surgical techniques provided humane treatment and adhered to approved procedures of the Consortium (17). Post-operative care consisted of both topical and intramuscular administration of antibiotics. After surgery, steers were randomly assigned to CONTROL or YEAST mineral mix groups during the first experimental period and rotated in the subsequent experimental periods.

The cows were weighed over two consecutive days and distributed equally between two groups based on body weight (kg) and hip height (cm) ratio in order to equalize body condition. Both groups were allowed free-choice access to CONTROL or YEAST mineral mix (Table 4-1) for approximately 1 m prior to the start of the first experimental period (December). Body weights were taken before each experimental period and periodically in between winter and summer. The body weights taken prior to the experimental period were used to compare organic matter intake corrected for body weight. The body weights taken in between winter and summer were used for general herd health assessment only and not used as end points to detect differences between CONTROL and YEAST groups.

The steers were allowed to graze with the cows in the appropriate group. Both groups were on a rotational grazing program within the same grazing site to alleviate pasture effects. The pasture site was predominantly unimproved Kentucky-31 fescue (*Festuca arundinaceae*).
**Experimental Period.**

On d 1, each cow was introduced to its own 4-ha parcel of pasture allocated for grazing. The two groups were rotated every two days to alleviate pasture differences. On d 7, the controlled release chromium capsule (Captec™, Laverton, Australia) was administered using a balling gun. The gun was designed to release the capsule in the rumen of the animal. The administration of the capsule prior to the collection period allowed the chromium to reach a steady-state within the gastrointestinal tract. Starting on Day 17, the animals were gathered (one group at a time) and moved to the corral at different times of the day for fecal grab samples. The collection times varied each day to account for changes due to diurnal variation. For example, collection times were 0800 and 1400 on Day 17 and 1000 and 1600 on Day 18. There were at least two collections a day, including one night collection during the five day collection period. There was a target of 10 collections per animal. The actual number of collections varied per animal. Approximately 250 mL of wet feces were collected at each time point. The fecal samples were frozen until subsequent analysis. On Day 18, forage was collected from each of the designated grazing areas. Twenty random sections (3 m x 0.5 m each) of pasture were cut with a forage harvester and compiled. The forage was dried (55⁰C, forced-air oven) and ground through a 2-mm screen (Wiley mill, Arthur H. Thomas, Philadelphia, PA) for later analysis.

**Experimental Period: Steers.**

An In situ Dacron bag technique was used to determine NDF degradability in the rumen. On Day 1, the steers were combined and given access to one 4-ha parcel of pasture allocated
for grazing. They were dosed with CONTROL or YEAST mineral mix once a day. Daily ruminal dosing continued during the incubation period of the experiment. The amount of mineral mix administered was based on average herd group mineral mix consumption. On Day 10, forage was collected from the designated grazing area. Twenty random sections (3 m x 0.5 m each) were cut with a forage harvester and compiled. The forage was dried (55°C, forced-air oven) and ground through a 2-mm screen (Wiley mill, Arthur H. Thomas, Philadelphia, PA). Dacron bags (Ankom Technology, Fairport New York; 10 cm x 20 cm, 53 ± 10 μm pore size) were filled with approximately 5 g of dried, ground forage. For each time point, three bags containing forage and one blank were sealed with two #19 rubber bands.

Each set of bags was incubated in the rumen for 0, 2, 4, 6, 12, 24, 36, 48, 72, and 96 h. Starting on Day 17, bags were introduced to the rumen in reverse order (96 h first) except for the 0-h bags. All bags were held in a large nylon mesh bag (38 cm x 46 cm) fitted with a zipper. The 0 h bags were not introduced into the rumen. The bags were then individually washed and massaged under warm water until the water ran clear. All bags were frozen for later analysis.

**Bolus release rate verification.** Three rumen cannulated steers were used to evaluate the controlled release capsule. The entire capsule was uniquely identified and weighed using an analytical scale before administering to the rumen. The animals were given a ad-lib access to a fescue-based hay diet designed to mimic the forage and forage quality used during the experimental periods. At the conclusion of the trial (after 11d), the chromium
boluses were removed, and re-weighed. The weight disappearance was divided by time to give an average daily release of chromium.

**Laboratory Analysis.** After each collection period, the individual fecal samples were thawed and dried in a forced-air oven at approximately at 55°C. All fecal samples were individually broken up by hand and weighed at room temperature. The lightest sample collected (within animal) was considered the weight-limiting sample and set the limit for the rest of the samples within animal, across time. Equal proportions of oven-dried feces (set equal to the lowest amount within animal) were compiled over time and ground through a 2-mm screen (Wiley mill, Arthur H. Thomas, Philadelphia, PA).

The Dacron bags were thawed and dried (55°C, forced-air oven), dessicated, and weighed. Residual samples were removed from the bags and stored at room temperature until analysis.

All fecal samples and forage clippings were analyzed for dry matter (DM), organic matter (OM), and ash concentrations (4). The NDF concentration of the In-situ residue and all fecal samples was determined according to Van Soest et al. (65). Due to the nature of the samples, neither ethanol nor heat-stable α-amylase were required. All fecal samples were prepared for Chromium (Cr) analysis as outlined by Williams et al. (71). Chromium concentration was determined by atomic absorption spectroscopy (air-plus-acetylene flame).
Indigestible ADF (IADF) was determined by a 120-h in vitro fermentation at 39°C (28). Innoculum was taken from two ruminally cannulated cows after the a.m. feeding, blended for 30 s in a Waring blender and filtered twice through eight layers of cheesecloth prior to combining on an equal basis. Each triplicate sample was inoculated with 30 mL of the buffered ruminal media. Following 120 h of fermentation, samples were centrifuged at 1000 x g for 20 min. The supernatant was decanted off, and the residue pellet was dried at 55°C and analyzed for ADF (4). The filter paper and residue from the ADF analysis was also analyzed for ash concentration.

