DETERMINING THE WATER NEEDS OF DAIRY CATTLE

by

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Abstract

Data obtained from 50 individual published studies recording water intake by dairy cattle were utilized in a meta-analysis to develop a prediction equation for free water intake (FWI). Studies were selected based on quantitative measurements of DMI, diet DM%, water intake (WI), and milk yield. Many of the studies determined FWI on multiple treatments resulting in 116 mean data points from the 50 studies. With the addition of Na in the meta-analysis, 40 data points were available from the studies to examine the effects of Na on FWI. The effects of DMI, ration water intake (RWI), and milk yield (MY) were used to develop a FWI prediction equation from the 116 data points. The effects of DMI, RWI, MY, and sodium intake were used to develop a second prediction equation from the 40 data points. These equations were then compared with five published FWI prediction equations from Castle and Thomas (1975), Dahlborn et al. (1998), Little and Shaw (1978), Murphy et al. (1983) and Stockdale and King (1983). This data set showed that the five published equations either over or under predicted ($P < 0.05$) FWI when compared the actual FWI calculated from the meta-analysis data points. It also showed that the equation developed from the meta-analysis data points is the more accurate in determining FWI from the data points selected from the studies.

A second project was conducted with the fresh water data collected from 13 freestall (FS) and 11 dry lot (DL) Kansas dairies over a 10-year period (2000-2009). Fresh water was recorded from water pumping records. Data were first summarized annually by operation and then converted to a per cow per day basis prior to analysis. Data were then analyzed by using the mixed procedures of SAS. Fixed effects included in the model were dairy type (FS or DL) and year was considered a random effect. The DL dairies averaged 186 L/cow per day and were

lower than the FS dairies which averaged 237 L/cow per day. Differences between DL and FS style dairies may have been due to differences in parlor fresh water usage or cow cooling systems.

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Table of Contents

List of Figures

List of Tables

Dedication

I would like to dedicate this work first to my wife, Meghan, for all the love and support for without her none of this adventure to Kansas would have been possible. To all my family and friends who have supported me along the way and to all the wonderful friends I have made here in Kansas. Thank you.

CHAPTER 1 - Review of Literature

Introduction

Water is an essential nutrient. An essential nutrient is a nutrient that the animal cannot synthesize quantities great enough to meet the requirements for growth, maintenance, milk production, and pregnancy (Beede, 2005). Essential nutrients must be supplied from the ration, air, or water (Church, 1998). Only oxygen is considered more important to life than water. As a percent of body weight, total body water content in dairy cattle is 56 to 81 percent of body weight and a loss of 20% of body water is fatal (Murphy, 1992). This is the importance of providing a dairy cow with unlimited access to clean fresh water.

In the mammal, water molecules represent 99% of all molecules (Church, 1988). To maintain normal tissue function, the concentration of water must be kept constant. Low water intake reduces body weight, milk yield, provokes aggressive behavior around waterers, reduces the respiratory rate, reduces rumen contractions, and increases hematocrit and blood urea (Cardot et al., 2008). Compared with any other land based mammals, the water requirements of the high producing dairy cow are the greatest. This is the result of milk containing 87% water, requirement of water for digestion and metabolism of energy and nutrients, transporting nutrients, excretion of waste, and maintenance of ion, fluid, and heat balance in the dairy cow (Beede, 2005).

Water turnover is correlated to the metabolic rate. A lower metabolism requires less water to transfer nutrients and for evaporative cooling because of the lower amount of heat generated. This explains the greater water turnover and metabolic rate observed in more productive animals such as the high producing dairy cow (Church, 1988).

In the animal all of the biochemical reactions and inter-conversions that take place require water. Water is the transport medium through which hemoglobin in blood plasma carries oxygen and carbon dioxide though tissues and transports them from the lung or gut though cells (Church, 1988). It also acts as the solvent for absorbed substances and moving substances to and from their sites of metabolism. Water also facilitates the removal of undigested particles and waste from the body. An example is urea which is the end product of nitrogen metabolism and needs water for its elimination (Church, 1988).

In the ruminant, body water is mainly located in the intracellular pool. This pool accounts for about two-thirds of the water in the body (NRC, 2001). The extracellular pool, which is comprised of the interstitial, plasma, and transcellular water, can make up 15 to 35% of body weight in ruminants (Murphy, 1992). Woodford et al. (1984), found that empty body water (intracellular, extracellular, and plasma) volume of 262 L in a lactating dairy cow and gut water (transcellular) was 149 L. Over 60 minutes, 140 L were exchanged between the empty body water and gut water leading to a resident time of 62 minutes for a water molecule in the rumen (Murphy, 1992).

Water has characteristics that allow it to maintain body temperature in ruminants. Ruminants utilize the cooling capacity of water through panting or sweating to dissipate heat. When water changes from a liquid to vapor, 1 gram binds about 2,425 J of heat (Church, 1998). The high latent heat of vaporization of water allows the ruminant to use very little water to expel large amounts of heat. This high heat capacity of water also provides a thermal buffer by conserving body heat in cold climates. Since water can store a large amount of heat it helps prevent drastic changes in body temperature within the ruminant (Church, 1988).

Water is an essential nutrient for the ruminant animal. It provides the animal with a means to help aid in the digestion process, sweat secretion, metabolizing nutrients, regulating body temperature, milk production, and the excretion of waste from the animal. This is why it is essential for the dairyman to have a quality water supply to raise healthy, high producing dairy cattle.

Water Loss

Water is lost from the body through milk, feces excretion, urine excretion, vapor loss from the lungs, and sweat. Winchester and Morris (1956) reported that 0.87 kg of water per kg of milk is expected since milk is 87 percent water. Richards (1985) reported the fate of water in British Fresian cows during their 16th and 20th week of lactation. These animals were producing 16.2 kg/day of milk and consuming 18 kg/d of an 88.4 percent DM complete diet. In this study they reported losses for fecal, urinary, milk, sweat, and salivary. Respectively, percentage losses for each one were as follows; 40.5 fecal, 28.9 urinary, 17.2 milk, 12.1 sweat, and .3 salivary. Loss of water though milk has been shown by Holter and Urban, 1992; Dado and Allen, 1994; and Dahlborn et al., 1998; to range from 26 to 34 percent of total water intake. Thirty to thirty-five percent of water is lost as feces and 15 to 21 percent is lost as urine in lactating dairy cows (NRC, 2001). Fecal water loss is closely related to DMI (positively) and DM (negatively) content of the diet. Feces are usually about 70 to 85% water which makes diet digestibility a factor in the amount of fecal water loss (Murphy, 1992). Paquay et al., (1970) reported that feeding forages high in moisture increased the water lost in feces by reducing the dry matter content of the feces. Finally, water can also be lost though sweat, salivary, and evaporative losses. Holter and Urban (1992) reported these losses at about 18 percent of water loss.

Murphy (1992) states that mean urine production of 25 kg/d is common in high producing cows. Urinary water excretion was positively related to water absorbed, urinary N, and urinary K excretion and is negatively related to DM content of diet and milk production (Murphy, 1992). Paquay et al., (1970) reported that consuming high moisture forages increased urinary water losses.

Water lost by evaporation is described as insensible or sensible. Insensible water loss is the water lost that cannot be perceived or directly measured like respiratory or cutaneous diffusion losses. Respiratory losses account for about one third and cutaneous diffusion two thirds of the insensible water loss. Sensible water loss is the water loss that can be seen and measured such as sweat, saliva, and nasal secretions (Murphy, 1992).

Little et al., (1984) conducted a study on the consequences of water deprivation on lactating British Friesian cows over a 72 hour period. They found that after 72 hours cows lost an average of 100 kg of body weight, had an 85 percent decline in concentrate consumption, and a 72 percent decline in milk yield. To compensate for this water deprivation the authors noted that the cows reduced the fecal water output and reduced water loss through respiration. These animals did recover in about 48 hours after the end water deprivation to previous levels of milk yield and intake levels. However, the authors noted very aggressive behavior among the deprived animals and conclude that if they were not housed in tie stalls they could have injured themselves (Little et al., 1984).

Dairy cattle are affected rapidly by water deprivation. They need large amounts of water to obtain and maintain high milk production, cool themselves, and to maintain water balance

(Murphy, 1992). Therefore it is essential to provide ample water to the dairy cow to meet the cow's high demands for this essential nutrient.

Water Intake of Dairy Cows

Water intake of dairy cows is affected by milk production, feed intake, stage of lactation, body weight, dry matter percent of diets, level of sodium intake, and air temperature (Murphy, 1992; Beede, 2005). Water requirements of cattle are met through free water intake (FWI), water that is contained in their diet, and to a very small extent the metabolism of nutrients in the body (NRC, 2001). Of these, an average of 83 percent of the total water consumed by lactating dairy cows is from the FWI (NRC, 2001).

Dry Matter

DM content of the diet has been shown in numerous studies to affect the FWI. Holter and Urban (1992) showed a 50 to 30 percent decrease as ration DM decreased FWI by 33 kg/d. In a pasture based study, Stockdale and King (1983) looked at the influence of dry matter intake and dry matter concentration in the diet on water consumption. They found that total water intake was affected negatively by ration dry matter content and positively by dry matter intake. They found that for each kg of food consumed, total water consumed increased by 4.52 kg/cow and it decreased by 0.048 kg/cow for each g/kg increase in dry matter content (Stockdale and King, 1983). However, when considering total water intake (ration water plus FWI), ration DM percent can have a negative impact. When ration DM percent increases, free water intake increases, but total water intake decreases. Murphy (1992), suggest this happens because of the need to excrete more N and K in urine when feeding wet diets. Holter and Urban (1992) concluded that this is only relevant to cows on high protein pasture or succulent silage.

Dewhurst et al. (1998) performed an experiment to examine the effects of silage characteristics on water intakes. They felt water intake could be affected by the digestibility of silage, milk yield, and the DM percent of the silage. In this study, 16 silages were used with DM ranging from 15.9 to 28.0 percent. Free water intake ranged from 20.1 to 89.9 L/d, total water intakes from 48.4 to 123.8 L/d, and milk production from 16.4 to 38.3 kg/d. They found that free water intake increased with increasing silage DM concentration. It also confirmed other reports suggesting that free water intake replaces silage water at a rate less than 1:1.

Minerals

Sodium levels in the diet have been shown to increase free water intake. Murphy et al., (1983) showed that water intake increases by 0.05 kg/d per gram of sodium intake. Beede (2005) notes the findings of Omer and Roberts (1967) that showed a high potassium diet can affect water intakes in beef steers. High dietary potassium (4.24% of dietary DM) increased water intakes when compared to 0.61 and 1.71% dietary potassium (Beede, 2005).

In other studies, minerals were added to the water to increase the total dissolved solids (TDS). TDS are the inorganic matter dissolved in water (Beede, 2005). High levels of TDS (over 3,000ppm) are considered undesirable and can indicate poor quality water. Beede (2005) states that iron and sulfates are the biggest factors in poor quality water. Iron concentrations of 0.3 ppm can negatively affect a dairy cow and reduce water intake. High iron concentrations in water can reduce the palatability of water and promote the growth of bacteria in waterers that may affect water intake. Sulfates can cause possible problems at levels greater than 2,000 ppm (Beede, 2005). High sulfate concentrations in water can lead to unpalatable water and reduced water consumption.

Temperature

Temperature also plays a role in water intake. Water transfers heat from the body to the environment through sweating and respiration to cool the animal. Water losses from sweating and respiration can increase by 50 to 59 percent during times of heat stress (NRC, 2001). Cows increase water intake in heat stressed environments. In heat stressed conditions cows need to replace water lost by sweat, feces, milk, and respiratory evaporation.

