Micro Feeding Machines in the Dairy Industry

by

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ABSTRACT

Micronutrient machines have been used successfully in the beef industry, however, their use was mostly for the addition of antibiotics into the rations. Their use in the dairy industry has been very limited. Feed cost is over 50% of the total cost on a typical dairy farm, thereby creating an area where minor changes in cost per cow can impact the bottom line. Because of the high feed cost on dairy farms, income over feed cost (IOFC) is one of the bench marks as to the overall farm financial health. The feed rations also impact animal health incidences and reproduction efficiencies.

Micro machines can add small amounts of a desired nutrient or product, generally less than 56 grams (± 2 oz) into the cattle's daily total mixed rations (TMR). These micronutrients are generally expensive, and their inclusion into the rations of only cows that need that particular micronutrient is one benefit of a micro machine. Micro machines also take out the human error of mixing small accurate amounts and can easily track inventories. Benefits also include the control of on-farm shrink through dust control, and environmental stewardship of resources. Lastly, by creating options to accurately add micronutrients, milk production may be increased and health incidences reduced. The dairy industry is a virtually an untapped field for this technology and this research will explore if there is a benefit from their use. As feeding systems have evolved and milk production has continued to climb, innovative technologies will continue to be implemented. Increased financial pressures will also continue to cause producers to become more efficient with their resources.

As production increases in any field, fine tuning of inputs becomes more exact. The rumen inner workings and how feedstuff blends affect rumen micros and the pH levels is an area in which there is much research completed, however, much more is still needed. The addition of micro machines to fine tune rations for dairy farms TMR rations can be a profitable way to manage income over feed cost, not only by saving money spent on micronutrients but by increasing production and reducing herd health incidences.

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CHAPTER I: INTRODUCTION

The United States dairy industry has seen many changes over the years, including but not limited to: increasing herd sizes, changing from diversified farms to specialized farms, working environments as well as the addition of employees, competition from outside markets including both dairy and non-dairy, increased dependence on the world market, new environmental laws and governmental record keeping, substantial increases in production per cow, and new concerns from consumers. Through it all, the U.S. dairy industry has remained, but only by being ever adapting to innovative ideas and technologies.

Total dairy cows numbers in the U.S. have fallen from a high of 26.5 million in 1944 (J. L. Capper, R. A. Cady, and D. E. Bauman 2009) to just over 9.3 million head in 2016 (USDA 2016 milk production data). While that shift was occurring, annual milk production per cow has increased from 2,074 kg (Capper et al 2009) to over 10,300 kg (USDA 2016 milk production).

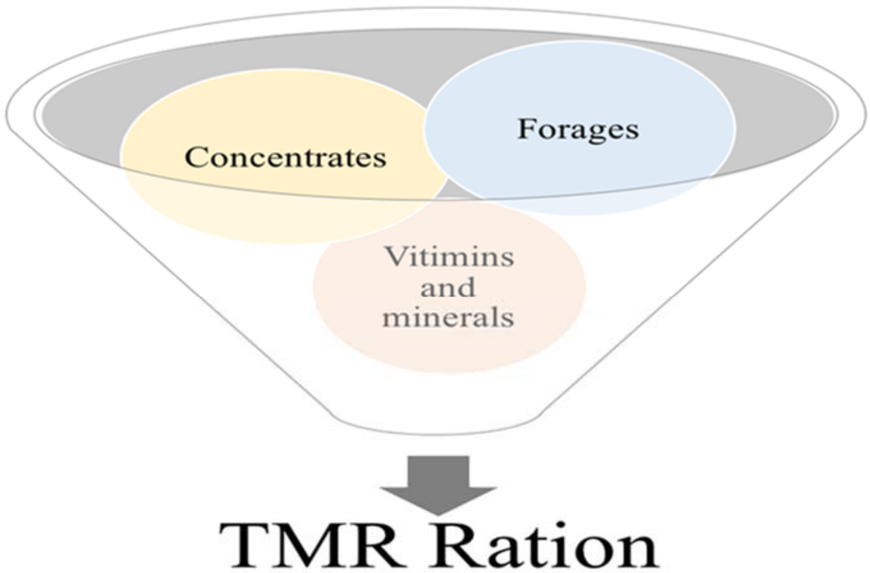
Meanwhile, the consumer is expecting that farming be done in an environmentally sound manner and that the animals are well cared for. Consumers and industry partners expect that their milk and milk products are not only environmentally safe but also safe and nutritious for their families to drink or eat. The ever-growing population requires the dairy industry to increase overall production, and most of the increase will come from milk production per cow. Increasing yields will occur through nutrition that matches exactly what the cow needs to produce higher levels of production. Dairy cows can only eat so much (pyhsical fill), so the ration must be changed to more exactly match the cow’s needs.

Consumers may have the opinion that the old days were better both in terms of animal welfare and the environment. What many fail to understand is that only healthy animals can produce high levels of milk production and the carbon footprint per unit of production has decreased. According to Capper et al. (2009), the dairy industry carbon footprint in 2007 is 37% of the equivalent milk production in 1944. Capper et al. also stated that the resources used are less when comparing 1944 to 2007, "with 21% of animals, 23% of feedstuffs, 35% of the water, and only 10% of the land required to produce the same 1 billion kg of milk. Waste outputs were similarly reduced, with modern dairy systems producing 24% of the manure output" (page 2160). As the precision of dairy feeding is increased, there continues to be reduction in the fecal waste that is created. With precision feeding, the fine details of the ingredients that the cow is lacking can be targeted, instead of adding whole ingredients. These whole ingredients may offer what the cow needs, however, they bring along other nutrients that are not needed that end up going out as waste.

To meet the demands of ever-increasing production, feeding the dairy animal has changed, by moving from pasture-based systems to component feeding where the feed is placed in front of cows as individual ingredients, to TMR's where all ingredients are mixed together and fed at the same time, and now to precision TMR feeding. As milk production continues to climb and the knowledge of the mechanics of the rumen has increased, TMR rations have changed, going from broad terms like crude protein (CP) and total energy, to metabolizable protein (MP), to a current shift to amino acids (AA) and fatty acids (FA).

Figure 1.1 shows the blending of those broad items, precision feeding will break these items up into smaller components.

Figure 1.1 Generalized TMR Inputs



Dairy cattle do not use ingredients for example like crude proteins. They use the building blocks of proteins, amino acids. Amino acids are classified as either essential or non-essential and rumen degradable and rumen undegradable. Ruminants can synthesize some amino acids that are considered non-essential, even though they are still needed. The other amino acids cannot be synthesized or synthesized in the quantities needed within the cow and are considered essential because they must come from the diet.