**Equations.** Equations used for this experiment can be found in Appendix A.

**Statistical design.** All organic matter intake, organic matter digestibility and neutral fiber digestibility data were analyzed using the MIXED procedure of SAS (58). Animal was used as the experimental unit. The data for all three seasons were combined and examined for treatment, season and tested for possible treatment x season interactions. Data was also observed within season for treatment, cow and cow within treatment. Computations associated with models used for in situ degradation rates were conducted using the non-linear procedure (Marquart Method) of SAS (58).

**RESULTS AND DISCUSSION**

The addition of the yeast culture at a 25% inclusion rate, to the control mineral mix (Table 3.1), reduced the total mineral and vitamin content. The mineral and vitamin concentration
in the YEAST supplement was not adjusted to the same concentration as the CONTROL supplement. The results from a 1-yr pilot study conducted prior to this experiment revealed yeast-mineral supplemented animals consumed more supplemental mineral mix than the animals provided mineral mix without the yeast included. Therefore, the intentional dilution was done to equalize mineral and vitamin intake between the groups, assuming the yeast-supplemented animals would consume more mineral mix. If mineral and vitamin intake was similar, the effect of yeast intake could be assessed without a possible confounding variable of increased mineral and vitamin consumption.

**Mineral Intake.** Figure 3.1 illustrates mineral mix intake data reported from December, 1998 to August, 1999. Consumption was based on monthly herd averages. Mineral mix consumption data were summarized and analyzed during and between the experimental periods. Monthly consumption was used as a repeated measure to detect differences in consumption between the two groups. Peak mineral-mix intake occurred in December for both groups and reached its lowest in June. Theses trends may have been due to weather conditions. December, 1998 was an usually warm month with forage still readily available to the cows and June, 1999 was an unseasonably warm month combined with regional drought conditions. The YEAST group consistently consumed more mineral mix for every month during and between the experimental periods. On average, the YEAST supplemented group consumed approximately 33% more (P < 0.01) mineral-mix compared to the CONTROL group. Although there were differences in mineral-mix intake between the two groups, individual mineral and vitamin intake was not different (P=0.43). The greater consumption in YEAST group did not result in increased mineral
and vitamin intake due to the fore-mentioned dilution effect in the yeast supplemented mineral-mix. On average the YEAST group consumed about 43 grams of yeast culture per day.

**Body Weights and Hip Height Measurements.** The herd was randomized and separated so there was no significant difference between CONTROL and YEAST groups based on the body weight to hip height ratio. The CONTROL group had a ratio of 3.75 compared to the YEAST group with 3.67.

**Cr₂O₃ Slow-Release Capsule.** Several studies have been conducted using slow release capsules to administer chromic oxide to animals (2, 9, 10, 11, 35, 51, 73). Using these capsules have substantial benefits for pasture research when knowledge of fecal output is desired. With fecal output and forage digestibility known, intake can be determined. There has been some research demonstrating the unreliability of the device (9, 10, 51, 73) and other research showing it to be reliable if calibrated for diet differences (2, 11, 35). Unreliability of the device was due to the actual release rate being different from the manufacturers suggested values. Release rate may vary because of diet differences.

The mean release rate from the chromic oxide capsule was determined to be 2.45 grams per day, with a standard deviation of 0.03 and a relative standard deviation of 0.01. This equates to 1.67 grams of Cr per day. Relative standard deviation was low enough to show consistency of the device. The mean release rate provided by the manufacturer was 1.46 grams of Cr₂O₃ per day. The differences in release rates can be explained by difference in
the species and animal diet in which it was tested. The difference (approximately 1 gram) could have drastically affected the estimated fecal output, and therefore organic matter intake and digestibility. Changes in diet can alter release rate. Therefore, bolus can be useful if one determines release rate for their particular environment.

**Organic Matter Intake (OMI).** OMI was examined in all three field trials (Table 3.2). Treatment was first analyzed within season. Although the YEAST group OMI was numerically higher in December and June, there was no (P>0.05) difference between the two groups. However, OMI (kg/d) was higher (P=0.04) in the YEAST group (5.69 kg/d) compared to the CONTROL group (4.79 kg/d) in the August trial. When intake was corrected for weight, OMI was also higher (P=0.02) in the YEAST group (11.6 g/kg BW) compared to the CONTROL group (9.0 g/kg BW) in the August trial. Other research (Adams et. al, 1994) with dairy cows fed a 50% concentrate diet and receiving similar yeast culture, showed an increase in DMI. In another study (Olson et. al, 1994) reported OMI was greater by YC-supplemented steers on a mixed grass prairie.

**Fecal Output.** There were no differences (P>0.05) in fecal output between groups (Table 3.2). Fecal output was not used to assess treatment differences, but used to determine organic matter intake.

**Apparent OM digestibility (OMD) and NDF digestibility (NDFD).** OMD and NDFD were also examined in all three field trials (Table 3.3). Although the YEAST group was numerically higher for OMD and NDFD in December and June, there was no difference
(P>0.05) between the two groups. Similar to OMI, OMD was higher (P=0.04) in the
YEAST group (27.2 %) compared to the CONTROL group (21.1%) in August. NDFD
was also higher (P=0.03) in the YEAST group (39.2 %) compared to the CONTROL
group (32.3%) in August. When OMD was analyzed across all seasons, there was a
tendency (P=0.18) for an interaction between treatment and season.

