THESIS

# EVALUATION OF MANAGEMENT STRATEGIES TO IMPROVE EFFICIENCY AND SUSTAINABILITY OF BEEF AND DAIRY CATTLE OPERATIONS

Submitted by

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In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Summer 2016

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# ABSTRACT

## EVALUATION OF MANAGEMENT STRATEGIES TO IMPROVE EFFICIENCY AND SUSTAINABILITY OF BEEF AND DAIRY CATTLE OPERATIONS

In the beef production side, the single-calf heifer model (SCHM) was evaluated. This model harvests females after early-weaning their first calf, reducing average age and maintenance requirements of the herd, hence increasing biological efficiency of beef production. However, some issues have been associated with this model, primarily related to lack of self-sufficiency in producing the required replacements to maintain the system, and feedlot performance and carcass quality as a consequence of estrogens affecting behavior and weight gain, and accelerating bone ossification of females in comparison to steers, which might affect carcass value of SCHM females.

The objective of this study was to evaluate reproductive performance, feedlot performance, and carcass quality of primiparous females fed grain-based diets after early weaning their calves.

Fifty-three Angus-based yearling heifers (initial BW = 353 ± 38.8 kg) and a second set of 58 (initial BW = 307 ± 29.9 kg), were synchronized and inseminated at a fixed-time with sexed semen during first and second year of the project. Pregnancy rates of 41.2% and 45.6% determined 30 d after fixed artificial insemination (AI); and 90.2% and 91.2% 140 d post fixed AI, were obtained for sets 1 and 2, respectively. Additionally, 39.2% and 44.6% of the heifers remained pregnant to fixed-time AI; 47.1% and 33.9% of the heifers got pregnant either to the bull or second AI; and 13.7% and 21.4% of the heifers did not get pregnant, for first and second set, respectively. Overall, it was possible to produce an amount of weaned-females equivalent to 58.5% (set 1) and 56.9% (set 2) of the total annual requirement of replacements. Calves were early weaned at 106 ± 22 and 120 ± 21 d, with average weaning weights of 147 kg and 133 kg for years 1 and 2, respectively.

After weaning, first-calf heifers (43 each year) were fed for 88 and 90 d at a feedlot, with overall daily weight gains of 1.7 and 1.9 kg•d-1, and final weights of 662 and 619 kg, for sets 1 and 2, respectively. Average hot carcass weight (HCW) at harvest was 388 kg (set 1) and 365 kg (set 2); based on grading scores, the carcasses were sorted by overall maturity (OM) as < 300 or ≥ 300, with 34% of the carcasses classified as ≥ 300 or hardbones. Significant differences between the two OM groups were found for bone maturity (BM) ($P < 0.001$). However, no differences were detected for lean maturity (LE) ($P = 0.81$), marbling (MA) ($P = 0.39$), Warner-Bratzler shear force (WBSF) ($P = 0.96$), slice shear force (SSF) ($P = 0.29$), or cooking loss (CL) ($P = 0.47$).

After evaluating the SCHM it was estimated that at least approximately 41 – 43% of annual replacements would have to be purchased from external sources if 100% of female weaned-calves survive and are retained (assuming no dropping out of calves born in late calving season); and also 34% of carcasses from primiparous females were discounted as hardbones. However, more research needs to be done in this area, since it is expected that pregnancy rates can be improved and parameters might change after the system reaches equilibrium. Additionally, an earlier start of feedlot phase, innovative marketing strategies for the product, and different methods for estimation of age at slaughter, might help to compensate the high incidence of hardbone carcasses.

Dairy production also represents a very important activity in the U.S., which has evolved through the years into intensively selected and more productive cattle managed in larger average-size dairies with feeding systems based on mixed rations prepared at the dairy where feedstuffs are stored. In this context, efficiency of nutrient utilization becomes more important every day not only for financial but also environmental reasons.

A project was executed with the objective of estimating shrink of mineral supplement due to handling and storage in 5 dairies, and doing a deviation analysis to the amounts of ingredients loaded to the mixing wagon for diet manufacturing. Samples of mineral supplement and total mixed ration (TMR) were taken at each farm every day in the morning and the afternoon during the sampling period for analysis of nutritive composition.

For mineral supplement an average shrink of 1.97% was estimated ($P = 0.02$). Evaluation of shrink for individual nutrients showed no significant losses for Ca, P, Mg, Al and Mo. However, a significant shrink ($P < 0.05$) was estimated for crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), energy fractions (DE = digestible energy; ME = metabolizable energy; $NE_m$ = net energy for maintenance; $NE_g$ = net energy for gain; $NE_l$ = net energy for lactation), K, Na, S, Co, Cu, Mn, and Zn, during storage. Significant correlations ($P < 0.05$) were found between the slopes for change in concentrations of Na (-0.95), Mn (0.96), and Zn (0.98) in the mineral supplement during storage, and the concentration of those nutrients in the TMR.

Deviation estimates for TMR ingredients showed overall means of 5.61, 4.42, 0.87, and 0.64% for hay, high moisture by-products, premix, and corn silage, respectively. Additionally, significant correlations ($P < 0.05$) were estimated between deviation of hay and TMR concentration of: DM ($r = 0.50$), ADF ($r = 0.27$), NDF ($r = 0.39$), Mg ($r = 0.64$), TDN ($r = -0.27$), $NE_m$ ($r = -0.28$), $NE_g$ ($r = -0.27$), Mn ($r = -0.46$), and Zn ($r = -0.42$). Very similarly, corn silage deviation was correlated ($P < 0.05$) to: ADF ($r = 0.26$), NDF ($r = 0.27$), K ($r = 0.26$), and Mg ($r = 0.39$), TDN ($r = -0.26$), ME ($r = -0.25$), $NE_m$ ($r = -0.25$), $NE_g$ ($r = -0.27$), Mn ($r = -0.26$), and Zn ($r = -0.37$). In the case of high moisture by-products, their deviation was significantly correlated ($P < 0.05$) to TMR concentration of CP ($r = 0.34$), K ($r = 0.36$), Mg ($r = 0.5$), P ($r = -0.34$), and Na ($r = -0.33$).

Significant losses of mineral supplement due to storage and handling were found for the dairies evaluated, which means that those nutrients are going to the soil, water or components of the system other than the ration to be consumed by the cows. Additionally, lack of accuracy and precision in ration formulation was correlated to nutrient concentration of TMR, which might affect not only cattle performance but also excretion of some nutrients to the environment.

# ACKNOWLEDGEMENTS

First, I would like to thank my beautiful wife Ana and my lovely daughter Ana Lucía for their enormous support during my master's program and for being always very patient.

I would also like to express my gratitude to my advisor Dr. Archibeque for giving me the chance to work as his graduate student, I will always be grateful for this great opportunity for my personal and academic development.

Additionally I have to say thanks to the members of my committee, other professors, staff and students of the Department of Animal Sciences who helped me during my master's program; and particularly to Dr. Kevin Pond, Dr. Terry Engle, Dr. Noa Roman, Dr. Jason Ahola, and Dr. Karen Sellins, for their generous support and convenient advice.

# DEDICATION

*This is dedicated to my parents who showed me the value of hard work and perseverance, and to my wife and daughter who teach me every day the real meaning of love and teamwork.*

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# CHAPTER I

# REVIEW OF LITERATURE

## SINGLE-CALF HEIFER MODEL COMBINED WITH THE USE OF SEXED SEMEN AND EARLY WEANING

### *Overview of the current U.S. beef industry*

Traditionally, beef production in the United States has involved different segments of the industry operating somewhat independently from each other in order to fulfill beef demand. According to Field (2007), the main segments or types of enterprises involved in primary production of beef are: seedstock, cow-calf, stocker and feedlot operations; all of these precede the slaughter and final processing performed by the packing segment. The seedstock producers are specialized cow-calf operations, usually of purebred cattle, that produce breeding animals, semen and/or embryos to supply cow-calf producers with top genetic stock. The main objective of cow-calf operations is to get cows pregnant efficiently and optimize weaned calf production to retain ownership of some female calves as future replacements and in most cases sell the surplus of male and female calves to stocker and feedlot operations to gain extra weight and be finished on grain-based diets before being slaughtered at the packing plant.

According to recent estimations, total U.S. cattle inventory was 92 million cattle and calves of which 30.3 million were beef cows, 13.2 million were cattle on feed, and 9.32 million were dairy cows (NASS, 2016). Moreover, U.S. total beef production (commercial carcass weight) for 2015 was 25.8 billion lbs (NCBA, 2016). Dairy cattle genetic improvement and high performance have allowed for a reduction in dairy cows numbers in the last decades, having some influence in total cattle inventory as well. The increased daily weight gain of beef steers has caused a similar effect in the amount of cattle on feed; as a result of better genetics and the inclusion of technologies to improve performance (i.e. ionophores and implants), in addition to a heavier slaughter weight, total beef production has increased with a rather reduced inventory of cattle on feed.

The above mentioned factors indicate that beef production is a very important sector for the national economy, but also represents a large share of total cattle numbers in the U.S.; beef cows are nearly one third of total bovine population. Consequently, any improvement in management of cow-calf operations would likely have a positive impact in the cattle business.

### ***Environmental impact of traditional cow-calf operations***

Efficiency of bovine meat production has been subject to evaluation for many years. Most of the research in the past was devoted to evaluate reproductive performance of cow-calf operations and feed efficiency of both cow-calf and feedlot cattle. However, in the recent years a growing interest for more comprehensive analyses evaluating other factors in addition to productive aspects has led to a broader perspective of beef and other food production systems. Such analyses, through a life cycle assessment (LCA), take into account not only the productive and reproductive parameters of cattle, but the emissions and resources used from all phases in the product’s life cycle to estimate its impact on several categories such as: global warming potential, acidification and eutrophication, non-renewable energy use, land use, toxicity, biodiversity, etc. (Röös et al., 2013).

Despite the lack of agreement on the role that some categories such as energy use and biodiversity play on environmental impact of meat production, LCA estimations have pointed out the reduced efficiency in primary production of beef when compared to other types of meat and dairy products (Roy et al., 2012; Röös et al., 2013; Eshel et al., 2014). In this regard, grazing has been identified as one of the main factors affecting efficiency of beef production, by increasing greenhouse gas emissions and requirements of land, water and nitrogen (Eshel et al., 2014). However, it has been also recognized that land use for grazing takes advantage of lands that are not suitable for other purposes (Garnett, 2011).

Reproductive performance of the cow plays a key role in general efficiency of cattle production and environmental impact (Garnsworthy, 2004; Tamminga, 2006). In the case of beef cattle, the cow-calf segment represents the main grazing population of the whole sector, suggesting that improved management of the beef cow herds would be a very effective way to positively impact sustainability of the beef industry. According to Tamminga (2006), to limit losses of nutrients to the environment, the proportion of energy and nutrients devoted to maintenance should be minimized; also optimal reproductive performance is needed, so the number of replacement animals can be kept as low as possible.

In a study evaluating different rearing systems, Nguyen et al. (2010) estimated that the environmental impact of beef produced from suckler calves reared with their mothers was significantly greater in comparison to meat produced from dairy bull calves reared on milk replacers. According to the authors, the main reason for the observed differences, is the high amount of feed required to produce beef under traditional suckling systems. Moreover, they mention that the reduction trend in dairy cattle inventories as a consequence of improved milk yield, might increase the environmental impact of beef production.

### *Single-Calf heifer model (SCHM)*

As a consequence of normal fluctuations in cattle inventory and prices, beef markets possess a particularly implicit risk, which due to the structure of beef industry, makes cow-calf producers particularly vulnerable to those usual changes in the cattle cycle (Sell et al., 1988). Alternative beef production models including SCHM have been previously discussed by some authors in an effort to evaluate vertical integration by cow-calf producers as an alternative to just selling weaned calves (Bourdon and Brinks, 1987; Cartens et al., 1988; Sell et al., 1988). The interest in evaluating alternative ways of beef production arose from the need for increasing either efficiency or flexibility of cow-calf production and the beef industry in general. More recently, this approach has been gaining importance in times where efficiency is very important for animal production systems, not just for financial, but also environmental reasons.

In the SCHM no adult cows are maintained in the herd; instead calves are early weaned and all the primiparous heifers are fed a finishing ration and slaughtered. All the steer calves are marketed while the females are kept as replacements. Early weaning and a fairly short finishing period are crucial to guarantee a young enough slaughter age to prevent carcass discounts that could affect profitability of the system (Sell et al., 1988).

The fact that all the cattle in the herd are growing animals younger than 30 mo of age is probably the main advantage of the SCHM; however other benefits like no need to rebreed heifers and reduced generation interval should be mentioned as well (Seidel and Whittier, 2015). Based on the energetic requirements for beef cattle (NRC, 2000), it is estimated that a younger cow herd allows for a more efficient utilization of the energy consumed. A pregnant lactating growing heifer utilizes around 64% of the energy intake for maintenance, while an adult lactating pregnant cow spends approximately 77% of the energy just to maintain herself.

According to Carstens et al. (1988), in traditional beef production a substantial proportion of feed energy is utilized for non-productive purposes; nearly 50% of total energy required to produce beef is being used to fulfill maintenance functions of the cow herd. Theoretically, it means that implementing the SCHM makes it possible for a larger proportion of the total energy intake to be used for production, allowing for a partial substitution of the maintenance requirements of cows for growing requirements of heifers. Bourdon and Brinks (1987) estimated an increase in biological efficiency of beef production when age at culling was decreased, suggesting that a smaller proportion of the TDN intake is invested in maintenance-related activities of younger animals.

However, a series of disadvantages related to the adoption of a SCHM could negatively impact the feasibility and practical application of the model. Bourdon and Brinks (1987) found that biological efficiency of a system does not necessarily imply economic efficiency; they observed that despite the fact that a decreased age of culling improves energy utilization, culling cows at an older age was optimal from the financial standpoint. However, the dynamics in cattle market prices are a crucial factor to determine the optimal culling age for cows; therefore when the price for cull cows increases relative to fed cattle prices, younger culling ages can be advisable. Additionally, Seidel and Whittier (2015) mention that carcass discounts, increased dystocia problems, and lack of self-sustainability in terms of heifers replacement, are the main aspects potentially affecting the SCHM; discounted carcasses may be the most significant issue.

## **Carcass quality of single-calf heifers**

In regard to carcass quality, it has been reported that in comparison to steers, beef from heifers has a higher early calpastatin activity which inhibits the μ-calpain, retarding tenderization and promoting longer aging periods for female carcasses. Hormones also play an important role in meat quality; estrogen is involved in excitement and temperament that reduces tenderness of beef and increases incidence of dark cutters in females (Tatum et al., 2007). Moreover, estrogens accelerate bone ossification in primiparous females, influencing carcass grade (estimated maturity) and potentially affecting carcass value (Field et al., 1996). Oral supplementation of melengestrol acetate (MGA) to feedlot heifers has become a very common practice in feedyards to suppress estrus and reduce estrogen induced hyperactivity, which induces a calmer behavior and increases weight gain and carcass quality (Tatum et al., 2007).

Some studies have been published evaluating the influence of management practices on carcass traits of heifers. The effect of a previous gestation and calving on carcass traits is of particular importance because pregnancy hormones accelerate bone ossification; as a consequence, carcasses from animals that have calved once show more ossification and are more likely to be discounted as 30 mo or older, when compared to carcasses from virgin or spayed females of similar age (Waggoner et al., 1990; Field et al., 1996).

Prenatal androgenization of heifers has been evaluated within the context of the SCHM as a way to increase weight gain and counteract estrogen action in bone ossification of first calf heifers. It consists on an early exposure of female calves to androgens before they are born, which is carried out by implanting the pregnant cow with testosterone propionate during early gestation.

In terms of the future reproductive performance of the heifer, there has been some concern for the possible effects of early exposure to androgens during fetal development. Aldrich et al. (1995) evaluated the effect of prenatal androgenization in periparturient blood levels of reproductive and metabolic hormones of first calf heifers. No changes were found in blood levels of progesterone, estradiol, testosterone, prostaglandin-$F_{2\alpha}$, insulin, triiodothyronine (T3), and prolactin of androgenized heifers with respect to controls.

Increased daily gain and gain:feed ratio have been reported for prenatal androgenizated heifers managed under the SCHM (Reiling et al., 1995). However, early androgenization with testosterone propionate has not shown any effect on bone and carcass maturity of first calf heifers (Reiling et al., 1995; Hermesmeyer at al., 1999). Despite failure to retard the accelerated bone ossification in first calf heifers by early exposure to androgens, no difference in meat quality and palatability has been found between carcasses of first calf heifers and virgin females of similar age (Waggoner et al., 1990; Field et al., 1996).

Lawrence et al. (2001a) found dentition (number of permanent incisors) to be a more accurate method of sorting beef carcasses into more homogeneous age groups when compared to skeletal and lean maturity based evaluation. Additionally, they found that male carcasses were more likely to be misclassified into a younger age category when bone maturity was used as a criterion. Currently, the USDA carcass grading system takes into account bone maturity and/or dentition as indicators of physiological maturity to determine the 30 mo cutoff (Seidel and Whittier, 2015).

Bone ossification is not always a good predictor of physiological maturity for cattle (Semler et al., 2016), especially for females, since it has been shown that carcass overall maturity and bone maturity of heifers and cows does not accurately predict either chronological age or meat quality (Shackelford et al., 1995; Field et al., 1997). Similar conclusions have been obtained from the carcass quality and meat tenderness evaluation of steers and heifers classified as less than 30 mo old at the time of slaughter (Acheson et al., 2014). Others have reported that carcass traits account for only a small proportion of the total variation in tenderness of longissimus steaks (Lawrence et al., 2001b).

## Reproductive management for dystocia problems and production of replacements

A higher incidence of dystocia problems could be expected from SCHM as all parturitions will be from primiparous heifers, which is the reason why it is important to breed well developed heifers with bulls selected for calving ease (Seidel and Whittier, 2015). In a simulation run by Bourdon and Bricks (1987), they found an increase in overall dystocia incidence as culling ages decreased from 10 to 2 yr, as a result of greater number of first-calf heifers calving. Additionally, when modeling sex controlled systems in order to obtain as many females as possible, they found that despite an increase in the incidence of dystocia and calving losses, there was a compensation by the fact of few bull calves being born; however they also pointed out the increased labor and management under this type of systems.

As a consequence of longevity, the annual replacement rate of cows is fairly low in traditional cow-calf operations; however the SHCM is not a self-sustaining system as long as all the single-calf heifers are being slaughtered for beef production. One strategy to partially overcome the deficit of replacements, is to use sexed semen as has been previously suggested by others (Ereth et al., 2000; Seidel and Whittier, 2015).

The basic technology for sexing sperm was originally developed at the US Department of Energy's Lawrence-Livermore Laboratory in California back in the early 1980s (Seidel, 2014); through the years the process has been improved to increase efficiency and reduce damage to the sperm (Seidel, 2007). However, the flow cytometry/cell sorting procedure to select good quality sperm of the desired sex is a time consuming, expensive process that discards most of the sperm (undesired sex, low quality sperm, and other technical factors) to produce a sexed dose. Consequently, for the technology to be feasible, sexed semen doses are commonly packaged at a much lower concentration than unsexed semen (only 2 million sexed sperm per dose), which together with the damage to sperm during the sorting process, results in lower fertility of sexed semen in comparison to unsexed semen (Seidel, 2014).

Although the main use of sexed semen in the U.S. has been for artificial insemination of dairy heifers to produce female calves (Seidel, 2014), some research has also evaluated the insemination of beef heifers with sexed semen. Seidel et al. (1999) reported pregnancy rates for sexed semen to be 70 - 90% of those obtained using unsexed sperm controls as part of 11 independent field trials, 7 of them performed with beef breed heifers. They explain that such results were obtained under specific conditions of well managed heifers and well trained inseminators, which are determinant factors for the success of any artificial insemination program, and might be considered even more important when sexed semen is used, since higher cost and lower fertility of sexed sperm make it indispensable to execute very good management to obtain adequate performance.