In 1956 Winchester and Morris reported that water intake per unit of DMI remained constant from -12.22 to 4.44°C. Above 4.44°C water intake per unit of dry matter intake increased rapidly. From -12.22 to 4.44 °C cows consumed about 1.36 L of water per kg of dry matter intake. At the peak of 32.2°C cows consumed 3.18 L of water per kg of dry matter intake (Winchester and Morris, 1956).

Beede notes in *Large Dairy Herd Management* that "water is unequivocally is the most important nutrient of lactating dairy cows in heat stressing environments (Beede, 1992)." Beede reported that water loss increased in non-lactating cows by 58% when cattle were maintained at 30°C compared to 20°C. During this time water losses increased 54 percent and 26 percent from respiratory and urinary secretion. In lactating cows housed in climate chambers of 17.77°C and 30°C, total drinking water increased 29% at the higher temperature. Loss of water through urine, skin surface, and respiratory evaporation increased by 15, 59, and 50 percent respectively as temperature increased (McDowell, 1972).

There are many factors that can affect the water intake of dairy cattle. Milk production, dry matter intake, mineral concentrations, and temperature affect water intake the greatest. Murphy (1992) notes that milk production is closely correlated to DMI and DMI to water intake.

Thus providing a dairy cow with high quality water is essential to maximizing her production and ensuring a healthy animal.

Management Effects on Water Intake

How cows are handled, housed, and watered can also affect water intake. Animal behavior research has examined the effects of eating patterns, temperature of water provided, cow dominance, flow rate of water, and stray voltage.

Drinking Water Temperature

Numerous studies have looked at the effects of offering chilled or heated water and its effects on water intakes. Osborne et al. (2002) studied the effect of just heated drinking water on production responses. They found that free water intake was 3.4 to 6 percent greater each time heated versus ambient water was offered. They also observed that cows would consume 40 percent of the daily water intake within 2 hours of milking and feeding time. Andersson (1985) looked at providing warmed water to Swedish Red and White cattle to improve milk yield. 3, 10, 17 and 24°C water sources were offered to 8 lactating cows averaging 25.8 kg/d milk. The lowest water intakes were recorded from the 24°C drinking water and similar when cows were offered water at the other three temperatures levels (Andersson, 1985).

Other published research has looked at the effect of chilled water on heat stress, production responses, reticular temperatures, DMI, and drinking behavior. Stermer et al. (1986) reported that the coldest water offered at 10˚C, reduced body temperature by .75˚C more than 28˚C water. However, the cows consumed the least amount of this cold water and consumed the most water at 22˚C. Milam et al. (1986); Baker et al. (1988); Wilks et al. (1989) and Lanham et al. (1986) all found similar results that cows consumed less of the chilled water than that of the control water temperature. They also found that the chilled water decreased respiration rates but did not have an effect on deep rectal temperatures. Baker et al. (1988) and Wilks et al. (1985) both showed that when cows were only given the choice of chilled water, cows did have lower respiration rates, lower body temperatures, increased feed intake, and higher milk yield. The authors also noted that the costs of offering the cows chilled water must be determined before providing chilled water to cattle.

Water Flow Rates and Social Rank

Andersson et al. (1984) looked at the effect of water flow rates on the consumption of water by tied up dairy cows. Using flow rates of 2, 7, and 12 L/min they reported that Swedish Red and White Breed cows drank 9.41 and 12.6 L/d more water with the increased flow rates. The time spent drinking by each group of cows also decreased from 37 min/d on the low flow rate to 7 min/d on the high flow rate. The cows also spent more times per day drinking with low flow rates (40 times/d) than the high flow rate (30 times/d). While the cows spent more time drinking, the flow rates did not affect milk production or dry matter intake. However, at the high flow rates there was a tendency for increased milk production. These results indicate that cows will adapt to slower flow rates by changing their drinking behavior (Andersson et al., 1984).

In this same study by Andersson et al., they examined social rank between the cows sharing a water bowl. Cows were separated into pairs and based on their behaviors from video recording the cows competing for water a dominant and submissive cow were determined. Data from this showed that submissive cows consumed 9% less hay, 7% less water, and had a lower fat percent in their milk (Andersson et al., 1984).

Andersson and Lindgren (1987) studied the consumption of water by cows by restricting access to water during feeding. The treatments were a control where cows had free access to drinking water, no drinking water for one hour after feedings and no drinking water for two hours after feeding. They reported that cows prefer to have water available during feeding. However, cows will consume 60 to 80% of total water consumption within a few hours after feeding. There were no differences in water intakes between treatments once water was made available. However, the cows with free access to drinking water drank within 15 minutes after eating (Andersson and Lindgren, 1987).

Stray Voltage

Gorewith et al. (1989) conducted a study on the effects of alternating current voltage on water bowls of lactating Holstein cows. Their objectives were to determine the effects of long term exposure to voltage on water intake, feed intake, milk yield, and milk composition. Cows in this study did not show any long term effects of the ac voltage applied to their water bowls. All of the animals subjected to 3 V or less and 91% of animals subjected to 4.0 to 6.0 V adapted within 1 to 2 d in water intakes. However, short term effects were noticed. As the voltage increased it took cows longer to consume the first 3.8 L of water (Gorewith et al., 1989). Similar results have been reported in other studies (Gorewitet al., 1992; Southwicket al. 1992; Aneshansley, et al., 1997; and Reinemannet al., 1996) Cows are affected initially by stray voltage in the water but adjust to the shock as long as the voltage is below 2 volts (Roberts et al., 2003).

The research shows that there are many factors that can affect water intake of dairy cattle. Low flow rates, overcrowding, aggressive cows, stray voltage and water restriction can all negatively impact water consumption of a dairy cow. To maximize water intake cows need an unobstructed access to a waterer that provides ample amounts of clean water.

Water Needs by Dairy Facilities

Brugger et al. (2008) compiled total dairy farm water usage from January 1, 2005 to December 31, 2006. This study was conducted on a 1,000 cow dairy farm in northwest Ohio where the average highest temperature is 15.6˚C and the average lowest temperature is 3.9˚C. Water meters were installed in 13 key locations to measure water usage by different areas of the facility. Over the 2 years the total farm water usage averaged 112.05 L/cow per day. Free water intake by the dairy cows was lowest during the month of December 2005 at 43.9 L/cow per day and the highest was in July 2005 at 127.9 L/cow per day. The cows alone consumed an average of 88.2 L/cow per day of free water intake over the entire study. However, this figure does not include the amount of water consumed from the ration by the dairy cows.

Bray et al. (2008) published water budgets for Florida dairy farms. They used the equation shown previously from Murphy et al. (1983) to predict water intakes. They used this equation with varying milk yields, dry matter intakes, and cool and warm season temperatures. They were able to determine an average consumption of 94.6 L/cow per day for Florida dairy cows (Bray et al. 2008). It is also noted that cows under heat stress can require 1.2 to 2 times more water per day.

Parlor Water

The area of the dairy that has been shown to use the largest amounts of water is the milking parlor facilities (Sweeten and Wolfe, 1993; Gamroth and Moore, 1995, Meyer et al. 2006). Large volumes of water can easily be used to flush parlor floors, wash udders in a wash pen, and to cool milk in plate coolers. It is noted in a few studies that some or all of this water from the parlors are recycled. Brugger's et al., (2008) study conducted on a single farm in Ohio recycled that water from the plate cooler to the drinking water supply for the dairy cows. In other situations farmers recycle gray water from the parlor by flushing the alleyways in the free stall barns.

Meyer et al. (2006) evaluated parlor water use on 16 dairies to calculate the amount of water flowing into dairy lagoons and holding ponds. The data for this study was collected over a 9 to 12 month period from August 1998-August 1999. This study was conducted in the Central Valley of California and farm sized ranged from 125 to 2,829 milking cows. Parlor water use was based on readings from the milk house, milking parlor, sprinkler pens, and included water used for udder hygiene, milk equipment sanitation, parlor cleaning, plate coolers, and ice makers. They found parlor and udder hygiene water comprised an average of 56% of the total water entering the farms lagoons. A range of 170 to 734 L/cow per day with an average of 291 L/cow per day was the water use on these farms. This shows a high variability among farms and the large amounts of water that can be used in the milking facilities. Like the other studies they reported that parlor water use was consistent throughout the year on each farm (Meyer et al., 2006). A second study from California in 2008 by Castillio and Burrow measured parlor water use in Merced County dairies. They chose 3 different dairies and installed 64 water meters. The average water use in the parlors on the 3 farms was 166, 193, and 185 L/cow per day.

In contrast to the previous warm climate California studies Janni et al., (2009) measured parlor water on 16 Minnesota dairy farms. These dairies were much smaller in size ranging from 41 to 130 milking cows. Here they found a range of 8.6 to 37.3 L/cow per day parlor water. The drastically lower water usage per cow per day can be mostly attributed by the Minnesota dairies not using wash pens to prep the udders before milking.

Brugger et al. (2008) in North West Ohio also measured parlor water use. They installed water meters to measure water used for parlor cleaning, hot and cold water for the milking equipment clean in place system, cold and hot water to clean bulk tank, and domestic water use in the dairy. Over the 2-year study Brugger found that the average use was 23.84 L/cow per day for parlor water. They also noted that this was a consistent usage rate in that it did not have seasonal variation. A 1993 study to determine milk house waste water characteristics on 5 farms in Wisconsin also reported on parlor water usage (Bougie, 1993). This report found milk house waste water use ranged between 870 to 2,081 L/day. The daily average use per cow ranged from 11.16 to 20.9 L/cow per day (Bougie, 1993). In 2008 Bray et al., reported parlor water usage in Florida dairies. They determined that 283 L is a common vat volume that is filled for the four cycles used to clean milking equipment. This would result in a usage of only 11 L/cow per day for a herd of 300 cows. Their findings also report on parlor water usage at 22.7 and 113 L/cow per day depending on using a hose or flush tanks to clean the parlor using the same 300 cow farm model (Bray et. al., 2008).

Parlor water can comprise a large volume of the total water use on a dairy farm. However, it is highly dependent on how the parlor is managed (i.e.: with or without wash pens) and the use should factor in the ability to re-use this large volume of water.

Cow Cooling Water Usage

Evaporative cooling is an effective method to cool cows during the hot summer months (Montoya et. al, 1995, Means et. al, 1992). This cooling method combines the use of water, fans, and shade to cool the animal. While this has been proven to be an effective method to cool cows it does require large amounts of water (Montoya et al., 1995, Means et al., 1992, Strickland et al. 1989).

Strickland et al., in 1989 used 454 L/cow per day rates to cool cows in their study. This is a large amount of water compared to a report by Means et al. (1992) which showed only 215

L/cow per day of water was needed to adequately cool the cows and decrease heat stress. Both of these studies took place in Florida, which is known for its heat and humidity. Means et al. (1992) reported that the lowest water application of 215 L/cow per day was sufficient to cool the cow. Montoya et al., (1995) noted that while the approach used in the Means et al. (1992) study does reduce the water needed to cool cows, the water used was still a large amount to handle on a dairy farm.

Brouk et al. (2001) studied the placement of sprinklers in 2-row freestall barn to maximize cow cooling. Sprinklers were added to the feedline only and to the feedline plus along the rear alley of a 2-row freestall barn. The sprinkler settings in this study were on a 15 min cycle with 3 min on and 12 min off. The sprinklers were turned on when the temperature was above 23.9° C and the application rate was 94.6 L/cycle. Their findings showed that there was no added benefit to the sprinklers along the rear alley of the barn thus saving water usage.