OMI, OMD, and NFDF were all higher in late August. Increases in these variables may
provide some indication of why increases in body weight and average daily gain were
observed in the late summer months. Since fecal output was not different between the
two groups, the differences in intake of organic matter indigestibility (based on the
IVDMD) must have been responsible. The feces from the YEAST group contained a
greater amount of indigestible material compared to the CONTROL group. More
indigestible feces could mean the cows from the YEAST group were able to digest more
compared to the CONTROL group.

The degree of responsiveness to the YC appeared to follow the NDF levels of the forage.
NDF levels were lower in December (52.4%) than June (55.7%) and August (59.7%).
Therefore, YC appeared to be more beneficial with lower quality fescue stands. Using the
same product, Olson et. al. (49) also found increases in OMI in the summer (late June)
and increases in OMD in late June and July. Although Caton et. al (14) used a different
yeast supplement, OMI and in vitro DM digestibility (%) were greater in supplemented
steers in July. All results may help strengthen one of the latter author’s conclusions that
these changes seem to vary with season. Seasonal changes in grass composition (increase
in fiber), along with weather change may increase the effectiveness of yeast 
supplementation during the summer months. Despite other obvious differences in study 
design such as dosing method (ruminally vs. free-choice), length of time of 
supplementation (few summer months vs. year round) and use of markers (ruminally vs. 
slow-release bolus), results are similar. Robinson et. el. (56) also found numerical 
increases in DMI using XP YC supplemented to dairy cows. Increases in intake were also 
found using other DFM supplements (1, 19, 52, 72).

**In Situ NDF Degradability.** Firkins (26) suggested it is not accurate to assume any wash 
out has from the bags at time 0 is assumed to have an infinite rate of digestion. Therefore, 
all bags were corrected for this factor. The summary of in-situ NDF degradability can be 
found in Table 3.4. NDF degradation was highest (~ 41%) in summer #1 and lowest in 
August (~ 24%). There were no treatment differences detected between the CONTROL 
and YEAST steers. This corresponds to the high NDF levels observed in the forage. 
Using the same product, Olson et. al. (49) found some instances of NDF disappearance. 
When looking at individual incubation times, however, they found no overall difference 
in NDF disappearance. Using a different YC product, Mir et. al. (45) also found no 
differences in NDF degradability.

The ability to detect differences may have been largely due to the small number of 
animals used to assess treatment effect. The steers were also ruminally dosed for three 
weeks compared to the cows that had longer free-choice access to the yeast mineral-mix. 
This time frame may not have been long enough for the rumen to adapt to the supplement
to create a significant effect. If there were indications yeast culture may increase
digestibility, a larger pool of ruminally-cannulated steers would be required to detect
small performance differences due to supplementation. Likewise, additional repeated
periods would also help increase the power of the analysis.
<table>
<thead>
<tr>
<th>Mineral</th>
<th>CONTROL</th>
<th>YEAST&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium, %</td>
<td>11.76</td>
<td>9.6</td>
</tr>
<tr>
<td>Phosphorus, %</td>
<td>6.86</td>
<td>5.18</td>
</tr>
<tr>
<td>Salt, %</td>
<td>22.54</td>
<td>16.32</td>
</tr>
<tr>
<td>Magnesium, %</td>
<td>3.92</td>
<td>2.88</td>
</tr>
<tr>
<td>Potassium, %</td>
<td>0.98</td>
<td>0.86</td>
</tr>
<tr>
<td>Copper, mg/kg</td>
<td>980</td>
<td>720</td>
</tr>
<tr>
<td>Zinc, mg/kg</td>
<td>3920</td>
<td>2880</td>
</tr>
<tr>
<td>Selenium, mg/kg</td>
<td>25.48</td>
<td>19.2</td>
</tr>
<tr>
<td>Vitamin A, KIU/kg</td>
<td>202.86</td>
<td>148.8</td>
</tr>
<tr>
<td>Vitamin D, KIU/kg</td>
<td>19.6</td>
<td>14.4</td>
</tr>
<tr>
<td>Vitamin E, IU/kg</td>
<td>431.2</td>
<td>307.2</td>
</tr>
</tbody>
</table>

<sup>a</sup> The yeast culture (Diamond V XP) was blended at a rate 1 to 4 (yeast:mineral).