Sperm concentration and site of deposition have been evaluated for sexed semen as well, with no increase in pregnancy rates when semen doses ranging between 1.0 and 6.0 x $10^6$ total sexed sperm were deposited either in the body or the horns of the uterus of dairy and beef females (Seidel and Schenk, 2008). Average pregnancy rates at day 60 post insemination for Angus females (mostly heifers, one trial with cows), were approximately 70.4% and 55.9% for control unsexed and sexed sperm, respectively; fertility of sexed semen was approximately 80% of the control unsexed doses with a dose of 2.0 x $10^6$ sperm.

Riggs (2001) evaluated the inclusion of sexed semen into a SCHM in two consecutive sets of Red Angus X Hereford females. In sets 1 and 2, they bred 46 and 48 heifers to sexed semen while fed in a feedlot. Heifers of sets 1 (341 ± 28 kg) and 2 (348 ± 32 kg) were synchronized and fixed time mated to sexed semen; 19% and 8% of the heifers were pregnant after the first fixed time service; subsequently heifers were inseminated one to three times before matting by a bull. After the end of breeding season, overall pregnancy rates achieved by heifers of years 1 and 2, were 58 and 16%, respectively.

Additionally, in the second set of heifers only two thirds of the females were bred to sexed semen and the rest were inseminated with regular unsexed semen. Nevertheless, the data published on reproductive performance corresponded exclusively to the first year set where heifers were bred to sexed semen for the 2 first inseminations, randomly assigned to sexed or unsexed semen for third insemination and bred to the bull for the fourth service. This protocol allowed for 69 and 60% of female calves out of heifers pregnant by sexed semen and total calves born, respectively. No specific reasons were attributed to such low pregnancy rates obtained in both years; however, Riggs (2001) mention that perhaps a combination of low dose insemination straws and very young age of heifers at breeding might have affected their performance.

Therefore, as long as proper management is provided to guarantee the successful implementation of a technique that will increase costs and labor, the inclusion of sexed semen into the SCHM may allow producing most of the heifer replacements needed every year. However, the impossibility to get all the heifers pregnant, plus normal calf losses, impede the system to be completely self-sustaining; it is estimated that approximately 20-30% of the replacements must be added to the system from outside each year if sexed sperm is used (Seidel, 2015).

## **Early weaning of beef calves**

Early weaning has been previously evaluated in beef cattle production, mostly as a way to improve reproductive performance of the cows through a faster return to ovarian activity, allowing reductions of the interval between weaning and conception. Houghton et al. (1990) found early weaning (30 d vs 7 mo) allowed improvement of the reproductive efficiency of Charolais X Angus mature cows when forage and feed sources are not sufficient to support lactation requirements. Peterson et al. (1987) evaluated the effect of early weaning (110 d vs 220 d) on cow and calf performance, and found significant differences in cow BW change between early and normal weaning; early weaned cows gained weight while normal weaned cows did not meet their energy requirements and lost weight during the same period; however, age of the dam interacted with BW and BW change during and after weaning.

The study of possible effects of alternative early weaning management has been of particular interest in the evaluation of subsequent reproductive management of first-calf heifers, since they are younger, growing animals with higher nutritive requirements, which make them more susceptible to a retarded return to reproductive activity after weaning. Arthington and Kalmbacher (2003), found that early weaned heifers were heavier at the time of normal weaning, and had improved body condition and higher pregnancy rates in comparison to traditionally weaned heifers. Lusby et al. (1981) found an increase in conception rate from 59.4 to 96.8%, and a reduction in the interval from parturition to conception from 90.5 to 73 d, as a consequence of early weaning.

Some studies have also evaluated the effect of early weaning in subsequent performance of steer calves and their final carcass quality. Peterson et al. (1987), observed that first 28 d after weaning, early weaned calves had a reduced weight gain in comparison to normally weaned calves, probably due to stress of weaning; however, afterwards early weaned calves gained weight faster. Grimes and Turner (1991) compared performance of Shorthorn X Angus X Hereford calves weaned at 110 vs 220 d of age, observing that early weaned steers had a greater weight gain from normal weaning age to slaughter, and were heavier at the time of slaughter in comparison to calves weaned at normal age. No differences between treatments were observed for carcass traits. Arthington et al. (2005) evaluated two weaning ages: 89 and 300 d, finding that at normal weaning age, early weaned calves had lower BW (221 vs 269 kg); however, gain:feed ratio for the overall period between 300 d of age and slaughter was improved for the early weaned steers. Additionally, carcass traits did not differ between weaning treatments. Myers et al. (1999) reported not only increased feed efficiency when early weaning was performed, but also improved quality grade of carcasses of steers.

According to previous findings on the effects of early weaning on following calf performance, it appears that similar results can be obtained from early and normally weaned calves. However, the quality of the ration fed to early weaned calves plays a key role, not only on their performance, but also on the feasibility of the management strategy as a whole.

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# CHAPTER II

## REVIEW OF LITERATURE

## ESTIMATION OF MINERAL SUPPLEMENT SHRINKAGE AND INGREDIENT DEVIATION ANALYSIS OF TOTAL MIXED RATIONS IN DAIRY FARMS

### *Overview of U.S. dairy industry*

Historically, the dairy industry has represented a very important sector of the U.S. economy, which has been propelled by the development of research, technology and general improvements at the farming level that have been key factors for promotion of the evolution of dairy industry to what it is today.

In accordance to NASS (2016) estimates, total milk production in the U.S. during 2015 was close to 95 billion kg, representing an increase of 1 billion kg compared to 2014 when the approximate value of total milk produced was close to $50 billion. However, the U.S. dairy industry has been through a very dynamic evolution with dramatic changes in cattle numbers and productivity. Statistics of NASS (2016) show that in 1924 a total of 40 billion kg of milk were produced by 21.4 million cows; meanwhile, by 2015 the population of dairy cows was estimated to be less than a half of that (9.3 million head) and produced more than double the milk (95 billion kg). These data indirectly show how selection of cattle for milk production and improvement of management practices such as improved nutrition and feeding, have resulted in an average fivefold increase in individual milk production throughout a period of approximately 90 yr.

Besides the increase in cow productivity, the dairy industry has also experienced significant changes in farm structure. In the past, the majority of the dairies were small family-operated type of farms; however, the proportion of large dairies has been increasing during recent decades. MacDonald et al. (2016) mention the midpoint herd size as a parameter that splits the national inventory such that 50% of the cattle are in smaller herds and the other 50% are in larger herds. They comment that back in 1987 the midpoint herd size for US dairy farms was 80 cows, however, by 2012 this midpoint had increased more than tenfold. According to MacDonald et al. (2007) by 2000 only 19.3% of the inventory was owed by large farms having more than 1000 cows; however, in 2006 that percentage increased to 34%. Moreover, during the last decade large dairies have become even larger, and it was estimated that in 2012 approximately 49% of the inventory was held in dairies with at least 1000 cows (MacDonald et al., 2016). Such evolution has modified the average farm model from a predominantly family owned and operated entity, to a much larger and technified type of farm with a large number of employees who very often are trained to assist with semi-automated processes, which allow more efficiency in general management.

Evolution of dairy farming has also involved very important changes in feeding practices. Definitely a cow producing 5 times more milk than its past century counterpart, has a significantly increased demand for nutrients and requires a much more nutritive diet, which has promoted feeding systems that offer total mixed rations to confined cows as a strategy to reduce energy expenses related to physical activity and increase digestibility of diets. Such feeding management faces the challenge to increase feed and nutrients consumption as much as possible in order to support milk production and prevent excessive negative energy balance typical of high producing cows (NRC, 2001), which might affect not only productive but also reproductive performance.

Increase in farm size has brought new challenges and issues to the industry, since precision in management practices is essential for the feasibility of the business. Additionally, the increase in financial risk in dairy farming during the past decades has been reported, mentioning the variations in milk prices as a very important driver of the risk (Mac Donald et al., 2016). However, milk prices are extrinsic factors that cannot be controlled at the farm, which highlights the importance of focusing on the factors that can be controlled and have a positive impact on farm efficiency. In this sense, feeding costs of dairy farms have been reported as 50 – 70% of total operating costs; consequently, management strategies have been presented as an effective alternative to reduce financial risk of dairy farms by implementing changes in feeding practices (Bozic et al., 2012).

Legislation has also been changing to better control and regulate new issues associated with larger size of farms and intensification of productive systems. In this context, U.S. EPA (2004) defines a concentrated animal feeding operation (CAFO) as an animal feeding facility having more than 1000 animal units, where animals are present for at least 45 d. Smaller facilities could also be classified as CAFO's based on their potential of discharging pollutants to the waters. Furthermore, a CAFO does not produce or store crops, which means that waste management and disposal should be carefully planned to prevent excessive accumulation of nutrients in the soil and contamination of the water sheds. Wastes should be properly collected and treated in lagoons or storage tanks to reduce microbial charge and organic matter before the residual waters can be disposed. Composting wastes is another common alternative allowing to reduce microbial charge; however, resulting compost should be transported and applied to crop fields as a fertilizer so the remaining nutrients can be utilized.

Both increased financial risk and environmental concerns and related regulations, are important factors that have been pushing dairy farms and other CAFO's to improve precision of their feeding systems in order to reduce not only feeding costs but also the investment for treatment and disposal of wastes.

Modern large-size dairy farms have implemented feeding systems including purchase, storage, and mixing of commodities as a strategy that allows not only reduction of feeding costs, but also customizing rations as desired, also having the flexibility to include new ingredients in the ration when it represents a good opportunity (Standaert et al., 1994). In this context, both commodity shrink (from handling and storage) and consistency of the nutrient composition of the ration are very important factors that influence feasibility and precision of the overall feeding system.

### *Commodity shrinkage in cattle operations*

Shrink of feeds or ingredients is defined as the amount of feed that is purchased and delivered at the farm, but not fed to the cows; these losses can occur during storage or during mixing and transportation, and can be due to weather conditions or as a consequence of rodents or birds. Multiple factors can influence feed shrink, most of them related to intrinsic characteristics of the feed and to management conditions like storage, handling and mixing. (Standaert et al., 1994; Loy, 2010).

A wide range of shrink values have been reported in the literature for the most common commodities used at dairies and feedlots, most of them within the ranges of 1 – 20% for dry ingredients and 20 – 40% for wet feeds stored under different conditions (Standaert et al., 1994;

Loy, 2010; Kertz, 1998). Nevertheless, very little to no information is provided on how these estimates were obtained, and most of the times only the values are reported with no specifications on the particular conditions for the estimation.
Most of the time it is not specified if the shrink estimate provided is expressed on a wet or dry basis. Additionally, the limited commodity shrink data available in the literature refer to silage, hay, grain commodities, or co-products of different industries (mostly ethanol and beer industries) either dry or wet, but no data have been published in regard to shrinkage of mineral supplements.

Standaert et al. (1994) provide a list of percent shrink and spoilage losses during bulk storage and handling of multiple feedstuffs under different storage conditions. According to the same source, under storage conditions in open uncovered piles, the highest losses correspond to distillery by-products (either brewers or ethanol) ranging from 12 to 22% for dry by-products and from 15 to 40% for wet by-products. Chopped alfalfa, middlings, soy hulls and beet pulp are listed with similar percent losses between 10 and 22%; and dry grains are mentioned as the feed category with the lowest losses (5 to 8%). It is also pointed out how storing the same feedstuffs in covered three sided bays might reduce shrink up to 70% for middlings; 50 – 60% for chopped alfalfa, beet pulp, dry distillers and soy hulls; 15 – 30% for dry meals and dry grains, and no reduction is reported in the case of wet distillers. Additionally, when these feeds are stored in closed bunk tanks, the losses range between 2 and 6% regardless of the feedstuff.

Loy (2010) provides shrink values for typical feedstuffs included in feedlot diets, reporting values of 2 – 4% for dry commodities, 8 – 9% for soybean meal, 4 – 10% for chopped alfalfa, 15 – 20% for wet brewers grains, and a large range between 5 and 50% for corn silage.

When evaluating shrinkage it is very important to consider moisture of feedstuffs. Normally, feed ingredients are purchased on a wet basis; however, their inclusion in rations is calculated on a dry basis formulation (Harner et al., 2011). In an evaluation of a model to estimate costs for dairy commodity programs, Standaert et al. (1994) run simulations under different scenarios including the effect of shrink on cost per ton of mixed feed, and by increasing shrink from 2% to 7%, they estimated a percent increase in total cost of feed ranging between 1.5 and 5.2%.

### *Variation in composition of feedstuffs*

Another factor influencing precision of feeding systems and nutrient utilization is the variation in composition of the feedstuffs. It is important first to consider that feed composition is estimated by analyzing the composition of a sample at the laboratory; therefore, inherent variation of the feed (biological and manufacturing variation), variation caused by sampling procedures, and variation from analytical methods, all contribute to total variation allowing the actual composition of the sample to differ from the average. Such variation in composition can be expressed as the standard deviation (SD) which is a measure of dispersion that indicates the distribution of the values; additionally SD can be expressed as a percentage of the mean, giving as a result the coefficient of variation (CV). The smaller the CV, the less likely it will be that using the mean value for any nutrient concentration will cause a substantial error in diet formulation (Weiss, 2005).

Handling variation in feed composition would depend on the type of process that generates the feed. Most of feed commodities are considered as an outcome of batch processes, which are handled in lots such as trucks, and usually have a small within-lots variation, and a small to large between-lots variation; therefore such commodities are not expected to be analyzed routinely and a mean derived from a large number of samples of different batches may be more adequate for ration formulation. However, some feedstuffs are the outcome of continuous processes, in such cases the processes are relatively constant, but there might be other factors like nutritionally heterogeneous particles which could make the composition of the sample vary depending on the proportions of different types of particles present in the sample, as would be the case of corn silage. For continuous process feedstuffs it is recommended to take periodic samples and reformulate the ration with the most recent data (Weiss and St-Pierre, 2009).

Weiss et al. (2012) evaluated within-dairy variation in nutrient composition of common feedstuffs in 50 dairies, finding that within farm variation for specific feeds differs widely among farms, concluding that sampling schedules should be defined specifically for each farm. In the case of corn silage and haycrop silage, a very large day to day variability was found, suggesting that formulation based on composition of single samples might not be the best approach; average results from 2 or 3 samples taken within a short period of time (1 - 2 wk) would provide a better estimate of composition.

### ***Variation in composition of TMR***

Uncertainty of nutritive concentration of a TMR ingredient is defined as the summation of the imprecision for every measurement required to estimate concentration of any nutrient in a given ingredient included in the TMR, which involves 3 possible sources of imprecision: ingredient amount, ingredient DM content, and concentration of the nutrient being evaluated. Therefore, in terms of diet formulation, deviation or uncertainty in nutrient composition may result from weighing errors, errors and variations in the DM content of the ingredients, and errors and variation in nutrient sampling and analysis. Consequently, uncertainty in amount of ingredient has a greater effect when an ingredient has either high DM or nutrient content; similarly, uncertainty in ingredient DM content has a greater effect when larger amounts of the ingredient are included in the ration or when the nutrient concentration of the ingredient is very different than that of the ration; also, uncertainty of the nutritive concentration of the ingredient has a greater effect when larger amounts of the ingredient are in the ration or when the DM content of the ingredient is high (Buckmaster and Muller, 1994).

Buckmaster and Muller (1994) evaluated the use of uncertainty analysis in nutritive measurements of mixed rations for dairy cattle. They found that improving measurement of nutrient concentrations and amounts of ingredients for feedstuffs having a high nutrient concentration would be the best approach to reduce variability among batches. Additionally, they estimated that by controlling amounts of ingredients within 1% it would be possible to keep uncertainty in nutrient concentrations of the TMR lower than 5%.

Based on the aforementioned information, the lack of accuracy and precision in TMR composition can be attributed primarily to variation in composition of ingredients and operator errors. Buckmaster (2009) mentions that different factors such as: ingredient mixing sequence, mixing time, mixing protocol, DM content of feedstuffs, and scale maintenance and calibration can affect mix uniformity by increasing variation among different batches.

Modern dairies have implemented systems to reduce the chance of operator errors, with computerized scales displaying the sequence of ingredients and indicating the exact amount of every ingredient required for the batch being mixed, which helps standardizing an important part of the mixing protocol. However, additional controls need to be implemented to evaluate and improve performance of operators. James and Cox (2008), evaluated operator error in 10 different dairies by comparing accuracy of loading and delivery information obtained from the

TMR software. As usual in most of the dairies, there were at least 2 or 3 people in charge of ration mixing and delivery on every farm; interestingly in most of the cases they found that secondary feeders had superior performance than primary feeders (performing mixing and delivery more than 75% of the total time), which was attributed to the oportunity of primary feeders to develop undesirable habits.

Evaluating average ingredient deviation by load for TMR of dairy farms, James and Cox (2008) found that corn silage had one of the greatest deviations (kg•load$^{-1}$) and also the greatest range in deviations (variation) of all the ingredients evaluated. Other ingredients with lower levels of inclusion, like corn gluten, mineral supplement, molasses, grain mix and cotton seed hull, showed the lowest average deviations (kg•load$^{-1}$) and smaller ranges of variations. Additionally, they found significant differences in loading accuracy between the dairies evaluated, which could be attributed to differences in operator ability and disposition but also to the status of the equipment.

Reducing the variation in nutrient composition of TMR is also a key factor to optimize feed refusals, guaranteeing an adequate feed intake by the cows to support nutrient requirements according to their physiological stage and corresponding feeding group at the farm. All the aforementioned factors improving accuracy and precision of TMR composition would also help to prevent large variations in DM intake, and consequently feed bunk management would be improved by reducing TMR orts and problems particularly associated with handling of feed refusals (Stone, 2008).

Modern dairies face particular challenges that can be assisted by the use of technology as a means to improve precision of management and efficiency of the enterprise; however, technology itself does not guarantee improvements if not accompanied by the right analysis and interpretation of the information obtained (Bewley et al., 2015). Detailed information on each load recorded by the scale of the mixing truck and available to be exported as reports, is a valuable resource for the nutritionist to analyze the suitability of a particular feeding program, and provides information on critical points of the process, allowing to determine possible strategies to improve precision and efficiency of ration formulation and feeding.

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# CHAPTER III

# SINGLE-CALF HEIFER MODEL COMBINED WITH THE USE OF SEXED SEMEN AND EARLY WEANING

## INTRODUCTION

Traditional beef production in the U.S. and many other countries, involves a series of segments representing the whole cattle cycle, which guarantees an adequate supply of animals to the industry to fulfill beef demands of the population. Relative to cattle numbers, the largest segment in U.S. beef primary production chain is represented by cow-calf ranches, which have a reproductive cowherd to produce calves that are either sent to other ranches to gain extra weight on pasture before fattening, or directly sent to a feedlot to be finished on a grain-based diet.

Adult cows have been shown to be less biologically efficient than younger and lighter females; the first ones requiring a larger proportion of their total energy intake to perform non-productive functions related to maintenance. The single-calf heifer model (SCHM), which consists of finishing females after weaning their first calf, has been proposed as an alternative by combining calf and beef production into the same system, allowing for a more efficient use of energy by reducing the average age and weight of the cowherd, which decreases the proportion of energy used for maintenance (Sell et al., 1988; Seidel, 2015).

However, biological efficiency does not always mean profitability. In this sense, feasibility of the SCHM might be affected by different factors, including: increased incidence of dystocia, lack of self-sufficiency to produce replacements, and reduced estimated carcass quality as a consequence of accelerated bone ossification due to pregnancy hormones (Sell et al., 1988; Waggoner et al., 1990; Reiling et al., 1995; Field et al., 1996; Riggs, 2001).