Sprinkler water usage was also recorded in a study by Meyer et al. (2002). This study was conducted over at 70 day period on 156 Holstein cows in August and September on a commercial dairy in Kansas. Three different cooling systems were being studied to determine the most effective. They were axial fans over freestalls and feed line, ceiling fans over freestalls and polytube cooling over freestalls. Sprinklers were set up on 15 min cycles of 3 min and 12 min off and were activated above 23.9°C. The rate of application of these sprinklers was set at 61 L/min. Total water usage from the sprinklers from across all experiments came to 10,024 L/day or 64.25 L/cow per day. Lin et al. (1998) also recorded sprinkler water usage over a 2 year study during the summer months. During the first summer maximum daily temperatures ranged from 27.5 to 32.5°C and the sprinklers used 42.8 L/cow per day. The second summer daily temperatures ranged from 31.9 to 37.5°C and the sprinklers used 102.84 L/cow per day.

Sprinklers were set up to run 3 min out of every 15 min and turned on when ambient temperature exceeded 27.8°C (Lin et al., 1998).

In a subsequent study done by Brouk et al. (2003) differing sprinkler frequencies were examined to determine the most effective for heat stressed dairy cows. Sprinklers were set up to run every 5, 10, or 15 min and provided 1.3 L of water per soaking for all treatments. Brouk et al., (2003) were able to determine that soaking every 5 min provided the best cooling method for severely heat stressed animals. To limit water usage it was recommend that during periods of moderate heat stress soaking cows every 10 minutes is adequate. All of these treatments were only effective when supplemental air flow provided by fans were used with the soaking (Brouk et al., 2003).

Evaporative pads are another method used to cool cows that uses water. Evaporative pads are designed to cool the air around a cow's body to reduce heat stress (Harner et al., 2007). Harner et al., (2007) presented their findings on the water usage of evaporative pads. The water usage data collected from this presentation was collected from a cross ventilated barn in the upper Midwest housing 1,200 dairy cows. Water measurements were taking from July 1 to July 31. Total water used during this time was 1.82 million L and average use per cow was 49 L/cow per day (Harner et al., 2007).

All of the studies showed a wide range in water usage per cow per day when using a sprinkler system along with fans to cool the dairy animal. The usage factors depend on the ambient air temperature, nozzle size, application rates, and the sprinkler on off cycle. While ambient air temperature cannot be controlled to limit water usage correctly, setting up the sprinkler system to maximize evaporative cooling will reduce water usage.

Prediction of Water Intake

Murphy et al. (1983), Holter and Urban (1992), Little and Shaw (1978), Stockdale and King (1983), Castle and Thomas (1975), and Dahlborn et al., (1998), have published formulas for predicting water consumption. The Murphy et al. (1983) formula is as follows: Water intake (kg/day) = 15.99 + 1.58 x DMI (kg/day) +0 .90 x milk yield (kg/day) + 0.05 x sodium intake (g/day) + 1.20 x minimum temperature °C.

Murphy et al. (1983) provided the recommended formula to predict free water intake (FWI) by the 2001 NRC. The NRC explains that the milk coefficient of 0.90 used in Murphy et al., (1983) equation is the closest to the 87% water content of milk. In Murphy's et al. (1983) equation all of the variables have been shown to effect water intake and it is the only formula that includes sodium intake as a variable. Murphy et al. (1983) formula shows that drinking water changes 1.58 kg for every for every 1 kg change in DMI, .90 kg for every 1 kg in milk yield, 0.05 kg for each 1 g change in Na intake and 1.20 kg for every 1°C change. This shows that DMI has the largest influence on drinking water intake. However, these formulas are only helpful in estimating FWI.

Beede notes in the proceedings of the Western Dairy Management Conference (2005) that from personal observation free water intake of a group of cows can vary by as much as 15 to 20% from predicted values. Many environmental factors can significantly affect water consumption that are not measured or quantified by these formulas (Beede, 2005). These formulas do have similar results in predicating water intake (Beede, 2005). The range of water intake predicated by these formulas is 78.7 to 95.7 L per day per cow (Beede, 2005). Beede notes that these formulas are a starting point to estimating on farm water intakes and should be combined with on-farm measured intakes (Beede, 2005).

Water prediction equations can help determine if the dairy cattle have proper water intakes. However, they do not factor in other water usage on the dairy farm and should always be compared actual on farm water usage.

Conclusion

Water is a resource that is used in large quantities on dairy farms. Lactating dairy cattle need to consume large amounts of water to support high levels of milk production and the farms can use vast amounts to run the dairy. This review shows that water usage was highly variable from farm to farm and it can be difficult to predict water usage on a single farm. The prediction by Murphy et al. (1983) takes into account DMI, milk production, sodium intake, and temperature to determine the water consumption of a dairy cow. This equation is helpful in predicting what a cow should be consuming but this review shows there are a number of factors that can affect water consumption. Not providing adequate waterer space, stray voltage, aggressive cows, high levels of minerals in water, and low flow rates can all inhibit the amount of water a cow consumes. Knowing how much water a cow should be consuming can help meet the cows water intake needs. It can also help a farmer determine if too much water is being consumed on the farm. How water is used to manage the farm from watering cows, cooling cows, and to operating the facilities greatly impacts the amount of water used on a farm. While the Murphy et al. (1983) equation allows for prediction of cows water intake, total water use on a dairy facility is not predicted. Being able to more accurately predict the total water usage of dairy facilities can enable better designs to handle the water needs of the specific dairy facilities. Also determining which facilities use the least amount of water can help the dairy industry design facilities that require less water to operate. As quality water resources become less abundant the total water use per cow of a dairy facility will be more important in determining the dairy facility that is built. The following research begins to asses these needs of dairies and compares water usage in different facility designs.

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CHAPTER 2 - **Meta-Analysis on Water Intake of Dairy Cattle**

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Abstract

Data obtained from 50 individual published studies recording water intake by dairy cattle were utilized in a meta-analysis to develop a prediction equation for free water intake (FWI). Studies were selected based on quantitative measurements of DMI, diet DM%, water intake (WI), and milk yield. Many of the studies determined FWI on multiple treatments resulting in 116 mean data points from the 50 studies. With the addition of Na in the meta-analysis, 40 data points were available from the studies to examine the effects of Na on FWI. The effects of DMI, ration water intake (RWI), and milk yield (MY) were used to develop a FWI prediction equation from the 116 data points. The effects of DMI, RWI, MY, and sodium intake were used to develop a second prediction equation from the 40 data points. These equations were then compared with five published FWI prediction equations from Castle and Thomas (1975), Dahlborn et al. (1998), Little and Shaw (1978), Murphy et al. (1983) and Stockdale and King (1983). This data set showed that the five published equations either over or under predicted ($P < 0.05$) FWI when compared the actual FWI calculated from the meta-analysis data points. It also showed that the equation developed from the meta-analysis data points is the more accurate in determining FWI from the data points selected from the studies.

A second project was conducted with the fresh water data collected from 13 freestall (FS) and 11 dry lot (DL) Kansas dairies over a 10-year period (2000-2009). Fresh water was recorded from water pumping records. Data were first summarized annually by operation and then converted to a per cow per day basis prior to analysis. Data were then analyzed by using the mixed procedures of SAS. Fixed effects included in the model were dairy type (FS or DL) and year was considered a random effect. The DL dairies averaged 186 L/cow per day and were

lower than the FS dairies which averaged 237 L/cow per day. Differences between DL and FS dairies may have been due to differences in parlor fresh water usage or cow cooling systems.

Introduction

Milk from dairy cows is composed of 87 percent of water and total body water in a mature lactating dairy cow can be as high as 81 percent of total body weight (Winchester and Morris 1956; Murphy, 1992). Therefore, water is the dairy cow's most important nutrient (NRC, 2001). To prevent problems with animal health, welfare, and performance a sufficient supply of water is needed (Murphy, 1992).

Dairy cows excrete large amounts of water through milk production, waste secretions, respiration, and sweating. Water loss is impacted by diet composition, temperature, humidity, and milk production which in turn affects the amount of water a lactating dairy cow will consume. Low intakes of water can lead to a reduction in body weight, milk yield, respiratory rate, and provoke aggressive behavior among animals (Cardot et al., 2008).

Murphy et al. (1983) published a prediction equation to predict the amount of FWI a lactating dairy cow will consume. The NRC (2001) recommends this equation to determine water drinking needs for dairy cattle. Murphy et al. (1983) is recommended because its coefficient for milk is the closest to the 87 percent water that milk contains. In addition, the other coefficients of DMI, Na intake, and temperature have all been shown to affect FWI (NRC, 2001).

The NRC (2001) also lists 4 other studies by Castle and Thomas (1975), Dahlborn et al. (1998), Holter and Urban (1992), Little and Shaw (1978), and Stockdale and King (1983), that developed equations to predict FWI in lactating dairy cattle. DMI, DM percent, and MY data from the 116 data point meta-analysis were then used in the prediction equations of Castle and

Thomas (1975), Dahlborn et al. (1998), Little and Shaw (1978), and Stockdale and King (1983) to compare their equations to the actual FWI determined by the meta-analysis data points. Holter and Urban (1992) equation was not used due to our inability to use the Julian Day coefficient. DMI, DM percent, sodium intake, and MY data from the 40 data point meta-analysis were used in the prediction equations of Murphy et al. (1983), Castle and Thomas (1975), Dahlborn et al. (1998), Little and Shaw (1978), and Stockdale and King (1983). For Murphy et al. (1983) temperature coefficient 20 °C is used in the equation.

Meta-Analysis

Materials and Methods

A meta-analysis was performed on data obtained from 50 individual studies recording water intake by dairy cattle. Papers were selected from throughout the world but the majority came from the Journal of Dairy Science. The goal of this literature review was to find studies that recorded water intake, DMI, ration DM percent, and milk yield. Search terms used in all of the data bases included “water intake”, “water”, and “dairy water.” The studies used in the analysis were selected based on quantitative measurements of DMI, DM percent, water intake (WI), and milk yield. Using these parameters, 116 data points were available from 50 individual studies. With the addition of Na, 40 data points were available to examine the effects of DMI, milk yield (MY), RWI, and Na on FWI of dairy cattle. The meta-analysis 116 data points were then used to develop a prediction equation based on DMI, MY, and RWI. The prediction equation developed from the 116 data points is (Table 1):

FWI = 29.65 + 1.81 DMI, kg/d + 1.02 Milk, kg/d – 0.87 RW kg/d.

A prediction equation was also developed from the 40 data points that included DMI, MY, RWI, and sodium intake. This equation is (Table 2):

FWI = 50.146 – 0.16 milk kg/d + 2.89 DMI kg/d + 0.14 Na, g/d – 1.11 RWI kg/d.

DMI, DM percent and MY reported in the studies were used in the first four prediction equations listed below to compare the prediction values of FWI of these equations to the actual FWI from the meta-analysis. The fifth equation by Murphy et al. (1983) was used for comparison only with the inclusion of the 40 Na data points. Listed below are the published FWI prediction equations:

1. -15.3 + 2.53 x milk, kg/d + 0.45 x DM% of diet (Castle and Thomas 1975).
2. 14.3 + 1.28 x milk, kg/d + 0.32 x DM% of diet (Dahlborn et al., 1998).
3. 12.3 + 2.15 x DMI, kg/d + 0.73 x milk, kg/d (Little and Shaw, 1978).
4. -9.37 + 2.30 x DMI, kg/d + 0.053 x DM% of diet (Stockdale and King, 1983).
5. 15.99 + 1.58 x DMI, kg/d + 0.90 x milk, kg/d + 0.05 Na intake g/d + 1.20 x min temp °C (Murphy et al., 1983).

The studies that were selected ranged from 1952 to 2009 and had water intakes ranging from 15.3 to 144.6 L/cow per day. After completing the analysis searches of the databases continued for new publications through June 2010.

Results and Discussion

Since the inclusion of Na into the data set reduced available number of data points to 40 and Na was shown to have the least impact on free water intake (FWI) in Murphy et al. (1983) prediction equation, the data set of 116 available data points was first used to analyze FWI. The data set included the effects of DMI (Figure 1), MY (Figure 2), and RWI (Figure 3) on FWI.