**Table 3.1: CONTROL and YEAST Mineral Mix Composition (DM Basis).**
<table>
<thead>
<tr>
<th>Season</th>
<th>Organic Matter Intake (kg)</th>
<th>CONTROL</th>
<th>YEAST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>Average</td>
<td>SE</td>
<td>N</td>
</tr>
<tr>
<td>Winter</td>
<td>4.58</td>
<td>0.28</td>
<td>10</td>
</tr>
<tr>
<td>Summer #1</td>
<td>6.46</td>
<td>0.33</td>
<td>9</td>
</tr>
<tr>
<td>Summer #2</td>
<td>4.79</td>
<td>0.29</td>
<td>9</td>
</tr>
<tr>
<td>Combined</td>
<td>5.23</td>
<td>0.23</td>
<td>28</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Season</th>
<th>Organic Matter Intake (g/kg BW)</th>
<th>CONTROL</th>
<th>YEAST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>Average</td>
<td>SE</td>
<td>N</td>
</tr>
<tr>
<td>Winter</td>
<td>10.13</td>
<td>0.51</td>
<td>10</td>
</tr>
<tr>
<td>Summer #1</td>
<td>13.28</td>
<td>0.60</td>
<td>9</td>
</tr>
<tr>
<td>Summer #2</td>
<td>8.98</td>
<td>0.69</td>
<td>9</td>
</tr>
<tr>
<td>Combined</td>
<td>10.68</td>
<td>0.48</td>
<td>28</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Season</th>
<th>Fecal Output (kg)</th>
<th>CONTROL</th>
<th>YEAST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>Average</td>
<td>SE</td>
<td>N</td>
</tr>
<tr>
<td>Winter</td>
<td>2.15</td>
<td>0.11</td>
<td>10</td>
</tr>
<tr>
<td>Summer #1</td>
<td>3.90</td>
<td>0.17</td>
<td>9</td>
</tr>
<tr>
<td>Summer #2</td>
<td>3.76</td>
<td>0.20</td>
<td>9</td>
</tr>
<tr>
<td>Combined</td>
<td>3.24</td>
<td>0.18</td>
<td>28</td>
</tr>
</tbody>
</table>

Table 3.2: Summary of Organic Matter Intake and Fecal Ouput in Winter (December, 1998) and Summer (June and August, 1999).
### Organic Matter Digestibility (%)

<table>
<thead>
<tr>
<th>Season</th>
<th>平均值</th>
<th>SE</th>
<th>N</th>
<th>平均值</th>
<th>SE</th>
<th>N</th>
<th>P - Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>52.64%</td>
<td>2.18%</td>
<td>10</td>
<td>55.57%</td>
<td>2.51%</td>
<td>10</td>
<td>NS</td>
</tr>
<tr>
<td>Summer #1</td>
<td>38.88%</td>
<td>3.33%</td>
<td>9</td>
<td>43.24%</td>
<td>2.58%</td>
<td>10</td>
<td>NS</td>
</tr>
<tr>
<td>Summer #2</td>
<td>21.10%</td>
<td>2.56%</td>
<td>9</td>
<td>27.16%</td>
<td>1.42%</td>
<td>10</td>
<td>0.04</td>
</tr>
<tr>
<td>Combined</td>
<td>37.47%</td>
<td>2.80%</td>
<td>28</td>
<td>41.99%</td>
<td>2.49%</td>
<td>30</td>
<td>0.03</td>
</tr>
</tbody>
</table>

### NDF Digestibility (%)

<table>
<thead>
<tr>
<th>Season</th>
<th>平均值</th>
<th>SE</th>
<th>N</th>
<th>平均值</th>
<th>SE</th>
<th>N</th>
<th>P - Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>57.90%</td>
<td>2.32%</td>
<td>10</td>
<td>61.17%</td>
<td>2.14%</td>
<td>10</td>
<td>NS</td>
</tr>
<tr>
<td>Summer #1</td>
<td>48.12%</td>
<td>2.86%</td>
<td>9</td>
<td>51.36%</td>
<td>2.13%</td>
<td>10</td>
<td>NS</td>
</tr>
<tr>
<td>Summer #2</td>
<td>32.28%</td>
<td>2.28%</td>
<td>9</td>
<td>39.17%</td>
<td>1.25%</td>
<td>10</td>
<td>0.03</td>
</tr>
<tr>
<td>Combined</td>
<td>45.89%</td>
<td>2.36%</td>
<td>28</td>
<td>48.53%</td>
<td>2.54%</td>
<td>30</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Table 3.3: Summary of Organic Matter Digestibility and Neutral Detergent Fiber Digestibility in Winter (December, 1998) and Summer (June and August, 1999).
<table>
<thead>
<tr>
<th>Month, Year</th>
<th>Steer Number</th>
<th>CONTROL or YEAST</th>
<th>Estimated NDF Degradability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>(using EXCEL)</td>
</tr>
<tr>
<td>December, 1998</td>
<td>8316</td>
<td>CONTROL</td>
<td>33.19</td>
</tr>
<tr>
<td></td>
<td>7331</td>
<td>CONTROL</td>
<td>35.31</td>
</tr>
<tr>
<td></td>
<td>8314</td>
<td>YEAST</td>
<td>39.44</td>
</tr>
<tr>
<td></td>
<td>8319</td>
<td>YEAST</td>
<td>33.50</td>
</tr>
<tr>
<td>June, 1999</td>
<td>8316</td>
<td>CONTROL</td>
<td>41.58</td>
</tr>
<tr>
<td></td>
<td>7331</td>
<td>CONTROL</td>
<td>42.41</td>
</tr>
<tr>
<td></td>
<td>8314</td>
<td>YEAST</td>
<td>41.83</td>
</tr>
<tr>
<td></td>
<td>8319</td>
<td>YEAST</td>
<td>41.16</td>
</tr>
<tr>
<td>August, 1999</td>
<td>8314</td>
<td>CONTROL</td>
<td>25.06</td>
</tr>
<tr>
<td></td>
<td>8319</td>
<td>CONTROL</td>
<td>23.75</td>
</tr>
<tr>
<td></td>
<td>8316</td>
<td>YEAST</td>
<td>25.08</td>
</tr>
<tr>
<td></td>
<td>7331</td>
<td>YEAST</td>
<td>22.64</td>
</tr>
</tbody>
</table>

Table 3.4: Summary of In-Situ Degradability in Winter (December, 1998) and Summer (June and August, 1999).
Figure 3.1: Mineral mix consumption (grams/head/day) from December, 1998 to August, 1999.
CHAPTER 4

Effect of Yeast (*Saccharomyces cerevisiae*) Culture Included In A Free-Choice Mineral Mix On Milk Production and Calf Performance in Beef Cattle On Fescue-Based Pasture

INTRODUCTION

Milk production is a commonly measured variable in the dairy industry. Increases in milk production from animals provided yeast, YC, and other DFM supplement(s) have been frequently reported (1, 19, 52, 56, 59, 72). The volume of research may be in part due to the popularity of using these supplements in the dairy industry. Regardless, yeast or yeast cultures may elicit a measurable increase in milk yield or other milk variables. Besides milk production, there have also been reports of increased calf weaning weights (16) and others showing no change (32) in calf body weight and average daily gain in response to yeast or yeast culture supplementation.