The objective of this project was to evaluate reproductive and productive performance of females managed under the SCHM, combined with the use of sexed semen and early weaning, to estimate the main biological parameters of the system.

## MATERIALS AND METHODS

Two consecutive sets of 53 and 58 black Angus-based yearling heifers, were purchased from commercial cattle vendors and managed under SCHM for the first and second year of the project, respectively. The exact age of most heifers was unknown. Each year, at the beginning of the trial, all heifers were weighed, body condition scored, ear tagged, processed and checked for reproductive status to prepare them for synchronization of ovulation approximately 1 mo ahead of artificial insemination (AI). Breeding was programed for heifers to calve at approximately 24 mo of age and then nurse their calves for 3 to 4 mo. Overall, heifers were kept on pasture for approximately 15 mo from processing until 2 wk prior to early weaning, when they were shipped to a research feedlot to be fed a grain based diet for approximately 3 mo before being slaughtered at a commercial abattoir.

### *Management from synchronization of heifers until weaning of calves*

Initially, heifers were checked for reproductive status, which was determined by rectal palpation. Synchronization protocol was initiated approximately 33 d prior to insemination, by inserting a controlled internal drug releasing device (CIDR; Eazi-Breed; Zoetis, Florham Park, NJ) into the uterus, which was removed 14 d after insertion. Seventeen days after CIDR removal, heifers got an intramuscular injection of 25 mg of $PGF_{2\alpha}$ plus an estrus detection patch (Estrotect; Rockway Inc., Spring Valley, WI).

Heifers having tripped patches 66 hr after $PGF_{2\alpha}$ injection were artificially inseminated with one dose of sexed X-bearing Hereford semen, while heifers with inactivated patches got an intramuscular injection of 100 μg of GnRH and were inseminated 18 hr later with X-bearing Hereford semen as well. Both years, 7 d after fixed time AI, heifers were placed with a Hereford clean-up bull for 150 d, with no interruptions in the case of year 1 heifers; or with one interruption from d 17 – 23 post first AI in the case of year 2 heifers, allowing for a second AI with sexed semen to the heifers that were observed in estrus during that period.

Pregnancy status of the heifers was diagnosed 30 d after first AI by ultrasound (Aloka 500; Corometrics Medical Systems, Wallingford, CT) fitted with a 5-MHz rectal probe, and a second pregnancy check was performed by rectal palpation 140 d after first AI. Late and non-pregnant heifers were sold, then 43 and 46 early pregnant heifers were kept for first and second year, respectively, to continue with the rest of the study. However, for second year, 3 early pregnant heifers were withdrawn from the study after calving; two of them had stillborn calves and the other lost her calf to coyotes. Heifers were maintained on native pasture since receiving and during the whole pregnancy period. At birth, weights and sex of the calves were recorded for both sets. After calving, cow-calf pairs were also maintained on native pasture during most of the nursing period, until 2 wk prior to early weaning.

### *Management from weaning to slaughter*

Two weeks before early weaning, cow-calf pairs were shipped to Colorado State University ARDEC's feedlot, and gradually weaned by placing cows and calves in 2 separate but nearby soil surface pens. Weights of calves and cows were recorded at the time of early weaning. First 3 d at the feedlot pairs were fed only long stem grass hay ad libitum, and from day 4 until weaning they were fed a low energy receiving diet, offered as total mixed ration (Table 1). Animals had free access to fresh water all the time.

After weaning was performed, calves stayed at the feedlot for 8 more weeks and afterwards were put on pasture. Primiparous females were kept on the low energy ration and the soil surface common pen for approximately 3 more weeks, and then fed a finishing ration (Table 1) for approximately 60 d to complete a total post-weaning grain based feeding period of 88 d (yr 1) and 90 d (yr 2). Post-weaning rations for cows were formulated to provide 0.5 mg of MGA to suppress estrus until the day before harvest. For the whole duration of the feedlot phase, cattle were fed every day at 0730 in the morning and 1400 in the afternoon. Feed bunks were evaluated every morning to adjust the amount feed offered, aiming towards optimizing feed intake and reducing orts to the minimum.

## **Feed intake measurement and performance evaluation**

Intake and weight gain evaluations were performed for both sets of cows at Colorado State University ARDEC's Feed Intake Unit (FIU). A radio frequency identification tag (TFIW/GESMW, Allflex$^{®}$) was placed on the left ear, and cows were sorted into two group pens at the FIU approximately 3 weeks after weaning and remained there for 42 d (yr 1) and 48 d (yr 2).

Cows were weighed the day they entered the FIU, and then on days 14, 28, and 42. For the second year, weights were also obtained for day 48. Weighing was performed early in the morning before cows were fed. Individual daily intake data were collected by an automated feed intake monitoring system (GrowSafe®). A regression of individual weight data allowed estimating average daily gain (ADG) for every cow. Additionally, individual dry matter intake (DMI) was calculated from measured feed intake and dry matter (DM) content of TMR; then individual feed:gain ratios (F:G) were also calculated. Intake data of days when cows were weighed or performed any other particular management practice, were withdrawn from the analysis to avoid accounting for changes in intake due to external factors. Additionally, to evaluate performance of female calves (43 for yr 1, and 42 for yr 2), weights at weaning (WW) were measured.

### Cattle management after feed intake measurement period

Once intake measurement was finished, cows were sorted into 5 different 9-head group pens according to body weight (BW), and implanted in the right ear with 140 mg trenbolone acetate plus 14 mg estradiol (Revalor®-H, Intervet) and continued to be fed the finishing ration as previously described.

Final or exit weight (FW) was calculated for every cow as the average of the weights of the 2 last days in the feedlot, and shrunk BW (SBW) was calculated assuming a 4% pencil shrink between the feedlot and the packing plant.

### *Evaluation of carcasses at slaughter and meat tenderness measurements after aging*

Each year of the project 43 single-calf females were slaughtered at a local processing plant located 30 miles from the feedlot. Carcass data for: hot carcass weight (HCW), adjusted fat thickness (AFT), *longissimus muscle* or ribeye area (REA), kidney pelvic and heart fat (KPH), yield grade (YG), marbling score (MA), lean maturity (LE), and skeletal or bone maturity (BM), were compiled by: online camera, Colorado State University (CSU) personnel, and USDA grading service. In the case of yr 1, quality grade and meat tenderness related evaluations, include only 42 carcasses, because one carcass was railed off and unavailable for sampling.

Data for REA, AFT, and MA were provided by the packing plant; while KPH measurements, along with LE and BM, were evaluated by CSU. In addition, stamped yield grade issued by USDA graders (USDA YG) was recorded for every carcass, and adjusted yield grade (Adjusted YG) was calculated by CSU according to the equation:

Adjusted YG = 2.5 + (2.5 AFT, in) + (0.20 KPH) + (0.0038 HCW, lbs.) – (0.32 REA, $in^2$).

Overall carcass maturity (OM) was estimated from LE and BM; for this estimation $A^{00}$, $B^{00}$, $C^{00}$, $D^{00}$, $E^{00}$, maturities corresponded to scores of 100, 200, 300, 400, and 500, respectively; and MA at the 12th – 13th rib cross-section was evaluated for every carcass, and scores assigned as follows: practically devoid = 100, traces = 200, slight = 300, small = 400, and modest = 500, moderate = 600, and slightly abundant = 700.

One 5 cm thick *longissimus-muscle* (LM) sample was removed from the 13th rib portion of the loin from the left side of every carcass for slice shear force (SSF), Warner-Bratzler shear force (WBSF), and percent cooking loss (CL) measurements, which were performed at the CSU Meat Laboratory. Samples were packaged in vacuum sealable bags on ice, and transported to the lab for vacuum sealing and aging at 2˚C until the 14th day post mortem. Then samples were sliced into 2.54 cm thick steaks and oven cooked to a peak temperature of 71˚C (Rational D88899, Landsberg am Lech, Germany). Pre and post cooking weights were recorded for CL estimation. After cooking, a 1 cm thick, 5 cm long slice was removed from each steak parallel to the muscle fibers; then samples were sheared perpendicular to the muscle fibers using a universal testing machine (Instron Corp., Canton, MA) equipped with a flat, blunt-end blade for SSF measurement. Then, the same testing machine was fitted with a Warner-Bratzler shear head, and used to record peak shear force measurement for 2 individual cores, which were averaged to obtain a single WBSF value per sample.

### *Data analysis*

Descriptive statistics was used to calculate means and standard deviations (SD) of the main parameters for both heifers and calves. In the case of heifers, BW and body condition score (BCS) at time of synchronization, as well as pregnancy rates at 30 d (PR-30) and 140 d (PR-140) post fixed-time AI were analyzed. Based on date of birth of the calves plus data from PR-30 and PR-140, and assuming a 283 d pregnancy length, the proportions of heifers pregnant to fixed-time AI (% heifers-AI), pregnant either to the bull or second AI (% heifers-repeats), and female calves born to AI (% female calves-AI) were calculated and evaluated. Additionally, BW at weaning, ADG while at FIU, average DMI while at FIU, F:G while at FIU, and feedlot exit weight (FW) of cows, were evaluated as productive parameters for cows. In the case of calves: BW at birth and WW were included in the analysis. Simple statistics was also used for describing the cows at slaughter and yield related attributes. Means and SD were calculated for SBW, HCW, dressing percent ([HCW/SBW]*100), REA, KPH, Adjusted YG, and USDA YG.

In regard to carcass grading and meat quality traits, given the large decrease in quality grade with OM ≥ 300 ($C^{00}$) and that according to approximate age, few heifers were supposed to fall into that category, carcasses were sorted by OM into 2 groups as < 300 or ≥ 300, and the resulting means for each variable (LE, BM, MA, SSF, WBSF and CL) were compared with a *t*-test. Data of both years were pooled for the *t*-test analysis, since similar results were obtained for each year separately, and every variable that differed ($P < 0.05$) between OM groups in year 1 also differed in year 2.

## RESULTS AND DISCUSSION

### ***Reproductive performance of SCHM-heifers***

In regard to the characteristics of heifers at the moment of synchronization for both years of the project, Table 2 shows that mean BW for the first set was 353 kg, while a lighter second set averaged 307 kg, both sets having an estimated average BCS of 5.1. Weight at the time of synchronization and breeding is very important to guarantee adequate pregnancy rates and future reproductive performance of the female, as well as preventing dystocia, usually aiming for BW at first breeding to be around 60% of mature BW (Lamb, 2012). In this case is difficult to estimate a mature BW because there was limited information on the background of the heifers; however, assuming 500 kg as an approximate adult weight, a recommended weight at first breeding would be 300 kg, which means that both sets had a good average BW to prevent problems following AI.

Pregnancy rates 30 d after fixed time AI were 41.2 and 45.6% for first and second set, respectively. Additionally, for yr 1 a 90.2% PR-140 was achieved after exposure to the bull, while 91.2% was obtained for yr 2 at the end of breeding season (Table 2). Busch et al. (2007) evaluated pregnancy rates of crossbred beef heifers (383 ± 3 kg BW) synchronized with CIDRs, and obtained 62 and 47% fixed time AI pregnancy rates, and 90 and 91% of heifers pregnant at the end of the breeding season for treatments evaluating CIDR insertion from d 0 to 14 (like our study) and from d 23 to d 30, respectively. Seidel et al. (1999) reported pregnancy rates for beef heifers of various breeds inseminated with sexed semen, ranging from 26 to 86% for different sperm concentrations and sites of deposition of the semen; they found pregnancy rates of heifers inseminated with sexed semen to be 70-90% those of heifers inseminated with unsexed sperm. In a similar study, Seidel and Schenk (2008) found an average pregnancy rate of 55.9% (ranging from 47 to 80%) when inseminated beef heifers were bred 12 – 24 h after observed estrus with different sexed sperm concentrations to evaluate site of cryopreserved semen deposition; use of sexed semen resulted in approximately 80% of control pregnancy rates using unsexed sperm.

Previous evaluations of the SCHM by Riggs (2001) yielded very low pregnancy rates after breeding the heifers with sexed semen (19 and 8% for first and second yr of the project, respectively), but also low percent of females were pregnant at the end of breeding season after bull exposure (58 and 16% for yr 1 and 2, respectively), which suggests that besides lower fertility of sexed semen, other factors related to the heifers, such as attempts to induce puberty, might have affected the results obtained.

According to calculations based on the date of birth of every calf and pregnancy checks, it was estimated that 39.2 and 44.6% of the heifers got pregnant to fixed-time AI, 47.1 and 33.9% of the heifers were repeats and got pregnant to the bull or to second AI, and 13.7 and 21.4% of the heifers either did not get pregnant or had a miscarriage through the breeding season, for yr 1 and 2, respectively (Table 2). These results suggest that the heifers getting pregnant to fixed-time AI were able to very successfully continue with the pregnancy, since when comparing PR-30 to % calves born to fixed-time AI, only a 2% (yr 1) and 1% (yr 2) decrease was observed. However, when comparing the percent of heifers pregnant at the end of breeding season (PR-140) to the percent of heifers able to finish pregnancy and produce one calf (% heifers-AI + % heifers-repeats), a reduction of 3.9% (yr 1) and 12.6% (yr 2) was observed, which might be attributable to miscarriage. As both heifers pregnant by fixed-time AI and repeats were subjected to the same environmental factors, it could be possible that failure to maintain a successful pregnancy might be mostly influenced by factors related to the heifer herself and also to the bull, apparently favoring the fixed-time AI pregnant heifers since they probably have better reproductive conditions (which allow them to get pregnant during early breeding season), and also getting pregnant to highly selected bulls, which could even increase the chance of a successful pregnancy.

As it is shown in Table 2, sexed semen was very effective to produce female calves, obtaining 100 and 95.8% of accuracy during first and second yr of the project, which coincides with the upper values of the range 74 – 95 % reported by Seidel et al. (1999). Such accuracy together with sperm fertility and pregnancy rates, plays a key role for obtaining a high proportion of female calves, as desired in the SCHM. For this project, 60.8% (yr 1) and 57.9% (yr 2) of female calves were obtained out from total calves born, which is very similar to the 60% obtained by Riggs (2001). By combining together the reproductive parameters obtained in the present study, it was possible to produce an amount of weaned female-calves equivalent to 58.5% (yr 1) and 56.9% (yr 2) of the total annual requirement of female replacements. This means that under such conditions and assuming that all female calves are kept, annually it would be necessary to purchase at least 41.5 – 43.1% of the replacements to guarantee the continuity of the system, which is higher than the 20 – 30% estimated by Seidel (2015). Furthermore, requirement of replacements from external sources could increase if other factors are taken into account, such as the case of post-weaning mortality of calves, but especially losses due to female-calves dropping out the system as a consequence of being born to late calving cows.

### *Production parameters of primiparous SCHM-cows during the feedlot phase*

Table 3 presents the production parameters of both sets of SCHM-cows during the post-weaning fattening period. Numerically speaking, cows of yr 1 had greater average BW at the beginning of feedlot phase than cows of yr 2 (517 kg vs 452 kg), which probably contributed to a numerically greater DMI, ADG, and F:G for yr 1 cows while at the FIU. The overall length of feeding period at the feedlot was 88 and 90 d for the first and second sets, respectively, and for that period, the overall ADG was 1.7 kg (set 1) and 1.9 kg (set 2). Lower daily gains have been published in the literature for SCHM females fed on high grain diets. Waggoner et al. (1990) evaluated the performance of Simmental X Hereford SCHM-females, calving at about 24 mo of age and early weaning their calves at 115 d after, to be implanted and fed a high grain diet at a feedlot for 137 d. They reported a feedlot entry weight of 401 kg and an average final weight of 539, resulting on an ADG of 1.0 kg during the feedlot phase. Field et al. (1996) reported the results of non-implanted Angus x Gelbvieh SCHM-females early weaning their calves on average at 120 d postpartum, and fed a grain based diet containing monensin for 100 d. Those females entered the feedlot weighing 525 kg and average slaughter weight was 656 kg, obtaining an ADG of 1.31 kg.

Several factors might affect the feedlot performance of SCHM-females, including genetics and a suite of environmental factors including nutrition, weather, management, etc. However, diet and management related factors, can be controlled at a certain point, and as mentioned above, most of evaluations have been done by feeding high-grain diets containing only 8 – 12% forage on an as fed basis, and also including performance enhancers like ionophores and implants, which are very widely used techniques across US feedlot industry. However, when it comes to genetics, and especially for the SCHM, feedlot performance results could be more variable, since originally heifers have not been mainly selected for weight gain related traits, but based on their reproductive performance instead. However, to some extent the good ADG observed in both sets evaluated in this study, might be an effect of compensatory growth, since primiparous females came from a pasture based diet while nursing and having a considerable demand of nutrients, and then were weaned and switched to a feedlot grain-based ration, improving the availability of nutrients for weight gain.

Nevertheless, average F:G estimates for both sets of heifers analyzed in this study (8.9 for set 1; and 8.6 for set 2) indicate lower efficiency than estimates from other studies published for females fed grain-based diets at feedlots. Walker et al. (2006) estimated F:G ranging between 4.5 and 6.37 for cross-bred heifers fed different protein sources with or without inclusion of ractopamine. A higher average F:G (7.69) was reported by Wertz et al. (2002) for 2 yr old Angus females, while Depenbusch et al. (2008) estimated F:G values of 7.87 – 8.06 for cross-bred yearling heifers fed steam-flaked corn based diets with different level of inclusion of corn distillers grains. In this sense, a large DMI and an increased F:G ratio observed in this study, suggest less efficiency to convert feed into weight gain, which might affect the efficiency of the SCHM, especially when feeding costs are elevated.

### ***Performance of early weaned calves***

Information on performance of calves from birth to weaning is shown in Table 4. Average birth weight of calves was the same for both sets analyzed (33.0 kg), however, on average calves were weaned at 106 d of age and 147 kg BW the first yr (ADG = 1.1 kg), while second set was weaned at 120 d of age and 133 kg BW (ADG = 0.83 kg). Similar results have been reported by Reiling et al. (1995) for 32.7 kg birth weight calves born to grain fed Angus X Simmental and Angus X Hereford SCHM-females, and early weaned at 117 d of age (WW = 159 kg) with an

ADG of 1.1 kg from birth through weaning. Similarly, Peterson et al. (1987) obtained ADG from birth to weaning and average WW of 0.76 kg and 109.4 kg, respectively, for cross bred calves born to primiparous and multiparous cows, and early weaned at approximately 110 d of age.

Low birth weights observed in the present study (Table 4), are likely to be the result of previous selection. This trait is extremely important when it comes to prevent calving difficulty problems. In the case of SCHM, it becomes very critical both to ensure adequate development of heifers by the time they are bred, and also to use bulls selected for relatively low birth weights which lowers the incidence of dystocia and helps increasing calf-crop close to the 85% goal of traditional cow-calf operations (Field, 2006). However, in this study, 83 and 74% calf-crop was obtained for yr 1 and 2, respectively. Different factors could reduce calf-crop of SCHM systems compared to traditional cow-calf operations, and particularly for the present study, the reduced fertility of sexed semen and unknown background of the heifers might play an important role in the incidence of late and non-pregnant heifers, influencing the results observed.

### *Performance and carcass attributes of primiparous SCHM-cows at slaughter*

General information of the SCHM-cows and carcasses was recorded the day of slaughter, and is presented in Table 5. With an assumed 4% shrink, the average SW for the cows the day of slaughter was 636 kg (yr 1), and 594 kg (yr 2). Very similar dressing percentages of 61.1% and 61.6%, resulted in HCW of 388 kg and 365 kg, for first and second set, respectively. For both sets, adequate HCW was achieved to prevent discounts for light or heavy carcasses out of the 250 kg – 476 kg weight range (550 – 1050 lbs) commonly set by the packing plants.