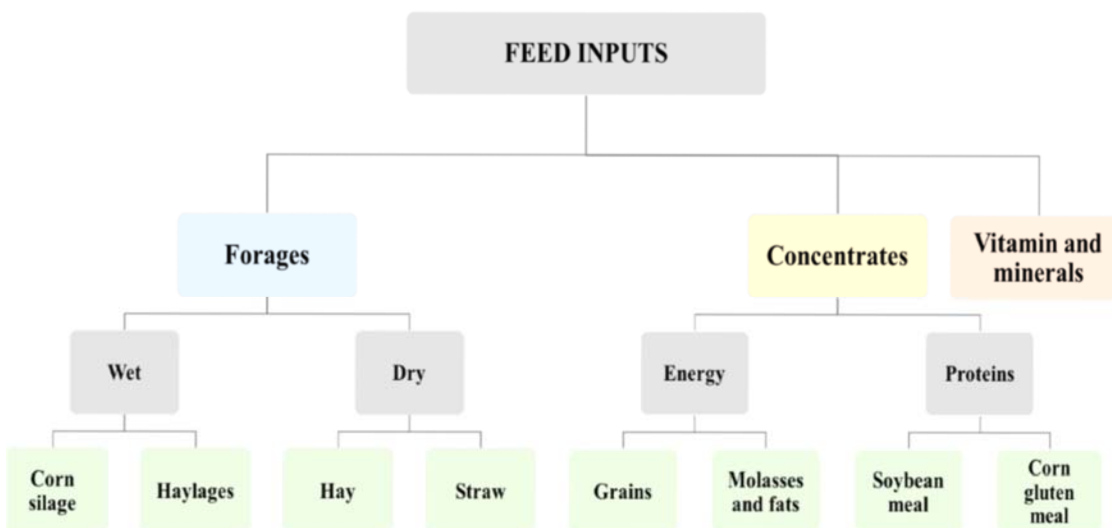
Traditionally rations have had higher levels of crude protein to make up for individual shortcomings in amino acids. By targeting the individual amino acids dairy farms can save money and/or increase milk production, while reducing waste concentrations. The difference can be thought of like the difference between a shotgun or a rifle, the rifle is more exact, instead of the blanket pattern of the shotgun.

This is more complicated than just placing some feed in front of the cows and hoping for the best. The nutritionist must fine-tune the TMR rations with the goal of maximizing milk production, herd health, and income over feed cost (IOFC). A plethora of research has been done on the rumen, the digestibility of feed stuffs and the interactions that take place. While the scientific community has learned much, there is still much more that is unknown than known. There is a common saying that the dairy industry doesn't feed cows, they feed rumen micros, and that adds another level of complication to feeding.

The amino acid profile can be changed five times before it is used in the cells. The micros convert the amino acid profile from the feed or the amino acids pass through the rumen along with the micros where they are absorbed in the small intestines. The epithelial cells that line the gut get first use of the amino acids as they are transported, changing the amino acid profile again as it is transported into the blood stream. Once absorbed into the bloodstream, the amino acids are carried to the liver that absorbs them and again changes the amino acid profile, before going back into the bloodstream where it is uptaken by the cells that once convert the amino acids profile. This conversion of the amino acids could be one of the reasons the micro machines may work well, because of the complexity, it is not currently clear what amino acid profile will create the highest milk production. If micronutrients can be changed rapidly and accurately, an amino acid profile to maximize production may be found earlier. The amino acids profile is an important part of maximizing milk and milk protein production (Blum et al. 1999).

With the onset of TMR feeding and the research into cattle metabolism, ration balancing computer models were used by the nutritionist, instead of the old hand calculator that was used to calculate the feed rations. Computer models have complex calculations that interpret how the TMR ration will be used and converted by the cow. The computer models use the available feedstuffs, type of cattle fed, production levels, stage of lactation, the age of cattle, goals of the farm, expected rate of passage, and of course the most complex part - the interactions that take place. But even the computer models differ from one another, sometimes dramatically, which underlies the fact that it is not understand what happens once the rumen gets involved in the digestion process. Figure 1.2 is part of the computer models feed inputs as they balance rations needs.

Figure 1.2 Divisions of feed input by ingredient types



1.1 Available feedstuffs

Farms plant different feeds depending on the area which they are located, their soil types, risk aversion, weather, herd size, and even the equipment available. Thus, a nutritionist will not only have different feedstuffs from farm to farm and year to year, they will also have different forage physical form and different quality of feeds available. The quality of forages has a substantial effect on the ration fed, as by-products fed tend to increase as forage qualities and digestibilities decrease. Dry matter intake is one of the many keys to high production as production needs must be fed to match the milk produced.

Feed efficiency is a measure of the productivity of the ration. The feed efficiency calculation is fat corrected milk (FCM) divided by the consumed dry matter intake (dry matter fed minus feed refusals). Feed efficiency can range from below 1.2 to over 1.8 and gives the nutritionist an idea on how well the ration feeds, as anything that is not used for the maintenance of the cow (breathing, heart, etc.) or turned into milk is usually fecal waste if the cow's body weight remains equal. Table 1.1 shows a benchmark guide for feed efficiencies (FE) from the USDA Extension Services (2010).

Table 1.1 Benchmarks for feed efficiency comparisons

Group	**Days in Milk**	**FE (lb. milk/lb. DM)**
One group, all cows	150 to 225	1.4 to 1.6
1st lactation group (1^{st} Calf heifers)	<90	1.5 to 1.7
1st lactation group (1^{st} Calf Heifers)	>200	1.2 to 1.4
2nd + lactation group (Adult Cows)	<90	1.6 to 1.8
2nd + lactation group (Adult Cows)	>200	1.3 to 1.5
Fresh cow group	<21	1.3 to 1.6
Problem herds/groups	150 to 200	<1.3

Source: USDA 2010

If a new ration increases feed efficiencys, the ration is most likely providing something that was in short supply in the old ration, if all other things remained equal. However, if the ration costs increase more than the value of the milk production, the "improved" ration may still not be fed.

Table 1.2 shows the reduction in the income over feed cost by reducing feed efficiency from 1.67 to 1.58 while holding milk production, milk price ($16.50/cwt) and feed cost ($0.14/dry matter lb.) steady.