The trends of Figure 1 thru Figure 3 indicate that FWI changes 1.81 L for each 1.0 kg change in DMI, 1.02 L for each 1.0 kg change in MY, and -0.87 L for each 1.0 kg change in RWI.

Ration water intake (RWI) was calculated from the DMI and DM percent reported in the meta-analysis. Data were subjected to the MIXED Procedure of SAS version 9.1 (SAS Institute Inc., Cary, NC) to analyze all 116 data points. Table 3 reports the actual FWI from the data set and what the prediction equations estimate for FWI using the meta-analysis data points.

Actual FWI for the 116 data points is 80.82 L/cow per day (Table 3). Castle and Thomas (1975) predict more ($P < 0.05$) FWI than the actual FWI. Little and Shaw (1978), Dahlborn et al. (1998), and Stockdale and King (1983) all predict less ($P < 0.05$) FWI than the actual FWI (Table 3). Castle and Thomas (1975) and Dahlborn et al. (1998) equations used diet DM percent. Little and Shaw (1978) used DMI to predict FWI. All three of these studies used MY in their prediction equations.

To make the comparison to the NRC recommend equation by Murphy et al. (1983) Na was added to the selection criteria. The data set included the effects of DMI (Figure 4), MY (Figure 5), RWI (Figure 6), and Na (Figure 7) on FWI. The trends of Figure 4 thru Figure 7 indicate that FWI changes 2.88 L for each 1.0 kg change in DMI, -0.16 L for each 1.0 kg change in MY, 0.14 L for each 1.0 g change in Na intake, and -1.11 L for each 1.0 kg change in RWI.

The inclusion of sodium reduces the number of available data points to 40 from the meta-analysis. The weekly mean temperature was set at 20 °C in Murphy et al. (1983) equation to make comparisons. With these parameters Murphy et al. (1983) equation predicts more ($P < 0.05$) FWI than the actual FWI of 86.86 L/cow per day (Table 4). Unlike the first comparison both Castle and Thomas (1975), Dahlborn et al. (1998), and Little and Shaw (1978) predict less ($P < 0.05$) than the actual FWI (Table 4). Once again without using MY as a parameter to estimate FWI, Stockdale and King equation predicts 52.06 L/cow per day less ($P < 0.05$) than the actual FWI (Table 4).

Each prediction equation predicts more or less ($P < .05$) FWI from the same milk yield. To compare if the equations predict similar FWI per kg of milk, a milk efficiency data set was run using the MIXED Procedure of SAS version 9.1 (SAS Institute Inc., Cary, NC). Milk efficiency estimation of FWI from each prediction equation for both data sets (116 and 40 data points) was calculated.

For the 116 data points actual milk efficiency is 2.82 L of FWI per kg of MY. Little and Shaw (1978), Stockdale and King (1983), and Dahlborn et al. (1998) equations estimate less ($P < 0.05$) FWI per kg of milk when compared to the actual (Table 5). Castle and Thomas (1975) equation estimates more ($P < 0.05$) than the actual milk efficiency.

The calculations of milk efficiency for the 40 data points that included Na are reported in (Table 6). The actual milk efficiency for this data set is 3.11 L of FWI per kg of MY. Little and Shaw (1978), Stockdale and King (1983), Dahlborn et al. (1998), and Castle and Thomas (1975) equations estimate less ($P < 0.05$) FWI per kg of milk when compared to the actual (Table 6). Murphy et al. (1983) equation estimates more ($P < 0.05$) FWI per kg of milk.

When comparing the equations developed from the meta-analysis of 116 or 40 data points (Table 1 and Table 2) the 116 data point equation is less correlated to FWI ($R^2 = 0.51$) than the 40 data points with Na included ($R^2 = 0.73$). The 40 data points with Na included in the prediction equation indicated that Na increases FWI by 0.14 L for every 1.0 g. The inclusion of Na into the data set improved the correlation of the prediction equation to FWI (Table 2).

Conclusion

The equations 29.65 + 1.81 DMI, kg/d + 1.02 Milk, kg/d – 0.87 RWI and 50.146 – 0.16 milk kg/d + 2.89 DMI kg/d + 0.14 Na, g/d – 1.11 RWI kg/d developed from the 116 and 40 meta-analysis data points both use RWI as a coefficient in determining FWI. The five published prediction equations included either DMI or DM percent to determine FWI. The meta-analysis prediction equation factors in both DMI and DM percent to determine RWI. Based on the statistical analysis the equations developed from the 116 data points and 40 data points with sodium from the meta-analysis was a more accurate prediction with the inclusion of RWI to determine actual FWI in the meta-analysis.

The meta-analysis equations being more accurate may be explained by Dewhurst et al. (1998) when they reported that FWI increased with increasing silage DM concentration and confirmed with other studies that FWI replaces ration water at a rate less than 1:1. This may explain why including a RWI coefficient improves the ability to predict actual FWI. Since the other equations only include DM or DM percent those equations do not allow for a difference if RWI does not replace FWI at 1:1 ratio.

Stockdale and King (1983) equation does not use MY as a factor in determining FWI and predicts 42.37 L/cow per day less FWI than the actual 80.82 L/cow per day from the meta-analysis ($P < 0.05$). Winchester and Morris (1956) reported that 0.87 kg of water per kg of milk is expected since milk is 87 percent water. Suggesting that milk yield will influence FWI. Additionally, all of the other four equations have indicated that MY has an influence in predicting FWI.

Murphy et al. (1983) equation indicates that sodium impacts FWI by increasing FWI by 0.05 L for each 1 g change in Na intake. The prediction equation from the 40 data points that include Na indicate that sodium increases FWI by 0.14 L for each 1 g change in Na intake. This equation is more correlated (R^2 = 0.72) than the 116 data points that did not have Na as a coefficient on FWI (R^2 = 0.51). This indicates that Na influences FWI and dietary Na should be considered when predicting FWI.

CHAPTER 3 - **Fresh Water Usage on Kansas Dairies**

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Introduction

Dairy facilities require vast amounts of water to operate. Facilities use water to cool cows and milk, flush alleyways, wash udders in wash pens, water cows, domestic purposes and clean milking equipment. Similar to dairy cow's water intake, dairy operations water use can vary greatly depending on management practices, location, and the recycling of water on the dairy. Determining how much water each facility uses and how much is actually needed can help dairy farmers conserve water on their farms and design water handling systems for their facility. The second part of the research involved collecting on farm water usage from dairies in western Kansas to compare water usage by facility type.

In the state of Kansas, farms with over 1,000 confined livestock or those diverting more than 15 acre-feet of water are required to have meters on their wells to monitor and regulate fresh water pumping (KDHE, 2008). The average dairy size used in this data set is 3,841 animals and average water utilization is 228 acre feet of water per year. As a result, dairy farmers need help to control their water use and be more efficient with water usage. A few studies have looked at the total water use on dairy farms (Brugger et al., 2008; Bougie, 1993; Castillo and Burrow, 2008; and Meyer et al., 2006). Brugger et al. (2008) was the most complete study metering water at 13 different locations on a dairy and showed an average of 112 L/cow per day for total water use in a single dairy facility in northwest Ohio.

Water usage on farms can vary based on location, facility type, and climate that the dairy is located. In this research dry lot (DL), free stall (FS), and a combination of DL and FS facilities from western Kansas were compared for water usage over a 10 year period. Determining the water needs of these dairy farms can help the dairy farmer's better plan and design their facilities based on water needs of that facility. The objective of this research was to report the differences of water usage by facilities

Dairy Farm Water Usage

Materials and Methods

The dairy farms that were used to analyze water usage were located in western Kansas. Fresh water pumping records were accessed from the state's Division of Water Resources in Topeka, KS. Water usage data from 24 farms 2000-2009 were used in the first data set and with a total of 189 data points to examine their water usage during this time frame. Out of the 24 farms there are 12 free stalls (FS), 10 dry lots (DL), and 2 combination DL/FS farms. Water usage was first adjusted annually by operation and then converted to a per cow per day basis before analysis. The MIXED Procedure of SAS version 9.1 (SAS Institute Inc., Cary, NC) was then used to analyze the data. Dairy type (FS, DL, FS/DL) were the fixed effects and year within farm was considered a random effect.

Since there was a large variation (57 to 731 L/cow per day) in water usage, outliers were removed from the data set. A minimum of 132 L/cow per day and maximum of three times the standard deviation (90.09 L/cow per day for FS and 104.20 L/cow per day for DL) were selected to remove the outliers. The combination DL/FS dairies were also removed from this data because one of the two farms in the data set reduced their milking herd in 2005-2007 and the lactating cows on this farm could not be accurately determined. This reduced the amount of data points from 189 to 126 to evaluate water usage over a 10 year period on 22 FS and DL dairies. The MIXED Procedure of SAS version 9.1 (SAS Institute Inc., Cary, NC) was again used to analyze this data. Dairy type (FS, and DL) were the fixed effects and year within farm was considered a random effect.

Results and Discussion

Twenty-four dairy farms consisting of dry lots, freestall, and a combination of the two facilities were used to compile 10 years (2000-2009) of fresh water pumping records. The DL dairies were the largest at an average of 4,387 cows per farm or 755 and 2,353 more cows per farm than the FS and DL/FS respectively (Figure 8). During this time all of the farms combined utilized and averaged 217 L/cow per day of fresh water. The three facility types averaged 199 L/cow per day for DL, 232 L/cow per day for FS, and 273 L/cow per day for DL/FS (Figure 9). The variation in water usage by facility may be caused by the presence of different methods of parlor water usage, cow cooling, wash pens, herd size, and water recycling. For example, Meyer et al., (2006) reported in their study that dairies with wash pens averaged 302 L/cow per day while dairies without averaged 202 L/cow per day. Sweeten and Wolfe (1993) also noted in their study on water use on Texas dairies the largest difference of water use on farm was wash pens (178.4 L/cow per day) compared to manual manure removal (75.2 L/cow per day). Using sprinklers to cool cows also uses large amounts of water. Means et al. (1992) reported 215 L/cow per day in Florida; Meyer et al. (2002) 64.25 L/cow per day; Lin et al. (1998) 102.84 L/cow per day, of water used to cool cows with a sprinkler system during the summer months.

Brugger et al., (2008) reported that on the dairy they studied, water from the plate cooler was recycled on the dairy farm. They found that reducing the flow of water through the plate cooler from 159 L/min to 80 L/min was sufficient to cool the milk and save water that was lost due to overflows of the reserve water tank. This also shows the vast quantities of water used in plate coolers. A good point to note is that all of the farms in this data set recycled the plate cooler water.

Figure 10 shows the dairies average water usage by year (2000-2009). The DL/FS have a wide range of 346L/cow per day to 123 L/cow per day and can be explained by their only being 2 dairies with a DL/FS facility in the data set. In addition, in every year except 2004, DL averaged less L/cow per day than the FS facility. While DL averaged the least amount of water usage there is no significant difference between facility types. When comparing the ranges of water usage on the three facilities on a month to month comparison over the 10 years there is a wide variation. The FS ranged from 76 to 731 L/cow per day; DL 57 to 644 L/cow per day; and DL/FS 117 to 344 L/cow per day. This is similar to what others have reported when studying water usage on dairy farms. Meyer et al. (2006) reported a range of 170 to 734 L/cow per day; Janni et al. (2009), 8.6 to 37.3 L/cow per day; and Sweeten and Wolfe (1993), 46.5 to 261.8 L/cow per day.

Figure 11 shows the FS and DL data average water usage by year (2000-2009) with the outliers and the DL/FS dairies removed from the data set. Removing the data points less than 132 L/cow per day is helpful in that these amounts would not even be satisfying the cow's drinking water requirements. Removing excessive values (greater than 3 times standard deviation) helps eliminate the possibility this excessive water usage may have been impacted by using fresh water for other uses besides the dairy. While this helped reduce the amount of variation in the data set there was no significant difference between the FS or DL facilities.