One of the main factors driving carcass value of beef cattle is related to yield of edible meat. At the packing plant, in an attempt to use time more efficiently, USDA graders assign USDA YG to every carcass by reading the HCW from the tag, and visually estimating KPH, REA and fat thickness, instead of using the equation that estimates adjusted YG from the measured attributes (Parish et al., 2009). Moreover, adjusted YG is used as an indicator of carcass cutability which estimates the amount of lean edible meat that can be obtained from the carcass; usually this is visually estimated and reported as USDA YG (Tatum, 2007), with lower values as better. Carcasses with estimated USDA YG of 1 and 2 get a premium, while yield grades of 3 remain unaffected in price, and estimated USDA YG of 4 and 5 are discounted for reduced cutability.

In regard to YG and related attributes (Table 6), average measured values of 89.8 $cm^2$ and 86.9 $cm^2$ for REA, and estimates of 1.6 % and 2.0% for KPH, were obtained for yr 1 and yr 2 carcasses, respectively. For both sets on average, an adjusted YG of 3.3%, and a USDA YG of 2.9% were estimated. Additionally, in the present study 49 and 45% of the carcasses were classified as either USDA YG 1 or 2 for first and second set of SCHM-cows, respectively. On the other hand, 47% (yr 1) and 49% (yr 2) of the carcasses were graded USDA YG 3, and only 5% (first set) and 7% (second set) got a yield grade greater than 3. According to these results, apparently USDA YG would not severely affect the grid of carcasses of SCHM-cows, which could be related to the relatively short high-grain feeding period of the cows, not allowing very heavy carcasses or a significant deposition of fat in the exterior of the carcass, the pelvic cavity or around the heart and kidneys (KPH).

Other authors have reported similar results when evaluating yield of carcasses of SCHM-females. For primiparous cows 24 mo of age at slaughter, weighing 613 kg, Riggs (2001) obtained 361 kg HCW, 60% dressing, 85.7 $cm^2$ REA, 2% KPH, 3.1 adjusted YG. Furthermore, Waggoner et al (1990) described lower carcass yields for implanted SCHM-females, obtaining 338 kg HCW, 62.7% dressing, 95.2 $cm^2$ REA, 1.8% KPH, and 2.1 USDA YG. For primiparous cows 32.5 mo of age, and managed under SCHM, Field et al. (1996) reported 406 kg HCW, 61.98% dressing, 100.4 $cm^2$ REA, and 2.05% KPH. Additionally, for first-calf cows 34 mo of age, and following a 90 d grain feeding period, Shackelford et al. (1995) obtained 375 kg HCW, 58.1% dressing, 86.8 $cm^2$ REA, 2.1% KPH, and 2.6 USDA YG.

Quality grade also represents a key aspect when it comes to the estimated value of carcasses, and it depends on both estimated carcass maturity (calculated from estimates of BM and LM) and estimated marbling score. According to Tatum (2011), there are 5 maturity groups designated as A through E, associated with approximate ages as follows: A = 9 to 30 mo, B = 31 to 42 mo, C = 43 to 72 mo, D = 73 to 96 mo and E = more than 96 mo. Current USDA system includes 8 different categories of quality grade, and only cattle with A or B carcass maturity (OM = 100 to 299) are eligible for prime, choice, select or standard grades, in descendent order and depending on marbling score. Meanwhile, cattle C or greater maturity (OM $\geq$ 300), commonly referred to as hardbones, only could qualify for lower quality grades of reduced value (in descendent order: commercial, utility, cutter or canner).

Quality grade attributes of carcasses of SCHM-cows and the corresponding carcass attributes are tabulated in Table 7. As can be observed, scores of: 170 and 161 LE; 281 and 234 BM; 249 and 213 OM; 475 and 428 MA, were obtained for carcasses of primiparous cows during yr 1 and yr 2, respectively. These data, indicate an average maturity between $B^{13}$ and $B^{49}$ for both sets of carcasses, indicating an average estimated age of 30 – 42 mo. Furthermore, the distribution of carcasses according to maturity, shows that 65% and 67% of the carcasses were classified as either A or B maturity (OM < 300) during first and second yr of the project, respectively. Conversely, 35% (first set) and 33% (second set) of the carcasses were classified as hardbones being all of them called C maturity. This aspect, could affect the feasibility of the

SCHM since approximately one third of the carcasses were classified as hardbones in both years of the project, impacting quality grade, and reducing average carcass value as a consequence of discounts.

Analyzing 22 carcasses of SCHM-females 24 mo of age, Riggs (2001) obtained BM = 200, LE = 175, OM = 187, and MA = 446; in this case no carcasses were classified as C maturity (OM $\geq$ 300), probably because of the young age of the females. Very similar results were reported by Reiling et al. (1995) for carcasses of SCHM-females around 28 mo of age at slaughter, showing BM = 196, LE = 168, OM = 182, and MA = 475. For carcasses of implanted SCHM-cows approximately 30 mo of age, Waggoner et al. (1990) found BM = 208, LE = 175, OM = 199, MA = 401, WBSF = 3.9, and CL = 21%. Field et al. (1996) reported BM = 302, LE = 159, OM = 265, and MA = 390, for primiparous females 32.5 mo of age; in this case they found 22, 11 and 67% of the carcasses classified as A, B and C maturity, respectively. For primiparous cows approximately 34 mo of age, Shackelford et al. (1995) reported BM = 278, LE = 208, OM = 249, MA = 427, and WBSF = 6.1; additionally, 72% of the carcasses were classified as either A or B maturity, while the remaining 28% were classified as C maturity.

Additional results related to meat tenderness after aging, and weight loss of meat during cooking, are presented in Table 8. Values of 25.2 and 27.0 kg for SSF, 4.9 and 5.0 for WBSF, and 25.8 and 26.5 for CL, were measured for carcasses during yr 1 and yr 2, respectively. Parish et al. (2009) mention that a good standard for beef industry is a WBSF < 3.6 kg, which was exceeded for both sets of carcasses in this study, coinciding with previous reports showing that carcasses from females are usually tougher than carcasses from steers as a result of increased calpastatin activity and consequently reduced tenderization during the aging period (Tatum et al., 2007). Furthermore, very diverse estimations of WBSF have been reported for meat of carcasses of primiparous females, ranging from 3.6 to 9.8 (Waggoner et al., 1990; Shackelford et al., 1995; Field et al., 1996; Field et al., 1997). However, so far research has failed to demonstrate a significant correlation between meat tenderness and estimated maturity of carcasses (Lawrence et al., 2001a; Lawrence et al., 2001b; Tatum, 2011; Acheson et al., 2014, Semler et al., 2016).

In the case of this study, despite not knowing the exact age at slaughter for both sets of cows, it seems unlikely for any of the cows to be 43 mo of age or older (OM = C, D, or E). As presented in Table 9, when data of quality grade attributes and meat tenderness of the 85 carcasses evaluated during the 2 yr of the project are sorted by OM as: $< 300$ (A and B maturity) or $\geq 300$ (C maturity) 34% of the carcasses were classified as OM $\geq 300$, and the remaining 66% were called as OM $< 300$. Additionally, carcasses classified as OM $\geq 300$ showed a significantly higher ($P < 0.001$) skeletal maturity (BM = 347) than carcasses classified as OM $< 300$ (BM = 211). However no significant differences were found for LE between both OM groups ($P = 0.81$), which in this case suggests that BM is being the main driver for the differences observed in OM of carcasses of SCHM-cows. Moreover, despite the differences in BM, no differences were found for MA ($P = 0.39$), SSF ($P = 0.29$), WBSF ($P = 0.96$), and CL ($P = 0.47$), between the 2 maturity groups analyzed. Similar results were reported by Field et al. (1997), when compared A vs C maturity carcasses of primiparous cows 32.5 mo of age after 100 d fed on grain, with no significant differences for LE, MA, WBSF and muscle collagen concentration, despite the significantly different BM between both groups. Additionally, Shackelford et al. (1995) compared carcass characteristics of heifers 22 mo of age that never got pregnant, to carcasses of first-calf cows around 34 mo of age, and did not find any difference for WBSF of their carcasses.

Results from these studies suggest that the increased maturity of hardbone carcasses of SCHM-females is probably an effect of accelerated BM due to pregnancy hormones, instead of greater chronological age itself, therefore, not necessarily affecting meat quality and palatability.

### *Limitations of the study and improvements required for future evaluations*

Main limitations of this study relate to its nature, as it is not an experiment but only an evaluation of the main parameters of the SCHM, which limits the statistically useful information that can be obtained from the data analysis.

For both sets evaluated most of the cattle had to be purchased, which not only limits the information known on the background of the females, but also is likely to increase variability in genetic standards and performance. Moreover, data analyzed correspond only to the first 2 sets of females, so no second or later generation data have been evaluated, which might allow for improved parameters once the system reaches the equilibrium.

This study evaluated only performance of late spring bred heifers and early spring born calves. However, performance of females and efficiency of the SCHM under a fall calving scheme could also be included in the study to evaluate the effects of seasonality of beef industry and cattle markets on the system.

For future evaluations it is worth considering obtaining the birth dates for every calf purchased or coming from external sources, so it strengthens the analysis and conclusions. Additionally, an earlier start of the feedlot phase would be recommended to try reducing the incidence of hard-bone carcasses.

Based on published results on pregnancy rates of heifers inseminated with sexed semen, an improvement on the parameters obtained in this study can be expected. As was mentioned previously, an improvement in reproductive parameters would be expected once the system is in equilibrium; also, there might be chance for improvement in management of heifers that could help increase pregnancy rates, especially when it comes to efficiency of management during synchronization and insemination protocols.

## CONCLUSIONS

By including synchronization protocols and artificial insemination with sexed semen into the SCHM system, it was possible to produce an amount of weaned female-calves equivalent to 58.5 – 56.9% of the annual replacements required for the continuity of the system. However, other factors reducing the number of weaned calves that are retained as replacements should also be evaluated.

At the feedlot phase, primiparous females showed a good ADG for both analyzed, averaging 1.8 kg•d$^{-1}$ while fed a high grain diet. However, due to an elevated DMI both sets showed similar F:G averaging 8.75, which suggests a low feed efficiency.

Performance of calves showed conveniently low birth weights (33 kg), probably as a result of genetics of the service sires. However, a lower than recommended calf-crop (74 – 83 %) was obtained for both sets, which might be influenced by unknown genetic background of the heifers and lower fertility of sexed semen compared to unsexed sperm.

As expected for female carcasses, a low dressing percent (61%) was observed on average for both sets of cows, which might potentially reduce the income of a SCHM system compared to feedlot steers. Conversely, a very low proportion of carcasses were discounted for high USDA-YG, which might be related to a shorter fattening period for the SCHM-females fed in this study

(88 – 90 d) compared to usual length of feeding period for steers, allowing for a reduced deposition of external fat when SCHM is implemented.

Nearly one third of the carcasses (33 – 36%) were classified as hardbones, as a consequence of increased skeletal maturity, which might represent a significant reduction of estimated carcass value for SCHM system. However, when compared hardbone carcasses to less mature carcasses, significant differences were found only for skeletal maturity; meanwhile no differences were found for other carcass quality traits and meat shear force.

By taking into account its pros and cons, the SCHM should be analyzed from a financial standpoint to estimate its feasibility under different possible scenarios including sensitivity analysis of feeding costs and cattle prices. Additionally, different methods for estimation of age of primiparous females should be explored in order to reduce the negative impact that a high incidence of hardbone carcasses might have in the feasibility of the model.

Table 1. Ingredient and nutrient composition of total mixed rations fed to primiparous SCHM-females during the feedlot phase.

| Item | Low energy ration | Finishing ration |
|---|---|---|
| Ingredient composition (as fed basis) | | |
| Alfalfa hay (%) | 23.5 | 8.08 |
| Hay treat (%) | 3.34 | 5.75 |
| Corn silage (%) | 30 | 18.09 |
| Corn grain cracked (%) | 35 | 67.01 |
| Dried distillers grains (%) | 7.78 | 0 |
| Limestone (%) | 0.26 | 0.95 |
| Salt (%) | 0.11 | 0.12 |
| Rumensin® (g•ton$^{-1}$)[1] | 100 | 149 |
| | | |
| Nutrient composition (DM basis) | | |
| Crude protein (%) | 16.48 | 12.58 |
| $NE_g$ (MCal•kg$^{-1}$) | 1.06 | 1.41 |
| Acid detergent fiber (%) | 25.16 | 8.48 |
| Ca (%) | 1.02 | 0.26 |
| P (%) | 0.33 | 0.32 |

[1] Elanco Animal Health, Indianapolis, IN 46285, USA.

Table 2. Reproductive parameters of heifers bred to sexed semen during first and second year of the project.

| Parameter | Year 1 | Year 2 |
|---|---|---|
| BW-Synch (kg)[1] | 353± 39 | 307 ± 30 |
| BCS-Synch[2] | 5.1 | 5.1 |
| Number of females exposed | 53 | 58 |
| PR- 30 (%)[3] | 41.2 | 45.6 |
| PR- 140 (%)[4] | 90.2 | 91.2 |
| % heifers-AI[5] | 39.2 | 44.6 |
| % heifers-repeats[6] | 47.1 | 33.9 |
| % heifers-not calving[7] | 13.7 | 21.4 |
| % female calves-overall[8] | 60.8 | 57.9 |
| % female calves-AI[9] | 100 | 95.8 |
| Female calves weaned[10] | 31 | 33 |
| % females weaned/replacements[11] | 58.5 | 56.9 |

[1] BW at time of synchronization (mean ± SD).
[2] BCS at time of synchronization.
[3] Pregnancy rate 30 d after timed AI.
[4] Pregnancy rate 140 d after timed AI.
[5] Percent of heifers pregnant to timed AI.
[6] Percent of repeat heifers pregnant either to the bull or second AI.
[7] Percent of heifers that did not produce a calf.
[8] Percent of female calves out of total calves born.
[9] Percent of female calves born from cows pregnant to timed AI with sexed semen.
[10] Number of female calves weaned every year.
[11] Percent of female calves weaned relative to total replacements required.

Table 3. Productive feedlot parameters (mean ± SD) of post-weaning primiparous cows.

|  | Parameter | Year 1 (n = 43) | Year 2 (n = 43) |
|---|---|---|---|
| Overall feedlot period | Initial BW[1] (kg) | 517 ± 49 | 452 ± 40 |
|  | Final BW[2] (kg) | 662 ± 55 | 619 ± 64 |
|  | ADG[3] (kg•d$^{-1}$) | 1.7 ± 0.3 | 1.9 ± 0.4 |
|  | Feeding period (d) | 88 | 90 |
| Feed intake unit period | DMI (kg•d$^{-1}$) | 15.6 ± 1.6 | 13.9 ± 1.9 |
|  | ADG[4] (kg•d$^{-1}$) | 1.9 ± 0.5 | 1.7 ± 0.5 |
|  | F:G | 8.9 ± 3.4 | 8.6 ± 2.8 |
|  | Period length (d) | 42 | 48 |

[1] Weight of cows at start of feeding period.
[2] Average weight of the last 2 days at the feedlot.
[3] Average daily gain during the entire feedlot period.
[4] Average daily gain while at the feed intake unit.

Table 4. Performance (mean ± SD) of early weaned calves born to SCHM-heifers.

| Parameter | Year 1 (n = 43) | Year 2 (n = 42) |
|---|---|---|
| Weight at birth (kg) | 33 ± 3.1 | 33 ± 3.7 |
| Weaning age (d) | 106 ± 22 | 120 ± 21 |
| Weaning Weight (kg) | 147 ± 24 | 133 ± 24 |
| Calf-crop (%)[1] | 83 | 74 |

[1] (N° of weaned calves / N° of exposed females) * 100.

Table 5. General characterization of SCHM-cows and carcasses at slaughter (mean ± SD)

| Parameter | Year 1 (n = 43) | Year 2 (n = 43) |
|---|---|---|
| Shrunk final BW[1] (kg) | 636 ± 53 | 594 ± 62 |
| HCW (kg) | 388 ± 33 | 365 ± 36 |
| Dressing[2] % | 61.1 ± 1.5 | 61.6 ± 4.2 |

[1] Average live shrunk weight assuming 4% pencil shrink.

[2] Dressing percent.

Table 6. Yield grade-related attributes (mean ± SD) of carcasses of SCHM-cows and proportion of carcasses in each USDA YG category.

| Attribute | Year 1 (n = 43) | Year 2 (n = 43) |
|---|---|---|
| REA ($cm^2$) | 89.8 ± 11.7 | 86.9 ± 9.6 |
| KPH (%) | 1.6 ± 0.3 | 2.0 ± 0.4 |
| Adjusted YG | 3.3 ± 0.2 | 3.3 ± 0.4 |
| USDA YG | 2.9 ± 0.6 | 2.9 ± 0.7 |
| USDA YG 1 (%)[1] | 7 | 5 |
| USDA YG 2 (%)[2] | 42 | 40 |
| USDA YG 3 (%)[3] | 47 | 49 |
| USDA YG 4 (%)[4] | 5 | 5 |
| USDA YG 5 (%)[5] | 0 | 2 |

[1] Percent of carcasses graded as USDA YG 1.

[2] Percent of carcasses graded as USDA YG 2.

[3] Percent of carcasses graded as USDA YG 3.

[4] Percent of carcasses graded as USDA YG 4.

[5] Percent of carcasses graded as USDA YG 5.

Table 7. Quality grade attributes (mean ± SD) of carcasses of SCHM-cows and distribution of carcasses according maturity.

| Attribute | Year 1 (n = 42) | Year 2 (n = 43) |
|---|---|---|
| MA[1] | 475 ± 75 | 428 ± 82 |
| LE[2] | 170 ± 14 | 161 ± 37 |
| BM[3] | 281 ± 55 | 234 ± 97 |
| OM[4] | 249 ± 41 | 213 ± 76 |
| % A-maturity carcasses[5] | 5 | 51 |
| % B-maturity carcasses[6] | 60 | 16 |
| % C-maturity carcasses[7] | 35 | 33 |

[1] Marbling scores as follows: practically devoid = 100, traces = 200, slight = 300, small = 400, and modest = 500, moderate = 600, and slightly abundant = 700.

[2,3,4] Lean, bone and overall maturities of $A^{00}$, $B^{00}$, $C^{00}$, $D^{00}$, $E^{00}$, corresponded to scores of 100, 200, 300, 400, and 500, respectively.

[5] Percent of carcasses with OM 100 – 199.

[6] Percent of carcasses with OM 200 – 299.

[7] Percent of carcasses with OM 300 – 399.

Table 8. Meat tenderness of carcasses of SCHM-cows (mean ± SD)

| Measurement | Year 1 (n = 42) | Year 2 (n = 43) |
|---|---|---|
| SSF (kg) | 25.2 ± 6.2 | 27.0 ± 10.7 |
| WBSF (kg) | 4.9 ± 0.9 | 5.0 ± 1.2 |
| CL (%) | 25.8 ± 3.7 | 26.5 ± 4.3 |

Table 9. Carcass and meat quality attributes (mean ± SD) of SCHM-cows. Comparison between carcasses with OM < 300 and OM ≥ 300 combining data across years.

| Attribute | Overall maturity | | $P > \|t\|$ |
|---|---|---|---|
| | < 300 | ≥ 300 | |
| % carcasses[1] | 65.9 | 34.1 | --- |
| MA | 446 ± 84 | 462 ± 78 | 0.39 |
| LE | 165 ±29 | 166 ± 27 | 0.81 |
| BM | 211 ± 53 | 347 ± 46 | < 0.001 |
| OM | 192 ± 39 | 305 ± 18 | < 0.001 |
| SSF (kg) | 25.4 ±8.6 | 27.6 ± 9.1 | 0.29 |
| WBSF (kg) | 4.9 ± 1.2 | 5.0 ± 0.8 | 0.96 |
| CL (%) | 25.4 ± 4.1 | 26.1 ± 4.2 | 0.47 |

[1] Percent of total carcasses evaluated.