Although measurable increases in milk production have been reported in the dairy industry with total mixed ration (TMR) diets, the goal of this experiment was to see if the same applies to beef heifers and cows provided yeast culture in a free-choice mineral
mix. Another goal was to record and analyze calf performance from those heifer and cows provided mineral-mix with or without the same yeast culture included.

MATERIALS AND METHODS

Calves born from the Angus and Angus-Hereford cows were used to determine the effect of yeast (*S. cerevisiae*) culture provided in a free-choice mineral mix. Cows and calves had access to free-choice CONTROL or YEAST mineral mix detailed in Table 3.1. Birth weight, average daily gain, weight change (from birth to weaning), weaning weight, and weight per day of age were recorded and/or calculated on all calves. The calves were also used to evaluate milk production. Calf performance and milk production were evaluated over two years.

**Calf Performance.** During calving season, the cow herd was checked at least once a day for new calves, and birth date and birth weight were recorded. The calves were periodically weighed until weaning to assess average daily gain and overall difference in weight from birth to weaning.

**Milk production.** In this experiment, milk production was measured using a weigh-suckle-weigh (WSW) technique. Weigh-suckle-weigh is a valid technique to measure milk production in the cow. Beal et al. (6) found a similar correlation between pre-weaning calf weight gain and dam's milk production estimated by WSW (*r* = .76) and correlation of milk machine (MM) estimates of milk yield and pre-weaning gain (*r* = .75).
They also found the repeatability of the estimated milk production by MM (.97) was higher (P<0.01) than by WSW. They suggested WSW is a valid technique; however, it can be variable. Benson et al. (7) also found more reliability in MM over WSW techniques in lambs, and they found milk production estimates determined using both techniques were similar (P=0.42). Rupert et al. (57) did not find much variability, but milk production estimates using WSW and MM were highly correlated (r=0.82).

The calves were used to evaluate milk production twice during lactation using a weigh-suckle-weigh technique detailed below. The first evaluation was done at approximately 60 days in milk, and the second was done at approximately 120 days in milk for the herd.

The cow-calf herds were already divided into CONTROL or YEAST groups. On each day of milk production evaluation, the calves in each group were separated from the cows for 8 h. After 8 h, one arbitrary group of calves was weighed and separated into six small pens. Each pen housed three to four calves. The cows were then sorted into the proper pens with their specific calf. The calves were allowed to suckle approximately 10-15 minutes, which on average was enough time for the calves to complete suckling. The calves were then quickly separated from the cows and re-weighed. The post-suckling weights were obtained quickly to minimize any loss in body weight due to defecation. Although excretion from the calf happened infrequently during the procedure, an attempt was made to collect and weigh feces if defecation occurred during the suckling procedure. The procedure was repeated for the second group of calves. The entire
procedure was repeated three times in a 24-h period. The three weight changes were combined and represent an estimate of milk production from the cow in a 24-h period.

**Experimental Design.** The experimental design over the two-year period as follows:

Pilot study. The cow/calf pairs were divided into two separate groups to test the WSW technique, and not used for data analysis.

Year 1. The cow/calf pairs were divided into 8 groups (4 CONTROL and 4 YEAST).

Year 2. The cow/calf pairs were divided into 6 groups (3 CONTROL and 3 YEAST).

**Statistical Design.** All calf performance and milk production data were analyzed using the GLM procedure of SAS (58). Animal group was used as the experimental unit. The statistical model over time (two years) included effects for treatment, year, group, group (year), and day in milk (year). Treatment x day in milk (year), treatment x year, and day in milk x year interactions were tested with both years combined. The same statistical model was used to analyze birth weight, weight change, weaning weight and weight per day of age for treatment effects.

**RESULTS AND DISCUSSION**

Since the cow-calf pairs were only divided into two groups in the pilot study, statistical analysis was not performed. The milk production estimate (over a 24-h period) on d 60
was numerically higher (7.1 kg) in the YEAST group vs. CONTROL (6.8 kg). YEAST was also numerically higher (6.0 kg) vs. CONTROL (4.6 kg) on Day 120. The pilot test did not have the statistical design or power to detect differences between control and treatment within year. However, test year was a successful test of the weigh-suckle-weigh technique. The technique proved to be a viable research tool to estimate milk production in a pasture environment. The numerically higher results of the YEAST group prompted a change to improve the experimental design for subsequent years. In order to detect differences in control vs. treatment groups, subsequent cow-calf herds were divided into smaller groups to serve as repeated measures. As Beal et al. (6) pointed out, WSW techniques were designed for practical on-farm use. It is less controlled than using MM, but by averaging measurement within a group, reliability could be improved. Starting with Year 1, pasture groups were used as the experimental unit and repeated measure (over time). The groups were maintained from birth to weaning within a single pasture. The pasture was large enough to provide ample forage throughout the season. Table 4.1 summarizes all three years of estimated milk production.