Brugger et al. (2008) reported that on their one dairy 53% of the total water usage came from parlor consumption and 47% from drinking water for cows. Meyer et al. (2006) reported that 57% of the total water entering the farms lagoons is from parlor water. This suggests that fresh water usage by free water intake of cows and fresh water usage in the parlor would not vary between facilities. The ability to reuse parlor water and the use of lagoon water to flush alleyways on the FS dairies both would be reasons there is not a significant difference between the FS and DL dairies.

Conclusions

Water is one of the world's most important natural resources and dairy farms need large quantities of water to operate. Dairy farming is also moving to drier regions of the United States and herd sizes are expanding, increasing the need for efficient use of water. Kansas is one of the states where dairy farming has expanded in the last decade and the state regulates and records water usage on these farms. To its credit the dairy industry has taken steps to limit water use, recycle water, and maximize the efficiency of water use on its dairy farms. Capper et al. (2009) reported that dairies require 35% less water to produce the same amount of milk today than they did in 1944. Dairy farms can use fresh water to cool milk in a plate cooler, recycle water from lagoons to flush alleyways, and finally irrigate crops.

One of the main conclusions of this research is that water usage is highly variable. Numerous factors play a role in how much water it takes to meet a cows needs and to operate a dairy facility. This is shown by the 90% variation in both water usages by facilities (76 vs. 731 L/cow per day) and water intakes in the meta-analysis (15.3 vs. 144.6 L/cow per day). For an accurate prediction of water intake or to design a facility that requires low water usage many factors must be considered. Temperature, DMI, ration water intake, sodium intake, milk production, water recycling, cow cooling needs, cleaning milking equipment, wash pens, deck washing, domestic water use, flush systems, and waterers all play a role in how much water is needed to run the facility and meet the cows requirements.

Further Research

Future research should focus on how water is managed on a dairy facility to reduce or maximize water usage. The current project shows that water use varies from farm to farm. Therefore, future researchers could install water metering stations throughout multiple dairies to more accurately monitor water consumption and identify the reasons for the variations in water consumption.

Aspects of the farm that use large amounts of water should be the focus of where to monitor water usage and to find savings. The area to start is the parlor water. Sweeten and Wolfe (1993), Gamroth and Moore (1995), Meyer et al. (2006), Brugger et al. (2008) have all reported large volumes of fresh water used in the milking parlor. While water used to clean the milking systems should be a known amount, water used during milking for wash-down and deck washing can vary based on the procedures of the farm. Operating procedures may also vary on farms with wash pens influencing fresh water usage. Changing parlor operating procedures, wash pen procedures, or cleaning methods of the personnel milking can reduce water usage in the parlor.

Being able to determine how much the cows should consume and comparing it to actual water intakes on the farm can lead to water savings. If cow drinking water increases or drops in a pen, waterers in that pen can be checked for leaks and cows for health problems. These water meters would need to be checked on a daily basis and the water usage averaged into the numbers of cows in the pen to determine if there is an issue with the waterers or cows. Finally, water used to cool cows could can be metered to check that those systems are working properly.

While there are numerous points on the farm to monitor and regulate water use, knowing the estimated water requirement compared to actual water use can lead to water savings. Being able to do this could be beneficial to dairies in states like Kansas that regulate and record water usage. The ability to reduce fresh water usage on a dairy farm can give farmers the option to expand their dairies or to utilize the saved water in other areas of the dairy farm.

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Figures and Tables

Figure 1 Effect of dry matter intake (DMI) on free water intake (FWI) from 116 data points in meta-analysis.

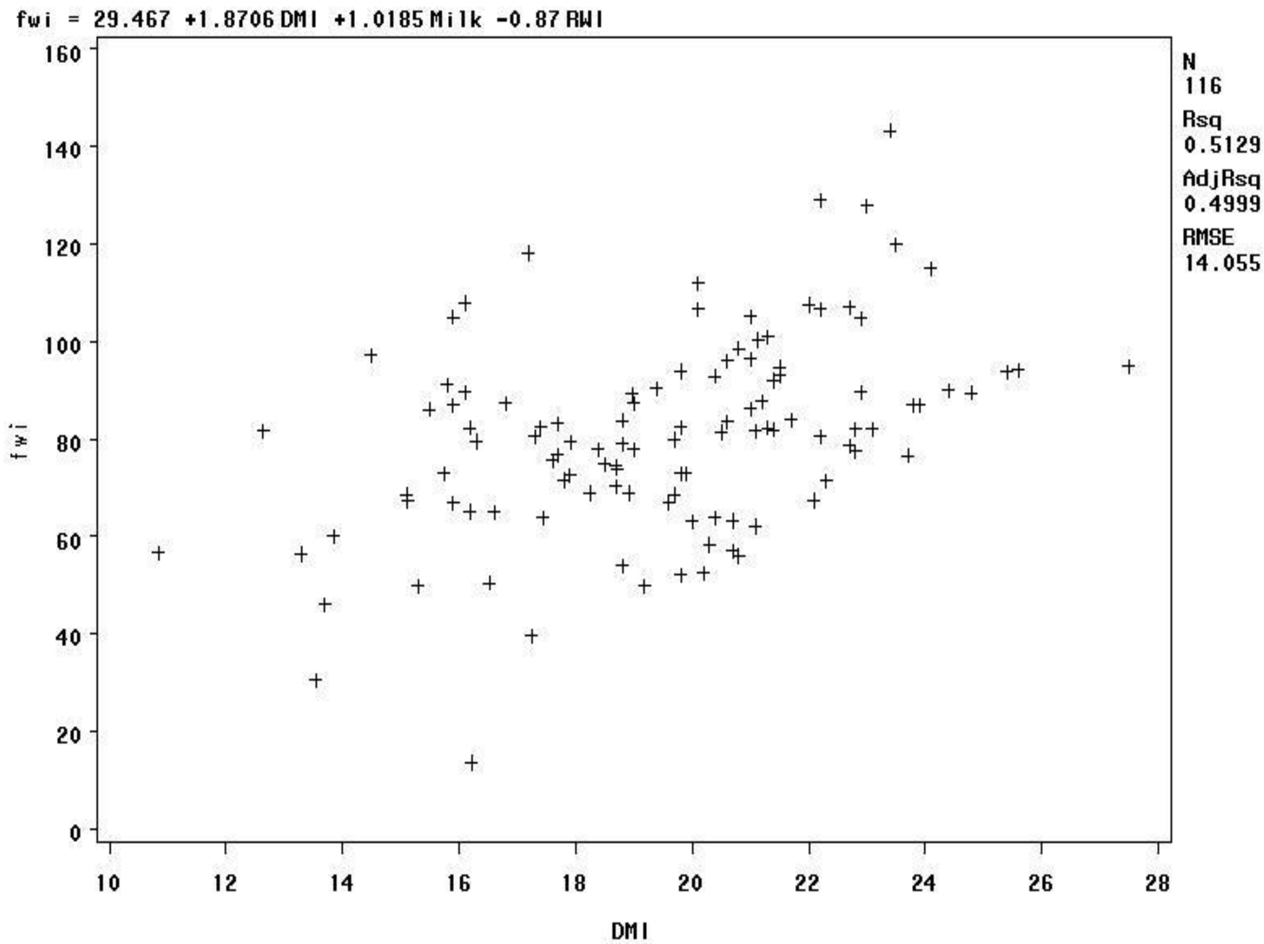


Figure 2 Effect of milk production on total water intake (TWI) from 116 data points in meta-analysis

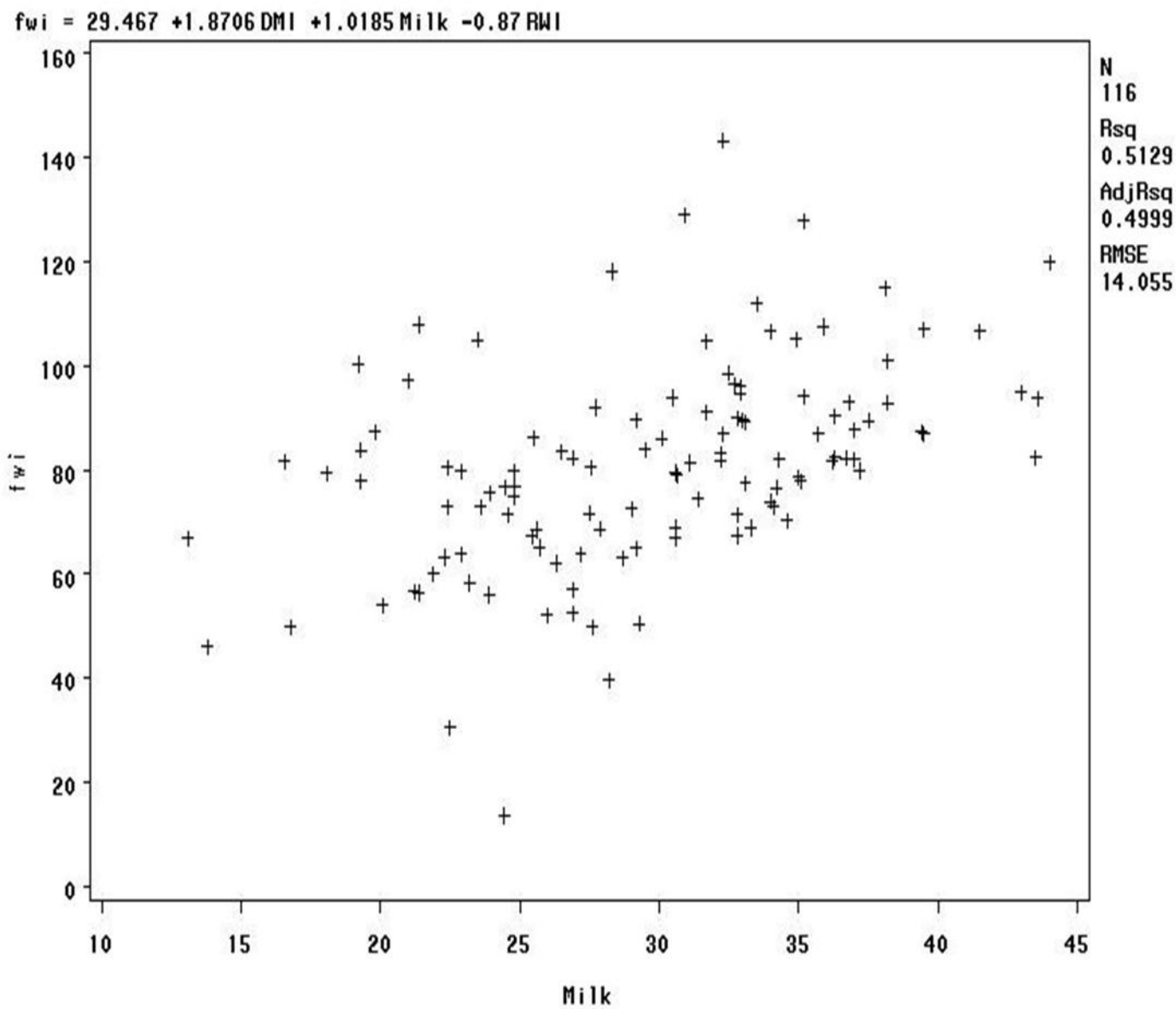


Figure 3 Effect of ration water intake (RWI) on free water intake (FWI) from 116 data points in meta-analysis.