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# CHAPTER IV

# ESTIMATION OF MINERAL SUPPLEMENT SHRINKAGE AND INGREDIENT DEVIATION ANALYSIS OF TOTAL MIXED RATIONS IN DAIRY FARMS

## INTRODUCTION

Throughout the years, the U.S. dairy industry has experienced dramatic changes not only in terms of the amount of milk produced, but also on how it is produced. According to the national statistics, currently around 95 billion kg of milk are produced by a national dairy herd of 9.3 million cows, compared to 1924 when less than a half the milk was produced by more than twice the number of cows (NASS, 2016).

Selection programs and reproductive biotechnologies have allowed for rapid genetic progress which has been very heavily devoted to increase individual milk production of cows. Increased nutrient requirements of high producing cows, have also brought the need for more digestible diets and intensification of management into confined feeding systems to allow the cow to consume a greater amount of nutrients while reducing physical activity and energy expenses. Reduced profit margins and increased financial risk of dairy business, have also pushed the tendency to increase average farm size, making large and technified dairies more common; it was estimated by 2012 that a half of US dairy cow inventory were held in dairies larger than 1000 cows (Mac Donald et al., 2016).

Modern large dairies feeding mixed-rations, purchase and store feedstuffs to prepare their own rations at the farm, having more flexibility to feed customized rations according to nutrient requirements of cows, and reducing feeding costs. However, these productive systems face new challenges to prevent negative consequences to the environment and to guarantee adequate profit.

Commodity shrinkage associated to handling and storage of feedstuffs and variation in composition of ingredients of the rations, are key factors that might reduce the efficiency of the feeding system of dairy farms by increasing losses and reducing the accuracy and precision of ration formulation, which ultimately affects performance of the cows and reduces profitability.

The objective of this project was to estimate shrink of mineral supplement due to handling and storage in 5 dairies, and to do a deviation analysis of the amounts of ingredients loaded to the mixing wagon for ration formulation.

## MATERIALS AND METHODS

Five dairies of size between 500 – 2000 cows milked per day, and located around Fort Collins, Colorado, were visited 2 times daily during the morning and afternoon feeding times to take feed samples and track inventory and daily expenses of mineral supplement. Length of sampling period was different for each dairy, depending on how many days were needed for the mineral inventory to be consumed.

### ***Description of evaluated dairies***

Selection of dairies was based on similarities among the feeding systems. All of them had a total mixed ration (TMR) system, with bulk storage of mineral supplement at the farm. Mineral supplement was delivered by truck and the weight of mineral purchased was recorded by the truck scale at each dairy.

Each dairy was equipped with loader and mixing trucks that were used for mixing of the ingredients. Mixing trucks had a computerized scale displaying instructions for the operator in terms of adding sequence and amounts required for every ingredient according to the load being prepared. Detailed information on every load prepared was sent wireless to a computer at each dairy, allowing recording and collecting the amounts of ingredients used for every load mixed.

In the dairies evaluated, the mineral supplement was premixed with other concentrated ingredients like grain, additives, and dry by-products, before being included in the TMR as one whole ingredient, usually called premix or grain mix. Premixing of mineral supplement with other ingredients allows for more efficient feeding management and better mixing of ingredients included at a low rate such as the case with minerals; therefore, all sampling activities were adjusted to the daily work routine of each dairy.

Dairies 1 through 4 prepared one or more loads of premix every 1 – 2 d depending on availability and requirement of premix for the rations of the next day. However, dairy 5 mixed 57% of the mineral supplement pile (as fed weight) into premix right after mineral supplement was delivered at the farm, and then 5 d later the remaining 43% was mixed before the first batch of premix was totally consumed. Therefore for dairy 5, a large amount of mineral supplement was stored as premix.

### *Collection and processing of feed samples*

Both mineral supplement and TMR were sampled every day in the morning and in the afternoon, according to the feeding schedule of every farm. Then, 2 samples of mineral and 2 samples of TMR were collected every day at each dairy.

Mineral supplement samples were taken with a plastic scoop from the front side of the pile by mimicking the action of the bucket of the loader while loading the mineral for mixing. In the case of TMR, feed bunks of every pen were sampled by hand right after delivery of the ration and before cows started eating. For each dairy and feed, morning and afternoon samples were kept separated and put into plastic 0.95 L storage bags. All samples were put in a cooler with ice packs immediately after collection, and transferred to a freezer at -20°C at the end of the day to be stored for approximately 2 mo until thawed for processing. Once thawed, both morning and afternoon samples were combined into daily composite samples for every feed and dairy tested. Then the composite samples were weighed and dried in a 60°C oven for 48 h to partially remove moisture. After obtaining the 60°C dry weights, all the samples were ground through a 2mm screen for further analysis.

### *Nutrient composition analysis of feed samples*

Mineral supplement and TMR samples were analyzed for: dry matter (DM; method 2.2.4 of National Forage Testing Association methodology; Shreve et al., 2006), crude protein (CP; method 920.176; AOAC, 1995), acid detergent fiber (ADF) and neutral detergent fiber (NDF) (Van Soest et al., 1991 adapted for the ANKOM® fiber analyzer). Mineral content of samples was also analyzed for: Ca, Mg, K, Na (Method 956.01; AOAC, 1995), P (method 965.17; AOAC, 1995), Co, Cu, Fe, Mn, Mo, S, and Zn (method 965.17; AOAC, 1995).

Additionally, total digestible nutrients (TDN) and energy concentration (digestible energy = DE, metabolizable energy = ME, net energy for maintenance = $NE_m$, net energy for gain = $NE_g$, and net energy for lactation = $NE_l$) of samples were estimated based on their nutrient composition according to NRC equations (NRC, 2001).

### *Tracking of weather parameters*

With respect to weather parameters, wind speed ($km \cdot h^{-1}$), temperature (°C), and relative humidity (%), were measured every day at each dairy using a portable Kestrel® meter model 4500.

Every day the weather tracker was set up next to the mineral pile before morning feeding to record the local weather conditions continuously until afternoon feeding time with a set tracking frequency of 30 s. Once afternoon feeding was done, the weather tracker was disassembled and data were uploaded to a personal computer. Daily average weather parameters were calculated for each farm analyzed.

### *Data analysis*

Statistical analysis of data was performed with SAS® 9.3. Means procedure was used to obtain descriptive statistics on nutrient composition of TMR and mineral supplement samples to evaluate average composition of ingredients as well as within-dairy and among-dairies variation.

## Estimation of shrinkage

Each dairy provided a report with the breakdown of the weight of the ingredients for all the TMR and premix loads that were mixed during the sampling period. This information was used to estimate how much from the mineral supplement purchased was actually mixed, and then indirectly estimate shrinkage as the losses during storage and handling, by estimating the difference between the amount of mineral purchased and the amount loaded to the mixer.

Shrinkage of individual nutrients was also estimated by multiplying the amounts of mineral supplement by the corresponding concentration of each nutrient. All the shrink estimates were calculated on a dry basis, and expressed as percentage of the total amount of mineral or nutrient initially purchased.

Significance of percent shrink was analyzed with a paired t-test (t-test procedure of SAS ) by comparing shrink estimate of every dairy to a theoretical zero shrinkage to calculate the difference (D), then the D values for the 5 dairies ($n = 5$) were hypothesis tested to determine if the average D was significantly different from zero ($H_0 : D = 0$).

## Estimation of slope for change in nutrient concentration of mineral supplement

Data on daily concentration of nutrients in the mineral pile over storage time were used to perform a simple regression analysis with proc reg of SAS to estimate the average slope ($m$) of the change in concentration of every nutrient during storage for each dairy.

Correlation coefficients ($r$) between nutrients slopes and weather parameters, and between nutrients slopes and nutrient composition of TMR were evaluated with proc corr of SAS to estimate the magnitude and significance of each possible correlation.

## Deviation analysis of ration ingredients

An ingredient deviation analysis was done to every load mixed during the sampling period, by comparing the amount of ingredient targeted to the amount actually loaded to the mixer. Since the ingredients used for ration formulation were similar among dairies but not exactly the same, the ingredients were sorted into 4 categories as follows: premix, hay, corn silage, and high moisture by-products (either corn distillers grains or brewers grains).

Deviations were expressed on an as fed basis and as a percentage of the targeted amount, negative deviations being indicative of a smaller than targeted amount of the ingredient loaded to the mixing truck, and the opposite holding true for positive deviations.

To evaluate the impact of formulation accuracy and weather on TMR composition, correlation analysis was performed between ingredients deviation estimates and weather parameters, and between ingredients deviation estimates and TMR nutrient composition using corr procedure of SAS to estimate magnitude and significance of each correlation coefficient (*r*).

## RESULTS AND DISCUSSION

### *Nutrient composition of mineral supplement and TMR*

#### Content of DM, CP, ADF and NDF

Main macro nutrients and components of mineral supplement and TMR of the dairies evaluated can be observed in Table 10. Average concentration of DM in the supplement ranged between 87.64 and 96.62 for the 5 dairies, showing a relatively low variation, with diary 2 being the one with the highest coefficient of variation and lower average for this component, which makes sense when considering that this dairy was the only one storing the mineral under no roof and therefore having an increased exposure to moisture from the environment. Ration DM also showed lower relative variation than the other major components; however dairy 5 showed higher variation than the others, indicating a probable influence of other ration ingredients with variable DM content.

As one of the most important nutrients to consider in dairy cattle diet formulation, it was observed that mineral supplements were very different in terms of mean CP content, ranging between 2.74 and 39.56%, indicating the flexibility of TMR feeding systems to use different feedstuffs and proportions according to convenience; however, larger coefficients of variation were observed for CP compared to DM content of mineral supplement, indicating certain susceptibility to variation in nitrogen content, which probably corresponds mostly to non-protein nitrogen, vulnerable to gaseous losses, especially under conditions of increased exposure to the sunlight and moisture, as was the case of mineral supplement in dairy 2 showing the largest coefficient of variation for this nutrient. However, estimated variability in CP content of TMR is fairly small, as reflected in coefficients of variation of 1.87 – 7.44% for every dairy, and an overall coefficient of 5.37%, which is lower than the 12.05% reported by James and Cox (2008) after evaluating TMR of 10 dairies in Virginia over a 12 mo period, for herds averaging 270 – 390 lactating cows producing 27 – 30 kg•d$^{-1}$ of milk.

Average CP content of TMR in this study ranged between 16.79% and 18.83%, while according to NRC (2001), diet concentration of CP for high producing Holstein cows in midlactation should be 16 – 16.7% depending on productive level. It means that the 5 dairies could be overfeeding protein to some extent, which would depend greatly on dry matter intake of cows. Such protein excess might not have a negative impact on milk production, and could eventually increase it; however, the economic and environmental cost of that protein excess should be considered. Diets containing 19% CP or more have been reported to impair reproductive performance (NRC, 2001), in the case of this study, dairy 3 not only had the highest CP concentration in the ration (18.83%), but also maximum protein levels surpassed 21%, which could increase the risk of reproductive issues.

For fiber fractions of mineral supplement, Table 10 shows similar contents for dairies 1, 2, 3, and 4, and higher values for both NDF and ADF in the case of dairy 5, which indicates how mineral formulations may vary from one dairy to another, being custom formulated according to the particular requirements and conditions of every farm. In 4 out of the 5 dairies evaluated, either ADF or NDF in the mineral supplement was the component with higher CV when compared to DM and CP, which indicates either more susceptibility to change under the influence of external factors like weather, or uneven distribution of particles with high fiber content within the mineral supplement formula. Concentration of fiber fractions in the ration is of considerable importance in dairy cattle nutrition; ideally rations should have 17 – 21% ADF and 25 – 33% NDF; these limits would guarantee the diet has adequate digestibility and also fiber content low enough to allow for adequate intake and at the same time high enough to prevent ruminal acidosis problems (NRC, 2001). Rations of dairies 1 and 5 show a higher than recommended average ADF concentration, and NDF levels of TMR in dairies 2 and 5 also exceed the ideal levels, which could reduce intake, and affect the supply of other nutrients to the cow even when formulated in the right concentration; this could be an issue, especially in dairy 2 with an average NDF of 35.8% and a maximum of 40.1%. For dairies 2, 3, and 4, ADF showed higher variation than DM and CP, suggesting that even when average ADF content of TMR meets NRC (2001) recommendations, variation might affect precision of TMR fiber composition.

## Energy concentration

As shown in Table 11, energy content expressed in its different fractions, was the least variable among all the nutrients and components evaluated, with coefficients of variation of 0.32 – 7.22 and 0.38 – 3.51 for mineral supplement and TMR, respectively. Coefficients of variation for all the energy fractions were larger for dairy 2, which might be related to the large variation in CP and fiber content observed in that dairy, since both components are included as factors in the equation for TDN and energy estimation.

Energy concentration of the ration expressed as $NE_l$ was sufficient to fulfill energy requirements of high producing Holstein dairy cows in midlactation requiring a concentration between 1.55 and 1.61 $MCal•kg^{-1}$ depending on average milk production (NRC, 2001). Dairies 3 and 4 showed an average TMR energy concentration slightly greater than recommended (1.63 and 1.62 $MCal•kg^{-1}$, respectively). Such small excess might help cows better managing negative energy balance during peak lactation or might be helpful as a tradeoff for reduced intake when fiber concentrations of the ration exceed the maximum recommended; however, in such cases body condition score should be carefully monitored to avoid over-conditioned cows by the end of lactation or dry period.

## Macro-mineral composition

Average macro-mineral composition of TMR and mineral supplement samples of the 5 dairies is shown in Table 12. Average content of Ca, P, K, Mg, Na, and S in the mineral supplement looks very diverse among dairies, as indicated by the large overall coefficients of variation of 26.43, 95.0, 72.85, 60.48, 47.03, and 36.13 for those minerals, respectively. However, it is not expected that all mineral supplements have the same concentration of macro-minerals, since they are formulated to complement different rations and are fed to herds differing in milk production and other conditions. Coefficients of variation for concentrations of Ca, P, K, Mg, and Na in the mineral supplement for dairy 2 were larger than same coefficients for other dairies, which may suggest that particular conditions of dairy 2, like absence of a roof covering the mineral pile, might have promoted variation in macro-mineral concentration.

Dietary concentrations of 0.67 – 0.6% Ca, 0.36 – 0.38% P, 1.06 – 1.07% K, 0.20 – 0.21% Mg, 0.22% Na, and 0.20% S, are recommended for high producing Holstein cows in midlactation (NRC, 2001). As observed in Table 12, with the exception of P content in TMR of dairies 4 and 5, which is in the upper limit recommended, the concentrations of other macro-minerals in the rations exceeded the recommendations, which could increase excretion of those minerals in manure, but adverse effects in production would not be expected at those levels (NRC, 2001). The most accurately balanced macro-minerals in the TMR are P and S, with average excesses of 10.5% and 25% over the recommended concentration; the reasons to keep both minerals closer to the requirement than the others are probably the elevated cost of P, and the risk of S toxicity and polioencephalomalacia.

Interestingly, when variance of the TMR macro-mineral content is analyzed, higher coefficients of variation are observed for most of these nutrients in dairies 2 and 3 as compared to the other dairies. Additionally, higher overall coefficients of variation were estimated for macro-minerals than for DM, CP, ADF, NDF, and energy fractions analyzed, particularly for Na having a high coefficient of 19.23, which might be partly due to high variation in Na content of distillery products as has been previously reported (Liu, 2011). Overall the coefficient of variation for P (7.14%) was smaller than for the other macro-minerals, and smaller than the 10.26% reported by James and Cox (2008) for rations of dairy cows averaging 0.39% P with a range between 0.29% and 0.51%.

## **Trace-mineral composition**

Very different average concentrations of trace-minerals were observed among the mineral supplements of the dairies evaluated (Table 13), and also high within-dairy coefficients of variation between 3.63 and 218.8 were obtained across the different minerals evaluated, which probably relates to the low concentrations of these nutrients in the supplement.

In the case of TMR, the concentrations of all the trace-minerals evaluated exceeded the minimum requirement (NRC, 2001), which means that no deficiencies would be expected due to a low supply of these nutrients in the diet. However, excess of some minerals and interactions should be evaluated as well, especially when high average levels of some trace-minerals are present in the ration, and variation in their concentration is large, which is the case for most of these nutrients, since they showed larger coefficients of variation than any other component or nutrient in the ration, being the overall coefficients within the range 13.60% – 62.50%.

Average concentration of Al in TMR varied from 151.45 to 615.96 ppm, with an overall average concentration of 410.58 ppm. These concentrations are below the maximum 1000 ppm recommended by NRC (2001); however, for dairy 2 some samples exceeded that limit with a maximum observed concentration of 1120 ppm, which could eventually interfere with the absorption of P.

In regard to average content of Co in the ration, it ranged from 0.39 to 1.09 ppm, exceeding in any case the 0.11 ppm requirement (NRC, 2001), but far enough from the toxicity level of 10 ppm. Ration average Cu content was the best balanced trace-mineral, with an overall mean concentration of 15.37 ppm to fulfill the 11 ppm requirement established by the NRC (2001).

Maximum levels of inclusion for both Fe and Mn in dairy cattle diets have been set at 1000 ppm (NRC, 2001); showing that the average concentration of these trace-minerals in the study (Table 13) are within the cautious levels recommended for dairy cattle to prevent toxicity problems, even in the case of Fe which reached high concentrations of 818 ppm in dairy 2.

NRC (2001) recommends levels of Zn to be less than twenty-fold the requirement of 52 – 55 ppm to prevent toxicity problems usually associated to reduced absorption of Cu due to increased production of metallothionein binding protein, which sequesters Cu and is promoted by high levels of Zn in the diet. However, Zn concentrations of TMR observed in Table 13 range between 70.19 and 172.09 ppm, being very distant from the toxicity limit of 1100 ppm.

Although no requirements have been established for Mo, it is important to control the presence of this mineral in the diet to prevent toxicity problems which are usually related to antagonistic relations to the absorption of other minerals. However, the average concentrations of Mo observed in the rations (0.83 – 1.33 ppm), indicate that content of this mineral is low enough (< 5 – 10 ppm) to prevent a negative interaction with Cu absorption (NRC, 2001).

### *Estimated shrinkage of mineral supplement and nutrients*

A description of the conditions for storage of mineral supplement of the dairies is provided in Table 14, showing that 4 of the evaluated dairies stored the mineral in roofed sheds; however, in the case of dairy 2, storage conditions were different since a 2 sided open bay was used to store the mineral which was covered with a tarp to give it some protection against the elements.

The 5 dairies in the study purchased similar amounts of mineral, ranging between 21,736 and 24,086 kg, which corresponds to a semi-truck load, being the differences in purchased weight probably due in part to different components and density for each product. However, besides similar amounts of mineral supplement were bought in each dairy, very different lengths of storage periods were observed (from 7 to 51 d), depending mostly on the daily mineral expenses of each dairy, which is related to the rate of inclusion of the mineral in the TMR, but mainly to the size of each farm and the number of cows milked and fed per day.

Total shrink of the mineral supplement, estimated as storage and handling losses, and expressed on a dry basis, ranged from 0.63% to 3.19% of the total mineral supplement initially purchased. Such wide range of shrinkage suggests that different management practices might influence losses of mineral supplement during storage and daily handling. However, as a word of caution, it is important to mention that in the case of dairy 5, the fact of mixing 57% of the mineral supplement into the premix on the same day of mineral delivery, and consequently storing a large amount of premix, might have reduced the mineral losses directly from the mineral pile and increased the losses out of the premix pile instead, however premix shrink was not evaluated in this study which might cause an underestimation of real mineral losses for dairy 5 in comparison to the other 4 farms.