No interaction was found between treatment x year x day in milk (year) and also between treatment x year. There appeared to be an interaction between treatment and day in milk (P=0.19), therefore Day 60 and Day 120 milk production were analyzed separately.

In yr 1, Day 60 milk production estimate was not different (P=0.30) between CONTROL and YEAST groups. However, the YEAST group had (P=0.06) a higher (5.6 kg) Day 120 estimated milk production over CONTROL (4.3 kg). Since there was no interaction
between Day 60 and 120, both were combined. YEAST had a higher (P=0.05) milk production (6.5 kg.) over CONTROL (5.3 kg.). Although no significance was found in Day 60, the tendency of higher estimates from Day 120 helped make a combined value significant.

In yr 2, pasture groups were formed and maintained in the same fashion as Year 2. The only difference was using three larger groups per treatment instead of four smaller groups as in Year 1. For year 2, Day 60 milk production estimate was not different (P=0.64) between CONTROL and YEAST groups. However, similar to yr 1, the YEAST group had higher (P=0.05) milk production (6.3 kg.) over CONTROL (5.0 kg.). There was a tendency (P=0.20) for a treatment x DIM interaction. When Day 60 and 120 were combined, YEAST tended (P=0.08) to have a higher (6.9 kg.) milk production estimate over CONTOL (6.1 kg.).

Analyzing Day 60 over both years, the estimated milk production had a tendency (P=0.20) to be higher for the YEAST group (7.4 kg) compared to the CONTROL group (6.7 kg). However, analyzing Day 120 alone, the estimated milk production was higher (P=0.002) for the YEAST group (5.9 kg) compared to the CONTROL group (4.6 kg).

There were obvious differences in milk production estimates from Day 60 to Day 120, irrespective of treatment. Day 60 always had higher milk production estimates than Day 120, due to higher milk production early in the lactation cycle. The YEAST groups always had a numerically higher estimate of milk production, regardless of days in milk.
or year. Besides some tendencies of increased milk production at Day 60 of lactation, the
detectable differences were always found at Day 120 of lactation.

Using the same yeast product, Steckley et. al. (62) found dietary yeast cultures also
increased actual and 150-d-adjusted milk yields by 0.90 kg/d when fed in a TMR to dairy
cows at a rate of 57 g/hd over a 30-d period. This may be evidence to suggest yeast may
have a greater impact to milk production later in lactation. Robinson et. al. (56) also
found numerical increases in milk yield later in lactation from dairy cows using Diamond
V XP YC. Using Yea Sacc, Adams et. al. (1) observed increases in milk production
when cows fed forage compared to those fed grain supplements.

The animals used in this experiment were exclusively on pasture, with no grain
supplementation. This may be indicate yeast are more effective when the animal is
provided a forage diet. However, Williams et. al. (72) noted more responses in milk
yield in a 60:40 (concentrate:forage) diet. Putnam et. al. (52) found trends when using
44% forage diets.

The increases in milk production late in lactation in this experiment may have been due
to several factors. With an average calving month of April, the first weigh-suckle-weigh
would have done in late spring and the second weigh would have been done in late
summer (prior to calving). The cow may have been recovering from the stresses and
weight loss following parturition and early lactation. We also observed a higher OMI,
OMD and NDFD in late summer, which corresponds to the 120 DIM period. These changes in intake and digestion may be a likely explanation of increased milk production.

Although Cole et al. (16) reported calves maintained heavier weights when provided a similar yeast supplement, there were no differences (P>.20) between CONTROL and YEAST for birth weight, weight change, weaning weight and weight per day of age (Table 4.2, Table 4.3).
### Milk Production (kg) - Day 60

<table>
<thead>
<tr>
<th>Year</th>
<th>Average</th>
<th>SE</th>
<th>N</th>
<th>Average</th>
<th>SE</th>
<th>N</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>6.8</td>
<td>--</td>
<td>1</td>
<td>7.1</td>
<td>--</td>
<td>1</td>
<td>--</td>
</tr>
<tr>
<td>1999</td>
<td>6.3</td>
<td>0.7</td>
<td>4</td>
<td>7.4</td>
<td>0.8</td>
<td>4</td>
<td>0.30</td>
</tr>
<tr>
<td>2000</td>
<td>7.2</td>
<td>0.5</td>
<td>3</td>
<td>7.5</td>
<td>0.4</td>
<td>3</td>
<td>0.64</td>
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<tr>
<td>Total</td>
<td>6.7</td>
<td>0.4</td>
<td>8</td>
<td>7.4</td>
<td>0.4</td>
<td>8</td>
<td>0.20</td>
</tr>
</tbody>
</table>

### Milk Production (kg) - Day 120

<table>
<thead>
<tr>
<th>Year</th>
<th>Average</th>
<th>SE</th>
<th>N</th>
<th>Average</th>
<th>SE</th>
<th>N</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>4.6</td>
<td>0.5</td>
<td>1</td>
<td>6.0</td>
<td>0.5</td>
<td>1</td>
<td>--</td>
</tr>
<tr>
<td>1999</td>
<td>4.3</td>
<td>0.5</td>
<td>4</td>
<td>5.6</td>
<td>0.3</td>
<td>4</td>
<td>0.06</td>
</tr>
<tr>
<td>2000</td>
<td>5.0</td>
<td>0.3</td>
<td>3</td>
<td>6.3</td>
<td>0.3</td>
<td>3</td>
<td>0.05</td>
</tr>
<tr>
<td>Total</td>
<td>4.6</td>
<td>0.3</td>
<td>8</td>
<td>5.9</td>
<td>0.2</td>
<td>8</td>
<td>0.002</td>
</tr>
</tbody>
</table>