Table 1.2 Differences in feed efficiencies on income over feed cost

Feed Lbs.	**Cost/lb.**	**Total**	**Feed Lbs.**	**Cost/lb.**	**Total**	**Difference**
54	$ 0.14	$ 7.56	57	$ 0.14	$ 7.98	$ 0.42
Milk Lbs.	**Price**	**Total**	**Milk Lbs.**	**Price**	**Total**	
90	$ 0.165	$ 14.85	90	$ 0.165	$ 14.85	$ -
Feed efficiency		**IOFC**	**Feed efficiency**		**IOFC**	
1.67		**$ 7.29**	**1.58**		**$ 6.87**	**$ (0.42)**

In a 1,000 cow dairy, a drop in feed efficiency of 0.09 equates into $153,000 per year of feed savings.

With lower quality forages, the dry matter intake of high producing dairy cattle will be reduced and feed efficiency will drop as well. There are two reasons for the reduced dry matter intake, higher fiber and lower digestibility (Hutjens 2009). With poorer feeds, physical fill becomes a factor that can limit the amount of dry matter intake. Dry matter intake can be improved by adding by-products and increasing concentrates to replace the lower quality forages, which in turn can increase milk production. By-products are feeds from manufacturing such as dry distillers grains from the ethanol industry. Increasing by-products and concentrates fed compared to low-quality forages tends to increases the cost of the ration, so it is usually avoided if possible. However, even if they are added, if the concentrate level is too high, sub-acute rumen acidosis (SARA) can be the result, as concentrates will reduce rumen pH levels.

Types of forages have different nutrient profiles that affect the makeup of the rations. For example, corn silage is higher than grasses in both methionine and lysine amino acids. Even the type of processing of forages can change the amino acid profile that escape the rumen as there will be different micro populations in different areas of the rumen. Processing reduces the particle size of feed stuffs, giving the micros easier access into cell walls and causes the feed to sink from the rumen mat quicker. The smaller particle size allows the micros to digest the feed at a higher rate, changing the interactions taking place and lowering the pH.

Production levels as well drive the formulated rations. Production levels can be driven by many items including: genetics, forage quality and availability, feed and feeding consistency, farm management, stage of lactation, and farm goals. Higher production levels have ever-increasing demands on the rations and the proper balancing. High milk production is where precision feeding can bring the highest rate of return.

1.2 Lactation stages

The lactation can be split into six stages; dry period, transition period consisting of pre-fresh and post fresh, early lactation, mid-lactation, and late lactation. Dry cows are not producing milk, but they are rebuilding for the next lactation and are feeding a fetus. The normal dry period is 50 to 60 days, but the last 21 days of the period is considered part of the transition period. At this stage, the ration must bring in the nutrients needed for the rapidly growing fetus, the cow must maintain her body condition score for her metabolic health. Either gaining or losing body weight in the dry period is detrimental to her health. Thus, the proper ration balance is critical at this stage of the cow's life. This seems like a quiet period in the cow's life, but it is a very important part of her lactation cycle. The transition period is the three weeks before and three weeks after calving. This is a time of major metabolic changes and the rations need to be precise, so the rations will be changing throughout this period. To add to the difficulty of feeding the cow in the transition period, the cow will have fluctuating dry matter intakes (DMI), so the DMI of the cattle must be monitored closely.

The cow will then enter into the early lactation stage of her lactation cycle, which is between roughly30 days in milk (DIM) to roughly130 days in milk (DIM). In this stage, her requirements cannot be met by the ration alone. As her DMI have not matched her rapidly climbing production output, she cannot eat enough volume of feed to supply the nutritents needed. She then starts to milk "off her back" as she pulls adipose tissue from her body reserves, to supply the energy needed. This can put undue stress on her liver and if it is severe enough leds to fatty liver, as she deals with the non-esterified fatty acids (NEFA's) from the fat tissue. Fatty liver is a major metabolic disease and is recognized as the percent of tricylglycerol (TAG) that causes health effects (Beitz D.C. 2014). The rumen once again dictates why she cannot achieve the required nutrients from her feed. The rumen micros require a delicate balance between forages that provide fiber and concentrates that supply the energy and proteins. If the concentrate portion of the ration is too high, the rumen pH will drop and one of the affects is SARA (sub-acute rumen acidosis) (Saleem et al. 2012).

The pH levels also affect the number and type of bacteria that is available for digestion. This is part of the reason you cannot simply increase the concentrate portion of the ration to meet the cows needs in this stage. On top of the negative energy balance, she will be rebred in this stage to prepare her for the next lactation. The mid-lactation stage starts around 130 DIM and ends around 230 DIM. Here she will continue milking heavy but, she begins to get all of her requirements for production from the ration fed as peak production has past and her dry matter intake has increased. In the late lactation stage, she will gain weight until she reaches her ideal weight, however, she needs to gain weight without getting fat. Weight is generally a "eyeball" body condition score from 1 to 5 given to the cows, 1 is emaciated and 5 is obese. Dairy farms generally try to achieve a 3.25 to 3.5 body condition score (BCS) at dry off time. If the cow is too skinny, they will not have the body reserves needed to reach peak milk production in the early lactation stage. If the cow is too fat and she will have metabolic problems one of which is fatty liver. So, either too skinny or too fat can lead to lower production, increased metabolic problems, and poor reproduction performance.

1.3 Age of cattle

The age of cattle also goes into the computer models as animal less than 3 years of age are still growing, however many are calving at 22 months of age. The last 14 months or so the first calf heifers are growing, which limits the physical amounts that can be consumed as the rumen is not full size yet. However, these first calf heifers have the demands of growing plus production including the fetus. Younger animals also have a higher metabolic rate, which increases their demands.

1.4 Goals

The goals of the farm can affect the production levels and the requirements of the rations. Some farms want to push for highers levels as they feel this keeps the farm on the cutting edge that is necessary for employee morale and farm growth. Another reason is often the pride of having high production and being considered as "one of the best".

Others are more comfortable being in the top 25% of production levels, with many feeling that this is a safer level. Some perhaps are getting closer to retirement and just want to maintain until the time comes to sell the farm. These are only a few of the reasons each farm has different goals, but the goals affect the ration and ration levels.

1.5 Interactions

Interactions are very complex and the computer models disagree here, as the scientific research in this area is inconsistent.