No estimates of shrinkage for mineral supplements have been previously reported in the literature. However, for other feedstuffs like hay, silage, distillers grains and dry grains, some estimates suggest a wide range for shrink losses between 1 and 40% depending on factors such as moisture content of the feed, storage conditions, and handling (Standaert et al., 1994; Loy, 2010; Kertz, 1998). The smallest shrink estimates have been reported for feeds with high concentration of DM and nutrients, like dry grains with estimated shrink losses of 2 – 8% (Standaert et al., 1994; Loy, 2010). However, shrink estimates for mineral supplement obtained in this study are even lower than that, which might be partly due to its low level of inclusion in the ration requiring different or extra management practices like premixing before being included in the TMR, which could help reducing losses as well.

Interestingly, as shown in Table 14, dairy 3 had the longest storage period (51 d) and also had the lowest shrink estimate (0.63%), which suggests the importance of handling as a factor influencing total shrink of mineral supplement. In this sense, dairy 4, showing the largest shrink estimate (3.19%), had particular storage conditions related to the size of the shed, since the most external side of the pile did not fit into the shed under the roof and had an increased exposure to the elements, including the rainy conditions that prevailed during the sampling period of that dairy in particular.

Table 15 shows the average shrink estimates for total DM and individual nutrients and components of the mineral supplement. A significant shrink was estimated for total DM of mineral supplement, averaging 1.97% ($P = 0.02$) for the 5 dairies evaluated. With an average load size of 22,605 kg as fed with 91% DM, on average each dairy is purchasing 20,570 kg DM of mineral supplement; therefore with a mean shrink of 1.97% they are having average losses of 405 kg DM of supplement approximately every 22 days, which are going to the soil, water sheds, or somewhere else but the ration.

Additionally, shrink estimates of 3.03% ($P = 0.03$), 3.93% ($P = 0.01$) and 3.34% ($P = 0.02$) were obtained for CP, ADF, and NDF, respectively, being the nutrients with larger shrink estimates together with Fe which was estimated to shrink 3.35% ($P = 0.01$). The shrink estimates for energy fractions were all within the range of 1.81 – 1.87% ($P = 0.02$), and for macro-minerals only K, Na, and S showed significant shrinkages of 2.37% ($P = 0.05$), 1.77% ($P = 0.01$), and 2.07% ($P = 0.008$), respectively. In the case of trace-minerals, Co, Cu, Mn, and Zn shrank significantly by 2.33% ($P = 0.03$), 2.25% ($P = 0.04$), 2.80% ($P = 0.002$), and 2.42% ($P = 0.01$). No significant shrink was estimated for Ca, P, Al and Mo, and a trend to 2.80% shrinkage was observed in the case of Mg ($P = 0.06$).

Apparent greater shrink estimates observed in fiber fractions and CP in comparison to other nutrients and components might be a consequence of less dense particles of fiber being more susceptible to losses during storage and handling, and gaseous loss of nitrogen in the form of ammonia after degradation of urea from the mineral supplement when exposed to the environment.

### *Slope of change in nutrient concentration of mineral supplement over storage*

Based on the hypothesis that some nutrients in the mineral supplement could be more susceptible to changes in concentration over storage than others, slope analysis was done to the concentration of nutrients of mineral piles.

Tables 16 and 17 show the estimated slopes for change in concentration of the main nutrients and components of mineral supplement for the 5 dairies evaluated. As can be observed, there was no nutrient which concentration significantly changed at each of the 5 dairies evaluated. Conversely, for some of the dairies most of the nutrients showed a significant slope of change in concentration. Therefore, instead of a nutrient-wise tendency, there seems to be a dairy based tendency, suggesting the importance of particular management and storage characteristics at each dairy on slope of change in concentration of nutrients of the mineral supplement. For dairies 2 and 3 a significant slope of change was estimated in the concentration of the majority of the nutrients evaluated ($P < 0.05$), with the exception of Al, Fe, Mn, and Zn for dairy 2; and CP, P, K, and Na for dairy 3. Meanwhile, for the other dairies only the slopes of a few nutrients were significant ($P < 0.05$): DM, CP, Al, and Cu for dairy 1; NDF, K, Al, Co, and Fe for dairy 4; and CP, ME, and P for dairy 5.

It is important to take into account particular conditions of mineral supplement storage for dairies 2 and 3 that might be influencing changes in concentration of nutrients over storage. In the case of dairy 2 (Table 14), mineral was not stored under roof and only covered with a tarp, which would presumably increase the exposure of the pile to the prevailing environmental conditions; dairy 3 presented a particularly long storage period of 51 d for the mineral supplement. Both factors –protection against elements and storage length- might be playing an important role in changes in nutrient concentrations of the mineral in those farms, and consequently increasing the number of nutrients with significant slopes in their concentrations.

Additionally, the correlations between slope of change in nutrient concentration of mineral supplement and either weather parameters or TMR nutrient concentration were analyzed. The objective was to evaluate if any of the weather parameters was associated with the changes in nutrient concentration of the mineral supplement, and also if such changes were associated to final composition of the ration. As shown in Tables 18 and 19, no significant interactions were found for DM, CP, ADF, NDF or any of the energy fractions evaluated. Moreover, it can be observed in Tables 20 and 21 that significant correlations ($P < 0.05$) were found between TMR final concentration and slopes for Na (-0.95), Mn (0.96), and Zn (0.98), which indicates that as concentration of Mn and Zn in the mineral supplement increased during storage, the concentration of those same minerals in the TMR also increased. In the case of Na, the negative correlation indicates that concentration of this mineral decreases in TMR as it increases in the mineral supplement; however, as correlation does not necessarily indicate causation, it could be a confounding effect not being accounted for in the analysis, like the highly variable Na concentration of distillers that could be influencing TMR composition (Liu, 2011). Also a positive correlation ($r = 0.99$; $P < 0.05$) was found between slope of Co concentration and average temperature, which might have a different reason than temperature effect, like the case of Na.

Moreover, it might be possible that only a few significant correlations were obtained between slope of nutrients and either TMR composition or weather variables, as a consequence of variability and lack of consistency and significance of slope estimates for most of the nutrients across the dairies evaluated.

### ***Deviation of TMR ingredient composition from formulation standards***

It has been reported that one of the factors influencing the precision and accuracy of the amounts of ingredients loaded to the mixing truck is the skills of the person driving the loader (Buckmaster, 2009). The busy feeding schedule at the dairies and the multiple loads of TMR that should be mixed every day both in the morning and in the afternoon, make the driver sometimes under or over-dose ingredients to save time by reducing the number of trips between the mixing truck and the ingredients piles.

As part of the analysis of this study, Table 22 shows the average deviation for TMR ingredients at each of the 5 farms evaluated. Overall mean deviations of 5.61, 4.42, 0.87, and 0.64% were estimated for hay, high moisture by-products, premix, and corn silage, respectively. However, it was observed that even for the same ingredient, very different average deviations were estimated among dairies. When compared to the other 4 dairies, dairy 5 showed a larger mean deviation for all the ingredients evaluated; this dairy had the least accurate loading of ingredients for TMR mixing. Additionally, dairy 4 was the only farm showing negative deviations for 3 out of the 4 feedstuffs (hay, corn silage, and premix) indicating that on average smaller amounts than required of those feeds were loaded to the mixer at that particular dairy; however, for the other 4 dairies all of the mean deviations were positive.

Precision of loading ingredients to the mixing wagon can be analyzed by evaluating the coefficients of variation for average deviations. A larger coefficient of variation for average deviations of hay, corn silage, and premix was obtained for dairy 4, followed by dairy 5 with the second largest coefficient of variation for those same 3 ingredients, which indicates lower precision while preparing the loads of dairies 4 and 5.

Errors in TMR formulation and variation of those errors, as indicators of accuracy and precision of ration formulation, respectively; can be influenced by a series of factors involving both operator skills and maintenance or calibration of the equipment (Buckmaster, 2009). Furthermore, ingredient deviation can vary among different feedstuffs. However, significant differences in loading accuracy between dairies have already been reported and mostly attributed to operator disposition and ability (James and Cox, 2008).

Variation of deviations expressed as coefficient of variation, can also be influenced by multiple operators in charge of loading and mixing (James and Cox, 2008). However, in this aspect all the dairies evaluated in this study had a very similar management, having a primary driver in charge of the feeding routine 6 d of the week and a second driver usually in charge of loading and mixing either Saturdays or Sundays.

## Correlation between deviation of ingredients and concentration of nutrients of TMR

Correlation estimates between deviation of ingredients and concentration of nutrients in the TMR samples of the 5 dairies evaluated are presented in Table 23. A significant positive correlation ($P < 0.05$) was estimated between deviation of hay and DM ($r = 0.50$), ADF ($r = 0.27$), NDF ($r = 0.39$), and Mg ($r = 0.64$) content of the ration, indicating that when an excess of hay is included in the ration, the concentration of those nutrients increases as well. Conversely, when hay is included above the formulation standards, a reduction in concentration of TDN ($r = -0.27$), $NE_m$ ($r = -0.28$), $NE_g$ ($r = -0.27$), Mn ($r = -0.46$), and Zn ($r = -0.42$) occurs in the ration ($P < 0.05$).

For deviation of corn silage inclusion in the ration, was estimated a positive correlation ($P < 0.05$) to ADF ($r = 0.26$), NDF ($r = 0.27$), K ($r = 0.26$), and Mg ($r = 0.39$); and a negative correlation ($P < 0.05$) to TDN ($r = -0.26$), ME ($r = -0.25$), $NE_m$ ($r = -0.25$), $NE_g$ ($r = -0.27$), Mn ($r = -0.26$), and Zn ($r = -0.37$). This means that excess corn silage included in the ration increased fiber content and some macro-mineral cations while reduced the concentration of energy, Mn and Zn.

Similar effects in TMR composition were estimated for deviations in the inclusion of both roughage sources: hay and corn silage; in both cases explaining around 26 – 39% of the variance observed in TMR content of fiber fractions, 25 – 28% of the variance in energy fractions concentration, and 26 – 42% of the variance in Mn and Zn content (Table 23). However, coefficients of correlation estimated for hay were greater than those for corn silage, suggesting a greater impact of hay loading inaccuracy on TMR final composition. These results coincide with previous research reporting that impact of loading inaccuracy is larger when the nutrient concentration of the ingredient is very different (lower or higher) than that of the ration (Buckmaster and Muller, 1994), like hay in this case.

In the case of high moisture by-products, namely brewer or corn distillers grains, deviation was positively correlated ($P < 0.05$) to TMR concentration of CP, K, and Mg; and a negative correlation ($P < 0.05$) was found for P and Na content of the ration (Table 23). Additionally, a tendency to a positive correlation was observed for S ($P = 0.06$), and no significant correlations were obtained for trace-minerals. Based on published data on average composition of distillery by-products, a positive correlation would be expected between deviation of wet by-products loading, and concentration of CP and some macro-minerals in TMR, specially P and S. However, the large variation in nutrient composition of these type of by-products has also been highlighted, variation in mineral content was particularly large in comparison to other nutrients. This is especially the case of some minerals such as S, Na, and Ca that sometimes can be increased by exogenous addition of some compounds during processing (NRC, 2001; Batal and Dale, 2003; Liu, 2011). Another aspect to take into consideration is that weighing of ingredients before mixing is performed on an as fed basis, so deviations are calculated based on as fed weights, which increases variation in TMR composition, particularly for high moisture by-products like distillers and brewers grains that not only are highly variable in DM content, but also most of the times stored in a bay with no roof, like the case of the 5 dairies in this study, which increases variation of DM content.

Furthermore, concentrations of NDF and Mg in the TMR were positively correlated ($P < 0.05$) to deviation of premix included in the formulation of the dairy rations evaluated. Conversely, a negative correlation ($P < 0.05$) was estimated for $NE_g$ and Zn. It is unlikely to think that overloading of premix would increase NDF concentration and decrease energy and Zn content of the ration, since this composite ingredient includes corn and mineral supplement, which have a low fiber content and in the case of supplement, a high content of Zn. However, some by-products like whole cotton seed, canola meal and soybean meal, are also added to the premixes, increasing not only their fiber content but also their variation in composition, which besides loading accuracy is the other main factor affecting composition of TMR (Buckmaster and Muller, 1994; Buckmaster, 2009).

# CONCLUSIONS

Significant average shrink of mineral supplement due to storage and handling were found for the dairies evaluated. Shrinkage implies losses of purchased nutrients, going to the soil, water or components of the system other than the ration to be consumed by the cows. The impact of such losses of nutrients cannot be mitigated by the waste management system of the dairy, which increases the importance of controlling these losses in the system.

Correlations between the concentration of some nutrients in the ration and the slopes for change in concentration of those nutrients in the mineral pile during storage, suggests that management strategies to reduce change in composition of mineral supplement might help increase accuracy of formulation.

Additionally, lack of accuracy in ration formulation was correlated to nutrient concentration of TMR, which might affect cattle performance, but also excretion of some nutrients to the environment. These results suggest that keeping track of operator loading error might be essential to prevent inadequate nutrient supply to dairy cows.

Table 10. Descriptive statistics for DM content, CP, ADF, and NDF composition of mineral supplement and TMR.

| Variable[1] | dairy | *n* | Supplement | | | TMR | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | SD | CV | Mean | SD | Min. | Max. | CV |
| DM | 1 | 14 | 95.06 | 1.29 | 1.36 | 56.80 | 0.85 | 55.22 | 58.04 | 1.50 |
| | 2 | 25 | 87.64 | 3.04 | 3.46 | 48.72 | 1.23 | 46.48 | 52.2 | 2.53 |
| | 3 | 8 | 96.62 | 0.28 | 0.29 | 60.09 | 1.45 | 56.86 | 61.51 | 2.42 |
| | 4 | 11 | 89.33 | 1.04 | 1.17 | 54.10 | 1.60 | 51.28 | 57.51 | 2.96 |
| | 5 | 6 | 91.90 | 0.51 | 0.55 | 47.03 | 1.40 | 44.48 | 48.34 | 2.98 |
| | Overall | 64 | 91.08 | 4.09 | 4.49 | 52.68 | 4.68 | 44.48 | 61.51 | 8.88 |
| CP | 1 | 14 | 19.59 | 2.24 | 11.45 | 17.49 | 0.56 | 16.75 | 18.36 | 3.23 |
| | 2 | 25 | 2.74 | 0.98 | 35.82 | 16.79 | 0.40 | 16.11 | 17.44 | 2.41 |
| | 3 | 8 | 21.63 | 1.03 | 4.77 | 18.83 | 1.40 | 17.12 | 21.36 | 7.44 |
| | 4 | 11 | 30.66 | 3.31 | 10.81 | 17.70 | 0.36 | 17.27 | 18.34 | 2.05 |
| | 5 | 6 | 39.56 | 0.56 | 1.42 | 18.39 | 0.34 | 17.86 | 18.85 | 1.87 |
| | Overall | 64 | 17.04 | 13.01 | 76.35 | 17.50 | 0.94 | 16.11 | 21.36 | 5.37 |
| ADF | 1 | 14 | 1.69 | 0.26 | 15.38 | 22.33 | 0.68 | 21.37 | 23.69 | 3.05 |
| | 2 | 25 | 1.46 | 0.45 | 30.94 | 20.62 | 1.29 | 17.68 | 24.12 | 6.27 |
| | 3 | 8 | 1.60 | 0.43 | 26.63 | 18.15 | 1.96 | 16.03 | 21.13 | 10.81 |
| | 4 | 11 | 1.76 | 0.50 | 28.36 | 18.65 | 0.80 | 17.45 | 20.06 | 4.28 |
| | 5 | 6 | 6.11 | 0.47 | 7.76 | 21.29 | 0.41 | 20.66 | 21.72 | 1.94 |
| | Overall | 64 | 2.02 | 1.39 | 68.81 | 20.41 | 1.84 | 16.03 | 24.12 | 9.02 |
| NDF | 1 | 14 | 5.55 | 1.13 | 20.37 | 32.98 | 0.88 | 31.9 | 34.58 | 2.66 |
| | 2 | 25 | 3.44 | 1.18 | 34.24 | 35.80 | 1.85 | 31.11 | 40.10 | 5.16 |
| | 3 | 8 | 5.24 | 0.58 | 11.01 | 31.33 | 2.04 | 28.93 | 34.49 | 6.53 |
| | 4 | 11 | 3.74 | 0.58 | 15.59 | 30.44 | 1.23 | 28.95 | 32.32 | 4.05 |
| | 5 | 6 | 15.82 | 1.31 | 8.26 | 33.38 | 0.90 | 32.14 | 34.9 | 2.71 |
| | Overall | 64 | 5.34 | 3.66 | 68.54 | 33.48 | 2.57 | 28.93 | 40.10 | 7.68 |

[1] Percentage of total dry matter, except for DM expressed on an as fed basis.