### Birth Weight (kg)

<table>
<thead>
<tr>
<th>Year</th>
<th>Average</th>
<th>SE</th>
<th>N</th>
<th>Average</th>
<th>SE</th>
<th>N</th>
<th>P - Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>31.4</td>
<td>--</td>
<td>1</td>
<td>33.1</td>
<td>--</td>
<td>1</td>
<td>--</td>
</tr>
<tr>
<td>1999</td>
<td>34.7</td>
<td>0.9</td>
<td>4</td>
<td>34.9</td>
<td>1.0</td>
<td>4</td>
<td>NS</td>
</tr>
<tr>
<td>2000</td>
<td>37.7</td>
<td>0.6</td>
<td>3</td>
<td>39.3</td>
<td>1.1</td>
<td>3</td>
<td>NS</td>
</tr>
<tr>
<td>Total</td>
<td>35.4</td>
<td>0.9</td>
<td>8</td>
<td>36.3</td>
<td>1.0</td>
<td>8</td>
<td>NS</td>
</tr>
</tbody>
</table>

### Weaning Weight (kg)

<table>
<thead>
<tr>
<th>Year</th>
<th>Average</th>
<th>SE</th>
<th>N</th>
<th>Average</th>
<th>SE</th>
<th>N</th>
<th>P - Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>205.1</td>
<td>--</td>
<td>1</td>
<td>217.1</td>
<td>--</td>
<td>1</td>
<td>--</td>
</tr>
<tr>
<td>1999</td>
<td>166.3</td>
<td>15.2</td>
<td>4</td>
<td>172.4</td>
<td>7.6</td>
<td>4</td>
<td>NS</td>
</tr>
<tr>
<td>2000</td>
<td>186.3</td>
<td>3.6</td>
<td>3</td>
<td>190.2</td>
<td>7.8</td>
<td>3</td>
<td>NS</td>
</tr>
<tr>
<td>Total</td>
<td>178.7</td>
<td>8.8</td>
<td>8</td>
<td>184.7</td>
<td>7.1</td>
<td>8</td>
<td>NS</td>
</tr>
</tbody>
</table>

Table 4.2: Summary of Calf Birth Weight, Weaning Weight, Weight Change, and Weight per Day of Age (1998-2000).
### Weight Change (kg/d)

<table>
<thead>
<tr>
<th>Year</th>
<th>Average</th>
<th>SE</th>
<th>N</th>
<th>Average</th>
<th>SE</th>
<th>N</th>
<th>P - Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>173.7</td>
<td>--</td>
<td>1</td>
<td>184.0</td>
<td>--</td>
<td>1</td>
<td>--</td>
</tr>
<tr>
<td>1999</td>
<td>132.3</td>
<td>14.9</td>
<td>4</td>
<td>137.7</td>
<td>7.4</td>
<td>4</td>
<td>NS</td>
</tr>
<tr>
<td>2000</td>
<td>148.6</td>
<td>3.4</td>
<td>3</td>
<td>150.9</td>
<td>8.2</td>
<td>3</td>
<td>NS</td>
</tr>
<tr>
<td>Total</td>
<td>143.6</td>
<td>8.7</td>
<td>8</td>
<td>148.4</td>
<td>7.1</td>
<td>8</td>
<td>NS</td>
</tr>
</tbody>
</table>

### Weight (per day of age) (kg)

<table>
<thead>
<tr>
<th>Year</th>
<th>Average</th>
<th>SE</th>
<th>N</th>
<th>Average</th>
<th>SE</th>
<th>N</th>
<th>P - Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>0.87</td>
<td>--</td>
<td>1</td>
<td>0.90</td>
<td>--</td>
<td>1</td>
<td>--</td>
</tr>
<tr>
<td>1999</td>
<td>0.92</td>
<td>0.06</td>
<td>4</td>
<td>0.90</td>
<td>0.03</td>
<td>4</td>
<td>NS</td>
</tr>
<tr>
<td>2000</td>
<td>0.93</td>
<td>0.04</td>
<td>3</td>
<td>0.92</td>
<td>0.02</td>
<td>3</td>
<td>NS</td>
</tr>
<tr>
<td>Total</td>
<td>0.914</td>
<td>0.05</td>
<td>8</td>
<td>0.908</td>
<td>0.01</td>
<td>8</td>
<td>NS</td>
</tr>
</tbody>
</table>

Table 4.3: Summary of Calf Birth Weight, Weaning Weight, Weight Change, and Weight per Day of Age (1998-2000) - continued.
CHAPTER 5

IMPLICATIONS

The goal of these experiments was to test the efficacy of providing a commercially available yeast (S. cerevisiae) culture (Diamond V XP YC) to beef cattle on fescue-based pasture. By mixing the yeast culture with a mineral supplement, it can be effectively provided on a free-choice basis. Animals consumed more mineral mix with the yeast culture included than those animals provided mineral mix alone. However, total supplemental vitamin and mineral intake were similar. Increases in organic matter intake, organic matter digestibility and neutral fiber digestibility were observed in late summer and correspond to the increases in milk production later (compared to earlier) in lactation. No changes were observed in calf performance. In conclusion, there is evidence to show providing yeast culture to grazing beef cattle is possible and may provide beneficial production responses, especially in the summer months.
LIST OF REFERENCES


active dry yeast supplement on performance of sows during gestation-lactation and 

Performance and nutrient digestibility in weanling pigs as influenced by yeast culture 
additions to starter diets containing dried whey or one of two fiber sources. J. Anim. 
Sci. 73:1381-1389.