Figure 1.3 Schematic of the model of Baldwin et al. (1987)

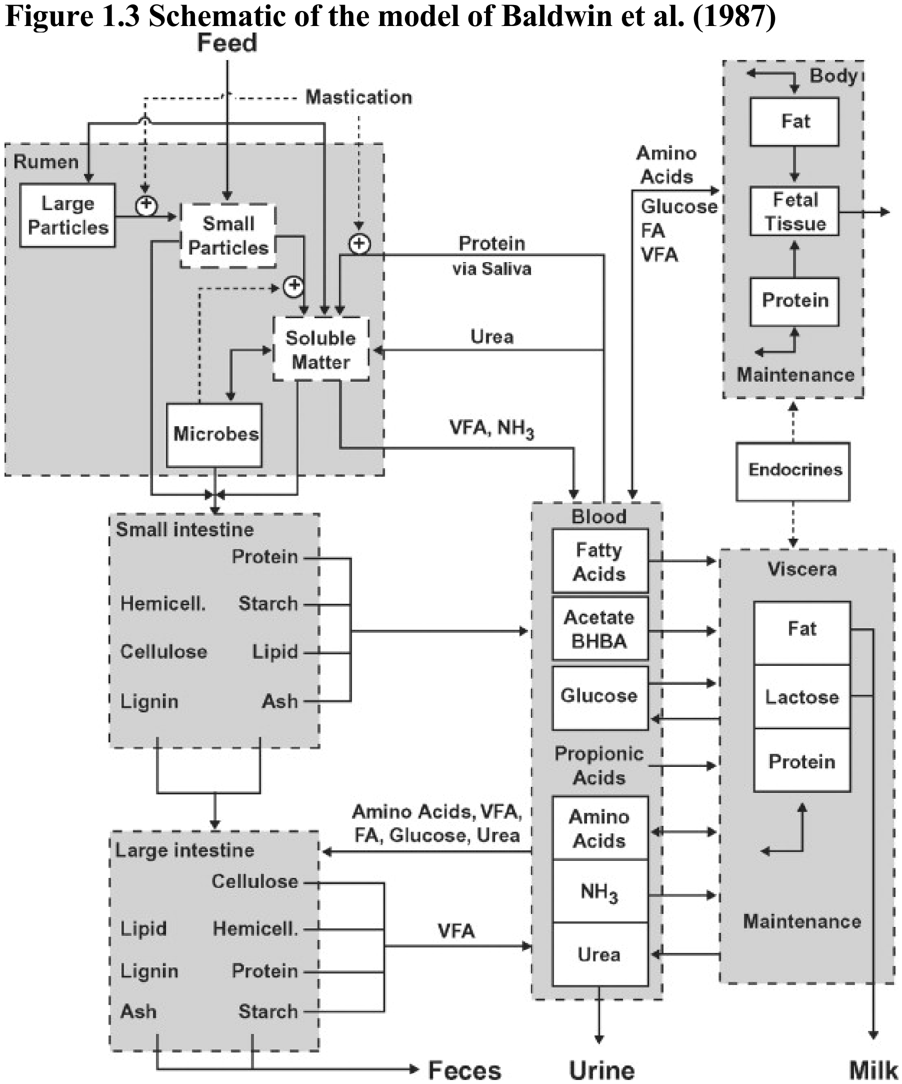


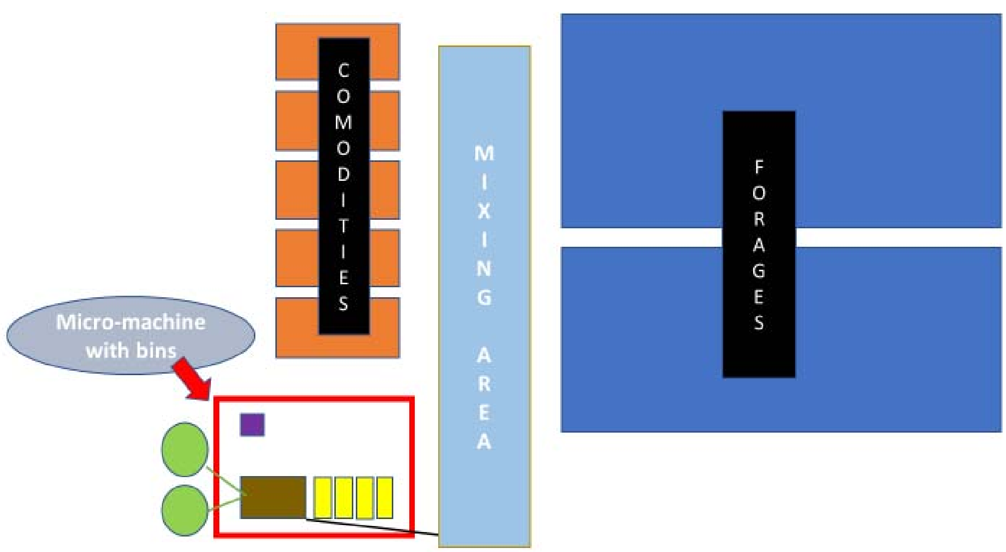
Figure 1.3 shows only a small portion of the interactions that take place. It does not show the interactions between different vitamins and minerals nor the competition for carriers that amino acids need for absorption. A whole intact amino acid must be broken down (deaminated) to be carried across cell walls via carriers and those carriers can be used by more than one amino acid. Those interactions are beyond the scope of this paper, but it highlights the need to experiment with different micro nutrients to find the most efficient ration.

There is also the common notion that there are three rations on the farm. There is the one that was formulated, the second is the ration that was mixed by the feeder, and the third is the one the cow actually eats. The first two are different due to changes in nutrient levels and digestestabilities in the feed and due to human error. The last is different, because like humans cows have preferences in their food choices, so they will sort the ration as they eat. How the ration is formulated, the processing of feedstuffs, and bunk management will all affect the ration the cow eats. Of course, the last ration is the one that matters and getting that as close to the formulated ration is critical. The micro machine may help with the differences between the first two rations as it will minimize the human error. All of these above factors dictate the rations which will be used on the farm at any one time.

1.6 Micro machine set up

Figure 1.4 shows a typical setup for the micro machines, and there will be some variations from this. The dark blue area is for forage storage, called bunker silos. These usually are large flat cement pads on which the forages are packed, covered with plastic and stored until feeding. The light blue is an extension of the bunker silo and is where the mixer wagon sits while being loaded for feeding. The orange area is commodities storage, usually a three-sided barn with high divided walls. Grains and concentrates are stored in here and the barn gives protection from rains and wind. The green circles represent grain (bulk) bins used to store protein mixes. These are augered into the micro machine, before being delivered into the feed wagon. The micro machine is stored inside a building (red square) where it is protected from the elements. The parts of the micro machine include the computer (purple square) that controls the flow of product. The mini-bins (yellow area) hold the micronutrients and the brown square is the mixing/holding bin.