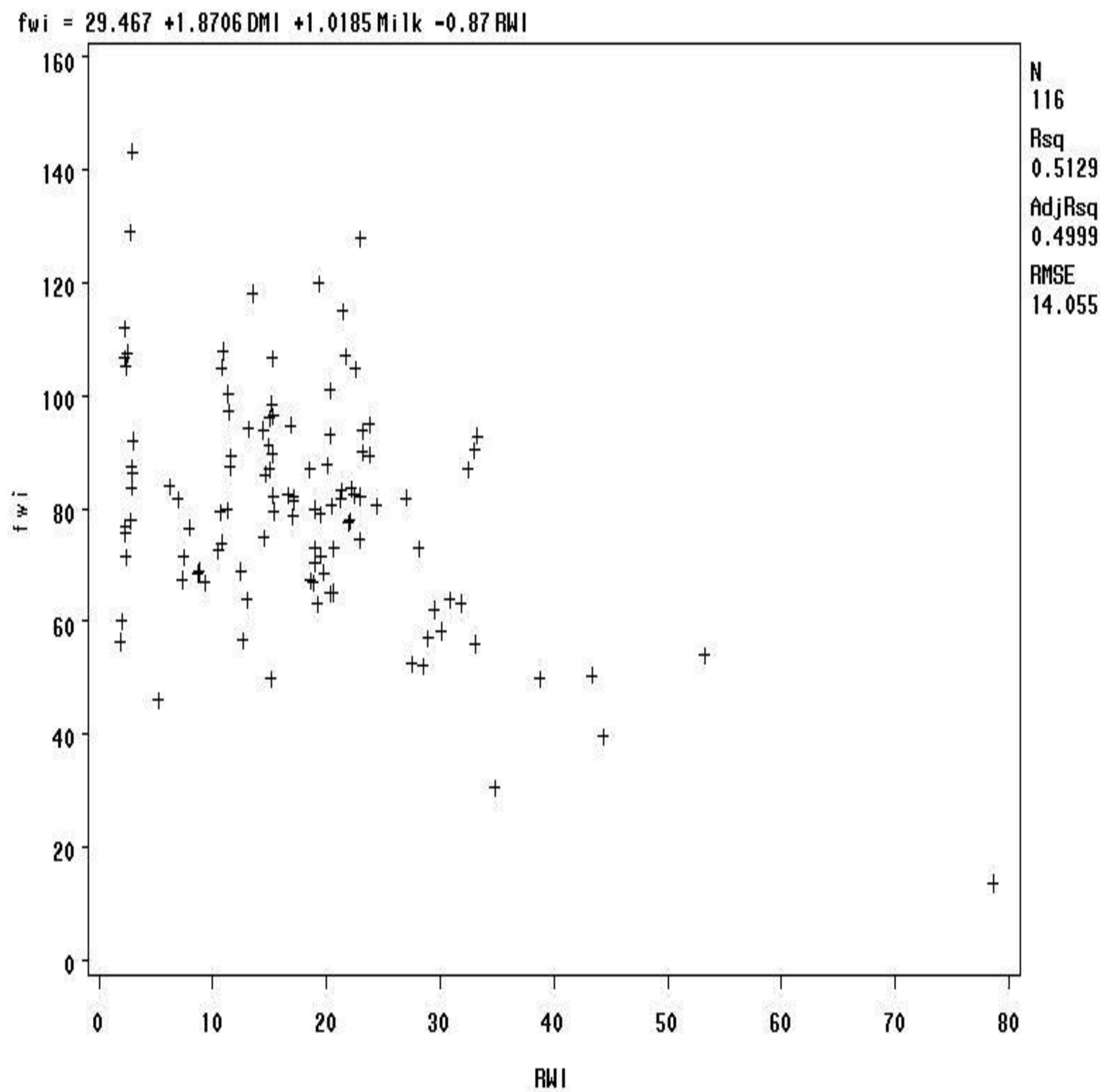


Figure 4 Effect of dry matter intake (DMI) on free water intake (FWI) from 40 data points from studies that included Na intake.

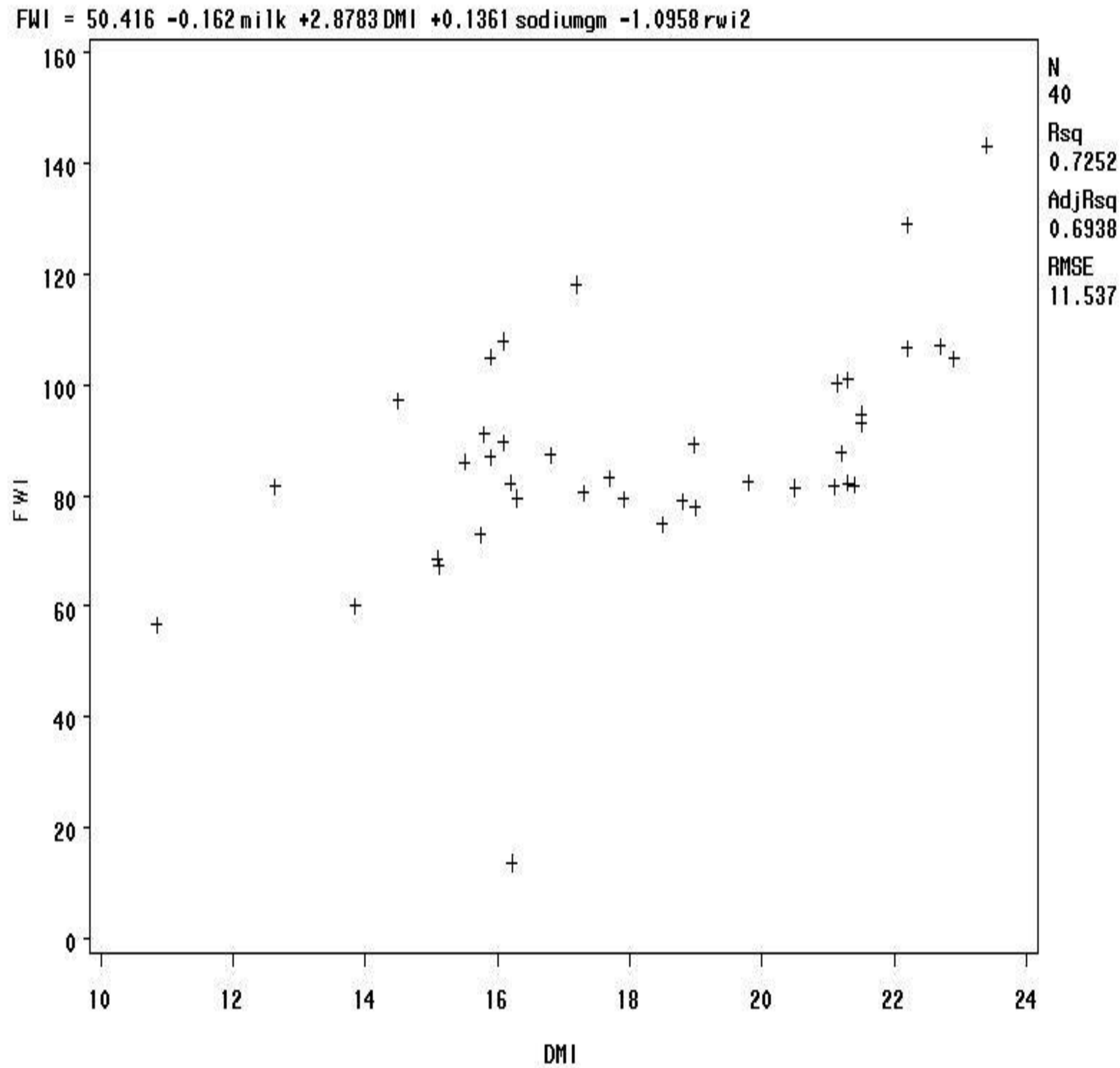


Figure 5 Effect of milk production on free water intake (FWI) from 40 data points from studies that included Na intake.

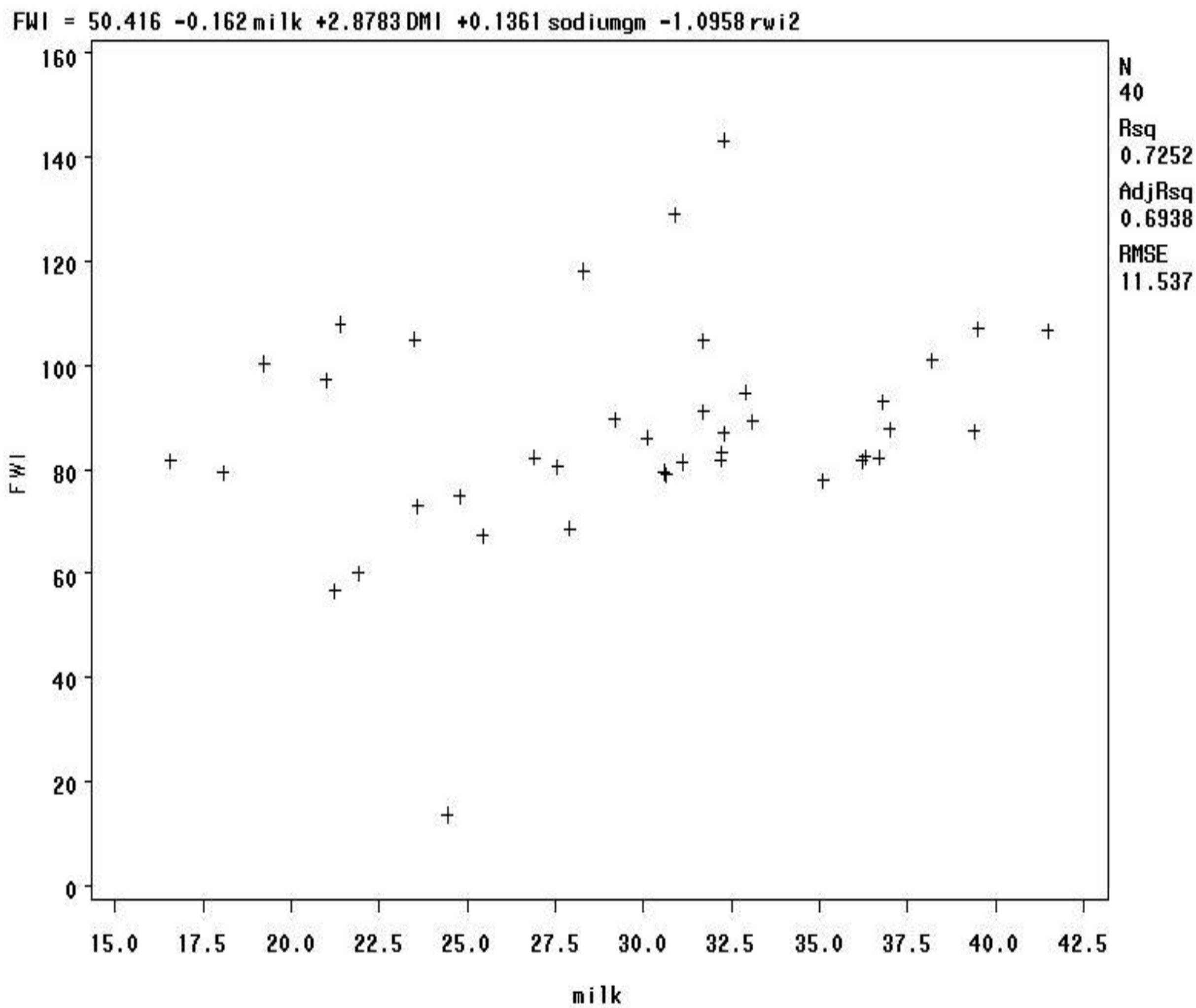


Figure 6 Effect of ration water intake (RWI) on free water intake (FWI) from 40 data points from studies that included Na intake.