Table 11. Descriptive statistics for energy concentration of mineral supplement and TMR.

| Variable[1] | dairy | *n* | Supplement |  |  | TMR |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Mean | SD | CV | Mean | SD | Min. | Max. | CV |
| $NE_l$ | 1 | 14 | 2.25 | 0.01 | 0.42 | 1.57 | 0.01 | 1.54 | 1.59 | 0.90 |
|  | 2 | 25 | 2.23 | 0.10 | 4.69 | 1.59 | 0.02 | 1.54 | 1.63 | 1.21 |
|  | 3 | 8 | 2.26 | 0.02 | 0.71 | 1.63 | 0.03 | 1.59 | 1.65 | 1.67 |
|  | 4 | 11 | 1.88 | 0.02 | 0.83 | 1.62 | 0.01 | 1.61 | 1.63 | 0.65 |
|  | 5 | 6 | 1.81 | 0.01 | 0.45 | 1.58 | 0.01 | 1.57 | 1.59 | 0.65 |
|  | Overall | 64 | 2.14 | 0.18 | 8.41 | 1.60 | 0.03 | 1.54 | 1.65 | 1.88 |
| $NE_g$ | 1 | 14 | 1.81 | 0.01 | 0.41 | 0.98 | 0.01 | 0.97 | 1.01 | 1.24 |
|  | 2 | 25 | 1.78 | 0.13 | 7.22 | 1.02 | 0.03 | 0.95 | 1.08 | 2.71 |
|  | 3 | 8 | 1.80 | 0.02 | 0.83 | 1.06 | 0.04 | 1.01 | 1.10 | 3.51 |
|  | 4 | 11 | 1.36 | 0.01 | 0.89 | 1.05 | 0.01 | 1.04 | 1.08 | 1.23 |
|  | 5 | 6 | 1.28 | 0.01 | 0.64 | 1.00 | 0.01 | 0.99 | 1.01 | 1.10 |
|  | Overall | 64 | 1.67 | 0.22 | 13.17 | 1.02 | 0.04 | 0.95 | 1.10 | 3.92 |
| $NE_m$ | 1 | 14 | 2.52 | 0.02 | 0.68 | 1.71 | 0.01 | 1.68 | 1.72 | 0.76 |
|  | 2 | 25 | 2.50 | 0.13 | 5.11 | 1.74 | 0.02 | 1.68 | 1.79 | 1.25 |
|  | 3 | 8 | 2.53 | 0.02 | 0.63 | 1.78 | 0.04 | 1.72 | 1.83 | 2.20 |
|  | 4 | 11 | 2.08 | 0.01 | 0.45 | 1.77 | 0.02 | 1.74 | 1.79 | 1.04 |
|  | 5 | 6 | 2.01 | 0.01 | 0.61 | 1.73 | 0.01 | 1.72 | 1.74 | 0.60 |
|  | Overall | 64 | 2.39 | 0.22 | 9.21 | 1.74 | 0.03 | 1.68 | 1.83 | 1.72 |
| ME | 1 | 14 | 3.51 | 0.01 | 0.38 | 2.49 | 0.02 | 2.47 | 2.51 | 0.63 |
|  | 2 | 25 | 3.48 | 0.16 | 4.47 | 2.53 | 0.03 | 2.45 | 2.6 | 1.30 |
|  | 3 | 8 | 3.51 | 0.02 | 0.55 | 2.59 | 0.05 | 2.51 | 2.65 | 1.75 |
|  | 4 | 11 | 2.96 | 0.02 | 0.69 | 2.58 | 0.02 | 2.54 | 2.6 | 0.76 |
|  | 5 | 6 | 2.86 | 0.02 | 0.54 | 2.52 | 0.01 | 2.51 | 2.54 | 0.49 |
|  | Overall | 64 | 3.34 | 0.27 | 8.08 | 2.54 | 0.04 | 2.45 | 2.65 | 1.57 |
| DE | 1 | 14 | 4.28 | 0.02 | 0.41 | 3.04 | 0.02 | 3.00 | 3.06 | 0.59 |
|  | 2 | 25 | 4.24 | 0.20 | 4.52 | 3.08 | 0.04 | 3.00 | 3.17 | 1.17 |
|  | 3 | 8 | 4.29 | 0.02 | 0.50 | 3.15 | 0.05 | 3.06 | 3.22 | 1.73 |
|  | 4 | 11 | 3.61 | 0.01 | 0.39 | 3.14 | 0.02 | 3.11 | 3.17 | 0.52 |
|  | 5 | 6 | 3.49 | 0.02 | 0.61 | 3.07 | 0.02 | 3.06 | 3.09 | 0.50 |
|  | Overall | 64 | 4.08 | 0.33 | 8.09 | 3.09 | 0.05 | 3.00 | 3.22 | 1.62 |
| TDN | 1 | 14 | 96.86 | 0.31 | 0.32 | 68.77 | 0.43 | 67.91 | 69.37 | 0.63 |
|  | 2 | 25 | 95.93 | 4.33 | 4.52 | 69.85 | 0.81 | 67.64 | 71.7 | 1.17 |
|  | 3 | 8 | 96.97 | 0.50 | 0.52 | 71.40 | 1.24 | 69.53 | 72.74 | 1.73 |
|  | 4 | 11 | 81.73 | 0.31 | 0.38 | 71.09 | 0.50 | 70.2 | 71.84 | 0.71 |
|  | 5 | 6 | 78.99 | 0.30 | 0.38 | 69.42 | 0.26 | 69.15 | 69.82 | 0.38 |
|  | Overall | 64 | 92.24 | 7.50 | 8.13 | 69.98 | 1.16 | 67.64 | 72.74 | 1.66 |

[1] Concentration Mcal•kgDM$^{-1}$, except for TDN expressed as percent of dry matter.

Table 12. Descriptive statistics for macro-mineral composition of mineral supplement and TMR.

| Variable[1] | dairy | *n* | Supplement | | | TMR | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | SD | CV | Mean | SD | Min. | Max. | CV |
| Ca | 1 | 14 | 12.06 | 0.51 | 4.26 | 0.83 | 0.04 | 0.76 | 0.93 | 5.06 |
| | 2 | 25 | 13.45 | 1.78 | 13.22 | 0.88 | 0.08 | 0.76 | 1.01 | 8.92 |
| | 3 | 8 | 12.16 | 0.40 | 3.31 | 0.92 | 0.14 | 0.74 | 1.13 | 14.82 |
| | 4 | 11 | 15.27 | 0.36 | 2.38 | 0.74 | 0.13 | 0.56 | 1.02 | 18.05 |
| | 5 | 6 | 3.54 | 0.39 | 11.02 | 0.82 | 0.13 | 0.70 | 0.98 | 15.29 |
| | Overall | 64 | 12.37 | 3.27 | 26.43 | 0.85 | 0.11 | 0.56 | 1.13 | 12.94 |
| P | 1 | 14 | 0.38 | 0.02 | 5.98 | 0.42 | 0.01 | 0.4 | 0.44 | 3.17 |
| | 2 | 25 | 0.05 | 0.04 | 80.83 | 0.44 | 0.03 | 0.38 | 0.49 | 6.47 |
| | 3 | 8 | 0.30 | 0.01 | 4.29 | 0.45 | 0.03 | 0.42 | 0.50 | 6.35 |
| | 4 | 11 | 0.04 | 0.03 | 69.98 | 0.38 | 0.02 | 0.36 | 0.40 | 4.16 |
| | 5 | 6 | 0.55 | 0.02 | 3.73 | 0.38 | 0.02 | 0.36 | 0.42 | 6.35 |
| | Overall | 64 | 0.20 | 0.19 | 95.00 | 0.42 | 0.03 | 0.36 | 0.50 | 7.14 |
| K | 1 | 14 | 2.45 | 0.09 | 3.72 | 1.65 | 0.05 | 1.57 | 1.72 | 3.28 |
| | 2 | 25 | 0.17 | 0.06 | 37.76 | 1.30 | 0.07 | 1.18 | 1.52 | 5.34 |
| | 3 | 8 | 2.45 | 0.07 | 2.97 | 1.66 | 0.07 | 1.52 | 1.74 | 4.26 |
| | 4 | 11 | 2.54 | 0.14 | 5.34 | 1.28 | 0.05 | 1.21 | 1.36 | 3.85 |
| | 5 | 6 | 1.79 | 0.05 | 3.02 | 1.64 | 0.10 | 1.53 | 1.75 | 6.07 |
| | Overall | 64 | 1.51 | 1.10 | 72.85 | 1.45 | 0.19 | 1.18 | 1.75 | 13.10 |
| Mg | 1 | 14 | 2.43 | 0.11 | 4.55 | 0.33 | 0.01 | 0.32 | 0.37 | 3.64 |
| | 2 | 25 | 5.68 | 2.53 | 44.62 | 0.37 | 0.04 | 0.30 | 0.49 | 11.94 |
| | 3 | 8 | 3.95 | 0.12 | 2.97 | 0.37 | 0.03 | 0.31 | 0.41 | 8.38 |
| | 4 | 11 | 2.31 | 0.13 | 5.73 | 0.32 | 0.01 | 0.30 | 0.34 | 3.42 |
| | 5 | 6 | 1.39 | 0.15 | 10.71 | 0.45 | 0.03 | 0.42 | 0.51 | 7.47 |
| | Overall | 64 | 3.77 | 2.28 | 60.48 | 0.36 | 0.05 | 0.30 | 0.51 | 13.89 |
| Na | 1 | 14 | 8.02 | 0.49 | 6.11 | 0.44 | 0.02 | 0.40 | 0.48 | 5.63 |
| | 2 | 25 | 17.45 | 1.99 | 11.43 | 0.64 | 0.04 | 0.59 | 0.74 | 5.60 |
| | 3 | 8 | 7.76 | 0.11 | 1.40 | 0.48 | 0.05 | 0.38 | 0.52 | 9.68 |
| | 4 | 11 | 9.89 | 0.46 | 4.66 | 0.42 | 0.02 | 0.40 | 0.45 | 3.94 |
| | 5 | 6 | 2.13 | 0.15 | 6.84 | 0.44 | 0.02 | 0.42 | 0.47 | 4.50 |
| | Overall | 64 | 11.44 | 5.38 | 47.03 | 0.52 | 0.10 | 0.38 | 0.74 | 19.23 |
| S | 1 | 14 | 0.43 | 0.03 | 7.70 | 0.28 | 0.02 | 0.25 | 0.31 | 5.52 |
| | 2 | 25 | 0.34 | 0.04 | 12.38 | 0.22 | 0.02 | 0.18 | 0.26 | 9.33 |
| | 3 | 8 | 0.42 | 0.06 | 13.96 | 0.27 | 0.02 | 0.25 | 0.32 | 8.23 |
| | 4 | 11 | 0.82 | 0.05 | 5.98 | 0.25 | 0.02 | 0.23 | 0.28 | 6.60 |
| | 5 | 6 | 0.41 | 0.03 | 8.11 | 0.27 | 0.01 | 0.26 | 0.28 | 2.81 |
| | Overall | 64 | 0.46 | 0.18 | 39.13 | 0.25 | 0.03 | 0.18 | 0.32 | 12.00 |

[1] Percentage of total dry matter.

Table 13. Descriptive statistics for trace-mineral composition of mineral supplement and TMR.

| Var.[1] | dairy | *n* | Supplement | | | TMR | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | SD | CV | Mean | SD | Min. | Max. | CV |
| Al | 1 | 14 | 715.43 | 162.64 | 22.73 | 358.36 | 77.81 | 260 | 506 | 21.71 |
| | 2 | 25 | 336.56 | 88.33 | 26.24 | 615.96 | 229.79 | 249 | 1120 | 37.31 |
| | 3 | 8 | 609.63 | 137.17 | 22.50 | 323.38 | 206.76 | 147 | 718 | 63.94 |
| | 4 | 11 | 151.28 | 114.33 | 75.58 | 151.45 | 32.79 | 122 | 236 | 21.65 |
| | 5 | 6 | 489.67 | 40.16 | 8.20 | 268.00 | 73.29 | 203 | 369 | 27.35 |
| | Overall | 64 | 436.08 | 228.60 | 52.42 | 410.58 | 242.24 | 122 | 1120 | 59.00 |
| Co | 1 | 14 | 15.59 | 0.57 | 3.63 | 1.09 | 0.47 | 0.80 | 2.47 | 43.18 |
| | 2 | 25 | 1.63 | 0.47 | 28.61 | 0.52 | 0.46 | 0.00 | 2.11 | 87.39 |
| | 3 | 8 | 12.73 | 1.18 | 9.29 | 0.99 | 0.15 | 0.84 | 1.30 | 14.88 |
| | 4 | 11 | 8.61 | 1.88 | 21.86 | 0.39 | 0.05 | 0.31 | 0.48 | 13.46 |
| | 5 | 6 | 5.56 | 2.73 | 49.16 | 0.89 | 0.04 | 0.83 | 0.95 | 4.35 |
| | Overall | 64 | 7.64 | 5.80 | 75.92 | 0.72 | 0.45 | 0.00 | 2.47 | 62.50 |
| Cu | 1 | 14 | 236.43 | 13.82 | 5.85 | 14.35 | 0.81 | 13.00 | 15.90 | 5.64 |
| | 2 | 25 | 239.64 | 48.28 | 20.15 | 15.90 | 2.82 | 12.70 | 24.00 | 17.76 |
| | 3 | 8 | 194.75 | 30.06 | 15.44 | 16.01 | 1.20 | 14.10 | 17.70 | 7.50 |
| | 4 | 11 | 339.45 | 88.17 | 25.97 | 15.45 | 1.87 | 12.90 | 19.70 | 12.09 |
| | 5 | 6 | 60.20 | 13.37 | 22.21 | 14.52 | 0.44 | 14.20 | 15.30 | 3.00 |
| | Overall | 64 | 233.66 | 85.46 | 36.57 | 15.37 | 2.09 | 12.70 | 24.00 | 13.60 |
| Fe | 1 | 14 | 1329.93 | 66.32 | 4.99 | 248.93 | 33.93 | 203 | 310 | 13.63 |
| | 2 | 25 | 252.56 | 32.51 | 12.87 | 436.84 | 180.50 | 155 | 818 | 41.32 |
| | 3 | 8 | 1380.88 | 289.10 | 20.94 | 285.29 | 118.83 | 184 | 520 | 41.65 |
| | 4 | 11 | 528.82 | 76.66 | 14.50 | 169.73 | 26.51 | 136 | 222 | 15.62 |
| | 5 | 6 | 634.83 | 42.62 | 6.71 | 266.00 | 60.36 | 199 | 328 | 22.69 |
| | Overall | 64 | 712.59 | 493.49 | 69.25 | 315.33 | 160.23 | 136 | 818 | 50.81 |
| Mn | 1 | 14 | 1102.14 | 50.56 | 4.59 | 69.93 | 3.24 | 63.8 | 73.7 | 4.63 |
| | 2 | 25 | 559.68 | 170.32 | 30.43 | 60.44 | 8.40 | 48.7 | 74.2 | 13.89 |
| | 3 | 8 | 869.38 | 109.28 | 12.57 | 77.23 | 4.14 | 70.6 | 84.0 | 5.37 |
| | 4 | 11 | 1571.82 | 230.21 | 14.65 | 84.26 | 7.65 | 74.9 | 98.3 | 9.08 |
| | 5 | 6 | 288.00 | 41.67 | 14.47 | 64.70 | 3.65 | 58.2 | 68.6 | 5.65 |
| | Overall | 64 | 865.55 | 435.76 | 50.34 | 69.11 | 11.02 | 48.7 | 98.3 | 15.95 |
| Mo | 1 | 14 | 0.00 | --- | --- | 0.83 | 0.08 | 0.68 | 0.98 | 9.78 |
| | 2 | 25 | 0.00 | --- | --- | 1.33 | 0.48 | 0.63 | 2.69 | 36.09 |
| | 3 | 8 | 0.30 | 0.17 | 58.27 | 0.99 | 0.11 | 0.74 | 1.12 | 11.50 |
| | 4 | 11 | 0.20 | 0.23 | 116.32 | 0.98 | 0.09 | 0.83 | 1.10 | 8.74 |
| | 5 | 6 | 1.62 | 0.09 | 5.84 | 1.09 | 0.06 | 1.01 | 1.19 | 5.57 |
| | Overall | 64 | 0.22 | 0.48 | 218.18 | 1.10 | 0.36 | 0.63 | 2.69 | 32.73 |
| Zn | 1 | 14 | 1204.71 | 207.45 | 17.22 | 70.19 | 3.75 | 63.70 | 77.50 | 5.34 |
| | 2 | 25 | 1502.60 | 348.11 | 23.17 | 70.83 | 8.28 | 59.20 | 92.60 | 11.69 |
| | 3 | 8 | 933.00 | 130.42 | 13.98 | 81.44 | 8.25 | 73.00 | 97.70 | 10.13 |
| | 4 | 11 | 3634.55 | 547.09 | 15.05 | 172.09 | 14.60 | 152.0 | 193.0 | 8.49 |
| | 5 | 6 | 361.00 | 23.55 | 6.52 | 82.42 | 5.51 | 78.30 | 92.80 | 6.68 |
| | Overall | 64 | 1625.64 | 1033.32 | 63.56 | 90.51 | 38.69 | 59.20 | 193.0 | 42.75 |

[1] Variables expressed in parts per million on a dry matter basis.

Table 14. Description of management and estimated shrink of mineral supplement of the 5 dairies evaluated.

| Dairy | Storage facilities | Storage length (d) | Premixing frequency (d) | As fed load size (kg) | Total shrink[1] (%) |
|---|---|---|---|---|---|
| 1 | shed | 15 | 1-2 | 22,761 | 2.64 |
| 2 | tarp | 26 | 1-2 | 21,736 | 2.70 |
| 3 | shed | 51 | 1-2 | 22,598 | 0.63 |
| 4 | shed | 11 | 1-2 | 24,086 | 3.19 |
| 5 | shed | 7 | 3-5 | 21,845 | 0.72 |

[1] On a dry matter basis.

Table 15. Average percent shrinkage of the main components and nutrients of the mineral supplement.

| Variable | | Mean[1] | 95% CI | | SD | *P* > \|*t*\| |
|---|---|---|---|---|---|---|
| | | | Lower limit | Upper limit | | |
| Main components | CP | 3.03 | 0.53 | 5.54 | 2.02 | 0.03 |
| | ADF | 3.93 | 1.30 | 6.57 | 2.12 | 0.01 |
| | NDF | 3.34 | 1.04 | 5.65 | 1.86 | 0.02 |
| | TDN | 1.86 | 0.42 | 3.29 | 1.16 | 0.02 |
| Energy fractions | DE | 1.86 | 0.43 | 3.29 | 1.15 | 0.02 |
| | ME | 1.87 | 0.45 | 3.29 | 1.14 | 0.02 |
| | $NE_m$ | 1.84 | 0.40 | 3.28 | 1.16 | 0.02 |
| | $NE_g$ | 1.81 | 0.40 | 3.23 | 1.14 | 0.02 |
| | $NE_l$ | 1.83 | 0.38 | 3.28 | 1.17 | 0.02 |
| Macro-minerals | Ca | 1.67 | -0.04 | 3.37 | 1.37 | 0.053 |
| | P | 2.77 | -2.83 | 8.37 | 4.51 | 0.24 |
| | K | 2.37 | 0.05 | 4.69 | 1.87 | 0.05 |
| | Mg | 2.80 | -0.28 | 5.88 | 2.48 | 0.06 |
| | Na | 1.77 | 0.61 | 2.93 | 0.93 | 0.01 |
| | S | 2.07 | 0.89 | 3.26 | 0.96 | 0.008 |
| Trace-minerals | Al | 3.16 | -1.39 | 7.70 | 3.66 | 0.13 |
| | Co | 2.33 | 0.42 | 4.24 | 1.54 | 0.03 |
| | Cu | 2.25 | 0.09 | 4.41 | 1.74 | 0.04 |
| | Fe | 3.35 | 1.12 | 5.59 | 1.80 | 0.01 |
| | Mn | 2.80 | 1.68 | 3.92 | 0.90 | 0.002 |
| | Mo | 18.96 | -50.88 | 88.80 | 28.11 | 0.36 |
| | Zn | 2.42 | 0.91 | 3.94 | 1.22 | 0.01 |
| Total % shrink | | 1.97 | 0.48 | 3.47 | 1.21 | 0.02 |

[1] Percent average shrink on a dry matter basis, average of the 5 dairies.

Table 16. Estimated slope for the change in concentration of nutrients and energy of mineral supplement during storage.

| Dairy | Slope | Nutrient or component[1] | | | |
|---|---|---|---|---|---|
| | | DM | CP | ADF | NDF |
| 1 | $m$ | 0.24 | -0.32 | 0.01 | 0.24 |
| | $r^2$ | 0.59 | 0.35 | 0.05 | 0.11 |
| | $P > \|t\|$ | 0.001 | 0.03 | 0.43 | 0.09 |
| 2 | $m$ | 0.34 | 0.11 | 0.04 | 0.13 |
| | $r^2$ | 0.69 | 0.71 | 0.53 | 0.63 |
| | $P > \|t\|$ | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| 3 | $m$ | 0.02 | 0.03 | 0.02 | 0.02 |
| | $r^2$ | 0.29 | 0.05 | 0.40 | 0.12 |
| | $P > \|t\|$ | <0.0001 | 0.13 | <0.0001 | 0.02 |
| 4 | $m$ | -0.01 | 0.07 | 0.03 | 0.14 |
| | $r^2$ | 0.001 | 0.004 | 0.05 | 0.65 |
| | $P > \|t\|$ | 0.93 | 0.85 | 0.53 | 0.002 |
| 5 | $m$ | 0.16 | -0.24 | 0.17 | -0.14 |
| | $r^2$ | 0.36 | 0.65 | 0.46 | 0.04 |
| | $P > \|t\|$ | 0.20 | 0.05 | 0.14 | 0.70 |

| | | Energy fractions[2] | | | | | |
|---|---|---|---|---|---|---|---|
| | | TDN | DE | ME | $NE_m$ | $NE_g$ | $NE_l$ |
| 1 | $m$ | -0.02 | -0.001 | -0.0005 | -0.0006 | -0.0001 | -0.0007 |
| | $r^2$ | 0.05 | 0.07 | 0.025 | 0.02 | 0.004 | 0.11 |
| | $P > \|t\|$ | 0.43 | 0.38 | 0.59 | 0.62 | 0.83 | 0.25 |
| 2 | $m$ | -0.25 | -0.01 | -0.009 | -0.008 | -0.007 | -0.006 |
| | $r^2$ | 0.18 | 0.18 | 0.17 | 0.19 | 0.17 | 0.18 |
| | $P > \|t\|$ | 0.04 | 0.03 | 0.04 | 0.03 | 0.04 | 0.04 |
| 3 | $m$ | -0.02 | -0.0005 | -0.0004 | -0.0003 | -0.0003 | -0.0003 |
| | $r^2$ | 0.40 | 0.43 | 0.40 | 0.31 | 0.39 | 0.24 |
| | $P > \|t\|$ | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | 0.0004 |
| 4 | $m$ | -0.02 | 0 | -0.001 | 0 | -0.0003 | -0.0008 |
| | $r^2$ | 0.05 | 0 | 0.03 | 0 | 0.006 | 0.03 |
| | $P > \|t\|$ | 0.52 | 1.00 | 0.63 | 1.00 | 0.83 | 0.61 |
| 5 | $m$ | -0.11 | -0.006 | -0.007 | -0.003 | -0.0006 | -0.0006 |
| | $r^2$ | 0.46 | 0.28 | 0.69 | 0.15 | 0.02 | 0.02 |
| | $P > \|t\|$ | 0.14 | 0.28 | 0.04 | 0.44 | 0.80 | 0.80 |

[1] Slope (*m*) for percent concentration of nutrients on a dry basis, except for DM expressed on an as fed basis.