Figure 1.4 Overhead view of a feeding area with a Micro Machine setup



The micro machine feeds the ingredients into the TMR mixer wagon through an auger system. The amounts are formulated by the nutritionist and are controlled by a computer as it weighs product into the mixer. There can be a varied amount of bins, but one common configuration is two large bins for protein mixes and four small bins for micronutrients and similar products. The TMR mixer has an electronic scale that tells the feeder how much and in what order to put each ingredient in for each pen of cows. This scale head on the TMR mixer is also tied wirelessly to the micro machine so they communicate with each other. The micro machine starts to premix the needed ingredients for each individual load when the mixer starts to mix the other ingredients for that load. This speeds up mixing times for each load as the micro machine has all of its ingredients pre-mixed and ready to be loaded into the TMR mixer as soon as the forages have been added. The weighing is done by load cells and helps take out the human error portion of adding ingredients. When it comes to low inclusion items on many farms, one common method that is used, because it is easier and quicker, is for the feeder to just pour in the amount needed into the payloader bucket. The products may come in 50 lb. bags and for example, 20 lbs. is needed, so the feeder just guesses at the amount. This can have two results, one is underfeeding which in many circumstances hurts efficacy or to put in too much product, which again could hurt efficacy but at least will raise costs. The lack of consistency for rumen micros can be another reason why just pouring in products by the bags is a poor choice. These products are needed in small amounts and are generally fairly concentrated. The micro machine can add these micronutrients quickly and accurately. The mix of possible bin combinations allows for the use of several high inclusion items like protein mixes and several micronutrients. Items like amino acids, chromium or other vitamins and minerals and even essential oils can be added. Chromium has been shown to increase milk in some research and essential oils are becoming more popular. Part of the essential oils interest is their use as natural antioxidants and research is being done now to find how they may benefit the dairy industry. They are a small inclusion item and may fit in well with the micro machine program.

The pictures in figures 1.5 to 1.8 show a working mico machine set up.

Figure 1.5 Control panel

Figure 1.6 Underneath Mini-bins load cells and auger system

Figure 1.7 Mixing/holding bin and discharge auger

Figure 1.8 Side view of mini-bins and auger

1.7 Research objective

The objective of this thesis was to examine if under today's high production environment a micro machine could increase profits enough to be justified. The intent is to provide data to farmers that can explain the possible benefit of micro machines to both production and profitibilty.

CHAPTER II: LITERATURE REVIEW

Micro machines do not have a lot of research behind them, especially when it comes to dairy farms, as they were made for beef units. The importance of micronutrients and their interactions have been researched and the literature review will highlight some of the research done with amino acids and chromium.

2.1 Amino Acids

Crude protein is essential in life, and in dairy cattle, crude protein can be divided into two categories, rumen degraded (RDP) and rumen undegraded (RUP). Amino acids are often supplemented in the dairy industry, with methionine and lysine being the most often added. Rumen degraded protein is used for microbial growth and rumen undegraded protein is absorbed in the small intestine. Crude protein is broken into individual amino acids that come in different levels of both types of amino acid and its location of absorption. Milk protein yield in high-producing dairy cows is often restricted by the first limiting amino acid (Rogers et al., 1984). The dairy industry is looking at the amino acid profiles of supplied crude protein and its absorption in the small intestines and amino acids importance to high yielding dairy cows (Blum 1999). Dietary changes not only change the individual amino acid profile but their rate and site of absorption. The insoluble protein in Table 2.1, adapted from MacGregor et al. (1977) shows what will not be digested. The nitrogen content of each feedstuff was determined by the Kjeldahl method and the acid-detergent insoluble nitrogen by the method of Goering and Van Soest (1970). In table 2.1 the differences between two cuttings of hay highlights the need to continually fine-tune a ration.

Table 2.1 Total and soluble amino acid concentration of feedstuffs

	Alfalfa Grass 1st Cutting		Alfalfa-Grass 2nd Cutting		Percent difference in Alfalfa/Grass cuttings		Corn Grain		Soybean Meal	
Amino Acid	Total	Soluble	Total	Soluble	Total	Soluble	Total	Soluble	Total	Soluble
Essential										
Arginine	2.42	0.2	1.82	0.48	24.79	58.33	2.24	1.47	40.28	0.75
Histoline	0.87	0.27	1.80	1.49	51.67	81.88	2.27	0.45	13.93	2.73
Lsoleuie	2.34	1.04	5.17	1.39	54.74	25.18	2.53	0.42	22.19	4.92
Leunine	4.61	1.44	9.33	2.29	50.59	37.12	9.09	0.78	38.95	8.26
Lysine	1.94	0.36	4.43	0.88	56.21	59.09	2.44	1.02	31.04	7.51
Methionine	1.01	0.45	2.05	0.66	50.73	31.82	1.00	0.27	4.21	0.54
Phenylalnine	2.98	0.81	5.59	1.12	46.69	27.68	3.88	0.46	26.73	5.87
Theranine	2.38	0.84	4.83	1.08	50.72	22.22	2.94	0.46	19.05	4.00
Sub total	**18.55**	**5.41**	**35.02**	**9.39**			**26.39**	**5.33**	**196.38**	**34.58**
Non Essential										
Alanine	4.59	2.98	9.07	5.66	49.39	47.35	5.87	1.14	21.49	4.93
Aspitic Acid	5.01	1.46	7.77	1.38	35.52	5.48	6.88	1.13	58.71	13.32
Glutamic Acid	6.54	2.48	11.04	3.39	40.76	26.84	27.21	2.17	103.33	21.92
Glycine	3.24	1.27	6.28	2.07	48.41	38.65	2.79	0.89	23.75	4.38
Proline	2.86	1.39	5.55	1.56	48.47	10.90	6.59	0.46	22.92	5.53
Serine	2.25	0.83	4.21	0.51	46.56	38.55	4.36	0.77	31.72	5.97
Tyrosine	1.8	0.51	2.94	0.38	38.78	25.46	2.72	0.41	18.36	3.13
Sub total	**26.29**	**10.92**	**46.86**	**14.95**			**56.42**	**6.97**	**280.28**	**62.18**
Total	**44.84**	**16.33**	**81.88**	**24.34**			**82.81**	**121.3**	**476.66**	**96.76**

Source: MacGregor et al. 1977

Table 2.2 is composed of information by MacGregor et al. (1977) and it highlights the minimum, maximum and range of each amino acid in common feedstuffs used on dairy farms taken from Table 2.1 above. While it is certainly not an all-inclusive list, it points out the variances of some feedstuffs and why it may be necessary to change amino acids in the diet often.