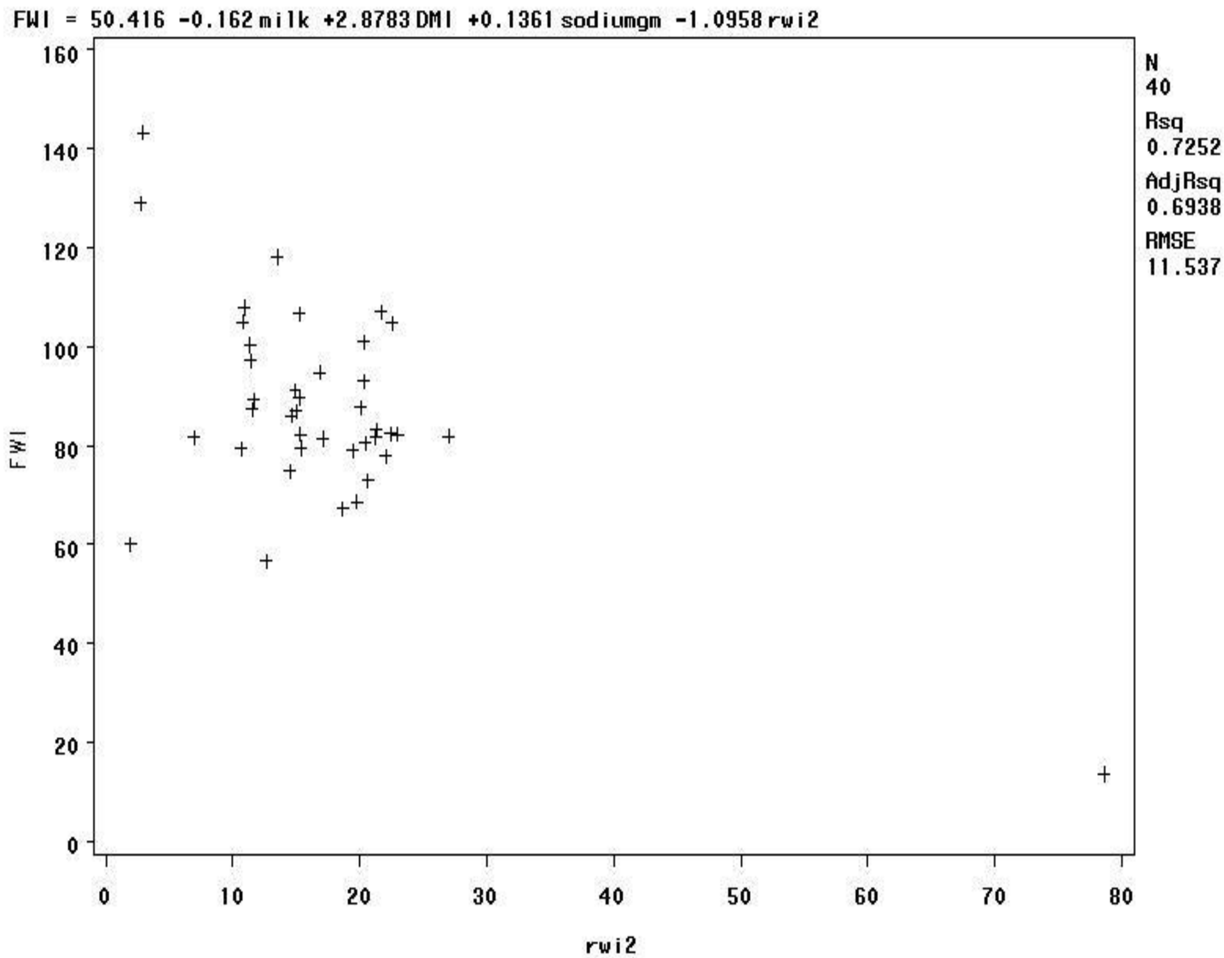


Figure 7 Effect of Na on free water intake (FWI) from 40 data points from studies that included Na intake.

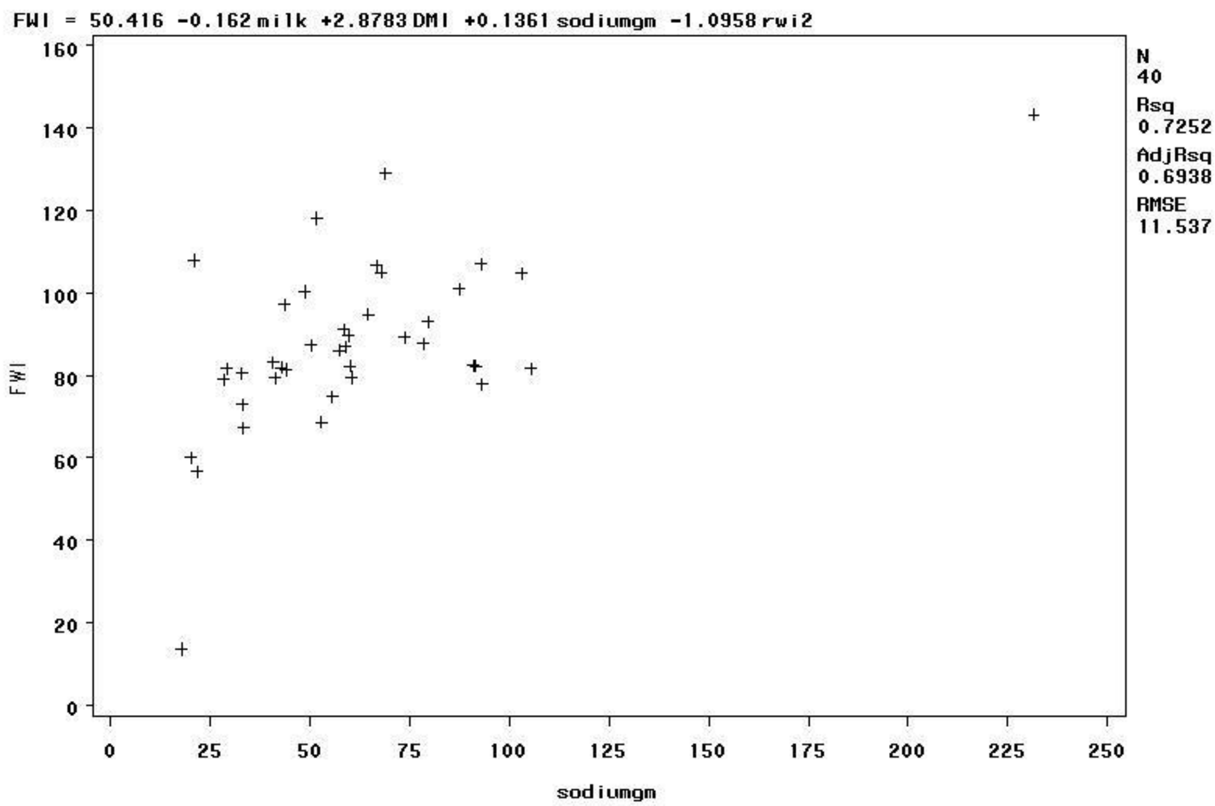
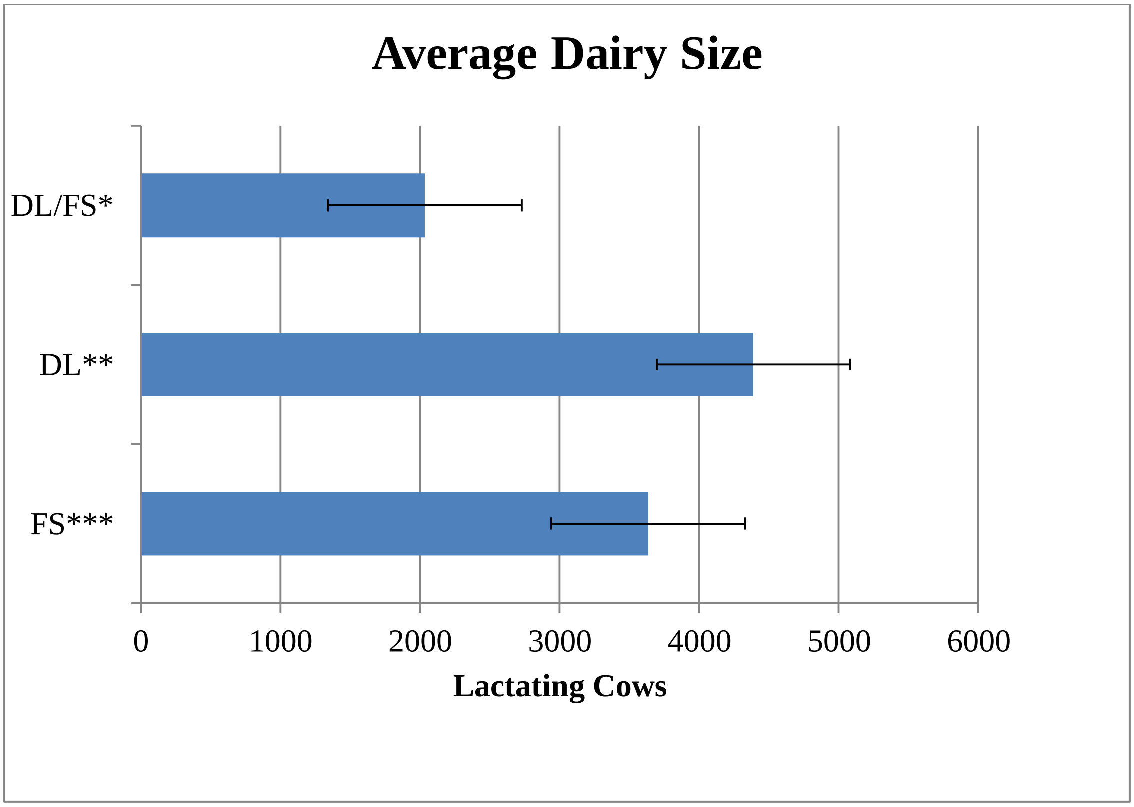


Figure 8 Average sizes of dairies from western Kansas.

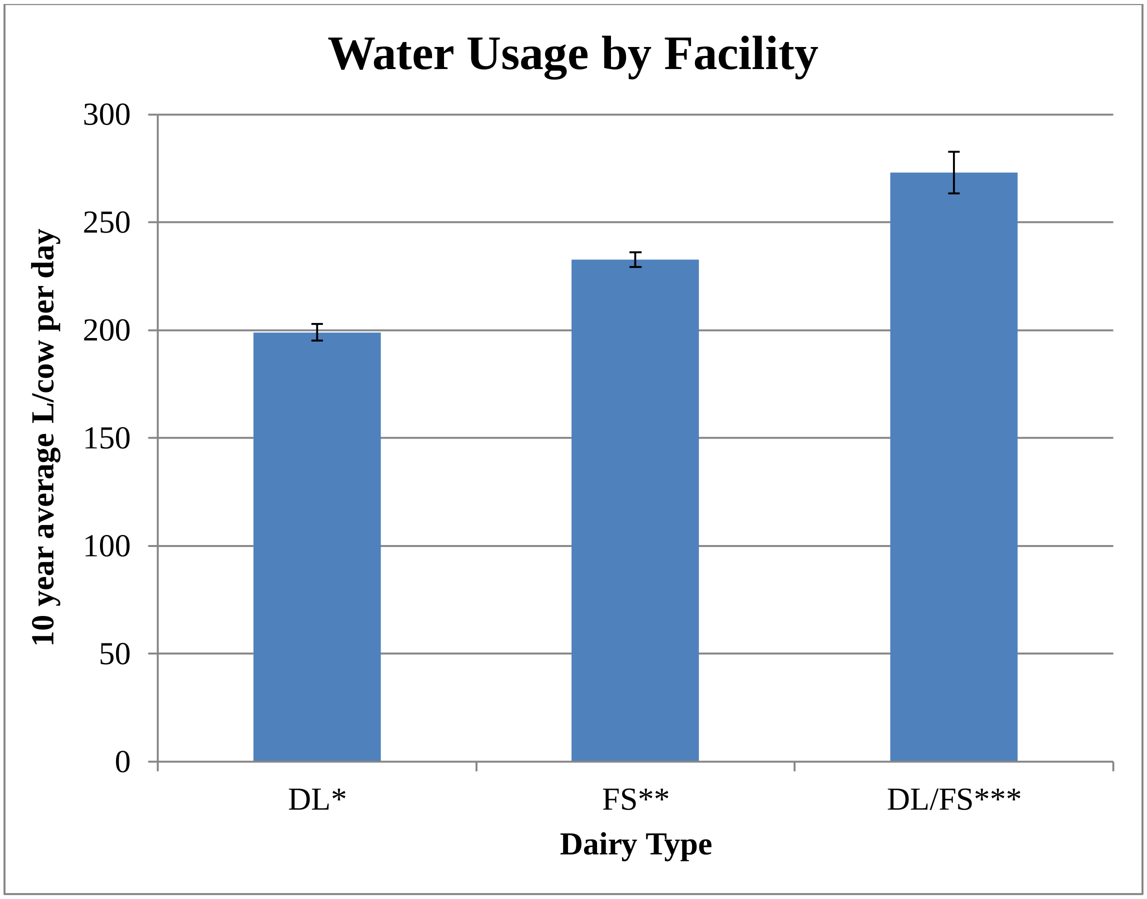


*Dry lot/Free stall

**Dry Lot

***Free Stall

Figure 9 Reported average water usage by Kansas dairy facilities between 2000-2009 on a L/cow per day basis