Verlagsgesellschaft, Weinheim (Federal Republic of Germany).

Biomedical Press, Amsterdam, Holland.

fermentation characteristics of steers fed high forage diets supplemented with 

42 Kung, Jr., L., E. M. Kreck, R. S. Tung, A. O. Hession, A. C. Sheperd, M. A. Cohen, 
80:2045-2051.


44 Mathew A. G., S. E. Chattin, C. M. Robbins, and D. A. Golden. 1998. Effects of 
direct-fed yeast culture on enteric microbial populations, fermentative acids, and 

45 Mir, Z. And P. S. Mir. 1994. Effect of the addition of live yeast (Saccharomyces 
cerevisiae) on growth and carcass quality of steers fed high-forage or high-grain diets 

46 NRC. 1996. Nutrient Requirements of Beef Cattle (7th Ed.) National Academy Press, 
Washington, DC.

47 NRC. 1996. Nutrient Requirements of Dairy Cattle (7th Ed.) National Academy Press, 
Washington, DC.

Strains of Saccharomyces cerevisiae differ in their effects on ruminal bacterial 


Appendix A

Calculations

**Intake and Digestibility.** Fecal output was estimated using Cr as the external marker and
the following equation:

\[
\text{Fecal output (g/day)} = \frac{\text{Cr marker released (g/day)}}{\text{Cr concentration of the feces (g/g OM)}}
\]  

[1]

The indigestibility of organic matter was estimated using IADF as the internal maker and
the following equation:

\[
\text{Indigestibility of OM (\%)} = \frac{\text{IADF (in the feed)}}{\text{IADF (in the feces)}} \times 100
\]  

[2]

Using both the fecal output and indigestibility of the forage, organic matter intake was
calculated using the following equation:

\[
\text{OM intake (g/day)} = \text{Fecal output} \times \frac{100}{\% \text{ Indigestibility of OM}}
\]  

[3]

Organic matter digestibility is determined by:

\[
\text{OM Digestibility (\%)} = 100 - \text{Indigestibility of OM (\%)}
\]  

[4]

Using the indigestibility of the forage and \% NDF in the feed and feces, \% NDF digestibility
was determined using the following equation:

\[
\text{NDF Digestibility (\%)} = 100 - 100 \times \frac{\% \text{ IADF in feed}}{\% \text{ IADF in feces}} \times \frac{\% \text{ NDF in feces}}{\% \text{ NDF in feed}}
\]  

[5]

**In Situ NDF Degradability.** After incubation, Dacron bags were weighed individually
and consolidated within time point. Any residue present in the blank bags was
consistently negligible but deducted to account for any influx of residue or bacteria. NDF analysis (65) was performed on the residue at each time point. NDF degradability in the rumen is related to the amount of potentially digestible NDF, rate of digestion, rate of passage and lag time associated with the feed and rumen using the following equations:

The NDF remaining at each time point, in each bag =

\[ \text{NDF \% of the residue remaining} \times \text{total residue (g)} \]  

[6]

The NDF remaining in each bag =

\[ \text{Proportion Remaining (\%NDF) \times Average Residue} \]  

[7]

The NDF remaining (% of the original) at each time point was calculated using the following equation=

\[ 100 \times \frac{1}{\text{Original NDF in each bag}} \times \text{(1-(Original NDF in each bag - NDF remaining in each bag))} \]  

[8]

The potentially digestible % NDF remaining over time=

\[ \frac{\text{(NDF remaining (% of the original) at time t - NDF remaining (% of the original) at 96 h)} \times 100}{\text{NDF remaining (% of the original) at time 0 - NDF remaining (% of the original) at 96 h)} \]  

[9]

Wash Out or W = 100 - NDF remaining % of original NDF at 0h.  

[10]

Residue or R = NDF remaining % of original NDF at 96h.  

[11]

Potentially digestible or PD = 100 - W - R  

[12]
The natural log of potentially digestible NDF remaining (%) was calculated at each time point and plotted against time. Microsoft® Excel 2000 was used to generate the plot and equation of the line. The slope of the line is considered the \( k_d \) or the rate of digestion.

The lag was determined using the equation:

\[
(y\text{-intercept}) - (\ln \text{ of } \% \text{ potentially digestible NDF remaining at 0 h.})/\text{slope} \quad [13]
\]

The following model was used to determine the kinetics of digestion over time:

\[
NDF_t = PD \ e^{k_d (t-L)} + R \quad [14]
\]

\( NDF_t \) = percentage of NDF remaining at time \( t \), \( PD \) = the percentage of potentially digestible NDF, \( k_d \) = fractional rate of digestion of NDF in the PD pool, \( L \) = lag time, \( R \) = residual or the percentage of indigestible NDF.

The following equation was used to estimate the extent of ruminal degradation:

\[
NDFD = (PD) (k_d) \left( e^{(kp)(t)} \right) + \text{washout} \quad \frac{(k_d + k_p)}{[15]}
\]

\( K_p \) = is the fractional rate of passage of digesta or NDF from the rumen. \( k_p \) can generally range from 0.04 to 0.06 / h. The dairy NRC (47) provides an equation for estimating \( k_p \) using DMI (as a percentage of body weight). Since DMI was already estimated in this study, an established rate of 0.04 / h for fescue grass was used (12).