Table 2.2 Minimum, Maximum, and range of total and soluble amino acid concentration of feedstuffs

Amino Acid	Total	Total	Total	Soluble	Soluble	Soluble
Essential	**Min**	**Max**	**Range**	**Min**	**Max**	**Range**
Arginine	1.82	40.28	38.46	0.20	1.47	1.27
Histoline	0.87	13.93	13.06	0.27	2.73	2.46
Isoleuie	2.34	22.19	19.85	0.42	4.92	4.50
Leunine	4.61	38.95	34.34	0.78	8.26	7.48
Lysine	1.94	31.04	29.10	0.36	7.51	7.15
Methionine	1.00	4.21	3.21	0.27	0.66	0.39
Phenylalanine	2.98	26.73	23.75	0.46	5.87	5.41
Theranine	2.38	19.05	16.67	0.46	4.00	3.54
Sub total	**18.55**	**196.38**	**177.83**	**5.33**	**34.58**	**29.25**
Non Essential						
Alanine	4.59	21.49	16.90	1.14	5.66	4.52
Aspitic Acid	5.01	58.71	53.70	1.13	13.32	12.19
Glutamic Acid	6.54	103.33	96.79	2.17	24.92	22.75
Glycine	2.79	23.75	20.96	0.89	4.38	3.49
Proline	2.86	22.92	20.06	0.46	5.53	5.07
Serine	2.25	31.72	29.47	0.51	5.97	5.46
Tyrosine	1.80	18.36	16.56	0.38	3.13	2.75
Sub total	**26.29**	**280.28**	**253.99**	**6.97**	**62.18**	**55.21**
Total	**44.84**	**476.66**	**431.82**	**12.30**	**96.76**	**84.46**

(MacGregor et al. 1977)

2.2 Chromium

Chromium is part of many metabolic functions and research into its use in the dairy industry has been inconsistent. This micronutrient has only just started being researched and it is still unclear how it interacts with amino acids or its effects on metabolism. Chromium (Cr) in the form of Cr propionate has been legal for supplementation to cattle diets in the United States at levels up to 0.50 mg of Cr/kg of DM since 2009. According to Spears et al. (2017) “Little is known regarding Cr concentrations naturally present in practical feed ingredients” (page 3,584). If the levels available in feed is unknown, the only way to know if the rations on any particular farm is to add Cr and measure the results. Either or both milk products and health events must be monitored. “Chromium has been reported to enhance immune function and improves insulin sensitivity and performance in beef and dairy cattle” (Garcia M. et al. page 6389, 2017). This increase in potential immune function is important in dairy cattle especially as they go through the transition periods. McNamara and Valdez (2005) have been shown to increase in milk production.

CHAPTER III: RESULTS

There are many products that could be used through the micro machine, this thesis will use three that have been researched and are used on many dairy farms. All have research that shows inconsistency in their results. However, in the dairy industry, this is common. This leads to the overall value of the micro machine, as it will include micronutrients accurately and producers can change amounts fed per cow or even change out whole products quickly. This thesis will use a positive response to the products that are used, and assumes that if the product does not generate a positive result, the farm will eliminate it from the ration. With the micro machine, a producer can switch the three products methionine, lysine, and chromium and use any of numerous products, all which work on some farms and not others.

3.1 Methionine

A meta-analysis by Zanton et al. (2014) shows, an increase in both pounds of protein and butterfat, however, once again research has been inconsistent in the results. Products increase output on average as high as 35 g per day of protein and butterfat. These components according to USDA (Aug 30, 2017) were priced at protein $1.5536/lb. and butterfat price $3.0109/lb. A meta-analysis done by Patton (2010) shows inconsistency in response to methionine (Met). However, there was an overall increase in the 75 comparisons of a total of 1040 cows. Table 3.1 compares the increase in components to the cost of the product at $0.19 per cow per day.

Table 3.1 Methionine financials with protein and butterfat increases

		Ave. lb Increase	$ Value Increase
Protein price per CWT	$1.5536	0.077	$0.12
Butterfat price per CWT	$3.0109	0.077	$0.23
		Total $ Increase cow/day	**$0.35**
		Methionine Cost cow/day	$0.19
		Difference cow/day	$0.16

3.2 Lysine

Lysine is often paired with methionine and most studies that have been done on lysine have a combination of the two, making a meta-analysis on lysine (Lys) alone difficult. The data from Wang et al. (2010) indicated milk yield was increased by supplementation of Lys or Met, and further increased when there was supplementation of both. The addition of Lys and Met to cattle rations were additive to milk production response. They reported an increase in milk production with methionine alone from 26.5 kg/day to 28.5 kg/day, and with methionine and lysine milk was further increased to 30.3 kg/day with no increase in dry matter intake. No increases in dry matter intake means any increases in production only needs to cover the added cost of the product. Table 3.2 shows the increase in milk from 1.8 (30.3 kg – 28.5kg) kg/day at a milk price of $16.50 cwt. The product cost of Lysine used in this thesis was $0.11 per cow per day.

Table 3.2 Lysine financials with 1.8 kg/d milk increase

Milk Price/lb.	$	0.165
Milk Increase (lbs./day)		3.968
$ Value cow/day	$	0.65
Lysine cost cow/day	$	0.11
$ Difference cow/day	**$**	**0.54**

3.3 Chromium

Table 3.3 is from the research done by McNamara and Valdez (2005) for chromium propionate. The research tested calcium propionate and chromium propionate on Holstein dairy cattle from 21 days prepartum to 35 days postpartum. All cows were switched to a control diet at 36 days in milk. The sampling continued to 90 days in milk.