[2] Slope (*m*) for energy concentration measured as MCal•kgDM$^{-1}$ except for TDN expressed as percent of dry matter.

Table 17. Estimated slope for the change in concentration of macro and trace-minerals of mineral supplement during storage.

| Dairy | Slope | Macrominerals[1] | | | | | |
|---|---|---|---|---|---|---|---|
| | | Ca | P | K | Mg | Na | S |
| 1 | $m$ | 0.03 | 0.12 | -0.0008 | 0.002 | 0.06 | 0.001 |
| | $r^2$ | 0.04 | -0.002 | 0.001 | 0.008 | 0.23 | 0.02 |
| | $P > \|t\|$ | 0.48 | 0.21 | 0.90 | 0.76 | 0.09 | 0.65 |
| 2 | $m$ | -0.15 | 0.005 | 0.007 | 0.33 | -0.22 | 0.0007 |
| | $r^2$ | 0.39 | 0.80 | 0.58 | 0.91 | 0.65 | 0.02 |
| | $P > \|t\|$ | 0.0008 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | 0.55 |
| 3 | $m$ | -0.02 | 0.0002 | 0.001 | 0.005 | 0.004 | 0.003 |
| | $r^2$ | 0.16 | 0.01 | 0.01 | 0.11 | 0.04 | 0.46 |
| | $P > \|t\|$ | 0.005 | 0.50 | 0.45 | 0.02 | 0.17 | <0.0001 |
| 4 | $m$ | -0.06 | -0.004 | -0.03 | -0.004 | -0.0007 | 0.01 |
| | $r^2$ | 0.30 | 0.21 | 0.49 | 0.01 | 0 | 0.13 |
| | $P > \|t\|$ | 0.08 | 0.16 | 0.02 | 0.76 | 0.99 | 0.27 |
| 5 | $m$ | -0.05 | 0.009 | -0.01 | 0.02 | -0.005 | 0.003 |
| | $r^2$ | 0.05 | 0.69 | 0.14 | 0.08 | 0.004 | 0.02 |
| | $P > \|t\|$ | 0.68 | 0.04 | 0.46 | 0.60 | 0.91 | 0.78 |

| Dairy | Slope | Trace-minerals[2] | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Al | Co | Cu | Fe | Mn | Mo | Zn |
| 1 | $m$ | 30.43 | 0.02 | 2.29 | 8.08 | 3.23 | -- | -0.15 |
| | $r^2$ | 0.61 | 0.02 | 0.48 | 0.26 | 0.07 | -- | 0 |
| | $P > \|t\|$ | 0.001 | 0.66 | 0.006 | 0.06 | 0.36 | -- | 0.99 |
| 2 | $m$ | -3.88 | 0.05 | -4.29 | -0.29 | -6.88 | -- | 14.37 |
| | $r^2$ | 0.10 | 0.73 | 0.43 | 0.004 | 0.09 | -- | 0.09 |
| | $P > \|t\|$ | 0.12 | <0.0001 | 0.0004 | 0.75 | 0.15 | -- | 0.14 |
| 3 | $m$ | 5.57 | 0.06 | 1.69 | 16.01 | 5.61 | -0.01 | 7.18 |
| | $r^2$ | 0.22 | 0.34 | 0.49 | 0.54 | 0.41 | 0.25 | 0.43 |
| | $P > \|t\|$ | 0.001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | 0.0002 | <0.0001 |
| 4 | $m$ | 23.67 | -0.38 | -3.10 | 17.65 | 19.82 | -0.02 | 88.82 |
| | $r^2$ | 0.47 | 0.44 | 0.01 | 0.58 | 0.08 | 0.11 | 0.29 |
| | $P > \|t\|$ | 0.02 | 0.03 | 0.73 | 0.006 | 0.39 | 0.32 | 0.09 |
| 5 | $m$ | 6.17 | -0.92 | 3.28 | -14.14 | -2.46 | -0.02 | 1.20 |
| | $r^2$ | 0.08 | 0.39 | 0.21 | 0.39 | 0.01 | 0.16 | 0.01 |
| | $P > \|t\|$ | 0.58 | 0.18 | 0.36 | 0.19 | 0.84 | 0.44 | 0.86 |

[1] Slope ($m$) for percent concentration of nutrients on a dry basis.

[2] Slope ($m$) for parts per million concentration of nutrients on a dry basis.

Table 18. Correlation of weather variables and TMR composition to the slope of change in the main nutrients of mineral supplement during storage.

| Variable | | Correlation to slope of nutrients[1] | | | |
|---|---|---|---|---|---|
| | | DM | CP | ADF | NDF |
| Wind speed (km•h$^{-1}$) | *r* | -0.44 | 0.33 | -0.19 | -0.35 |
| | *P* >\|*r*\| | 0.46 | 0.59 | 0.76 | 0.57 |
| Temperature (°C) | *r* | 0.35 | 0.29 | -0.82 | 0.67 |
| | *P* >\|*r*\| | 0.57 | 0.64 | 0.09 | 0.22 |
| Relative humidity (%) | *r* | -0.22 | -0.61 | 0.52 | -0.19 |
| | *P* >\|*r*\| | 0.73 | 0.28 | 0.37 | 0.76 |
| TMR main composition | *r* | -0.53 | -0.20 | 0.22 | 0.11 |
| | *P* >\|*r*\| | 0.36 | 0.75 | 0.72 | 0.86 |
| *n* | | 5 | 5 | 5 | 5 |

[1] Pearson correlation coefficients (*r*) for nutrient concentrations expressed on a dry basis.

Table 19. Correlation of weather variables and TMR composition to the slope of change in energy content of mineral supplement during storage.

| Variable | | Correlation to slope of energy fractions[1] | | | | | |
|---|---|---|---|---|---|---|---|
| | | TDN | DE | ME | NE$_m$ | NE$_g$ | NE$_l$ |
| Wind speed (km•h$^{-1}$) | *r* | 0.21 | 0.15 | 0.22 | 0.27 | 0.23 | 0.19 |
| | *P* >\|*r*\| | 0.74 | 0.82 | 0.72 | 0.66 | 0.71 | 0.77 |
| Temperature (°C) | *r* | -0.24 | -0.42 | -0.44 | 0.18 | -0.07 | -0.15 |
| | *P* >\|*r*\| | 0.70 | 0.48 | 0.47 | 0.77 | 0.91 | 0.81 |
| Relative humidity (%) | *r* | 0.43 | 0.58 | 0.55 | 0.11 | 0.30 | 0.40 |
| | *P* >\|*r*\| | 0.47 | 0.31 | 0.34 | 0.86 | 0.62 | 0.51 |
| TMR Energy fractions | *r* | 0.30 | 0.17 | 0.21 | 0.31 | 0.35 | 0.23 |
| | *P* >\|*r*\| | 0.62 | 0.79 | 0.74 | 0.61 | 0.56 | 0.70 |
| *n* | | 5 | 5 | 5 | 5 | 5 | 5 |

[1] Pearson correlation coefficients (*r*) for energy concentrations expressed on a dry basis.

Table 20. Correlation of weather variables and TMR composition to the slope of change in macro-mineral content of mineral supplement during storage.

| Variable | | Correlation to slope of macro-minerals[1] | | | | | |
|---|---|---|---|---|---|---|---|
| | | Ca | P | K | Mg | Na | S |
| Wind speed (km•h$^{-1}$) | *r* | 0.15 | -0.39 | 0.35 | -0.15 | 0.07 | 0.09 |
| | *P* >\|*r*\| | 0.81 | 0.52 | 0.56 | 0.81 | 0.92 | 0.89 |
| Temperature (°C) | *r* | -0.06 | 0.33 | 0.71 | 0.43 | -0.32 | -0.54 |
| | *P* >\|*r*\| | 0.92 | 0.59 | 0.18 | 0.47 | 0.60 | 0.35 |
| Relative humidity (%) | *r* | 0.38 | 0.22 | -0.73 | -0.58 | 0.58 | 0.41 |
| | *P* >\|*r*\| | 0.53 | 0.72 | 0.17 | 0.31 | 0.31 | 0.50 |
| TMR macro-minerals concentration | *r* | -0.16 | 0.12 | 0.35 | 0.06 | -0.95 | 0.16 |
| | *P* >\|*r*\| | 0.80 | 0.85 | 0.56 | 0.92 | 0.01 | 0.79 |
| *n* | | 5 | 5 | 5 | 5 | 5 | 5 |

[1] Pearson correlation coefficients (*r*) for macro-mineral concentrations expressed on a dry basis.

Table 21. Correlation of weather variables and TMR composition to the slope of change in trace-mineral concentration of mineral supplement during storage.

| Variable | | Correlation to slope of trace-minerals[1] | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Al | Co | Cu | Fe | Mn | Mo | Zn |
| Wind speed (km•h$^{-1}$) | *r* | -0.43 | 0.31 | 0.25 | 0.32 | -0.02 | 0.99 | -0.27 |
| | *P* >\|*r*\| | 0.47 | 0.61 | 0.69 | 0.60 | 0.98 | 0.06 | 0.66 |
| Temperature (°C) | *r* | -0.07 | 0.99 | -0.29 | 0.47 | -0.21 | 0.81 | -0.27 |
| | *P* >\|*r*\| | 0.91 | 0.002 | 0.64 | 0.42 | 0.73 | 0.40 | 0.67 |
| Relative humidity (%) | *r* | 0.58 | -0.79 | 0.36 | -0.30 | 0.35 | -0.94 | 0.27 |
| | *P* >\|*r*\| | 0.30 | 0.11 | 0.56 | 0.62 | 0.57 | 0.23 | 0.66 |
| TMR trace-minerals concentration | *r* | -0.60 | 0.06 | -0.61 | -0.38 | 0.96 | -0.20 | 0.98 |
| | *P* >\|*r*\| | 0.29 | 0.92 | 0.28 | 0.53 | 0.01 | 0.87 | 0.004 |
| *n* | | 5 | 5 | 5 | 5 | 5 | 5 | 5 |

[1] Pearson correlation coefficients (*r*) for trace-mineral concentrations expressed on a dry basis.

Table 22. Average deviation of ingredients in TMR formulation of dairy farms.

| TMR ingredient | dairy | $n^1$ | Mean$^2$ | SD | Minimum | Maximum | CV |
|---|---|---|---|---|---|---|---|
| Mineral$^3$ | 1 | 14 | 1.29 | 1.81 | -0.27 | 6.22 | 140.31 |
| | 2 | 25 | 1.64 | 1.78 | 0.00 | 6.01 | 108.54 |
| | 3 | 8 | 2.80 | 3.66 | 0.26 | 10.96 | 130.71 |
| | 4 | 11 | 1.69 | 1.09 | 0.20 | 3.85 | 64.50 |
| | 5 | 6 | 0.26 | 0.08 | 0.09 | 0.29 | 30.77 |
| | Overall | 64 | 1.58 | 2.00 | -0.27 | 10.96 | 126.58 |
| Hay$^4$ | 1 | 14 | 3.64 | 1.22 | 2.53 | 6.01 | 33.52 |
| | 2 | 25 | 7.38 | 3.02 | 1.82 | 12.25 | 40.92 |
| | 3 | 8 | 3.45 | 1.17 | 1.78 | 5.32 | 33.91 |
| | 4 | 11 | -0.89 | 5.30 | -11.75 | 6.42 | 595.51 |
| | 5 | 6 | 17.63 | 7.68 | 7.62 | 30.66 | 43.56 |
| | Overall | 64 | 5.61 | 6.08 | -11.75 | 30.66 | 108.38 |
| Corn silage | 1 | 14 | 0.88 | 0.35 | 0.34 | 1.51 | 39.77 |
| | 2 | 25 | 0.95 | 0.56 | -0.01 | 2.12 | 58.95 |
| | 3 | 8 | 0.58 | 0.19 | 0.30 | 0.97 | 32.76 |
| | 4 | 11 | -1.98 | 5.14 | -13.01 | 4.94 | 259.60 |
| | 5 | 6 | 3.72 | 3.34 | 0.35 | 9.13 | 89.78 |
| | Overall | 64 | 0.64 | 2.72 | -13.01 | 9.13 | 425.00 |
| High moisture by-products$^5$ | 1 | 14 | 3.99 | 2.12 | 1.65 | 10.60 | 53.13 |
| | 2 | 25 | 0.95 | 2.80 | -11.75 | 3.75 | 294.74 |
| | 3 | 8 | 2.60 | 0.85 | 1.57 | 3.97 | 32.69 |
| | 4 | 11 | 2.55 | 5.53 | -8.80 | 11.27 | 216.86 |
| | 5 | 6 | 25.70 | 12.29 | 5.01 | 41.64 | 47.82 |
| | Overall | 64 | 4.42 | 8.36 | -11.75 | 41.64 | 189.14 |
| Premix | 1 | 14 | 0.92 | 0.51 | 0.31 | 2.23 | 55.43 |
| | 2 | 25 | 1.23 | 0.84 | -0.12 | 3.06 | 68.29 |
| | 3 | 8 | 0.83 | 0.51 | 0.27 | 1.80 | 61.45 |
| | 4 | 11 | -1.58 | 5.07 | -12.66 | 4.97 | 320.89 |
| | 5 | 6 | 3.78 | 3.89 | 1.07 | 11.27 | 102.91 |
| | Overall | 64 | 0.87 | 2.74 | -12.66 | 11.27 | 314.94 |

[1] Number of days TMR loads were evaluated.

[2] Percent deviation of TMR ingredients on an as fed basis.

[3] Inclusion of mineral supplement into the premix.

[4] Either grass or alfalfa hay.

[5] Either brewer or corn distillers grains.

Table 23. Correlation between ingredients deviation and dry basis composition of TMR.

| Ingredient | Correlation[3] | Correlation coefficients for main components | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | DM | CP | ADF | NDF | | | |
| Hay[1] | *r* | 0.50 | 0.06 | 0.27 | 0.39 | | | |
| | *P* > \|*r*\| | <0.0001 | 0.63 | 0.03 | 0.002 | | | |
| Corn silage | *r* | -0.18 | 0.11 | 0.26 | 0.27 | | | |
| | *P* > \|*r*\| | 0.15 | 0.38 | 0.04 | 0.03 | | | |
| High moisture by-products[2] | *r* | -0.24 | 0.34 | 0.20 | -0.03 | | | |
| | *P* > \|*r*\| | 0.06 | 0.006 | 0.11 | 0.79 | | | |
| Premix | *r* | -0.18 | 0.11 | 0.24 | 0.27 | | | |
| | *P* > \|*r*\| | 0.17 | 0.38 | 0.06 | 0.03 | | | |
| | | Correlation coefficients for energy fractions | | | | | | |
| | | TDN | DE | ME | $NE_m$ | $NE_g$ | $NE_l$ | |
| Hay[1] | *r* | -0.27 | -0.24 | -0.24 | -0.28 | -0.27 | -0.22 | |
| | *P* > \|*r*\| | 0.03 | 0.06 | 0.06 | 0.04 | 0.03 | 0.08 | |
| Corn silage | *r* | -0.26 | -0.23 | -0.25 | -0.25 | -0.27 | -0.23 | |
| | *P* > \|*r*\| | 0.04 | 0.07 | 0.05 | 0.05 | 0.03 | 0.07 | |
| High moisture by-products[2] | *r* | -0.20 | -0.17 | -0.20 | -0.19 | -0.21 | -0.17 | |
| | *P* > \|*r*\| | 0.11 | 0.17 | 0.12 | 0.13 | 0.09 | 0.18 | |
| Premix | *r* | -0.24 | -0.21 | -0.21 | -0.23 | -0.24 | -0.21 | |
| | *P* > \|*r*\| | 0.06 | 0.10 | 0.09 | 0.07 | 0.05 | 0.09 | |
| | | Correlation coefficients for macro-minerals | | | | | | |
| | | Ca | P | K | Mg | Na | S | |
| Hay[1] | *r* | 0.14 | 0.11 | 0.15 | 0.64 | 0.24 | -0.13 | |
| | *P* > \|*r*\| | 0.26 | 0.38 | 0.23 | <0.0001 | 0.06 | 0.31 | |
| Corn silage | *r* | 0.18 | 0.19 | 0.26 | 0.39 | 0.13 | 0.05 | |
| | *P* > \|*r*\| | 0.16 | 0.14 | 0.04 | 0.002 | 0.30 | 0.71 | |
| High moisture by-products[2] | *r* | -0.18 | -0.34 | 0.36 | 0.50 | -0.33 | 0.24 | |
| | *P* > \|*r*\| | 0.15 | 0.007 | 0.003 | <0.0001 | 0.008 | 0.06 | |
| Premix | *r* | 0.20 | 0.22 | 0.23 | 0.39 | 0.15 | 0.04 | |
| | *P* > \|*r*\| | 0.12 | 0.08 | 0.07 | 0.001 | 0.24 | 0.78 | |
| | | Correlation coefficients for trace-minerals | | | | | | |
| | | Al | Co | Cu | Fe | Mn | Mo | Zn |
| Hay[1] | *r* | 0.20 | 0.06 | -0.08 | 0.16 | -0.46 | -0.07 | -0.42 |
| | *P* > \|*r*\| | 0.11 | 0.62 | 0.54 | 0.21 | 0.0001 | 0.57 | 0.0005 |
| Corn silage | *r* | 0.14 | 0.14 | -0.02 | 0.12 | -0.26 | -0.02 | -0.37 |
| | *P* > \|*r*\| | 0.26 | 0.27 | 0.89 | 0.36 | 0.04 | 0.86 | 0.003 |
| High moisture by-products[2] | *r* | -0.19 | 0.17 | -0.16 | -0.10 | -0.03 | -0.07 | -0.03 |
| | *P* > \|*r*\| | 0.13 | 0.19 | 0.21 | 0.43 | 0.84 | 0.60 | 0.82 |
| Premix | *r* | 0.13 | 0.11 | -0.004 | 0.11 | -0.24 | -0.04 | -0.33 |
| | *P* > \|*r*\| | 0.32 | 0.40 | 0.97 | 0.38 | 0.06 | 0.74 | 0.01 |

[1] Either grass or alfalfa hay.

[2] Either brewer or corn distillers grains.

[3] Pearson correlation coefficients (*r*) for concentrations of TMR nutrients.

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