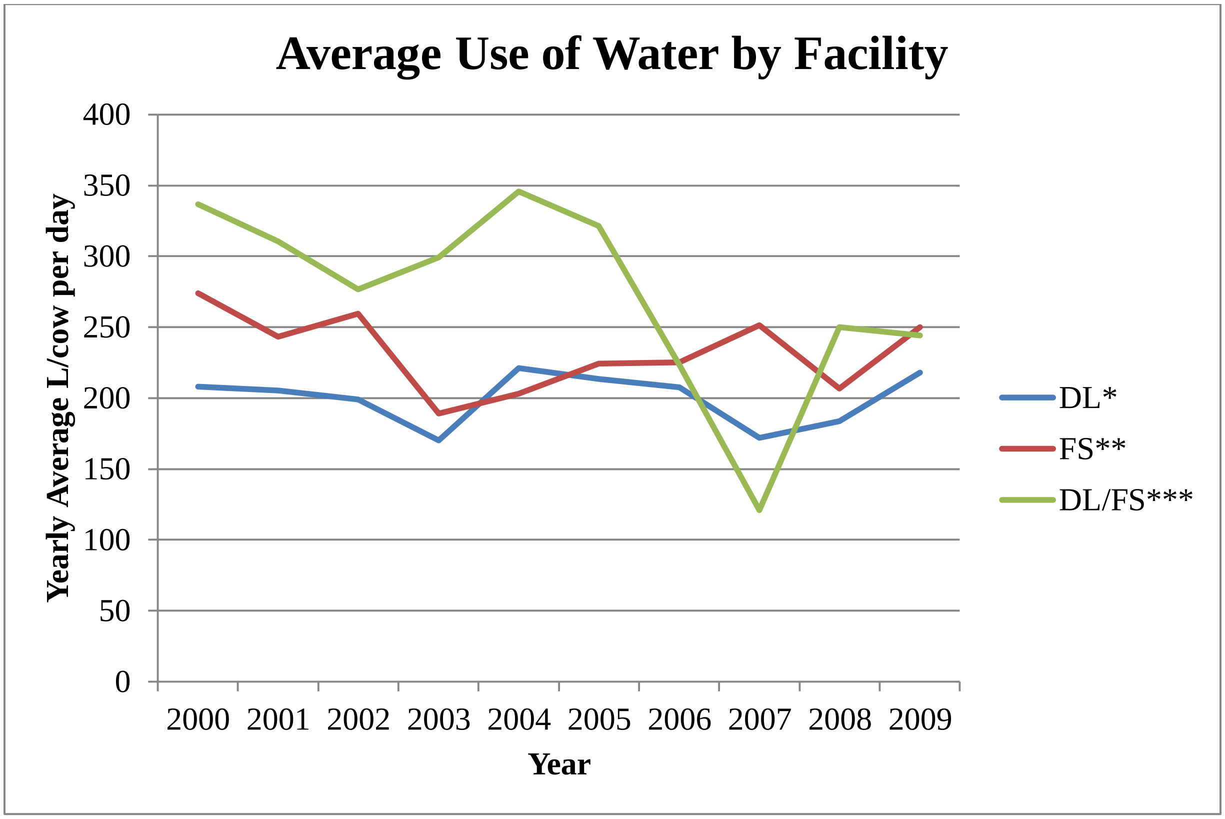


*Dry Lot

** Free Stall

***Dry Lot/Free Stall

Figure 10 Comparison of average use of water by DL, FS and combination DL/FS facility over 10 year period.

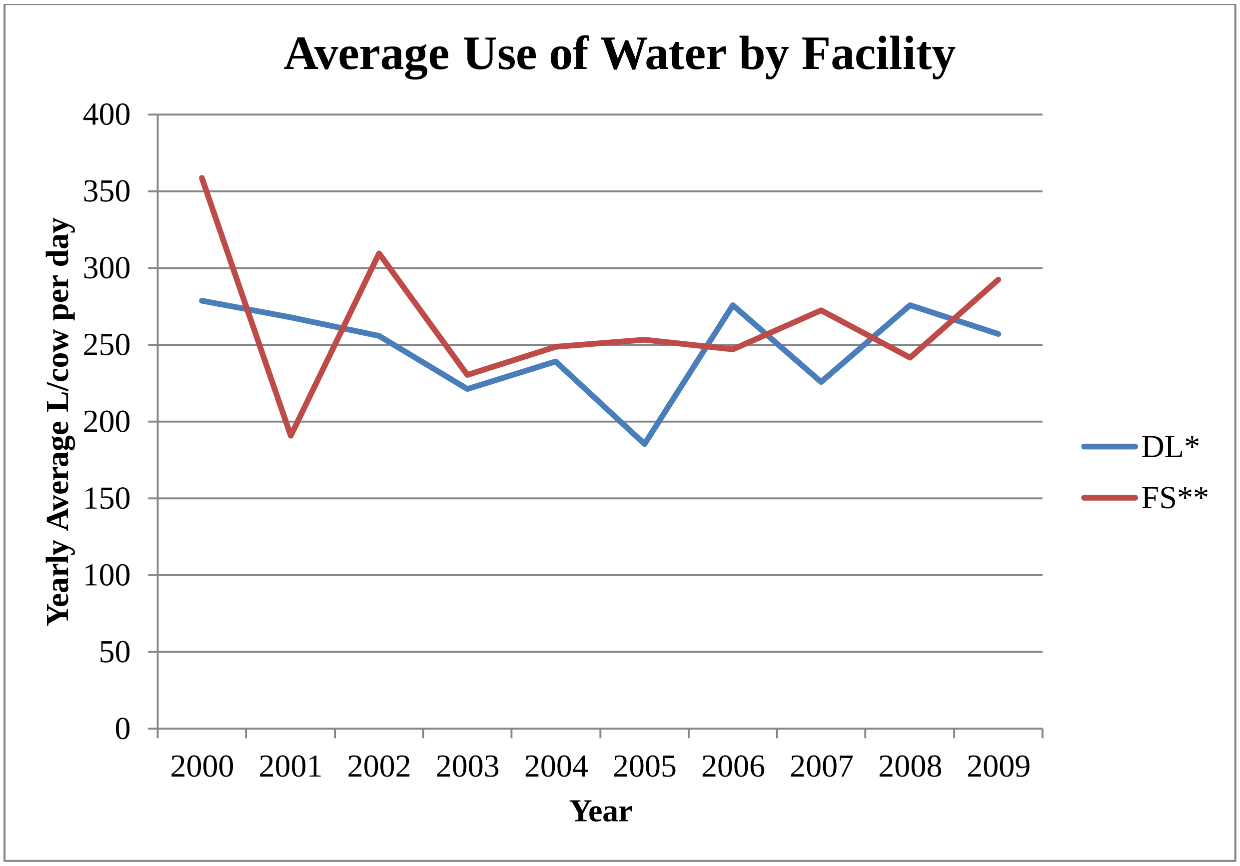


*Dry Lot

**Free Stall

***Dry Lot/Free Stall

Figure 11 Comparison of average use of water by DL and FS facility over 10 year period with outliers removed.



*Dry Lot
**Free Stall

Table 1 Prediction equation for free water intake based on the 116 data points from the meta-analysis.

Variable	Estimate	SE	P-value
Intercept	29.65	8.67	.0009
DMI[1]	1.81	0.54	.0008
Milk	1.02	0.25	.0001
RWI[2]	-0.87	0.11	.0001

[1]Dry matter intake

[2]Ration water intake

Table 2 Prediction equation for free water intake based on 40 data points from meta-analysis with Na.

Variable	Estimate	SE	P-value
Intercept	50.42	12.27	0.002
Milk	-0.16	0.39	0.680
DMI[2]	2.88	0.87	0.002
Sodium	0.14	0.07	0.057
RWI[3]	-1.09	0.17	0.001

[1]Dry matter intake

[2]Ration water intake

Table 3 Comparison of four prediction equations of free water intake to prediction equation of actual water intakes from all data points (116) from meta-analysis.

Equation	Estimated FWI[1] L/Cow per day	SE	P-value
Actual	80.82	1.34	.001
Little and Shaw (1978)	75.85	1.34	.001
Stockdale and King (1983)	38.48	1.34	.001
Potts et al. (2012)	80.82	1.34	.001
Castle and Thomas (1975)	85.38	1.34	.001
Dahlborn et al. (1998)	70.53	1.34	.001

[1] Free water intake

Table 4 Comparison of four prediction equations of free water intake of lactating dairy cows to prediction equation of actual water intakes from Na data points (40) from meta-analysis.

Equation	Estimated FWI[1] L/Cow per day	SE	P-value
Actual	86.86	2.47	.001
Little and Shaw (1978)	72.64	2.47	.001
Stockdale and King (1983)	34.86	2.47	.001
Potts et al. (2012)	86.86	2.47	.001
Castle and Thomas (1975)	83.83	2.47	.001
Murphy et al. (1983)	92.08	2.47	.001
Dahlborn et al. (1998)	69.21	2.47	.001

[1]Free water intake

Table 5 Comparison of four prediction equations estimation of milk efficiency on free water intake of lactating dairy cows to actual milk efficiency on free water intake from 116 data points from meta-analysis.

Equation	Predicted milk efficiency[1]	SE	P-value
Actual	2.82	0.05	.001
Little and Shaw (1978)	2.64	0.05	.001
Stockdale and King (1983)	1.35	0.05	.001
Potts et al. (2012)	2.82	0.05	.001
Castle and Thomas (1975)	2.92	0.05	.001
Dahlborn et al. (1998)	2.46	0.05	.001

[1] Milk efficiency = Milk yield kg / FWI L

Table 6 Comparison of five prediction equations prediction of milk efficiency on free water intake of lactating dairy cows to actual milk efficiency on free water intake from Na (40) data points from meta-analysis.

Equation	Predicted milk efficiency[1]	SE	P-value
Actual	3.11	0.09	.001
Little and Shaw (1978)	2.56	0.09	.001
Stockdale and King (1983)	1.26	0.09	.001
Potts et al. (2012)	3.11	0.09	.001
Castle and Thomas (1975)	2.91	0.09	.001
Murphy et al. (1983)	3.46	0.09	.001
Dahlborn et al. (1998)	2.45	0.09	.001

[1] Milk efficiency = Milk yield kg / FWI