Table 3.3 Milk production from cows treated with calcium propionate (CrP)

DIM Milk	Control	CrP	Kg.Milk Difference
1-35 DIM	40.8 kg/day	41.6 kg/day	0.8 kg/day
36-56 DIM	47.4 kg/day	49.9 kg/day	2.5 kg/day
57-90 DIM	45.2 kg/day	50 kg/day	4.8 kg/day
1-90 DIM	44.2 kg/day	46.8 kg/day	**2.60 kg/day**

Source: Adapted from McNamara and Valdez (2005)

For the results in Table 3.4, this thesis used half of the milk production increase from the research for Chromium giving an increase of 2.87 lbs. (1.3 kg), as chromium has limited research and sometimes what happens in the "real" world is different from the research results.

Table 3.4 Chromium Financials with 2.87-pound Milk Increase

Milk Price/lb.	$ 0.165
Milk Increase (lbs./cow/day)	2.87
Value cow/day	$ 0.47
Chromium cost cow/day	$ 0.035
Difference cow/day	**$ 0.44**

3.4 Total Costs and Profit

Table 3.5 shows the cost of the three products when fed to the higher production cows. One advantage of the micro machine is the capability to remove the cows by feeding only to the pens that require the micronutrient. This increases the return on investment by eliminating the lower production cows that show no profit above the added feed cost of those products. For this thesis, the bottom 25 percent of the cows were removed from the costs and from the income, as these cows will most likely not show an increase in production. The total cost of the three products on a 5,000 milking dairy is $636,469 (Table 3.5).

Table 3.5 Cost of Products per Year with 25% of Low Production Cows Excluded

	Product			
# Cows	**Methionine Cost**	**Lysine Cost**	**Chromium Cost**	**Total Cost/yr.**
2,000	$ 104,025	$ 131,400	$ 19,163	**$ 254,587.50**
3,000	$ 156,038	$ 197,100	$ 28,744	**$ 381,881.25**
4,000	$ 208,050	$ 262,800	$ 38,325	**$ 509,175.00**
5,000	$ 260,063	$ 328,500	$ 47,906	**$ 636,468.75**
6,000	$ 312,075	$ 394,200	$ 57,488	**$ 763,762.50**
7,000	$ 364,088	$ 459,900	$ 67,069	**$ 891,056.25**
8,000	$ 416,100	$ 525,600	$ 76,650	**$ 1,018,350.00**
9,000	$ 468,113	$ 591,300	$ 86,231	**$ 1,145,643.75**
10,000	$ 520,125	$ 657,000	$ 95,813	**$ 1,272,937.50**

* Example: 2000 milking cows (not including dry cows) = product fed to 1500 cows

Table 3.6 shows the cost of the three products when fed to the top 75 percent of the milking cows. Total income for a 5,000 milking cow dairy is $2,540,163, using $0.1650 per pound milk price.

Table 3.6 Income from Products per Year with 25% of Low Production Cows Excluded

	Product			
# Cows	Methionine Value	Lysine Value	Chromium Value	Total/yr.
2,000	$ 192,427.91	$ 477,945.60	$ 345,691.50	**$ 1,016,065.01**
3,000	$ 288,641.86	$ 716,918.40	$ 518,537.25	**$ 1,524,097.51**
4,000	$ 384,855.82	$ 955,891.20	$ 691,383.00	**$ 2,032,130.02**
5,000	$ 481,069.77	$ 1,194,864.00	$ 864,228.75	**$ 2,540,162.52**
6,000	$ 577,283.73	$ 1,433,836.80	$ 1,037,074.50	**$ 3,048,195.03**
7,000	$ 673,497.68	$ 1,672,809.60	$ 1,209,920.25	**$ 3,556,227.53**
8,000	$ 769,711.64	$ 1,911,782.40	$ 1,382,766.00	**$ 4,064,260.04**
9,000	$ 865,925.59	$ 2,150,755.20	$ 1,555,611.75	**$ 4,572,292.54**
10,000	$ 962,139.54	$ 2,389,728.00	$ 1,728,457.50	**$ 5,080,325.04**

* Example: 2000 milking cows (not including dry cows) = product fed to 1500 cows

Table 3.7 combines the tables 3.5 and 3.6 shows the yearly profit/loss from the three products, and since they are often fed as additive ingredients, there is a total column, that assumes all three products are fed. While the results are inconsistent in research, all have shown positive results, and it is assumed that a dairy producer will not use a product that shows no benefit. There are many products that could be used in the place of any of these products and finding the limiting ingredient on each farm will take trial and error effort.

A 5,000-milking dairy could realize a yearly profit of $1,903,694 from the combination of the three products. This assumes that all other expenses are equal including dry matter intake. Often as dairy cattle increase milk production, they also increase dry matter intake. However, research has shown that you can increase in milk production if you are adding these products without increasing dry matter intake. This is accomplished by the dairy cow being more efficient with the whole ration by adding the limiting micronutrients. Because of this phenomenon, this paper did not raise dry matter intake.

Table 3.7 Profit/Loss per Year from Products Fed with 25% of Low Production Cows Excluded

	Product-Income Over Feed Cost			
# Cows	**Methionine**	**Lysine**	**Chromium**	**Total Income**
2,000	$88,402.91	$346,545.60	$326,529.00	$761,477.51
3,000	$135,604.36	$549,818.40	$489,793.50	$1,142,216.26
4,000	$176,805.82	$693,091.20	$653,058.00	$1,522,955.02
5,000	$221,007.27	$866,364.00	$816,322.50	$1,903,693.77
6,000	$265,208.73	$1,039,636.80	$979,587.00	$2,284,432.53
7,000	$309,410.18	$1,212,909.60	$1,142,851.50	$2,665,171.28
8,000	$353,611.64	$1,386,182.40	$1,306,116.00	$3,045,910.04
9,000	$394,813.09	$1,559,455.20	$1,469,380.50	$3,426,648.79
10,000	$442,014.54	$1,732,728.00	$1,632,645.00	$3,807,387.54

Example: 2000 milkingcows (not including dry cows)= product fed to 1500 cows

3.5 Sensitivity Analysis

Milk prices are varied and this sensitivity analysis shows scenarios with variable prices, including protein and butterfat. Milk and milk component responses will also not be consistent. Not only will farm to farm responses vary, so will the response on a farm from season to season and forage to forage.

Table 3.8 shows profit from the inclusion of methionine at the stated levels in this thesis until protein price drops to $0.90/lb. and butterfat drops to $1.50/lb. A 50 percent drop in the stated increase in milk components production at the current market price nets a breakeven scenario.

Table 3.8 Methionine Sensitivity Analysis

Methionine profit loss cow/day								
Protein Price lb.	$ 0.90	$ 1.00	$ 1.10	$ 1.20	$ 1.30	$ 1.40	$ 1.50	$ 1.60
Butterfat price lb.	$ 1.50	$ 1.75	$ 2.00	$ 2.25	$ 2.50	$ 2.75	$ 3.00	$ 3.25
Profit/Loss								
At Previously Stated Increases	$ (0.01)	$ 0.02	$ 0.05	$ 0.08	$ 0.10	$ 0.13	$ 0.16	$ 0.18
Minus 10% of increase	$ (0.02)	$ -	$ 0.02	$ 0.05	$ 0.07	$ 0.10	$ 0.12	$ 0.15
Minus 20% of increase	$ (0.04)	$ (0.02)	$ -	$ 0.02	$ 0.04	$ 0.07	$ 0.09	$ 0.11
Minus 30% of increase	$ (0.06)	$ (0.04)	$ (0.02)	$ -	$ 0.01	$ 0.03	$ 0.05	$ 0.07
Minus 40% of increase	$ (0.08)	$ (0.06)	$ (0.05)	$ (0.03)	$ (0.01)	$ -	$ 0.02	$ 0.04
Minus 50% of increase	$ (0.10)	$ (0.08)	$ (0.07)	$ (0.06)	$ (0.04)	$ (0.03)	$ (0.02)	$ -

As shown in Table 3.9, Lysine's sensitivity analysis doesn't show a loss until milk production increases are cut by 50 percent and milk price drops to $12.00 cwt.

Table 3.9 Lysine Sensitivity Analysis

Lysine profit loss/cow/day

Milk Price/lb.	0.11	0.12	0.13	0.14	0.145	0.15	0.155	0.16	0.165
Lysine profit loss									
At Previously Stated Increases	$ 0.19648	$ 0.23616	$ 0.27584	$ 0.03155	$ 0.33536	$ 0.35520	$ 0.37504	$ 0.39488	$ 0.41472
Minus 10% of increase	$ 0.15283	$ 0.18854	$ 0.22426	$ 0.02600	$ 0.27782	$ 0.29568	$ 0.31354	$ 0.33139	$ 0.34925
Minus 20% of increase	$ 0.10918	$ 0.14093	$ 0.17267	$ 0.20442	$ 0.22029	$ 0.23616	$ 0.25203	$ 0.26790	$ 0.28378
Minus 30% of increase	$ 0.06554	$ 0.09331	$ 0.12109	$ 0.14886	$ 0.16275	$ 0.17664	$ 0.19053	$ 0.20442	$ 0.21830
Minus 40% of increase	$ 0.02189	$ 0.04570	$ 0.06950	$ 0.09331	$ 0.10522	$ 0.11712	$ 0.12902	$ 0.14093	$ 0.15283
Minus 50% of increase	$(0.02180)	$(0.00190)	$ 0.01792	$ 0.03776	$ 0.04768	$ 0.05760	$ 0.06752	$ 0.07744	$ 0.08736
Minus 60% of increase	$(0.06540)	$(0.04950)	$(0.03370)	$(0.01780)	$(0.00990)	$(0.00190)	$ 0.00602	$ 0.01395	$ 0.02189
Minus70% of increase	$(0.10910)	$(0.09720)	$(0.08520)	$(0.07330)	$(0.06740)	$(0.00614)	$(0.05550)	$(0.04950)	$(0.04360)

Table 3.10 shows the sensitivity analysis on chromium which does not drop below a profitable level. However, the lack of research with chromium should be taken into consideration. As more research is completed with chromium inclusions, predictability in total milk production increases and improvements in animal health will also increase.

Table 3.10 Chromium Sensitivity Analysis

Chromium profit loss/cow/day									
Milk Price/lb.	$ 0.11	$ 0.12	$ 0.13	$ 0.14	$ 0.145	$ 0.15	$ 0.155	$ 0.16	$ 0.165
Chromium profit loss									
At Previously Stated Increases	$ 0.28	$ 0.31	$ 0.34	$ 0.37	$ 0.38	$ 0.40	$ 0.41	$ 0.42	$ 0.44
Minus 10% of increase	$ 0.25	$ 0.27	$ 0.30	$ 0.33	$ 0.34	$ 0.35	$ 0.37	$ 0.38	$ 0.39
Minus 20% of increase	$ 0.22	$ 0.24	$ 0.26	$ 0.29	$ 0.30	$ 0.31	$ 0.32	$ 0.33	$ 0.34
Minus 30% of increase	$ 0.16	$ 0.21	$ 0.23	$ 0.25	$ 0.26	$ 0.27	$ 0.28	$ 0.29	$ 0.30
Minus 40% of increase	$ 0.15	$ 0.17	$ 0.19	$ 0.21	$ 0.21	$ 0.22	$ 0.23	$ 0.24	$ 0.25
Minus 50% of increase	$ 0.12	$ 0.14	$ 0.15	$ 0.17	$ 0.17	$ 0.18	$ 0.19	$ 0.19	$ 0.20
Minus 60% of increase	$ 0.09	$ 0.10	$ 0.11	$ 0.13	$ 0.13	$ 0.14	$ 0.14	$ 0.15	$ 0.15
Minus70% of increase	$ 0.06	$ 0.07	$ 0.08	$ 0.09	$ 0.09	$ 0.09	$ 0.10	$ 0.10	$ 0.11

CHAPTER IV: CONCLUSION

Feeding the lactating dairy cow for high performance and efficiency has become a balancing act between the micronutrients that are needed and what can be supplied, at the farm level. As knowledge of the metabolic requirements for high producing dairy cows has increased there is an understanding of the importance of breaking into parts the ingredients that are feed.

Higher production will only accentuate the need to have the ability to change quickly and accurately. This capability to change diet will increasingly important as high production is met by finely tuned rations that matches the most limiting micronutrient. Micro machines can alleviate this requirement as ingredients can be added in very small amounts and the amounts and ingredients can be changed quickly.

The environmental aspects of the micro machine are worth noting as well. By increasing the efficiency of the dairy ration that is fed to the dairy cow, waste per pound of milk produced can be lowered. As stewards of the land, this is an important concept that must not be ignored. Even though it is hard to put a number on environmental concerns, it should be considered.

The income from micro machines as shown in this thesis already makes them an important addition to the dairy industry. As shown by this thesis, a 5,000 cow dairy could realize a profit of $1.9 million while reducing the waste concentrations with the use of a micro machine. As production continues to climb, micro machines will be a technology that helps steer the dairy industry as it continues to find ways to be more efficient.

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